

# Collapse of caves at shallow depth in Gaziantep city center, Turkey: a case study

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**Abstract** This paper focuses on an investigation of the possible causes for the collapse of limestone caves in Gaziantep, Turkey. The city contains a lot of man-made caves, at a shallow depth, of various width and length. These caves were mainly excavated to provide work or storage space. As the city has been growing fast with increased population, many structures were constructed over these caves. Recently, two caves collapsed and five houses were damaged. These caves are all made of limestone and it was observed after the collapse that the limestone was saturated with water due to sewer pipe leakage and surface water. Tests were carried out on the limestone and it was determined that the compressive strength of limestone decreases by about 50% and the tensile strength decreased by about 80% when saturated with water. It was concluded that the reduced strength of the limestone combined with additional loads due to the factors mentioned above seem to be the main reason for these collapses.

**Keywords** Limestone · Saturation · Rock mechanics · Compressive strength · Tensile strength

## Introduction

Gaziantep is an important crossing from Anatolia to Syria and Mesopotamia (Fig. 1). Its province extends over a territory of 7,642 km<sup>2</sup> with a population of around one million. The city is the most developed province in southeastern Turkey in terms of industrial and commercial

activities. The population of the city keeps increasing due to immigrants coming from nearby cities and towns.

There are a lot of man-made caves at shallow depths in the city center. They were excavated to produce work and storage space or to obtain dimension stones for house construction. The caves are around 100 years old. Most of these caves are still being used for some work activities, such as yarn production, and as a storage space as shown in Fig. 2 (Canakci and Gullu 2004). The caves are 2–30 m wide and up to 70 m long. Some of the caves have pillars. During the investigation, a total of 17 caves were identified and their dimensions were measured (Table 1). Also, the exact locations of the 12 collapsed caves, whose sites are now used as parks, were found. However, when we talked to the local people, they claimed of the existence of many more caves. Some of these mentioned caves collapsed naturally and some were destroyed by the people. There are also some caves hidden below the houses and streets, but their exact locations are unknown. They are often found during excavations for different construction activities in the city. Unfortunately, no noticeable work had been carried out previously to determine the number of caves and their locations. This work is the most current and comprehensive investigation on caves in the city of Gaziantep.

During the development of the city, many structures were constructed over these caves. They are generally single, two and three-story residential houses. Most of the structures were constructed without conducting any geotechnical investigation.

Some of the caves were reported to have collapsed in the past. However, the numbers and locations of most collapsed caves are not known. Recently, there have been two collapses in the city. One of them, named Karakabir, collapsed on 28 March 2003. This collapse caused considerable damage to five houses; killed one person and injured

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**Fig. 1** Location of Gaziantep

five. In the second case, a cave located in Hamdi Kutlar Street, a busy road, collapsed on April 13, 2005 with no reported injury to people or damage to the buildings. Both of these events triggered wide media coverage and caused great concern among people.

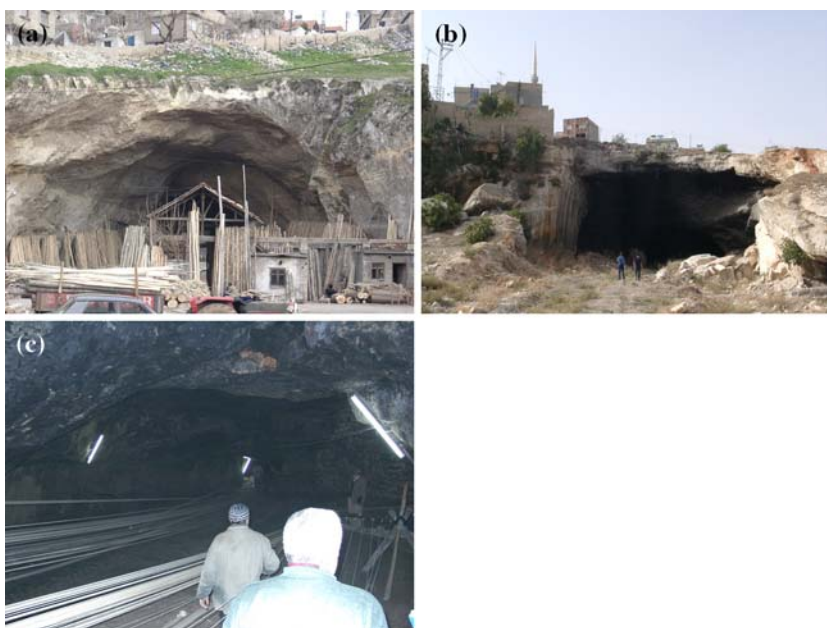
The existence of caves at shallow depths in the city center is a potential hazard for the structures over and around these caves. The construction of any structures in the area requires special consideration. There is a growing concern among people for the known and unknown caves that have a potential of collapsing at any time. In this paper, an investigation of the possible causes of cave collapses in the city of Gaziantep is presented. The results of experiments on the strength characteristics of limestone from which the caves were excavated are provided. The results of this study may be used to prevent possible catastrophic collapse of the caves in the future.

### Information on collapsed caves

Interviews with the local people revealed that there are a lot of collapsed caves in the city. However, information on the time, cause and size of the collapsed caves were not documented. Almost all the collapsed caves were filled and rearranged as local parks. The two recently collapsed caves named Hamdi Kutlar and Karakabir were investigated in detail. Some information on these caves are presented and may be used to determine the potential factors influencing the failure of these caves.

A cave roof collapse occurred in Hamdi Kutlar Street, Gaziantep, in the morning of April 13, 2005. The cave was believed to be a part of a resting castle (Kervansaray) constructed in the seventeenth century. In the first half of the twentieth century, it was used as a storage space; and then, its gate was closed until it collapsed. People residing

**Fig. 2** Caves in different locations of the city. **a** Cave used for wood storage. **b** Abandoned cave. **c** Cave used for yarn production



**Table 1** List of investigated caves in the Gaziantep city center

Cave no.	District	Name of caves	Current status	Cover thickness (m)	Width (m)	Height (m)	Length (m)	(W/T)	Risk condition (According to Waltham and Park 2002)
1	Ismet Pasa	Direkci	Stable	1.8	33	14.8	70.15	18.0	R <sup>a</sup>
2	Kurtulus	Sumakli	Stable	7	8.2	2.5	15.5	1.2	NR <sup>b</sup>
3	Kurtulus	Sumakli	Stable	8	25	6	5.6	3.1	NR
4	Kurtulus	Sumakli	Stable	4	10	4	3	2.5	NR
5	Kilincoglu	Mazman	Collapsed	(Dimensions not known)				–	–
6	Kilincoglu	Kamali Sk.	Stable	3	6	3.2	18	2.0	NR
7	Delbes	Uzumcu	Stable	4	29	7.8	40	7.3	NS
8	Kilincoglu	Gokce	Stable	1.7	30	7.5	49.5	17.6	R
9	Kahvelipinar	Semt pazar	Collapsed	(Dimensions not known)				–	–
10	Kıbrıs	Leylek	Collapsed	(Dimensions not known)				–	–
11	Kolejtepe	Gocerler	Collapsed	(Dimensions not known)				–	–
12	Hosgor	Deniz Sk.	Collapsed	(Dimensions not known)				–	–
13	Hosgor	Sht. Ahmet Sk.	Stable	2.5	1.5	1.8	3	0.6	NR
14	Dumlupınar	Besihane	Stable	1.5	16	8	14	10.7	R
15	Çağlayan	Besni Cad.	Stable	2	20	8	16	10.0	R
16	Aydınbaba	Karakabir	Collapsed	3.0	15	6	17	5.0	R
17	Sihcan	Hamdi Kutlar	Collapsed	1.0	8	4	7	8.0	R
18	Çağlayan	Besni Cad.	Stable	1	15	7	5	15.0	R
19	Çağlayan	Besni Cad.	Stable	2	4	6	15	2.0	NR
20	Aydınlar	Mezarlık	Stable	2	8	10	12	4.0	R
21	Aydınlar	Urfayolu	Stable	3.5	25	9	30	7.1	R
22	Umut	Besihane	Stable	10	8	15	18	0.8	NR
23	Aydınlar	Urfayolu	Collapsed	(Dimensions not known)				–	–
24	Turktepe	Tasli Sk.	Collapsed	(Dimensions not known)				–	–
25	Kilincoglu	Ali Baba	Collapsed	(Dimensions not known)				–	–
26	Hosgor	6 Nolu Sk.	Collapsed	(Dimensions not known)				–	–
27	Kilincoglu	Sulu	Stable	2	20	5	50	10.0	R
28	Dumlupınar	Bos	Stable	2	15	8	20	7.5	R
29	Hosgor	Keles Hoca	Collapsed	(Dimensions not known)				–	–

<sup>a</sup> R risk for collapse, <sup>b</sup>NR no risk for collapse

near the cave reported that the collapse occurred suddenly. Subsidence occurred in the pedestrian path connecting shops to the main street. The thickness of the roof of the cave was around 1 m and the width was approximately 8 m (Fig. 3). The collapse of the cave revealed a group of caves located nearby. The caves are located below a very busy street. There are also single and two-story houses, and shops over and around the caves. During the investigation, it was observed that water was leaking from the joint on the roofs of the caves. The bottom of the caves was full of water. Also, there were some cracks on a narrow gate connecting two caves. It was also observed that an older sewage system was passing across the roof of the cave as seen in Fig. 3. Some extension of the roots of live trees seemed to have caused fractures on the failed surface. A local shopkeeper also reported another collapse in the same

locality 4 months before the major incident. The actual size of the cave and the thickness of its roof were not known.

Another catastrophic cave failure occurred near Karakabir on the evening of 28 March 2003. The cave had been used for different purposes for a long time before it collapsed. The collapse was reported to have occurred suddenly. The roof thickness was around 3 m and its span length was approximately 15 m. There is a narrow road over the cave, which connects the surrounding houses. There are also single, two and three-story buildings over and around the cave (Fig. 4). As a result of the collapse, five houses were damaged. Five people living in those houses were injured and one person died. Some cracks occurred on the walls of some houses around the cave after the subsidence. Ten days before the failure of the cave, it had snowed heavily in the city. The thickness of the snow



**Fig. 3** General view of the collapsed cave in Hamdi Kutlar Street

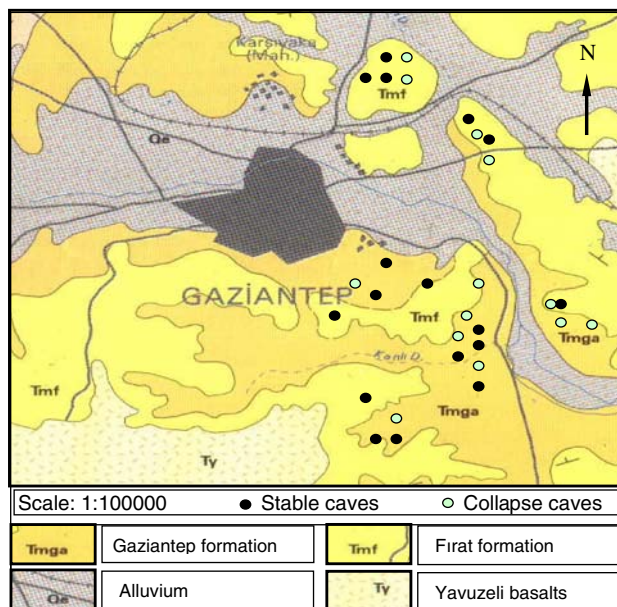


**Fig. 4** General appearance of the collapsed cave near Karakabir

had reached 750 mm and it had remained on the ground for more than a week. Finally, the cave area was filled and rearranged as a park by the local authorities.

### Geology of the site

A geological map of Gaziantep city, prepared by the General Directorate of Mineral Research and Exploration (MTA), Turkey, is shown in Fig. 5. There are mainly two units in the city, namely, lower Oligocene–Miocene age Firat formation (Tmf) and middle upper Eocene age Gaziantep formation (Tmga). The Firat formation composed of medium thickly bedded reefal limestone has a thickness of 150 m. The Gaziantep formation consists of thickly bedded clayey limestone and chalky limestone. The thickness of this formation varies between 100 and 250 m (Terlemez et al. 1997).



**Fig. 5** Geological map of Gaziantep (Terlemez et al. 1997)

### Experimental studies

A series of experimental studies were carried out to determine the geological and geotechnical properties of limestone. The study was carried out in three stages. In the first stage, the collapsed caves were visually inspected. Attention was given to the dimensions of the collapsed caves (such as width, height and thickness of the roof), discontinuities around the roof, water leakage and water systems around the caves and loads on the caves.

In the second stage, rock samples were collected from and around the collapsed caves. Core borings were made at ten different points around the collapsed cave in Karakabir. The depths of the boreholes varied from 15 to 20 m. Core samples were taken with the core barrel designation as NX.

Rock quality designation (RQD) was determined for each borehole. RQD values of the cored limestone were between 25 and 50%. Also, block samples were collected from the collapsed part of the caves in both Karakabir and Hamdi Kutlar Street. These samples were used to obtain cylindrical core samples for uniaxial and tensile strength tests.

In the third stage, experiments were carried out on the collected samples. The rock core samples were tested for uniaxial compressive strength (both in oven dry and saturated conditions), tensile strength, density (dry and saturated surface dry) water absorption and ultrasonic pulse velocity. In order to investigate the effect of saturation on the compressive and the tensile strength of the core

samples, they were left in the water for 30 days. Sample sizes were adjusted in accordance with ISRM for each test. All tests were performed in accordance with the procedures given in ISRM (Brown 1981). Dry compressive strengths of the limestone were 25.51 and 10.20 MPa for Karakabir and Hamdi Kutlar, while saturated compressive strengths were 11.53 and 5.36 MPa, respectively. The tensile strengths of the limestone in dry condition for the former and the latter caves were 3.12 and 2.41 MPa, which reduced to 0.65 and 0.31 MPa upon saturation, respectively. Water absorption values of the limestone were 24 and 11% for Karakabir and Hamdi Kutlar, respectively. The test results are given in Table 2. The strength values given in Table 2 were obtained from intact core samples, but the mass strength values of limestone are expected to be lower than that of the intact rock due to low RQD values.

**Potential causes of cave failures**

Cave failures have occurred in different parts of the world. One of them, from the Nottingham city center (UK), was reported by Waltham (1993). The authors reported hundreds of man-made artificial caves that had been cut into outcrops of Triassic Sherwood sandstone. Some of these caves had collapsed. The causes of the collapse of the Stanford Street crown hole were investigated along with previous collapses by the author. Geotechnical properties of the Sherwood sandstone, especially the strengths of the saturated and dry states of the cave material were investigated. The collapse of the Stanford Street crown hole roof was mainly attributed to the loss of strength of sandstone (40–80%) due to saturation caused by leakage from water pipes.

Waltham and Park (2002) reported the existence of 59 lava tubes with a total length of 42 km in Cheju Island, South Korea. They discussed three different causes for the failure of the tube roof. These are: collapse of the thin roof during the flow of lava, minor earthquakes that are common on active volcanoes and weathering and weakening of

the thin arches above the lava tubes. The authors proposed microgravity survey to be the most useful method to determine the location of lava tubes during subsurface investigation. A simple guide is recommended for checking the stability of the lava tube roof. It is the tube width (W) to roof thickness (T) ratio. A ratio of  $W/T > 3/1$  is suggested to be unsafe and prone to failure of the lava tube roof.

The (W/T) ratios of the inspected caves in Gaziantep are calculated and the risk conditions of the caves are given in Table 1. Both of the collapsed caves have W/T ratios higher than 3/1. The stability ratio suggested by Waltham and Park (2002) seems to work for these two caves. Even though some of the caves have a high W/T ratio, they are still stable. This may be explained by the variation in the strength of limestone from which the caves were excavated. The compressive strength of the limestone in Gaziantep ranged from 3.76 to 49.79 MPa (Marangoz 2005). The caves with high W/T ratios can be stable due to their higher strength value, which in turn indicates that this ratio cannot be used as a unique parameter for the stability condition. Apart from the W/T ratio, some other parameters such as shape of the roof (flat or arch) and the shear strength parameters of the cave material have to be taken into account for stability control.

Waltham (1993) discussed four different causes for the collapse of the crown hole in Nottingham, UK. These are loss of strength of the rock material due to saturation, discontinuities, weathering and vibrations. These four parameters are believed to be the most important factors that triggered the failure of the caves. These factors are discussed below to find out the causes of cave failures in Gaziantep.

The strength of some rocks reduces considerably when they are saturated (Waltham 1993; Morgestren and Eigenbrod 1974; Goodman 1989; Ojo and Brook 1990; Vutukuri 1994; Gutierrez et al. 2000; Benavente et al. 2004; Duperrret et al. 2005; Xie and Shao 2006). This reduction is attributed to various factors. According to Scherer (2000), a decrease in the tensile strength of rocks is due to crystallization pressure that creates tensile stress over the pore surface. This stress initiates microcracking and propagation of new cracks or widening of existing microcracks, leading to disintegration, detachment and fracturing of rocks. Xie and Shao (2006) discussed two effects on the strength reduction of rocks due to saturation. These are short-term and long-term effects. According to the authors, in short term, water saturation reduces the yield stress and failure strength of equivalent solid matrix due to a decrease in the capillary force of the liquid contact. In long term, water saturation enhances the dissolution process of the cemented contact.

The compressive and the tensile strength values of the rock samples collected from the collapsed caves are given

**Table 2** Properties of limestone obtained from collapsed caves

Test	Karakabir	Hamdi Kutlar
Dry unit weight (kN/m <sup>3</sup> )	16.76	18.64
Saturated unit weight (kN/m <sup>3</sup> )	20.79	20.60
Water absorption by weight (%)	24	11
Compressive strength, dry (MPa)	25.51	10.2
Compressive strength, saturated (MPa)	11.53	5.36
Tensile strength, dry (MPa)	3.12	2.41
Tensile strength, saturated (MPa)	0.65	0.31
USP velocity, dry (m/s)	2906	2656
Modulus of elasticity, dry (GPa)	11.3	4.45

in Table 2. It is observed that saturation caused a reduction in the compressive strength of the limestone, about 55% for Karakabir and 47% for Hamdi Kutlar. Saturation also caused 79 and 87% reduction in the tensile strength of the limestone at Karakabir and Hamdi Kutlar, respectively. Test results showed that there is a significant reduction in the compressive and tensile strength of the limestone due to saturation.

Inspection made after the collapse of caves showed that sewer pipes were buried in the roofs of the collapsed caves (Figs. 4, 5). Also, it was observed that the surface water drainage system over and around the caves was very poor. The failure of the cave in Karakabir occurred 10 days after a heavy snowfall. Thickness of the snow was around 750 mm and it remained on the ground for more than a week. The density of snow was measured 1 day after the snowfall and was found to be  $275 \text{ kg/m}^3$ . Snow acted as a distributed load on the roof of the cave and increased the stress on the pillars/walls.

Investigation of the caves in Hamdi Kutlar Street also showed that the caves were full of water. This water most probably came from the leaking sewer pipes. During the examination of the cave, it was observed that water was leaking from the joint on the roofs of the caves.

The tensile stress developed at the midpoint of the roofs of the collapsed caves was calculated considering the roofs of the caves as simply supported beams (Rahn 1996). When the saturated unit weights of the limestone given in Table 2 were used, the tensile stress values at the center of roofs of the collapsed caves were 1.2 for Karakabir and 0.5 MPa for Hamdi Kutlar. It was seen that the computed tensile stresses were lower than that of the measured dry tensile strength, but higher than the measured saturated tensile strength. These results indicate that saturation of the roofs of the caves caused a significant reduction in the tensile strength of the limestone, thus, possibly leading to failure of the caves.

The mechanical behavior of rocks is significantly affected by the presence of discontinuities such as bedding planes, joints, shear planes and fault (Walsh 1965; Bieniawski 1967; Paterson 1978; Jaeger and Cook 1979). The initiation and propagation of stress-induced crack damage is a sign of brittle failure in rocks, eventually leading to abrupt failure of underground excavations in mining and tunneling. Whittaker et al. (1992) defined three basic crack propagation modes in a fracture process, namely: Mode I (tension, opening), Mode II (shear, sliding) and Mode III (shear, tearing). Accordingly, a crack can propagate in any of these modes or a combination of them. During the investigation of caves in Hamdi Kutlar Street, it was found that the caves had cracks on the roofs. Stress on the cracks due to traffic and pedestrian load may have led to propagation of the cracks at the intersection point between the

roof and the pillar/wall of the cave. Reduction in the strength of the rock due to saturation most probably accelerated the propagation of the cracks and initiated the collapse of the roof. There is a very good sign of this propagation of crack at the top of a small gate connecting the two caves (Fig. 6). This may be a sign of future failures of the remaining parts of the cave. It was not possible to investigate the discontinuities on the roof of the Karakabir caves, because it was filled a few days after it collapsed.

Weathering processes cause progressive changes in rock porosity due to changes in pore size distribution, pore geometry, pore connectivity, pore infilling and new pore formation (Tugrul 2004). Chemical weathering on the caves might occur due to the leakage of sewerage pipes. At the collapsed caves, it was observed that most of the original mass strength was lost. Limestone was discolored and the weathered part of the cave could be excavated easily by hand. All parameters showed that the limestone below the sewage pipes was highly weathered. The influence of weathering can be easily seen on the pillar in the cave (Fig. 7). The size of the pillar near the roof was reduced considerably when compared with its lower part.

Freezing and thawing mechanisms influence physical and mechanical properties of rocks. Freezing of the water in pores causes an increase of 9% in volume of water when it is transformed into ice. It exerts volumetric expansion pressure to the rock material. When this pressure exceeds the tensile strength of the material, the material is damaged (Chen et al. 2004). Gaziantep city is located in an arid zone. During the winter season, the temperature is frequently below freezing. The process of freeze and thaw most probably caused mechanical weathering of the rocks, which may have led to the opening of fissures. This process reduces the overall strength of the rocks and may be considered as a reason for the collapse of the roofs of both caves.

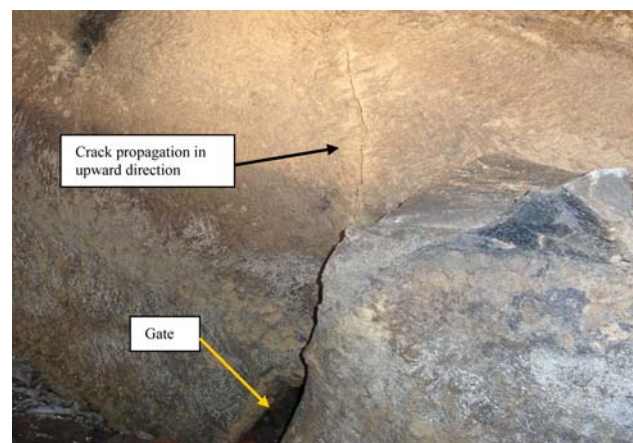


Fig. 6 Crack propagation at the top of the passage

Tree roots may also be considered as one of the important factors that contribute to the failure of the caves. The roots appear to be fragile, but their appearance can be deceptive. The roots split the rocks and keep growing despite the tremendous weight of the rocks above them. Investigation made in the cave of Hamdi Kutlar Street showed that the roots of a tree penetrated into the cracks of the roof of the collapsed cave (Fig. 8). These roots probably weakened the rock by enlarging the existing cracks, which caused the reduction in the strength of the rock mass.

A study carried out by Zhu and Tang (2006) showed that the amount of cracks significantly increased when rocks were subjected to dynamic loading. The collapsed cave is located below a very busy road at the Hamdi Kutlar Street. Both heavy and light vehicles that frequently pass over the road may be considered as the main source of vibration on the roof of the caves. Also, Gaziantep is close to the East Anatolian Fault Zone (EAFZ). The occurrence of earthquake is not frequent and the magnitudes of the recorded earthquakes are generally less than 4.0 in the Richter scale (BUKOERI 2007). The vibration caused by dynamic vehicle loading and the seismic activities may have increased the propagation of the cracks on the roof and eventually contributed to the process of collapse.

**Conclusions**

The collapse of the roof of limestone caves in Gaziantep may have developed progressively or instantaneously due to some or all reasons discussed in the previous section. It is very difficult to determine the exact cause of the collapse, which may have occurred due to a combination of many factors over a long time period. However, the most significant factor for the failure of the caves seems to be saturation of the limestone from sewer pipes and surface



**Fig. 8** Roots on the roof of the collapsed cave in Hamdi Kutlar Street

water, which caused considerable reduction in the strength of the soft limestone.

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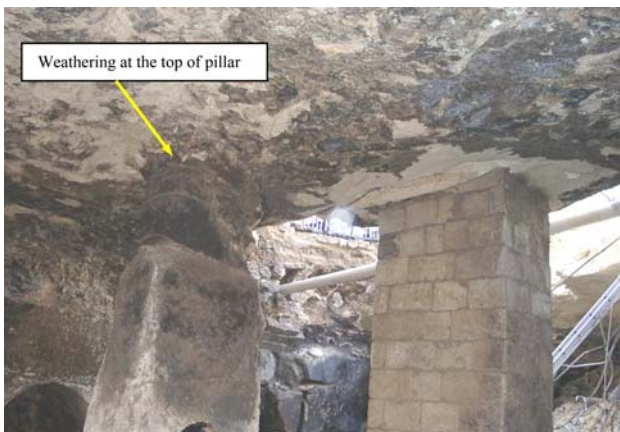
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**Fig. 7** Weathering of pillars of the cave in Hamdi Kutlar Street

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