ACTA MONTANA IRSM AS CR (1998)
Series A No.12 (107), 5–15

PRESENT DYNAMICS OF A LANDSLIDE PROCESS IN THE BLACK SEA COAST REGION N OF VARNA (BULGARIA)

[1] Avramova-Tacheva, E., [2] Košťák, B., [1] Dobrev, N.

[1] Geological Institute, Bulgarian Ac. Sci.
Sofia 13, G.Bončev Street, kv. Geo Milev, Bulgaria

[2] Institute of Rock Structure and Mechanics, Ac. Sci. Czech Rep.
182 09 Prague 8, V Holešovičkách 41, Czech Republic

Abstract. Complex extensometric monitoring in the main scarp of a Black Sea coast block–type slope deformation has shown creep movements in the underlying clayey–marly beds of Sarmatian limestone blocks and also block deflections influenced by earthquakes. Prognosis of a mechanism relevant to the local geological conditions of the deformation is given. Necessary measures including monitoring are recommended to be accepted regarding the reality of extensive landslides that occurred recently here, and resulted into vast damage to this densely populated tourist and recreation area.

Keywords: Landslide; block–type slope deformation; deformation monitoring; creep movement registration; earthquake effects

1. Description of the Landslide and Monitoring

In the area of ancient landslides in the Varna Black Sea coast region, which suffered several cycles of development, a series of reactivated landslides occurred during last 30 years (Kamenov and Demirev, 1965; Pašek and Rybář, 1969; Iliev and Tzvetkov, 1971; Stoikov and Evstatiev, 1983; etc.). The reactivation of the landslides resulted from local construction activity and use of the terrain as a tourist resort and a recreation area, from newly constructed roads and traffic which occur in the coastal area, as well as from an abnormal water saturation in slopes. Also, one can see sea abrasion as a factor, or a process of suffusion that may be present in some sections of the coastal slope. Most of the landslides take the form of consistent and compact types of deformations (typification after Avramova-Tacheva, Voutkov 1974, block–type after Pašek, Košťák 1977) predisposed by the local geology and lithology. The deformations caused serious material damage, and, at the same time attracted a serious concern in looking for remedy measures. Problems were in design and construction. Serious damage occurred due to 6 landslides during the spring of 1997 after abnormal precipitation, and affected the northern section of the Bulgarian Black Sea coast. Two of them occurred at the foots of Frangya Plateau near Zlatni resort. The first was 400 m wide and 300 m long and developed on 4th of April 1997 near bus station "Journalist". It interrupted the road between Zlatni Piasaci and Varna (Varbanov et al., 1997) (Fig. 1). The second one was triggered on 17th of April 1997 at a camping site "Panorama", Zlatni Piasaci (Fig. 2). It is about 200 m wide and 250–300 m long. Both the landslides reached a depth of 5–15 m. As a result many houses and the road were destroyed, power lines and local connections were disrupted, etc. (Varbanov et al., 1997; Evstatiev et al., in print). Parallel to such present deformations primal deformation processes continue to develop at several sections in the upper part of the present sea shore slope.

FIG. 1. Road destruction between Zlatni Piasaci and Varna near the bus station "Journalist" at the Bulgarian Black Sea coast. Landslide of April 4, 1997. Photo by G. Frangov

The lower section of the slope is built generally by Neogene clayey sediments characteristically plastic and of low resistance to shear, especially when higher water content is found (Stoikov, 1971). The clays are covered by water permeable and water bearing fine grained sands of variable thickness which diminish to NE, and disappear finally near the Batova River valley. North–west of the town of Varna the sands in the upper section of the slope are covered by Sarmatian limestones. In the Aladjamanastir – Zlatni Piasaci region, where a well known tourist centre is located, the layer of limestones reaches a thickness of 20 to 25 m. By the time of field landslide investigations and mapping by the group of specialists from Geological Institute, Bulgarian Academy of Sciences, under leadership of late Prof. B. Kamenov, a recent crack was discovered, separating a long block step from the Frangya Plateau. The step is 3 to 8 m wide (Fig. 3). It represents the most recent cycle in the development of the primal process of sliding at this coastal zone. The step shows all the main features of a block–type slope deformation. Not far beyond the crack a village agglomeration can be found.

FIG. 2. Camping site destruction at the camping site "Panorama", Zlatni Piasaci, NE of Varna, Bulgarian Black Sea coast. Landslide of April 17, 1997. Photo by G. Frangov

To verify the present activity of the primal sliding process at this place, and its practical role in the stability of the zone, a highly sensitive extensometer TM71 (Košťák, 1991) was installed here in 1981 in co-operation with Institute of Rock

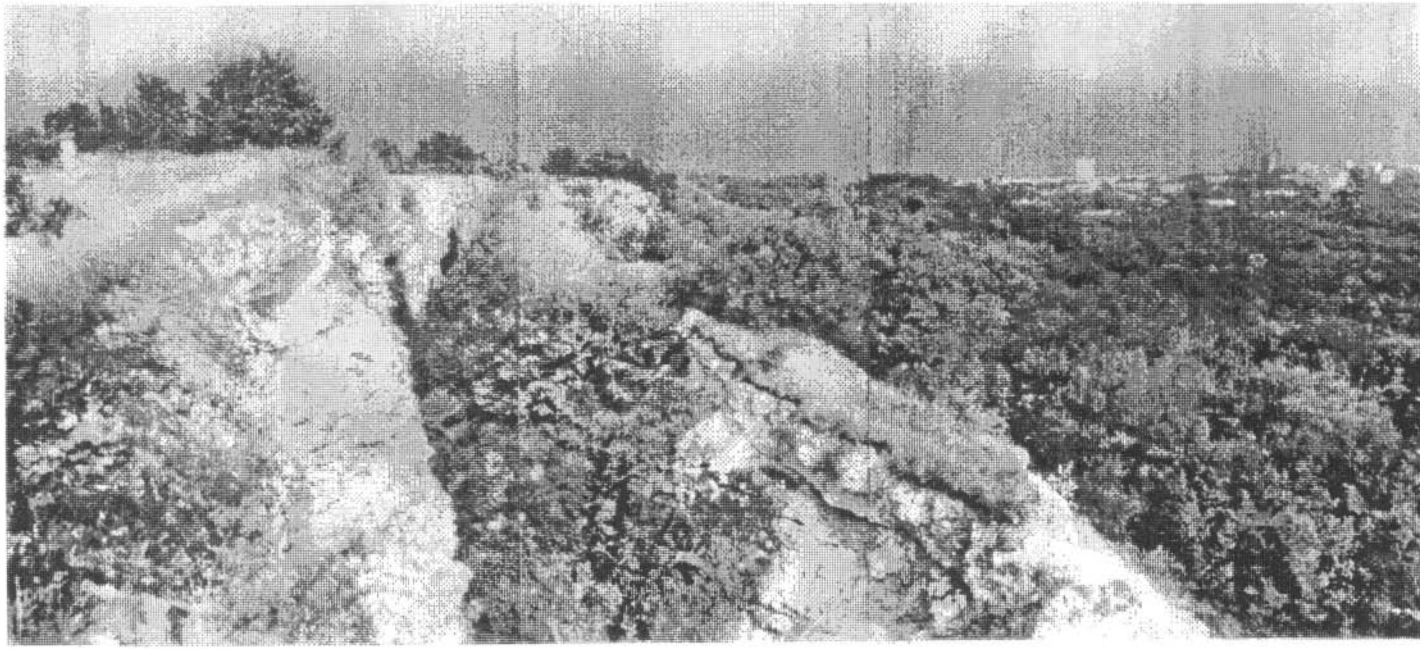

FIG. 3. A general panoramatic view of the Aladjamanastir – Zlatni Piasaci landslide deformation from the plateau edge to the sea showing the main crack with the uppermost step. Monitoring of movements takes place at the crack bottom. The sea resort hotels Zlatni Piasaci on the right side of the horizon. Photo by B.Košťák

Structure and Mechanics, Czech Ac. Sci., Prague. The extensometer works on a principal of mechanical–optical interferometry, moiré, and allows for detection of movement rates in 3-D of up to 0.1 mm per year. The instrument was mounted to the upper scarp of the deformation at a depth of 12 m from the plateau edge. (Figs. 4a,b). Beginning the end of the same year the instrument was equipped with special grids to detect even angular deviations of the step in respect to the edge zone of the plateau.

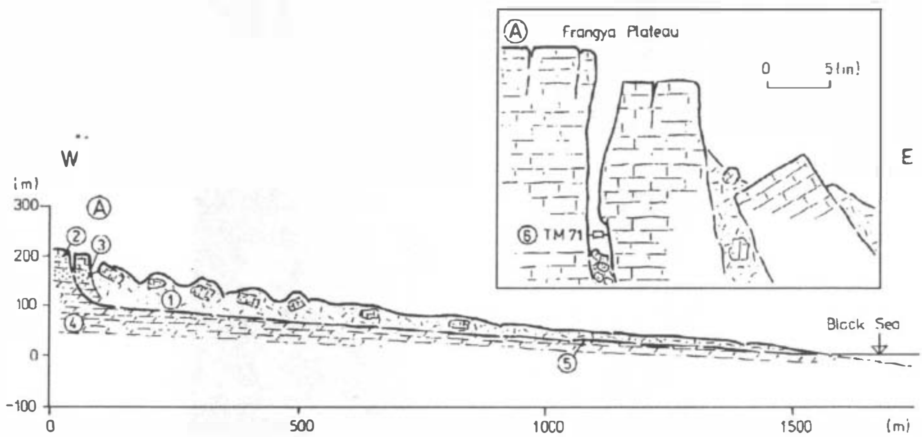

FIG .4a. A cross section of the Aladjamanastir – Zlatni Piasaci landslide
1 – mixed slope materials; 2 – limestones; 3 – sands; 4 – clays; 5 – slip surface; 6 – crack gauge TM71

Originally, till the year 1988 readings were taken regularly in one month intervals, later in three month intervals, with one exceptional break in 1985, which happened due to organization problems. After that, due to budget shortcuts, the frequency was decreased to two or one readings per year only. During the period of 15 years of registration, there were only two breaks in the operation after external damage to the instrument. (Between 13.06.1990 and 19.08.1990 the instrumentation was damaged due to a natural event most likely, and then until 1.04.1991 out of operation; between 18.03.1992 and 9.08.1992 found broken by bad will). Then, there was one period when no record taken due to problems in organization (5.06.1985 – 24.03.1986). Later, when registration frequency decreased, chances for more detailed interpretation became lower, and some episodes of displacements may have not been detected. In spite of that, general tendencies and rate of movements could be clearly characterized.

2. ANALYSIS OF RESULTS

Data registered by the said instrumentation in the scarp can be seen at Fig. 5. First, they show deformations in the primal process of slope failure along the investigated step. There is an obvious tendency of the step to downslope movements,

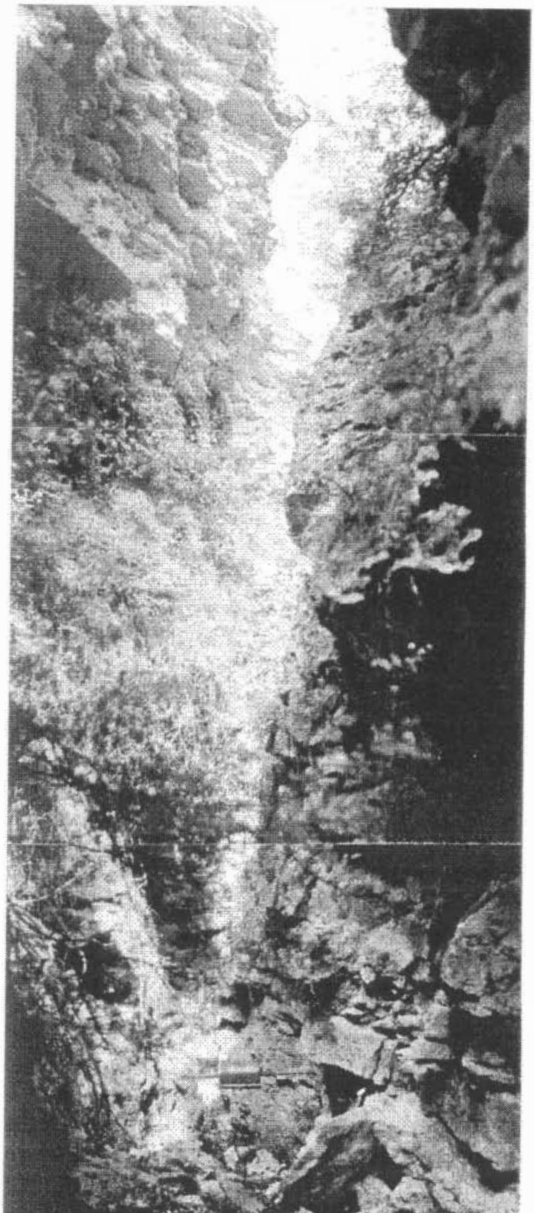

FIG. 4b. View of the instrument TM71 as mounted and covered with a protective box at the bottom of the upper scarp of the Aladjamanastir - Zlatni Piasaci landslide between the shattered rock walls about 12 m high. Plateau to the left – the uppermost step to the right. Photo by B.Košťák

as well as to widening of the scarp trench (see x co-ordinate in Fig. 5). Monthly registration during first five years of observation allows for some more detailed conclusions.

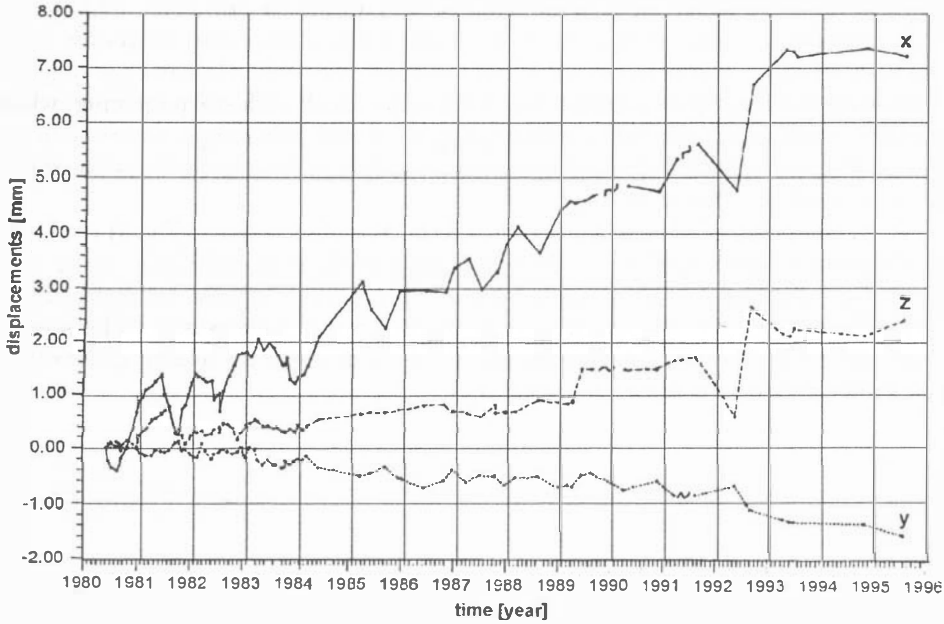

FIG. 5. Diagram of displacements monitored in the main scarp of the Aladjamanastir – Zlatni Piasaci landslide deformation between 1981 and 1996

$+x$ – horizontal scarp opening; $+y$ – horizontal shearing movement in the scarp, the step moving to E; $+z$ – subsidence of the step block; years given at the end of the time intervals

The x co-ordinate shows variations with some irregular parameters. The length of individual periods varied between 12 and 18 months within amplitudes of 1.36 to 1.90 mm. Maxima appear during spring periods, minima at the end of summer, and in fall. As shown by maxima, mean rate of horizontal movements reads 0.40 mm per year as a possible result of long term creep in clayey sediments. Minima show the same rate approximately. At the same time the step produced sinking with a mean value of 0.17 mm per year as seen by inspection of z co-ordinate development. Co-ordinate y shows small variations in the initial period. There was a trend of the movement to W, reading totally approx. 1.5 m for the full period 1980/1996. In our particular case temperature variations affecting rock near the instrument (known to appear delayed in respect of air temperature) are better compensated in y and z co-ordinates than those in the x co-ordinate. Therefore, y and z co-ordinates express better a function of other factors that those of the temperature variation. Some variations (those of x mostly) can be at least partially due to a water content variation in the thin upper zone of the clayey sediments which is able to affect creep rates in narrow limits.

After 1984 there are rather lower effects of temperature, which can be seen only in x co-ordinate. Due to that maxima and minima lose their extremes. In the middle of 1993 one can observe an extreme amplitude in all the co-ordinates. This short-time movement can be interpreted as a process of a new step crack formation along the plateau edge. The process comes first to subsidence of the plateau edge together with scarp closing, then to subsidence of the outer block with scarp opening, which persists. Such an interpretation can be supported with other signs observed in the morphology, as well as with an observation that a top plateau geodetic point proved to be unstable at that time.

From the point of view of long-term effects, the observations (Fig. 5) read generally permanent downslope movement in all the three co-ordinates, along with downslope angular deviations of the high step (Fig. 6), and also temperature effects. It is difficult to discern which one of the present processes is to be seen as most effective. However, displacements and deflection can be related generally to the same process of downslope movements.

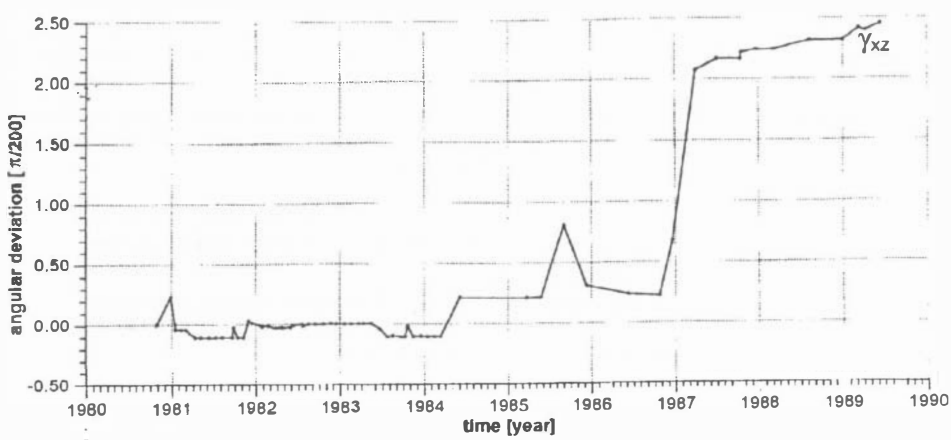

FIG. 6. Diagram of angular deviations between the walls of the upper scarp of the Aladjamanastir – Zlatni Piasaci landslide deformation between 1981 and 1990.
$+\gamma_{xz}$ – downslope rotation of the uppermost step; years given at the end of the time intervals

As to angular deviations or block rotation monitoring (Fig. 6), two extremes were observed, notably those of 1986, which finally appeared as a reversible turn, and that of 1987/88, which appeared to be irreversible. Those do not coincide with any special displacements observed at that time (Fig. 5), yet they might be invoked by earthquakes, which did occur at that time (Strašica – W of the locality, December 1986, or any other of weaker local earthquakes). An earthquake can obviously induce slow vibration movement of the high rock step which then will set to either positive or negative extremal deflection, as that of December 1986 coincident with Strašica earthquake, which appeared as negative, i.e. opposite to downslope.

Detailed inspection of Figs 5 and 6 will support a view that it is creep that is to be observed as the main mechanical process in clayey beds inducing movements towards the sea. Such movements are combined with downslope block deflections. Thus, the upper zone of the slope where observations proceeded, can be defined as a block–type deformation. There are some irregularities here which contrast to a model situation of Taukliman Black Sea coastal block–type deformation described in an earlier paper (Košťák and Avramova-Tacheva, 1981). The said irregularities are possibly due to a serious internal rock fracturing, and to local earthquakes. Some observed are: Vrancea 23.1.1984; 31.8.1986; 30. and 31.5.1990; Strašica 7. 12.1986. Resulting effects are seen in reversal displacements, variable orientation and rate, explicable by local acceleration of creep combined with sudden block deflections. There were some supplementary observations, like that after Strašica earthquake which reported separations of individual rock blocks from the plateau and from the rock step, rotation of several boulders in the scarp, and partial disintegration of rock walls with traces of grinding between blocks.

If a deeper attempt for detailed analysis made, temperature effects could be possibly found (Gasharov and Avramova-Tacheva, 1976). However, necessary parameters in the vicinity of the observation point are not known.

3. PROGNOSIS

A supplementary analysis of results has been made (Dobrev and Avramova-Tacheva, 1997). A trend analysis supports the presence of a well expressed trend in movements and intensive influence of temperature. The analysis is going to increase significance of results in periods of lower registration frequency or disconnection, and provides a certain chance to make prognosis for a near future. The prognosis concerns development of the slope deformations of block–type.

Persistent creep deformation is to be expected for a relatively long period of time. The length of this period depends on rheological properties of clayey and clayey–marly sediments found under the limestone. However, the properties are not defined, therefore the prognosis cannot go too far. Besides, it is possible to expect transitory periods of creep rate increase, as well as those of decrease. At the end of the extended present period, there should come to a phase of acceleration, after a limit shear deformation will be reached as a limit stage which mark transition to a new phase. The phase will turn to a slipping shear plane formation along the creep zone, together with cracking in the marginal zone of the plateau, and the separated step sinking into the sliding mass, then joining the landslide body of the primary deformation, which could be described as of a blockage–consistent type (after typification of Avramova-Tacheva and Voutkov, 1994). Further on, a new sliding cycle of the block–type deformation will develop in the marginal zone of the plateau, characteristic of separation of a next new marginal step form the plateau (c.f. Fig. 7).

In near future, there is little danger of a large catastrophic deformation that would involve a larger part of the coastal slope here, unless an unexpected and

FIG. 7. The crack wall above the uppermost step of the Aladja-manastir – Zlatni Piasaci landslide. A typical example of the last stage of creep movements in a deformation described as of the blockage–consistent type – a shear plane propagating to the surface results in tensile crack formation and new step subsidence. Photo by B.Košťák

impressive factor will come into effect. Such a factor may appear in a strong local earthquake within a close epicentral area.

Regarding the reality of recent landslides that occurred in this area during the springtime of 1997 it is necessary to accept preventive as well as stabilization measures here. In that, there is a need to launch a program for complex monitoring of the coastal slope in this area which would cover the slope from the foot to the upper edge of the plateau and allow to select endangered places. Then stabilization remedy measures are to be designed and implemented.

Acknowledgements

The study has been sponsored by the Bulgarian Ministry of Education and Sciences in a grant No. NZ–635/96, and Grant Agency of the Czech Republic, Grants No 205/94/1769 and 205/97/0526 which is fully acknowledged. During the years of the field research into the Black Sea coast deformations a successful co–operation was carried out thanks to joint efforts of scientific staffs of the Geological Institute of the Bulgarian Academy of Sciences in Sofia, and the Institute of Rock Structure and Mechanics of the Academy of Sciences of the Czech Republic in Prague. Efforts of all both staff members in this research are very appreciated.

REFERENCES

Avramova-Tacheva, E. and Voutkov, V.: 1974, On the typification on landsliding phenomena, *Bulletin of the Geol. Inst. BAS, Series Eng. Geol. and Hydrogeol.* **23**, 133–147. (in Bulgarian)

Gasharov, S. and Avramova-Tacheva, E.: 1976, On the effect of temperature fluctuations of measuring the velocity of block movements, *Engineering Geology and Hydrogeology* **5**, 34–44. (in Bulgarian)

Dobrev, N. and Avramova-Tacheva, E.: 1997, Analysis and prognostication of monitored rock deformations, *Proc. "Engineering Geology and the Environment"*, Greek Nat. Group IAEG, Athens, 23–27 June 1997, 613–618, Balkema, Rotterdam.

Evstatiev, D., Frangov, G. and Varbanov, R.: 1997, Landslide activation along the Northern Black Sea coast – causes, consequences and lessons, *Journal of the Bulgarian Academy of Sciences* **6**, in print. (in Bulgarian)

Iliev, I. and Tzvetkov, S.: 1971, Landslides south from the village of Kranevo, *Stroitelstvo* **12**, 19–21, Sofia. (in Bulgarian)

Kamenov, B. and Demirev, A.: 1965, Sliding phenomena on the Black Sea coast between the towns of Varna and Kavarna, *Proc. VIIth Congress CBGA*, part V, 91–95, Sofia.

Košťák, B.: 1991, Combined indicator using moiré technique, *Proc. 3rd Int. Symp. "Field Measurements in Geomechanics"*, 53–60, Oslo.

Košťák, B. and Avramova-Tacheva, E.: (1981), Propagation of coastal slope deformations at Taukliman, Bulgaria, *Bull. IAEG* **23**, 67–73, Krefeld.

Pašek, J. and Košťák, B.: 1977, Block–type slope movements, *Rozpravy Čs.Ak.Věd* **87**, 3, 58p., Academia, Prague. (in Czech, English Summary)

Pašek, J. and Rybář, J.: 1969, Analysis of the slope movements on the Black Sea coast in Bulgaria, *Časopis pro mineralogii a geologii* **14**, 3–4/1969, 273–284 + Tab.I–IV, Prague. (in Czech, English Summary)

Stoikov, D.: 1971, Physico–mechanical properties of the clayey soils in the region of sea–side resorts near the town of Varna, *Stroitelstvo* **10**, 17–21, Sofia. (in Bulgarian)

Stoikov, D. and Evstatiev, D.: 1983, The landslide in the Panorama resort zone near Varna, *Engineering Geology and Hydrogeology* **13**, 20–32. (in Bulgarian)

Varbanov, R., Frangov, G. and Evstatiev, D.: 1997, New destructive landslides northward from the town of Varna, *Minno Delo i Geologia Journal* **5**, 6–12. (in Bulgarian)