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Seismic response of SDOF systems under doublet earthquakes

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ABSTRACT

A single event scenario has been adopted in seismic design process of buildings by current design codes however seismic sequences may influence the structural safety. On 11th August 2012, two earthquakes took place in East-Azerbaijan province in the north-western part of Iran. In this study, effect of different features of this special seismic sequence that is named “doublet events” has been considered in the analysis. Artificial earthquake ground motion sequences are constructed based on real single events and results are compared with real sequences in terms of displacement time history. Results of analysis would help to highlight the effect of such type of motion in seismic evaluation of structures.

1. INTRODUCTION

Based on observations in the past, the seismic events with strong or moderate intensity levels may be followed by aftershocks with considerable level of intensity. Large aftershocks after the mainshocks of the 2010 Haiti (Mw=7.0), 2010 Chile (Mw=8.8), 2008 Sichuan, China (Mw=8.0), 2011 Tohoku (Mw=9.0), 2009 L’Aquila, Italy earthquakes caused considerable structural and non-structural damages in suffering regions. Building seismic design codes does not typically provide any explicit guideline to consider seismic sequences effect on analysis or design procedures.

A large body of literature exists about seismic sequences effects (or multiple events) on nonlinear behavior of buildings (Parisi and Augenti 2013; Zhai et al. 2013; Penna et al 2014). However, Seismic sequences studies have frequently been focused on mainshock-aftershock events in the past. Aftershocks generally refer to the smaller size earthquakes that related to mainshock 's source, release less total energy than mainshock. “Doublet earthquakes” refers to a pair of seismic events which take place closely spaced in time and location. Yaghmaei-Sabegh and Ruiz-Garcia (2016) investigated the ground motion features of the Varzaghan-Ahar doublet events in terms of seismic energy contribution of each decomposition level, cumulative energy profiles and distribution of energy vs. pseudo-period. They used the discrete wavelet transform analysis to decompose the earthquake ground-motion records at 12 levels of

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frequencies. Wavelet analysis showed that energy concentration position or the power of earthquake ground motion changes if ensemple of seismic events are considered as input motions.
In this study, a special class of seismic sequences called "doublet events" is used in the analysis. Linear and nonlinear response of doublet events on SDOF systems are illustrated for the case study of the 2012 Varzaghan-Ahar earthquake (Mw=6.4,6.3) occurred in the East-Azerbaijan province of Iran. Results of real events are compared with those of artificial seismic sequences generated by the back-to- back method.

2. THE VARZAGHAN-AHAR DOUBLET EARTHQUAKES

On 11th August 2012 two earthquakes took place in the NW of Iran. These events are the only significant earthquakes occurred in the study area since the catastrophic 1780 Tabriz earthquake. The shaking due to energy radiated by these earthquakes could be felt in most part of the East-Azerbuijan province.
The first mainshock with magnitude of 6.4 Mw (USGS) was recorded by 57 stations of accelerometer network of BHRC of Iran. The observed peak ground acceleration of 364 cm/s2 is recorded in Varzeghan station. Eleven minutes after the first event, the second event with magnitude of 6.3 Mw (USGS) occurred and caused heavy level of damages in Varzaghan. 73 BHRC stations recorded the second event and higher peak ground acceleration of 532 cm/s2 is observed in Varzeghan station. The epicenter of the two mainshocks (the red circles) and 184 Ahar-Varzaghan aftershocks from 11 Aug to 7 Nov. 2012 (the yellow circles) have been illustrated in Fig 1. Based on precise relocation of the seismic cluster by Ghods et al. (2015), the events lie on two different seismogenic sources.

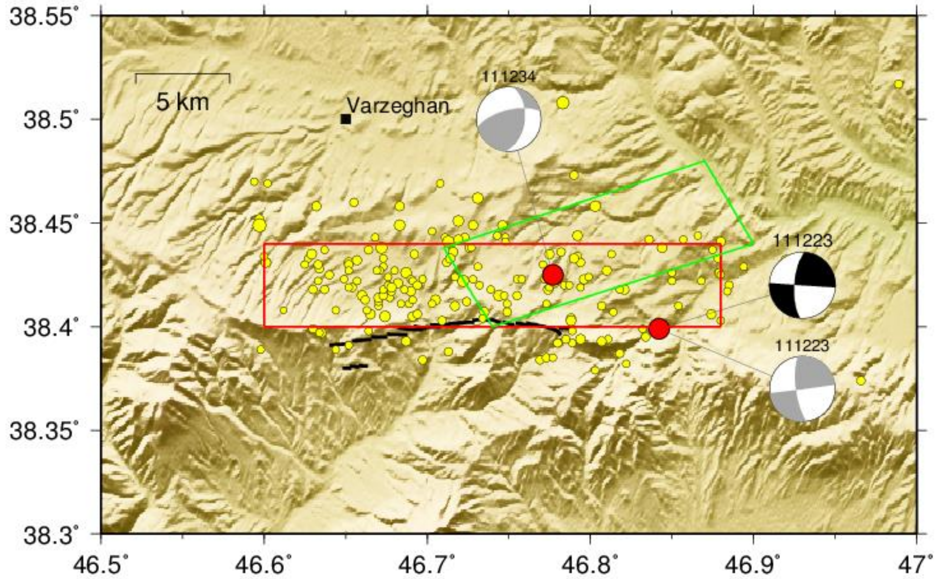

Fig. 1 Surface projections of the source models (the causative faults) for the first and second mainshocks along with epicenter location of two events (Yaghmaei-Sabegh and Ghods 2016)

3. RESULTS

Acceleration time history of Varzaghan-Ahar earthquakes recorded at Varzaghan station has been used as real sequences in the analysis herein (M1M2 case). Linear time history analyses have been performed based on real and simulated seismic sequences where the first event is repeated after a time gap of about 40 seconds with zero acceleration to cease gradually the moving of systems after the previous event. Generated sequences named M1M1 in the plots. Nonlinear time history analyses for three level of ductility are completed for different SDOF systems. Displacement time histories at different level of ductility have been presented for vibration period of T=0.5 and 1 second through Fig 2 to 5. These figures highlight real doublet events effects on linear and nonlinear response of SDOF systems. Different residual displacement is observed for artificial seismic sequence than observed real sequences. These differences are significant for higher level of ductility at vibration period of T=0.5 second. Residual displacement for vibration period of T=1 sec corresponding to ductility level $\mu = 6$ is 4 cm when real sequences used in the analysis. This value is equal to 5.6 cm for artificial generated events.

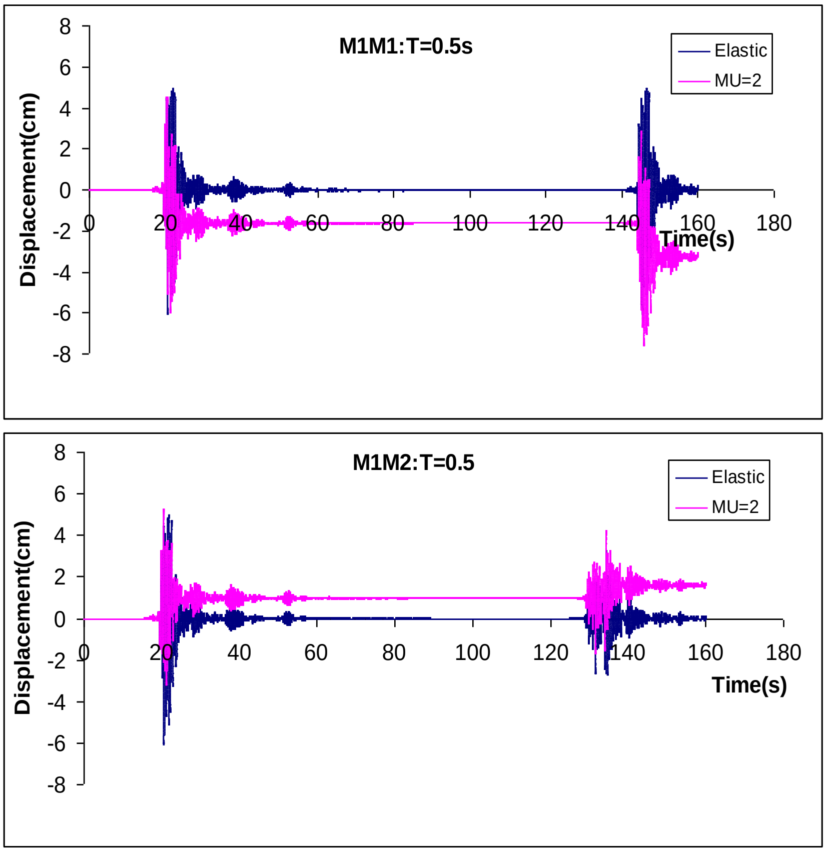

Fig. 2 Displacement time history for vibration period T=0.5 s at ductility level $\mu = 2$

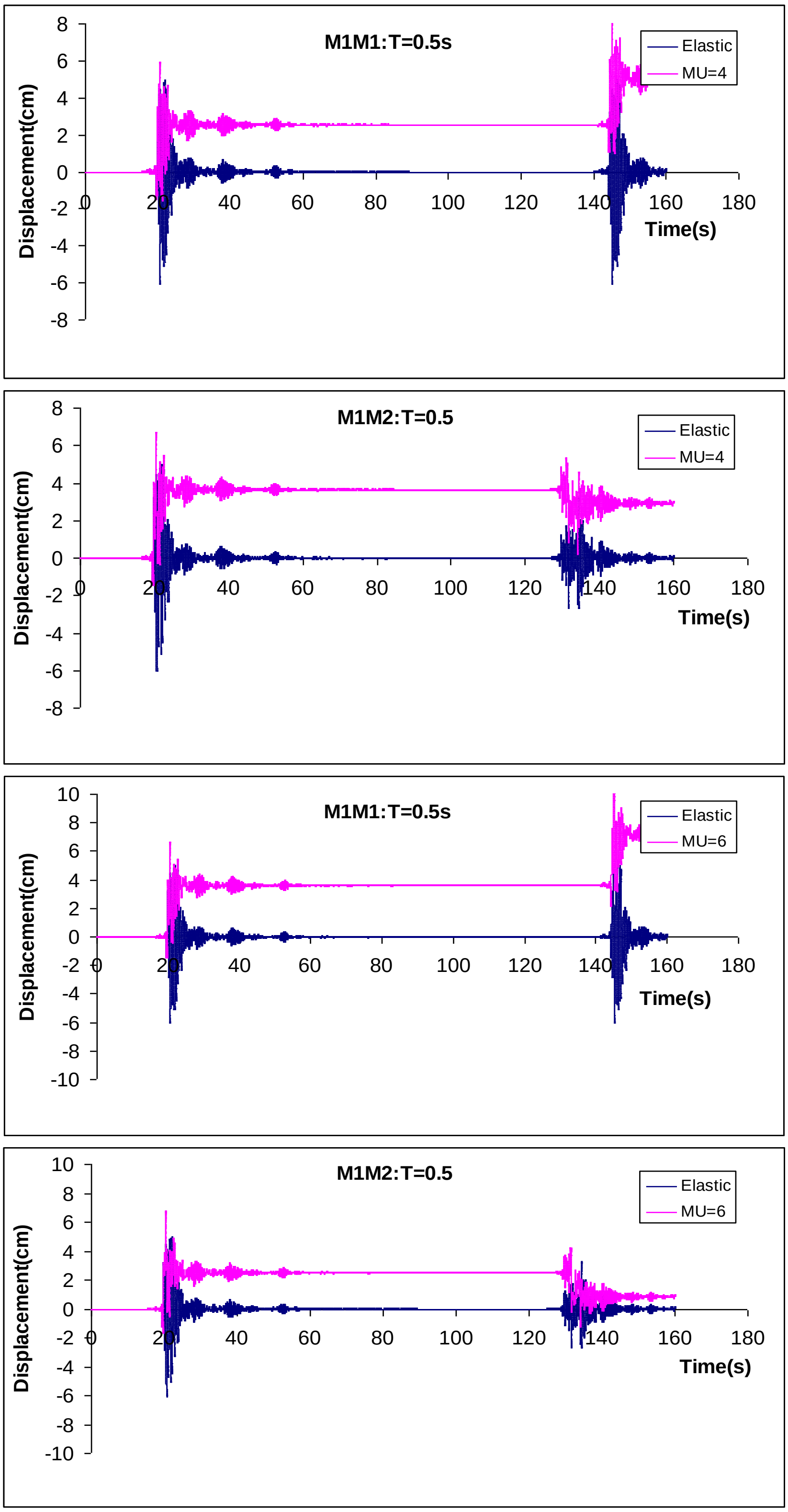

Fig. 3 Displacement time history for vibration period T=0.5 s at ductility level $\mu = 4,6$

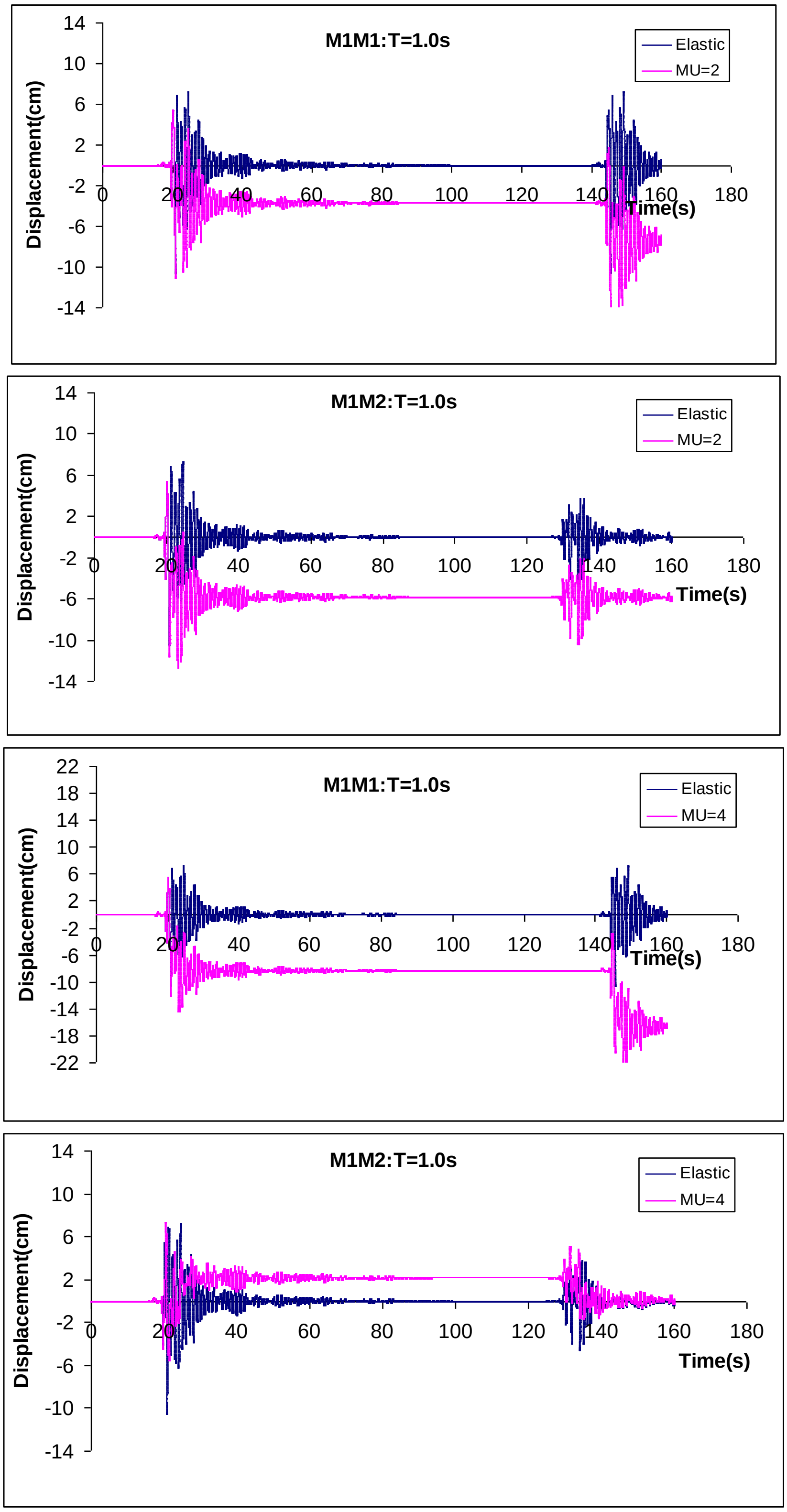

Fig. 4 Displacement time history for vibration period T=1.0 s at ductility level $\mu = 2,4$

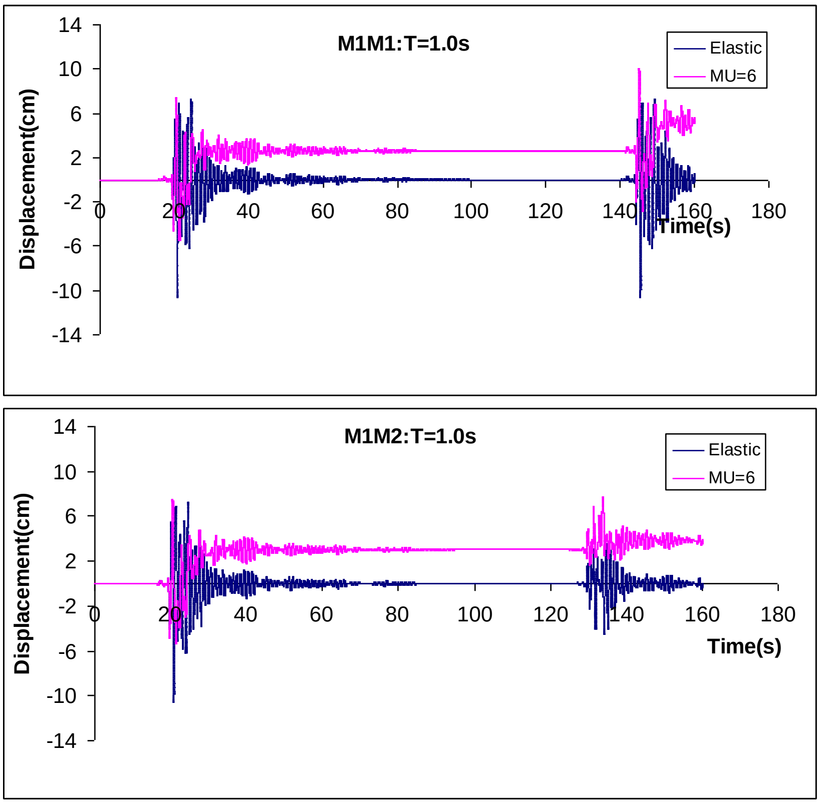

Fig. 5 Displacement time history for vibration period T=1.0 s at ductility level $\mu = 6$

4. CONCLUSIONS

This paper investigated doublet earthquake events effects as a special ground motion excitation on linear and nonlinear response of SDOF systems. Three ductility level have considered in the analysis. Results highlighted the differences of real and artificial sequences features on response estimation. As a suggestion, artificial seismic sequences based on back-to-back method could be used with caution in the analysis procedure. It is found that second event may increase or decrease the residual displacement.

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