Device Description and Mechanism

Cornell University's proposed cable damper design integrates a string system and a spring system, arranged in series to form a network of four pretensioned cables running diagonally behind each facade of the tower, as shown in Figure 1, resulting in a total of 16 cables. The string system (Figure 2a) is constructed by twisting five nylon strings together and folding the twisted length upon itself. This process enhances strength, prevents unraveling, and creates a uniform material that maintains constant tension. The resulting cable is 0.9 mm thick and consists of ten individual nylon threads. The spring system (Figure 3) incorporates three springs connected in parallel, each with a spring constant of 8.53 lb/in, resulting in a combined spring constant of 25.6 lb/in. The upper plate connects the spring system to the string system by gluing cable caps to the end of each string, while the lower plate secures the assembly to the hook connected to the baseplate.

To pretension each cable, the pipe cleaner connecting the bottom plate to the hook is removed. Once disconnected, the spring piece is twisted to shorten the string until its end is approximately 1 cm from the base connection. The dampers are then secured by stretching the springs by 1 cm, aligning the bottom plate's holes with those of the hook. The pipe cleaner is then reinserted to lock the connection. Pretensioning ensures that the cables remain taut, enabling them to respond immediately to motion and preventing slack-induced delays that could amplify vibrations. At the top of the tower, the twisted string passes through a loop and feeds back through itself, as shown in Figure 2b. This connection uses a glued component designed to distribute force evenly across the corner floorplan members and columns (Figure 4). Aside from the springs, all solid damper components are 3D-printed using polylactic acid (PLA). Together, the damper fixings add 78.4 grams to the tower's weight.

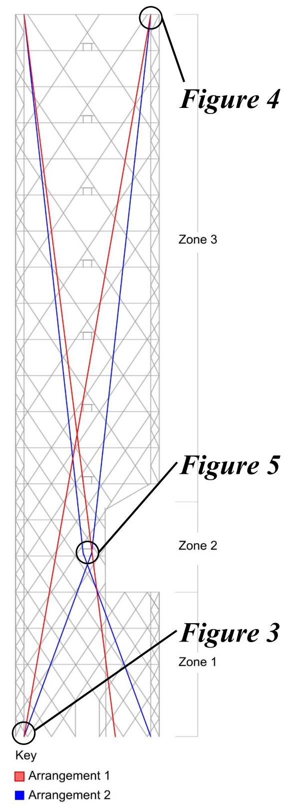

Figure 1: Façade view of competition tower with damper locations.

The cable dampers are deployed in two distinct arrangements, each involving two cables (Figure 1). Arrangement 1 is designed to dissipate kinetic and elastic deformation energy concentrated at the roof of the tower. As nylon can only sustain tension, a real steel cable would additionally be capable of handling compression. As the roof displaces, one cable shortens and goes slack, losing its ability to resist motion, while the opposite cable extends and remains in tension, providing a displacement-dependent resisting force. The tensioned cable converts the roof's kinetic energy into elastic potential energy within the string-spring system, reducing the roof's velocity and limiting overall displacement. When the roof reverses direction, the previously slack cable regains tension while the other goes slack, continuously transferring energy into the springs rather than the structural components of the tower. Arrangement 2 operates on similar principles but interacts with the drum secured to the lowest dead load connection (Figure 5). As the cable extends, it applies an orthogonal force to the 0.5-inch radius drum, which transfers the force to the members surrounding the dead load. This mechanism counteracts the lateral forces generated by the dead load during shaking, thereby reducing the energy within Zone 2 of the tower.

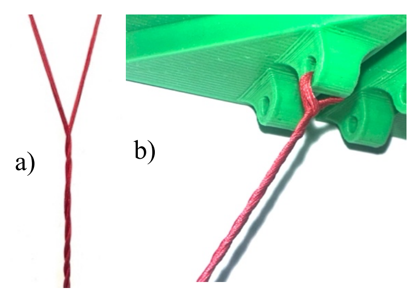

Figure 2: a) String system cable. b) Connection of string system to roof hook.

Structural Benefits and Research

Numerous studies have demonstrated the effectiveness of cable damping systems in dissipating energy during seismic events. These studies have shown that such systems increase the damping ratio while reducing maximum displacement and acceleration, as validated through analytical, FEM, and experimental testing [1, 2, 3,4]. Traditional damping systems, such as elastic, viscous fluid, and friction dampers, dissipate energy primarily through elastic deformation, with much of the energy returning to the structural system [3]. In contrast, Cornell University's proposed cable damping system dissipates energy through the

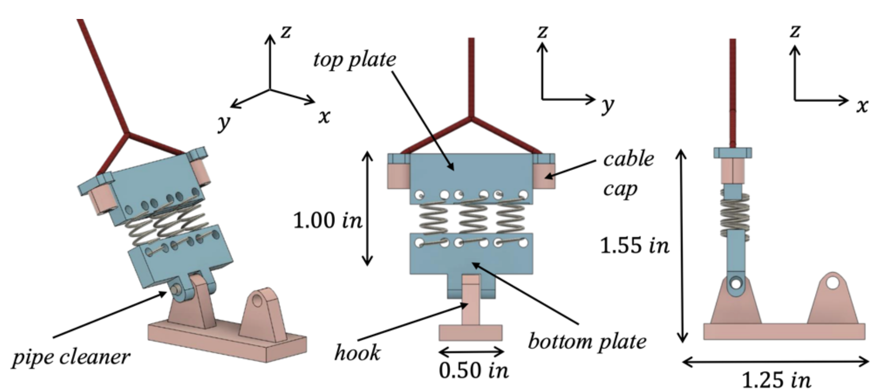

Figure 3: Spring system from three angles.

deformation of elastic strings and springs [3]. A key distinction is that one end of the cable is connected to the baseplate, allowing energy to dissipate directly into the ground. This design minimizes the energy retained within the tower's structural members, thereby reducing acceleration and displacement during seismic events [2].

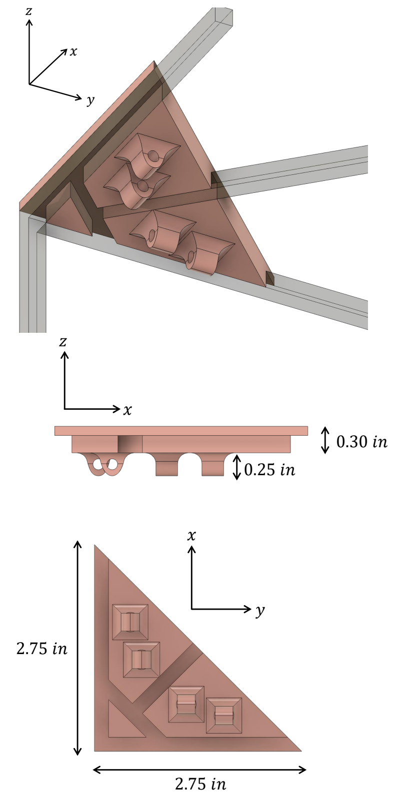

Figure 4: Hook to attach damper to the roof of the tower.

The placement of the damper cable system within the tower was carefully designed to optimize energy dissipation and address key structural challenges identified through research and analysis. A study from Beijing University highlighted the importance of optimizing the slope angle of cables to maximize displacement, identifying it as the most critical factor in damping effectiveness [3]. To achieve this, the cables were arranged diagonally across the tower's facade behind the diagrid, maximizing elongation during lateral motion. Additionally, tests revealed that floor displacement increases approximately linearly with height, which informed the decision to connect the cables to the roof for maximum effectiveness. A SAP2000 analysis of the undamped full-scale competition structure further revealed that the members surrounding the lowest dead load connection experience the highest axial forces. Consequently, Arrangement 2 of the damper system was strategically placed to target this area, counteracting dead load forces and reducing axial stress.

Experimental testing of the cable damper design was conducted using a small-scale, ten-story balsa wood tower. The placement of the dampers mirrored that of the competition tower, with two cables spanning corner to corner and two cables extending from the roof to the fourth-floor dead load connection. Eight pullback test trials were conducted for each arrangement, and the damping ratio was calculated based on the characteristic logarithmic decay, shown in Table 1. The results align with similar experiments conducted by the University of Chile [4]. Both arrangements demonstrated a significant increase in the damping ratio, providing confidence in superimposing the two arrangements for the competition tower and proceeding to ground motion testing.

Overall Structural Analysis

<u>Expected Effect on Competition Structure:</u> The test tower was subjected to Ground Motion 1 (2025) and Ground Motion 2 (2023), both provided by EERI. The ten-story, small-scale test tower featured 8 effective dampers and a light dead load. By contrast, the competition building will consist of 20 stories, 8 effective dampers, and significantly heavier dead loads. Based on experimental results, similar reductions in peak roof acceleration and relative roof displacement are anticipated for the damped competition structure. To account for uncertainties in scaling damper performance to a larger structure, a conservative reduction factor of 0.9 was applied. Table 2 summarizes the expected performance of the damped tower. Reductions were less pronounced for Ground Motion 1 due to the damper's dependence on displacement. Ground motions inducing smaller displacements result in reduced energy dissipation by the damper.

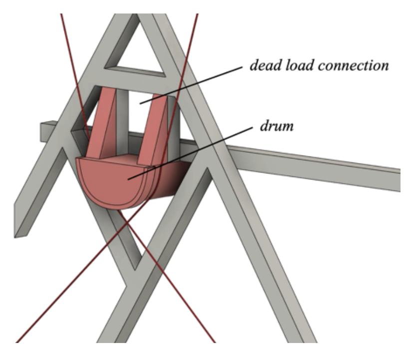

Figure 5: Drum piece surrounding dead load connection.

<u>Damper Cost:</u> For real-world implementation, the silk cables would be replaced with high-tensile, pre-stressed steel cables, which have been extensively tested and modeled for damping cable systems [7]. The clamping and anchoring mechanisms would be constructed from structural-grade steel or aluminum to ensure durability and reliability under cyclic loading. The total estimated cost of the cable damping system, including cables ($39,200), anchors and fittings ($16,000), labor and installation ($98,000), and structural analysis ($30,000), is $183,200 ± $30,000. [5, 6].

Table 1.

Damping Ratio Experiment	Mean Damping Ratio	Standard Deviation	% Increase
Control	0.152	0.007	0%
Arrangement 1	0.175	0.031	15%
Arrangement 2	0.184	0.016	21%

Table 2.

Effect on Competition Building	Relative Peak Acceleration (m/s^2)		Relative Peak Disp. (cm)	
	GM1	GM2	GM1	GM2
No Damping	17.06	23.92	2.23	2.52
Damping	15.82	21.84	1.99	2.03
AVG %Reduction	7.8%		16.2%	

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