

ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ – СОФИЯ

Първа научно-приложна конференция с международно участие
„СТОМАНОБЕТОННИ И ЗИДАНИ КОНСТРУКЦИИ – ТЕОРИЯ И ПРАКТИКА“

22 – 23 октомври 2015

22 – 23 October 2015

First Scientific-Applied Conference with International Participation

“REINFORCED CONCRETE AND MASONRY STRUCTURES – THEORY AND PRACTICE”

ANNUAL OF THE UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY – SOFIA

48 ^{ТОМ}
vol.

2015

св. 12 – II
fasc.

SEISMIC RETROFITTING OF A HOSPITAL IN ROMANIA

P. Nawrotzki¹, D. Siepe²

Keywords: historic buildings, passive control, seismic retrofit

Research area: seismic protection

ABSTRACT

The history has shown that there is a threat to existing structures caused by seismic excitation. There are many examples worldwide of cultural heritage structures and existing buildings which are not sufficiently protected against earthquakes. A retrofitting strategy has to be developed if the seismic safety of these structures is inadequate. Conventional methods like strengthening are well-known. Nowadays there are several projects for which different or additional protection measures, like the implementation of a Tuned Mass Control System (TMCS) are used. Such systems consist of an additional mass, elastically connected with the building. Viscous dampers are arranged additionally to reduce the relative motion between additional mass and building and to widen the effective frequency band accordingly. The TMCS causes a significant reduction of induced acceleration and displacement levels as well as of internal stresses.

The following paper deals with the description of the seismic retrofit of a hospital in Slobozia, Romania. Results of numerical and experimental investigations are described to verify the effectiveness of the mitigation measures. Another important advantage of Tuned-Mass systems is the possibility to operate inside the building as there is no disturbance by the upgrade activities. Several pictures of details of the installed systems demonstrate the general applicability of the TMCS for the seismic retrofit of new or existing structures.

¹ P. Nawrotzki, Dr., Roedernallee 174 – 176, 13407 Berlin/Germany, peter.nawrotzki@gerb.de

² D. Siepe, Dipl.-Ing., Ruhrallee 311, 45136 Essen/Germany, daniel.siepe@gerb.de

1. Introduction

This contribution describes the seismic upgrade of a hospital in Slobozia, Romania using a consolidation strategy consisting of conventional strengthening measures and the application of a Tuned Mass Control System (TMCS). The increase of structural damping of constructions is a common and well-examined strategy to reduce the dynamic responses due to seismic excitations. One approach to achieve the increased damping is the application of the mentioned Tuned Mass Control Systems. Finite element models of the original and of the protected structure have been used to verify the effectiveness of the specified system. Some chosen results of the analysis, the design and the implementation of the TMCS units to the hospital in Slobozia will be introduced in this paper.

In the context of the TMCS, also details of experimental and analytical research will be discussed and two example projects will be introduced. The first example presents the implementation of a TMCS as part of the seismic retrofitting of Palatul Victoria, a historical monumental building. The other example explains the application of a TMCS to the Puente Oriente, a low damped elevated steel bridge structure.

2. Seismic Protection using Tuned Mass Control Systems

The development of seismically efficient Tuned Mass Control Systems (TMCS) is based on the vast experience from Tuned Mass Damper systems working against wind and men-induced vibration worldwide. TMCS provide passively working earthquake protection. They absorb horizontal forces and are practically maintenance-free. Requiring no electrical power supply or any other form of drive or control mechanism they are immediately effective when an earthquake strikes. TMCS are applicable for the protection of existing or new structures against seismic demands. They consist of an additional mass that is usually arranged at the highest level of the structure. This mass is connected with the structure by springs such that the corresponding frequencies are related according to specific rules. Dampers are arranged additionally to reduce the relative displacements between additional mass and structure and to widen the operating frequency band of the TMCS. The TMCS causes a significant reduction of induced acceleration and displacement levels as well as of internal stresses and support reactions due to seismic excitation, even when the design is considering nonlinear structural effects as verified in [1].

The following chapters provide details about numerical and experimental research. Furthermore, some information about executed projects is presented.

2.1. Experimental Investigations

A five-storey steel frame model, equipped with a Tuned Mass Control System. Shaking table tests with and without activated TMCS have been performed at IZIIS (Institute of Earthquake Engineering and Engineering Seismology) in Skopje, Macedonia. The total mass of the steel structure amounts to approximately 19 tons. The mass of the TMCS is 0.26 tons, representing 1.4% of the entire mass. Each floor has got a height of 0.75 m, leading to a total height of 3.75 m. The dimensions of the three longitudinal spans are 1.5 m. The one transversal span has got a length of 1.5 m. The red braces are used to adjust the required stiffness and damping for the tests. The structure with installed TMCS is shown in Fig. 1.

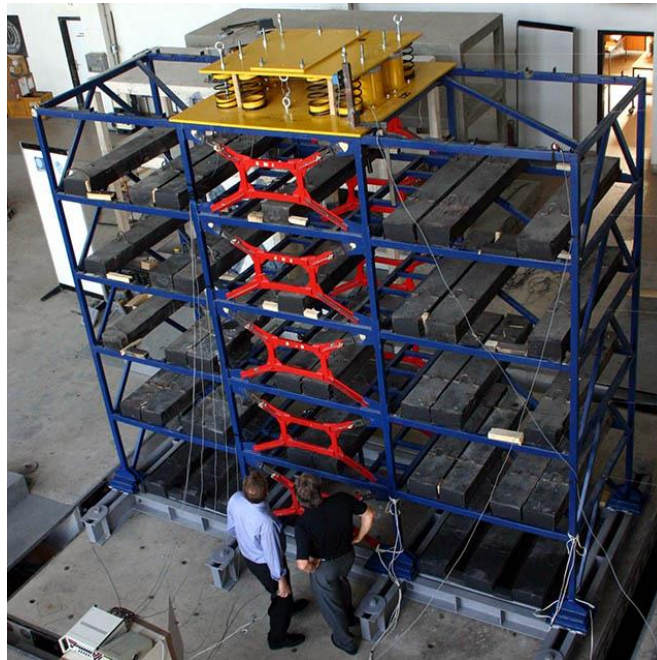


Figure 1. Steel frame with horizontal TMCS on shaking table

The shaking table excited the structure with several measured and artificial seismic time-histories with different intensities. The results in terms of absolute accelerations, relative displacements and bending strain of the frame with activated and with blocked TMCS are compared to investigate the efficiency of the system. Some typical results of the evaluated structural responses are shown in Fig. 2.

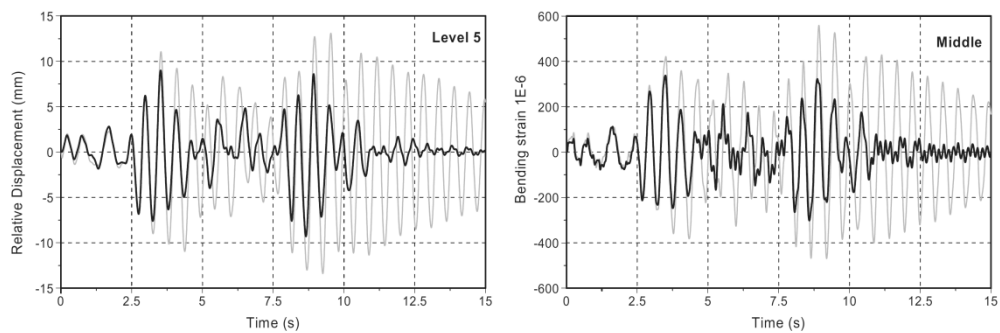


Figure 2. Measured responses with activated (black curves) and locked TMCS (grey curves)

Here, the activated TMCS causes an improvement of performance by nearly 40%. More detailed information can be taken from [4]. The large number of recorded time history responses verifies that the TMCS reduces the structural responses by about 25 – 40%. The efficiency is depending on mass of the main structure, mass ratio of TMCS, seismic input, internal damping, arrangement of the TMCS and other structural parameters.

2.2. Analytical Investigations

Numerical analyses are performed in parallel to the experimental shaking table tests. Fig. 3 shows an example for the finite element models of a building without and with a Tuned Mass Control System.

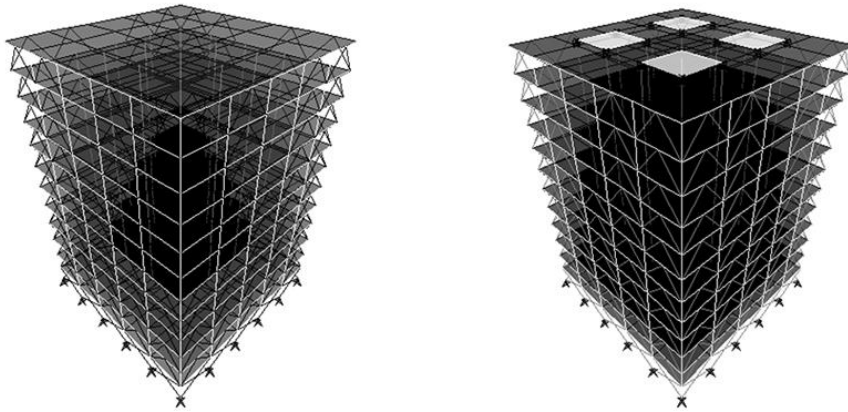


Figure 3. Finite element model without (left side) and with TMCS (right side)

The efficiency of the protection system is guided by the choice of the parameters of the TMCS as effective mass, tuning frequency and internal damping ratio. The well-known optimization criteria according to [2] are not fully applicable here. They are developed in regard to harmonic excitations. For seismic excitations it is recommended to use a higher internal damping ratio to widen the working frequency band of the TMCS. Values up to 20 – 30% are usually chosen, depending also on the target motion values. The structural responses of the building are significantly reduced by the TMCS. Internal forces, absolute accelerations, relative displacements and interstorey drift values are decreased.

Fig. 4 presents the comparison of the horizontal displacement at the top and the axial force at a corner column as example. The responses of the original, unprotected building are plotted as grey curves and the black, dotted curves show the behaviour of the protected structure.

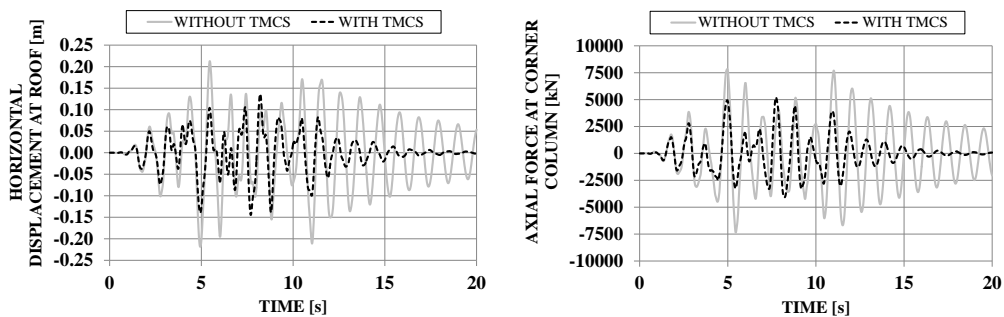


Figure 4. Typical structural responses with/without TMCS

The seismically induced peaks are reduced by about 40%. The time history curves show that the TMCS causes an increase of damping for the building. In the model with TMCS the residual motion after the strong motion phase at about 10 s is significantly damped out during 2 – 5 s. During this time domain the unprotected model still shows high amplitudes.

2.3. Project Examples

New buildings or new structures can be improved in their seismic resistance by arranging a TMCS; anyhow, the system can also be used for the upgrade of the seismic performance in existing structures. In this context it is a very interesting possibility for sensitive buildings such as hospitals, industrial structures, office and residential buildings as well as historical monuments.

The seismic retrofit of Palatul Victoria in Bucharest, Romania is an example for a monumental building structure. The building was built around 1937 and is used by the government of Romania. Fig. 5 shows the front view and one part of the Tuned Mass Control System during its installation in 2011.



Figure 5. Front view of Palatul Victoria (left side) and TMCS at roof (right side)

The building consists of reinforced concrete members, as well as of brickwork. The total length is about 100 m, the width about 50 m and the height of the main parts amounts to 24 m. The seismic retrofitting strategy consisted of the combination of conventional strengthening measures, the arrangement of additional shear walls and the implementation of a TMCS. According to [3] the seismic responses in terms of top storey displacements, response accelerations, internal forces and interstorey drift values could be reduced by about 50%. The decisive advantage of the mitigation measures was the possibility to install the TMCS at the roof – without interrupting the use of the building.

For this particular building the seismic demands were not considered during the planning phase of the structure. Thus, a seismic retrofit was required to keep the limits of current standards, especially in regard to the interstorey drift. If seismic effects are taken into account during the design of a structure, Tuned Mass Control Systems can be applied initially to improve the seismic behaviour. The following project is a corresponding example for this issue.

The Puente Oriente, also known as Puente El Alamo, is an elevated steel bridge structure with a reinforced concrete deck located near Guadalajara, Mexico. Fig. 6 presents a view of this bridge and the installed mass of the TMCS.

The total length of the bridge is approximately 500 m with an average span of each bay of 40 m and is equipped with 8 TMCS units. The effective mass structures of the TMCS

have been applied underneath the deck in range of the central column structures to reduce the rocking vibrations of the bridge under seismic loads. Time history analyses of the structure with and without protection system verified that the TMCS lead to significant reductions of seismic displacements, accelerations and base reactions in a range of 20 to 50%.



Figure 6. Bridge with TMCS

3. A Hospital in Slobozia

Slobozia is the capital of Ialomita County, Romania and is a small city, located approximately 120 km east of Bucharest. The construction of this hospital of Slobozia started in 1965. Since 1970 the hospital is an important county hospital with more than 700 beds. The building consists of reinforced concrete members, especially columns, beams and floors. The total length is about 110 m, the width about 13 m and the height of the main parts about 31 m. The total mass of the building is assessed with approximately 18100 tons. Fig. 7 shows a picture of the structure.



Figure 7. Front view of Hospital Slobozia in 2007

Slobozia is located in a seismic zone. The seismic input can be described by the peak ground acceleration of 0.28 g and a spectral amplification factor of 2.75. The structure consists of several different parts, which are separated by joints. The clearance is very small and in case of an earthquake high interstorey drift ratios as well as hammering effects can be expected. Corresponding damage may affect columns, walls and slabs and the necessary repair work would be tremendous. As a consequence the building could not be used in the meantime, which is not acceptable because of its importance for the health care in this region of Romania.

A retrofitting strategy was developed to improve the seismic behaviour of the hospital. This strategy paid special attention to the fact that important rooms of the hospital (e.g. emergency rooms) must be used during the construction works. The following chapters describe the chosen strategy and important design and retrofit details.

3.1. Consolidation Strategy

A mitigation measure is developed which consists of a combination of conventional strengthening and the arrangement of a Tuned Mass Control System. The aim of the strengthening was to provide the building with more resistance to seismic loads. In the first step the floors at the roof are coupled in a way that the relative motion between the separated parts becomes very small in case of an earthquake. Hammering effects between adjacent building parts can be avoided now. During the second step the possibility to arrange new shear walls inside the building to reduce the interstorey drift ratio was investigated. In general, the space for strengthening measures was very limited inside the hospital. Due to the importance of the building the areas where steel frames / shear walls can be placed are very restricted and hence, it was decided to arrange three new additional steel frames outside the building with a rigid connection between building and steel frame as shown in Fig. 8.



Figure 8. Steel frame connected to existing building by chemical anchors

The number and size of these new steel frames are not sufficient to achieve the required seismic safety. Therefore this strategy has to be completed by additional measures. For this purpose a suitable TMCS was developed. The corresponding details of this system are provided in the following chapter.

3.2. Details of the Tuned Mass Control System

The TMCS at the hospital in Slobozia consists of three mass blocks made of reinforced concrete. Each of the three steel frame structures is equipped with one mass, weighting about 53 tons. The mass blocks are arranged inside each upper, horizontal part of the steel frame structures. The mass ratio between TMCS and total mass of the building amounts to about 0.9% only. The concrete blocks are hanging on ropes and are elastically connected to the steel structure in both horizontal directions by spring elements. Two viscous dampers are used for each unit. The optimum parameters of the TMCS are defined based on the results of several seismic calculations. Response spectrum analyses and time history analyses of the three dimensional finite element models are performed using the commercial software SAP2000.

The computer model was adjusted to the results of field measurements in terms of eigenfrequencies and corresponding mode shapes. Altogether three different finite element models are created to consider the single steps of the consolidation strategy. They can be described as follows:

- Model A: Structure with joints, without steel frames and without TMCS.
- Model B: Structure with steel frames and coupled slabs at the roof.
- Model C: Structure with steel frames, coupled slabs and TMCS.

Fig. 9 presents the comparison of some typical results in relation to the original, unprotected structure.

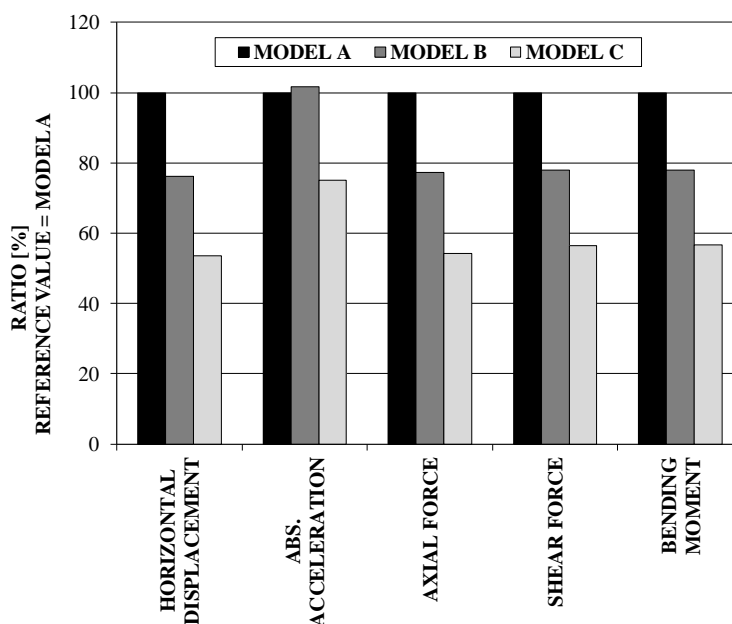


Figure 9. Efficiency of conventional retrofit and efficiency of conventional retrofit and TMCS

The results show that the TMCS significantly reduces the top story displacements, response accelerations and induced internal forces due to seismic loading.

3.3 Construction and Commissioning

The construction works started with the coupling of the slabs and the arrangement of the three new steel frame structures. The view of the building structure at this stage is shown in Fig. 10.



Figure 10. View of the retrofitted hospital

Ambient vibration measurements of the building were performed after finalizing these strengthening measures. The results show a slight increase in the first natural frequency in longitudinal and in transversal direction in comparison to the results of the original structure. The tuning frequency of the TMCS was determined to about 2.0 Hz in longitudinal and about 1.6 Hz in transversal direction. The spring devices provide the possibility to change the helical steel spring, used inside. Thus, it was possible to implement the springs inside the elements to reach the desired frequency of the TMCS. Finally also the modal parameters of the TMCS are measured and verified. Due to the subcritical tuning frequency for both directions and the high viscous damping it is ensured that the operating range is within approximately 60% to 98% of the measured main frequencies of the structure. All performed calculations verify that this range covers all realistically occurring dynamic events.

4. Conclusion

The paper presents the technical background for the use of Tuned Mass Control Systems as seismic protection measures. Details of analytical and experimental investigations together with executed projects are explained. Afterwards the most important details of the seismic retrofitting of a hospital in Romania are presented. Here, the seismic retrofit included the combination of conventional strengthening with the implementation of a TMCS.

The application of a TMCS, not necessarily in combination with strengthening measures, is able to significantly reduce the seismic results of the structure in terms of

relative displacements, absolute accelerations and internal forces. These systems could be used for existing structures as well as for new structures.

LITERATURE

1. *Brendike, A., Y. Petryna.* Seismic retrofitting of reinforced concrete frame structures by Tuned-Mass damper. Proceedings of 8th International Conference on Structural Dynamics, EURODYN, 2011.

2. *Den Hartog, J. P.* Mechanical Vibrations. McGraw Hill Book Company, New York, USA, 1956.

3. *Meinhardt, C., D. Siepe, P. Nawrotzki.* Passive Damping Devices for Earthquake Protection of Bridges and Buildings. The Journal of the Anti-Seismic Systems International Society (ASSISI) DOI: 10.2140/siaps.2011.2.35, 2011.

4. *Rakicevic, Z., A. Zlatevska, D. Jurukovski, P. Nawrotzki.* Analytical Estimation of the Effectiveness of Tuned-Mass Control Systems using Shaking Table Experiments. Proceedings of 4th World Conference on Structural Control and Monitoring, 2006.