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EARTHQUAKE LOAD BEHAVIOR OF A RC BUILDING WITH TUNED-STEEL ROOF SYSTEM

KÜTLE SÖNÜMLEYİCİ ÇELİK ÇATI SİSTEMLİ BETONARME BİR BİNANIN DEPREM DAVRANIŞI

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Abstract

In this paper Tuned-Steel Roof system is proposed to reduce the earthquake effects on existing RC buildings. The idea is to replace the conventional wooden truss roof system by a steel roof system which will be connected to the RC building with low lateral stiffness steel bars. The steel roof can be tuned to have the same natural frequency of the building. All the construction works are applied from outside of the building and do not affect the building function, that there is no need to evacuate the building. Time history analysis on a RC building finite element model was performed to investigate the effectiveness of proposed technique. Analysis results shows that the building with tuned roof get a reduction of top displacement , top acceleration , and base shear by about 20 to 50 percent compared with the building without tuned roof. The reduction is affected by earthquake characteristics and roof mass.

Keywords: Earthquake, RC buildings, steel roof system, tuned-mass.

Öz

Kütle Sönümleyici Sistemleri (TMD), demiryolu trenleri gibi rüzgar ve trafikten kaynaklanan titreşimin azaltılması için yaygın olarak kullanılmaktadır. Bu makalede, mevcut betonarme binalar üzerindeki deprem etkilerini azaltmak için TMD Çelik Çatı sistemi önerilmektedir. Bu öneride, geleneksel ahşap kafes çatı sisteminin yerini, düşük yanal sertlik çelik çubuklarla betonarme binaya bağlanacak bir çelik çatı sistemi ile değiştirmektir. Çelik çatı, binanın aynı doğal frekansına sahip olacak şekilde ayarlanabilir. Tüm inşaat işleri binanın dışından uygulanır ve bina işlevini etkilemez, binanın boşaltılmasına gerek yoktur. Önerilen tekniğin etkinliğini araştırmak için betonarme yapı sonlu elemanlar modelinde zaman tanım analizi yapılmıştır. Analiz sonuçları, önerilen çatı sistemine sahip binanın, geleneksel çatılı binaya kıyasla yer değiştirme, ivme ve taban kesme kuvvetini yaklaşık yüzde 20 ila 50 oranında azalma elde ettiğini göstermektedir. Azalmanın değeri deprem karakteristiklerinden ve çatı-bina kütle oranından etkilenir. Analiz sonuçları önerilen tekniğin etkinliğini gösterir.

Anahtar kelimeler: Betonarme binalar, Çelik Çatı sistemi, deprem, kütle sönümleyici.

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1. INTRODUCTION

Recent earthquakes in Turkey (Van 2011, Izmit 1999) and Taiwan (1999) demonstrated the power of nature and the catastrophic impact of such power upon urban cities. During these earthquakes many older reinforced concrete (RC) buildings (i.e. built before 1980) suffered heavy damages and some of them resulted in brittle pancake failures causing loss of lives (Santhi, 2005; Langenbach, 2007). To save this type of existing buildings during future earthquakes especially school and hospital buildings, fast and economical strengthening techniques are needed to upgrade their structural systems. To strengthen reinforced concrete (RC) structures against possible future earthquakes, several techniques are used in practice such as adding new RC shear walls, column jacketing using steel or RC or carbon fibers, adding steel bracing, and using seismic isolation and dampers. To apply these techniques, the whole building or part of it should be evacuated for several months and if this building is a school or a hospital it means that the building will lose its function for several months during the strengthening construction. Tuned-Mass Damper Systems (TMD) are widely used for the reduction of vibration caused by wind and traffic like pedestrians or railway trains. Some researches in the literature propose the use of TMD to reduce the earthquake effects on structures (Nawrotzki, 2005; Nawrotzki, 2002). In these studies tuned lamped masses were installed at the top of the building. The tuned masses were connected to the structure with rubber bearings (i.e seismic isolators). Previous research show that tuned-mass systems can well be applied for the control of seismically induced responses. In this paper, Tuned steel roof technique is proposed to reduce earthquake effects of existing RC buildings. The idea is to replace the conventional wooden truss roof system by a steel roof system which will be connected to the RC building with low lateral stiffness steel bars. The steel roof can be tuned to have the same natural frequency of the building. All the construction works are applied from outside of the building and do not affect the building function, that is no need to evacuate the building. Time history analysis on a RC building finite element model was performed to investigate the effectiveness of proposed technique. The following sections present in detail the model, analysis results and connection details.

2. FEM MODEL AND INPUT MOTIONS

To investigate the effectiveness of the proposed tuned steel roof in reducing the earthquake effects on reinforced concrete buildings a finite element model of a five story RC building was created using SAP2000 software. The structural system of the building consists of RC frames with equal spans with spacing of 5 m and 6m in the x and y direction respectively. Story plans are identical and story heights are identical and equal to 3 m.

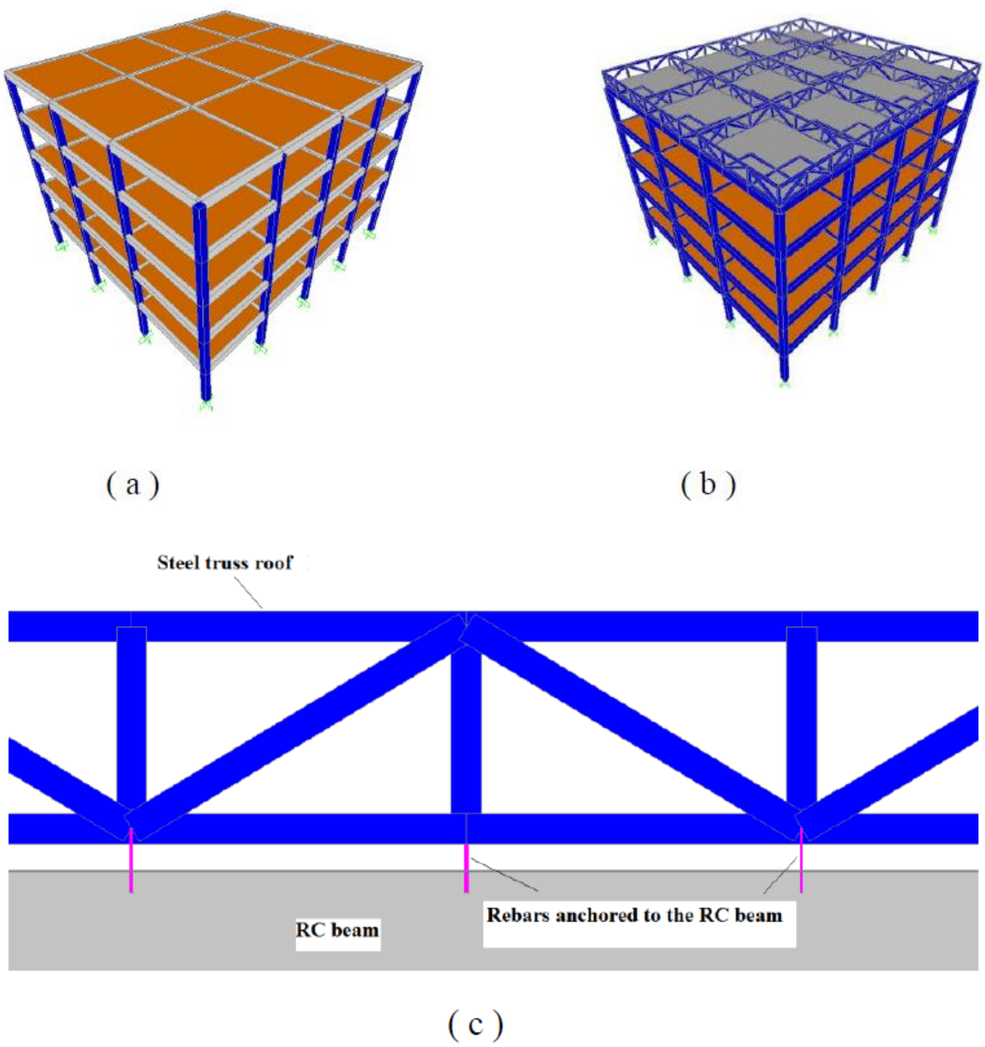


Fig 1. a) FEM Model, b) Model with TMD Steel Roof, c) Roof-building Connection Details

The cross-sectional dimensions of all columns are 40 cm by 40 cm. All beams have a cross sectional dimension of 25 cm by 50 cm. Floor slabs are 16 cm thick solid slabs and the foundation system is a continuous footing system. Concrete compressive strength was assumed to be 20 MPa and the yield strength of the reinforcement steel is 420MPa. Frame elements were used to model the beams and columns and floor slabs were modeled by shell elements.Fig1 shows the model with and without the proposed steel roof. The steel roof was connected to the top floor beams by means of steel bars anchored to the concrete beams as shown in figure Fig1c. The steel roof –building mass ratio was assumed to be 9%. Modal analysis was performed and the first natural period of the building was 0.65 sec. The diameter, height, and numbers of the steel bars that connect the steel roof to the building were selected in such a way that first period of vibration of the steel roof to be equal to the building first period of vibration (i.e tuned to be equal to 0.65 sec). Then time history analysis on the building model with and without the tuned steel roof was performed. Three time history input motions are shown in Fig 2.

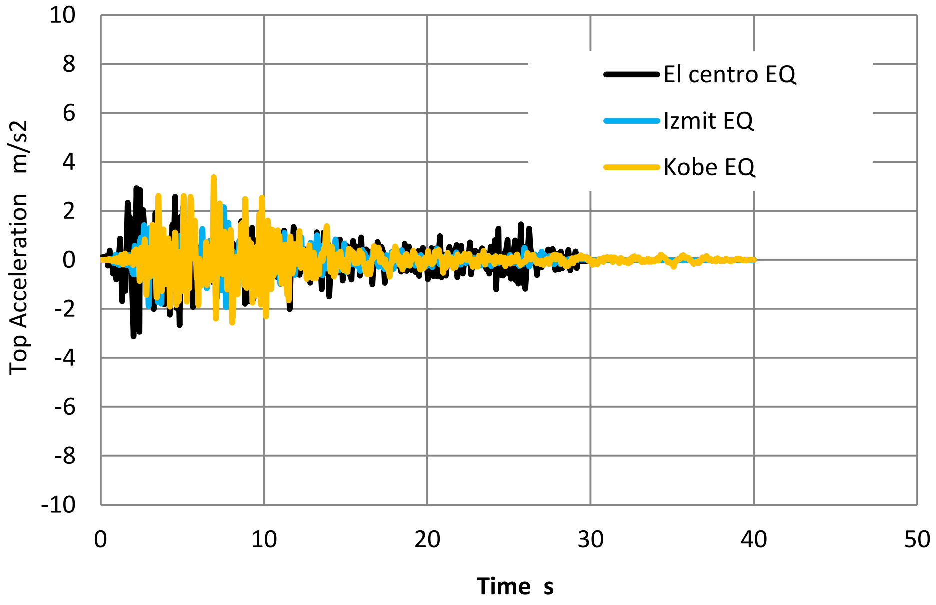
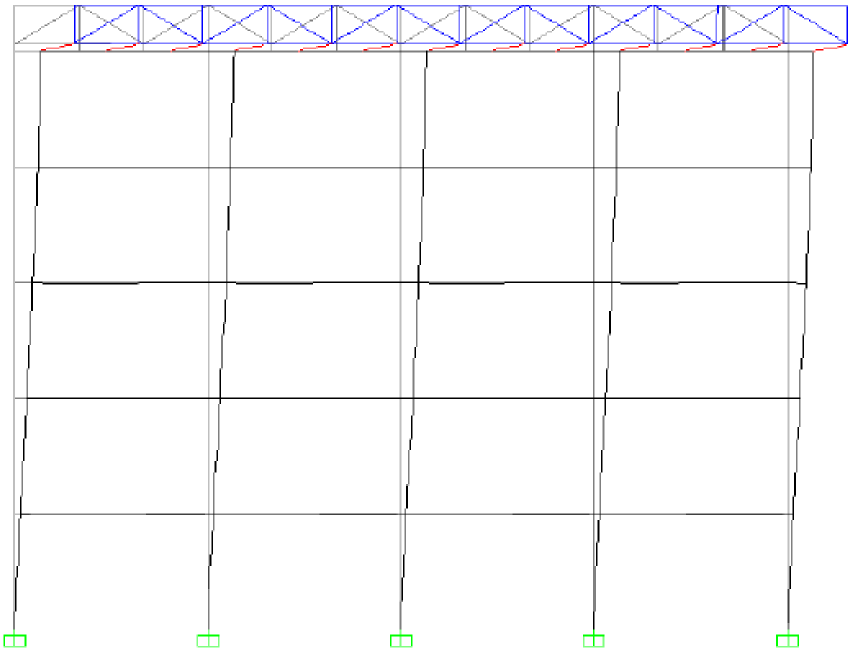


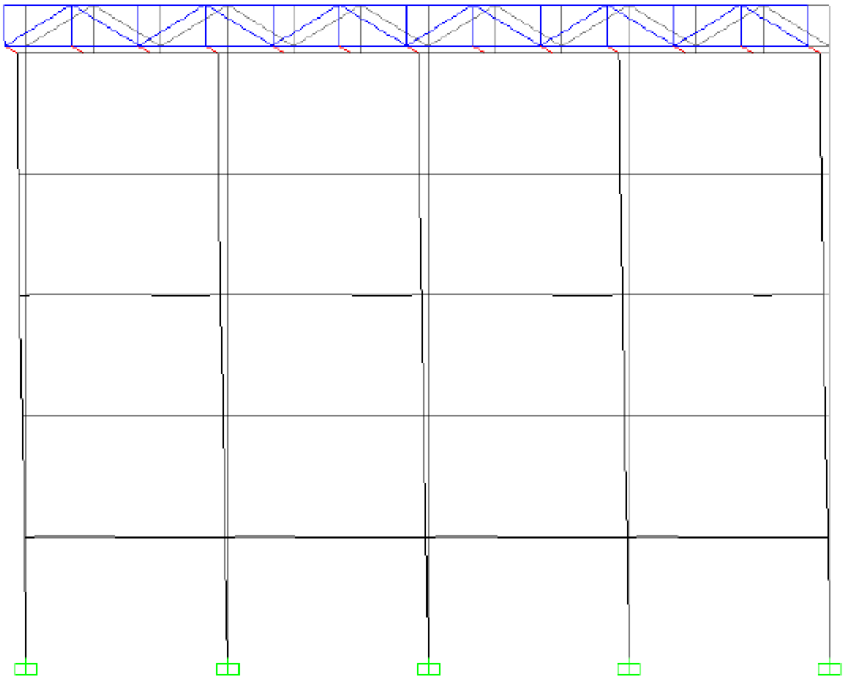
Fig 2. Time History Input Motions

3. ANALYSIS RESULTS

Modal analysis results shows that the first natural model (in the x direction) of the building without TMD steel roof is 0.65 sec. However the first and the second natural modes (in the x direction) of the building was equal to 0.74 sec and 0.69 sec respectively and the mode shapes are shown in Fig 3.



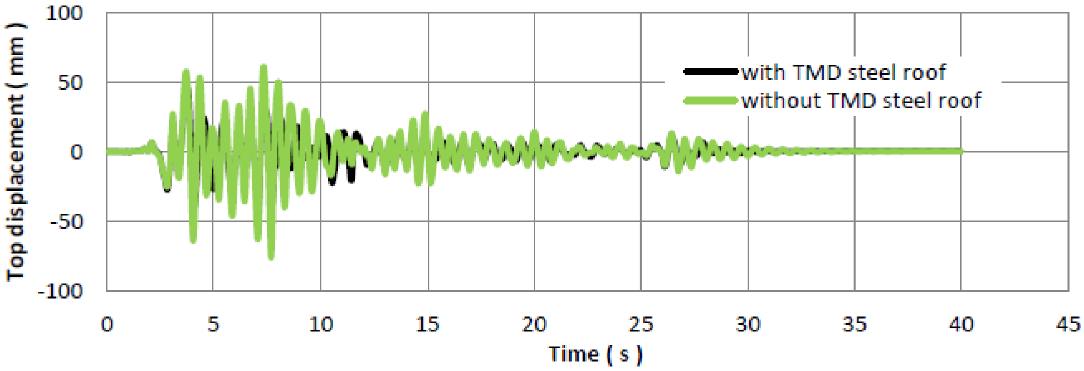
a) First mode T=0.74



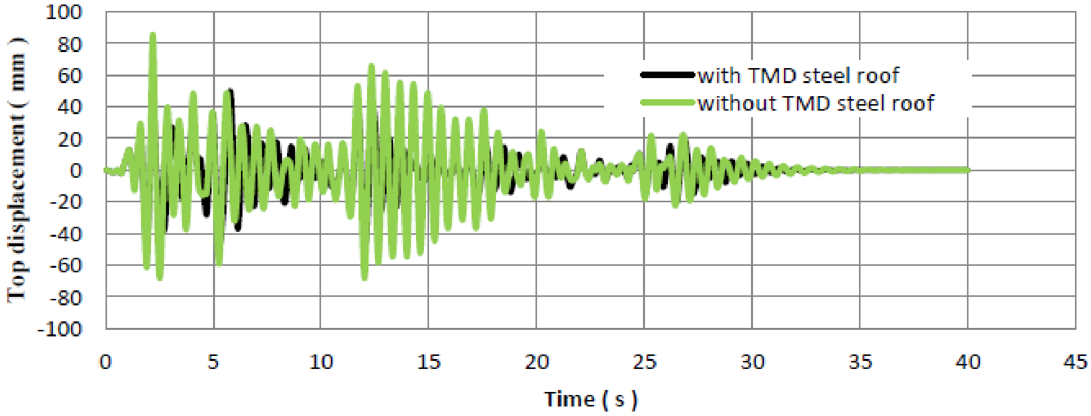
b) Second mode T=0.69

Fig 3. First and Second Modes in X Direction of the Building with TMD Steel Roof

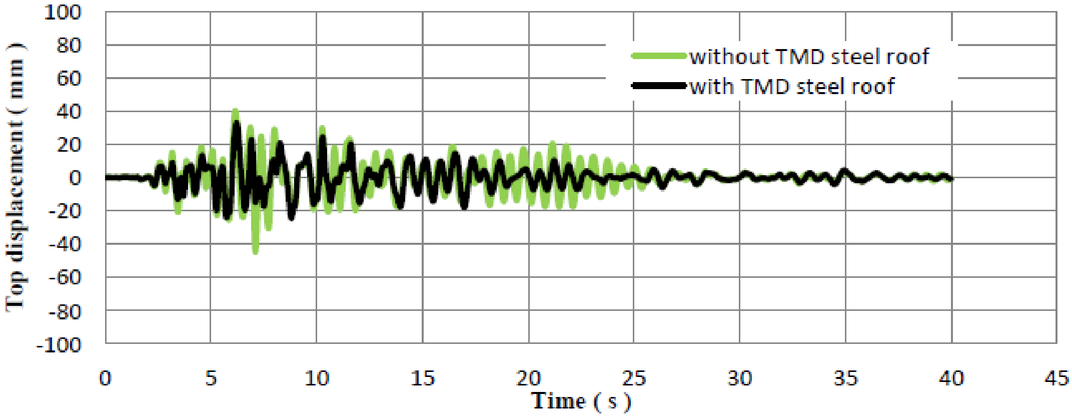
From the figure it is observed that in second mode the steel roof moves in opposite direction of the first mode. That is the effect of the second mode will reduce the earthquake effects on the RC building. Top displacement responses of the building with and without TMD steel roof are given in Fig4.



a) Top Displacement Response under Izmit Earthquake

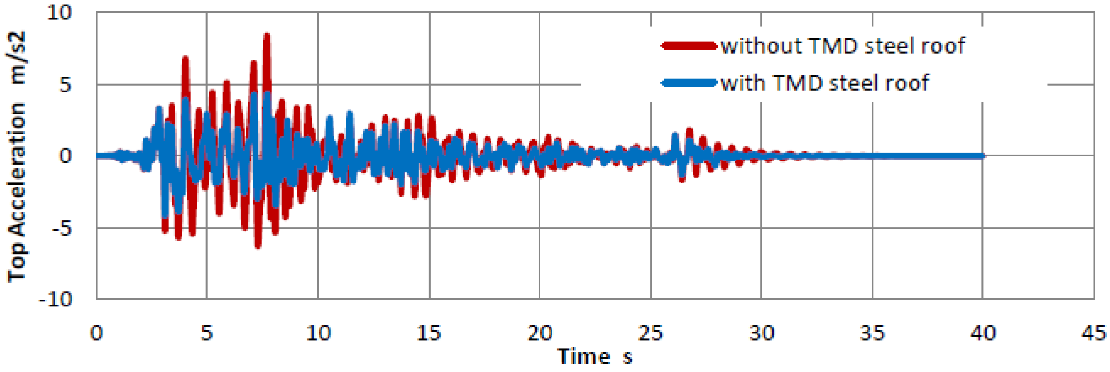


b) Top Displacement Response under El Centro Earthquake

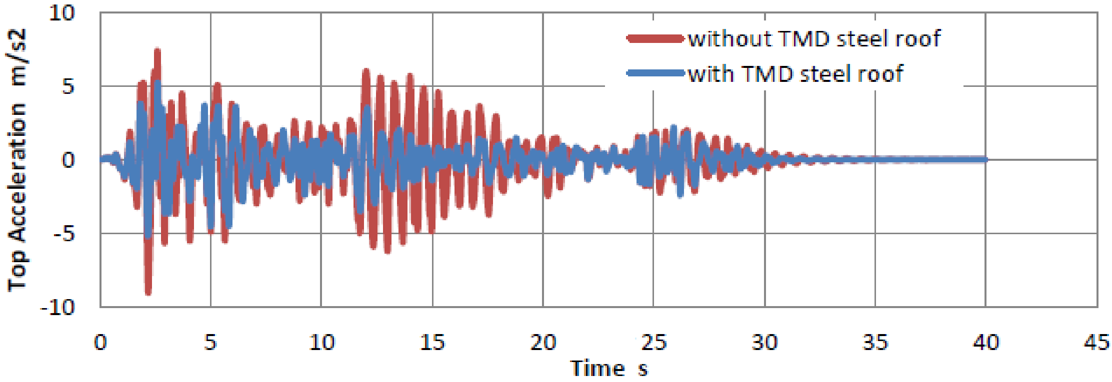


c) Top Displacement Response under Kobe Earthquake

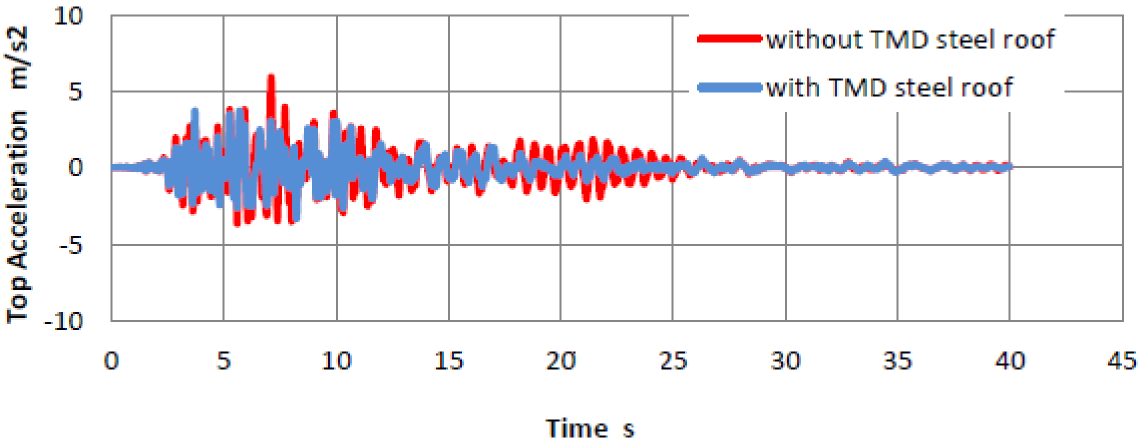
Fig 4.Top Displacement Response of the Building with and without TMD Steel Roof



a) Top Acceleration Response under Izmit Earthquake



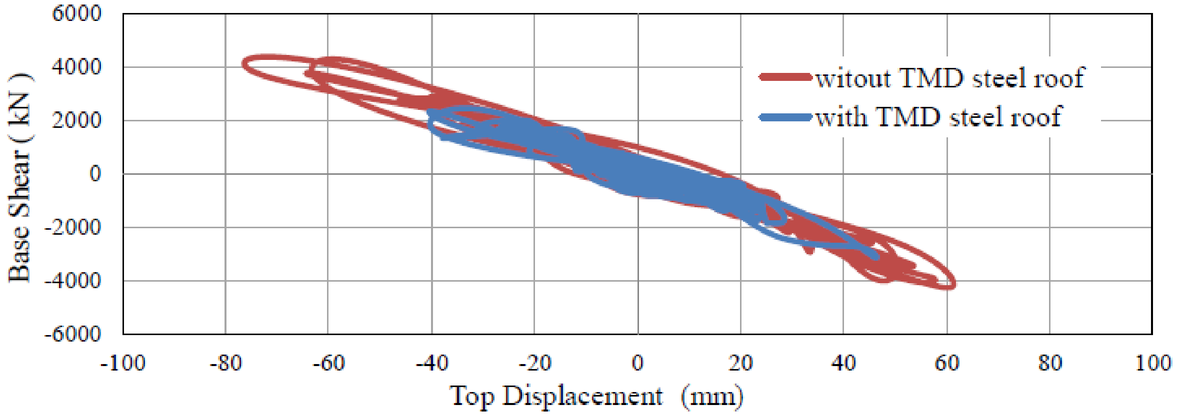
b) Top Acceleration Response under El Centro Earthquake



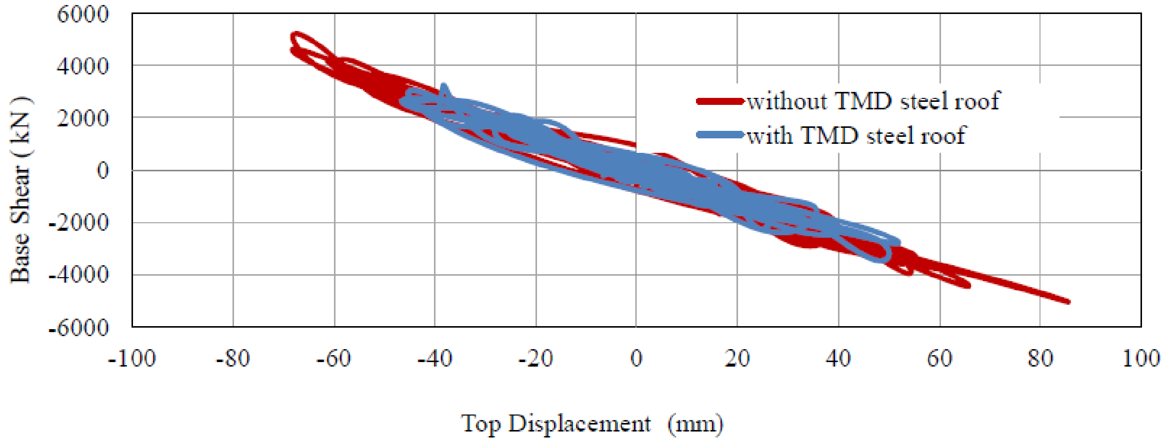
c) Top Acceleration Response under Kobe Earthquake

Fig 5.Top Acceleration Response of the Building with and without TMD Steel Roof

Under the effect Izmit earthquake the top displacement of the building with TMD steel roof reduced by about 40% compared with the building without TMD. Also Under the effect El centro earthquake the top displacement of the building with TMD steel roof reduced by about 50% compared with the building without TMD. However the reduction of displacement response under kobe earthquake is smaller and it is about 20%.Top acceleration response of the building with and without TMD steel roof are given in Fig5.



a) Base Shear-Top Acceleration Response under Izmit Earthquake



b) Base Shear-Top Acceleration Response under El Centro Earthquake

Fig 6. Base Shear-top Displacement Response

From the figure it is observed that the top acceleration response for the building with TMD steel roof reduced compared to the building without TMD. Base shear-top displacement response of the building with and without TMD steel roof are given in Fig6. It is observed that when the TMD steel rrof install on the building both global drift and base shear reduced in half in case of Izmit earthquake and reduced by about 38% in case of El centro earthquake .

4. CONCLUSIONS

Theoretical investigations have shown that the proposed TMD steel roof system can be applied to control the seismic responses of existing RC buildings. The proposed TMD steel roof is low cost and can be easily constructed by replacing the conventional wooden truss roof in an existing RC building by a steel truss system which will be connected to the RC building with steel bars. The steel roof can be tuned to have the same natural frequency of the building. All the construction works are applied from outside of the building and do not affect the building function, that is no need to evacuate the building. Analysis results indicate that both global drifts and base shear can be reduced by about 50% to 20% depending on the base ground motion and the roof-building mass ratio. In future research it is advised to conduct shake table tests on RC building models with TMD steel roof systems.

REFERENCES

Langenbach, R., (2007), Preventing Pancake Collapses: Lessons from Earthquake-Resistant Traditional Construction for Modern Buildings of Reinforced Concrete, 6th International Conferans Forensic Engineering Failure Diagnosis and Problem Solving, 9th December, Mumbai, India.

Nawrotzki P., Jurukovski, D., Rakicevic, Z., (2005), Shaking Table Testing of a Steel Frame Structure with and without Tuned-Mass Control System, Proc. Eurodyn, Paris.

Nawrotzki P., (2002), Artificial Increase of Elasticity and Damping for Seismically Excited Structures, Proc. 12th European Conference on Earthquake Engineering, 58, London.

Santhi, H.M., Knight, G.M.S., Muthumani, K., (2005) "Evaluation of Seismic Performance of Gravity Load Designed Reinforced Concrete Frames," Journal of Performance of Constructed Facilities, 19(4), 277–282.