Statistical Investigation of Lift Damages after Large Earthquakes in Turkey

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Abstract. Lifts are expected to continue their services after earthquakes, especially in critical and strategic public buildings such as hospitals. However, from investigations carried out in the field after earthquakes, it is known that lifts are out of service due to damage to critical components. In this study, after large earthquakes in Turkey, field investigations carried out on lift installations are discussed, and the structural elements of the lifts are classified and statistically expressed. The results obtained are shown graphically, and the distribution of the damages in critical components is given. It is aimed to reveal which components should be focused on in lift design for earthquakes and the points to be taken into account in lift design for seismic test suit. Although the EN 81-77 standard was introduced in Turkey in 2014, it has been observed that the standard is not mandatory, and the structural characteristics of the damaged lifts during the period are the same.

1 MAJOR EARTHQUAKES IN TURKEY

Turkey is a seismically active country, with large earthquakes recorded throughout history. Since 1900, 22 earthquakes with a magnitude greater than 7 have occurred. These earthquakes and their details are displayed in Table 1 [1, 2]. There were 269 earthquakes in Turkey between 1900 and 2023 that resulted in fatalities or damage. The 2023 Kahramanmaraş earthquake, the 1939 Erzincan earthquake, and the 1999 İzmit earthquake were the most destructive and fatal earthquakes [3].

According to the Earthquake Hazard Map of Turkey, which was published in 2018 and depicts Turkey's earthquake hazard, the majority of Turkey's territory is located in earthquake-prone areas. Figure 1 shows Turkey's seismic hazard map [4].

Table 1 Earthquakes with magnitude over 7 in Turkey (1900-2023)

	Earthquake Name	Date	Time (UTC)	Longitude (°)	Latitude (°)	Depth (km)	Magnitude (AFAD)	Magnitude (Kandilli)	Loss of Life	Damaged Building
1	1912 Tekirdağ	09.08.1912	01:29:00	27.2	40.75	10	7.4	7.3	216	5540
2	1914 Burdur	04.10.1914	22:06:00	30.1	37.6	10	7	6.9	300	6000
3	1916 Tokat	24.01.1916	06:55:15	36.83	40.27	10	7.1	7.3		
4	1919 Balıkesir	18.11.1919	21:54:50	26.71	39.26	10	7	7		
5	1926 Datça	26.06.1926	19:46:38	27.33	36.54	100	7.7	7.7		
6	1930 Near Persian	06.05.1930	22:34:32	44.48	37.98	70	7.6	7.6	2514	
7	1939 Erzincan	26.12.1939	23:57:21	39.51	39.8	20	7.9	7.9	32968	116720
8	1942 Tokat-Erbaa	20.12.1942	14:03:08	36.47	40.87	10	7	7	3000	32000
9	1943 Çankırı-Ilgaz	26.11.1943	22:20:41	33.72	41.05	10	7.2	7.5	4000	40000
10	1944 Bolu-Gerede	01.02.1944	03:22:36	32.6	40.9	10	7.3	7.2	3959	20865
11	1948 Mediterranean	09.02.1948	12:58:19	27.2	35.41	30	7.2	7.2		
12	1953 Çanakkale	18.03.1953	19:06:16	27.36	39.99	10	7.2	7.2	265	6750
13	1957 Mediterranean	25.04.1957	02:25:45	28.68	36.42	80	7.1	7.1	67	3200
14	1957 Düzce-Bolu	26.05.1957	06:33:35	31	40.67	10	7.1	7.1	52	5200
15	1964 Bursa	06.10.1964	14:31:23	28.23	40.3	34	7	7	23	5398
16	1970 Kütahya	28.03.1970	21:02:24	29.51	39.21	18	7.2	7.2	1086	19291
17	1976 Van	24.11.1976	12:22:16	44.029	39.08	8.6	7	7.5	3840	9232
18	1999 İzmit	17.08.1999	00:01:39	30.004	40.77	15	7.6	7.8	17480	73342
19	1999 Düzce	12.11.1999	16:57:21	31.226	40.806	11	7.1	7.5	763	35519
20	2011 Van	23.10.2011	10:41:00	43.4657	38.689	19.02	7.1	7.2	644	17005
21	2023 Kahramanmaras-Pazarcık	06.02.2023	01:17:32	37.043	37.288	8.6	7.7	7.7	50000	500000
22	2023 Kahramanmaras-Elbistan	06.02.2023	10:24:47	37.239	38.089	7	7.6	7.6		

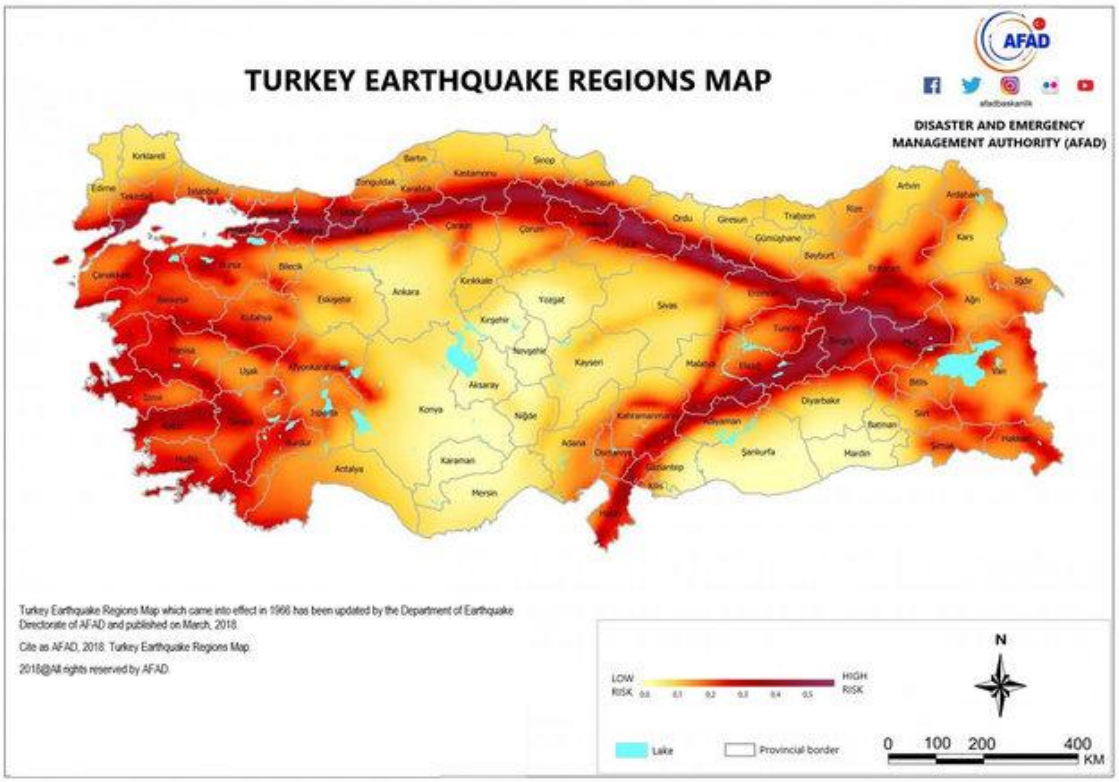


Figure 1 Earthquake hazard map of Turkey [4]

2 LIFT DAMAGE (STATISTICS) AFTER EARTHQUAKES

Lifts are expected to continue operating after earthquakes, particularly in crucial and strategic public buildings like hospitals. However, post-earthquake investigations revealed that the lifts' mechanical elements were damaged and rendered inoperable. This study examines the damage to lift structural elements following large earthquakes in Turkey. In this context, the 1999 İzmit earthquake, 2011 Van earthquake and 2023 Kahramanmaraş earthquakes will be analysed. Figure 2 shows the centres of earthquakes on the map of Turkey.

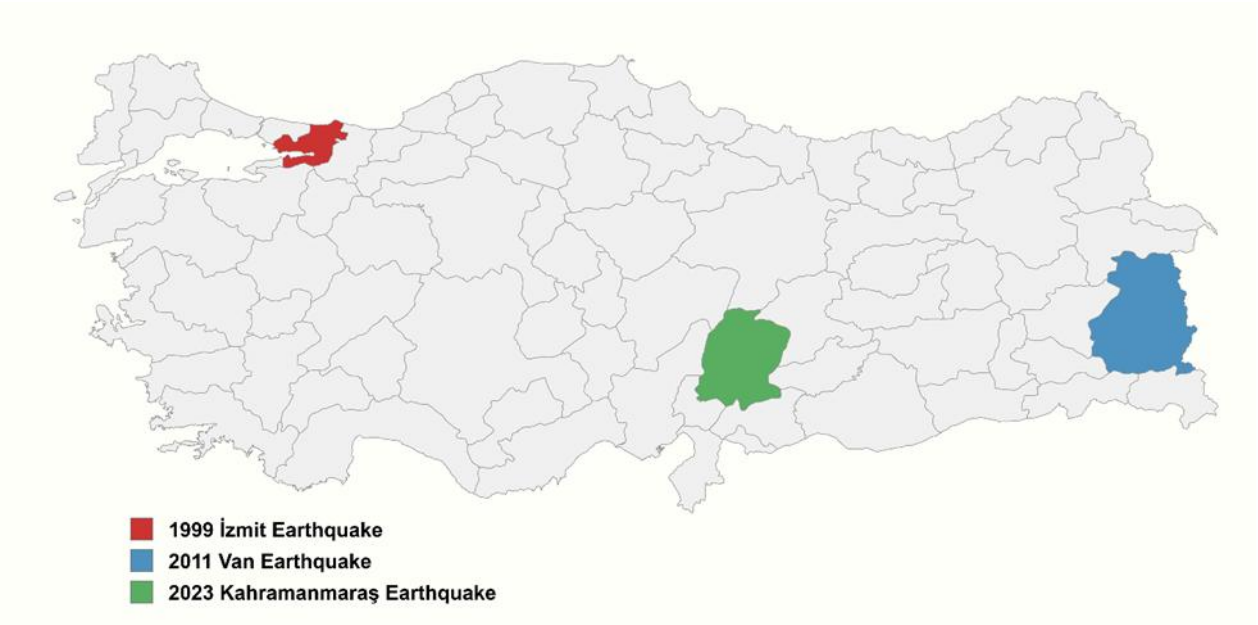


Figure 2 Centres of selected earthquakes on the map of Turkey

2.1 The 1999 İzmit Earthquake

On August 17, 1999, at 00:01:39 in coordinated universal time (UTC) (03:01:39 local time), the İzmit earthquake took place. The earthquake's depth was 15.0 kilometres, its epicentre was located at 40.77°N 30.004°E, and its magnitude was 7.6. The earthquake killed roughly 18000 individuals and damaged around 75000 buildings [1, 2].

The following damage was caused to lifts by the İzmit earthquake. Some counterweights came out of the rails and hit the cabin, hoisting ropes were damaged or came out of their sheaves, rail brackets were broken or damaged, governor ropes that were cut, roller guides that were broken or loose, compensating cables that were damaged or came out of their grooves, some hoistways that collapsed, and cabins that stayed at the bottom and were crushed [5].

2.2 The 2011 Van Earthquake

On October 23, 2011, at 00:01:39 10:41:00 in UTC (13:41:00 local time), the Van earthquake took place. The earthquake's depth was 19.02 kilometres, its epicentre was located at 38.689°N 43.4657°E, and its magnitude was 7.1. The earthquake killed roughly 750 individuals and damaged around 20000 buildings [1, 2].

İmrak studied the sorts of damage to lifts following the Van earthquake. The following damage types have been observed: the counterweight derailment, the guide shoes of the counterweight frames breaking, the guide rails on the counterweight side bending, the bracket element bending, the landing

doors jamming, the rope dislocating from the pulleys and becoming damaged, the carrier ropes snagging on the bracket elements, and the falling of the counterweight weights on the car. Lift damage following the earthquake is depicted in Figure 3 [6].

Figure 3 Lift damage of the Van Earthquake [6]

After 25 lifts were examined in Van, it was observed that the counterweights came out of their guide rails, and brackets were bent, resulting in counterweight derailments and guide rails forced to break their guide shoes, as shown in Figure 3.

2.3 The 2023 Kahramanmaraş Earthquakes

Two consecutive large earthquakes occurred in Turkey. The first earthquake was Kahramanmaras-Pazarcık on February 06, 2023, at 01:17:34 in UTC (04:17:34 local time). The earthquake's depth was 8.6 kilometres, its epicentre was located at 37.288°N 37.043°E, and its magnitude was 7.7. The second earthquake was Kahramanmaras-Elbistan on February 06, 2023, at 10:24:48 in UTC (13:24:48 local time). The earthquake's depth was 7.0 kilometres, its epicentre was located at 38.089°N 37.239°E, and its magnitude was 7.6. The earthquakes killed roughly 50000 individuals and damaged around 500000 buildings [1, 2].

According to the report following the Kahramanmaraş earthquakes, the following types of damage were recorded in lifts. Some lift shafts collapsed, cabins sank to the bottom, roller guides were loose or broken, regulator ropes were damaged, rail brackets were broken, balancing cables were out of their slots or damaged, counterweights were coming out of their rails, and some of them were hitting the cabins. Lift damage following the earthquake is depicted in Figure 4 [7].

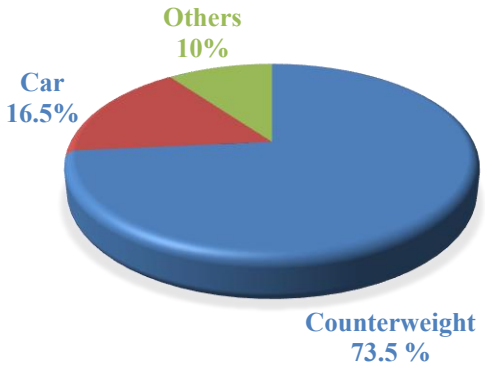
Figure 4 Lift damage of the Kahramanmaraş Earthquakes [7]

Field work was carried out in Malatya, one of the provinces affected by the Kahramanmaraş earthquakes. Although the hospital lifts examined were installed after the EN 81-77 standard was

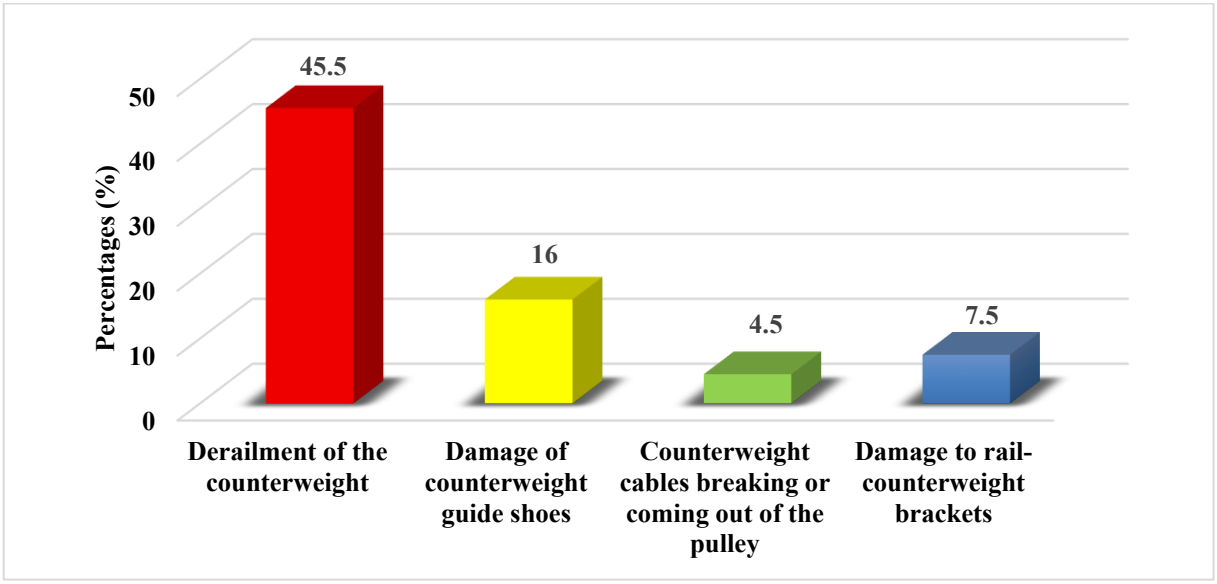
implemented, it was observed that the brackets were not specially designed for earthquake zones. Many of them had structural damage, and the counterweight was displaced, caused by the effects of the earthquake, as shown in Figure 4.

2.4 Statistics of Lift Damage After Earthquakes

As a result of the research and observations made in the field after the major earthquakes in Turkey, the percentage distribution of damage to lifts is shown in Figure 5. While examining the statistical data, the lift system is divided into the car part, counterweight part and others (Figure 5 (a)). The counterweight part consists of rail, shoes, bracket, cables and counterweight, and the part that includes all the elements here can be referred to as the rail-counterweight system. When the earthquake statistics are examined, it is seen that the total damage rate of the rail-counterweight system is 73.5%. According to statistical data, the most common type of damage is derailment of the counterweight (Figure 5 (b)).



(a)



(b)

Figure 5 Percentage of damage types in lifts

Although the EN 81-77 standard was introduced in Turkey in 2014, it has been observed that the standard is not mandatory, and the structural characteristics of the damaged lifts during the period are the same. Although the lifts damaged in the Van earthquake correspond to the period before this

standard was applied, and the lifts damaged in the Kahramanmaraş earthquake correspond to the subsequent period, it is understood that there is a lack of awareness and supervision on this issue.

It is known that building seismic-proof conditions and the lift seismic-proof condition minimise the lift damage after earthquakes. The classification and evaluation of lift damage after earthquakes is useful for understanding the damage and effectiveness of seismic proofing procedures.

3 COUNTERMEASURES TO REDUCE EARTHQUAKE DAMAGE

In the event of an earthquake, countermeasures should be taken to ensure that lift systems receive the least possible damage. In the reports prepared as a result of field studies conducted after earthquakes, the following countermeasures were recommended.

Imrak said that seismic switches should be used in lifts, box brackets should be used to strengthen the counterweight rails to prevent displacement of the counterweight, guide rails of sufficient size should be used, retaining plates are required under the roller guide assemblies, and anti-tripping guards are required in the lift track to prevent tripping of ropes and travelling cables [6].

Çelik et al. suggested that seismic switches should be used, measures for counterweight tie rods and electrically charged wire with displacement ring should be taken, an appropriate size guide rail should be used, structural support frames for seismically isolated buildings, and rope guards should be used [7].

4 CONCLUSIONS

Observations and assessments of large earthquakes in Turkey reveal repeating types of damage to lift systems. These damages are counterweight derailments, hoistway component damage, cable dislocation, and shaft structural failures. Statistical analyses show that the most common damage is in the rail-counterweight system, and within this system, the most common is derailment of the counterweight. When the statistical analysis is evaluated, it shows that lift designs should focus on the rail-counterweight system. Recommendations such as the installation of seismic switches, reinforced guide rails, box brackets, retaining plates, and anti-tripping mechanisms are critical for increasing lift resilience and further reducing the risk of failure during earthquakes.

These findings, and the implementation of advanced seismic design standards and regular maintenance protocols, are essential. These measures can ensure the functionality and safety of lift systems in earthquake-prone regions, reducing operational downtime and protecting human lives.

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BIOGRAPHICAL DETAILS

Yakup Artun has been working as a Research Assistant at Yıldız Technical University (YTU). He received his bachelor's degree in Mechanical Engineering from Bozok University in 2014. He completed his master's degree at YTU, Department of Mechanical Engineering. In 2022, he started his PhD education in the field of Construction, Department of Mechanical Engineering at YTU and is still continuing his PhD education. Machine design and machine elements, materials handling and especially lift systems, mechanical vibrations are among the areas of study and research.

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C. Erdem İmrak has been employed as a full-time Professor at Istanbul Technical University (ITU). Professor Imrak received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from ITU in 1990, 1992, and 1996, respectively. He has carried out research into computer-aided engineering, CAD/CAM, numerical analysis, materials handling and especially lift systems. Currently, his activities include: an Honorary Member of ASYAD; a Member of the Safety, Education & Training Committee of ELA; a Member of the ASME; a Member of the OIPEEC; a Member of the IAEE; and a Member of the Chamber of Mechanical Engineers in Turkey.

Ahmet Sagirli has been employed as a full-time Professor at Yıldız Technical University (YTU). Professor Sagirli received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from YTU in 1988, 1990, and 1997, respectively. Construction and manufacturing, machine design and machine elements, computer-aided design and manufacturing, materials handling, machine theory and dynamics, and modelling and simulation of dynamic systems are among the areas of study and research.

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Hamit Kenan completed his BSc degree in Mechanical Engineering at Uludağ University and Yıldız Technical University (YTU) between 2006-2011, his MSc degree at Istanbul Technical University in 2015 and his PhD degree at YTU in the Construction Program in 2022. His research interests include the behaviour of cranes under earthquake effects, finite element analysis, mechanical performance of functionally graded auxetic structures and machine design. Dr. Kenan worked as a research assistant at YTU between 2014-2022 and has been working as a faculty member at Antalya Bilim University, Department of Mechanical Engineering since 2022.

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