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Optimization of Tuned Mass Damper for Enhancing Seismic Performance of a RC Building During the 2023 Earthquake in Turkey

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Abstract. On 6th February 2023, a strong earthquake of magnitude Mw7.8 struck the central and southern parts of Turkey and the northern and western parts of Syria. The epicentre of the earthquake was located approximately 35 km west–northwest of the town Gaziantep, followed by more than 570 strong aftershocks. A strong aftershock measuring Mw 6.7 occurred about 11 minutes after the main shock, while the stronger one (Mw 7.5) around 9 hours later, with an epicenter 95 km to the northeast of the first earthquake. Recorded peak ground accelerations reached 2g, while the vertical acceleration was approximately equal to 1.4g. There was widespread damage with collapsed buildings and countless life loss (humans and animals). The aim of the present paper is to study the response of a nine-story reinforced concrete building (RC), during this seismic sequence. The benchmark building was redesigned with the optimal design of a tuned mass damper (TMD) at the roof of the building. The comparison of the results shows the TMD's effectiveness in minimizing 50% of the max-story drift, as well as the horizontal displacement in both directions of the building. In addition, the use of the TMD protects the structure from collapse.

Keywords: RC building, TMD, earthquake, numerical modeling.

1. Introduction

Measures for protection and dealing with crisis situations such as earthquakes, fires, floods, and extreme weather events have been of considerable concern to scientists recently [1]. The earthquake that hit Turkey and Syria on February 6 at 04:17 in the morning was described as "Europe's worst natural disaster in a century" by the World Health Organization, and left behind a country full of trauma. The 7.8-magnitude earthquake killed nearly 51000 people and injured another 105000 in Turkey and Syria, according to the so far inconclusive tally. More than 214000 buildings, many of which were ten stories tall (mid-rise buildings) were also completely or largely destroyed in

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eleven of the country's 81 provinces. The account is tragic and difficult for the human mind to understand, with many questions remaining unsolved [2].

This paper aims to study the response of a nine-story reinforced concrete (RC) building, similar to the building development of the country, during the main seismic sequence. The benchmark building [3] investigated in this study is regular in plan according to EC8 [4] and it was designed to support all the vertical loads. In the second part of this study, the benchmark building was redesigned with the optimal design of a tuned mass damper (TMD) at the top. This type of damper is part of the passive energy dissipations systems [5-6]. Its first application was first in 1909 [7] while its effectiveness is attributed to minimizing structural damages by absorbing the structural vibratory energy. It is a tuned and damped oscillator, usually hidden on the top of the structure and linked to the movement of the last one, in such a way that it ideally oscillates in opposition to it and thus recovers energy. Tall-buildings, skyscrapers as well as bridges have been occupied with TMDs [8-10]. The comparison of the results shows the TMD's effectiveness in minimizing 50% of the max-story drift and the maximum horizontal displacement. In addition, the use of the TMD minimizes the plastic hinges of the columns as well as protects the structure from collapse.

2. Engineering Characteristics

2.1. Strong Ground Motion

The central and southern regions of Turkey as well as the northern and western regions of Syria were both severely damaged by a powerful earthquake on February 6, 2023, measuring Mw7.8 in magnitude. More than 570 powerful aftershocks were recorded following the earthquake, which had an epicentre around 35 km west-northwest of the town of Gaziantep. Eleven minutes after the primary earthquake, a powerful aftershock with a magnitude of 6.7 occurred, and nine hours later, a bigger aftershock with a magnitude of 7.5 with an epicenter 95 kilometers northeast of the first earthquake [2]. Peak ground accelerations measured approached 2g, while vertical acceleration was around 1.4g. Many engineers have already analyzed the characteristics of the vibration, which are judged in terms of seismic engineering, and examined whether there are peculiarities [11-13].

The horizontal acceleration records of Station 4614 in two horizontal directions and the vertical acceleration are presented in Figure 1.

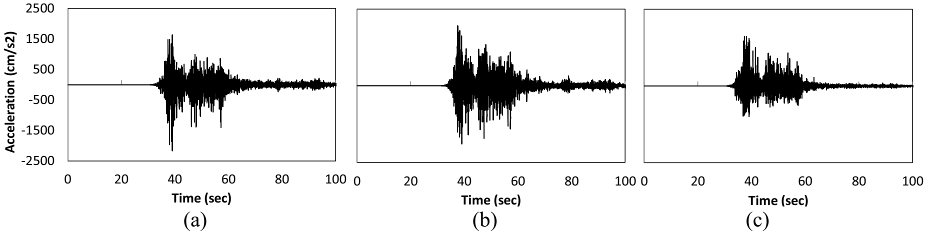
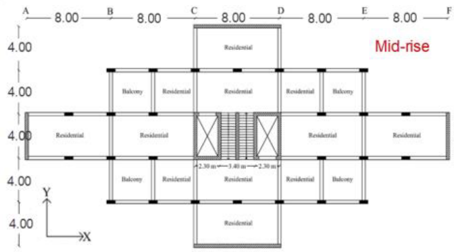


Figure 1. Waveforms of recorded at station 4614. (a) The first horizontal acceleration record, (b) the second horizontal acceleration record, and (c) the vertical acceleration record.

2.2. Benchmark Building

The investigated building (see Figure 2) is regular in the plan according to part 8 of Eurocode [4], it was designed to support all the vertical loads and it is presented in detail by Mrad et al [3]. The external dimensions of the building are 40.00 m in the x-x direction and 20.00 m in the y-y, as illustrated in Figure 2. It consists of 9 floors and it has a total height of 31.50m. The height of each floor is 3.50 m. The horizontal loads are transferred to the foundation trough the strong walls, which are distributed around the perimeter of the building symmetrically to avoid additional torsional effects. Figure 3 shows modelling of the investigated building.



Notation:

1. Concrete C30/37 E=32.9 GPa
2. Steel rebar S500B E =210 GPa

Area	Dead load G [kN/m²]		Live load Q [kN/m²]
Residential	Self-weight +	6	1.5
Balcony		2	3.5
Stairs		2	3.5
Roof		0.12	0.8

Figure 2. Plan of the investigated building.

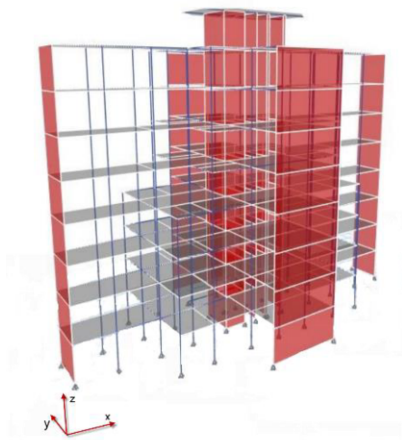


Figure 3. 3D model of the building.

2.3. Redesigned Building

The ideal optimal design is based on the properties of ν and ξ_d, which include the structural damping ratio of the primary structural system ξ, the derived stiffness k_d, and the damping coefficient c_d of the TMD [3, 14]. In addition, the mass ratio $\bar{m}$ is the most important consideration in the process of the optimal design, which in this study is equal to 3%, and has a limit that must not exceed 10% for economic reasons[15].

TMD has been modeled with an additional mass $m_d = 129000\ Kg$, a spring with stiffness $k_d = 7083\ kN/m$, and a damping coefficient $c_d = 200\ kN.s/m$. Frame components have been utilized to represent the beams and columns in both structures, while shell elements have been used to depict the walls. An appropriately selected mesh has been used which includes 272400 degrees of freedom (DOF).

Table 1 presents the fundamental period for the two cases with and without TMD.

Table 1. Period of each building.

Mode	Period (sec)	
	Building without TMD	**Building with TMD**
1	0.982	0.834
2	0.697	0.588
3	0.671	0.575
4	0.2	0.191
5	0.162	0.152

3. Results

Bidirectional horizontal acceleration records from the 2023 Turkey earthquake were used as seismic inputs for nonlinear dynamic analysis (section 2.1). The results are evaluated in terms of base shear load, interstory drift, and maximum horizontal displacement at the structure's top.

The benchmark building (Undamped) and the redesign with TMD optimization (Damped with TMD) both show the horizontal displacement of each level in the longitudinal and transverse directions, respectively, in Figures 4a and 4b. The reduction percentage for the building equipped with TMD dampers, compared with the building without dampers, exceeds 55% in the longitudinal direction on the last floor and 73% in the transverse direction on the last floor.

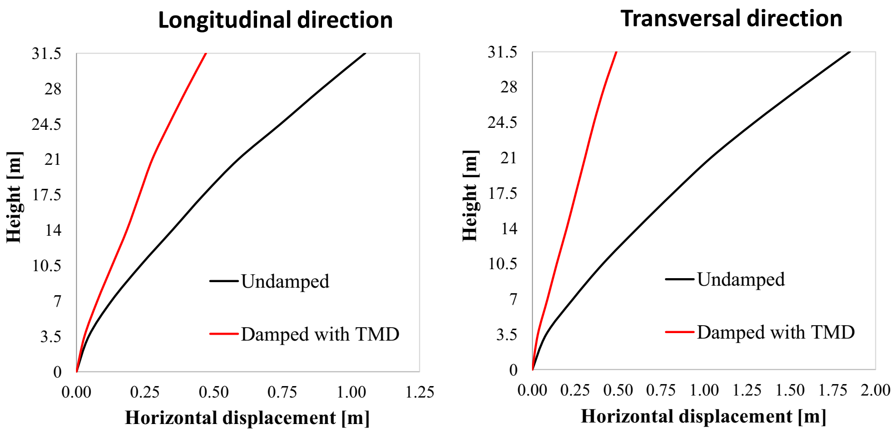


Figure 4. Horizontal displacement of each floor in both longitudinal and transverse directions.

The interstory drift is determined by dividing the interstory displacement $\delta_{s,i}$, by the story height, h_i. The relationship between the interstory drift index and the global drift index δ_t/h_t depends on the extent of inelasticity in the structure, the type of plastic hinge mechanism, and the importance of higher mode effects. According to FEMA [16], the hinge rotation behavior of RC members represents acceptance criteria which are IO ("Immediate Occupancy"), LS ("Life Safety"), and CP ("Collapse Prevention"). A floor displacement drift of 1.6% corresponds to a seismic performance level of "Life Safety", and a drift of 2.1% corresponds to a seismic performance level of "Collapse" [17, 18].

The inter-story drift is depicted in Figure 5 in both longitudinal and transverse directions. We can notice that the redesigned building with the TMD remains in the criteria before CP with less than 2% intestory drift, compared with the benchmark building which achieves the 4.5% in the longitudinal direction and 8.0% in the transversal one, which occurred to complete damage of the building. Buildings with and without TMD dampers have base shear ratios that are respectively 39.93% and 59.14% in both directions.

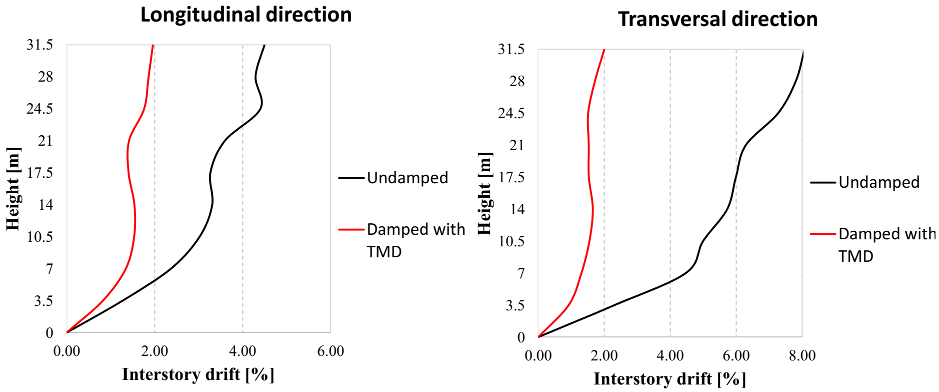


Figure 5. Comparison of the interstory drift of both buildings in both longitudinal and transverse direction.

4. Conclusions

The comparison of the data obtained between the benchmark building (Undamped) and the redesign with TMD, addressed in terms of maximum displacement, inter-story drift and base shear, has resulted in the following interpretations, as well as the confirmation of prior research' conclusions. The results demonstrate the TMD's effectiveness in reducing more than 50% of the maximum-story drift and maximum horizontal displacement. Furthermore, the use of TMD reduces the plastic hinges on the columns and safeguards the building from collapse.

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