Remediation of the geotechnical problems of the Hasankeyf historical area, southeastern Turkey

H. Akgün

Abstract The castle, palaces and man-made historical and recent cave dwellings of Hasankeyf will be partly flooded by the reservoir of the Ilısu dam which is planned to be constructed over the Tigris River. Hasankeyf is entirely within the Germik formation which is composed of whitish to light gray and/or beige, medium strong, fresh to slightly weathered, thick to very thick bedded, locally massive, almost horizontal or gently dipping silty, sandy limestone. The major geotechnical concerns in the area consist of the possibility of kinematic failure of the foundation of "Little Palace" and the collapse of some of the roofs of the adjacent man-made cave dwellings carved in rock due to insufficient pillar (wall) thicknesses to carry the overburden load. A limit equilibrium analysis of the kinematically unstable planar rock block underlying the foundation of "Little Palace" was performed as a function of the water level in the reservoir. The maximum required anchor force was calculated as approximately 3,000 kN/m which led to a total anchor force of about 42,000 kN for the 14-m-wide slope face of the unstable planar block. The results of the finite element analysis to determine the minimum stable pillar (wall) thickness required between adjacent caves led to a recommendation to apply a steel arch support to one of the adjacent caves at Hasankeyf in case the wall thickness was less than or equal to 0.60 m.

Keywords Rock mass characterization · RMR Method · Rock slope stabilization · Cave stability · Finite element analysis · Southeastern Turkey

Received: 7 February 2002 / Accepted: 12 November 2002
Published online: 1 February 2003

H. Akgün
Department of Geological Engineering,
Middle East Technical University,
06531 Ankara, Turkey
E-mail: hakgun@metu.edu.tr
Tel.: +90-312-2105727
Fax: +90-312-2101263

Introduction

Hasankeyf is in southeastern Anatolia which plays a very important role in the history of civilization. The ruins and monuments at the site link the past to the present. The area is part of the Upper Mesopotamian region favorably irrigated by the Euphrates and Tigris rivers. The Southern Anatolian Project (GAP) initiated by the Turkish Government has improved the region and the country. The project includes construction of several dams on the Euphrates and Tigris for the development of the region with irrigation and the production of electricity. However, when the Southern Anatolian Project (GAP) is completed, some localities suitable for human occupation will be covered by the reservoirs. Hasankeyf will be partly flooded by the reservoir of the Ilısu dam which is to be constructed on the Tigris River (Tuna and others 2001).

Observations in the area of the Ilısu reservoir proved that the historical past of the region began during the Paleolithic age from 100,000 years ago to the Middle ages (Tuna and others 2001). Hasankeyf, one of the important historical sites in the region that has served as a capital for several medieval cultures, is approximately 35 km southwest of Batman, in southeastern Anatolia on the southern banks of the Tigris River (Fig. 1). Figure 2 shows a view of Hasankeyf. Its castle, palaces and artificial historical and recent cave dwellings that are carved in rock will also be partly under the Ilısu dam reservoir with a planned maximum reservoir level of 526.85 m.

Geological investigations at Hasankeyf revealed that the major geotechnical concerns in the area constituted the possibility of kinematic rock failure and the collapse of some of the roofs of the cave settlements carved in rock that are presently used as dwellings, restaurants, cafes, etc. "Little Palace (Küçük Saray)" is one of the important historical buildings in Hasankeyf that is under the threat of planar kinematic failure along a pre-existing fracture in the rock block underlying its foundation (Fig. 3). The collapse of the roofs of adjacent man-made cave dwellings carved in rock due to insufficient pillar (wall) thicknesses to carry the overburden load is another major geotechnical concern in the area.

After Hasankeyf is partially flooded by the reservoir of the Ilısu dam, the Turkish Ministry of Tourism is planning to arrange boat trips to the area for those who wish to visit the historical structures that remain above the maximum reservoir level, and also to utilize the area for scuba diving

DOI 10.1007/s00254-002-0743-4

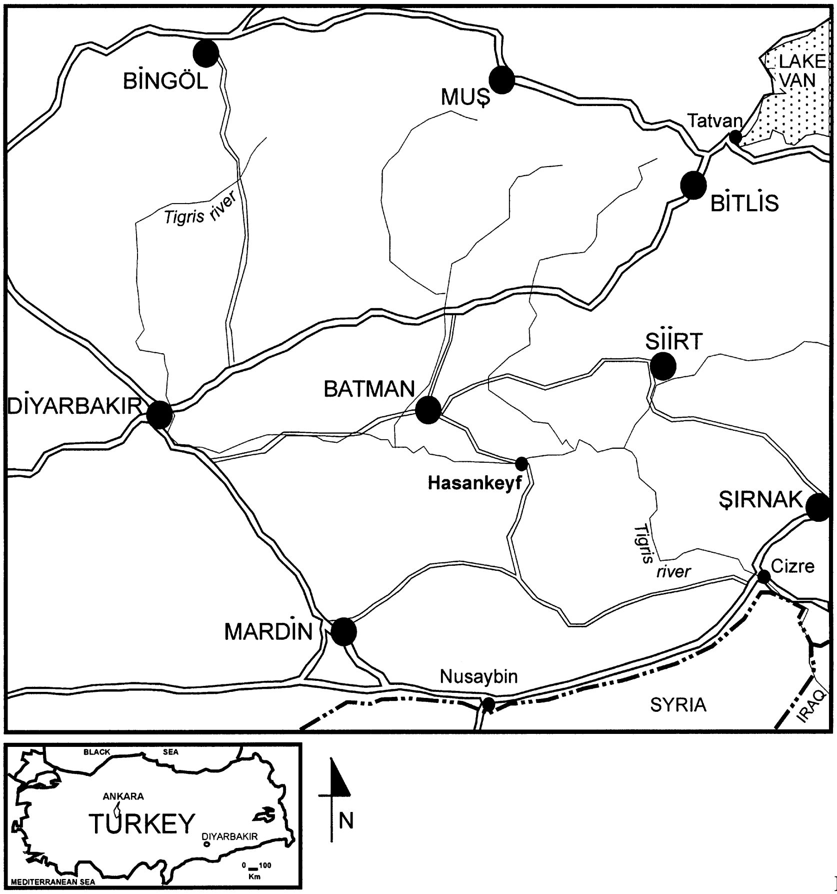

Fig. 1
Location map of the project area (scale: 1/25,000)

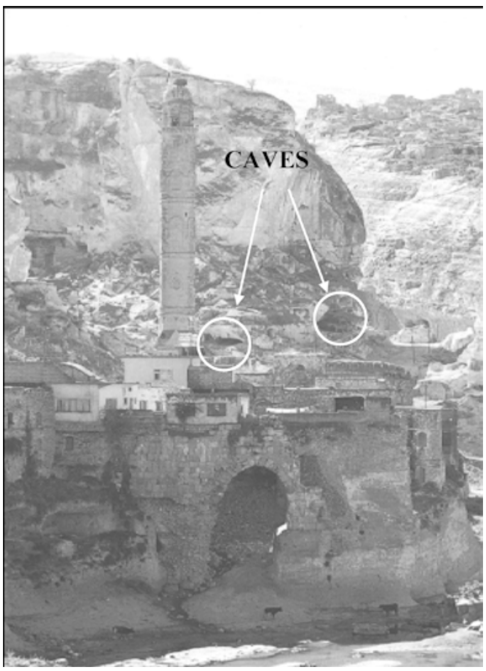

Fig. 2
A view of Hasankeyf looking south

activities. After the filling of the Ilısu dam reservoir, water may accelerate rock failure phenomenon in the area. The objective of this study is to investigate and remediate the geotechnical problems of the cave settlements of which a good portion will stay below the water level and of "Little Palace" that will be above the maximum reservoir level of the Ilısu dam.

General geology, earthquake susceptibility and rock mass characteristics

According to Arni (1939), Paige (1946), MTA (1962), Duran and others (1988), Perinçek and others (1991) and as quoted by Doyuran and others (2001), the study area is within a sedimentary terrain represented by thick sequences of marine origin. These sequences are a part of the northern margin of the Arabian Plate and are exposed extensively throughout southeastern Anatolia. Two widespread rock associations in the area are the Şırnak and Midyat Groups of Cretaceous to Oligocene age. These rocks are unconformably overlain by Pliocene continental clastic rocks which form the low topography in the region. Basaltic lava flows of Quaternary age are erupted from volcanic centers scattered in the area. The youngest rock units are the recent alluvial deposits that form along the river channels of the major streams. The main lithological units exposed in the vicinity of Hasankeyf are the Germik

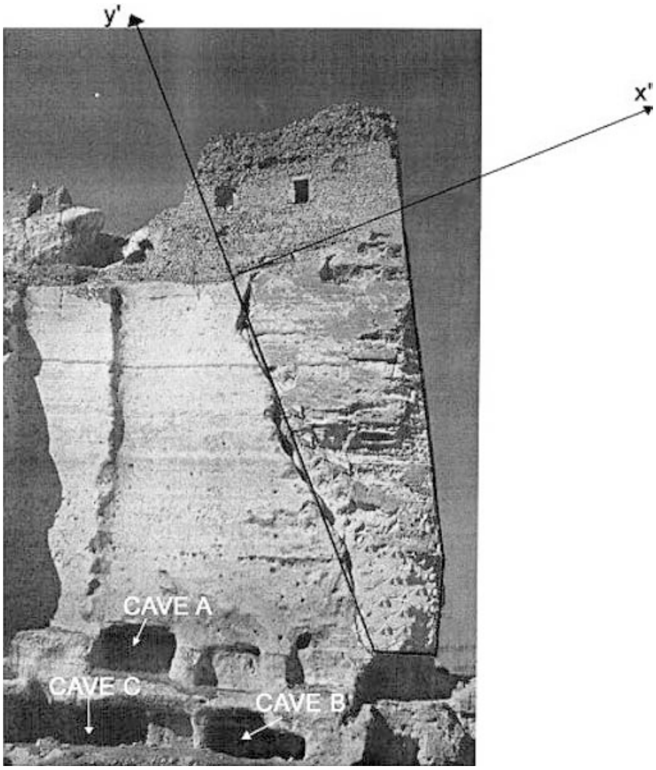

Fig. 3
A view of "Little Palace (Küçük Saray)" looking NW. An outline of the unstable planar block on which its foundation is resting is denoted by *straight solid lines*

and Haya formations of the Midyat Group which conformably overlie the Gercüs formation of the Şırnak Group. All units consistently strike in almost an E-W direction which parallels the course of the Tigris River. The dip direction is generally towards the north, with an average amount of about 7–10°.

Four earthquakes have occurred in the region during the period of 1900–2000 with magnitudes ranging between 3.5 and 4.9 on the Richter scale. Hasankeyf is in a second-degree earthquake zone with an expected earthquake generated peak horizontal ground acceleration coefficient (a_h/g) ranging from 0.30 to 0.40 (Turkish General Directorate of Disaster Affairs 2002).

Hasankeyf is entirely within the Germik formation, which is composed of whitish to light gray and/or beige, medium strong, fresh to slightly weathered, thick to very thick bedded, locally massive, almost horizontal or gently dipping silty, sandy limestone. The limestone is occasionally crossed by joints and locally irregular fractures and/or cracks are also observed. The discontinuities observed within the bedrock comprise joints, bedding planes and irregular fractures. The joints are widely spaced according to ISRM (1981). The surfaces of the joints and the fractures may be classified as slightly rough. The persistence of the joints is medium, whereas the fractures show medium to high persistence. The apertures of the joints are moderately wide and of the fractures, moderately wide to wide (ISRM 1981).

Rock failure mechanisms at the site include rock fall and kinematic planar failures. Originally, massive to moderately strong rock has been weakened due to the carving of the cave dwellings, particularly within very thick bedded and/or massive layers that led to rock fall. The detached limestone blocks which have accumulated at the foot of the cliffs suggest that the block sizes range from large to very large according to ISRM (1981). Since the blocks are mainly formed as a result of crack and/or fracture propagation, their shapes are extremely irregular.

Rock mass classification and the determination of rock mass strength

The rock mass classification system used for the project area was the rock mass rating system (RMR) by Bieniawski (1989). The rock mass rating (RMR) for the rock mass under dry conditions is calculated as 57, which classifies the rock mass as fair rock. The RMR value for the saturated rock mass that simulates an adverse condition where the reservoir impounds water is calculated as 42, which still classifies the rock mass as fair rock. The parameters, values and ratings for calculating the RMR, total rating and the shear strength parameters (cohesion, c and internal friction angle, φ) of the rock mass is given in Table 1. The shear strength parameter ranges of such fair quality rock mass are: cohesion (c)=200–300 kPa and internal friction angle (φ)=25–35°. Considering average values, the cohesion (c) and internal friction angle (φ) values of the rock mass are taken as 250 kPa and 30°, respectively.

Assessment and remediation of the instability of "Little Palace"

"Little Palace" is one of the important historical structures in Hasankeyf that is under the threat of planar kinematic failure along a pre-existing fracture in the rock block underlying its foundation. Figure 3 shows a view of "Little Palace". The dip of the fracture (ψ_f) is 69° and the strike is N49°W. The straight solid lines in this figure are drawn to highlight the approximate outline of the unstable planar block the structure is resting on. The block is about 27 m high, 11.55 m wide at the crest, 4 m wide at the toe and about 14 m thick.

Kinematic assessment of slopes is helpful in determining kinematically possible modes of failure (i.e., planar, wedge or toppling failure), but cannot take into consideration important geotechnical parameters such as cohesion, unit weight, water pressure, surcharge, etc. To obtain the necessary design parameters and to assess possible remedial measures for safe slope design, limit equilibrium analysis is required (Jaeger 1971; Hoek and Bray 1981). Therefore,

Table 1
Rockmass rating (RMR) classification parameters, values and ratings for the rockmass under dry and saturated conditions

Parameter	Value	Rating for dry conditions	Rating for saturated conditions
1. Strength of intact rock material (σ_{ci})[a]	25 MPa	4	4
2. Drill core quality (RQD)	70%	13	13
3. Spacing of discontinuities	0.6–2 m	15	15
4. Condition of discontinuities	Separation: 1–5 mm	10	10
5.Ground water condition	Completely dry or fully saturated	15 (completely dry)	0 (fully saturated)
TOTAL RATING	–	57	42
Rock mass class	–	Fair quality rock mass	Fair quality rock mass
Cohesion of the rock mass (c; kPa)	–	200–300	200–300
Internal friction angle of the rock mass (φ; °)	–	25–35	25–35

[a]According to ISRM (1981)

a limit equilibrium analysis of the kinematically unstable planar rock block was performed. Figure 4 shows the force distribution and the decomposition of the forces acting on the unstable planar block ACDH along the x′ and y′ axes, respectively. Equation (1) below defines all the variables in Fig. 4. As mentioned previously, the maximum reservoir level of the Ilısu dam (526.85 m) is indicated by point F in Fig. 4; this level is equal to two thirds of the full reservoir column denoted by vertical distance IJ. The full reservoir column IJ is equal to 23.41 m; two thirds of the full reservoir column, denoted by h_w in Fig. 4 is equal to 15.61 m. The resultant force acting along the x′ axis ($\Sigma F_{x'}$; noting that the water level is at point F which represents the most likely reservoir water level and that the forces acting in the negative directions of the axes are considered positive) is:

$$\sum F_{x'} = Q\sin\delta + W\sin\alpha - W_e\cos\alpha + P_h\cos\lambda + P_{h'}\cos\theta - P_u\sin\alpha - P_w + T\cos\theta \qquad (1)$$

$$W = A\gamma_{rock} \qquad (1a)$$

$$W_e = W\frac{a_h}{g} \qquad (1b)$$

$$P_h = \frac{1}{2}\gamma_w h_{WE}(EF) \qquad (1c)$$

$$P_{h'} = \frac{1}{2}\gamma_w (h_{WE} + h_{WD})(ED) \qquad (1d)$$

$$P_u = \gamma_w h_{WD}(CD) \qquad (1e)$$

$$P_w = \frac{1}{2}\gamma_w h_{WC}(BC) \qquad (1f)$$

where, Q is the surcharge load of "Little Palace" per unit width (kN/m); W is the weight of the planar block per unit width (kN/m); A is the cross-sectional area of the planar block ACDH (m^2); γ_{rock} is the unit weight of rock (kN/m^3); W_e is the earthquake load per unit width (kN/m) due to the expected earthquake-generated peak horizontal ground acceleration coecient (a_h/g); P_h, $P_{h'}$, P_u, P_w are

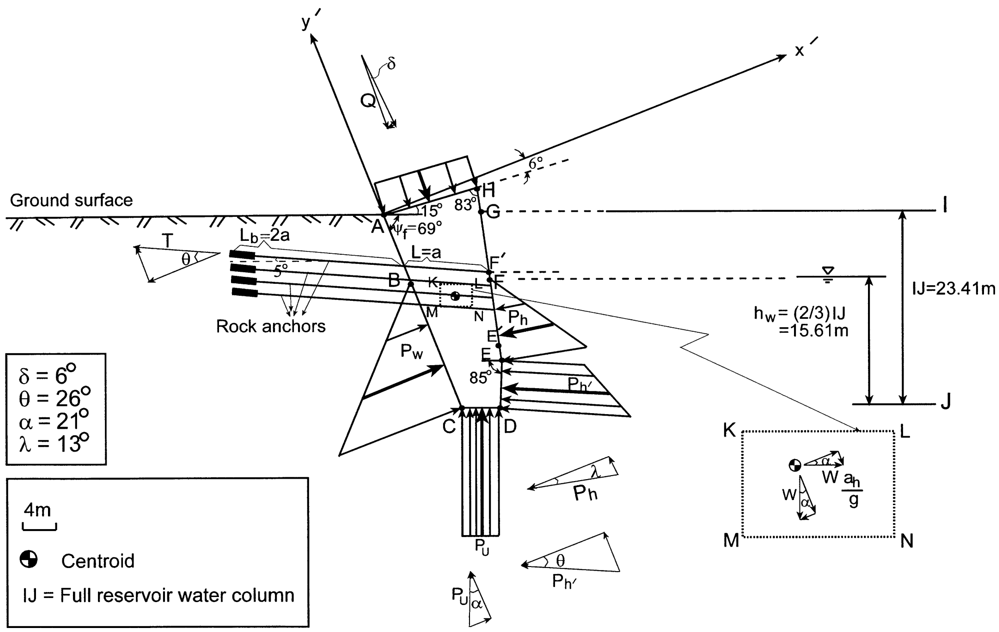

Fig. 4
The force distribution and decomposition of the forces acting on the unstable planar block ACDH along the x′ and y′ axes. The water level is assumed to be at point F. Definition of all parameters is given by Eq. (1)

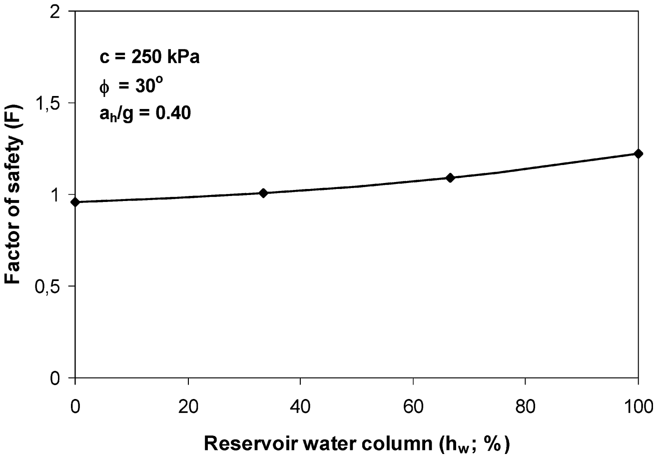

Fig. 5
Factor of safety as a function of the water level in the reservoir

water forces per unit width due to a water level at point F along block sections EF, ED, CD and BC, respectively (kN/m); T is the required rock anchor force per unit width (kN/m); γ_w is the unit weight of water (kN/m^3); h_{WE}, h_{WD}, h_{WC} are water heads at points E, D and C, respectively (m); and, δ, α, λ, θ are angles defined by Fig. 4.

The parameters of Eq. (1) are given as follows: Q=606 kN/m; A=210 m^2; γ_{rock}=26.48 kN/m^3; γ_w=9.807 kN/m^3; h_{WE}=9.68 m; h_{WD}=15.61 m; h_{WC}=15.61 m; EF=9.86 m; ED=5.95 m; CD=4 m; BC=16.84 m; δ=6°; α=21°; λ=13° and θ=26°.

The resultant force acting along the y′ axis ($\Sigma F_{y'}$; noting that the water level is at point F which represents the most likely reservoir water level and that the forces acting in the negative directions of the axes are considered positive) is:

$$\sum F_{y'} = Q\cos\delta + W\cos\alpha + W_e\sin\alpha - P_h\sin\lambda - P_{h'}\sin\theta - P_u\cos\alpha - T\sin\theta \qquad (2)$$

where all the parameters are as defined by Eq. (1).

The factor of safety (F) of the block against sliding is defined as the total resisting forces over the total driving forces (e.g., Hoek and Bray 1981) and is expressed by Eq. (3):

$$F = \frac{\sum \text{Resisting forces}}{\sum \text{Driving forces}} = \frac{c(AC) + \sum F_{x'}\tan\phi}{\sum F_{y'}} \qquad (3)$$

where c is the cohesion and φ is the internal friction angle of the sliding rock block along fracture AC (Fig. 5); $\Sigma F_{x'}$ is the resultant force along the x′ axis [Eq. (1)]; and, $\Sigma F_{y'}$ is the resultant force along the y′ axis [Eq. (2)]. It was assumed that the shear strength parameters along the rock block fracture were equal to the average values of those of the rock mass (i.e., c=250 kPa, φ=30°).

A limit equilibrium sensitivity analysis of the unstable planar block as a function of the water level in the reservoir (h_w) was performed. In the sensitivity analysis, four different reservoir water levels were assumed: dry condition which represents the possibility of a drawdown in the reservoir that corresponds to a water level at point D; wet conditions where one third, two thirds and the entire reservoir is filled with water. One third of the full reservoir column corresponds to a water level at point E′ and is equal to (1/3)IJ or 7.8 m (Fig. 4). As noted before, two thirds of the full reservoir column represents the most likely reservoir water level and corresponds to a water level at point F which is equal to (2/3)IJ or 15.61 m. A full reservoir column or the entire reservoir filled with water implies that the reservoir water level is at point G and is equal to the full reservoir column IJ or 23.41 m (Fig. 4). As noted previously, Hasankeyf is in a second-degree earthquake zone with an expected earthquake-generated peak horizontal ground acceleration coefficient (a_h/g) ranging from 0.30 to 0.40. For a conservative approach, a_h/g is taken to be equal to 0.40 in the sensitivity analysis. Wyllie (1992) gives the optimum rock anchor inclination angle (ψ_{Topt}) from the east in the counter-clockwise direction as:

$$\psi_{Topt} = 180^\circ - \psi_f + \phi \qquad (4)$$

where ψ_f is the dip of the planar rock block which is equal to 69° and φ is the internal friction angle equal to 30°. Hence, ψ_{Topt} is calculated from Eq. (4) as 141° from east in the counterclockwise direction or 39° from the west in the clockwise direction which is equal to a rock anchor inclination angle (θ) of 60°. An anchor inclination angle (θ) of 60° is not possible since the thickness of the sound rock beyond the fracture is not enough to place the anchor ends within rock, i.e., the anchor ends would punch out of the crest of the rock body that they are emplaced in. For θ=31°, a vertical distance of only about 2 m would remain between the crest of the slope and the anchor ends. This might lead to anchor failure due to insucient overburden thickness to carry the anchor load. Hence, the anchor inclination angle (θ) is selected as 26° which represents an anchor inclination of 5° from the west in the clockwise direction. Point F′ in Fig. 4 shows the point of application of the topmost rock anchor row.

Figure 5 gives the factor of safety as a function of the water level in the reservoir for a_h/g=0.40. In this figure, h_w=0% represents a dry reservoir condition and h_w=33.3%, h_w=66.7% and h_w=100% represent wet conditions where one third, two thirds and the entire reservoir is filled with water, respectively. The factor of safety decreases with decreased water level of the reservoir. The lower bound of the factor of safety is calculated for dry conditions from Eq. (3) for no anchor support (i.e., T=0) as 0.96. The higher bound of the factor of safety which is equal to 1.22 is calculated for conditions for which the entire reservoir is filled with water (i.e., h_w=100%).

Figure 6 gives the required anchor force (T) for a factor of safety of 1.5, an anchor inclination angle (θ) of 26° and a_h/g of 0.40 as a function of the four different reservoir water levels. The required anchor force decreases with increased reservoir water level. The lowest required anchor force T is calculated for a full reservoir level (h_w=100%) as 1,174 kN/m and the highest T for a dry reservoir as 3,042 kN/m. Hence, a conservative analysis suggests considering dry conditions which simulate a drawdown in the dam reservoir. These conditions lead to an anchor force of

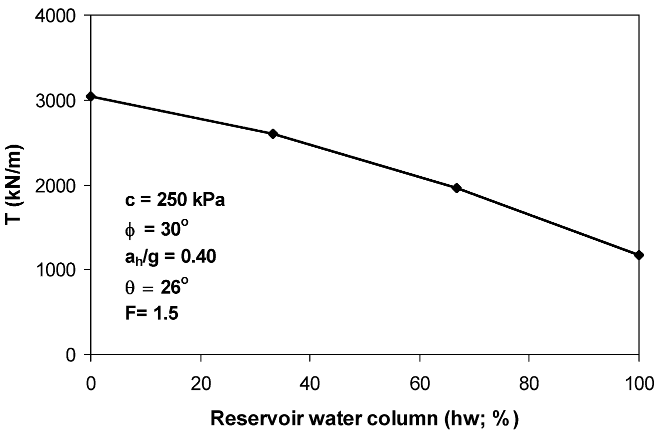

Fig. 6
The required anchor force (T) for a factor of safety of 1.5, anchor inclination angle (θ) of 26° and an earthquake-generated peak horizontal acceleration coefficient (a_h/g) of 0.40 as a function of four different reservoir water levels

about 3,000 kN/m or a total anchor force of about 42,000 kN for the 14-m-wide slope face of the unstable planar block ACDH. A total of 56 rock anchors with a service load capacity of 750 kN/m each that are spaced 1 m apart are recommended for stability. Point F′ in Fig. 4 shows the point of application of the topmost anchor row (note that there are a total of four anchor rows). According to the specifications of the Turkish General Directorate of Highways (1989), the anchor embedment or free length should be at least twice the fixed anchor length (i.e., length of the anchor portion emplaced in the unstable block). As illustrated in Fig. 4, the anchor fixed length up to the rock fracture is length a and the anchor-free length is 2a. Note that for θ=26°, the free anchor length (a) is 10.4 m; the fixed anchor length (anchor body length; 2a) is 20.8 m; and the total anchor length (a+2a) is 31.2 m.

Stability of the man-made caves

The collapse of the roofs of adjacent man-made caves that are presently used for dwellings, restaurants, cafes, etc. due to insufficient pillar (wall) thicknesses to carry the overburden load is a major geotechnical concern in the area. Upon filling of the Ilısu dam reservoir, water may further accelerate cave failure. The objective of this section is to investigate and remediate the stability problems of the cave settlements at Hasankeyf by using the finite element method.

The finite element software package Phase^2 by Rocscience (2001) was utilized to determine the induced stresses, deformations and stability around the man-made caves located beneath "Little Palace", and specifically, to demonstrate that a wall thickness of 0.93 m between adjacent caves B and C is sufficient since these caves do not show any signs of distress or collapse (Fig. 3). The geotechnical parameters tabulated in Table 1 were used as input for Phase^2. The Poisson's ratio of the rock mass was assumed to be 0.25. The ratio of the in situ horizontal stress to the

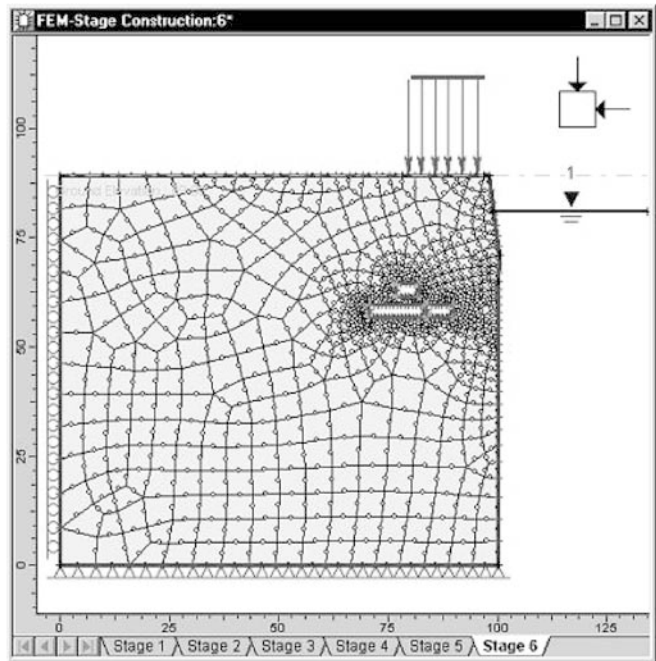

Fig. 7
Mesh indicating stage 6 of the finite element analysis (i.e., inserting the water table)

in situ vertical stress (σ_h/σ_v) was assumed to be equal to 1.

The Phase^2 finite element model included six stages. The first stage included gravity loading followed by applying the far field stresses. The following three stages consisted of excavating cave A, then cave B and finally cave C in stressed rock. The last two stages consisted of applying the surcharge load of "Little Palace" and inserting a full reservoir water column at the level of point G in Fig. 4. Figure 7 gives the finite element mesh and boundary conditions of the sixth stage. A Mohr-Coulomb plastic constitutive relation assuming plane-strain and full face cave excavation was used.

The consequences of the six stages were analyzed through examining the peak-induced total displacements and the strength factors developed at the boundaries of caves B and C. Table 2 gives the peak total displacements and strength factors on the wall between caves B and C after the fifth stage (i.e., before the insertion of the water table) and the same after the final (sixth) stage (i.e., after the insertion of the water table) as a function of pillar thickness. Comparison of the two stages shows that the presence of the water table increases the magnitude of the peak total displacements and decreases the strength factor. The strength factor for the 0.93 m wall decreases from 1.73 to 1.64 and the total displacements at the cave boundaries almost double.

Geological investigations at the project site revealed that adjacent man-made caves with a pillar (wall) thickness of about 0.20 m or less showed roof collapse. These caves were generally beneath a rock overburden of about 30 m. To analyze this phenomenon and to determine the minimum required stable wall thickness, the analysis presented above was repeated for wall thicknesses of 0.20, 0.40, 0.50,

Table 2
The peak total displacements (δ_t) and strength factors (SF) developed on the wall between caves A and B (Fig. 3) after the fifth stage (i.e., before insertion of the water table) and after the sixth stage (i.e., after insertion of the water table) as a function of pillar thickness

Pillar thickness (m)	Fifth stage (i.e., before insertion of the water table)		Sixth stage (i.e., after insertion of the water table)	
	δ_t (mm)	SF	δ_t (mm)	SF
0.93	22	1.73	43	1.64
0.80	35	1.66	56	1.57
0.60	55	1.60	74	1.51
0.50	76	1.49	99	1.39
0.40	92	1.10	120	1.01
0.20	113	1.01	148	0.88

0.60 and 0.80 m, respectively. Table 2 gives the results of the analyses. The total displacement of the 0.20-m wall under dry conditions increases up to 113 mm and the strength factor decreases down to 1.01. With the water table, the total displacement further increases to 148 mm and the strength factor decreases down to 0.88. It is evident from these results that a wall thickness of 0.20 m leads to failure for both dry and saturated conditions. The total peak displacement and strength factor for a 0.60-m-thick wall between caves B and C after the final (sixth) stage (i.e., after the insertion of the water table) decreases down to 74 mm and the strength factor increases up to 1.51, which indicates that the minimum required wall thickness for stable conditions is 0.60 m.
The results of the finite element analysis on a 0.20-m-thick wall with a steel arch support applied to cave B indicates that the total displacement for the reinforced (supported) 0.20-m-thick wall decreases down to 73.5 mm and the strength factor increases up to 1.47. Hence, the displacement and strength factor results of the steel arch supported 0.20-m-thick wall are almost identical to those of an unsupported 0.60-m-thick stable wall under saturated conditions. These results lead to a recommendation to apply a steel arch support to one of the adjacent caves in case the wall thickness is less than or equal to 0.60 m.

Summary and conclusions

Investigations at Hasankeyf revealed that the major geotechnical concerns in the area constituted the possibility of kinematic rock failure along a pre-existing fracture in the rock block underlying the foundation of "Little Palace" and the collapse of some of the roofs of the adjacent man-made cave dwellings carved in rock due to insufficient pillar (wall) thicknesses to carry the overburden load.
After the filling of the Ilısu dam reservoir, water may accelerate rock failure phenomenon in the area which may be of potential threat to those who wish to visit the historical structures that remain above the maximum reservoir level. The objective of this study is to investigate and remediate the stability problems of the cave settlements of which a good portion will stay below the water level and of "Little Palace" that will be located above the maximum reservoir level of the Ilısu dam.
The rock mass classification system used for the project area was the rock mass rating system (RMR). According to this method, the rock mass was classified as fair rock with a cohesion of 250 kPa and an internal friction angle of 30°.
A limit equilibrium sensitivity analysis of the kinematically unstable planar rock block underlying the foundation of "Little Palace" was performed as a function of the water level in the reservoir (h_w). The factor of safety decreased and the required rock anchor force increased with decreased water level of the reservoir. The highest required anchor force was calculated for a dry reservoir as 3,042 kN/m which lead to total anchor force of about 42,000 kN for the 14-m-wide slope face of the unstable planar block. A total of 56 rock anchors with a service load capacity of 750 kN/m each that are spaced 1 m apart are recommended for stability.
Finite element analysis was utilized to determine the minimum pillar (wall) thickness required between adjacent caves in the region for stability. Pillar thicknesses of 0.20, 0.40, 0.50, 0.60, 0.80 and 0.93 m were analyzed. The results of the finite element analysis led to a recommendation to apply a steel arch support to one of the adjacent caves in case the wall thickness is less than or equal to 0.60 m.

Acknowledgements The work reported in this paper is part of a project entitled "Salvage project of the archeological heritage of the Ilısu and Carchemish dam reservoirs", performed by the Middle East Technical University (METU) Centre for Research and Assessment of the Historic Environment (TAÇDAM), Ankara. Prof. Dr. Numan Tuna is the director of TAÇDAM. Permission to publish this paper is gratefully acknowledged. The author would like to thank Dr. A. Pırıl Önen and Mr. Mustafa K. Koçkar, Department of Geological Engineering, Middle East Technical University, Ankara for their assistance in drafting Figs. 1, 4–7 and Dr. Vedat Toprak of the same department for lending Fig. 3.

References

Arni P (1939) Contribution to the geology of the Siirt region with some conclusions in regard to possible oil reserves. MTA Report No 1284, Ankara
Bieniawski ZT (1989) Engineering rock mass classification. Balkema, Cape Town, 251 pp

Doyuran V, Toprak V, Akgün H (2001) Geotechnical problems of Hasankeyf Settlement Area. Salvage project of the archeological heritage of the Ilısu and Carchemish dam reservoirs activities in 1999. In: Tuna N, Öztürk J, Velibeyoğlu J (eds) METU Centre for Research and Assessment of the Historic Environment (TAÇDAM), Ankara, pp 833–854
Duran O, Şemsir D, Sezgin İ, Perinçek D (1988) The stratigraphy, sedimentology and oil potential of the Midyat and Silvan Groups in southeastern Anatolia (in Turkish). Bulletin of the Society of the Turkish Petroleum Geologists, Ankara 1(2), pp 99–126
Hoek E, Bray JW (1981) Rock slope engineering, revised 3rd edn. Institution of Mining and Metallurgy, London, 358 pp
ISRM (1981) Suggested methods for the quantitative description of discontinuities in rock masses. In: Barton T (ed) Rock characterization, testing and monitoring. Pergamon Press, Oxford, 221 pp
Jaeger JC (1971) Friction of rocks and stability of rock slopes. Geotechnique 21:97–134
MTA (1962) Explanatory map of 1:500.000 scale geological map of Turkey. In: Tolun N, Erentöz C, Ketin İ (eds) Mineral Research and Exploration Institute Publication, Diyarbakır sheet, Ankara
Paige S (1946) The geology of a portion of southeastern Anatolia between Mardin and Diyarbakır, Siirt and Cizre. MTA Report No 217, Ankara
Perinçek D, Duran O, Bozdoğan N, Çoruh T (1991) Stratigraphy and paleogeographical evolution of the autochthonous sedimentary rocks in SE Turkey. In: Turgut S (ed) Tectonics and hydrocarbon potential of Anatolia and surrounding regions. Bulletin of the Society of the Turkish Petroleum Geologists, Ankara, pp 274–305
Rocscience (2001) Phase^2 user's guide. Rocscience, Toronto, Ontario, Canada, 163 pp
Tuna N, Öztürk J, Velibeyoğlu J (2001) Salvage project of the archeological heritage of the Ilısu and Carchemish dam reservoirs activities in 1999. METU Centre for Research and Assessment of the Historic Environment (TAÇDAM), Ankara, 854 pp
Turkish General Directorate of Disaster Affairs (2002) Earthquake Research Department Database (www.deprem.gov.tr)
Turkish General Directorate of Highways (1989) List of specifications for slope stability analysis (in Turkish). Ankara, 100 pp
Wyllie DC (1992) Foundations on rock. E & FN Spon, London, 333 pp