Environ Geol (2008) 54:1489–1500
DOI 10.1007/s00254-007-0930-4

ORIGINAL ARTICLE

The 2001 Adana landslide and its destructive effects, Turkey

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Received: 1 February 2007 / Accepted: 29 June 2007 / Published online: 21 July 2007
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Abstract The current study deals with a catastrophic landslide that occurred due to heavy rainfall in Adana, Southern Turkey in 2001. The research area, which is one of the largest populated districts in Adana, and one of the most tropical places between the Middle East and southern Europe, has about 25,000 people. On the basis of geological and geotechnical surveys, the landslide phenomena and the effects of landslide are examined. To understand the slide mechanism of the landslide, ground reconnaissance, laboratory and in situ tests are conducted. It is observed that the clayey and silty layers of the site are heavily saturated due to extreme rainfall in winter, and consequently sheared. The landslide consists of a block sliding in the upper portions and a debris flow/soil flow component around the margins of the sliding blocks in the middle parts and at the toe. Although there was no loss of human life, it has caused significant economic losses. Besides, it is determined that if precautions are not taken around the landslide area, larger landslides could definitely occur in the future.

Keywords Landslide · Heavy rainfall · Geotechnical investigation · Adana (Turkey)

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Introduction

No part of the earth's surface is entirely free from the effects of natural hazards. Due to increasing population densities and uncontrolled or not well-planned developments, more and more people are affected by natural disasters. Turkey is heavily exposed to natural hazards such as earthquakes, landslides and floods. Landslides are significant natural hazards in many areas of the world. They are one of the natural catastrophes causing heavy loss of human lives and extreme damages to property (Aleotti and Chowdhury 1999). Landslides account for the second most common natural hazard in Turkey (Ildir 1995). The total loss caused by landslides in terms of affected buildings constitutes 27% of the entire loss from all natural hazards between 1959 and 1994 after earthquakes. Data does not exist for either direct or indirect losses due to landslides on a national scale (Duman et al. 2005).

A wide variety of landslides take place in the ground, depending on the materials involved and the triggering mechanisms. Landslides occur due to changes in the effective stresses, variation of material properties or changes in the geometry. Changes in effective stresses can be induced either directly by the earthquakes and human actions or indirectly by pore pressures due to rainfall effects. The causes of landslides are numerous, complicated and sometimes unknown. One of the most commonly occurring landslide is the rainfall-induced landslide which

constitutes significant hazards in many parts of the world's rainy regions, because these circumstances occur frequently. Heavy rainfall is commonly known as a major landslide trigger. Numerous researchers have investigated the landslides triggered by rainfall (Canuti et al. 1985; Azzoni et al. 1992; Finlay et al. 1997; Polemio and Sdao 1999; Zezere et al. 1999; Paul et al. 2000; Ocakoglu et al. 2002; Petrucci and Polemio 2003). It is generally recognized that the rainfall-induced landslides are caused by excess pore pressures and seepage forces during periods of intense rainfall (Sidle and Swanston 1982; Sitar et al. 1992; Anderson and Sitar 1995). It is the excess pore water pressure that decreases the effective stress in the soil and thus, reduces the soil shear strength, consequently resulting in slope failure (Brenner et al. 1985; Kayadelen et al. 2007).

The study site is in the western part of the 100th Year district in the city of Adana which is the fourth largest city in Turkey with a population of about 1.5 million (MTA 2002) (Fig. 1). The 100th Year district covers an area of about 290 km^2. On 30 December 2001, a catastrophic landslide, which caused significant economic losses, occurred affecting nearly 250 buildings and 25,000 people. Climatic characteristics resemble the characteristics of both the Marmara and Black Sea regions. In the winter, weather conditions are generally rainy and mild, and in the summer, it is hot and humid. Relative humidity levels are high throughout the year.

In the current study, it is aimed to explain the mechanism of the soil movements and their damage effects on the buildings. In the first stage, field observations and mapping studies are carried out. In the second stage, additional field observations and samplings are performed in order to describe the slide materials. Four boreholes (BH-1, BH-2, BH-3 and BH-4) were drilled at different points and the standard penetration tests (SPT) are carried out in the field. In addition, various soil mechanic tests are conducted in the laboratory on the disturbed and undisturbed samples taken from the field. As a result of the laboratory and field tests and ground reconnaissance, the sliding mechanism of the landslide and its damage effects on the buildings are determined.

Landslide site

Regional geology

Various tectonostratigraphic units with distinctive features by means of stratigraphy, structure and rock type are exposed around the city of Adana (Fig. 2a, b). The *Bolkar Dağı unit* is represented by carbonate and clastic rocks together with olistostrome rocks with ages changing from Devonian to lower Tertiary. The *Bozkır unit* is composed of acidic tuff, basic, ultrabasic rocks and serpentinites and also shelf units and oceanic crust rocks of Triassic–Senonian age that were formed in various facies and environments. Paleozoic and Mesozoic rock units in the region that were described as the Adana basin by Yetiş and Demirkol (1986) were later included to the Aladağ unit by Özgül and Kozlu (2002). The *Aladağ unit* comprises shelf carbonates and various clastic rocks of Devonian to Cretaceous age. The

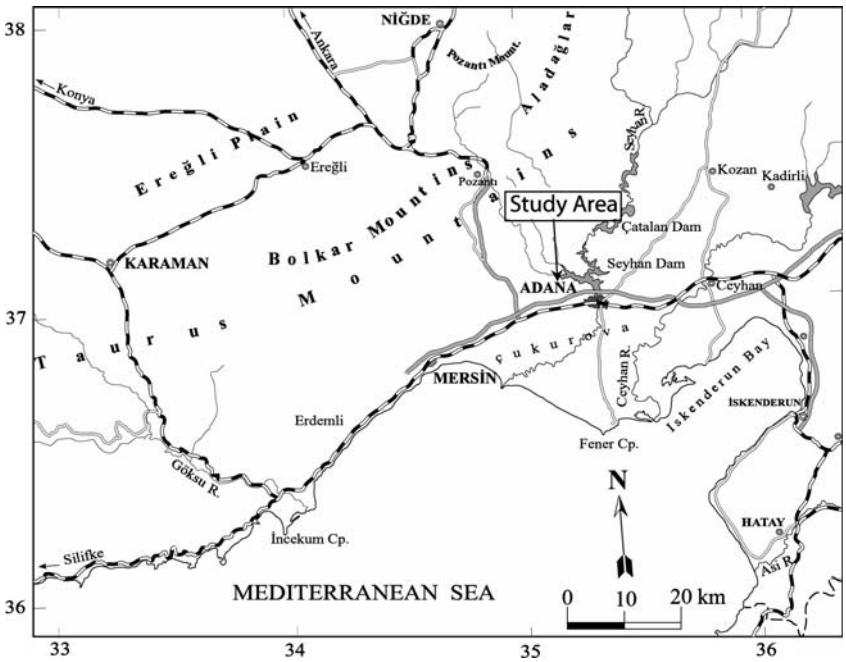


Fig. 1 Location map of the study area

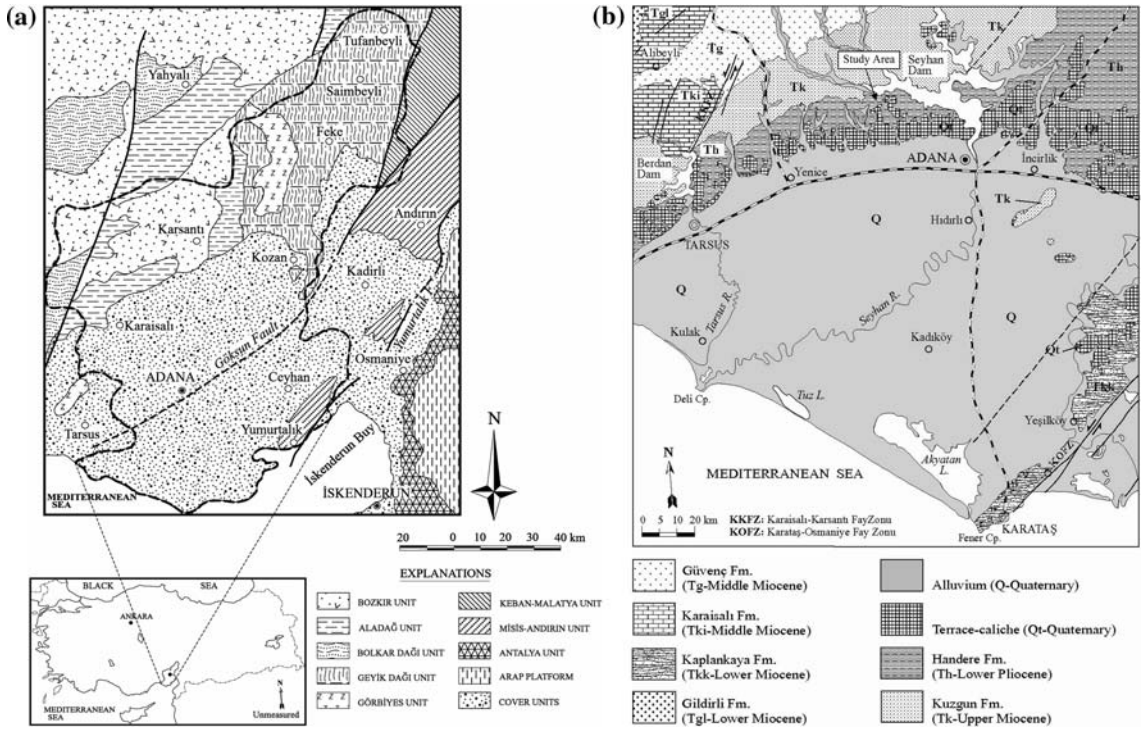


Fig. 2 **a** Major tectonics units (modified from Özgül and Kozlu 2002) and **b** simplified geological map (modified from MTA 2002 and Okyar et al. 2005) of the study area

Geyik Dağı unit consists of Cambrian-early Tertiary carbonates and clastic rocks. The *Görbiyes Dağı unit* is composed of a carbonate sequence, olistolite and olistostromal occurrences of probably Jurassic-late Cretaceous age, and rocks of this unit are slightly metamorphosed. The *Keban–Malatya unit* is represented mainly by platform type, metamorphosed metaclastics and metacarbonates of upper Paleozoic–lower Cretaceous age. The *Misis–Andırın unit* is made of mélange type and volcanosedimentary rocks in Cretaceous–Tertiary age. The cover units are composed of shallow marine deposits and pelagic (deep marine >1000 m) sediments of Tertiary–Quaternary age (Fig. 2a).

The study area and its geology

The Adana basin is set above the Paleozoic–Mesozoic limestones (Fig. 3). Units of the Adana basin start with a tertiary sequence consisting of terrestrial Gildirli and lacustrine Karsantı formations of Oligocene–lower Miocene age. Transgressive deposits of the Miocene sea are comprised by the Kaplankaya formation with shallow marine-beach clastics, the Karaisalı formation of reef character, the Güvenç formation consisting of shales with pelagic foraminifers and Cingöz formation of turbiditic character. The regressive deposits of the basin are characterized by the Kuzgun and Handere formations composing of shallow marine and terrestrial clastics (Fig. 3). The Quaternary terrace and caliche unconformably overlie the upper Miocene–Pliocene formations (Yetiş 1988; Nazik and Gürbüz 1992; Satur et al. 2005).

The 100th Year settlement site that comprises the study area has been established on terrace and caliche. A landslide just western part of the 100th Year settlement is developed within the Handere formation, terrace and caliche units. They are therefore studied in detail (Fig. 2b).

Handere formation

This formation that was named by Schmidt (1961) is composed mainly of dark yellow conglomerate, pebbly sandstone, sandstone, siltstone and mudstone-marl alternation and it also contains gypsum lenses. Conglomerate level is characteristic with cross beddings while fine clastic units are distinguished with parallel laminations. The thickness of the Handere formation is 120–700 m. The Handere formation is transitional to underlying Kuzgun formation and is overlain by alluvium and terrace–caliche deposits which are very common for the Adana basin. The age of the unit is reported as Messinian–Pliocene (Figs. 2b, 3).

Terrace

There are mainly two types of terrace deposits in the Adana basin. The first one is exposed at the elevated parts of the

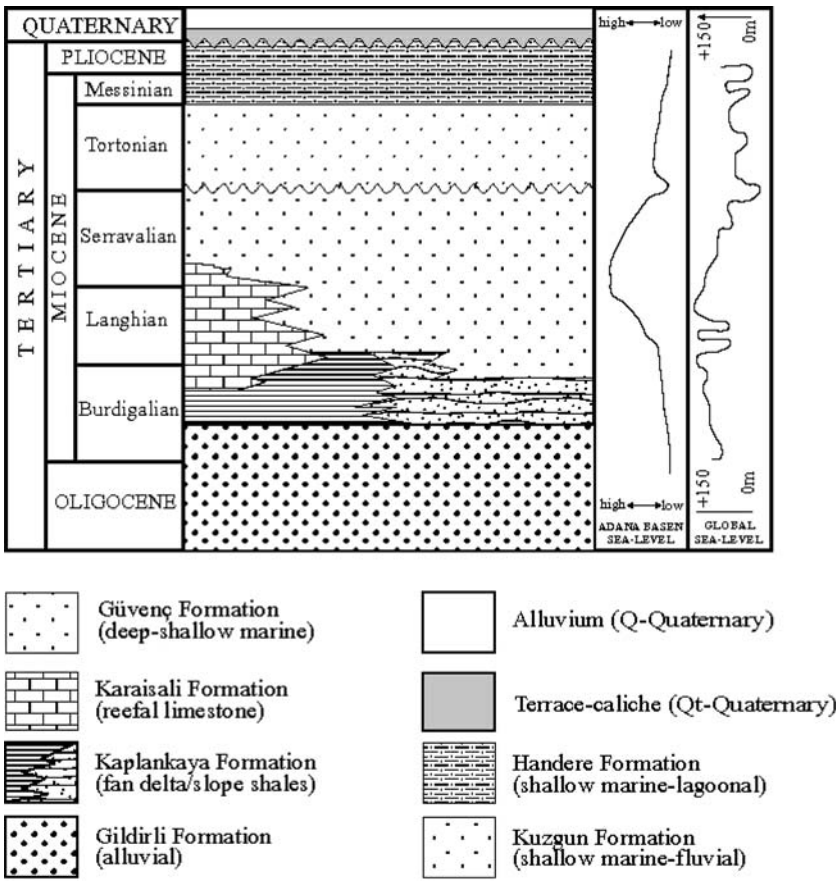


Fig. 3 Generalized stratigraphic section of the study area and the surrounding region (revised from Satur et al. 2005)

Handere formation and is covered with recent alluvium, which is 20–30 m. The second one is irregularly exposed along the creeks and rivers. The unit starts with conglomerate and pebbly sandstone at the base and continues to the top with gray colored, cross bedded, pebbly coarse sandstone and blocky conglomerate. River terrace deposits have a thickness of about 30 m (Figs. 2b, 3).

Caliche

Caliche is formed by evaporation and subsequent carbonate precipitation from the groundwater that rises to the surface through the terrace deposits. Caliche deposits are formed on hill sides in parallel to the topography and attain a thickness of 3–5 m (Figs. 2b, 3).

Alluvium

Old alluvium forming the Adana plain and the recent alluvium deposited in the river bed are found together in the Adana basin. Old alluvium could be accepted as delta deposits. This unit that is covered with an organic soil layer and deposited by the Seyhan and Ceyhan rivers which flow in to the sea comprises the fertile Çukurova plain. Recent alluvium is developed along the river sides and is composed generally of poorly sorted, loosely cemented conglomerate and sand (Figs. 2b, 3).

Geomorphology of the study area

Post Miocene erosion surfaces as thin belts and small clusters are very common in the study area. Moreover, ridges and steep hill sides are comprised by flood erosions of various rock lithologies, rock falls, bedlands topography and erosion deposits in transition to the plain basement (Yaşar et al. 1999) (Fig. 4).

Tectonics

The study area is located between the Ecemiş and Yumurtalık Faults on the Taurid belt. The city of Adana is surrounded with the East Anatolian Fault Zone at east and the Ecemiş Fault Zone at west and northwest (Aktar et al. 2000). In addition, there are also two more main faults affecting the region; Karaisalı-Karsantı Fault Zone and Karataş-Osmaniye Fault Zone (Fig. 5).

The East Anatolian Fault Zone is a left-lateral strike slip fault extending NE–SW from Antakya to Karlıova. The

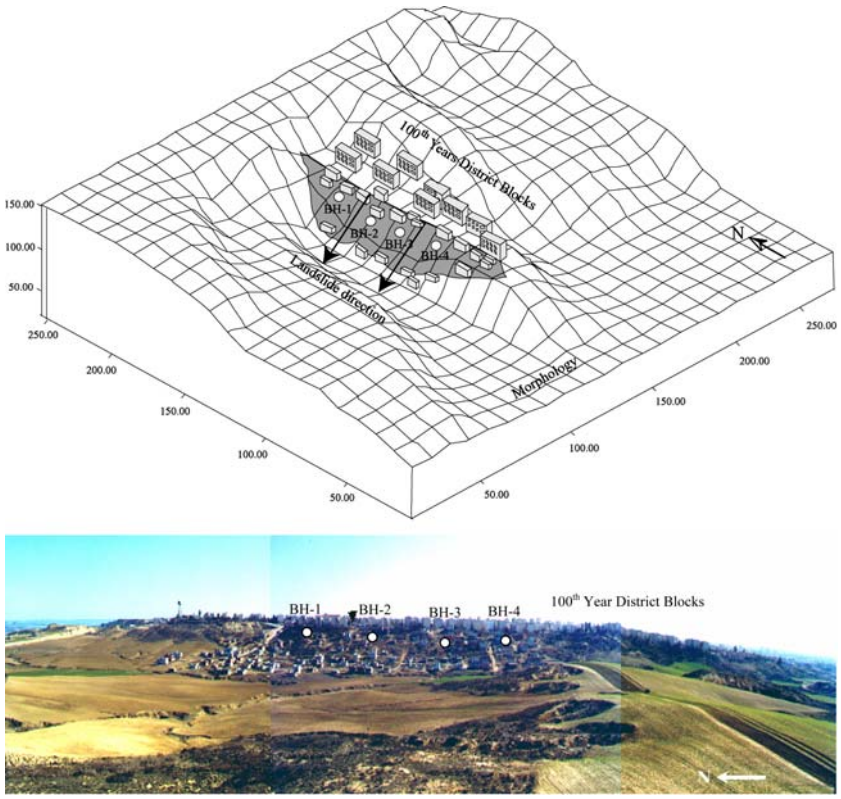


Fig. 4 Geomorphologic block diagram of the study area and the general view

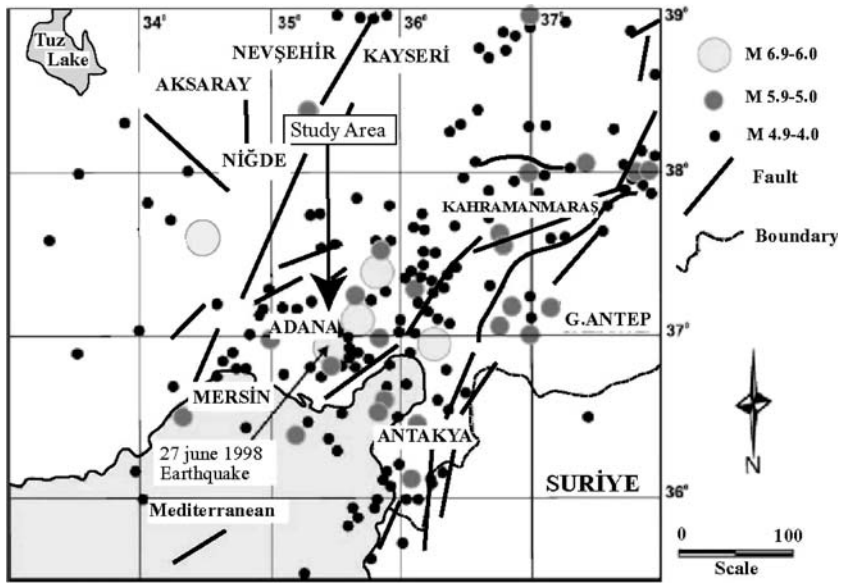


Fig. 5 Seismicity map of the study area and the surrounding region (modified from Kandilli Obsevatory Earthquake Research Institute 2004 and Acar and Dincer 2005)

fault is observed as several well defined isolated faults rather than a single fault. The width of the fault measured by previous workers is about 2–3 km and total slip was found as 22 km. The total vertical slip along the fault is 400 m. The East Anatolian Fault Zone was formed in the late Miocene by a convergence between the Arabian and the Anatolian plates. The East Anatolian Fault Zone, which is one of the largest faults in Turkey, is still seismically active (Arpat and Şaroğlu 1972).

The Ecemiş Fault Zone is located at NW of Adana and extends in the NNE–SSW direction. It starts from the Dündarlı village at west of Kayseri-Yahyalı at north and extends about 107 km to the vicinity of Mersin-Gülek area at south. The fault with a general strike of N27°E is composed of

several parallel branches. In the 78 km part between Dündarlı and Pozantı, fault morphology is very significant and fault is active in this area. In the Pozantı-Gülek area, fault splits into several small branches and it shows some deviations in strike and becomes peculiar towards the south. The southern part of the fault is active. Although fault has mainly a left-lateral strike slip character, due to Quaternary tectonism, it is also observed as a dip slip fault (Uçar 1997).

The Karaisalı–Karsantı Fault Zone is located at north of the Adana basin and south of the Ecemiş Fault Zone and it comprises several segments with various sizes and directions between Karaisalı and Karsantı (Aladağ). These faults extend in two main directions; NE–SW and E–W. The faults in this zone have different mechanisms. Some are of left-lateral strike slip character while some are of right-lateral strike slip faults (Uçar 1997).

The Karataş–Osmaniye Fault Zone is observed between Karataş and Osmaniye at southwest of the Adana basin and it is composed of several small parallel faults extending to 120 km in NE–SW direction. These faults most of which are parallel to the coast display significant morphologic features and disturb the Quaternary units.

Seismicity

The study area is one of the most active seismic fields in Turkey. The historical earthquakes occurred in the vicinity of the study area and their effects on the region are shown in Fig. 5. The major earthquakes killed several hundreds of people and caused damages to buildings in densely populated areas in the city of Adana. Life losses and intense damages were recorded during the 1114 earthquake in Adana, K.Maraş and Mersin, 1855 earthquake in Tarsus, 1896 earthquake in Adana and Mersin, 1908 earthquake in Osmaniye and Adana, 1915 earthquake in Misis, 1919 earthquake in Adana and 1925 earthquake in Adana. 1926 Kepez, 1929 Adana, 1930 Adana–Misis, 1930 Samandağı, 1932 Misis, 1933 Misis, 1936 Payas, 1940 Antakya, 1941 İmamoğlu and 1942 Payas-Dörtyol earthquakes also caused significant damages. As a result of 1944 Antakya and 1945 Ceyhan–Misis earthquakes, which were also felt in Kozan and Adana, 2,500 buildings collapsed and 13 people were killed. The 1947 earthquake resulted in heavy damages in Ceyhan, Misis and Adana. The 1951 İskenderun earthquake caused six dead, 10 casualties and collapsing of 13 buildings. The 1952 Misis-Adana earthquake resulted in 10 dead and heavy damages to 438 buildings and collapsing of 179. The 1961 earthquake was felt in Adana, İskenderun and Osmaniye, 1962 and 1964 earthquakes were felt in Adana, 1965 earthquake in Hatay, 1967 earthquake in Kozan, Bahçe and Andırın, 1969 earthquake in Adana and Karaisalı, 1993 and 1994 earthquakes in Adana, Ceyhan and İskenderun regions (MTA 2007).

From that date till the present time, total number of earthquakes larger than magnitude five on the Richter Scale are nearly 34. Also another recent and important earthquake occured on 27 June 1998 in Adana–Ceyhan region with a magnitude 6.3 (on the Richter Scale). This Adana–Abdioğlu earthquake caused 146 life loss, heavy damages to 11,000 houses and collapsing of 1,300 buildings (Adalier and Aydingun 2001; Ulusay et al. 2000; Çağatay 2005). This earthquake showed that Adana and its vicinity are one of the most important seismic regions of Turkey.

Climatic features and ground water

Adana has an area of 14,030 km^2. The elevation of city center is 23 m. The study area is one of the most tropical places between the Middle East and southern Europe. Occasionally, the weather conditions could constitute the hottest conditions between 40 and 50°C degrees in the city of Adana. January and August are the coldest and hottest months of the year, respectively. Typical Mediterranean climate features are seen in the city of Adana. Summers are hot and winters are warm and rainy. Southeastern parts of the Bolkar Mountains, the north of the study area, are governed by an inland climate and during the winter season, precipitation is observed as snow. The rest of the year is generally followed by rain.

According to Adana Meteorology Station (AMS) records, the average monthly rainfall value in 2001 is 63.06 mm. However, it is measured as 59.75 mm in the period 1990–2000. In the period 1990–2000, the driest month with an average precipitation of 3.04 mm is August while the rainfall reached the highest value of 132.3 in December (Fig. 6). In December 2001, the region experienced an extreme rainfall. Total monthly precipitation in

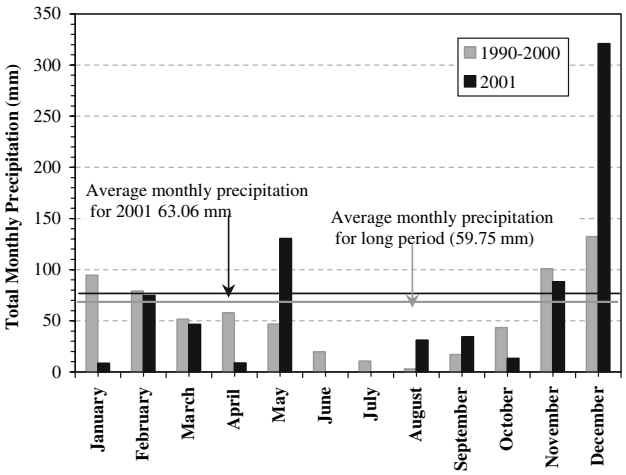


Fig. 6 Histogram showing the long term (1990–2000) and 2001 monthly precipitation

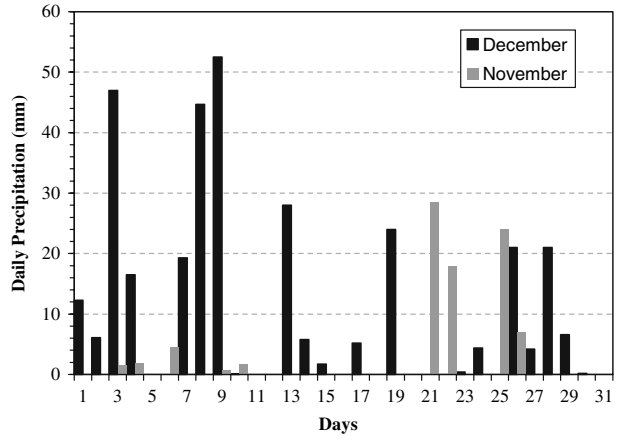


Fig. 7 Histogram showing monthly precipitations of November and December 2001

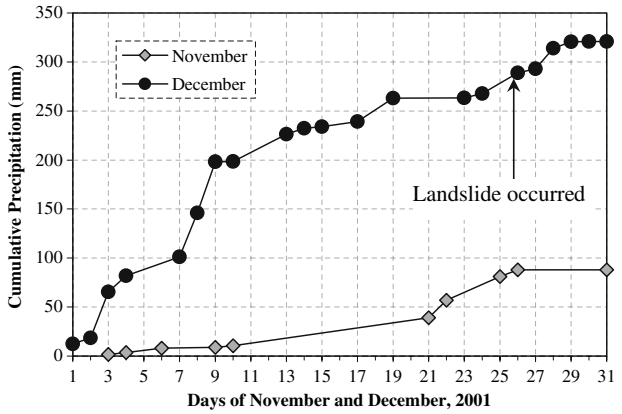


Fig. 8 Daily precipitations of November and December 2001

December 2001 reached up to 320.9 mm, which is approximately six times the rainfall in December in the period 1990–2000, which is the wettest month (AMS 2002) (Fig. 6). The precipitation value for December 2001 is a meteorological anomaly (Figs. 7, 8). Figure 7 shows the daily precipitation of November and December 2001. It reveals that while the daily precipitation for November 2001 is 2.9 mm, it is 10.7 mm for December 2001. In other words, the daily precipitation in December 2001 is approximately four times the precipitation in November 2001. As a result of this meteorological event, the landslide has occurred in the study area at the end of last week of December 2001 and has caused significant economic losses (Fig. 8). In the light of Figs. 7 and 8, it is thought that it rained heavily and the precipitations were enough to saturate the soil at the first and second week of December. The soil became heavily saturated. Hence, the soil lost the strength, landslide occurred on December 26th, 2001. Therefore, it is highly possible to conclude that the heavy precipitation in December has induced the landslide.

In the study area, through the field observations, signs of underground water have not been found within the Handere formation. However, the Handere formation is found to carry small amounts of groundwater in the gypsum-bearing horizons. According to the topography of the region, the amount of run-off water increases substantially due to the rainfalls. Significant amount of run-off waters are retained by absorption due to dominant clay components of the soils. In recent months, heavy rainfall in the Adana area has caused heavy saturation of the soil. Accordingly, the soil has had soft consistency causing loss of strength and an increase in tendency for sliding due to the construction loads. Consequently, heavy saturation of soil has resulted in hazardous problems for the structures.

Landslide features

To understand the mechanism and the cause of a landslide, how soil is formed, the stages in soil formation and other effects have to be investigated carefully. The formation of the study site is schemed in Figs. 2 and 3. The slide region has a slope of approximately 33° to the west and has no vegetation. A 3D general view of the landslide is given in Fig. 4. The precipitation was observed almost every season in the study area and the soil swelled absorbing the water continuously from time to time. It is thought that mainly due to heavy saturation of the soil after extremely heavy rainfall and the effects of weight of the buildings with five stories on the top of the slope and of sporadic individual houses along the slope, the landslide has occurred. According to the onsite observations, the landslide consists of a block sliding in the upper portions and a debris flow/soil flow component around the margins of the sliding blocks in the middle parts and at the toe (Fig. 9). The first movement started near the head of the slide towards the west. The landslide had to continue as a block sliding on the circular planes which had soft consistency. It is thought

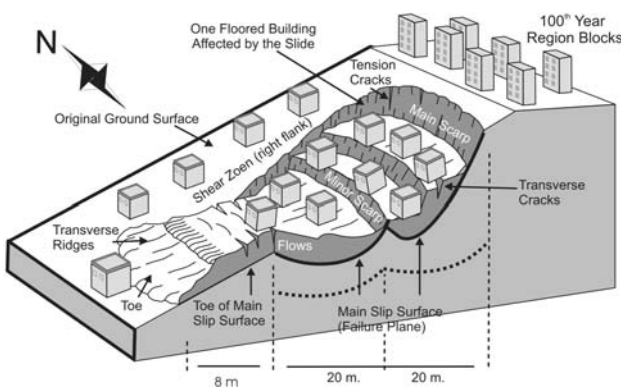


Fig. 9 Schematic view of landslide in the study area (unscaled)

that the disturbance created by block sliding should play an important role in the initiation of debris flow. According to the European Community Programme (EPOCH) classification (Dikau et al. 1996), the landslide is a complex mass movement. Thus it makes landslide very interesting and scientifically valuable.

The top soil is over consolidated due to the subtropical climate systems. The observations on the slide site materials show that the decomposition degree of the saturated layers in the soil is disseminated. In the unsliding part of the soil mass, the soil is observed as slightly decomposed.

Geotechnical investigation

In order to examine the cause and mechanism of the landslide, four different boreholes with a depth of 16 m are drilled through the Handere formation, and various soil tests are performed (Fig. 4). The standard penetration test (SPT), undisturbed soil sampling, various laboratory tests on these samples and ground reconnaissance are carried out. The soil tests in the laboratory are conducted on disturbed and undisturbed samples taken from each borehole in Mining Engineering Department, Cukurova University. All soil tests are conducted in accordance with ASTM standards (ASTM 1994). Table 1 shows the results of the geotechnical tests carried out on the soils.

The particle size distributions of the soil samples taken from each borehole are determined and their variations with depth are shown in Fig. 10. It clarifies that fine-grained soil (silt and clay) ratio is approximately 95%, which is susceptible to landslide when it gets heavily saturated due to its consistency. The test results indicate that the large amount of soil contains the clay layers with an

Table 1 Geotechnical properties of the landslide materials

	Minimum	Maximum	Mean	Standard Deviation
Gravel (%)	0.75	3.70	2.21	1.44
Sand (%)	3.00	5.75	4.26	1.12
Clay (%)	30.00	44.00	37.00	6.00
Silt (%)	49.00	76.00	61.75	12.64
γ (kN/m^3)	15.19	17.25	16.50	0.65
S_r (%)	85.75	92.50	89.75	2.72
w_n (%)	24.50	71.80	48.50	23.00
LL (%)	45.50	89.80	67.40	20.50
PL (%)	19.80	37.50	28.80	7.80
PI (%)	23.00	60.50	40.00	16.00
A_c	0.38	1.07	0.73	0.16
I_c	0.24	0.89	0.58	0.30
S_u (kPa)	34.00	198.00	72.00	45.00
SPT-N$_{60}$	3.00	11.00	6.00	3.00

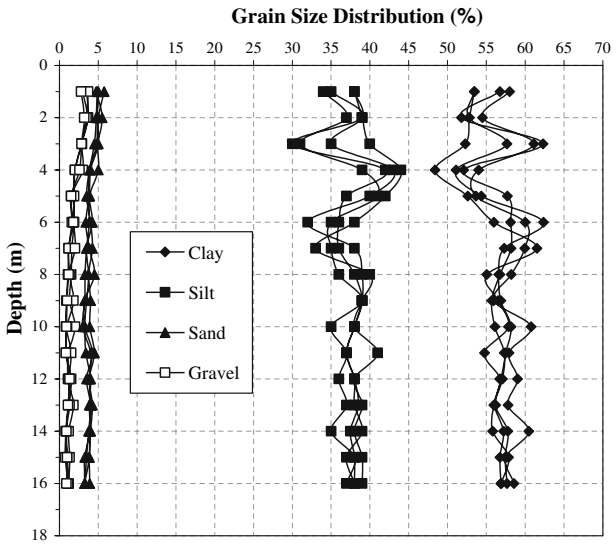


Fig. 10 Variation of grain size distribution with depth for each borehole

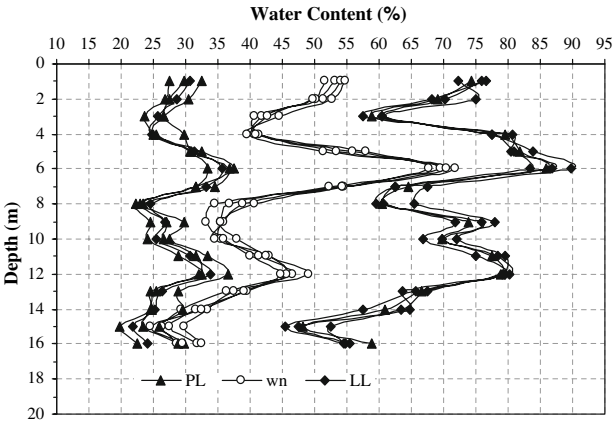


Fig. 11 Variation of consistency limits with depth for each borehole

average value of 56.53% and the silt layers with an average value of 37%. However, gravel and sand rates are 2.21 and 4.26%, respectively, which can be considered very low (Table 1).

The variation of the consistency limits (plastic limit and liquid limit) and natural water content with depth are measured and shown in Fig. 11. The average values of the liquid limit (LL), plastic limit (PL) and plasticity index (PI) for the soils are 67.40, 28.80 and 39.95%, respectively (Table 1). The liquid limit ranges from 45.48 to 89.80%. The plastic limit varies from 19.80 to 37.50% and the plasticity index from 23.00 to 60.50% (Fig. 11). The unit weights of soil layers vary between 15.19 and 17.25 kN/m^3 with an average of 16.50 kN/m^3. The average values of the water content and the degree of saturation for cohesive layers are 48.50 (min. 24.50%; max. 71.80%) and 89.75%

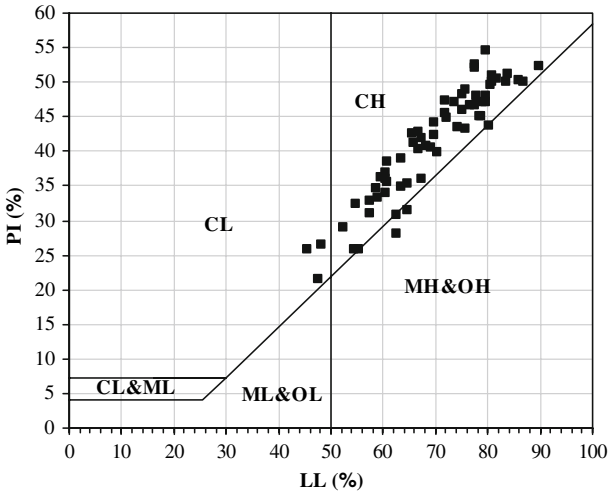


Fig. 12 Soil type of materials obtained from boreholes according to plasticity chart

(min. 85.75%; max. 92.50%), respectively. The soil is classified in accordance with the unified soil classification system (USCS). They are plotted on the plasticity chart as shown in Fig. 12 and found to be dominantly inorganic clay of high plasticity (CH). From activity point of view, clay is characterised by low activity (Table 1).

Performing triaxial unconsolidated undrained compression (UU) tests, undrained shear strength (S_u) of the soil with depth is measured (Fig. 13). The undrained shear strengths are found to be 35 kPa at the failure depths of 1–2 m and 6–7 m. The data obtained from all the tests show identical homogeneous layers with depth for each borehole in terms of particle size distributions, consistency limits and undrained shear strengths (Figs. 10, 11, 12, 13). All data appear to be consistent with each other.

The SPTs are performed down to the depth of 16 m in the boreholes (BH-1, BH-2, BH-3 and BH-4) as shown in Figs. 4 and 14. The measured SPT values in the field are corrected taking SPT correction factors into consideration in the current study (Sivrikaya and Togrol 2002, 2003, 2006). The corrected SPT-N values, SPT-N_{60} values, which is the blow count corrected to 60% of the theoretical free-fall hammer energy, vary between 3 and 11 (Fig. 13). Undrained shear strength and SPT-N_{60} value also give the information about the consistency of cohesive soils. According to Terzaghi and Peck (1967), SPT-N_{60} value of 2–4 and 4–8 stand for soft and medium stiff respectively. In addition, these results support the other test results and site observations in terms of failure depths.

The consistency index is a very good parameter providing information about the consistency of soils. Table 2 reveals the consistency of soil layers with depth. As a result of the site investigation and the consistency of soil, the failure surfaces are found to have occurred at the depths of 1–2 m and 6–7 m soil layers, which seem to be soft (Table 2). In these depths, total stress slope analyses were performed for different sliding surfaces and factor of safety was found to be less than 1. The top surface of the Handere Formation in which the slope failed had the fissures and thus the rain penetrated through the fissures until it reached the sliding surface. In the light of field and laboratory test results, precipitation data and field observation, the cause of the landslide is attributed to heavy rainfall. As a result of heavy rainfall, the soil became heavily saturated. Subsequently, the sliding surface became soft in consistency and the land slide, thus, occurred (Figs.9, 14).

Effects of landslide on the buildings

Landslides have occurred due to block sliding, associated debris flow and soil flow in the region (Fig. 9). There are many single or double storey buildings on the slope and on the blocks in the landslide site. In the blocks on the top of the slope, minor settlements and small discontinuities on the soil are observed. However, the landslide, which contains the clay layers, finest grains and crocked structures in

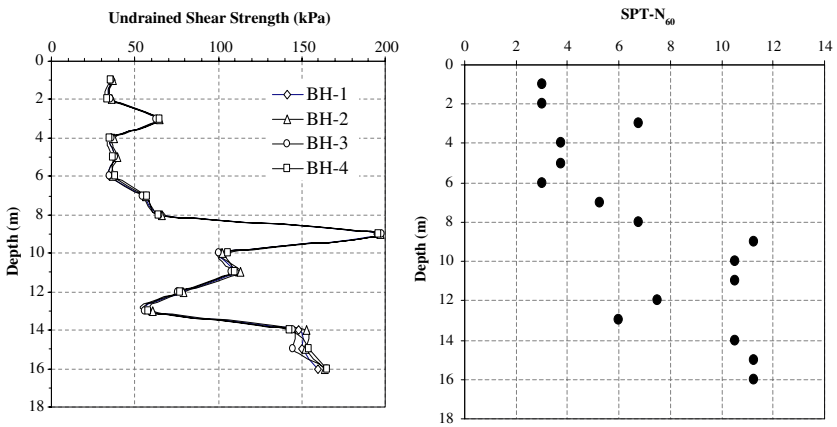


Fig. 13 Variation of undrained shear strength and SPT-N_{60} value with depth for each borehole

Table 2 Variation of consistency of the landslide materials with depth

Depth (m)	Consistency index (I_c)					Soil type
	BH-1	BH-2	BH-3	BH-4		
1	0.48	0.48	0.56	0.39	Soft	CH
2	0.47	0.42	0.52	0.46	Soft	CH
3	0.51	0.54	0.52	0.43	Soft-Medium Stiff	CH
4	0.71	0.77	0.70	0.73	Medium Stiff	CH
5	0.51	0.55	0.51	0.59	Soft-Medium Stiff	CH
6	0.33	0.33	0.42	0.24	Soft	CH
7	0.39	0.29	0.36	0.27	Soft	CH
8	0.66	0.58	0.58	0.68	Medium Stiff	CH
9	0.82	0.82	0.88	0.82	Stiff	CH
10	0.78	0.82	0.75	0.72	Stiff	CH
11	0.77	0.76	0.80	0.76	Stiff	CH
12	0.72	0.71	0.71	0.74	Medium Stiff	CH
13	0.75	0.67	0.75	0.65	Medium Stiff	CH
14	0.88	0.82	0.89	0.76	Stiff	CH
15	0.82	0.86	0.82	0.82	Stiff	CL
16	0.87	0.88	0.89	0.78	Stiff	CH

the soil, has caused great damages to these buildings (Fig. 15). In single storey buildings near boreholes; intense damages and rotational movements are observed due to the landslide (Figs. 14, 15). The sliding surface is heavily saturated. The bench height created by the main discontinuity on the landslide is approximately measured at a depth of 6 m (Fig. 15a) and also large discontinuities are observed in pieces. It is observed that the soil due to heavy rainfall became saturated. Consequently, the discontinuities in the soil have occurred in the saturated formation and the little settlements between the bases of the buildings have created several cracks on building walls, columns and rafters (Fig. 15b). The soil surface in this site is heavily saturated and the main and secondary discontinuities exist in the formation. Too many vertical and lateral movements in the bases of buildings have occurred due to the settlements and slides (Fig. 15c). The deformation and slide have taken place due to the soil structure, water content and the weight of the buildings. Cracked surfaces on the columns and rafters in the single/double storey buildings and movements on the soil are also observed in the field (Fig. 15d).

Results and conclusions

Current study attempts to explain the landslide that occurred in Adana, Turkey on December 26, 2001 in terms of geology, geomorphology, soil mechanics and rainfall. The study area is located on the Terrace–Caliche formations in the western parts of the Adana Basin. It consisted of silt, clay formations with very small sand and gravel contents about 20 cm below the organic rich top soil.

In December 2001, extremely heavy precipitation had occurred in the study area. Thus, the soil became heavily saturated and consequently resulted in the landslide. The topography, weathering of sand–silt–clay stone sequence and buildings on the slope have also contributed to the event in various degrees. The landside consists of the three types: block sliding in the upper portions, associated debris flow and soil flow around the sliding blocks in middle parts and at the toe. The field observations, field and laboratory test results clearly show that landslides have occurred at the depths where the consistency of soil in the failure surface is soft. Geology and morphology of the area and heavy rainfall are considered as the main factors for the landslide.

The landslide has resulted in damages to the buildings. In single storey buildings, significant damages and rotational movements are observed. The differential settlements in the buildings have generated several cracks on building walls, columns and rafters. Besides, the vertical and lateral movements in the bases of buildings have occurred due to the differential settlements and slides. In

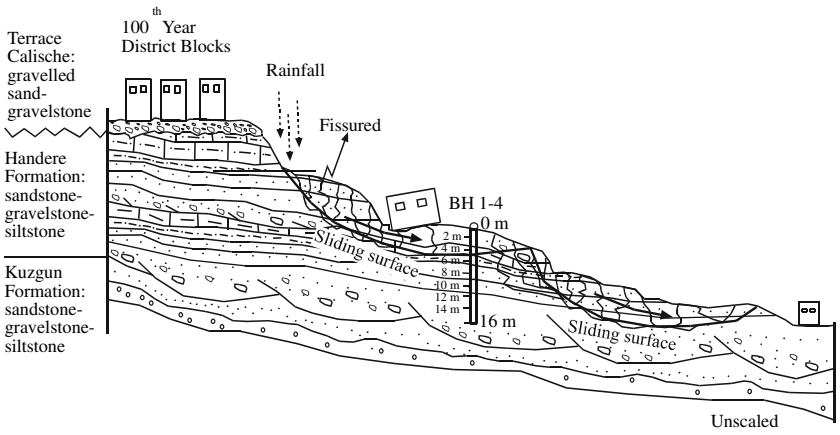


Fig. 14 Scheme of the intense damages and rotational movements on one floored buildings



Fig. 15 **a** The view of the slope failure and soil mass movement near BH-1; **b** The discontinuities and settlements between the buildings near BH-3; **c**, **d** The movements and cracks on the buildings near BH-4

addition, since the study area is in an active earthquake region, the seismicity is a big dangerous risk for the sliding region. Unless necessary precautions are taken around the region, slide movements with larger radius could possibly occur in the future.

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