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BEHAVIOUR OF SOIL-STRUCTURE SYSTEM WITH TUNED-MASS DAMPERS DURING NEAR-SOURCE EARTHQUAKES

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SUMMARY

The paper addresses the influence of a tuned mass damper on the behaviour of a frame structure during near-source ground excitations. In the investigation the effect of soil-structure interaction is considered, and the natural frequency of the tuned mass damper is varied. The ground excitations are the ground motion at the station SCG and NRG of the 1994 Northridge earthquake. The investigation shows that the soil-structure interaction and the characteristic of the ground motions may have a strong influence on the effectiveness of the tuned mass damper. In order to obtain a general conclusion further investigations are necessary.

INTRODUCTION

In order to reduce the structural response of a structure many approaches exist. The dynamic characteristic of the structure can be modified so that the dynamic load will not excite the structure. One possible way is to base isolate the structure, for example by using rubber bearings. The fundamental frequency of the structure is shifted away from the expected dominant frequencies of the ground excitations in the location of the structure. In near-source regions, however, because of their stiffness in the vertical direction for carrying the heavy weight of the structure and the possible strong vertical ground motions, rubber bearings may have difficulty to isolate the structure from the vertical ground excitation [1]. Another possibility is to provide the structure with more damping ability by adding dampers at the structural member [2].

Tuned mass dampers are often used if the excitations are almost periodically and the structural response is dominated by its fundamental mode, like in the case of working machine or bridge under wind loading. By tuning the added mass and spring the load will mainly affect the added mass, and the supplementary viscous damper will reduce the load effect on the added mass gradually. The ground excitations during an earthquake have, however, a broader range of dominant frequencies. Investigations on the effectiveness of tuned mass dampers in reducing the earthquake effect are still very limited, for example, by Villaverde [3 and 4]. Soto-Brito et al. [5] studied the effectiveness of a multi-storey structure with the fundamental frequency that coincides with the dominant frequency of the ground motions. Ziyaeifar et al. [6] proposed to use part of the building storeys as the tuned mass. Abdullah et al. [7] investigated the effect of shared

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tuned mass damper for reducing the pounding potential of two neighbouring buildings. In most of the investigations the effect of soil-structure interaction is not included. If it is considered, the dynamic stiffness of the subsoil is approximated by a frequency-independent dynamic stiffness [8].

GROUND EXCITAITON AND SOIL-STRUCTURE SYSTEM

Figure 1 shows the considered frame structure with the tuned mass damper and subsoil. The material data of the structure is given in Table 1. The tuned mass damper (TMD) consists of a mass, horizontal and vertical springs and viscous dampers. The frequency $f_{f,h}$ and $f_{f,v}$ of the fundamental mode of the structure with an assumed fixed base in the horizontal and vertical direction are 1.256 Hz and 10 Hz, respectively.

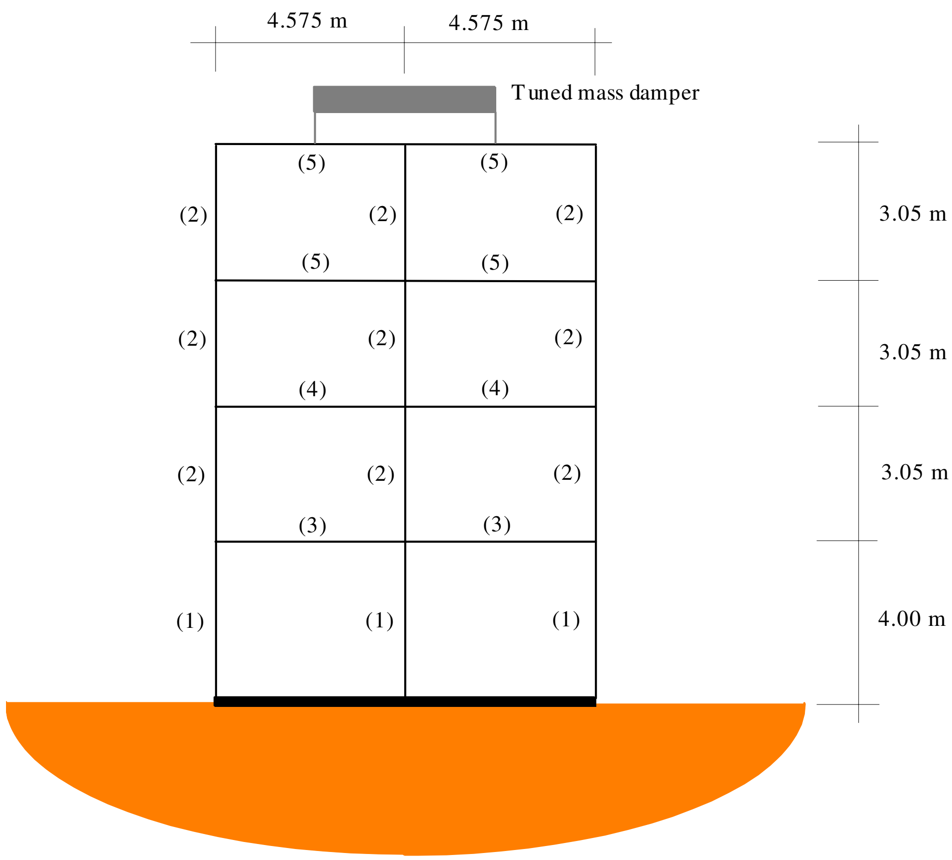

Figure 1. Frame structure with tuned mass damper.

Table 1. Material data of the structure

Member number	Mass [t/m]	EA [10^6 kN]	EI [10^4 kNm^2]	Length [m]
(1)	0.067	1.1467	1.400	4.000
(2)	0.033	0.5580	0.654	3.050
(3)	2.447	3.1900	20.00	4.575
(4)	2.358	3.1900	20.00	4.575
(5)	1.209	2.3600	11.00	4.575

The subsoil is assumed to be a half-space with a shear wave velocity of 100 m/s, a density of 2000 kg/m^3, and a Poisson ratio of 0.33. In order to focus on the effect of the tuned mass damper the material damping of the frame structure as well as of the subsoil is not considered. The influence of the material damping will be taken into account in the further investigation. In this study only the damping effect of the tuned mass damper and the radiation damping due to wave propagation in the subsoil are investigated. In the case of the frame structure with an assumed fixed base the natural frequency of the TMD vibration in the horizontal direction is varied as a ratio of the fundamental frequency $f_{f,\,h}$ of the frame structure. For the TMD vibration in the vertical direction, however, a 90 per cent of the natural frequency $f_{f,\,v}$ of the frame structure is chosen. Because of the soft subsoil the soil-structure system has 8.76 per cent lower fundamental frequency f_s of 1.146 Hz. For the numerical analyses the frame structure and the subsoil are modeled by a finite element method and a boundary element method [9 and 10].

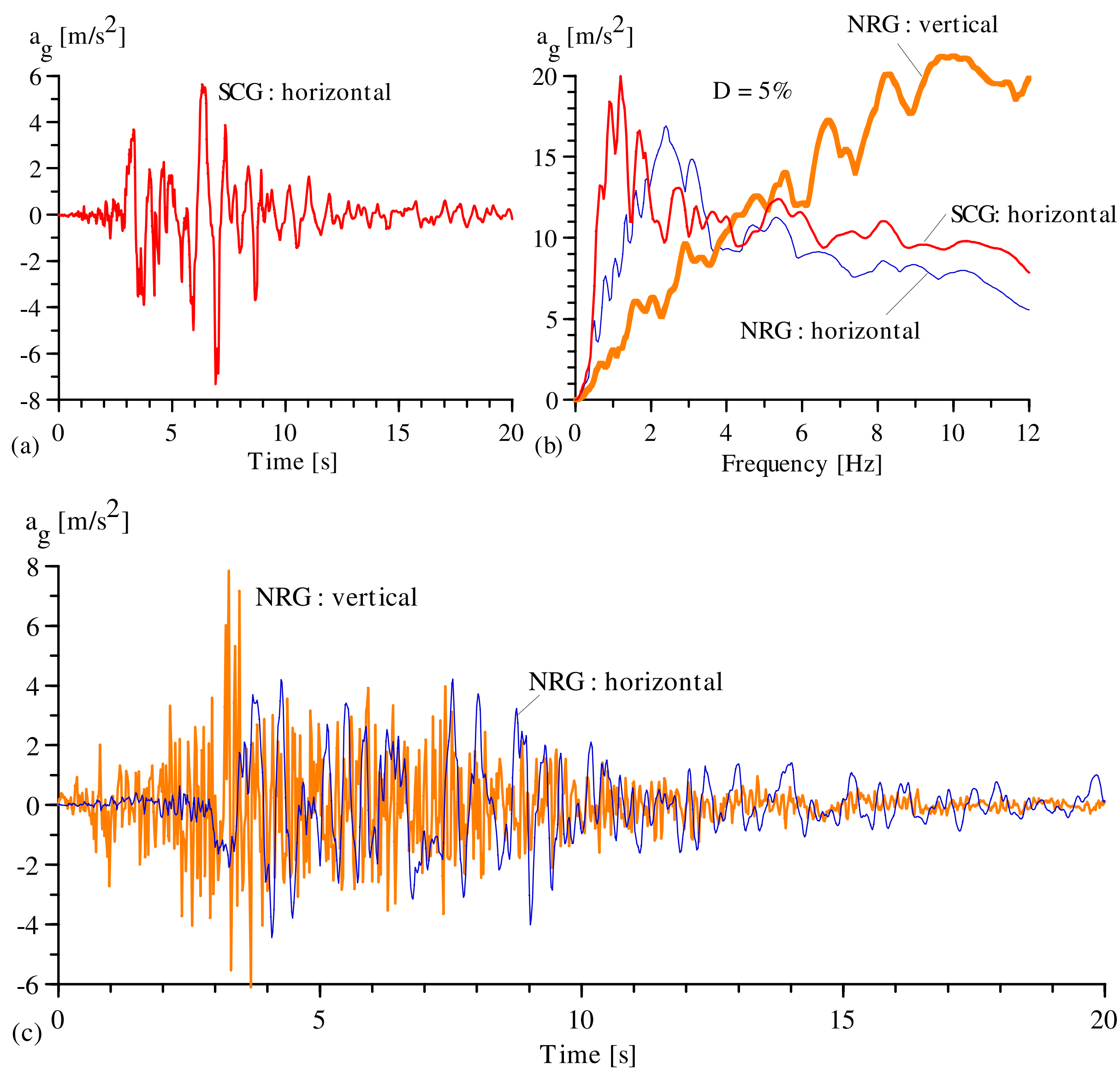

Figure 2(a) and (c). Considered near-source earthquakes (a) Northridge ground motions at SCG station and (c) NRG station, (b) their response spectrum.

Figure 2(a) and (c) show the ground motions at the station SCG and NRG during the 1994 Northridge earthquake. They have the epicentral distance of 10.8 km and 2.31 km, respectively. Some of the characteristics of near-source earthquakes [11] can be seen in the ground motions. Both horizontal ground excitations have strong long period pulses, and the peak vertical ground motion of 7.85 m/s^2 is 1.76 times larger than the peak ground motion in the horizontal direction. Since the ground excitation at the SCG station is very strong, only 50 % of the load is considered. Figure 2(b) shows the corresponding response spectrum with the damping ratio of 5 %. The high frequencies in the vertical ground excitation can be clearly seen.

NUMERICAL RESULTS

Figure 3 shows the influence of the soil-structure interaction on the horizontal displacement at the end of the top left column. The ground excitation is the horizontal SCG ground accelerations, and no TMD is considered. The lower fundamental frequency of the soil-structure system can be clearly seen in the delay of the response. In the considered case the soil-structure interaction causes an amplification of the displacement. Since no structural material damping is considered after the strong excitation around 10 s the structure will continue to vibrate. The response of the structure with subsoil becomes smaller gradually due to the radiation damping.

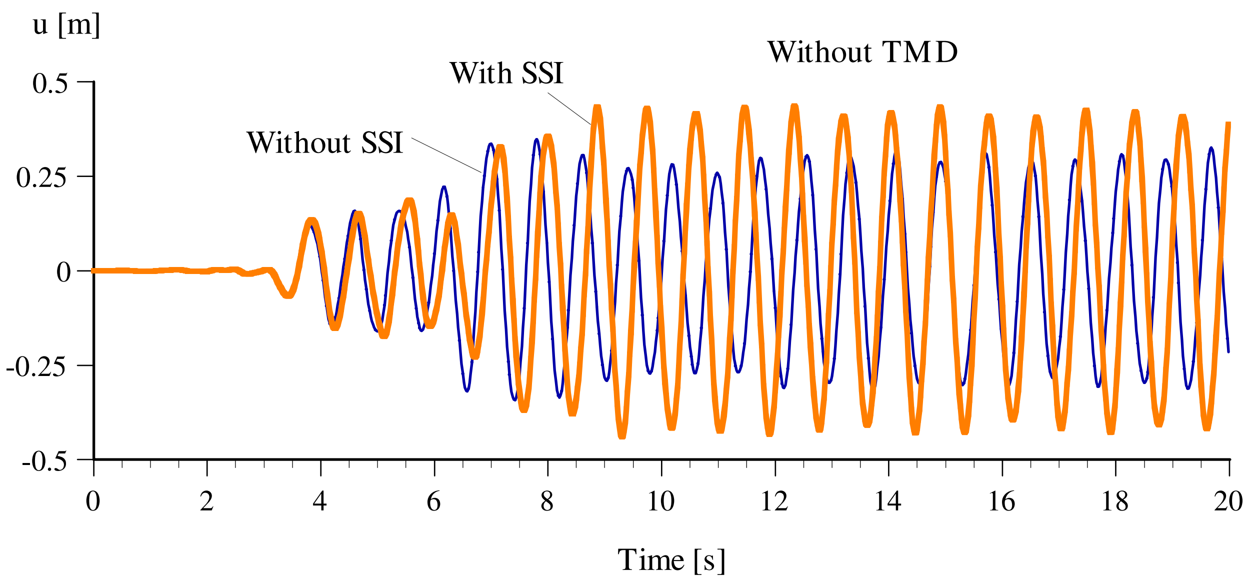

Figure 3. Influence of soil-structure interaction on the top left roof displacement u.

In this study the TMD mass is kept constant, and is equal to 5 per cent of the mass of the frame structure. Figure 4(a) and (b) show the influence of the TMD damping on the development of the bending moment M at the support of the left column due to the horizontal SCG and NRG ground excitation, respectively. The soil-structure interaction effect in considered. The natural frequency of the tuned mass damper is equal to 85 per cent of the fundamental frequency of the frame structure with subsoil. The TMD has the damping ratio of 10 % or 30 %. The result shows that in both cases the effectiveness of the tuned mass damper increases with the time. As expected the larger the damping ratio is the more reduction can be achieved.

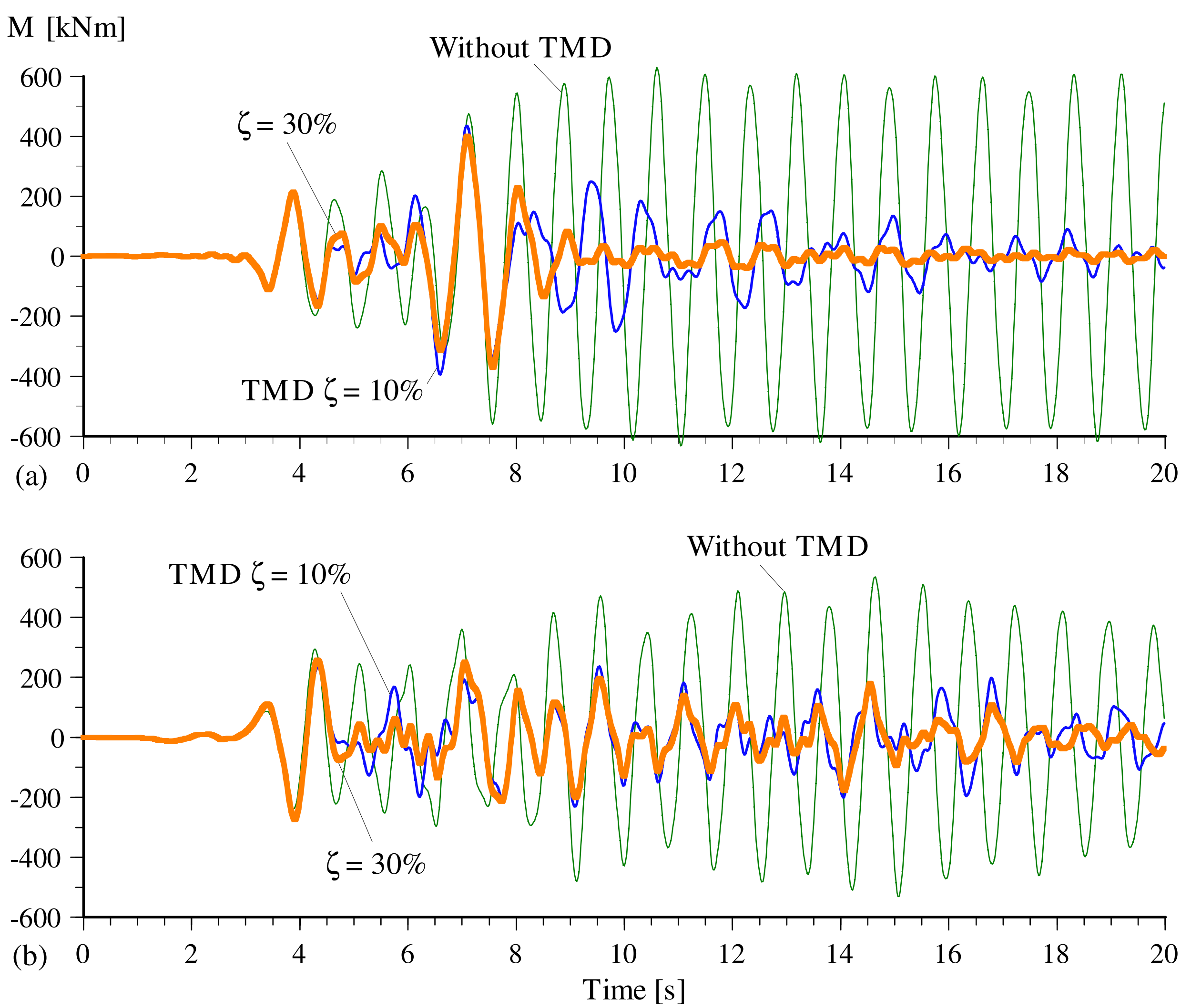

Figure 4(a)-(b). Influence of the TMD damping ratio on the development of bending moment M due to (a) the SCG and (b) NRG ground motions.

Figure 5(a)-(b) and 5(c)-(d) shows the influence of the soil-structure interaction, the TMD damping ratio and the ratio between the TMD natural frequency and the fundamental frequency of the considered system in the case of the horizontal SCG and NRG ground excitation, respectively. u_w and u are the maximum horizontal displacement at the end of the top left column of the structure with and without TMD, respectively. f_f and f_s are the fundamental frequency of the fixed-base frame structure and the structure with subsoil, respectively. The symbols indicate the calculated values. The results show that the TMD is most effective if its natural frequency is equal to around 85 per cent of the fundamental frequency of the considered system. Larger damping ratio helps in most of the cases. The soil-structure interaction can have beneficial as well as adverse effect on the effectiveness of the tuned mass damper. The results also reveal that the effectiveness of the considered tuned mass damper depends not only on the frequency ratio and its damping ratio, but also on the soil-structure interaction and the characteristic of the ground motions.

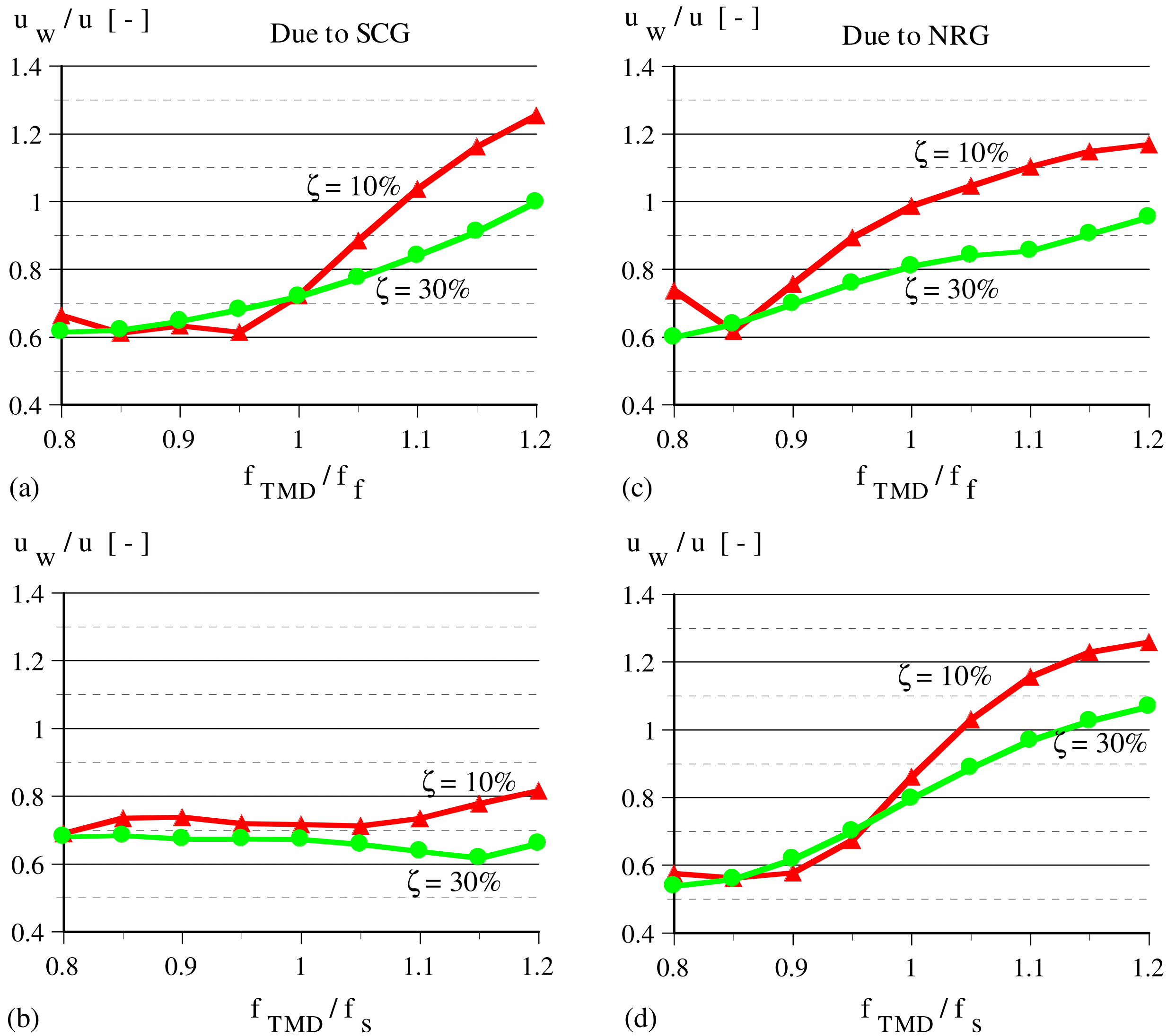

Figure 5(a)-(d). Effect of soil-structure interaction and TMD damping ratio on the response ratio u_w/u in the case of (a)-(b) SCG ground motions, and (c)-(d) NRG ground motions.

Figure 6(a) and (b) display the TMD influence on the development of the axial forces in the upper most left column due to the horizontal and simultaneous horizontal and vertical NRG ground excitation, respectively. It is assumed that the frame structure is fixed at its base, and the TMD has a damping ratio of 30 per cent. The TMD natural frequency is equal to 85 per cent of the fundamental frequency of the frame structure. In the vertical natural vibrations the TMD has the natural frequency equals to 90 per cent of the fundament frequency of the vertical vibration mode of the frame structure. In the case of the horizontal ground excitation the development of the axial forces is mainly determined by the horizontal vibration mode of the frame structure. In the case of the simultaneous ground excitation the development is also strongly defined by the direct excitation of all columns. Consequently, the axial forces are characterized by the high frequencies of the vertical ground motions (see also Figure 2(c)). The influence of simultaneous near-source ground excitations on structural responses is described in [11]. The effectiveness of the tuned mass damper develops with the structural vibrations. Previous study [12] showed that TMD can be used for reducing induced vibrations in the structures.

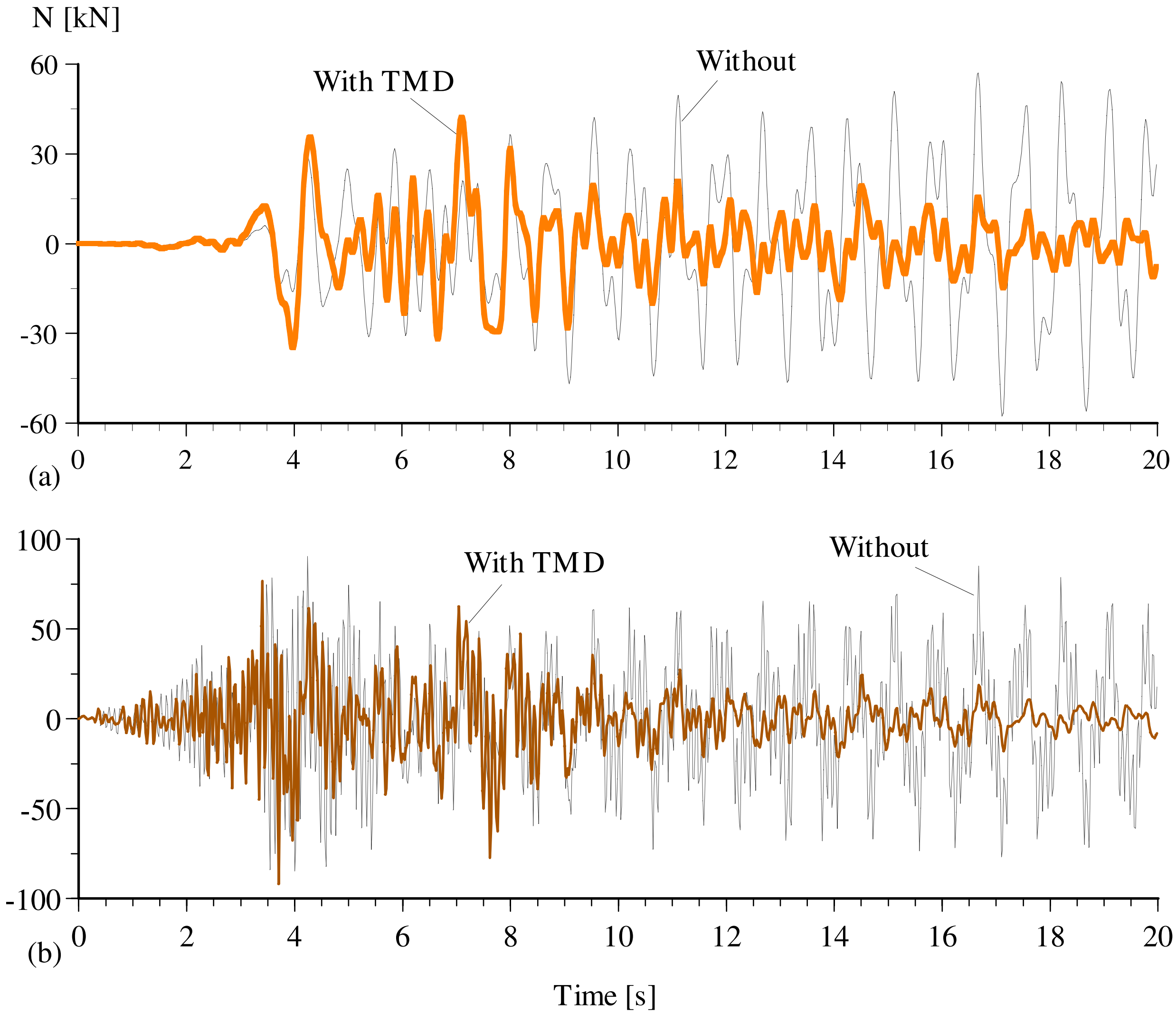

Figure 6(a)-(b). Influence of TMD and a simultaneous ground excitation on the development of axial forces in the top left column.

CONCLUSIONS

In this paper the first results of the investigation of the effect of a tuned mass damper on a frame structure are presented. The considered frequency ratio ranges from 0.8 to 1.2. The result shows that the best frequency ratio between the TMD natural frequency and the fundamental frequency of the frame structure is around 0.85. The damping ratio is a significant factor.

The soil-structure interaction can increase or decrease the effectiveness of the tuned mass damper.

The investigation reveals the significance of the relationship between the characteristic of the structure with tuned mass damper and the properties of the ground excitation. In order to obtain general conclusions more near-source ground motions should be considered in the further study.

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