FIRST STEPS FOR MONITORING ON POSSIBLY ACTIVE FAULT ZONE IN EAST RHODOPES, BULGARIA

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ABSTRACT
A large impressive landslide occurred in 2001 at the General Geshevo Village area, East Rhodopes, SE Bulgaria. After the sliding, a system of preserved faults was observed in the area. The present paper relates the detailed study, mapping, selection and installation of movement monitoring site. Preliminary results establish displacements that could be related to slow tectonic movements.

KEYWORDS: landslide, crack gauge, Balkan region

1. INTRODUCTION

In January 2001, a large and impressive landslide developed in the SE Bulgaria (Fig. 1). It took place in the East Rhodopes between the villages of General Geshevo and Ustren. A territory of about 4 km^2 with road of local significance has been damaged. The detailed study and mapping of the area were accomplished just after the landslide (Fig. 2). A system of preserved faults can be well observed (Varbanov & Frangov, 2002).

An overall analysis of the factors indicated negligible contribution of ground waters and precipitation. This view is supported by the fact that the landslide occurred during a dry period of the year and followed a longer dry period of the previous year 2000 when only negligible rainfalls were reported. Also, the river flowing at the foot of the slope with a characteristic wide accumulative terrace provided low discharge without any erosion impact on the landslide toe. At the same time, even a thorough analysis of other conditions established negligible influence of the ground waters on the landslide activation. A water sample, taken from one captured spring, has shown chemical composition that is characteristic for waters coming from fault zones. Due to the above reasons, we focused our study on other possible factors, notably to search connection between slow tectonic movements and the landslide phenomenon. There was a decision to arrange movement monitoring at a point characteristic of a significant outcropped fault. The observation point is equipped with high precision technique for in-situ observation of slow movements – 3D extensometer TM-71 (Kostak, 1991).

2. GEOLOGICAL AND SEISMOLOGICAL NETWORK

The research area is situated to the ENE of the town of Zlatograd, near the Bulgarian-Greek boundary. It is characterized by a complex tectonics and diverse geological structures. Two main geological units build the studied area: Praecambrian metamorphites and Palaeogene volcanic-terrigenous rocks (Boyanov and Mavrudchiev, 1961; Goranov, 1960; Goranov et al., 1960; Kozhoukharov, 1984; Kozhoukharov and Boyanov, 1995).

The Vacha Formation represents the oldest rocks of this region. The rocks are well represented in the Zlatograd and its surrounding. They take place to the west of the landslide's territory. This formation includes mainly gneisses, gneiss-schists, schists, quartzites, marble and amphibolites. The most distributed biotite's and two-mica's gneisses are in irregular alternation with gneiss-schists, schists and marble. There are local inclusions and lens of ultrabasites, gabbroides and orthoamphibolites.

The Paleogene (Upper Eocene and Oligocene) volcanic rocks and terrigeneous sediments lay over the block fragmented Precambrian rock complex. Faulting and block fragmentation occur in the investigated territory. Several graben-like depressions, including the depression of Momchilgrad, formed here. Specific conditions define development of several rock

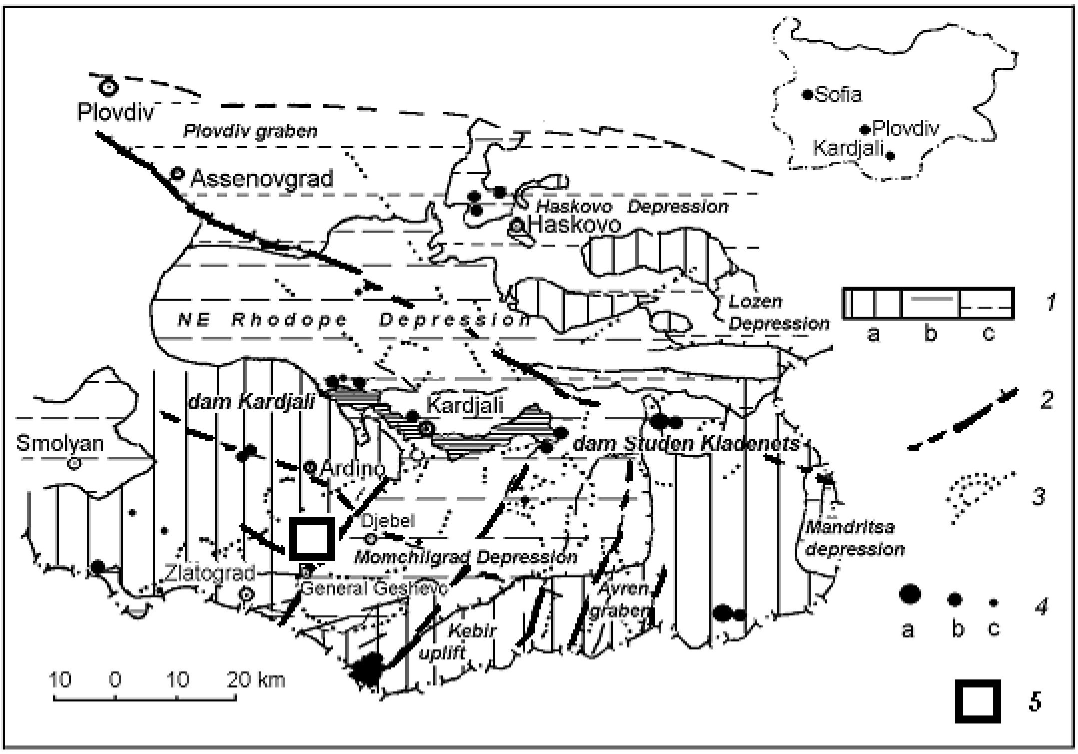

Fig. 1 Geological-tectonical scheme of E Rhodopes (acc. to Kozhoukharov & Boyanov, 1995, with modification) and the seismic events (1993-1999): 1 – Rocks: a) metamorphic, b) Paleogene sediments and volcanites, c) Neogene-Quaternary sediments; 2 – faults; 3 – photo lineament; 4 – earthquake epicentres: a) with M >3, b) M = 2.0 to 3.0; c) M < 2; 5 – landslide research area.

formations. The well-distributed Oligocene rocks include the following formations:

- Formation of first acidic volcanism

The materials lie on the crystalline bedrock. Two basic lithological units are distinguished in the profiles – the terrigenous group and the pyroclastic complex. The terrigenous rocks usually alternate with acidic volcanic tuffs in the upper parts of the terrigenous group, where their main component is the volcanic glass. The tuffs are partially or entirely transformed into montmorilonite clays at some places as a result of the volcanic glass alteration. The tuffs contact at some places by a steep lithological boundary with almost horizontal layers of grey and greyish-green terrigenous materials (tuffaceous sandstone, slightly to strongly calcareous sandstone and sandy limestone).

A slide slope had been formed in the tuffs at the western boundary of the landslide with clearly expressed mirror shear surfaces. They had inherited mechanical deformations of the rock massif provoked by old tectonic movements.

- Formation of second acidic volcanism

The materials of the second acidic lava-pyroclastic horizon lie on the rocks of the first acidic pyroclastic horizon. The volcanic glass is the main tuff component. The tuffs are characterized by well-expressed stratification. The thick-layered varieties with massive texture are predominant.

The volcanic tuffs of this horizon cover the materials of the first horizon. Grey to greyish green terrigenous rocks are observed under the tuffs in some stripping in the ravines – layers of calcareous sandstone and sandy limestone, intercalated with tuff sandstone.

- Djebel Formation

The eastern boundary of the studied zone is built of the sediments of the Djebel Formation, presented by sandstone, sands, aleurites and clays. They lie on the rocks of the second acidic lava-pyroclastic horizon. The thickness of these sediments in the area of the landslide is 10 – 30 m. The thick-layered horizontal texture is predominant. The sandstone is intercalated with clayey sandy sandstone and silty sandy clays.

The investigated territory represents a part of the recent active Balkan region. On the Balkan Peninsula, numerous fault zones and structural units with specific degree of mobility are formed as a result of the Alpine development.

The area under study is found to the south of the superimposed Upper Thracian Depression and the NE Rhodope Depression (Atanassov et al., 1976); in the superimposed Momchilgrad Depression (Fig. 1).

The regional Pg-Q Upper Thracian Depression (WNW-ESE) is one of the most mobile structural units in the region of South and SE Bulgaria. It is more then 150 km long and up to 50 km wide. The local Pg-Q NE Rhodope and the Pg-Q Momchilgrad Depressions are to the S and in vicinity with the Upper Thracian Depression. The NE Rhodope Depression (WNW-ESE) is 75 km long and up to 30 km wide, the Momchilgrad Depression (SW-NE) – 60 km long and up to 30 km wide. The General Geshevo landslide took place in the Momchilgrad Depression.

The Momchilgrad Depression represents a graben structure situated between 2 horst structures. It is developed partially over the faulted peripheries of the positive structures. It is filled with Pg-Q sediment, volcano-sediment and volcanic rocks. The boundaries of the depression are: to the north - the Kardjali (Ardino) fault zone, to the west - the faulted east periphery of the Madan-Davidkovo swelling, including the Dobromirtsi Fault (Gocev, 1969, Popov et al., 1971, Kozhuharov and Boyanov, eds., 1995), to the south – the faults along the Kecebir block and to the east - the Xanthi (Mountrakis and Tranos, 2004; Rondoyanni et al., 2004, etc.) Faults (Fig. 2).

Seismic events in the E Rhodopes are of low magnitudes between 1993 - 1999. They are generally with magnitudes M <3.0. Only several earthquakes reach values of M >3.0. The seismic information include events from the last tens years (Fig. 1).

The seismic effects are very limited on the ground surface. Seismic zoning of the country provided relatively lower values of intensity in the studied locality. Here the maximal intensity could reach VII th degree of MSK-64, according the State Normative Documents for Constructions (1997).

Seismic manifestations are localized in several territories of the Momchilgrad Depression. Generally, they could be related mainly to the Kardjali (Ardino), the Xanthi and the Dobromirtzi faults.

It was especially during the period of 1993 - 1999, at the beginning of the landslide formation, when the local weak earthquakes appeared to be relatively frequent. They mark considerable concentration into small fragments of the Dobromirtzi and the Xanthi faults. The most considerable local concentration of the earthquake epicenters takes place in the area 20-25 km to the SE from General Geshevo Village. In the locality of the General Geshevo Village itself the seismic events are rare.

3. THE GENERAL GESHEVO LANDSLIDE

The impressive General Geshevo landslide takes place on the western boundary of the Momchilgrad Depression. In this locality, the Pg-Q Depression is in contact with the faulted east periphery of the Madan-Davidkovo swelling, where the Precambrian rocks are well represented.

The Xanthi (ENE-WSW) and the Dobromirtzi (NE-SW) faults cut the Momchilgrad Depression in the locality of the General Geshevo landslide (Fig. 2).

The Xanthi Fault (Mountrakis and Tranos, 2004; Rondoyanni et al., 2004, etc.) extents at a length of about 100 km and has a regional significance in the southern part of the Balkan Peninsula. Greek scientists define it as a normal fault along which several right lateral displacements are not excluded. The main fault characteristics are obvious in the Northern Greece: to the E-ENE of the town of Kavala. Montrakis and Tranos (2004) describe five sectors of the Xanthi Faults. The Chrisoupolis - Xanthi Fault is extended also in Bulgaria to the east of the town of Zlatograd. Its direction on the Bulgarian territory is approximately 55º.

The Dobromirtzi Fault (Gocev, 1969, Popov et al., 1971, Kozhuharov & Boyanov, eds., 1995) is well represented in western part of the Momchilgrad Depression.

3.1. FIELD SURVEY

Two faults are found to be developed in the area of the studied landslide. Furthermore, the Dobromirtsi Faults pass near the top of the landslide and just at his toe. Several other faults with NW-SE, N-S and E-W directions are of local importance.

Shiroka Laka Fault (NW-SE) takes place near the northern periphery of the General Geshevo landslide. The fault forms the NE border of the landslide and is developed also inside the landslide - in the Paleogene tuffs of the main landslide scarp. Slickensides on the fault plane indicate oblique sinistral movements. Orientation of striations coinsides with the position of open fractures. Such fractures cut the road outside of the landslide as well. Normal component of the movement is predominant. Horizontal component is only limited. Subsidence takes place in the northern blocks. Stroke pitches read a value about 70 - 80º. The fault revealed between the road and the main scarp – in a length of the outcrop of about 50 m. Maximum height of the fault plane outcrop is approximately 10 m. Behind the scarp the fault follows a direction of 300º. Some fractures could be followed along this fault plane, approximately 20 m behind the main scarp. Faults of E-W direction are also observed in the investigated landslide territory.

3.2. MONITORING AND INSTRUMENTATION

Repeated geological mapping of the landslide was carried out after the activation of the sliding process (Fig.2). All the mapped points were recorded by GPS, and marked on a topographic base in the scale 1: 5 000. A benchmark network was developed for the monitoring of the landslide processes, its initial positioning and measurement being made by high accuracy GPS. Two boreholes were drilled near the main landslide caving to a depth of 115 and 125 m. Vertical electrical sounding was performed in points of the landslide body in order to establish the geological structure into higher depth (Fig.3).

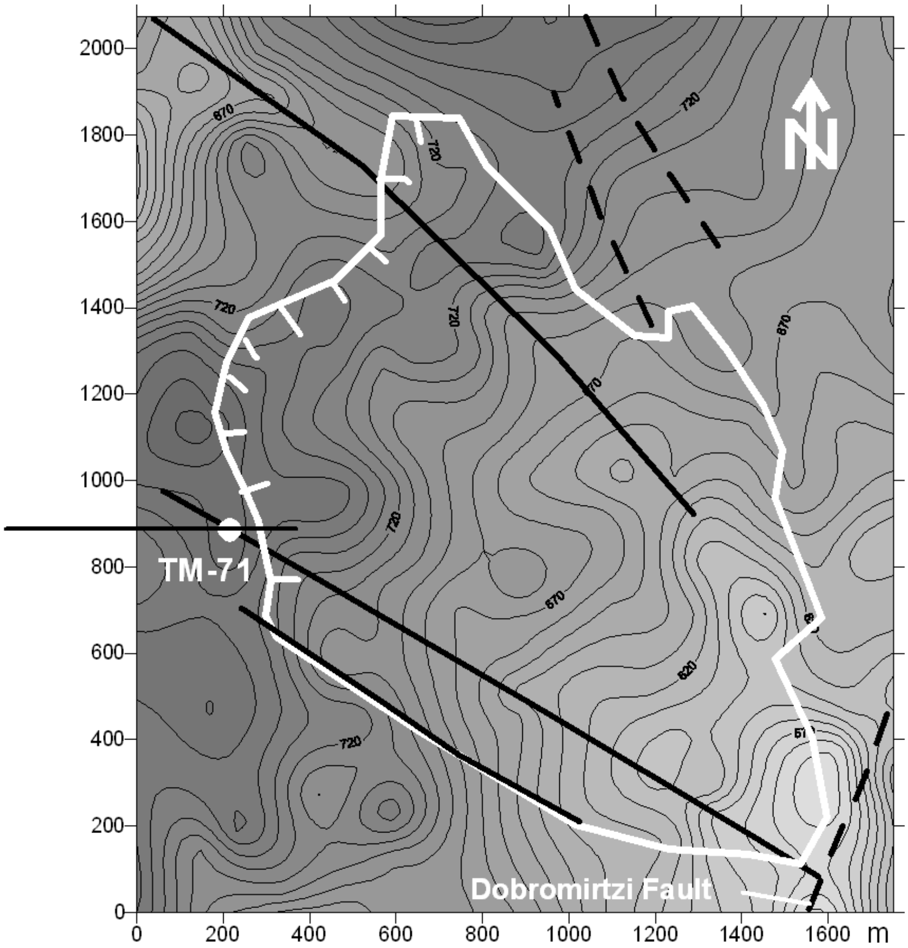

Fig. 2 Geomorphologic map of the General Geshevo landslide. The borders of the landslide are shown by white contours; the new faults and the Dobromirtzi Fault are presented by bold black lines; the vertical sounding profile (see Fig. 3) cut through the border fault along a thin black line; the monitoring site is marked by a white circle.

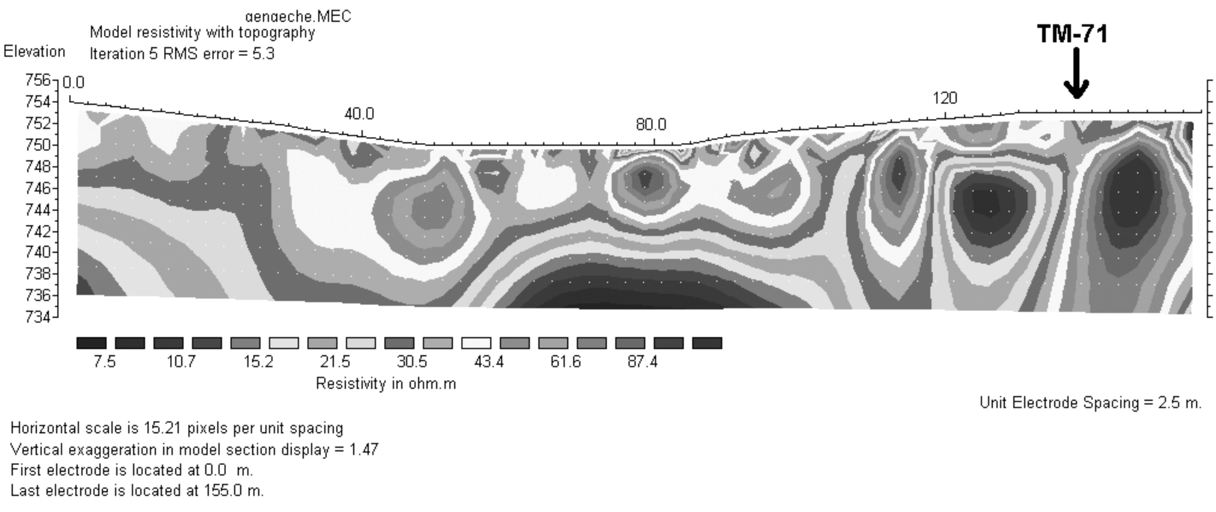

Fig. 3 Vertical electric sounding profile through the landslide body and the location of the fault where the selected monitoring site instrumented by the TM-71 extensometer can be found (see also location in Fig. 2)

Fig. 4 View of the new monitoring site

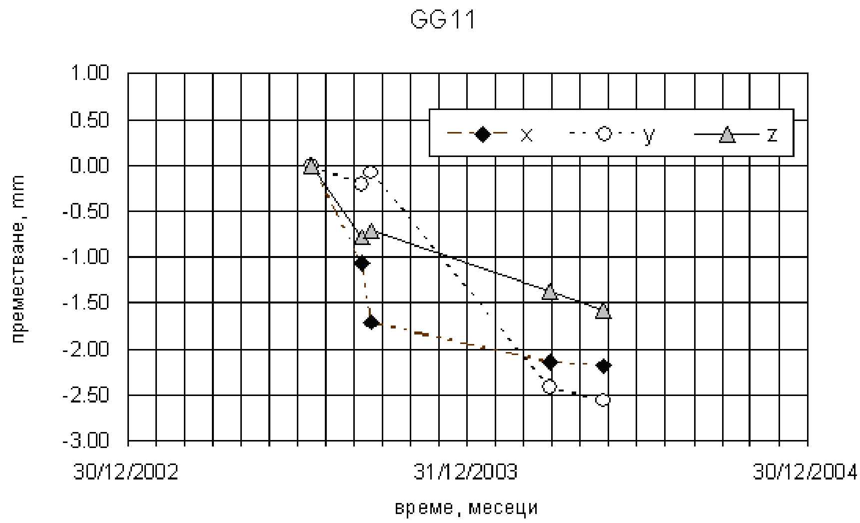

Fig. 5 Preliminary results of 3D movement monitoring at the fault of the General Geshevo site

The selection of the movement monitoring site was made after a detailed investigation of several suitable points in the area. The site (Fig. 4). is located about 30 m to NW from the main scarp. The movement monitoring is intended to indicate micro-displacements in 3D along the fault that is assumed active, and it is arranged in a relatively very small trench (Fig.4). The trench has been dug out in soft tuffs that form the fault zone and the extensometer is placed on a steel bridge between the fault faces. The tuff zone is 0,8 – 1.2 m wide. Local fault orientation reads: azimuth N112º, dip 50º NE.

The site is instrumented with the extensometer TM-71. The device is produced by GESTRA Sedloňov in the Czech Republic. Its operation has been described by Kostak 1991. Each device consists of two planar indicators, and register the displacements in two perpendicular planes, i.e. in all the three spatial directions – X (opening or compressing of the fault zone), Y (strike-slip movements) and Z (vertical movements). The device is regularly installed on steel holders made of thick tubes and cemented to drill holes. The holders bridge the side walls of the fracture or fault carrying the gauge. The accuracy of the device reaches 0.01 mm.

CONCLUSION

The first results from the fault monitoring are shown in Fig. 5. The rates of the fault movements registered at the monitoring site are preliminary till now. As for now, providing results of the first year of observation, they could be characterized as follows:

- Movements along X-axis – compression of the fault zone by 2.0 mm/year (coefficient of correlation r = 0.75).
- Movements along Y-axis – left lateral movement by 3.5 mm/year (coefficient of correlation r = 0.97).
- Movements along Z-axis – uplift of NE block by 1.5 mm/year (coefficient of correlation r=0.87).

However, it is our view that there is a need for at least 3 to 5 years of observation in order to acquire enough information for assessing long-term displacement rates in the investigated zone more significantly.

As for local factors that could interfere possibly with the fault movements, we find that till this moment the seasonal and daily temperature fluctuations could be accepted as low or negligible along axes Y and Z. This is due to the position of the gauge in a trench as well as because the short length of the steel gauge tubes.

The investigation calls urgently for the existing monitoring site to be completed to a system with several more points. Appropriate system could be arranged with sites in other parallel structures outside the landslide body, and also along the transversal fault structures. The completion of the system is expected after a thorough analysis over the whole area using more detailed field studies including tectonic stress field, local earthquake distribution, and geomorphology.

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REFERENCES

Atanassov, A., Boyadzhiev, S. and Cheshitev, G., edit.: 1976, Tectonic map of P.R. Bulgaria 1:500 000. Sofia, Institute of Cartography.

Boyanov, I., Mavrudchiev, B.: 1961, Palaeogeme magmatism in NE Rhodopes. Anniv. Sofia Univ., Biol.-geol.-georg. faculty, 2, Geology, 113-151 (in Bulgarian).

Broutchev, I., Frangov, G. and Yanev, Y.: 2001, Catastrophic phenomena in East Rhodopes. Minno delo i Geologia Journal, 6, 33-36. (in Bulgarian).

Gočev, P.: 1969, The Tvarditsa Fault System in the Tectonic Force Field of the Balkan Peninsula. Review of the Bulgarian Geological Society, XXX, 3, p. 281-293 (in Bulgarian, English abstract).

Goranov, A.: 1960, Lithology of the Palaeogene sediments at a part of the Eastern Rhodope Mts., Works of the Geology of Bulgaria, 1, 259-310. (in Bulgarian).

Goranov, A., Vutkov, V.G. and Petrov, P. S.: 1960, Perlites in the East Rhodopes. – Geofund of the Geological Institute of the Bulg. Acad. of Sci.

Kostak, B.: 1991, Combined indicator using moiré technique. Proceedings of the 3rd Int. Symp. on Field Measurements in Geomechanics, Oslo, Norway, 53-60.

Kozhoukharov, D.: 1984, Lithostratigraphy of pre-aecambrian rocks of the Rhodope supergroup in the Central Rhodope Mts. Geologica Balcanica, 14, 1, 43-88. (in Russian).

Kozhoukharov, D. and Boyanov, I. (Eds.).: 1995, Explanatory Note to the Geological Map of Bulgaria in Scale 1:100 000. Committee on Geology and Mineral Resources, Geology and Geophysics Ltd.

Mountrakis, D.M. and Tranos, M.D.: 2004, The Kavala-Xanthi-Komotini fault (KXKF): a complicated active fault zone in Eastern Macedonia – Thrace (Northern Greece). 5th Int. Symp. On Eastern Mediterranean Geology, Thessaloniki, Greece, 14-20.04.2004, 857-860.

Popov, P., Yanev, Y., Stefanov, N. and Bahneva, D.: 1971, The Dobromirtzi fault bundle. Annuaire de l'École Superieure des Mines et de Géologie, 16, 2, p. 61-75 (in Bulgarian, English abstract).

Rondoyanni, Th., Georgiou, Ch. and Galanakis, D.: 2004, Evidences of active faulting in Thrace region, North-eastern Greece. 10th GSG Congress, Thessaloniki, Abstracts, 578-579.

State normative documents for the constructions in seismic regions: 1997, Sofia, Publ. House "Technica", 223 p.

Varbanov, R. and Frangov, G.: 2002, Large active landslide in East Rhodopes – Bulgaria. Jub. Sci. Session for Acad. Strashimir Dimitrov, GI – BAS, poster report.