Journal of Structural Engineering and Geotechnics,

5 (3), 1-7, Summer 2015

Performance of industrial facilities and lifelines during the October 23rd, 2011 Van, Turkey Earthquake

Kiarash Nasserasadi*[a], Mehran Seyed Razzaghi[b]

a Assistant Professor, University of Zanjan, Zanjan, Iran

[b] *Assistant Professor, Qazvin Branch, Islamic Azad University, Qazvin, Iran*

Received 1 July 2015; Accepted 29 September 2015

Abstract

Damage to essential facilities (e.g. lifelines and industrial facilities) due to extreme loads may cause remarkable indirect impact as well as direct physical loss. Hence understanding seismic performance of essential facilities is very important in high seismic risk regions. On October 23, 2011 an earthquake of magnitude M_w7.2 occurred in Van province in eastern Turkey. Several damages occurred at industrial plants. Damage to equipment and buildings caused work abandon in some industrial plants. In this paper the observed damage to essential facilities such as transportation systems, silos and gas stations are presented.

Keywords: Van Earthquake; lifelines; damage; seismic performance

1. Introduction

During the past decades earthquakes have caused significant amount of social and economic losses due to physical damage to buildings and structures. On the other hand damage to essential facilities has caused noticeable indirect impacts such as environmental pollutions, and work stoppage of industries. Experience of the performance of lifelines and industrial facilities during the past earthquakes revealed that many of such facilities are seismically vulnerable. Following the Izmit earthquake of 1999 significant direct and indirect impacts were suffered by industries especially in Tupras oil refinery [1]. The Bam earthquake of 2003 which triggered south-eastern Iran caused serious damage to essential facilities, lifelines and industrial plants [2,3]. During Darb-e-Astaneh (Silakhor) earthquake of 2006 which occurred in western Iran some industrial plants suffered noticeable damages [4]. In addition to the above mentioned events, several essential facilities suffered heavy damage during the recent earthquakes which have occurred all around the world [5,6].

On October 23, 2011 an M_w7.2 earthquake occurred in Van province in eastern Turkey. The earthquake causes many damages to buildings and essential facilities in the Van and Ercis cities. The earthquake claims more than 600 lives and 4100 injuries. Most of the buildings in the cities were RC buildings which experienced different damage degree in both cities, but the damages in Ercis city were significantly higher. Several essential facilities are located in the Van province. Many of them were located in an industrial zone between Van and Ercis cities. These industries are: Sugar factory, at least 4 flavor factories and several concrete mixing. Other important lifeline facilities such as airport, railways, etc. were located in Van province. Industrial facilities experience different degrees of damage.

In this paper, performance of essential facilities during the Van earthquake of October 2011 is presented. Herein the seismic performance of lifelines (electrical facilities, transportation systems and gas stations) and industrial facilities are presented.

2. Description of seismic event

The Van earthquake of October 2011 was occurred at 10:41:21 (GMT). The epicenter of the earthquake was located at 38.691°N, 43.497°E according to USGS [7]. The focal depth of the earthquake was about 16 Km and the focal mechanism was reported as strike slip [7]. At least 22 stations have recorded the strong ground motion [8]. The largest PGA was recorded at Moradiyeh station (station number 6503) which is located near the Ercis city. The recorded PGA in this station was 178.5 cm/Sec^2 [8].

3. Performance of industrial facilities and components

---

* Corresponding Author Email: razzaghi.m@gmail.com

3.1. Wheat Silos

Silos are special structures which contain granular material such as grains, coal, cement, etc. These structures are important components in many industrial plants. Silos may subject to complex and unconventional loading conditions [9]. Hence many different failure mechanisms should be considered during the design process of silos [10]. One of the important load cases which may apply to silos is seismic loads. Many codes such as Eurocode 8 (part 4) [11] and AIJ [12], have presented some provisions for seismic design of steel and/or concrete silos.

Four types of silos were observed in food industrial plants in an industrial region near Van city. The specifications of the silos are presented in table 1. Following the earthquake several silos suffered damage. All of the observed silos of type “A” and “B” collapsed due to the earthquake (See figure 1). The main reason for collapse of Silo type “A” was buckling of supporting system. As indicated in figure 1 the columns and braces in this type of silos were cold-formed and extremely slender (KL/r>120). Furthermore as indicated in figure 2 the junction of shell and stiffeners strakes was ruptured the main reason for this failure mode is insufficient distance of bolts to the edge of the strake.

All of the four observed silos of type “B” were collapsed due to failure of cold formed vertical stiffeners of the shell (See figure 3). Local buckling, rupture of stiffener and failure of shell to stiffener connection was three main failure modes of the stiffeners in collapsed silos. Since all of the stiffeners were attached to the supporting system, the silos were felt down after failure of vertical stiffeners. Type “C” is basically type "B" silo but two of them are connected to each other by some ad-hoc connections. These silos suffered slight damage and were operable after the earthquake. As indicated in figure 4, plastic hinges were took place in the columns of silos and connecting truss of this type of silos. Moreover slight local buckling was happened in lower part of one the vertical stiffeners close to the column junction. In Silo type “D”, shell bulge occurred in lowest strike of a cylindrical bin. The silo was repaired and was operable twelve days after the earthquake. As shown in Figure 5, the cement finishing of foundation around the anchor bolts were cracked due to the bin uplift. Type "E" silos, were not damaged.

Table 1. Specification of the observed silos of food industries

Silo Name	Type	Description
A	Elevated-Single	Cold formed columns and braces, cold formed shell.
B	Elevated-Single	Hot rolled columns and braces, cold formed shells.
C	Elevated-Twin	Hot rolled columns and braces, cold formed shells.
D	Flat bottom (Bin)	Cold formed cylindrical shell, mechanically anchored to foundation.
E	Flat Bottom	Cylindrical steel shells mechanically anchored to the foundation.

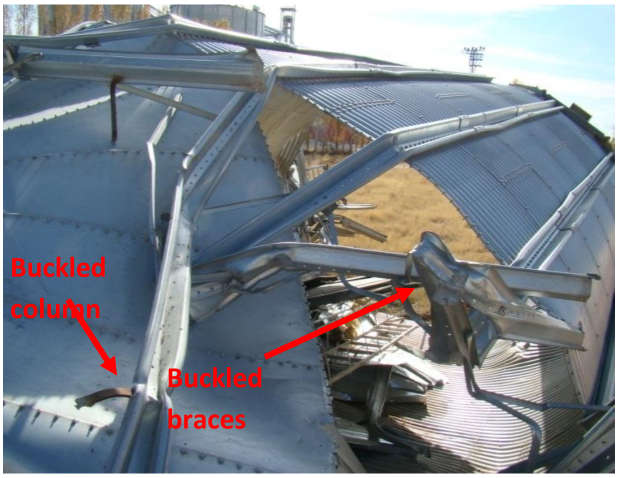

Figure 1. Damaged Silo type "A". Buckling of the cold formed column and braces are shown.

Figure 2. Rupture of shell in junction of strikes

Figure 3. Collapsed silo type "B".

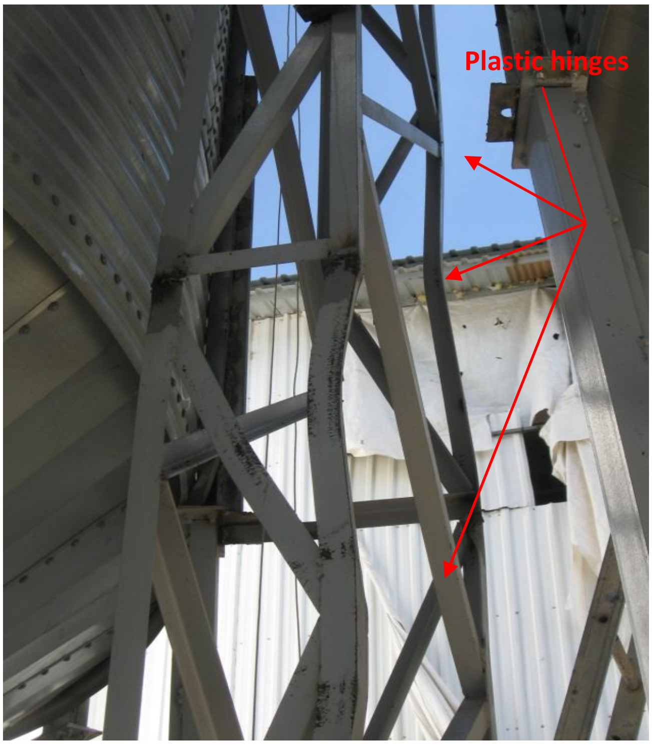

Figure 4. Damage to connecting truss of type “C” silos

Figure 5. Detail of type "D" silos. Damage to foundation due to uplift of a bin

3.1. Cement Silos

Several cement silos experienced strong ground motion and most of them didn't suffer observable damage. There were two similar cement silos belonging to a concrete factory in an industrial region near van city. One of the silos was full of cement and the other one was 50% full. During the earthquake the silo which was full of cement was overturned and its supporting system and foundation were damaged. The main reason for damage to above mentioned cement silo was failure welding of the shell to column connection in one of the supports (See figure 6). Following the failure of the connection, the silo overturned and one of the columns was buckled. Due to the overturning of the silo its foundation was seriously damaged.

Figure 6. Failure of welds in shell to column connection of a cement silo

3.2. Liquid storage tanks

There were three cylindrical fuel storage tanks in a factory in Ercis city. The tanks were interconnected by pipes with several rigid links as shown in figure 7. During the earthquake, the piping connections were damaged and leakage of fuel occurred. The cylindrical tanks were repaired two weeks after the main shock. It seems that the stress concentration and complexity of stress field in piping connection was the main reason of failure of the connection.

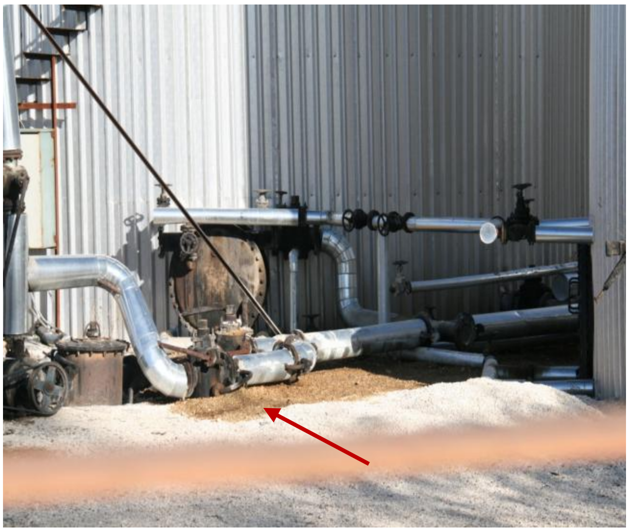

Figure 7. Repaired connection of piping system of cylindrical tanks

4. Performance of Industrial Buildings

Several industrial buildings near Van and Ercis experienced the earthquakes and experience different degree of damages which is described here. At least four flavor factories were located near Van. Following the earthquake three of them were damaged and put out of commission. All of the damaged industrial buildings were RC frames. Most of them built during the 1970s with low ductility and most of them with plain reinforcement bar. No observable structural damage occurred in two of buildings but noticeable damage occurred in nonstructural elements (e.g. brittle light weight roofs and infill walls). Figure 8 shows the out of plane failure of infill masonry walls. Another RC industrial building suffered observable cracks in its wing walls (See figure 9). There was a steel structure flavor factory in the Van industrial zone which slightly damaged due to the earthquake and was brought back to operation in two days. The structural system of the main industrial building of the factory was steel frame with moment resident frame in transverse and brace frame in longitudinal direction. No observable structural damage occurred in the steel frame. The infill walls of the building were light weight sandwich panels and didn't suffer damage. From all of the equipment in the plant, only one of the hanged heavy equipment was felt down during the earthquake and fixed in two days. There were several pipes in the building which didn't suffer any observable damage. It is worth mentioning that as indicated in figure 10 all of the pipes had flexible joints next to their junction with equipment.

Figure 8. Out of plane failure of masonry infill walls of industrial buildings

Figure 9**.** Observable crack in a RC wing walls in a low ductility RC industrial building.

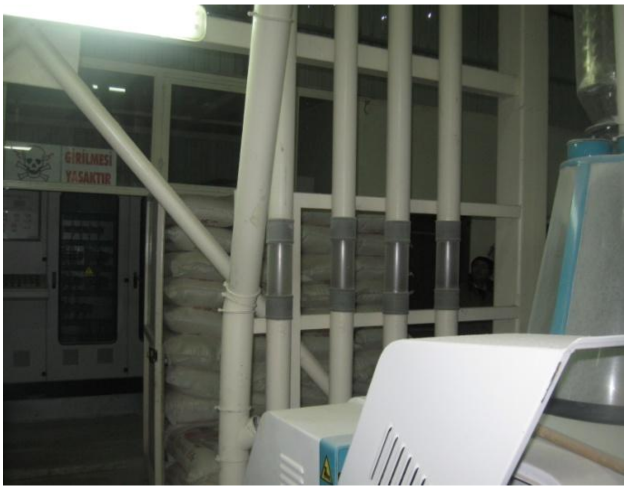

Figure 10**.** Undamaged pipes with flexible joints

5. Performance of Gas stations

Several gas stations were located in earthquake affected area. Most of them didn’t suffer observable damage and were operable after the earthquake. Figure 11 shows a damaged gas station. The light weight roof of the station was connected to a RC annex building before the earthquake. During the earthquake due to lack of anchorage the connection damaged and part of the roof felt down. Moreover as indicated in figure 12 the two story annex RC building were damaged due to the earthquake. Following the seismic event the gas station was not working after the earthquake but some temporarily tanks are located there for emergency uses.

Figure 11. Collapse of the light weight roof of the gas station

Figure 12. Noticeable damage to annex building of the gas station

6. Performance of Transportation Systems

Although roads suffered some damage due to the earthquake, they were serviceable after the earthquake. The asphalt pavement of the Van-Ercis road cracked in several parts of the road due to the fault rupture, geotechnical instabilities and settlement of the bridge abatement. Figure 13 indicates some of the cracks observed in Van-Ercis road.

At least two concrete bridges damaged due to the earthquake. Figure 14 shows a damaged bridge in Van-Ercis road. As indicated in this figure, the bridge deck suffered residual lateral displacement. Moreover pounding of deck to abatement happened due to longitudinal movement of the bridge deck. There was an observable evidence of the sand boiling next to the one of the bridge columns. The bridge was serviceable right after the earthquake. In another bridge, remarkable rotation of pier happened due to the liquefaction but the bridge didn’t collapse.

The airport suffered some nonstructural damages but was serviceable after the earthquake. No Observable damage occurred in railways and they were serviceable after the earthquake.

Figure 13. Cracks observed on road surfaces

Figure 14. Damage to a RC bridge.

7. Performance of Electrical facilities

No observable damage occurred in electrical substations. Some electrical poles damaged because of debris from the damaged buildings**.** Figure 15 indicates one of the damaged electrical poles. In some other poles the connections of cables from poles were cut due to the main shock. Most of them have been repaired twelve days after the main shock.

Figure 15. Collapse of an electrical pole due to collapse of adjacent building

8. Conclusions

Following the Van earthquake of 23 October 2011 in eastern turkey, a field investigation was conducted. Results of field observations revealed that:

- Performances of cold formed silos were not acceptable. Even in silos with partial cold formed members, extensive damage to cold formed elements caused collapse of the silo.
- Special attention should be made in design of bolted shell junctions in cold formed silos.
- Total or partial collapse of heavy masonry infill walls of industrial frames may cause serious damage to equipment.

9. Acknowledgements

This study was supported by Iranian Earthquake Engineering Association (IEEA), the authors are thankful for this support. Also the cooperation of Mr. A. Kheyri Motlagh is highly appreciated.

10. References

[1] EQE. (1999). Izmit Turkey earthquake of August 17, 1999 (M7.4). EQE international. www.eqe.com.

[2] Eshghi S., Nasserasadi K. (2005), Performance of Essential Buildings in the 2003 Bam, Iran Earthquake, J. Earthquake Spectra, 21 (S1): 375-393.

[3] Eshghi S., Razzaghi M. S. (2005), Performance of Industrial Facilities in the 2003 Bam, Iran Earthquake, J. Earthquake Spectra, 21 (S1): 395-410.

[4] Eshghi S., Razzaghi M. S. (2007), Performance of Liquid Storage Tanks during the Silakhor Iran Earthquake of March 31, 2006, Bulletin of NZSEE, 40 (4).

[5] Tang A. (2011), Lifelines Performance of the Mw 8.8 Offshore BIOBÍO, Chile Earthquake, J. Structural Eng. and Geotechnics, 1 (1): 7-17.

[6] Krausmann E., Cruz A.M., Affeltranger B. (2010), The Impact of the 12 May 2005 Wenchuan Earthquake on Industrial Facilities J. Loss Prevention in the Proc. Industries, 23: 242-248.

[7] USGS (2011), www.earthquake.usgs.gov.

[8] Dogangun A., Karaca Z., Durmus A., Sezen H. (2009), Cause of Damage and Failures in Silo Structures, 23 (9): 65-71.

[9] METU-EERC (2011), Processed Main shock Accelerometric Recordings of the 23 October 2011 Van Earthquake, Report No. METU/EERC 2011/02.

[10] Sadowski A. J., Rotter J.M. (2011) Steel Silos with Different Aspect Ratios: II- Behavior under Eccentric Discharge, J. Const. Steel Research 67: 1545-1553.

[11] ENV 1998-4 (1999), Eurocode 8: Design provisions for earthquake resistance of structures -Part 4: Silos, tanks and pipelines.

[12] AIJ (2010), Design Recommendation for Storage Tanks and Their Supports with Emphasis on Seismic Design. Architectural Institute of Japan.