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Slope stability investigation in relation to the neotectonic conditions along the south-western coast of Athos peninsula (N. Greece): The case of Simonos Petra Monastery

Étude de stabilité des pentes en relation avec les conditions néotectoniques le long de la côte sud-occidentale du prèsque île Athos (N. Grèce): Le cas du Monastère Simonos Petra

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ABSTRACT: Simonos Petra Monastery is a historical building of the 13th century lying at the south-western coast of Athos peninsula that consists part of a seismically very active region. In the present investigation geological, neotectonic, seismotectonic and geotechnical condisions are studied. Characteristics of N-S and E-W treding joint and fault systems, which mainly affect the area, are described. The local and regional stress patterns, quantitatively calculated, show a N-S main extension (σ_3) and secondary E-W one. The geomechanical conditions of the Monastery foundation area are also studied, regarding the classification of the rock-mass and the analysis of the rock slope stability, while the estimation of the response of the construction at the continues aseismic creep and sliding is discushed.

RESUME: Le Monastère de Simonos Petra est un bâtiment historique, du 13e siècle, situé sur la cote sud-occidentale du presque île Athos, qui fait partie d' une region de sismicité active. Dans cet étude les conditions neotectoniques, sismotectoniques et geotecniques ont été étudiées et les caractères des failles et des joints de directions generales N-S et E-W ont été determinées. Les modèles de tension, local et general, ont été calculés, montrant une extension dominante $\sigma 3$ de direction N-S et une extension secondaire de direction E-W. Les conditions géotecniques de la region de fondation du monastère ont été étudiées par rapport à l' analyse de la stabilité des pentes. La reponse de la construction au fluage sismique a été aussi discutée.

1. INTRODUCTION

Foundation rock stability conditions are of particular interest, especially in regions like the Mediterranean Basin, where tectonic conditions are very active. In this framework a particular area of Mount Athos was studied by means of the neotectonic and geotechnical conditions at the sites where many important monasteries are built. Simonos Petra Monastery was used as a good example to provide the influence of the tectonic conditions existed to the stability of the building.

Mount Athos peninsula is located in Northern Greece and belongs administratively directly to the Patriarchate of Constantinople (fig. 1). It is an area of great historical and religious interest, where only Monasteries for men are built. Many, pobably active, neotectonic faults, of N-S and E-W directions, traverse the area, causing damage to the Monasteries.

Simonos Petra Monastery was built up around 1257 AD, on an isolated and uplifted rock (altitude 305 m) at the S/SW site of the peninsula. It was burnt down several times, so as only the lower parts of the construction, near the rock base is of that age. The western part of

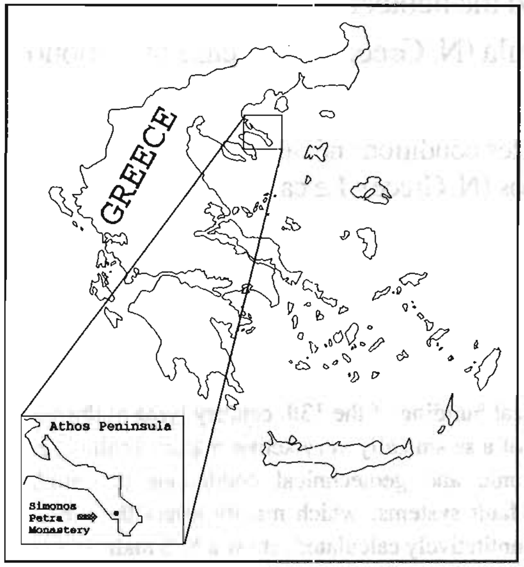

Fig. 1. Location of Athos peninsula.

the present building was built in 1590 AD while the eastern part in 1890 AD. The tower at the shipyard of the Monastery was built in 1563 and no restoration activities have been done until today (Xygopoulos, 1963, Kadas, 1989)

The Monastery was investigated, regarding the slope stability of the construction area, in relation to the neotectonic conditions, so as the most proper measures for preservation to be taken. A part of preliminary data, used in the interpretation was presented in STREMA-93 (Christaras et al., 1993).

The foundation area was investigated by means of slope stability analysis. The interpretation of the collected data determined the probable surfaces of sliding that can be activated under specific conditions and loading. The activity of important discontinuities was also investigated, with *in situ* measurements, using specific instruments, such as strainmeters and extensionmeters, so as to determine their probable relationship with the existed neotectonic faults.

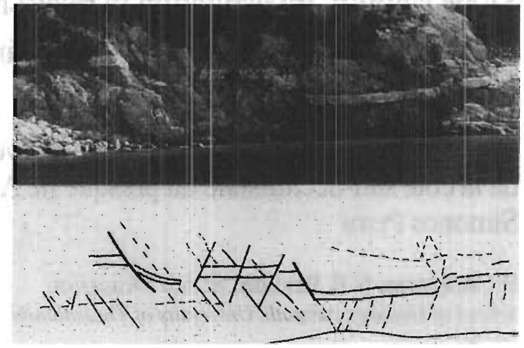

Fig. 2. An example of brittle neotectonic deformation (top: photograph, bottom: sketch.

2. GEOLOGY - NEOTECTONICS

The broader study area geologically belongs into the Serbomacedonian zone, an old massif. It consists of palaeozoic or older two mica gneisses, plagioclase - microcline gneiss, marbles and amphibolites, as well as mesozoic indrutions (biotite granite with transitions into biotite hornblende granite-granodiorite). Sills and dykes of leucocratic aplitic muscovite-granite are frequent.

The neotectonics of an old geological area, where there are no young sediments to indicate recent and active structures can be studied by:

- The spatial distribution of earthquakes.
- The morphotectonics (drainage system, scarp morphology and decradation, landscape contrasts etc.).
- The young geological features, such as keen and steep tectonic surfaces, cataclasites, polished striated mirors, etc.).

The distribution of earthquake foci during historical times (Papazachos & Papazachou 1989) and the epicenters which occured during the present century (Voidomatis 1989) show that the present tectonic activity in the area is very high. It is clearly distributed along two disting seismic zones: a) the NNN-SSE trending Serbomacedonian zone, and b) the ENE-WSW striking North Aegean Trough. South Mnt Athos is the angular-cross of these two seismic zones.

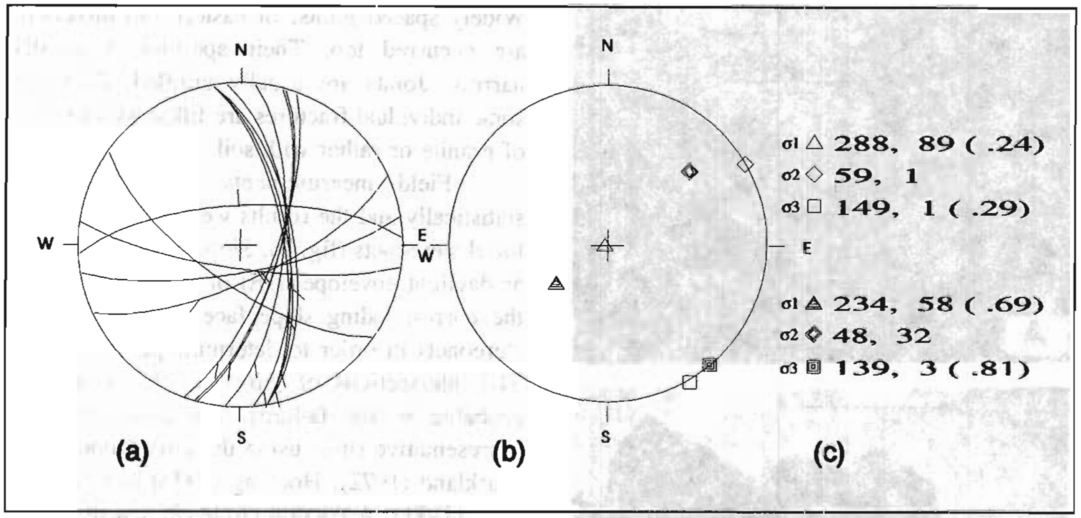

Fig. 3. Stress analysis of neotectonic faults in the area of Simonos Petra Monastery (details in the text).

Morphotectonic criteria used to study neotectonics of Simonopetra area are Landscape contrasts, e.g. steep sea shores, high gradient relief, very steep scarps, gravitational slides associated mainly with normal faulting which constitute a typical environment of active tectonics. In contrast, although the geology of the area is dominated by granites-granodiorites-gneisses, the typical granitic core stones-fores landform is absent. Normal faults (N-S and E-W) and typical extension joints and open fractures, which post date the ductile deformation , characterize the neotectonic pattern of the area. Polished steep fault sufaces in the granite, mainly uneroded, striated mirors, rock faulls, open cracks establish the neotectonic, if not active, tectonic regime.

Under these circumstances morphotectonic and britlle tectonic data (fig. 2) are of special importance in defining certain seismic fault parameters. While striae, which represent the slip vector on the fault plane, can be used in calculating tectonic stress (strain) elipsoide. An example of stress analysis from the striated mesofaults of simonopetra area is shown in fig. 3, where: (a) is a stereonet showing the measured faults (as cyclographic traces) and correspon ding striae (as arrows). The faults strike mainly E-W with normal component and N-S with strike-slip components. (b) is the application of the mathematical methodology of Caputo & Caputo (1988) on the "right-dihedrons" and "mean stress tensor" methods, and (c) the results in degrees.

The stress field is extensional with the $\sigma3$ trending more or less N-S or in a more precise analysis it can be distinguished in ENE-WSW and NNW-SSE directions ($\sigma3$). It is known from the broader area (Pavlides & Kilias 1987; Mercier et al 1987; Pavlides et al, 1990) that NE-SW trending extension is an older neotectonic phase, while N-S to NNW-SSE is the active one.

The change of the opening in tectonic structures of the above directions, in the foundation area, ensure their influence on the stability of the Monastery.

3. GEOTECHNICAL APPROACH

The area is totally fractured and is traver-

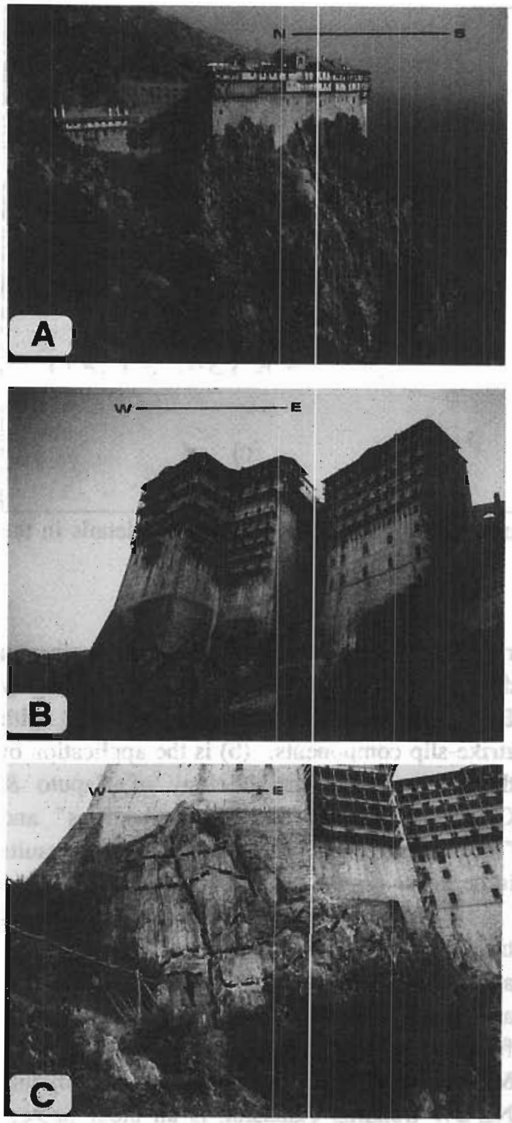

Fig. 4. The western (A) and the southern site (B, C) of the Monastery. Important discontinuities can cause sliding phenomena.

sed by joints of various directions. Many important faults of E-W and N-S general directions are occured. From a first point of view, these discontinuities can cause unstable geotechnical conditions, especially at the slopes of the construction area (fig. 4). Joints are generally medium to closely spaced with routh surfaces. Widely spaced joints, of eastern dip direction, are occurred too. Their aperture is usually narrow. Joints are usually unfilled. Although some individual fractures are filled with breccia of granite or rather with soil.

Field measurements were interpreted statistically and the results were ploted in equatorial stereonets (fig. 5). Slope direction as well as daylight envelope (DE) of joints that rise on the corresponding slope face are given in the stereonets in order to determine plane failures. The intersections of joint sets that determine probable wedge failures, are also given for representative sites, using the tests proposed by Markland (1972), Hocking (1976) and Hoek & Bray (1981). A friction circle (FC) with probable, general $\phi=30^o$ was also ploted in every stereonet for this purpose.

The interpretation of these stereonets determined wedge and plane failures and the factors of safety (F) were calculated separately for each one of them (fig. 6). According to the above interpretation, the wedges created at the points C and E of fig. 5, on the western slope of the foundation area, gave factors of safety higher than 1 (fig. 6). On the other hand, the factors of safety calculated for the failures determined at the points J1, J2 and I of fig. 5, on the southern slope of the foundation area, take values from 0.48 to 0.98, creating unstable conditions in the area (fig. 6).

The geometry of the tectonic data is not the only cause for the instability of the rockmass. The tectonic structures determined in the broder area could also affect the foundation rockmass. In this framework an important neotectonic fault or megajoint of SW dip direction ($216^o/80^0$) devides the rockmass in two halfs at the site C (figs. 4A, 5) decreasing the safety of the Monastery. A similar probable fault (200^o/-80^0) also exists at the site E (figs. 4A,**5**). Small faults aslo affect at the southern part of the Monastery (fig. 4C). Furthermore, an important fault of N-S direction, cut the building near by its western wall, causing also damage both to the

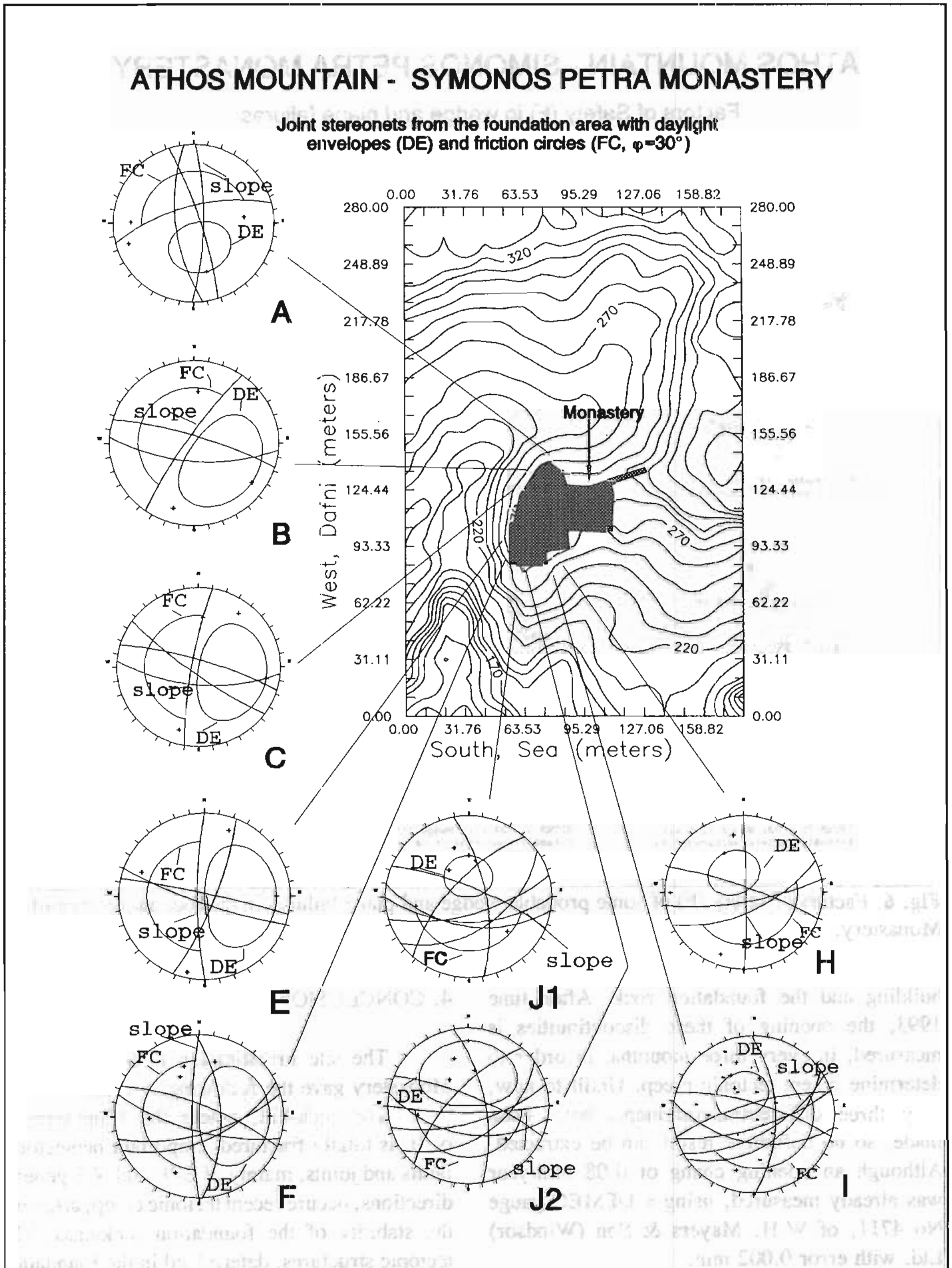

Fig. 5. Geotechnical at the site of Symonos Petra Monastery

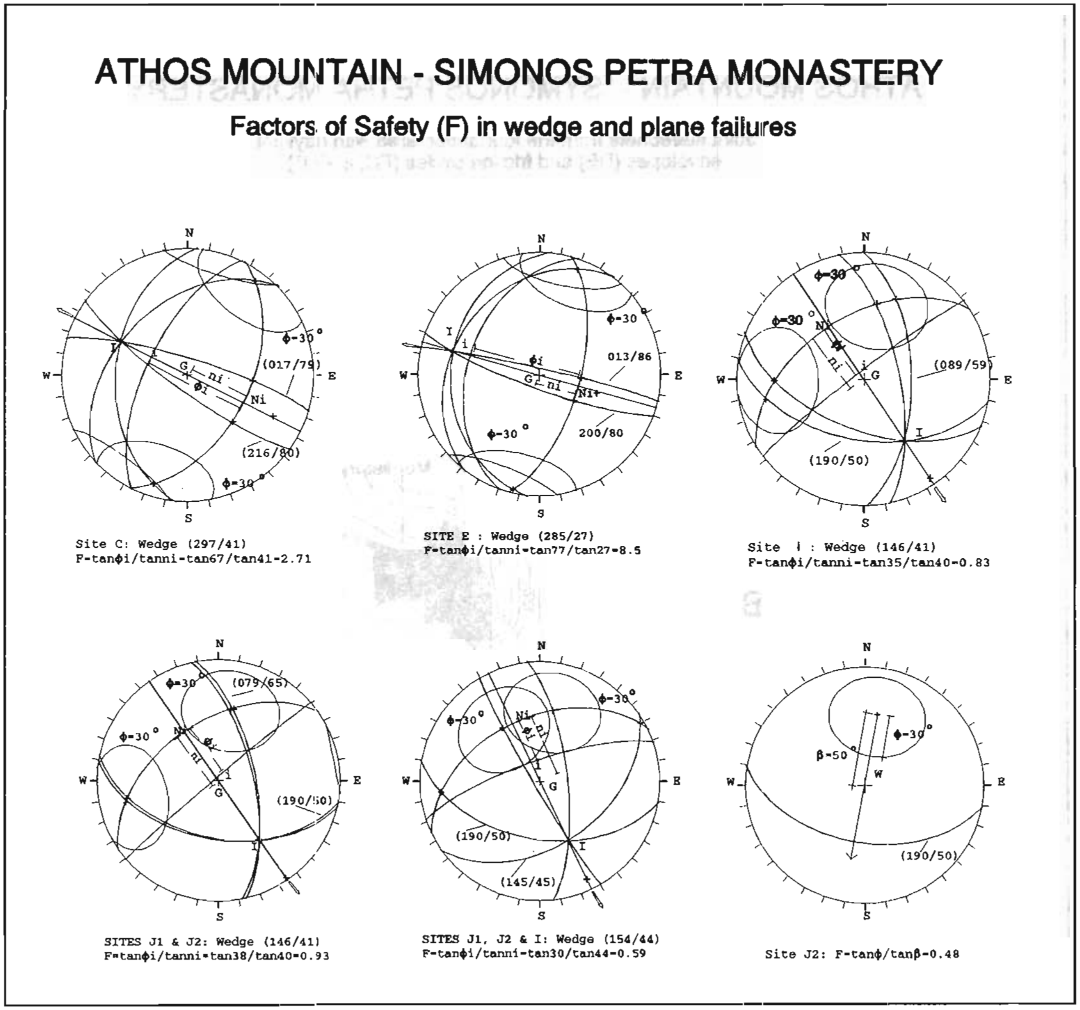

Fig. 6. Factors of safety (F) of some probable wedge and plane failures in the foundation area of the Monastery.

building and the foundation rock. After June 1993, the opening of these discontinuities is measured, in every three mounths, in order to determine recent tectonic creep. Untill to now, only three differentmeasurements have been made, so no definitive result can be extracted. Although an opening chang of 0.08 mm/year was already measured, using a DEMEC gauge No 4711, of W.H. Mayers & Son (Windsor) Ltd. with error 0.002 mm.

4. CONCLUSIONS

The site investigation at Simonos Petra Monastery gave the following results:

The rock-hill, where the Monastery is built, is totally fractured. Important neotectonic faults and joints, mainly of E-W and N-S general directions, occure recent tectonic creep, affecting the stability of the foundation rockmass. The tectonic structures, determined in the foundation area, create also wedge and plane failures causing damage to the building. The factors of safety of these failures were calculated resulting values lower than 1. These instability phenomena related to the neotectonic conditions of the broder area, are more impresive at the southern and western slopes of the rock-hill.

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