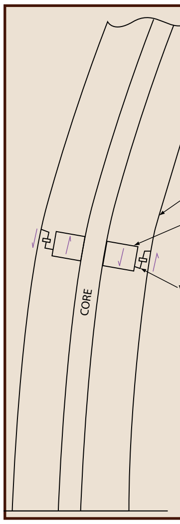
Viscous Dampers Come of Age

A New Method for Achieving Economy in Tall Buildings

By Michael Willford, Rob Smith, David Scott and Matt Jackson, S.E.

It is often found that the design of tall buildings is governed by the need to limit the wind induced structural vibrations to an acceptable level. This leaves the designer with the option of either increasing the amount of steel or concrete in the building's lateral system to add stiffness, or of adding a complex and expensive damping system in order to ensure the comfort of building occupants. Various damping systems have been employed on tall buildings throughout the US and overseas, and have proved to be economic for buildings above a certain height, particularly in windier climates. A new type of damping system employing viscous dampers is currently being designed for tall buildings in Europe, Asia and the Americas, that achieves higher levels of damping than other damping systems, and reduces the design wind loads that these buildings are designed for. This scheme offers a new way to improve efficiency in tall buildings.

The commonly used methods for adding damping to tall buildings include Tuned Mass Dampers (TMDs), and Tuned Liquid Dampers (TLDs). Both of these require a mass of steel, concrete, or water, located at the top of the building, which is tuned to the motion of the building to absorb energy. This mass is significant, usually a few percent of the building mass, and thus, in addition to the cost and complexity of the damper itself, additional structure is required to support the load and prime real estate at the top of the tower is lost.



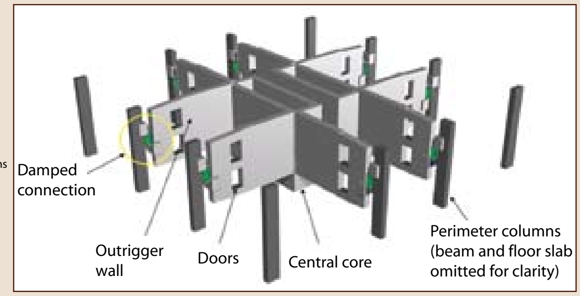


Figure 1: Damped Outrigger Concept.

In recent years, engineers have patented systems that use viscous dampers to reduce wind and seismic induced vibrations, using numerous dampers distributed throughout the core in place of bracing, such as the system used for Torre Mayor, reported in STRUCTURE® Nov 2007. These systems principally damp the shear deformation of the core, and are not very efficient at damping the flexural cantilever mode of vibration that dominates wind movements. Some of these systems have employed 40-60 dampers to achieve similar levels of damping to that of a TMD.

A new system for providing damping, the Damped Outrigger concept (patent pending), is currently being installed in towers in the Philippines, and is in the design stage for several other towers around the world. In this system, viscous dampers are used to damp the relative motion between outriggers attached to the core and the perimeter structure, thus efficiently damping the first mode of vibration. (*Figure 1*). Many similar alternate configurations are possible to achieve the same effect, including dampers located in outriggers, at the end of outriggers, or between outriggers extended between dual cores, shear walls and columns.

Analysis shows that with viscous dampers at just 4 to 8 locations in these configurations, similar or greater levels of damping than a TMD can be achieved, whilst adding no weight and only occupying a small area of an available mechanical floor. This system can be installed on both steel and concrete frame systems and, depending on the position of the outrigger level or by using multiple outrigger levels, damping up to 10% of critical can be achieved, with further significant benefits for the structure.

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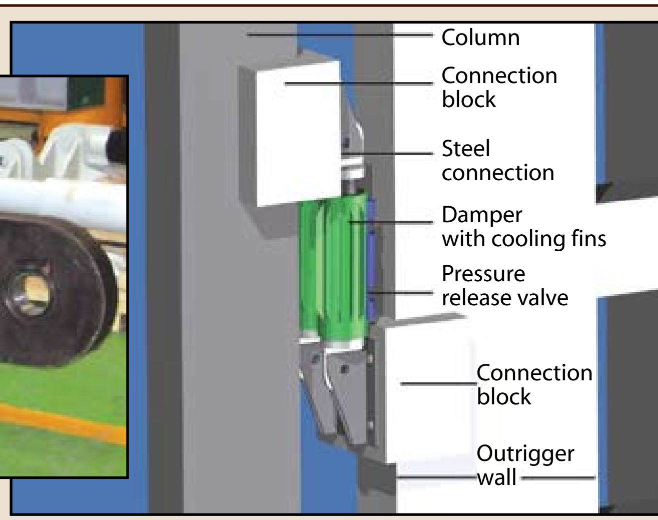
Damper and Attachments.



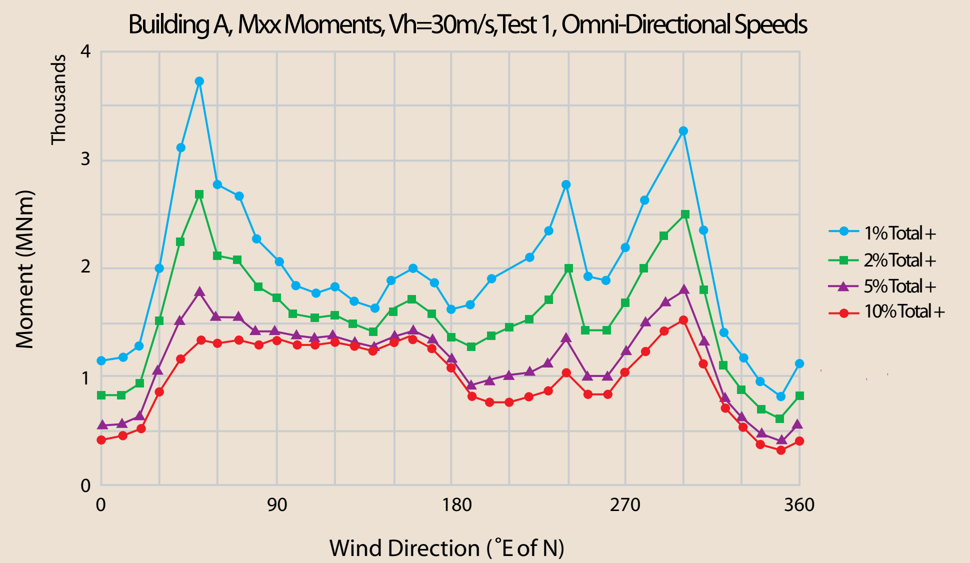


Figure 2: Base Moment Against Wind Angle for Various Damping Levels.

Damper Design

The design considerations for dampers used in damped outrigger systems to resist both wind and seismic movements, are somewhat different from those that have been widely used in systems to provide energy dissipation for seismic events only. The dampers under wind loading will be cycling constantly whenever the wind speed is above a certain level, whereas seismic dampers are normally intended to only cycle during seismic events.

For this reason, friction dampers or other dampers that have wearing surfaces are not a realistic choice, and viscous dampers must be designed so that the seals provide a long life and the static friction is low enough that the dampers move in relatively modest wind events. These dampers must also be designed to dissipate sufficient energy in the form of heat, so that their performance does not degrade during a wind storm that may last many hours. An analysis is needed to assess the power dissipation requirement, and devices such as external cooling fins may be added to aid in cooling.

These dampers however are not dissimilar to some of the large dampers used in the shipping and manufacturing industry, and even with very onerous specification requirements, manufacturers will provide performance warranties for 20 years or more.

To design the damped outrigger system, it is necessary to analyze the dampers within the whole building structure, as the stiffness of the structure to which the dampers are attached has a significant effect on the damping which is achieved. The analysis of the damping system for the projects discussed here has been carried out using MSC Nastran, with the assumption that the dampers are linear with velocity (F = C V, where F is the force of the damper, C is the damper rate, and V is the velocity with which the piston of the damper is moving). Through the use of custom written optimization routines it is possible to optimize for both the damper rate and the stiffness of the structure, to maximize the overall level of damping achieved. In general it is found that the overall level of damping is not very sensitive to the precise damper rate, and therefore it is possible to use dampers that do not have an exactly linear characteristic – which allows more damper manufacturers to compete for their production.

Reduced Wind Loads

Additional reliable damping can reduce the design lateral and overturning forces. This is due to the fact that the damping reduces the resonant response of the building to the fluctuating component of the wind, and to the fluctuating forces produced by vortex shedding in the cross wind direction. This reduction in load can be very significant, and can lead to a large reduction in materials both in the superstructure and foundations. The plot in *Figure 2* shows an example of this, in which the maximum base moment of the building is reduced by a factor of more than 2 when the total damping is over 5% of critical, compared to the same building with 1% damping, which may typically be assumed for the undamped structure.

If the designer wishes to take benefit of the reduced forces in his design, the damping system needs to be designed with sufficient redundancy so that it will perform adequately with several dampers out of commission. This requires a careful approach, education of the client, and agreement with the authorities. Reliability can be achieved by using well designed dampers, by using multiple dampers on each outrigger and by an appropriate inspection plan.

A further benefit of the damped outrigger system is that it provides damping in all modes of vibration. For super tall structures, the higher modes of vibration may also be excited by the wind, and in seismic events the higher modes will be the dominant ones excited.

It is interesting to note that it is common practice for engineers and wind tunnels to assume damping levels of 1% for steel buildings and 1.5% for concrete buildings.


St. Francis Shangri-La Place, Construction Photos.

However, recent measurements show that the damping levels on very tall buildings may be as low as 0.5%. This reduction in damping may occur because the size of structural elements becomes very large on tall towers and the damping effect from internal partitions and cladding becomes proportionally less compared to the structure. However *Figure 2* shows how significant the damping level is to the design forces and the predicted movements and accelerations.

Design Example

This example is a development of two similar residential buildings 690 feet tall and approximately 125 feet square in plan, located in a region of typhoon winds and UBC Zone 4 seismic conditions. Each building has a reinforced concrete core (coupled in one direction) and an irregular arrangement of perimeter columns and walls.

For each of the two buildings, 8 outrigger walls are attached to the core approximately half way up the building. Two dampers are attached to the end of each of these outrigger walls, giving a total of 16 dampers per building.

The additional damping achieved in each direction varied between 5.2% to 11.2% of critical for the two buildings and two principal directions.

At the time of writing, this building is under construction and the viscous dampers have been installed and tested.

Wind Effects

The building is subjected to regular typhoon winds. The likely dynamic response was initially calculated using the Detailed Method of the National Building Code of Canada for both along-wind and across-wind directions. For occupant comfort, 10-year and 1-year return periods were considered, and 100-year return period was taken for strength design. Following initial design, wind tunnel testing was used to better quantify the wind loading. Alongside the wind tunnel tests, a directional climate study was performed. This made a significant difference to the final assessment of wind induced response.

Considering one load direction only, the base overturning moments are shown in *Table 1*.

It can be clearly seen from *Table 1* that the use of dampers, alongside a climate study, has reduced the overturning moment by 50%, representing a significant reduction in load and associated structural cost.

Lateral accelerations were predicted for the 10-year wind, using wind tunnel tests. From

Effect	Method	Assumption	Factored overturning moment (GNm)
Wind	Code	Code winds, damping = 1.0%	7.4
Wind	Code	Code winds, damping = 7.5%	4.5
Wind	WTT	Winds from climate study, damping = 7.5%	3.7

Table 1: Variation of wind loading with damping.

Effect	Method	Assumption	Lateral acceleration (milli-g)
Lateral acceleration - 10 year wind	WTT	Climate study winds intrinsic damping = 1.0%	25.6
Lateral acceleration - 10 year wind	WTT	Climate study winds, Damping = 7.5%	9.4
Lateral acceleration - 10 year wind	WTT	Suggested limit for 10 year wind	15

Table 2: Variation of lateral acceleration with damping.

the results shown in *Table 2*, it is clear that the addition of damping substantially reduces the lateral accelerations below the recommended limit for the return period. In addition, the reduced design wind loads and improved seismic performance led to construction savings in excess of $5m USD. The quantity of concrete in the buildings was reduced by 30%, and the net floor area increased by about 2%.

Conclusions

The use of the damped outrigger and related systems promises to significantly change the approach that may be taken to tall building design. For very tall buildings, the damped outrigger system offers higher levels of damping compared to conventional TMDs. The high level of reliable damping can significantly reduce the dynamic forces which the structure must be designed for. This requires some new approaches to design, and must be completely integrated in to the structure from an early stage to obtain maximum benefit.

If the level of damping is sufficiently high, then the resonant response of the structure to the wind is virtually eliminated. In this case only the quasi-steady component of the wind load needs to be designed for, and thus a tower may be shaped to minimize drag, with reduced concern for vortex shedding and cross wind response.▪

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