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Geotechnical site investigation and evaluation of 20 March 2019 Mw 5.5 Acıpayam (Denizli) earthquake

20 Mart 2019 Mw 5.5 Acıpayam (Denizli) depreminin jeoteknik saha incelemesi ve değerlendirmesi

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Abstract

An earthquake with a magnitude of (Mw) 5.5 occurred in Yeniköy village of Acıpayam district (Denizli) on 20 Mart 2019 caused heavy damages on masonary structures in Acıpayam basin. Groundwater level from ground surface in the basin varies between 1m and 11m, and soil structure of the basin is made up of silty, gravely and sandy clay. Soil liquefaction was not observed in the basin after the earthquake. The main reasons of the heavy damage on the structures are mainly, high value of soil amplification, use of clayey adobe bricks and hollow bricks for building masonary houses, unpermitted construction of roof floors by using hollow bricks.

Keywords: Acıpayam (Denizli), Earthquake, Geology, Geotechnic.

Öz

20 Mart 2019 tarihinde merkez üssü Denizli ili Acıpayam ilçesinin Yeniköy Mahallesi sınırları içerisinde 5.5 (Mw) büyüklüğünde meydana gelen deprem sonucunda, Acıpayam ovası içindeki yerleşim yerlerinde yığma yapılarda ağır hasarlar meydana gelmiştir. Ova içinde yeraltısuyu derinliği zemin yüzeyinden 1 m-4.5 m arasında değişmektedir ve zemin yapısı genellikle siltli çakıllı ve kumlu kil biriminden oluşmaktadır. 5.5 büyüklüğündeki deprem sonrası ova içerisinde zemin sıvılaşması gözlenmemiştir. Yapılardaki ağır hasarların ana nedeni, zemin büyütmesinin yüksek olduğu yerleşim yerlerinde kerpiç, biriket ve delikli tuğla ile yapılmış yığma yapıların olması ve betonarme yapılarda da mühendislik hizmeti almamış ve dayanımsız yığma çatı katlarının inşa edilmesinden kaynaklanmıştır.

Anahtar kelimeler: Acıpayam (Denizli), Deprem, Jeoloji, Jeoteknik.

1 Introduction

An earthquake occurred with a magnitude of (M_w) 5.5 [1], 5.7 [2] in Yeniköy Village of Acıpayam district in Denizli city in SW Turkey at 09:34 with the local time on 20 March 2019. The hypocenter depth of the earthquake was given as 10.76 km by [1] and 10.76 km by [2]. The earthquake caused many adobe and masonry houses to collapse in many villages in the Acıpayam basin (Figure1).

The largest acceleration according to the preliminary assessment results by [1] was measured at 361.24 gal in N-S component, 184.4 gal in E-W component, 30.95 gal in U-D component of AFAD 2017 coded accelerometer station, 7 km far from the epicenter of the earthquake. The epicenter of the 1936 earthquake with a magnitude of 5.3 [2] was approximately 3 km far from the 20 March 2019 earthquake.

Fault plane solution of the earthquake given by [3] depicts that NW-SE trending a normal fault caused the earthquake (Figure 2). The earthquake was triggered by the activity of NW-SE trending normal fault intersecting Acıpayam fault of the Fethiye-Burdur Fault Zone in the southeast of the basin [4].

The Burdur-Fethiye Fault Zone is one of the important neotectonic and seismic zones of Turkey. There are different studies on paleo-seismology of this neotectonic zone [5]-[12]. Active fault zones in Burdur-Fethiye neotectonic zone (Figure 2) were classified as NE-SW trending, NW-SE trending and N-S trending fault zones 12]. Especially NE-SW trending faults, bounding Burdur Lake from north and south, have left strike slip character.

These faults cut through the Quaternary alluvium sediments in many locations resulting step like morphology with steep slopes. The NW-SE trending faults mostly have normal fault character and they resulted in forming different segments by displacing N-S trending fault zones 12].

Geotechnical investigations [26]-[30] carried out in Acıpayam basin depicted that soft sediments having low SPT values are deposited in the inner part of the basin. In addition to that, groundwater depth from ground surface in the same area varies from 1m to 5m.

In this paper, geotechnical site investigation and evaluation of 20 March 2019 M_w 5.5 Acıpayam earthquake was performed by using and evaluating existing geological and geotechnical data, site investigation in study area after the earthquake and seismicity of the region.

2 Tectonics and seismic activity of the Burdur-Fethiye fault zone

The Burdur-Fethiye fault zone is an active fault zone, produced earthquakes with a magnitude of 7.1 in Burdur Province on 03.10.1914 and in Fethiye District in Muğla Province on 25.04.1957 (Table 1).

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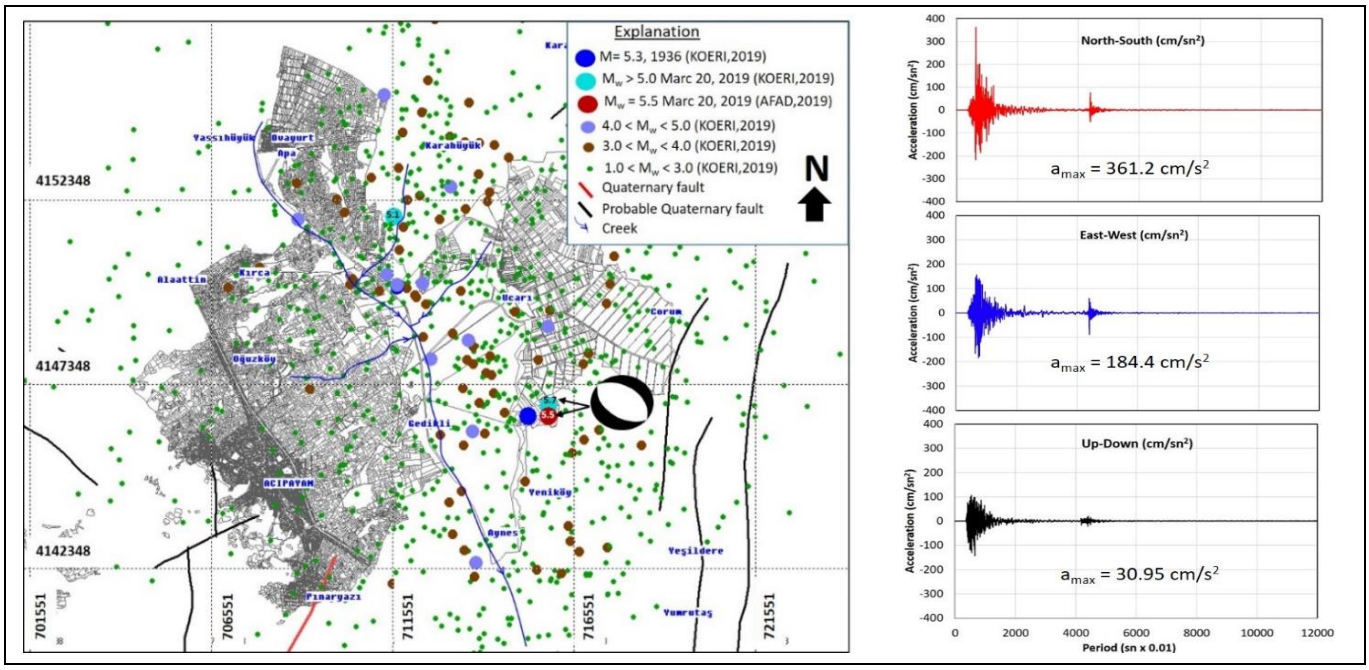

Figure 1(a): Epicenters of 20 March 2019 earthquakes on the tectonic map and urban planning map of Acıpayam on SLOPAC program [15]. (b): Acceleration records of Acıpayam strong motion station [3].

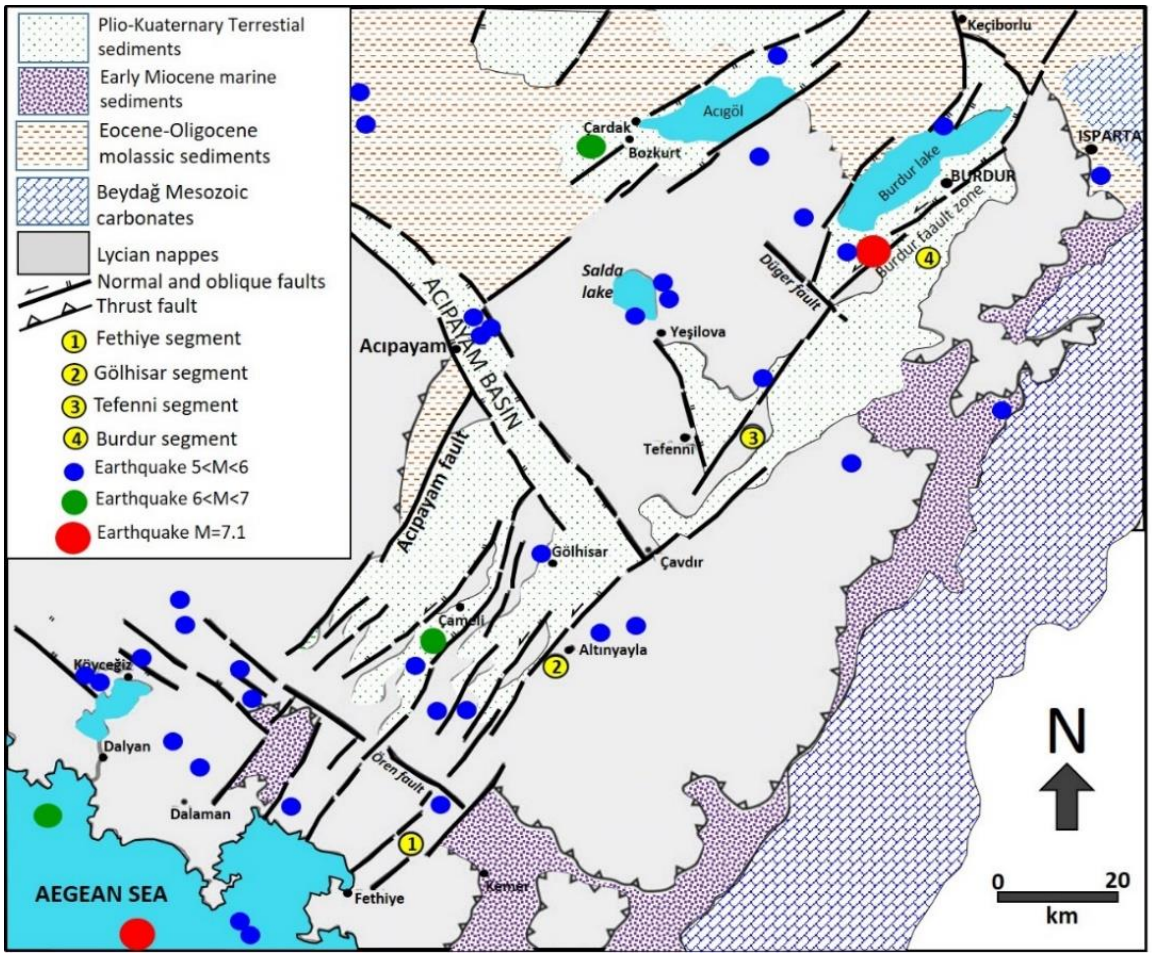

Figure 2. Relationship of between tectonic zones located in the Burdur-Fethiye Fault Zone [12] and earthquake epicenters of M>5 [1] since 1900.

Table 1. Earthquakes occurred in Burdur-Fethiye Fault Zone between 1900 and April 2019 [1][1], [2][2].

Date	Place	Magnitude
03.10.1914	Burdur	$^{1}M_S$ = 7.0
03.01.1926	Gölhisar - Burdur	$^{1}M_S$ = 6.1
08.12.1936	Uçarı Acıpayam - Denizli	$^{2}M_S$ = 5.3
25.04.1957	Fethiye - Muğla	$^{1}M_S$ = 7.1
14.01.1969	Fethiye - Muğla	$^{1}M_S$ = 6.2
12.01.1971	Burdur	$^{1}M_S$ = 6.2
06.10.2012	Fethiye - Muğla	$^{1}M_S$ = 6.0
29.10.2007	Çameli-Denizli	$^{1}M_S$ = 5.1
20. 03. 2019	Yeniköy Acıpayam-Denizli	$^{1}M_W$ = 5.5
31. 03. 2019	Karahüyük Acıpayam-Denizli	$^{2}M_S$ = 5.1

The magnitude of the post-1900 earthquakes that occurred in the inner and central parts of this fault zone did not exceed 6.2 (Figure 2). On the plain of Acıpayam, a 5.3 magnitude earthquake occurred in 1936 centered on Uçarı neighborhood. The epicenter of this earthquake is very close to the 20 March 2019 earthquake, with a recurrence of the earthquake in 83 years [13], [14].

Seismic activity of Acıpayam fault in Holocene was dated between 3030 ± 30 BP and 2410 ± 30 BP by [17] based on the trench microstratigraphy, structural pattern and ^{14}C dating on the samples take in a fault trench survey in Ören section of the Acıpayam fault.

3 Geology and tectonics of Acıpayam basin

Acıpayam Basin is a N-S extending Neogene basin in Burdur-Fethiye Fault Zone. Topographic altitude of the basin varies from 850m to 950m and, the surface water of the basin drains out into Dalaman creek at SW. Mesozoic and Cenozoic rocks form high mountains bounding the basin.

Mesozoic (Trias-Jura-Cretaceous) rocks are composed of carbonated and ophiolitic rock groups belong to Lycian nappes. The Mevlütler region, southwest of the Acıpayam district center, is one of the places where ophiolitic rocks are well observed [18]. The Cenozoic units consist of early Miocene conglomerates, shallow marine limestone [19] and late Miocene-Pliocene period alluvial, fluvial and lake sediments [20], [21], [22]. The morphology of the N-S trending fault along the western edge of Mount Malı, which borders the basin from the east, is quite evident (Figure 3). In the middle of the basin, a normal fault line having a N-S strike and dipping to the west has developed. Bedirbey, Yeniköy and Uçarı (Figure 3) villages are settled on this fault zone. The epicenter of the 5.5 magnitude earthquake, which occurred at 9.34 am on March 20, 2019, falls on this fault line [14].

The younger units of the Quaternary period consist of lacustrine, fluvial, alluvial and colluvial deposits along the western slopes of the Malı month (1745 m) in Yumrutaş-Yeşildere-Corum neighborhoods in the east.

After 20 March 2019 earthquake, surface cracks were observed in the south of Yeniköy district, with a direction of N5°E and a length of approximately 1500 m and a width of 1-4 cm (Figure 3). The surface crack developed on a possible fault surface in the contact zone between the Pliocene lacustrine limestone and alluvium [14].

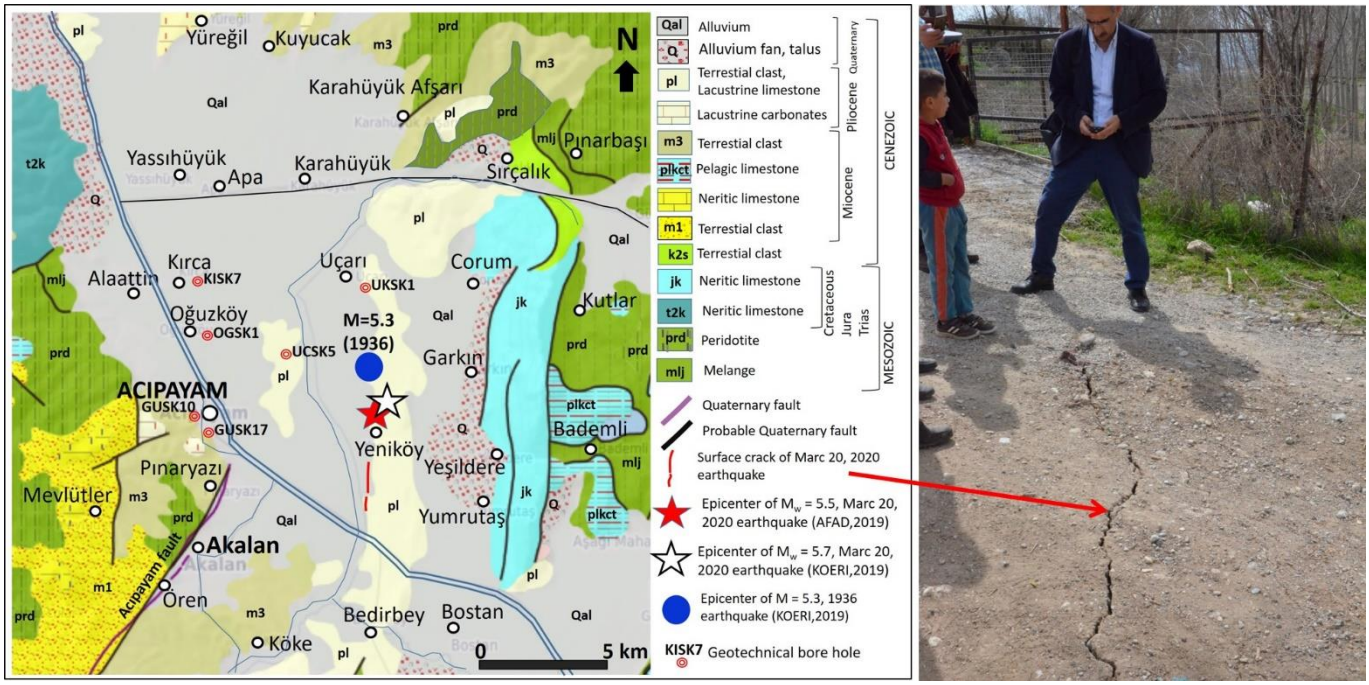

Figure 3. Geology and tectonic outlines of Acıpayam and surroundings [23],[24],[25],[14], earthquakes M>5 since 1900 [1],[2] and geotechnical borehole locations.

4 Geotechnical properties of soils in the Acıpayam basin

The Acıpayam Plain has a mostly alluvial ground structure and is generally composed of silty, sandy and clayey units. As a result of the decomposition of the lacustrine limestone of Pliocene age in the inner and eastern parts of the plain, clayey, silty and sandy alluvial units are yellowish-beige in some places due to the high carbonate content in the lowland floor of the basin. As part of the work carried out by [26]-[28], and geotechnical boreholes were drilled in the area between Acıpayam district center, Oğuzköy, Kırca, Uçarı, Yeniköy and Pınaryazı (Figure 3).

Borehole locations were drawn on urban planning and geological maps on a geological and geotechnical information system software written by [15] and applied to Denizli city [16] (Figure 1).

KISK7 geotechnical borehole was drilled in the Kırca village having 15m depth [29]. Groundwater level in the borehole is 1.8 m deep from ground surface. Soil profile of the borehole made up of soft sediments in the first 12.5 m from the ground surface. Standart penetration test (SPT) values at this depth change from 10 to 14. Grain size distribution curves of soil samples are given in Figure 7. Soil sample of 4m depth consists of 13.33% gravel, 70.28% sand and 13.33% silt and clay. Soil type of the sample according to Unified Soil Classification System [37] is SW (well graded sands and gravely sands). This soil is liquefiable soil but in the field liquefaction was not observed in this location after M=5.5 earthquake on 19 March 2019. Soil sample of 12 m depth contains 0.75% gravel, 28.9% sand and 70.35% silt and clay. Soil type of the sample in Unified Soil Classification System [37] is CL (inorganic clays of low to medium plasticity, gravely, sandy and silty clays).

According to the bounds for liquefiable soils [35] and 70.35% of silt and clay content, this soil is not liquefiable (Figure 4).

OGSK1 geotechnical borehole was drilled in Oğuz village and it has 15.5m depth [28]. Groundwater level in the borehole is 1.1m deep from ground surface. Soil profile of the borehole from ground surface to the bottom contains 0.4m of vegetable soil, 1.6m tick sand, 4.5m gravely clayey sand, 4.5m clayey sand and 3m gravely clayey sand (Figure 4).

SPT values from 1.5 m to 6 m varies from 11 to 24. The soil profile after 6 m gets stiffer with increasing SPT values from 36 to over 50. Grain size distribution curves of soil samples are given in Figure 4. Soil sample of 4.5 m depth consists of 21.58% gravel, 33.06% sand and 43.36% silt and clay. Soil type of the sample in Unified Soil Classification System [37] is SC (clayey sands, sand clay mixture). This soil is not liquefiable [35] (Figure 7).

UCSK5 geotechnical borehole was drilled in Uçarı village and it has a depth of 16 m. The Groundwater level in the borehole is 1.5 m below the ground surface [26].

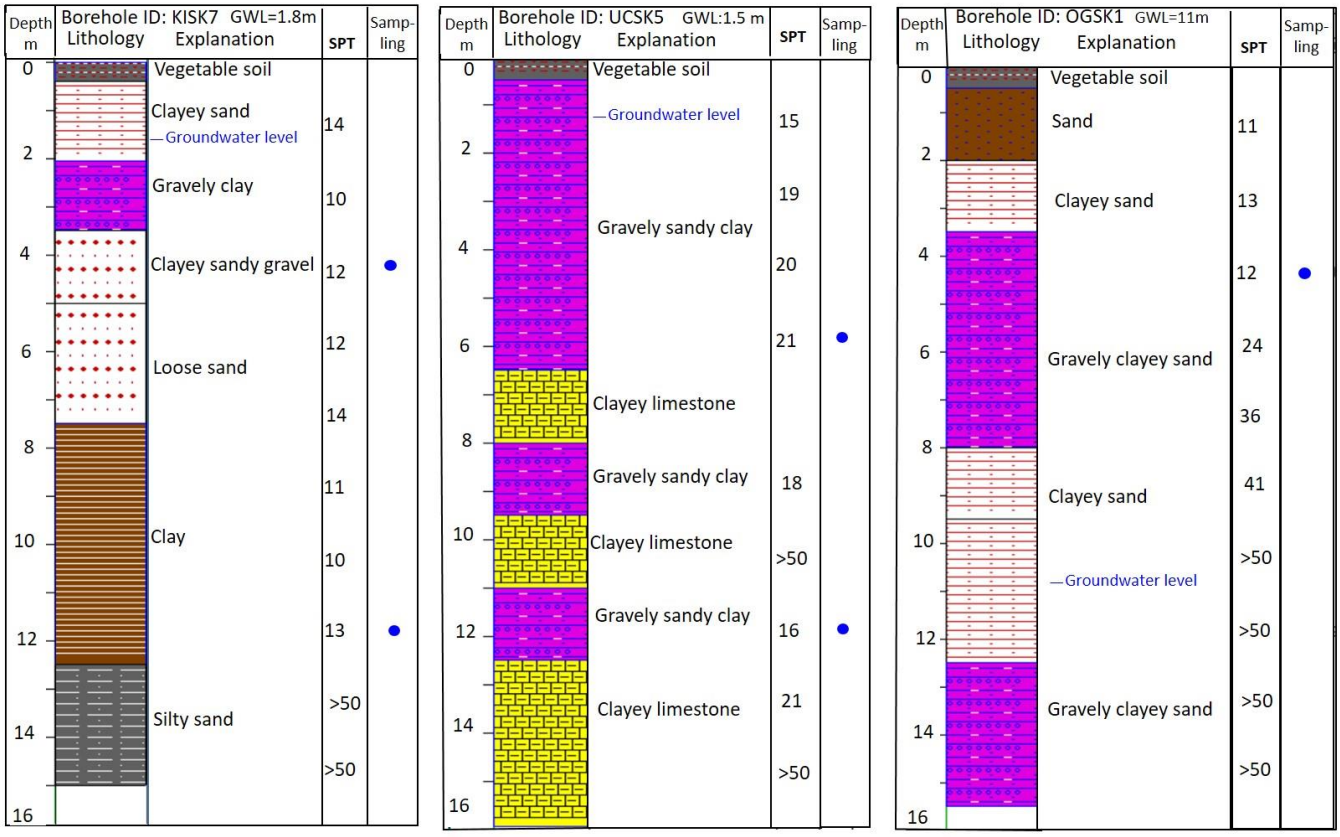

Figure 4. Geotechnical logs of the boreholes numbered as KISK7, OGSK1 and UCK5 in the Acıpayam Basin.

Soil profile of the borehole from ground surface to the bottom contains 0.4 m vegetable soil and succession of gravely sandy clay and clayey limestone. Gravely sandy clay layers have STP vales between 15 and 21 while clayey limestone levels have SPT values bigger than 50 (Figure 4). Soil samples of 6 m and 12 m depths contain 82.44% and 76.04% silt and clay respectively. Soil type of the both samples in Unified Soil Classification System [37] are CL. Soils in both levels are not liquefiable [35] (Figure 7).

GUSK10 geotechnical borehole was drilled in the center of the Acıpayam District having 11m depth [29]. Groundwater level is deeper than the depth of the borehole. Soil profile from ground surface to the bottom of the borehole contains 0.4 m vegetable soil and 10.6 m weathered claystone (Figure 5). Soil sample taken at 3 m depth consists of 28.42% sand and 71.58% clay. Soil type of the sample in Unified Soil Classification System [37] is CL. Soil liquefaction is not possible in this borehole location [35] (Figure 7).

GUSK17 borehole was drilled in the center of the Acıpayam District having 11m depth. Groundwater level is deeper than the depth of the borehole. Soil profile of GUSK17 borehole, having 11m depth and located in the district center, from ground surface to the bottom contains 0.4 m organic soil and 10.6 m sandy stiff clay. The SPT values in the borehole were bigger than 50 (Figure 5).

Most of the buildings around GUSK10 and GUSK17 borehole locations had no damage. There are slightly damaged buildings having chimney toppling and fissures in hollow brick built walls. Stiffness of weathered claystone and sandy stiff clay having SPT values bigger than 50, and having groundwater levels deeper than borehole depths (>12m) had an important effect on the slight damages of the structures at these borehole locations.

UKSK1 borehole was drilled in Uçarı village and 10 m in the lacustrine limestone was cut through the borehole. The groundwater level is 5 m deeper than the ground surface [30]. Lacustrine limestone is weathered and, has pores and karstic cavity (Figure 5). Groundwater discharging through karstic limestone in western area of Uçarı village forms the lake of Uçarı (Figure 6). Weathering, karstic cavity, groundwater pressure in lacustrine limestone and close distance to the earthquake epicenter location had an important influence on the heavy damages of the masonary structures in Uçarı village.

[31] compiled some data on the earthquakes in Turkey and developed relations between the magnitude of the earthquake and the distances of the areas where liquefaction occurred and did not occur. The average distance from the epicenter of the earthquake where liquefaction may occur can be calculated with the following equation:

$$R=36M_s-200 \text{ (average) [31]} \quad (1)$$

If the distance R is less than zero, liquefaction does not occur. For values greater than zero, local ground condition and groundwater level values are effective. For the Acıpayam earthquake, R = -2 km has been obtained. It is very close to M_s = 5.56 liquefaction magnitude of lower boundary [31] but outside the lower limit of the possibility of liquefaction.

Liquefaction analyses of the soils sampled in OGSK1, UCSK5, KRSK7 and GUSK10 boreholes were performed by using the suggested method of [36] for the M_w 5.5 earthquake. The factor of safety against liquefaction for all samples were obtained bigger than 1.5. This means that, these soils are not liquefiable under the effect of M_w 5.5 Acıpayam earthquake.

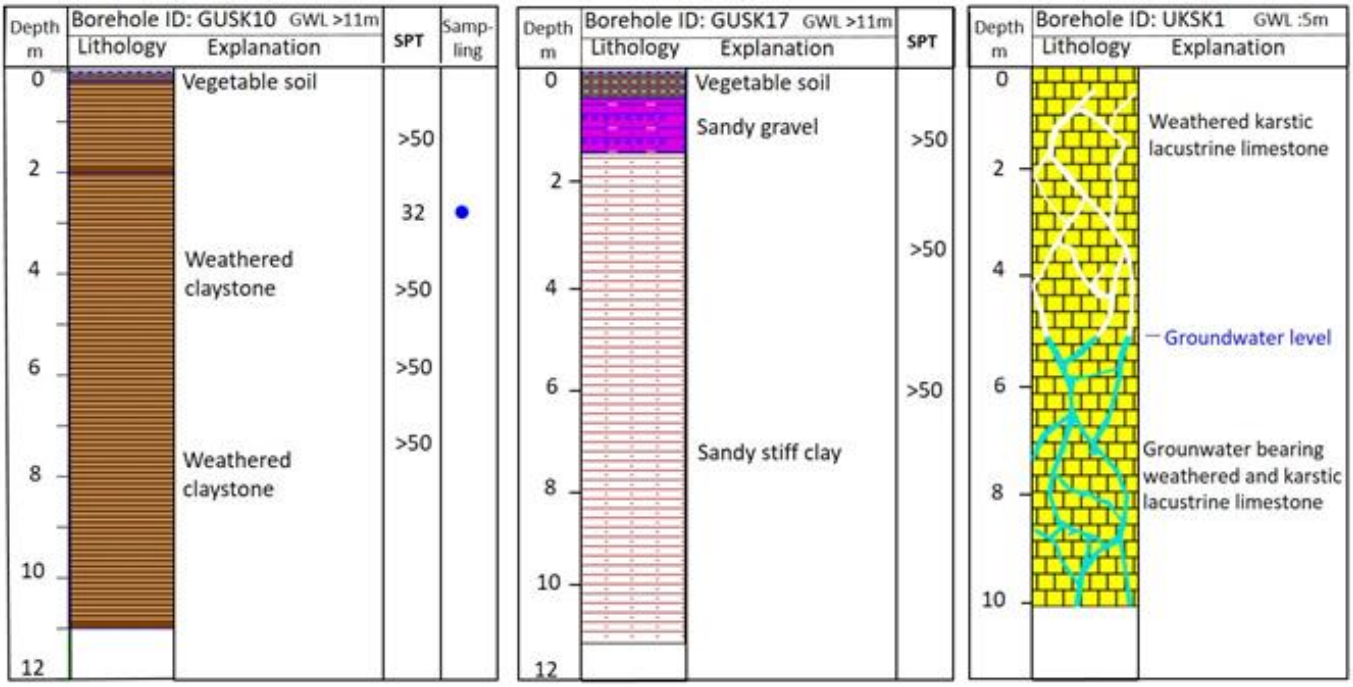

Figure 5. Geotechnical logs of the boreholes numbered as GUSK10, GUSK17, UKSK1 in the Acıpayam Basin.

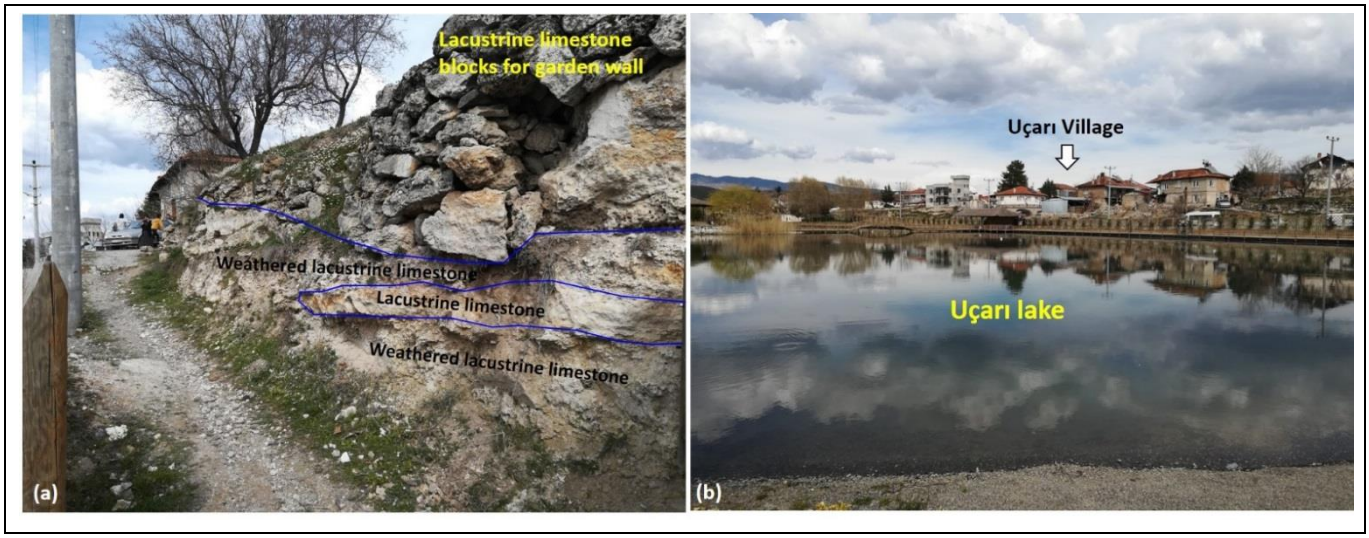

Figure 6(a): Field view of weathered lacustrine limestone in Uçarı village settlement area, (b): Uçarı village and the lake of Uçarı.

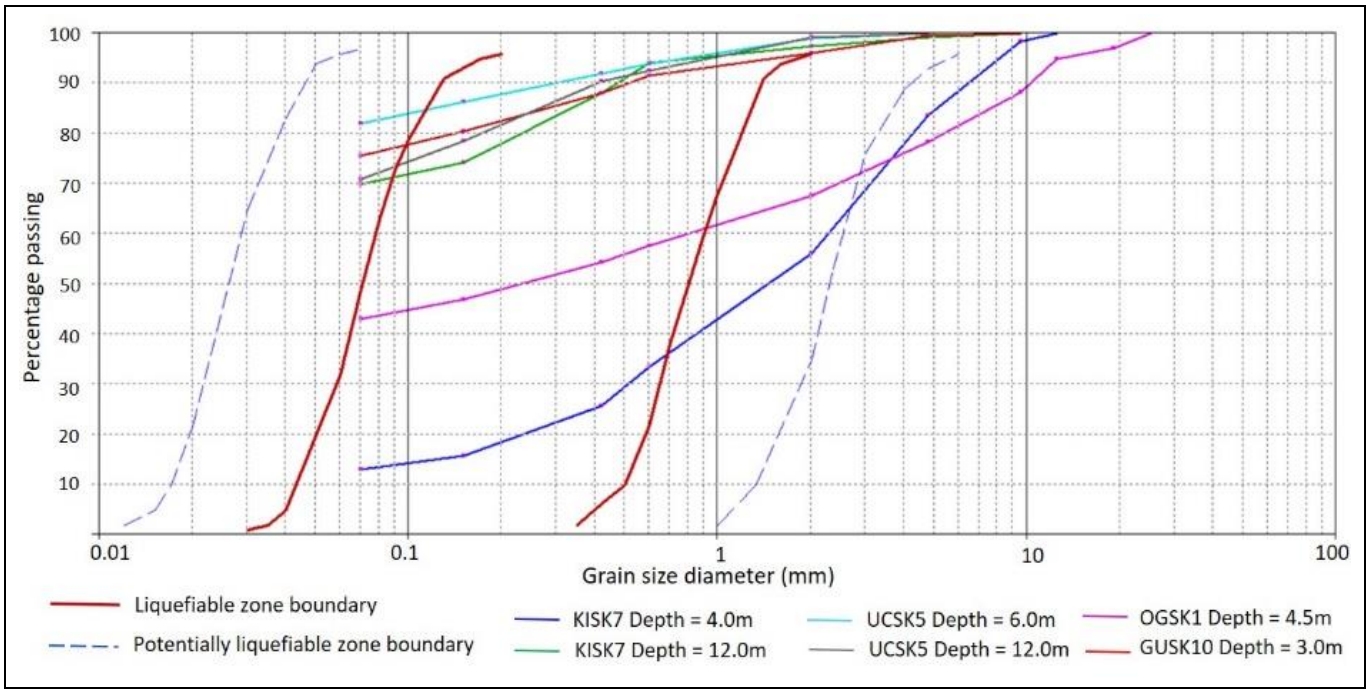

Figure 7. Grain size distribution of soils sampled in different boreholes in the Acıpayam basin with known bounds for liquefiable soils [35].

Liquefaction phenomenon was not observed in these drilling sites as a result of the earthquake that occurred on 20 March 2019. Due to the fact that R is less than zero, and high ratio of clay, silty and fine grain in the soil structure of the Acıpayam basin liquefaction did not occurred.

Shear wave velocities of top soils obtained from multi-channel analysis of surface wave (MASW) measurements at each borehole location by using WZG-12A brand seismic measurement device having 12 channels [26]-[30] were analysed and interpreted (Table 2).

Shear-wave velocities (V_s) at KISK7, UCSK5 and OGSK1 boreholes are 190 m/s, 189 m/s and 233 m/s, respectively. The groundwater depth from ground surface in KISK7 and UCSK5 boreholes are 1.8 m and 1.5 m in turn while it is 11m deep in OGSK1 borehole. Soil profile at these locations contains soft soils between ground surface and 6 m depth. Shear-wave velocities of soils at GUSK10 and GUSK17 borehole locations in the Acıpayam district center are 343 m/s and 443 m/s, respectively. At these locations there is hard soil profile and groundwater was not observed in the boreholes. Shear-wave velocity at UKSK1 location in Uçarı village is 430m/s and litology in the borehole is lacustrine limestone having cavity, weathering due to groundwater 5 m below ground surface.

Table 2. Shear-wave velocities of soils, amplification factors and local soil types at borehole locations.

Measurement Location	Shear-wave velocity V_s (m/s)	A (Joyner & Fumal, 1984)	A (Midorikawa, 1987)	A (Borcherdt et al, 1991)	Local soil type [39]
KISK7	190	2.17	2.92	3.68	ZD
UCSK5	189	2.17	2.93	3.70	ZD
OGSK1	233	1.98	2.58	3.00	ZD
GUSK10	343	1.66	2.04	2.04	ZC
GUSK17	443	1.48	1.76	1.58	ZC
UKSK1	430	1.50	1.79	1.63	ZC

ZD: Medium dense - dense sand, gravel or stiff clay strata [39], ZC: Layers of very dense sand, gravel and stiff clay, or weathered and too fractured weak rocks [39].

Soil amplification factors (A) of soils for peak ground velocities at the borehole locations were calculated by using equations 1, 2 and 3 given by [32], [33] and [34], respectively. Hazard level depending on soil amplification criterion of a settlement area is studied in three groups for microzonation investigations as in Table 3 [38].

$$A=68V_s^{-0.6} \quad [32] \quad (2)$$

$$A= 23V_s^{-0.45} \quad [33] \quad (3)$$

$$A=700/V_s \quad [34] \quad (4)$$

Table 3. Hazard levels depending on soil amplification criterion in microzonation studies [38].

Soil amplification factor	Hazard level
0.0 – 2.0	Low
2.0 – 4.0	Medium
4.0 – 6.0	High

[33] equation gives lower A values than [32] and [34] equations (Table 2). Maximum A values of at KISK7, UCSK5 and OGSK1 locations are 3.68, 3.70 and 3.0 respectively and, they are in medium hazard level as given in Table 2 [38]. At these locations adobe, brick made masonary houses were heavily damaged due to earthquake. Reinforced structures were slightly damage and non-damaged (Figure 8a,b; Figure 9a,b; Figure 10a,b).

5.5 magnitude Acıpayam earthquake caused slight damages on precast factory structures built on soft soils in the Acıpayam basin. These damages are usually fissures and cracks at the connection parts of precast elements. Such as, beam and wall connections, beam and column connections, column and wall connections. There are also damages on suspended ceilings of the factory structures in the basin (Figure 11a). Single-storey reinforced structures, built on soft soil sediments in the basin, are usually undamaged (Figure 11b). However, multi-storey reinforced modern structures have damages on the hollow brick built walls in the basement floor (Figure 11b) masonary roof floor (Figure 8a). These reinforced structures had no damages on their beams and columns.

Figure 8(a): Heavily damaged hollow brick structure, (b): Collapsed adobe structure in Kırka village.

Figure 9(a): Hollow brick built roof floor failure of a reinforced structure. (b): heavily damaged masonary mosque in Oğuz village.

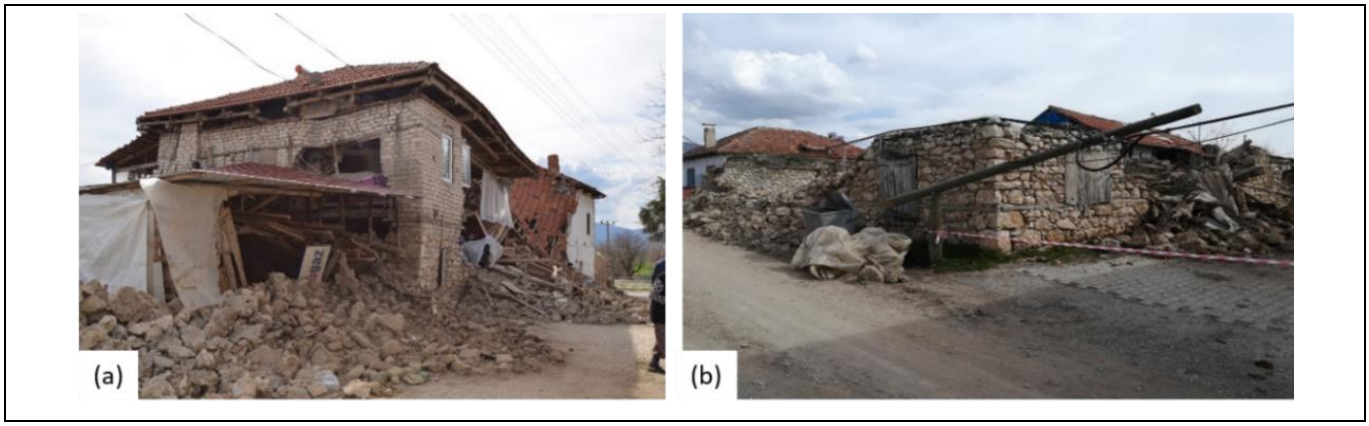

Figure 10(a): Collapsed adobe structure, (b): heavily damaged masonary structure and broken electric pole in Uçarı village.

Figure 11(a): Damages on precast concrete modern textile factory structure in Yassıhüyük village, (b): Partly damaged three-storey reinforced structure and undamaged single-storey reinforced structure in Apa village.

Soil amplification factor of soils at UKSK1 location in Uçarı village is 1.79. At this location and in close area adobe, brick made masonary houses were heavily damaged and weak reinforced structures were moderately damaged. As the epicenter of the earthquake is 4 km close to Uçarı village, heavy damage on the masonary structures occurred during the earthquake.

5 Conclusions

In the Acıpayam extensional area of the Burdur-Fethiye fault zone, magnitude 5 and above 1 earthquake occurred between years 1900 and 2019. The epicenter of this 5.3 magnitude earthquake, which occurred on 08.12.1936, is in the Uçarı district and is approximately 3 km north of the 5.5 magnitude Yeniköy earthquake, which occurred on March 20, 2019. This shows that the same earthquake was repeated 83 years later. Surface cracks ranging from N5°E to N20°W with a length of about 1.5 km and width up to 4 cm were observed in the southern part of Yeniköy village.

The epicenter of the M=5.5 earthquake is 1 km north of Yeniköy and 4 km south of Uçarı village. The structural damage in Yeniköy village settlement area, which is located on the lacustrine limestone unit, is less than the damage in Uçarı village. The main reason for this can be interpreted as the fact that the lacustrine limestone in Uçarı village contain groundwater and that the degradation of limestone is greater than in Yeniköy area. Structural damages in both neighborhoods are mostly in masonry adobe structures, stone masonry structures with clay binders, and masonry structures built with hollow brick. Only chimney topples occurred in reinforced concrete structures.

The damage is greater in Karahüyük, Apa, Kırca and Oguzköy neighborhoods located on the soft alluvial sediments where groundwater level is close to the ground surface. In addition to masonry structures in these neighborhoods, slight damage to reinforced concrete structures also occurred. The main reason for this is higher values of ground amplification factors of soft alluvial soils.

Soil liquefaction was not observed although groundwater level is close to the ground surface. The high fine (silt and clay) contents (changing between 40% and 80%) of the alluvial sediments were effective in preventing the phenomenon of liquefaction as a result of the 5.5 magnitude earthquake.

As the Acıpayam basin is an extensional basin in the Burdur-Fethiye Fault Zone, NE-SW trending fault called Acıpayam Fault extending through Pınaryazı, Akalan can result in bigger earthquake magnitude than normal faults in the basin. Therefore, the region should be prepared to be resistant for M>6.5 earthquakes.

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