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ENHANCING DYNAMIC PERFORMANCE OF LIGHTWEIGHT SUPERSTRUCTURES USING SUPPLEMENTARY DAMPING

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ABSTRACT: Ensuring that lightweight superstructures perform satisfactorily in terms of serviceability and safety requires close attention to how they respond to dynamic loadings in undamaged or damaged states. This reflects that their modal characteristics can cause acceleration levels under wind, seismic and other loadings that impinge on functionality, or propagate damage in extreme circumstances. Discussion here addresses application of supplementary damping technologies as cost effective ways of ensuring lightweight superstructures have desirable dynamic response characteristics in new or retrofit construction situations.

KEYWORDS: Cross-laminated-timber, Design, Dynamic response, Joints, Support conditions, Vibration serviceability

1 INTRODUCTION

Large physical objects like buildings, bridges and industrial structures oscillate as a result of surrounding ambient dynamic excitations. Mostly those motions are not perceptible to humans, and do not impinge on functionality or damage the objects. However this is not always the case, as everyday events and famous instances like wind induced disintegration of the Tacoma Narrows Bridge and disturbing swaying of London's Millennium Footbridge demonstrate. In most cases the source of the problem is failure on the part of the designer(s) to fully appreciate, or not appreciate at all, how structural systems can be excited in service or will respond to excitations. Unlike with exotic structures, design of normal structures can involve little or no explicit design attention to possible dynamic response characteristics. In fact, best practice guidelines and design codes will often not bring attention to need to perform other than static force design analysis.

Discussion here addresses situations where use of lightweight construction methods (e.g. substitution of lighter structural elements for traditional ones) introduces need to explicitly address dynamic performances of superstructures. Exemplary of this is substitution of ultralight engineered wood products (EWP) like glulam framing and cross-laminated-timber (CLT) in lieu of relatively heavy reinforced concrete (RC) elements on which contemporary design practices are predicated.

It is routine with tall buildings and long span and/or flexible bridges for designers to account for their dynamic responses. Even so however, design code requirements and engineering design practices are predicted on use of relatively heavyweight construction materials. Therefore it remains important when elevated substructures contain ultralight construction elements to fully consider the possibility of vibration serviceability issues arising, even when superstructure heights and spans lie below values where no previous problems have been found. Also to note is that apart from altering weight and modal masses, material substitutions and other design innovations can introduce semi-rigidities at inter-element interfaces that invalidate extrapolation of past experience of when problems may occur.

2 RELATED RESEARCH AT THE UNIVERSITY OF NEW BRUNSWICK

Researchers at the UNB are developing Distributed Mechanical Damper (DMD) systems, and new highly efficient yet economic Tuned Mass Damper (TMD) devices for control of serviceability and overload of structural systems containing ultralight substructures. Figures 1 and 2 illustrate the concept of employing multiple damper arrays attached to elevated substructures within large superstructures. The underlying principles and logic is discussed in the full manuscript, together with

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discussion of experiments that demonstrate the benefits of installing TMD in multi-storey structures. Part of the UNB research team's premise is that it has now become normal in civil engineering to seek technological solutions on an everyday (non-exotic) basis. More specifically, they accept that there is no need to simply attempt to control dynamic motions and associate force flows through structures by simply stiffening and strengthening those structures.

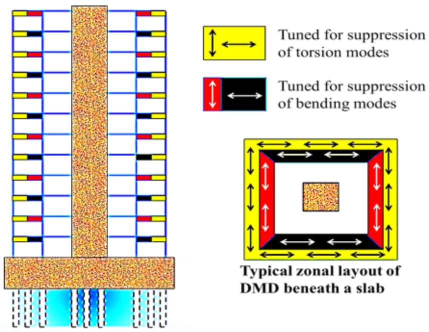

Figure 1*: Zonal placement of tuning of damper arrays in DMD system (courtesy of Advanced Construction Technologies III)*

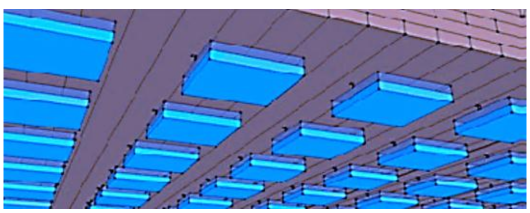

Figure 2*: DMD array on undersides of CLT floor slab(adapted from Weckendorf and Smith)*

DMD systems are an effective way of counteracting adverse effects that physical irregularities introduced into structural systems for architectural or other reasons have on dynamic responses of structural systems. To illustrate, when ultralight EWP floor slabs are interspaced with much heavier RC fire floor slabs within tall building superstructures the resulting uneven vertical distribution of mass can amplify internal force flows and acceleration levels during seismic and other dynamic loading events. A powerful application of DMD systems in conjunction with use of new ultralight materials and substructures is to facilitate creation of new architectural possibilities.

TMD of other damper technologies can provide highly cost effective design solutions or remedy behaviour of existing structures.

3 CONCLUSIONS

Various types of supplementary damping devices have proven effective in terms of ability to protect building and bridge structures against effects of motions that could impinge on their serviceability or safety. Despite this, application of such technology has mostly been limited to relatively unusual situations involving slender or otherwise flexible systems. Yet, widespread use of supplementary damping technologies in non-civil engineering applications (notably the automobile industry) shows, it need not be prohibitively expensive employ them. Arguably, partly why dampers are not routinely employed in civil engineering structures is that design practices have become excessively constrained, and too orientated toward simplified equivalent force and resistance methods and acceptance that structural damage is acceptable. However, introduction of performance-objective based design codes in various countries during recent years provides the means of changing such a status quo. Innovative engineers have opportunities to creatively go beyond the constraints of contemporary material design codes and be creative.

The table is ready to be set for widespread application of supplementary damping technologies to building and bridge superstructures that constitute the bulk of engineered structures. The essential question is whether or not engineers are willing to walk through the door of opportunity that could lead to use of new products like cross-laminated-timber in ways never previously contemplated as being accessible by timber-based products. If the answer is yes engineers could be on the cusp of a new structural engineering era just exciting as when at the end of the 19th and beginning of the 20th centuries innovative thinkers combined widespread availability of structural steel with innovations in structural engineering and invention of suitable elevators, into ability to realise architectural dreams. Then dreams included realisation of architectural modernism and skyscrapers. New dreams can include realisation of new architectural forms, and transition from designing structures that certainly will be damaged during events like earthquakes to one that will survive them unscathed.