Engineering Failure Analysis 96 (2019) 31–43

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis of an un-anchored steel oil tank damaged during the Silakhor earthquake of 2006 in Iran

Sina Miladi, Mehran S. Razzaghi*

Department of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

ARTICLE INFO

Keywords:
Seismic performance
Unanchored tank
Buckling, uplift
Failure analysis

ABSTRACT

On March 31, 2006, a destructive earthquake (M_w = 6.1) occurred in western Iran. Because of the earthquake, some of the old un-anchored cylindrical steel fuel storage tanks were damaged. The damaged tanks experienced the horizontal peak ground acceleration (PGA) of 0.44g. During the earthquake, the most affected tank experienced shell uplift. Because of the tank-to-foundation impact, the concrete cover of the tank foundation was damaged. In addition, the evidences of slight buckling were observable on tank shell. In this study, failure analysis was performed on the most affected tank. In order to evaluate the seismic performance of the studied tank, existing analytical relations were carried out as well as the inelastic response history analysis. To this end, the accelerogram of the recorded earthquake at a station close to the selected tank was used. Numerical analysis was performed using ABAQUS software. In addition, a parametric study was carried out to evaluate the effect of amount of stored liquid on seismic behavior and performance of the studied tank. Results of this study revealed that the numerical model is capable of estimating the actual performance of the tank. It was shown that the critical PGA of the dynamic buckling of the considered tank is 0.285g. Additionally, the uplift threshold PGA is 0.23g.

1. Introduction

Aboveground cylindrical steel tanks play an important role in storing various types of liquid in chemical industries, especially in refineries and petrochemical plants. Inappropriate performance of tanks, specially unanchored tanks, in previous earthquakes, including Anchorage (Alaska) earthquake in 1964, Izmit (Turkey) seismic event in 1999 and Bam (Iran) earthquake in 2003 indicated the seismic vulnerability of such structures [1–5]. In many process industries, tanks store a remarkable volume of flammable and toxic materials. Hence, damage to such structures may causes environmental pollution, fire disasters and work abandon in addition to physical losses. For instance, in the 1999 Izmit earthquake, a number of tanks in the Tupras refinery were burned. Due to spread of fire, the wooden cooling tower of the refinery was completely burned [6]. Furthermore, in Niigata earthquake of 1964 in Japan, ignition of six petroleum tanks in an oil refinery caused burning of more than 250 neighboring houses [7].

Because of the importance of the acceptable performance of the tanks during earthquakes, various researchers have focused on evaluation of seismic performance of such structures [5,8]. Researches showed that, during an earthquake, the upper parts of the liquid, so-called the convective liquid, move in a long period motion. Meanwhile, the lower parts experience high-frequency motions. The later part of liquid is known as impulsive liquid [9]. The dynamic response of the liquid to the earthquake causes overturning moment at the tank bottom. In anchored tanks, the overturning moment may causes tension of mechanical anchors. While, in unanchored tanks, shell uplift may happens due to the overturning moment. Since the uplifting response of the tank is geometrically

* Corresponding author at: Department of Civil Engineering, Qazvin Branch, Islamic Azad University, Nokhbegan Blvd., Qazvin, Iran.
E-mail address: razzaghi.m@gmail.com (M. S. Razzaghi).

https://doi.org/10.1016/j.engfailanal.2018.09.031
Received 2 June 2018; Received in revised form 17 September 2018; Accepted 24 September 2018
Available online 26 September 2018
1350-6307/

nonlinear, the seismic behaviors of unanchored tanks are remarkably complex [5,10]. Although, uplift cannot be considered as a damage itself, it can cause significant damages; such as shell buckling, rupture of pipes connected to the tank and damage to foundation. Previous studies and performances of unanchored tanks during occurred earthquakes revealed that these tanks are more vulnerable than mechanically anchored ones [11]. The complex behavior of unanchored liquid storage tanks, their significant seismic vulnerability and remarkable direct and indirect consequences of their inappropriate performance, enhance the necessity of evaluation of the seismic performance of these structures.

Investigating the performances of structures during happened earthquakes is an important approach to perceive the seismic performance of structures. In other words, seismic events can be considered as full-scale experiments to study the seismic behavior of structures. Therefore, in order to get a better idea about dynamic performance of a particular complex structure, such as an unanchored tank, numerical analysis can be employed to simulate the actual performance of the structure to a happened earthquake. In such a case, causes of structural failures can be investigated by interpreting the results of numerical analysis and comparing the numerical results with actual performance of the structure during the occurred earthquake.

This study focuses on failure analysis of an unanchored liquid storage tank subjected to the Silakhor earthquake of 2006 in Iran. To this end, the behavior and seismic performance of the damaged tank was evaluated using analytical relations and numerical nonlinear response history analyses. Results of numerical dynamic analyses and analytical relations were compared with actual performance of the damaged tank during the earthquake.

2. Description of the event

On March 31, 2006, an earthquake of $M_w = 6.1$ occurred in Silakhor in western Iran. The earthquake was occurred at 33.56°N 48.73°E, at a focal depth of 7 kms [12]. The focal mechanism of the earthquake was strike-slip. The maximum PGAs were recorded at Chalanchulan strong ground motion station (4.32 m/s^2 and 5.24 m/s^2 for horizontal and vertical component respectively) [12]. The recorded accelerograms of the earthquake and its response spectra are shown in Figs. 1 and 2 respectively.

Due to the earthquake, urban and rural areas were widely damaged. Moreover, the earthquake caused failure of many industrial facilities in the affected area. At least 28 on-ground cylindrical tanks experienced earthquake. As listed in Table 1, twenty-five of the tanks were unanchored and three were mechanically anchored.

During the earthquake, none of the anchored tanks was damaged. Meanwhile, 75% of unanchored tanks, which were located at sites with epicentral distances of 5 km or less experienced minor to moderate damages. As mentioned in Table 1, the evidence of shell uplift were observed in all damaged tanks. It should be noted that 70% of the undamaged unanchored tanks were completely empty.

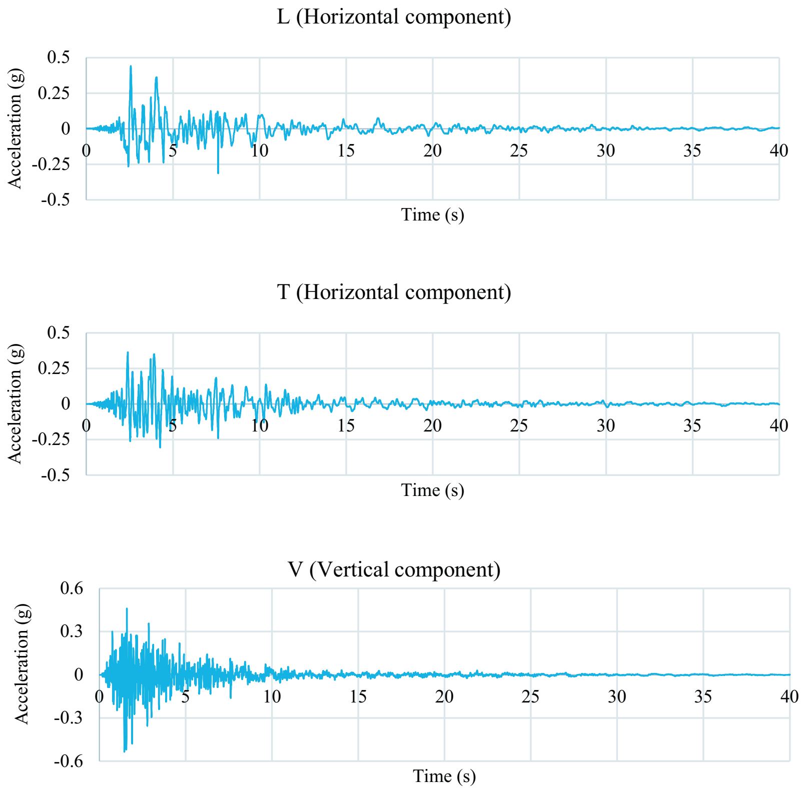

Fig. 1. Acceleration time-history of the Silakhor earthquake components record at chalanchulan station.