Studies on the Application of Tuned Liquid Dampers (TLD) to Up-Grade the Seismic Resistance of Structures

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Summary

The risk of occurrence of severe damage or structural failures during a catastrophic event (eg. Earthquakes and hurricanes) can be reduced by adopting techniques to increase the damping characteristics of a structure. Damping is defined as the ability of the structure to dissipate a portion of the energy released during a dynamic loading event. A tuned liquid damper (TLD) system represents an efficient and simple technique to increase the damping of a structure. It involves the attachment of one or multiple liquid-filled tanks to the structures. The TLD system relies on the sloshing wave developing at the free surface of the fluid to dissipate a portion of the dynamic energy. The growing interest in liquid dampers is due to their low capital and maintenance cost and their ease of installation into existing and new structures.

While the behavior of tuned liquid dampers under low level of oscillation has been well documented, their response to large oscillation (that can be exhibited during a strong seismic event) are fairly complicated especially with the potential of occurrence of surface wave breaking.

An extensive research program to investigate the behavior of a TLD system as a technique to up-grade the seismic resistance of existing and new structure has been recently initiated at the University of Western Ontario. Three Ph.D. students are currently searching various aspects of this challenging problem. A summary of this research programs is presented in this report.

Introduction

An increase in the frequency of occurrence of natural disaster event (Earthquakes and hurricanes) has been evident over the past few years. Strong vibration and possible collapse of structures during these events can lead to catastrophic human and economical losses. Damping is one of the most important parameters that limit the response of the structures during these dynamic events. Recently, a technique to increase the damping of a building has been developed by attaching one or multiple liquid-fluid tanks to the structures. The sloshing motion of the fluid that results from the vibration of the structure dissipates a portion of the energy release by the dynamic loading and therefore increases the equivalent damping of the structure. These tank devices are referred to as Tuned Liquid Dampers (TLD). In the past few years, a number of TLD was attached to various buildings to reduce the level of vibrations of the structures during their normal operational (Tamura et al.1992, Wakahara et al. 1992 and Isyumov et al. 1993)

As a consequence of various experimental and analytical studies conducted during the last few years, the response of a TLD system under low level of oscillation is well defined. However, under large oscillation (that are expected to occur during a strong earthquake), a TLD system exhibits a complex behavior especially with the occurrence of breaking wave. While, Sun et al. (1985 and 1995) were able to develop a technique to express the behavior of a TLD, such a technique has shown a good correlation only in the low amplitude range. Koh et al. (1994) have studied experimentally and numerically the response of rectangular TLD to earthquake motion. In this study, the amplitude of the earthquake signals was limited to prevent wave breaking and the developed numerical model was only applicable to this small amplitude range.

The author believes that the TLD concept represents an excellent technique for up-grading the seismic resistance of both existing and new structures. The spread of the applicability of this technique is hindered by the lack understanding of the behavior of the TLD under high level of excitations. A research program is currently progressing at the University of Western Ontario to understand the behavior of this device. The final objection is to develop means that can be used in designing tuned liquid dampers to be attached to structural buildings for up-grading their seismic resistance.

As a result of this development, the integrity of a building strengthened using TLD, can be maintained during a strong earthquake motion occurring in the vicinity of this building. This could reduce the huge human and economical losses that might occur during this disaster event. The research program carried out at UWO consists of three complimentary studies.

The first study is carried out experimentally by a Ph.D student M. Tait. It involves studying the behavior of TLD system and developing an equivalent simple model based on test results. The second study is carried out analytically by the Ph.D. student, T. El Soukary. It involves developing a software that can accurately predicts the fluid motion inside the tank. The third study is conducted both analytically and experimentally by the Ph.D student M. Saafan. This study uses the finding of the two previous studies to investigate the earthquake response of a structure with a TLD attached. A design procedure for the TLD as a mean for seismic up-grading of structures, is excepted to result from the above studies. A brief summary of the above three studies is provided in the next sections. Although the studies are still in-progress, some of the preliminary findings are presented.

Study I Experimental Evaluation for the Behavior of TLD Systems

This study is conducted experimentally using a shaking table device and a system test tower both available at the BLWTL at UWO. Fig. 1 shows the photo of a tested TLD attached to the shaking table.

Fig. 1 TLD attached to Shaking Table

This table can simulate various types of dynamic loads, including earthquake loads, acting on the tested specimen. Wave probe were used in the tests to measure the free surface sloshing motion, while load cells were attached underneath the tank to determine the interaction force occurring between the tank and the table. Results of these tests were used to develop a simplified equivalent mechanical model having the same energy dissipation as the TLD system.

Fig 2 shows a schematic of a building with a TLD attached. The equivalent mechanical model simulating the structure/TLD system is shown in the same figure. It consists of a mass M* and a spring K* representing the properties of the building. The TLD is simulated using a rigid mass attached to the structure using a spring and a dashpot. The behavior of this equivalent system called tuned mass damper, TMD, is well understand by structural engineers.

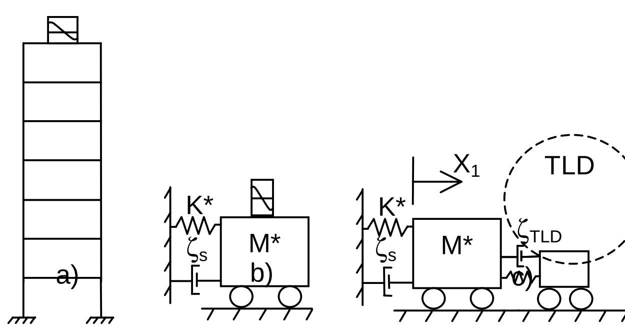

Fig.2 a) Structure-TLD b) Equivalent Representation c) TMD Analogy

Fig. 3 shows a picture of the system tests conducted on a tuned liquid damper (TLD). In this set-up, a real structure is represented by a ballast mass and a spring system. By attaching a tank to this mass / spring system, the real configuration of a structure having a TLD attached is simulated.

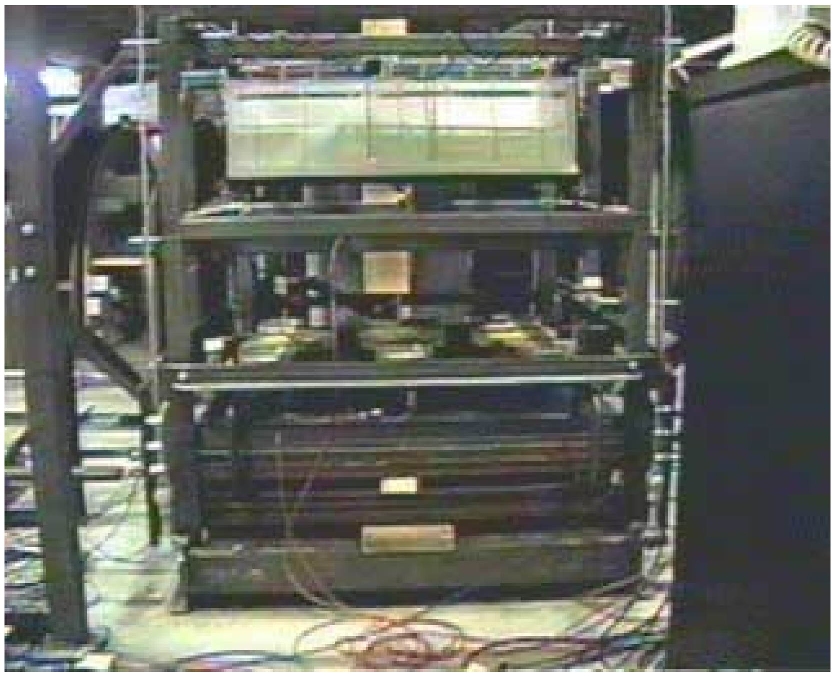

Fig. 3 The TLD System Test

The response of the structural model with and without TLD attached to dynamic loading was recorded. The tests have revealed the great efficiency of the TLD system in damping the vibrations of the structural model. Results of the tests were also used to verify the concept of equivalent tuned mass damper (TMD) discussed above.

Currently, the shaking table and the system test tower can provide only uni-directional excitation to the tested specimen. The author and his colleagues at UWO were able to secure some funds that are currently used to up-grade these two systems to two-directional excitation. This development will allow the simulation of a more realistic type of wind and earthquake loads. The research of Mr. Tait will then proceed to study the behavior of a TLD system under two-directional type of excitation. Such a study is considered to be a unique. This research is carried in collaboration of Prof. Isyumov, The research director at the wind tunnel, who has an extensive experience in the dynamic behavior of structures.

Study II Development of a Software Simulating the Fluid Motion

This study is carried out analytically by Mr. El Soukary under the joint supervision Prof. El Damatty and Prof. Strattman.

The study involves the development of a computer program that simulates the behavior of the fluid contained inside a TLD system. Mr. El Soukary has a very good experience in the area of computational fluid dynamics (CFD) as it is directly related to his master dissertation. Prof Strattman is an expert in this field. The test measurements conducted in the previous study will be used to validate the developed software. The research will involve tanks subjected to both uni-directional and two-directional excitations.

Study III Seismic Behavior of Structures with TLD Attached

This study, carried out by Mr. Saafan, consists of three phases that are conducted in parallel. These phases of study will provide a clear understanding for the seismic behavior of structures having TLD attached. They are also expected to result in establishing a procedure that can be used to up-grade the seismic resistance of building using the TLD concept. A brief description of these three phases of the study are provided below:

a) Phase I:

The equivalent TMD system, evaluated from the tests conducted in study I, has been incorporated into a structural analysis computer program to gain an insight about the seismic behavior of a structure (TLD) system.

An eight-story steel building, located in Vancouver, B C, was designed according to the NBCC (1995). A schematic of this building is shown in Fig. 4, indicating the dimensions and the steel member cross sections.

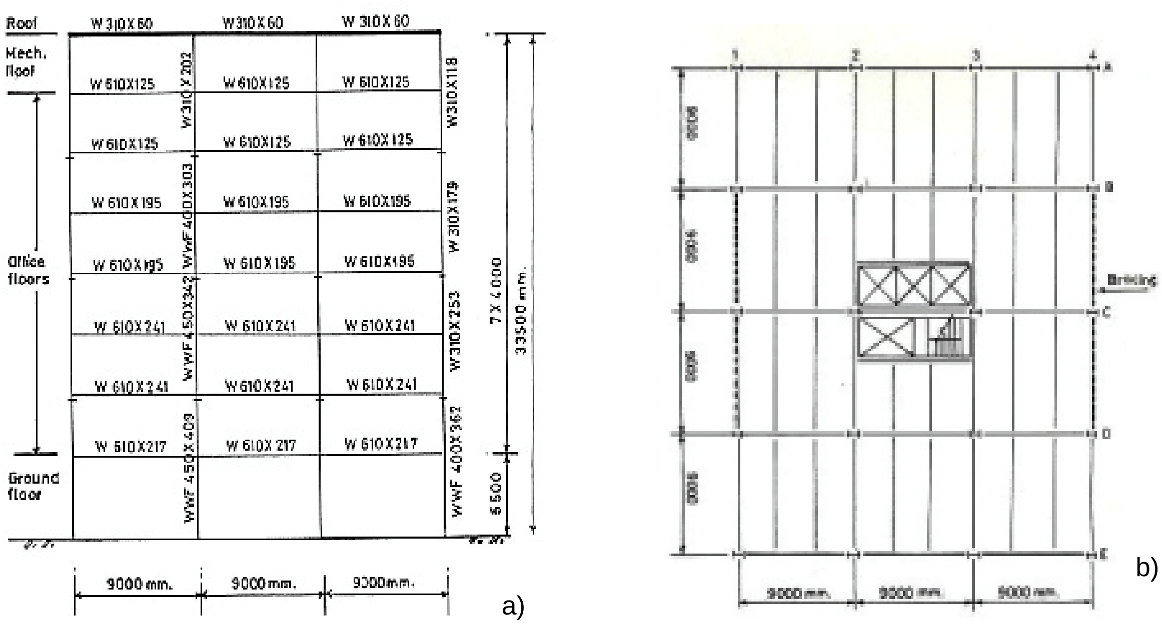

Fig 4 a) Elevation with cross sections and dimensions b) plan

The building was modeled using the computer analysis program SAP2000 and then subjected to a number of pre-recorded real earthquake motions. The most critical earthquake, in terms of the vibration of this building, was determined. Fig. 5 shows the time history of the ground acceleration pertaining to this earthquake (Long Beach California – Marsh, 10, 1933).

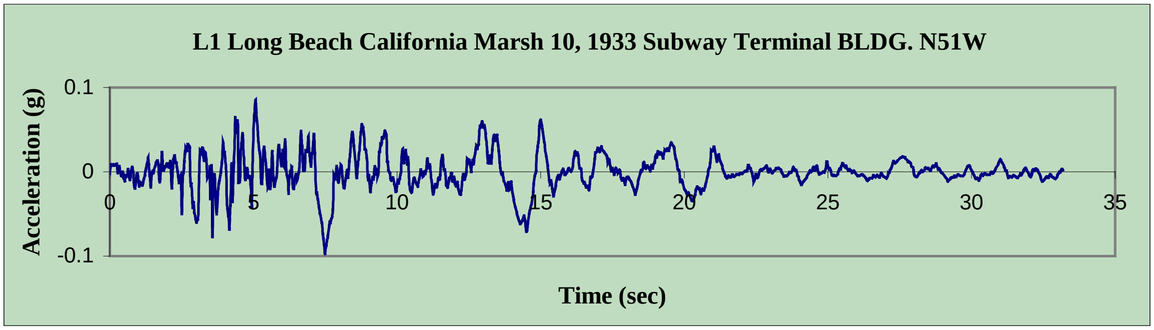

Fig 5 Time History of Long Beach California Earthquake.

The time history of the top displacement of the structure, resulting from the analysis of the structure under this particular earthquake motion, is given in Fig. 6. The study proceeded by considering the equivalent tuned mass damper simulating the TLD that was evaluated experimentally in study I. This TMD was attached to the structure which was then analyzed using the same earthquake record. The time history of the top displacement of the structure, obtained in this case is given in Fig.7. Comparison between Figs 6 and 7 reveals the efficiency of the tuned liquid damper system. Under the same type of excitation, the addition of a TLD has reduced the top displacement by approximately 60 %. Such a reduction in vibrations can save the integrity of the structure in case of occurrence of a strong earthquake.

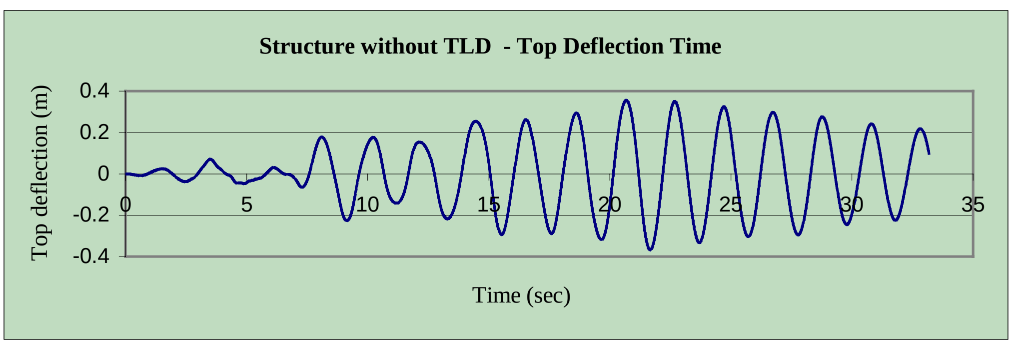

Fig. 6 Time History – Top Deflection - Structure without TLD

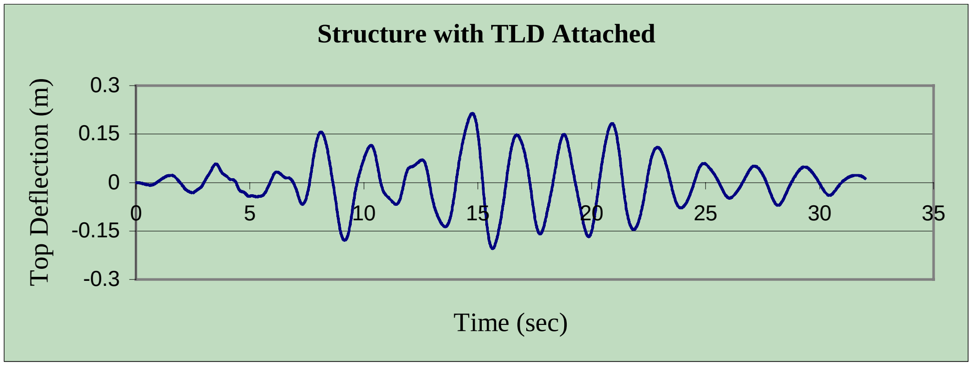

Fig. 7 Time History – Top Deflection - Structure with TLD

b) *Phase II:*

The fluid program developed in study II will be linked with an in-house developed structural analysis program. The integration between these two programs will lead to the development of a unique tool that can predicts the seismic performance of a building strengthened using a TLD system.

c) *Phase III:*

A very innovative approach of real time interaction between a physical test and a numerical model is to be developed in this phase. The full-scale structure (without TLD) will be simulated numerically using a computer analysis program. The full-scale TLD will be Physically attached to the shake table and subjected instantaneously to the acceleration at the top of the structure as predicted by the computer analysis program. An interactive and continuous feed back of response between the physical test and the computer model will allow a prediction for the real time response of the structure (with TLD attached) under high level of oscillations. This development will allow a prediction for the structure response even during the occurrence of wave breakings.

About 50% of this phase of the study has been already accomplished.

Utility of Research Results for the Insurance Industry

Preliminary experimental and analytical results have indicated that the TLD concept represents a very efficient mean for up-grading the seismic resistance of buildings. This Simple concept which involves attaching shallow water tanks to the top of a structure, has a lot of advantages. These include the ease of construction and the low capital and maintenance cost. The current study will provide a clear understanding about the behavior of structures with supplementary tuned liquid damper (TLD). In addition, an expected outcome of this study is the development of tools that can be used to design a TLD system and to predict the seismic response of a structure with a TLD attached. This is expected to assist in spreading the applicability of this simple and efficient structural up-grading concept. As a result, the integrity of building, with TLD attached, can be saved in case of occurrence of a strong earthquake. This will significantly reduce the devastating effect of an earthquake occurring in a city like Vancouver, and will definitely benefit the public and the insurance industry.

Conclusions

An extensive research program to study a promising technique for seismic up-grade of structures is currently progressing at the University of Western Ontario. The technique involves the attachment of shallow water tanks at the top of the structure and relies on the developed sloshing wave to dissipate a portion of the energy released during an earthquake.

Various aspects of this problem are currently under investigation by three Ph.D students. The investigations are conducted both experimentally and analytically and they involve studying both the fluid and the structural aspects of the problem. In addition to the author of this report, two research directors are involved in this program. Preliminary results have clearly shown the efficiency of this concept. As an example, an attachment of a TLD system to an eight story steel building, led to about 60% reduction in the vibrations of this building that result from a real pre-recorded earthquake. Such a reduction could save this building in case of occurrence of a strong earthquake at the building's location. An expected outcome of this study is to develop tools that can be used in designing tuned liquid dampers that can be attached to specific buildings for up-grading their seismic resistance. These tools will encourage engineers to apply this simple concept and as a result human and economical losses can be saved in case an earthquake occur in one of the Canadian cities.

Acknowledgement

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