Damped Link Element in Coupled Truss or Wall System

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Supplemental damping devices have become increasingly widespread in seismic and wind control applications in building design. Damping elements have proven to be an effective method of absorbing an appreciable portion of seismic energy transmitted through a building to reduce sway. Similarly, in wind design, dampers are most effective in reducing the wind induced lateral floor acceleration. Conventionally, supplemental damping devices are connected to adjacent floors within a structure in order to utilize the differential story displacement or velocity, depending on the type of damper.

This article presents a unique approach in the placement of dampers within a building such that their placement would enhance their performance by maximizing their energy absorption performance, thus reducing the stress and strain on the structure. The proposed approach, which is called the Damped Link System, creates a coupling effect between the structure and the damper in such a way as to engage the damper in both the building's vertical and horizontal differential displacements.

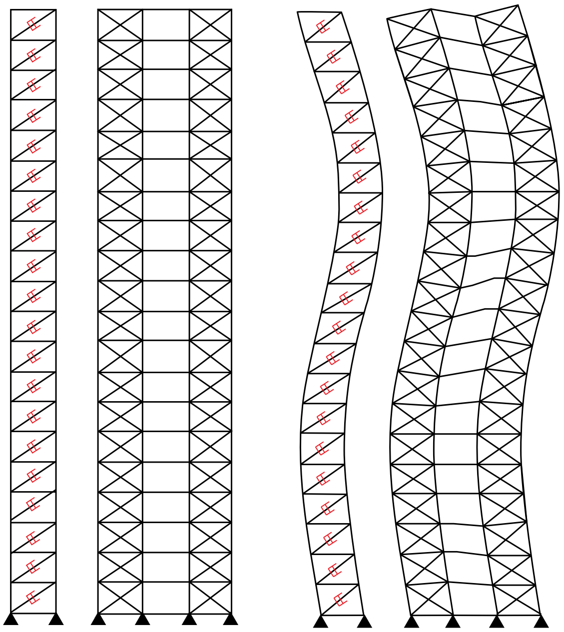

Figure 1: Conventional damping arrangement & third mode shape.

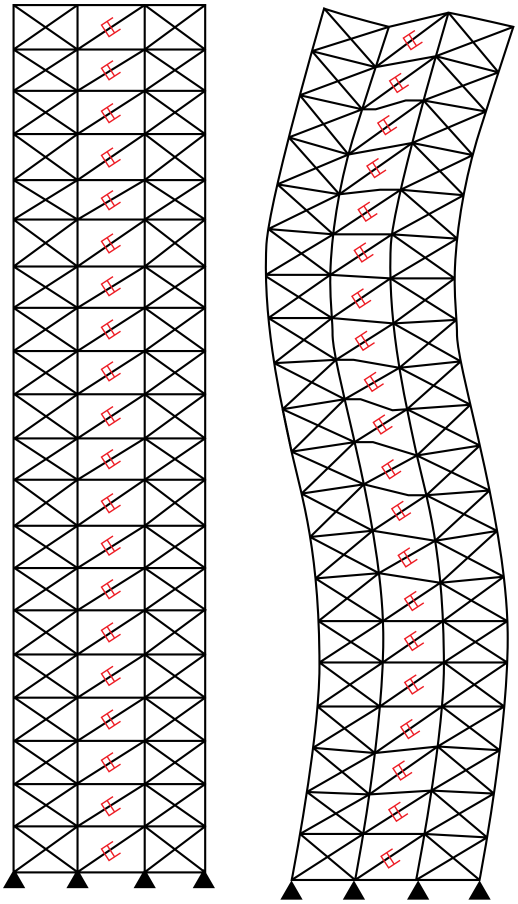

Figure 2: Damped Link System & third mode shape.

Background

There are three basic approaches to introduce supplementing damping into buildings:

Base Isolation – the primarily goal is frequency shift. This solution does not eliminate the superstructure response, which may still be excessive. However, some amount of energy can be absorbed through enhanced damping of the base isolator units and/or additional supplemental energy absorption devices at the foundation. This is primarily useful for seismic applications in low-rise buildings on relatively stiff soils.

Tuned Mass Damper – widely used in wind acceleration. It is a free-to-move mass (with limited movement) connected via dampers to the structure designed to respond out-of-phase to the primary tuned modes of vibrations – usually the first modes in each orthogonal direction. Such behavior is similar to damping.

Direct Application – requires placement of energy absorption devices within the structure at various levels. Depending on the type of energy absorption device, it may be suitable for both wind and seismic applications. It also responds efficiently to higher modes of vibrations.

The energy absorption devices, or so called "dampers", are available in a variety of forms such as fluid viscous dampers, viscoelastic, metallic hysteresis, and friction dampers. Fluid viscous dampers are velocity dependent with practically zero stiffness. Viscoelastic, metallic hysteresis, and friction dampers are displacement dependent and exhibit stiffness. Viscous and viscoelastic dampers, showing practically no threshold for activation, are suitable for wind as well as seismic applications. Metallic hysteresis and friction dampers, having a distinct threshold for engagement, are primarily used for seismic applications. Since viscous dampers are velocity dependent, their response is out-of-phase with displacements and, as a result, their induced forces are not compounded on the structure's stiffness related forces, thus minimizing the overall effect on the member stresses. *Earthquake Engineering Research Institute Monograph* (Hanson and Soong) provides a comprehensive reference for seismic design with energy absorption devices.

Extensive studies have been done during the past two decades to determine the optimal placement of supplemental damping devices. However, the major focus of these studies was on obtaining suitable algorithms for sizing, placement and distribution of dampers along the height of the structure in buildings with essentially shear deformation behavior where axial deformations did not influence the effectiveness of the dampers, such as the case where dampers were placed within low rise buildings or within gravity framing bays of high rise buildings.

The other equally important aspect of optimal design is the creation of a structural condition where the performance of the dampers can be intrinsically enhanced. This is the subject of this article. Several novel approaches to the optimal application of dampers have been introduced. These are the DREAMY Systems by Taisei, the Toggle Brace Damper by Taylor Devices, and the Viscoelastic Damper acting as outriggers, by Ahn, et al.

The key to an optimal utilization of dampers is based on locating the dampers in relatively high differential displacement zones within a building for a given external excitation. One of the well known signatures of tall building behavior is the axial deformation of the vertical elements participating in resisting lateral loads. Depending on where dampers are placed within a structure, the axial deformation of the vertical elements can have a negative (reducing) effect, no effect, or a positive (enhancing) effect on the performance of the dampers. For instance, axial deformation can have a negative (reducing) effect on the damper performance if it is placed within a moment frame or within a truss in a tall building.

Figure 3: Damped Link Element acting as coupling element between independent trusses, Torre Mayor, Mexico City.

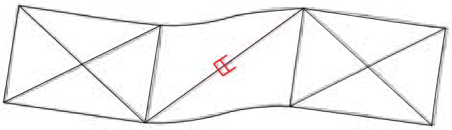

Figure 4: Damped Link System deformation.

In conventional applications, dampers are usually placed between two building columns, with each end connected to adjacent levels. The orientation can take any of the configurations, which have been the subject of extensive research and literature. In this scenario, dampers are exposed to the component of differential inter-story horizontal motion in line with the damper axis. *Figure 1* shows a typical configuration of conventionally placed dampers within a building. Dampers are placed within a gravity framing bay where columns are not subjected to axial deformations induced by lateral forces. The lateral force resisting system of the building is represented by two vertical trusses. *Figure 1* also shows the deformation of the structure and the dampers under a higher mode of vibration.

Damped Link System

The Damped Link System is a patented system that maximizes the performance of the damper without increasing the damper capacities. This is accomplished by placing the dampers between uncoupled trusses, walls or in combination with columns, as shown conceptually in *Figure 2*. Also shown is the deformation of the structure and the dampers under a higher mode of vibration. The system has been implemented in the design of the Torre Mayor, currently the tallest building in Mexico City. *Figure 3* shows the damper placement in Torre Mayor.

The concept takes advantage of the vertical differential motion at adjacent columns, in addition to the horizontal differential inter-story motion. *Figure 4* shows the typical panel deformation for the Damped Link System. The fundamental concept lies within the notion of how to tap into the stored potential energy of a structure. This is achieved by attempting to maximize the relative velocity of the end nodes of a damper for a given inter-story velocity and sway. This is a function of the structural system and the position of the damper within the structure.

Example

The following study of a 40-story structure compares the results of conventionally placed damper system with that of the Damped Link System. All structural parameters are identical except for the method of placing the damper. *Figure 5* shows the elevation of the typical braced frame used for the lateral force resisting system. The studies were performed using SAP2000 analysis software in one of the principal directions only. Also, the effect of the variation in number of dampers along the height of the structure was studied. A building with a 120- x 120-foot floor plan

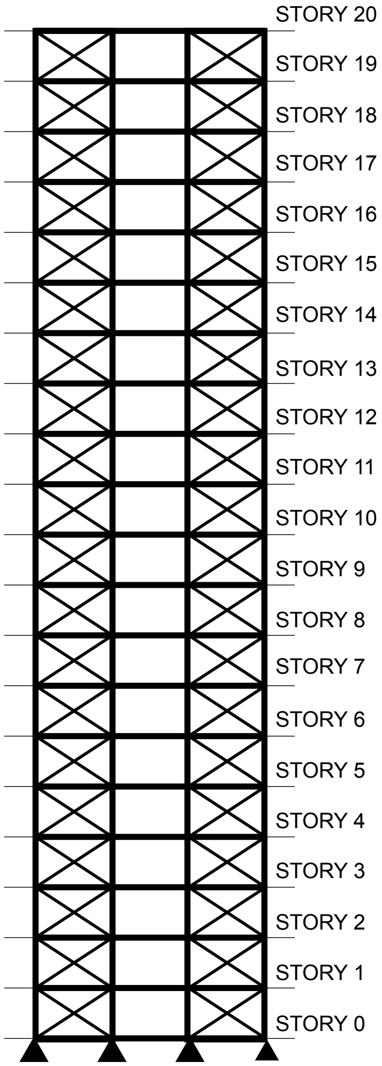

Figure 5: Structural model.

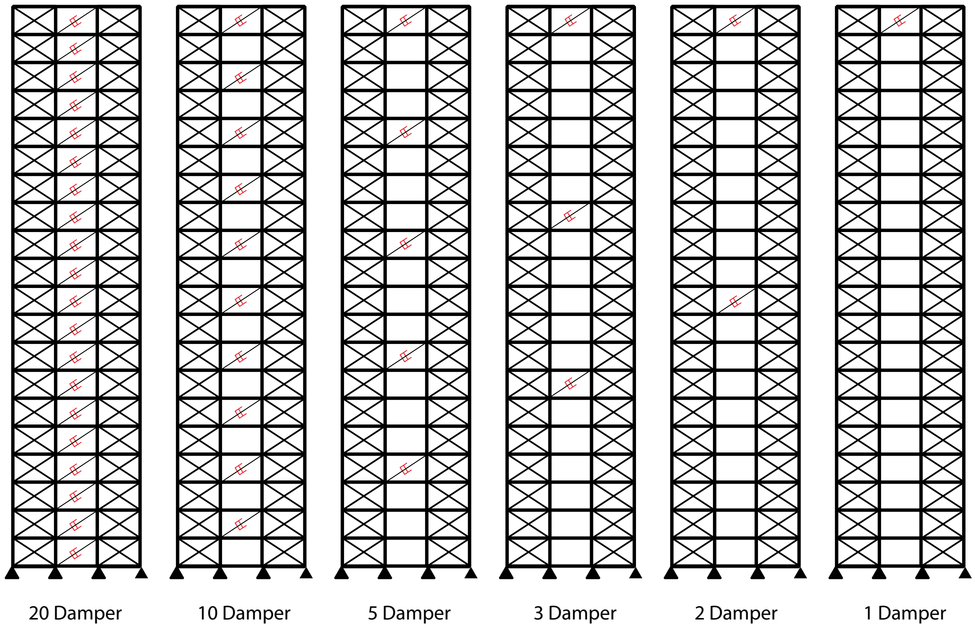

Figure 6: Alternate systems with varying number of dampers.

with three spans of 40 feet column grids in both directions was considered for this study. Inter-story height was 26 feet and the overall height was 520 feet.

A series of time-history analyses was performed using the 1995 Hyogo-Ken-Nanbu (Kobe) Earthquake and a simple impulse loading. The efficiencies of the two damping arrangement methods were compared by measuring the structural responses. The effective damping values were also evaluated.

For this study, the total amount of the damper coefficient, ΣC, was kept constant, with a value equal to 1000 k-sec/inch. The dampers were considered to be linear in relation to the velocity, although in reality, this relationship is usually designed to be non-linear. (This nonlinear velocity relationship would have an exponent in the range of 0.1 to 1. The lower exponent value would increase the energy absorption capacity and limit the maximum damper force, thus adding to the overall reliability of the system.) However, this consideration did not influence the comparative nature of this exercise. The structure's mass, stiffness, undamped frequencies and mode shapes were all identical in all different scenarios. The variables were the method of placement of the dampers (Conventional vs. Damped Link System) and the number of dampers along the height of the structure. The lateral force resisting system was considered to be a Concentric Braced Frame system for both alternatives.

For each scheme, a total of six studies were performed to cover a range of damper distributions along the height of the structure. The following damper distributions were considered: 20 dampers uniformly placed at every level, 10 dampers placed at every other level, 5 dampers, 3 dampers and 2 dampers equally spaced along the height of the structure, and finally one damper at the top level, as shown in *Figure 6* for Damped Link System and similarly for the conventionally damped system. In all the studies, the total damper coefficient, ΣC, was kept constant and the individual damper coefficients were adjusted proportionally to the number of utilized dampers.

Conventional Damper System

In the conventional damper arrangement, the dampers were placed between two gravity columns and connected to the floors at different levels, as shown in *Figure 1 (page 30)*. In this case, the dampers were only exposed to the horizontal differential velocity between floors since the columns were not engaged to resist the overturning seismic forces. *Figure 7a* shows the building's lateral motion under free vibration at the top floor.

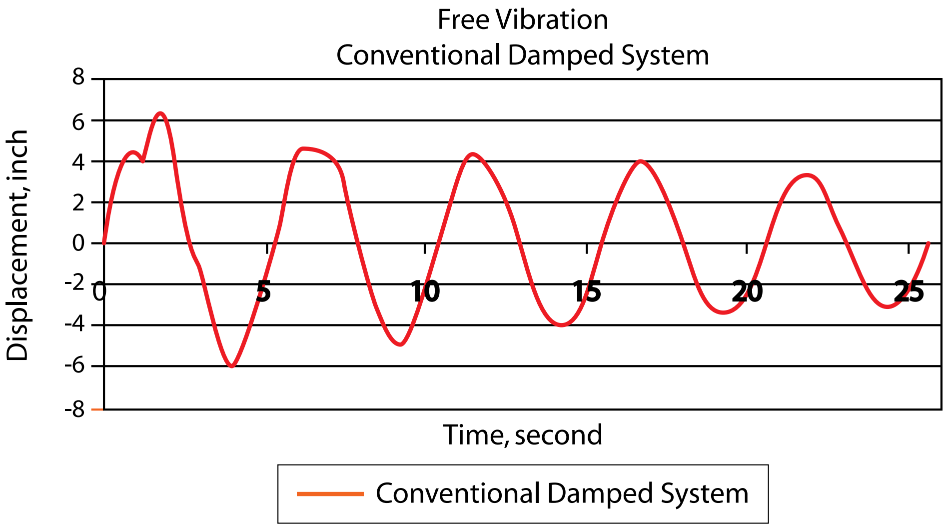

Figure 7a: Free vibration – Conventional Damper System.

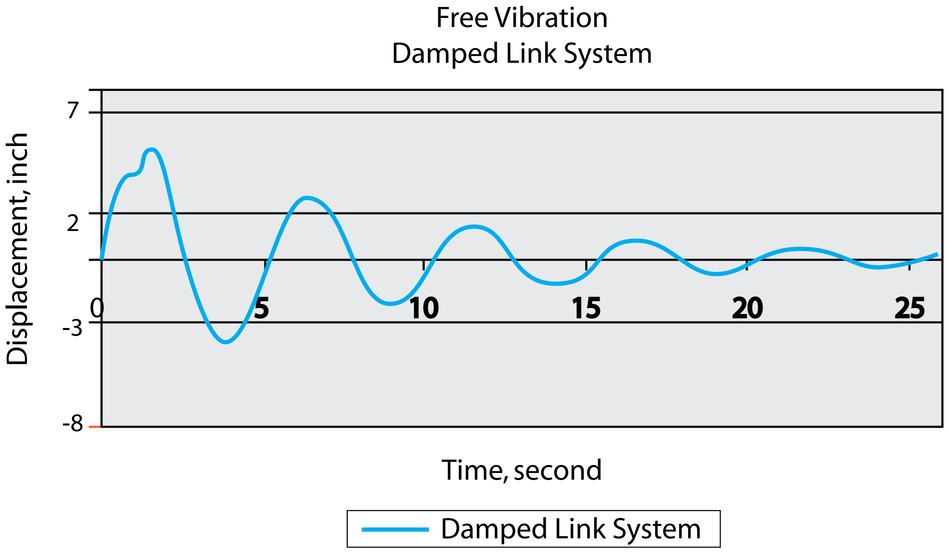

Figure 7b: Free vibration – Damped Link System.

Damped Linked Element between Truss Systems

In this method, the dampers were placed between two effectively uncoupled vertical truss elements (*Figure 2, page 30*), where, in addition to the horizontal differential velocity between consecutive floors, they were also exposed to vertical differential displacements as a result of axial deformations of the adjacent columns. Thus, under a given base excitation, the dampers placed in this configuration were exposed to higher velocities as compared to the conventional application of dampers. As a result, the overall contribution and effectiveness of the damping were higher. *Figure 7b* shows the building's lateral motion under free vibration at the top floor. It is noticeable that the free vibration decays much quicker than the conventionally placed damper as shown in *Figure 7a*.

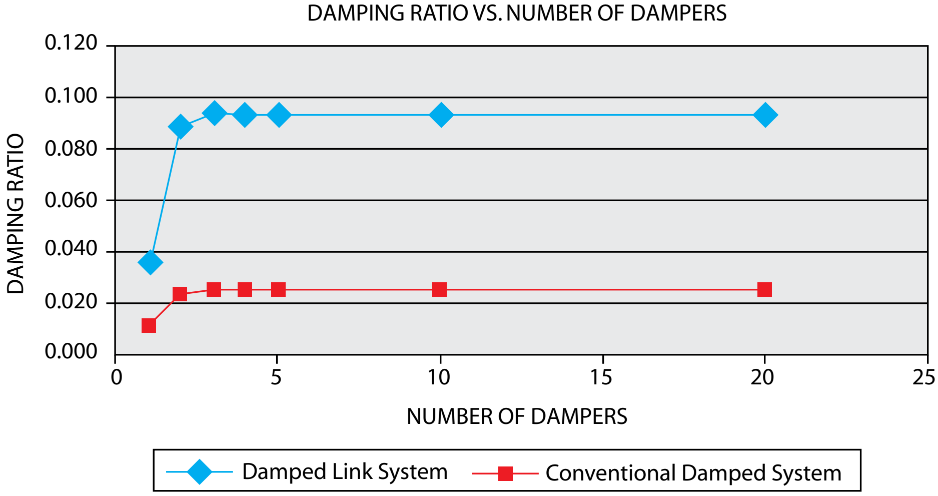

Figure 8: Effective overall damping as a function of damper distribution.

Discussion & Conclusion

In these studies, it was assumed that the inherent structural damping was negligible compared to the added damping. Therefore, all the exhibited damping was associated with the damper's performance.

Figure 8 shows the effective damping for the two systems. The chart also shows the overall effective damping as a function of the number of utilized dampers. The total damper coefficient, ΣC, was kept constant throughout this study. The results clearly show the advantage of the Damped Link System over the conventional damper arrangement. The Damped Link System shows up to 400% higher damping (9.5% damping) in comparison to the conventional damper arrangement (2.5%) with the identical number of dampers.

The results also show that the rate of improvement of the damper performance converges quickly after placement of the dampers at a minimum of three separate zones along the height of the structure. This can be attributed to two factors: the effect of the higher modes of vibrations and the effect of the joint stiffness at the connection to the damper relative to the damper capacity. This, in effect, means for identical conditions for a given total damper constant, using fewer large capacity dampers yields a lower performance than using more low capacity dampers.

In response to the 1995 Hyogo-Ken-Nanbu Earthquake excitation, *Figure 9* shows the roof level's maximum displacement and

Figure 10 shows the base shear as a function of the structure's mass. The charts show that the Damped Link System exhibits 25% less deformation and 30% less base shear imposed on the structure as compared to the conventionally placed damper system. The 5% and 10% modal damping responses are also shown as a reference which shows the consistency of the results with the damping evaluation on *Figure 10*.

Figure 11 shows the maximum drift index for both the conventional damping arrangement and the Damped Link System for the uniform arrangement of dampers. The graph shows a 40% reduction in the maximum interstory drift index by using the Damped Link System instead of using the conventionally placed dampers with the identical damper sizes.

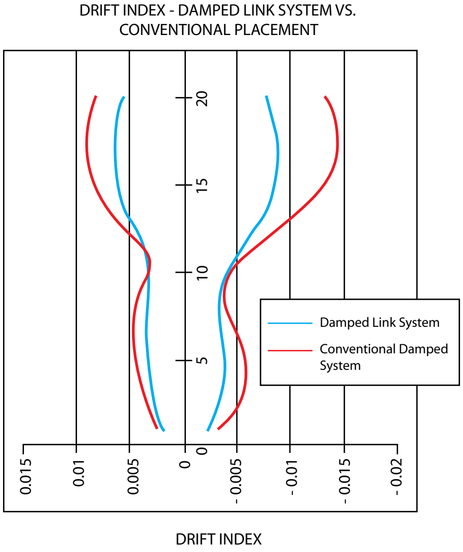

Figure 11: Maximum Drift Index

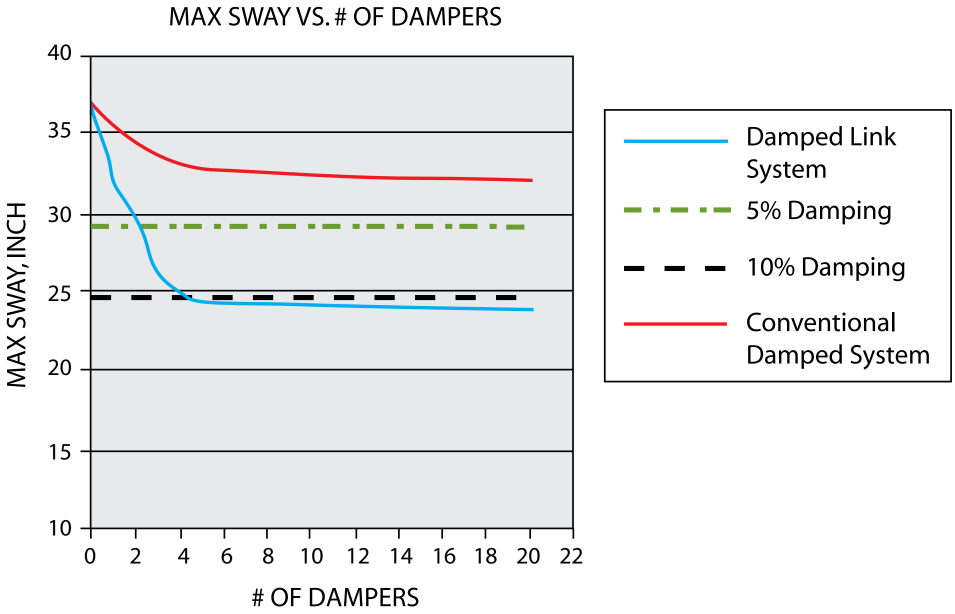

Figure 9: Maximum lateral deflection.

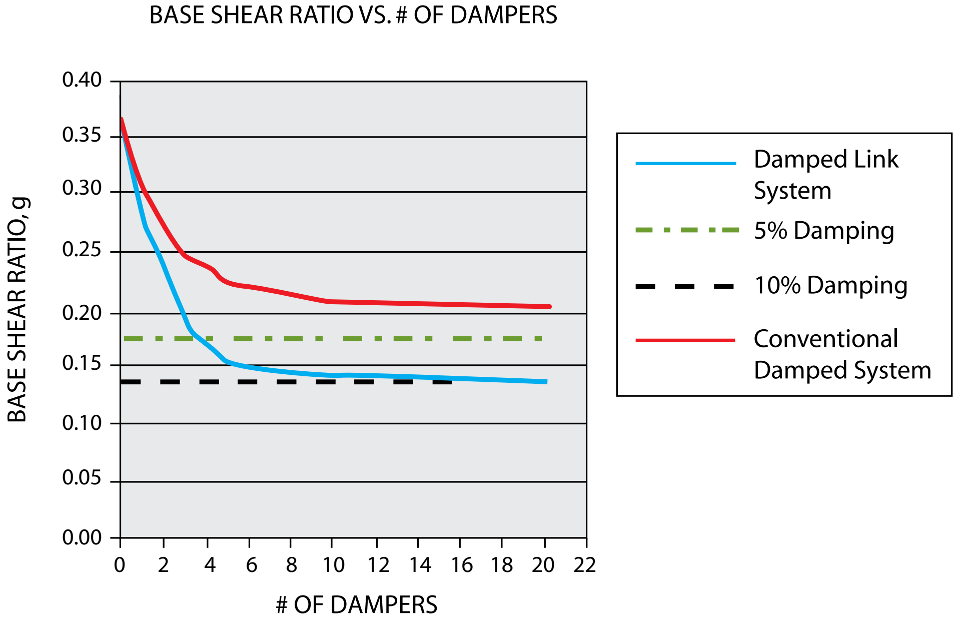

Figure 10: Maximum base shear.

Summary

The example above demonstrates the effectiveness and superiority of the Damped Link System in creating an optimal solution for damper utilization in comparison with a conventional damper arrangement. The example above shows the effective damping of the structure can be increased multifold without increasing the damper capacity but by simply placing them strategically within the lateral force resisting system. This concept is more effective in high-rise buildings than low-rise buildings since axial deformations of the lateral force resisting system have a higher importance.▪

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