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Damping system to increase dynamic strength of slender structure

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ABSTRACT: Several trends indicate that the design of structures is becoming more slender and filigree for esthetical and financial reasons. The innovative damping system offers new solutions for the contemporary construction with slender light-weight structures, higher strength materials and an increased awareness of earthquake risk. This paper describes how slender structures could be made more resistant against dynamical forces caused by wind and earthquake. On the structures dampers are mounted which are located parallel to the center line of the structure. The damping system can be implemented in different structure types like high rise buildings and bridges and in several ways along the structure. Experiments were carried out in the laboratory in order to show the efficiency of the new damping system. In order to predict the structural damping ratio of future structures several numerical models were elaborated and the results were compared to the laboratory experiments.

1 INTRODUCTION

Humankind always tended to build higher and more slender structures. Many details have been solved to increase technical progress and adapt the strength of the construction material to new construction methods. Nowadays the precise analysis of the structures is one of the fundamental reasons that such slender construction can be built. Contemporary architecture and modern bridge design show an increased sensitivity for dynamic excitation. Due to these trends the innovative damping system could make a useful contribution to the future design of slender light-weight structures. There are many different types of damping systems for the reduction of the dynamic hazards of earthquakes or strong winds. The damping system depends on the one hand on the choice of the type of the damper e.g. metallic dampers, friction dampers, viscoelastic dampers, viscous fluid-dampers, tuned mass dampers and tuned liquid dampers, and on the other hand the method of implementation. Our objective is to find a system of placing dampers along the whole structure which achieves energy dissipation from the bottom to the top of the structure. The alternative way requires the development of dampers which can easy be build and handled in the civil engineering world, without having the costs of the dampers derived from the mechanical engineering area.

2 SYSTEM DESCRIPTION

The new method protects structures like e.g. high rise buildings, towers, chimneys and bridges from vibrations, due to wind or earthquake loading. The structure supports dead, variable and dynamical loads in horizontal and vertical direction. Waves produced by an earthquake or wind affect the structure less if the damper is integrated. A structure equipped with the damper can be seen as a compound beam which improves the bending resistance. The damper is situated parallel to the centre line of the structure and is activated as soon as the structure is subjected to bending and longitudinal elongation (Fig. 1). The kinematical relationship for the determination of the axial deformation Δl depends on the strain- deformation equation for a bending beam, which is determined by the curvature κ. The curvature depends on the radius of curvature of the beam axis through the centroids of the cross-section. Under the dynamical loading the structure oscillates and the relative displacement causes the damper to dissipate energy. The innovation consists in the application and the shape of the dampers. For high rise buildings or chimneys the viscous dampers are running along the entire height of the building und are part of the supporting structure.

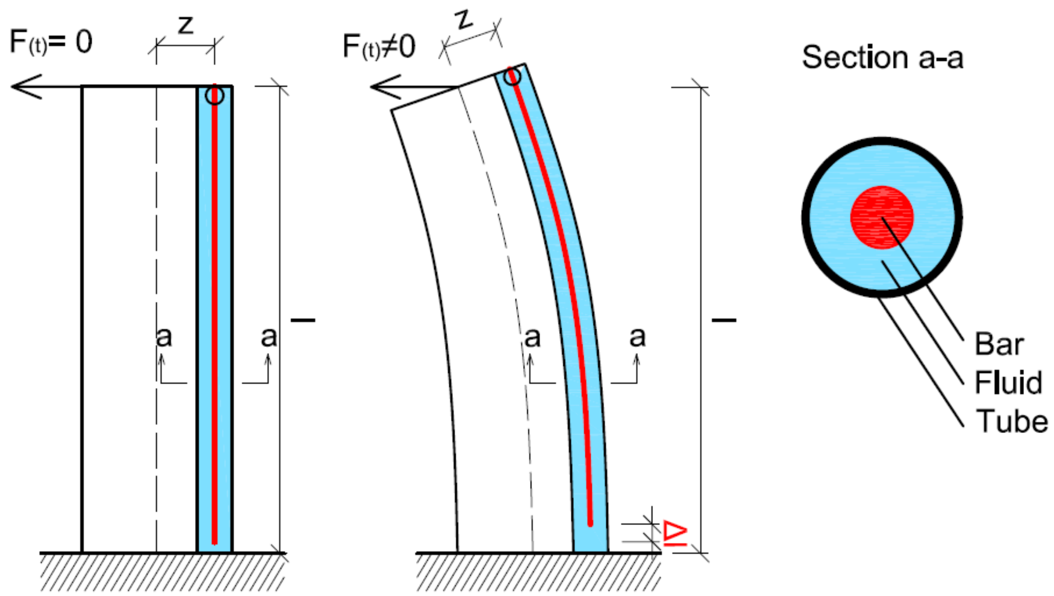

Figure 1. Cantilever beam with an integrated damper (Kollegger, 2009)

The dampers can be integrated in columns or in structural walls by leaving just a void formed by a steel or plastic tube. In the tube a steel bar with ribbed or profiled surface connected to the structure at one point only is installed. After installation of the bar the tube is filled with a viscous liquid. The bar moves relatively to the tube when the structure oscillates (Kollegger, 2009). The damping value depends on the size, shape and filling of the damper. For each single structure the damper has to be calibrated in order to achieve the highest damping value in the state of resonance.

For arch bridges the dampers could be placed along the hanger between the arch and the bridge deck or in a stay cable bridge, in the stays. It would also be possible to integrate the tube and the bar in the bridge beams so that the damper would not only reduce the ambient vibrations but also the ones caused by cars and trains.

One of the main objectives of the structural damping method is to simplify the installation of the dampers without any more expenditure for corrosion prevention.

3 DESCRIPTION OF THE EXPERIMENTS

3.1 Experiment to evaluate the damping ratio of different types of dampers

In the laboratory of the Institute for Structural Engineering at Vienna University of Technology experiments were carried out to prove the theoretical thesis of the topic. The first experiment consisted in testing the different types of dampers in order to evaluate their damping constants. The shells of the dampers were round fiberglass tubes with different diameters. The tubes were filled with water or silicon oil. Different shaped bars were plunged into the tubes. The bars were either threaded bars or threaded bars with screwed nuts and washers or threaded bars surrounded with perforated steel plates. In order to excite vibrations a shaker or an impulse hammer was used.

The evaluated results published in the master thesis of Christian Neubauer (2009) have shown that the bars with the screwed nuts and washers had the highest damping effect. However for the second experiment we chose the bar surrounded with perforated steel plates because the damping effect was just slightly lower and more perforated steel plates could be placed around the bar thus the damper gave the expected damping-values.

3.2 Laboratory test of the damping system

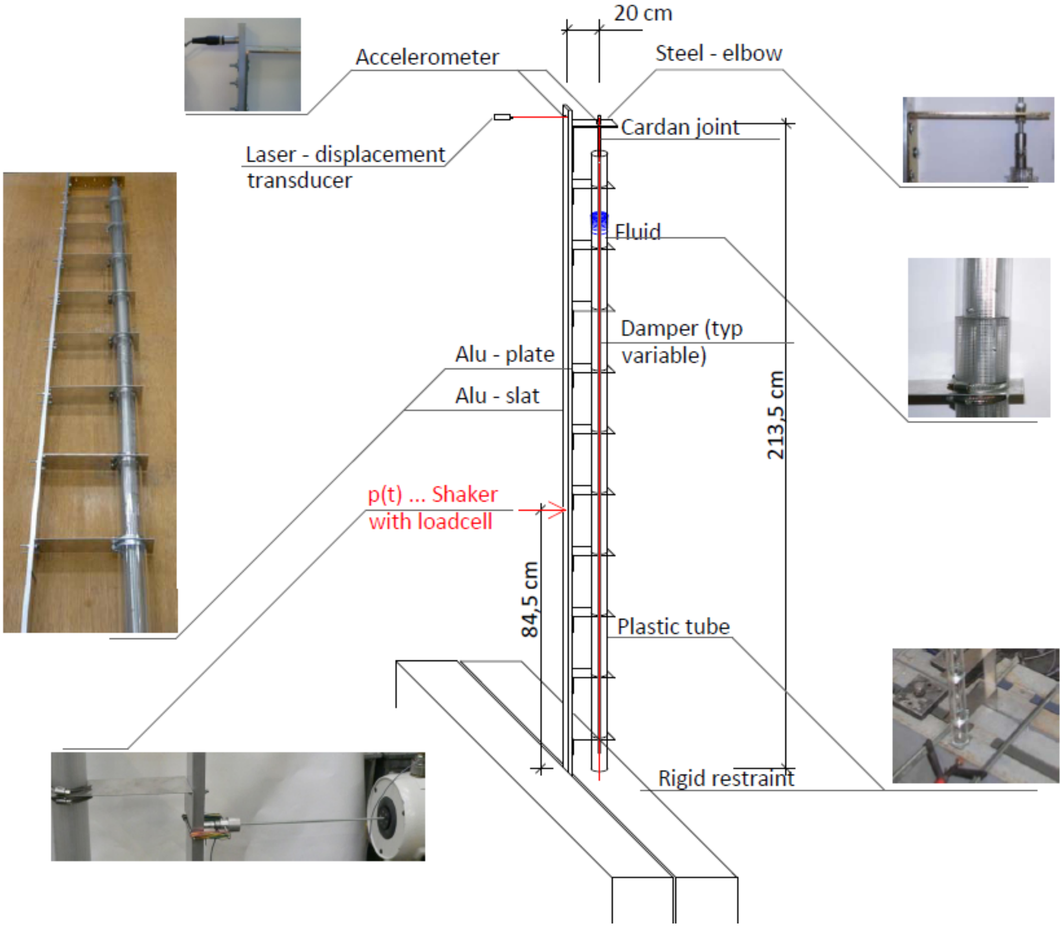

Figure 2. Experimental construction to test the new damping system (Neubauer, 2009)

The second experiment shows a structure with the implemented new damping system. The cantilever beam with the eccentric connected damper is shown in Figure 2. Steel plates jointed on both sides serve as spacers between the damper and the beam. The damper has the same shape as the one used in the first experiment where it was analyzed and the damping constant was ascertained. The damper is 2 m high and has an eccentricity of 0,2 m from the aluminum beam. In order to determine the stiffness of the structure a static experiment was carried out. A calibrated weight was placed on the aluminum beam in order to displace the structure, and with the laser – displacement transducer the precise distance was measured. Due to these results the stiffness of the structure could be calculated. After this the structure was excited by a sinusoidal force or an impulse hammer and the dynamic damping values could be determined.

The plastic tube was gradually filled once with water and once with silicon oil with 5000mm²/s kinematic viscosity. The bar moved up to ±1,3mm relatively to the tube in the state of resonance. The diagram (Fig. 3b) shows the result of the experiment using the profiled bar with perforated steel sheets (Fig 3a). By using silicon oil the damping ratio increases from 3 to 10% by gradually filling the tube from the zero to 1,8m. The diagram shows that the damper filled with water is less efficient than the one filled with silicon oil.

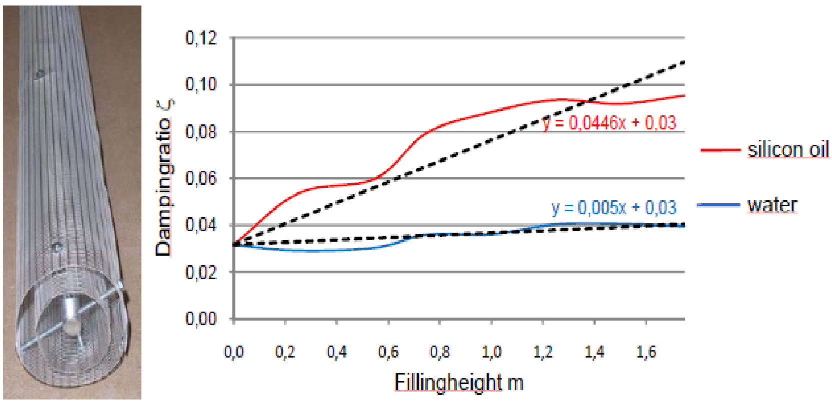

Figure 3. (a) Bar surrounded with perforated steel plates; (b) Diagram of the damping ratio (Neubauer, 2009)

3.3 Field experiment on a concrete cantilever beam

A third experiment on a larger scale was carried out employing the bridge pillar which had been used for the balanced lift method experiment (Kollegger, 2008). The pillar has a height of 8,3 m and on top a base area of 1,10m by 0,40m. The cantilever is made of reinforced concrete with the concrete quality C40/50 and steel bars quality BSt 550. On top of the pillar four electro-dynamic force generators were placed to produce dynamic forces in the direction of the two principal axes and around its centre line in order to generate a torsion moment. The damper was placed in four different places eccentric to the centre to enable the analysis of several cases. For one experiment (Fig. 5a) the damper was applied in a distance of 0,80m from the centre line of the cantilever beam. The damper was built once again using a fiberglass tube filled with silicon oil 5000mm²/s kinematic viscosity. The profiled bar with three rings of perforated steel sheets was moved along the tube every time the pillar moved. The damping ratio ζ of the structure increased by 1,0% in accordance with the numerical analysis.

Figure 4. (a) and (b) bridge pillar with implemented damping system; (c) electro dynamic force generator

4 NUMERICAL SIMULATION

To predict the structural damping ratio, computational models were developed by means of the commercial software SOFiSTiK. The FEM-model consists in beam elements for the concrete cantilever beam and the fiberglass tube. The damper was modeled with viscoelastic damping springs, which were connected to the pillar with kinetic constraints. By using the dynamic tools DYNA and ASE (SOFiSTiK AG, 2009) the finite element model (Fig.5a) was excited by the sinusoidal force. For the numerical calculation the modal analysis and the time integration method were chosen respectively. The results of the natural frequencies, the results of the displacements and accelerations of the numerical models are very much in accordance with the experimental laboratory tests. Figure 5b and 5c show a comparison of the dynamic displacement amplitudes of the numeric analysis and the laboratory tests after the transient oscillation.

For the field tests the numerical simulation proved to be much more difficult. First of all the stiffness properties of the pillar could not be ascertained by a precise static experiment which had been performed in the second laboratory experiment. In the laboratory test, it could be assumed that the cantilever beam had a nearly rigid restraint, which was not the case in the field test, even if the threaded bars were prestressed in order to achieve a higher restraint.

To develop the numerical model the eigenfrequencies of the field experiments and the simulation were compared. The bearing properties of the computational model were adjusted until the natural frequencies matched the ones evaluated from the experimental tests. By exposing the numerical model to the same dynamical forces as the pillar in field test, the results of the displacements and accelerations concurred. Unfortunately, due to the low force power of the four electro dynamic force generators and the high stiffness of the cantilever, the concrete pillar never reached the cracked state. In the state of resonance the pillar, applied with maximum sinusoidal force, the maximum oscillation displacement on top of the pillar amounted to ±15mm at the natural frequency of 1,7 Hz and the bar moved ±1mm up and down in the fiberglass tube. Consequently, there are no differences between linear or nonlinear material model simulations. Even when calculating with linearized geometrical relationships or a more precise third order theory, the approach made no significant alteration.

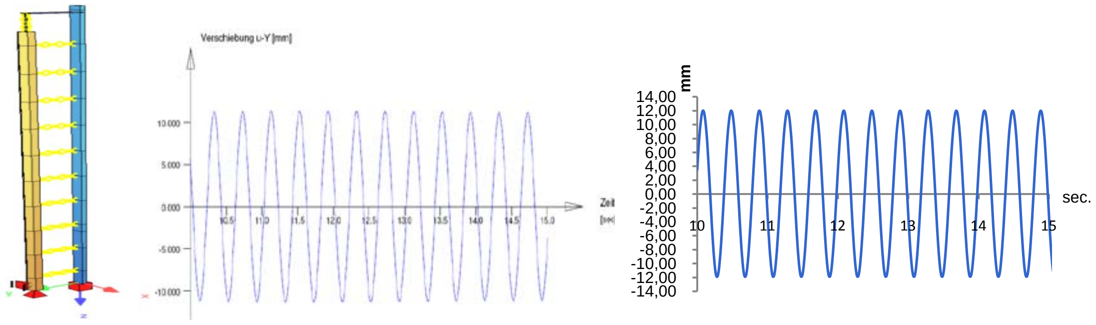

Figure 5. (a) Numerical model; (b) time- displacement results from FEM; (c) time- displacement results from laboratory tests

5 OUTLOOK

In the future we will analyze this easy way of placing dampers along structural walls for common buildings in order to reduce the shear deformations under earthquake loadings (Fig. 6) and to find out by using numerical models when the concrete structure changes from the uncracked state to the cracked state and to analyze the loss of the structural safety.

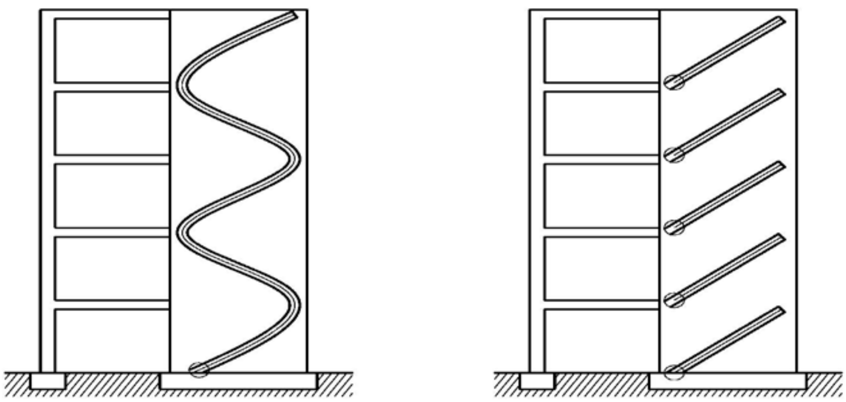

Figure 6. Damping system for shear deformation (Kollegger, 2009)

6 CONCLUSION

The innovative damping system can be integrated in many types of structures and also in many ways. Dynamical excitations are becoming more and more important and the newly developed system could offer a solution. The experiments have shown that the applicability of the system is uncomplicated and the damper can be mounted in a new construction as well as in already existing structures which need increased dynamic strength. Important issues are the simple handling during the construction process and the low cost maintenance over the lifespan of the structure.

7 REFERENCES

Kollegger, J. & Egger, P.(2009) Tragkonstruktion. Patent application T12456 Austria, March 18, 2009

Neubauer, C. (2009) Untersuchungen zur Entwicklung einer Tragkonstruktion mit hoher Strukturdämpfung. Vienna : Vienna University of Technology

Kollegger, J.& Blail, S.(2008) Balanced Lift Method for Bridge Construction. *Structural Engineering International*. Volume 18, 2008

SOFiSTiK AG.(2009) DYNA. Oberschleißheim : SOFiSTiK AG

SOFiSTiK AG.(2009) ASE. Oberschleißheim : SOFiSTiK AG

Mang, H & Hofstetter, G.(2008) Festigkeitslehre. Wien : Springer

Chopra, A. K.(2007) Dynamics of Structures: theory and applications to earthquake engineering. Upper Saddle River, NJ : Prentice Hall

Bachmann, H.(1995) Erdbebensicherung von Bauwerken. Basel: Birkhäuser

Soong, T.T.& Dargush, G.F.(1997) Passive Energy Dissipation Systems in Structural Engineering. Chichester: Wiley