DOI: https://doi.org/10.5592/CO/EUROENGEO.2024.240

SEISMIC ZONE "KRESNA" IN SOUTH-WESTERN BULGARIA AND THE INFRASTRUCTURE PROJECTS IN THE AREA

KIRIL ALEXANDROV ANGUELOV[1], DOBRIN DENEV DENEV[2], KIRIL KIRILOV ANGUELOV[3]

[1] *Todor Kableshkov University of Transport, angelov@bondys.bg*

[2] *University of Architecture, Civil Engineering and Geodesy, dobrin_denev@yahoo.com*

[3] *University of Mining and Geology St. Ivan Rilski, office@bondys.bg*

Abstract

On April 4th, 1904, an earthquake with a magnitude of 7.9 on the Richter scale occurred on the territory of the Kresna Gorge (southwestern Bulgaria). The earthquake is a consequence of activity along a fault (Krupnishki Fault), which crosses almost perpendicularly the meridional Struma fault zone along which the Struma River flows. As a result of the earthquake, several deep cracks were formed, and the waters of the Struma River were completely drained in a few hours. At the moment, designers and builders stands the significant goal for the construction of the last highway section of the Struma Highway. The highway is built almost entirely between Sofia and the border with Greece ("Kulata – Promachonas" customs). Considering the complex seismic situation, the question about the best and safest construction remains the part of the highway near the Kresna Gorge. There are several options for the construction of this section - with a long tunnel, with short tunnels and bridges or with the construction of one-way high-speed road sections in both directions. In the following report, we will make a comparative assessment of the proposed options.

Key words

Earthquake, Struma Highway, Seismic risk, Bridge, Tunnel, Safety assessment

1. Introduction

The Struma motorway is one of the most important motorways in the Republic of Bulgaria, and it has almost entirely been constructed (from Sofia city to Kulata-Promahon), except a section of 15km (from Simitli town to Kresna town), which goes through a very complicated geomorphological structure, called the Kresna gorge (*Figure 1*). Three alternatives have been designed for going through that section: Alternative One – tunnel 15 km long, Alternative Two – speed road near the Struma River (short tunnels, bridges and open road sections); Alternative Three – eastern alternative – along the higher sections of the eastern slope of the gorge. Engineering-geological investigations have been carried out for all the above alternatives to meet the requirements of the “concept design” phase and have an environmental impact assessment. The selection of the best, economically most efficient alternative, however, proved to be very difficult.

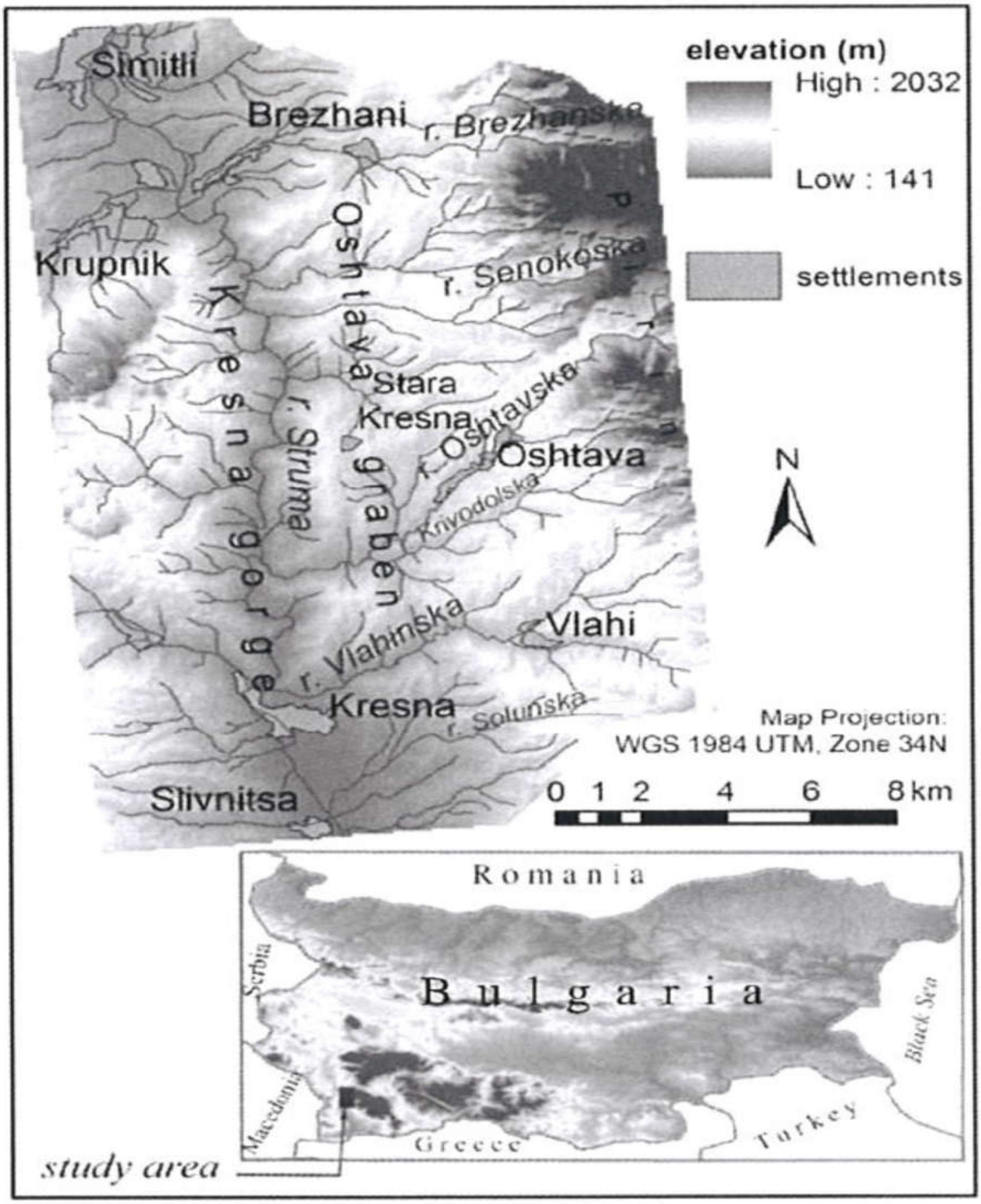

Figure 1. Location of study area in Bulgaria.

1.1 Geological conditions

The investigated section of the "Struma-Lot 3.2" motorway goes through the Kraishte structural zone, through its southern block, in particular the Belasitsa-Ograzhden block.

The rocks of the Ograzhden group compose almost entirely the Ograzhden block and the Lisiiski horst of the Vlahina block. These are amphibolites, mica gneisses and migmatites. The slopes, situated northward from the town of Kresna, are composed of the rocks of the so-called "gneiss-migmatite complex" (Marinova, Zagorchev, 1993). They are composed of biotite and two-mica gneisses and migmatites, noted by Zagorchev (1984) as the "Maleshevska" Group. It is characterized by complicated tectonic structure – almost isoclinal folds and development of zones of shearing.

After km 394+800 the route of the motorway goes into the zone of the Struma (Sandanski) graben. The graben is filled with Neogene, Plio-Pleistocene and Quaternary sediments. The lithostratigraphy of the Neogene sediments, filling the graben within the scope of the freeway, includes the Sandanski Formation and Kalimanska Formation. The Sandanski Formation outcrops as a stripe of different width between Kresna town and Gradeshnitsa village. The sediments of the Kalimanska Formation occur above it. The Kalimanska Formation is composed of sandy, alleurolites, sandy clays, irregularly alternating one with another or laterally adhering.

The Kalimanska Formation is widely distributed, according to Kojumdjgieva et al. (1982). It outcrops eastward from the valley of the Struma River. Monogenic marble breccia, composing the Ilinden Member, occurs at the Gorna Gradeshnitsa. Conglomerates in alternation with sands of 4-5 m thickness (lower sandy-conglomerate formation) follow upward in the section of the Kaliman Formation, northward from the Gorna Gradeshnitsa village. The upper conglomerate-sandy formation is also composed of breccia-conglomerates, with sandy-gravel filling. The age of the Kaliman Formation has been defined as Pondok (Kojumdjgieva et al. 1982). (*Figure 2*)

Quaternary sediments are characterized by different lithogenetic types. However, the alluvial and delluvial-prolluvial sediments are prevailing. The delluvial-prolluvial sediments (dpQ) include blocks, boulders, clays, sands, gravel) and they are observed at many locations along the route.

1.2 Tectonic structures and faults, crossing the Lot 3.2 of the “Struma” motorway

The tectonic conditions of the investigated section of the motorway are defined as a complicated geotectonic complex on the territory of the Republic of Bulgaria. The route of the highway (including tunnels) either crosses or goes in parallel, but very close to multiple faults, which refer to two groups, according to their direction: Kraishtidna group (150 -1700) and Tvardishka group (40-600).

Prevailing are the faults of the first group (Kraishtidna group), which belong to a fault bunch of nearly 5 km width, noted as the Struma fault zone. The route of Lot 3.2 of the Struma Motorway (including the tunnels at the beginning of the gorge) goes in parallel to that fault zone, and at some locations, it crosses some of the composing fault structures (*Figure 2*). In regional aspect, formation of the grabens along the river and its general direction (1700) is pre-defined by that fault zone.

The second fault group defines the crosswise fragmentation of the section. That group is most clearly shown in the Krupnishka fault zone, where the Oranovo-Simitli graben is formed (*Figure 2*)

In the section composed of the metamorphites of the gneiss-migmatite complex, the main fault is the Yavorovski fault. It is presented by a group of faults following a NW-SE direction (120-1350) and dipping predominantly to SW. It is most properly shown on the south bank of the Struma River. The fault has indicated the southern boundary of the Kresna horst, Vrablianski and Milev (1973) and it has defined the rate of vertical rise of +3.4mm/year at Yavor, and then at the Kresna village, the rate sharply falls down to +1.4mm/year.

1.3 Estimate of the seismic risk

The seismic risk is defined by the endogenous processes and phenomena in the investigated region; earthquakes and slow tectonic movements refer to the above processes and phenomena.

The first estimates of the magnitude of the bigger earthquake of the two earthquakes, which took place on 4th April 1904 are as follows: Ms=7,5 (Gutemberg and Rickter, 1954), Ms= 7,85 (Christoskov and Grigorova, 1968) and M= 7,75 (Karnik, 1969). Lower estimates were made later, presented by Abe and Noguchi (1983), who estimated it as Ms = 7,1.

Different authors came to similar estimates for the magnitudes of both the earthquakes on 4th April 1904. (for example Pacheco and Sykes, 1992; Ambraseys, 2001, Dineva et al., 2002; Papazachos and Papazachos, 2002; Meyer et al., 2002, 2007; Pavlides and Caputo, 2004; Ganas et al., 2005; Bayliss and Burton, 2007), which were much lower that the estimates of the 1950s and the 1960s.

We will not comment on those estimates of our colleagues seismologists. We would like to mention that we do not have similar data. According to Eurocode 8, the coefficient of seismicity for that region is Re= 0,32. That coefficient is extremely important for sizing all the structures and slopes.

Three (3) alternatives for the route of Struma Motorway Lot 3.2 were proposed under the above complicated geomorphological, engineering-geological and seismological conditions.

2. Overview of the alternatives

2.1 Alternative One

This alternative presents a tunnel, 15 km long, going through two highly active seismic zones (Krupnishka zone, M 7,9 – the earthquake in 1904 and the Yavorovska zone, with an expected magnitude 6,2. Faults that are almost perpendicular and/or skew to the tunnel axis as well as the very fracturing and weathering of the rocks were the reasons for rejecting that alternative at a large forum, organized by the Bulgarian Construction Chamber some time ago. Nevertheless that, it was approved in the previous year by environmental organizations (non-profit organizations).

An important factor for rejecting that alternative was the radioactivity of the rocks as well as the potential hazard of accidents inside the tunnel. Evacuation and rescue of people in such unfavourable cases inside the tunnel would be almost impossible, unless there are evacuation openings at every 100-200 m. However, the seismicity of the area around Kresna is a decisive factor. Strong earthquakes (which have already taken place in the Kresna gorge) may result in faults that will cause failure and (vertical and lateral) displacement of the tunnel tube. That will make the tunnel unusable – without an option for future repair. A similar example of an abandoned tunnel after an earthquake with a magnitude M=7,5 is the tunnel at Shenzhen, China (*Figure 3*) (*2008 Sichuan earthquake Wikipedia*). It is possible that the factors mentioned above may be the reasons for drivers to start avoiding passing through the long tunnel, which will make the investment unnecessary. With respect to the environment, the tunnel alternative is also arbitrary – the tunnel will bring a change in the hydrodynamics of groundwater flow. For example, drying of streams or changing their course and appearance in the tunnel. An appropriate location for depositing immense excavated rock masses will be needed – with the accompanying factor that some of the rock masses are radioactive. The tunnel alternative needs continuous forced ventilation and artificial lighting, which may be a decisive financial argument for not accepting it. The tunnel alternative also involves a long period of construction, the use of expensive equipment for excavation of the tunnel and complicated operation later. Inside the tunnel, traffic speed is reduced to 50-70 km/h – therefore, the road will not be a speed road – another fact that makes the investment inadvisable. The long tunnel will evidently be avoided by drivers, who have even a slight form of claustrofoby, eye-seeing difficulties and orientation, and other reasons, as well. The above means that the old road through the gorge will continue to be used with all its unfavourable consequences (such as the ones recently observed).

According to preliminary estimates (reduced estimates, in our opinion), the value of that alternative will account to 0,6 – 0,7 billion EUR. We do not know whether operational cost estimates have been prepared, but they will not be low (*Figure 2)*.

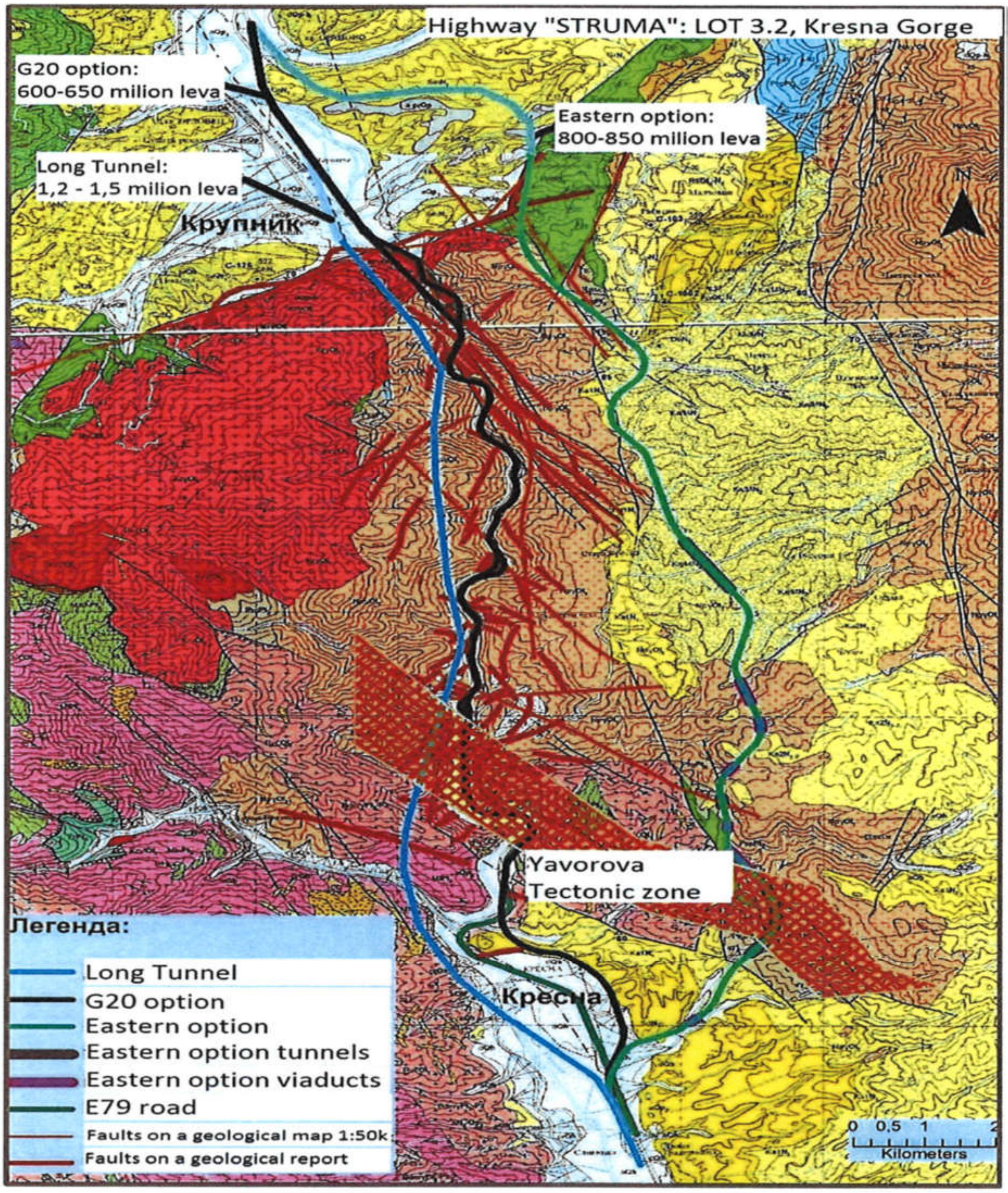

Figure 2 Priced alternatives for the Lot 3.2 of the Struma Motorway-placed on geological map

TO CLARIFY: Prices in EUR G20 option – 300-350 million EUR; Long tunnel – 0.6 -0.7 billions EUR; Eastern option – 400-425 million EUR

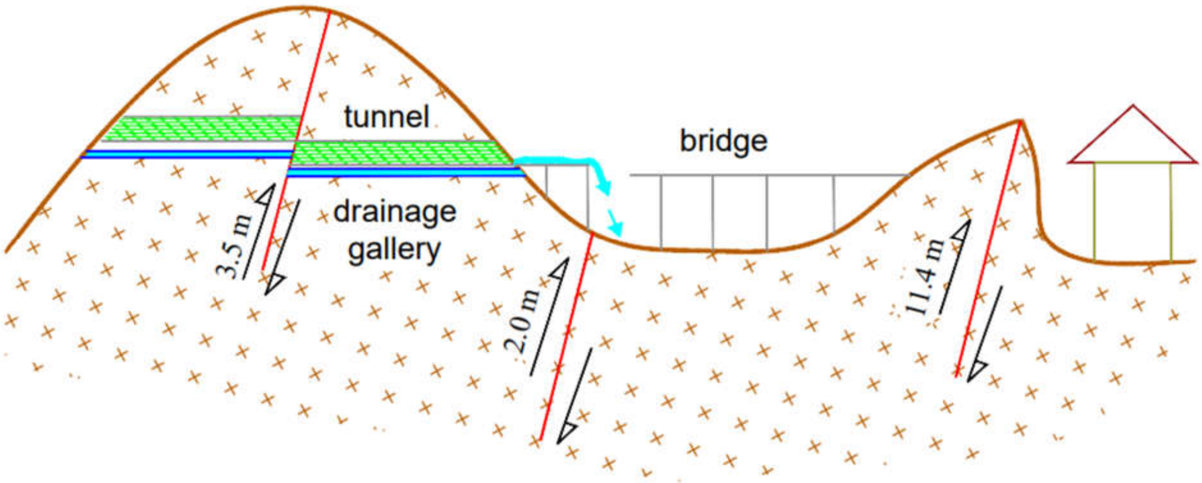

Figure 15 Abandoned tunnel after an earthquake of magnitude 8,0 at Shenzhen, China .Schematic cross-section of displacement during the earthquake in 2008

2.2 Alternative Two

This alternative presents an option to preserve the existing road through the gorge in the direction Sofia – Thessaloniki and construction of a second carriageway along the so-called "eastern alternative" at the slopes of the Pirin mountain – for the direction Thessaloniki – Sofia. Regarding that alternative, from an altitude of 350 m at Krupnik village, the vertical alignment goes up to 750-800 m altitude and then falls steeply down to the Dolna Gradeshnitsa village (elevation nearly 175 m). Therefore, the alignment involves long and critical gradients, which are not allowed, according to the standards for a high-speed road (gradient of 5.2%) between Krupnik and Stara Kresna, and between Stara Kresna and Dolna Gradeshnitsa (*Figure 4*).

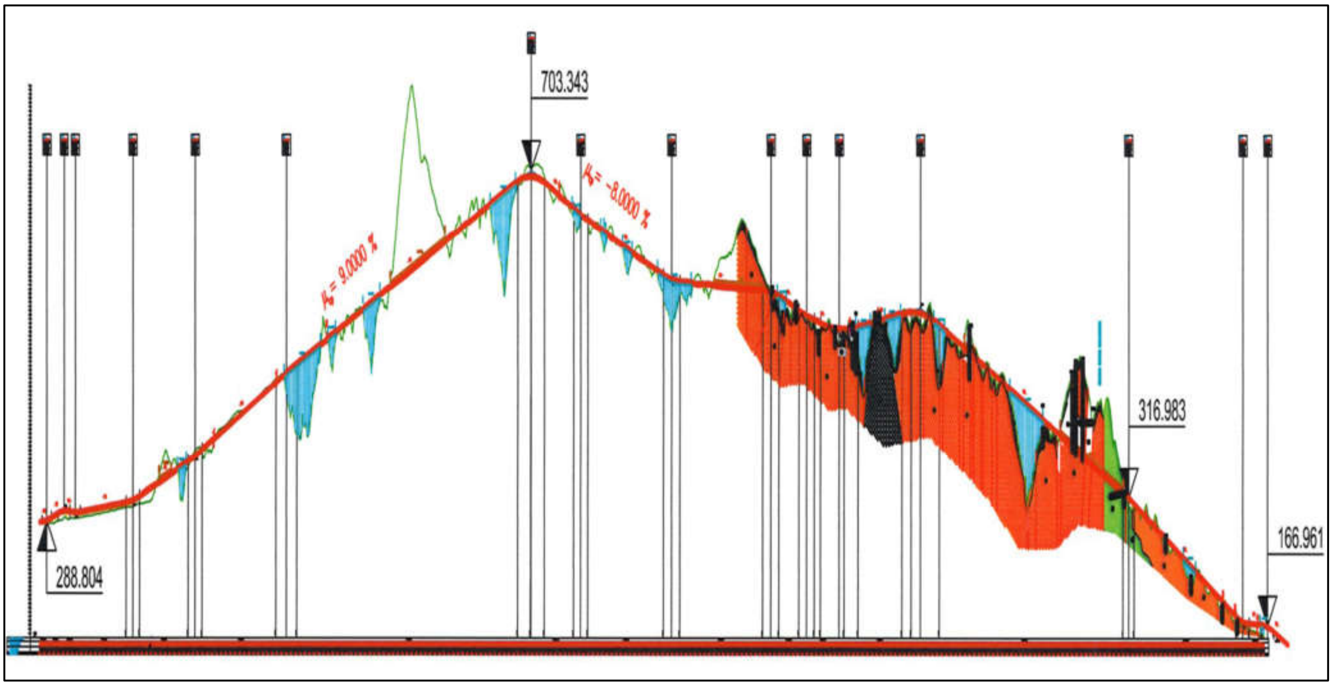

Figure 4 Summary profile of an eastern variant LOT 3.2 – AM Struma, Mx= 5000, My= 1000

The above means that a high probability of accidents during the exploitation of the road section will be incorporated into the phase of the design. In addition, this alternative involves complicated construction works within unfavorable geological conditions (the foundations would be placed in highly weathered and fractured rock varieties, where foundation of structures and arching of tunnels will be a problem). This will result in an even more complicated maintenance and repair of the system “bridge-tunnel, bridge-tunnel” in extremely unfavorable engineering-geological and climatic conditions. In addition to the above circumstances is the existence of the two seismic zones (Krupnishka zone and Yavorovska zone). It will require complicated and expensive winter maintenance – due to the high level of weathering and fracturing of the rocks and high temperature amplitude within the road section. A large bridge structure is also presented in the section – a bridge structure with the largest span in Bulgaria. The value of that alternative has been estimated at 490 million EUR.

A substantial disadvantage of that alternative is the fact that environmental issues will not recover – traffic in the gorge will continue, even with a reduced intensity, however with time it will again become the same as nowadays.

There is an additional option – two highways along the same route (i.e. achieving a full highway width), and completely liberate the Kresmna gorge from transit traffic. As far as we know, such a technical decision has not been investigated yet. However, it is evident that it will be much more expensive than the already designed one - with one carriageway.

2.3 Alternative Three

That alternative present upgrading of the existing road along the Struma River and the section immediately close to it, i.e. the construction of a speed road with four active lanes is envisaged, short bridges and seismic-proof bridges. This alternative is technically possible for construction. All the requirements of environmental scientists shall be strictly followed, namely preserving the unique landscape of the Kresna gorge, preserving the protected vegetation and animal species (their habitats, migration paths etc.) and preserving the “Tisata” natural reserve. Regarding that alternative, the highway may pass through environmentally sensitive zones with road widths, longitudinal gradients and radians of curves etc. The road gradients are minimal, there is no danger of frosting of pavement and drainage systems in winter etc. The construction of bridge structures at two levels is advisable. The alternative is defined as comparatively less expensive, nevertheless the special nature-protection measures, which will be applied in the design phase, in the construction and in the operation. Speed in the gorge may be reduced to 100 km/h, and zones for short-time recreation and platforms for nature observation may be segregated in the section between Krupnik and Kresna. The estimated value of the alternative is nearly 300 million EUR.

3. Conclusion

Based on the analysis of the engineering geological condition and seismological factors, we propose the alternative three to be selected for financing – an alternative that goes along the Struma River valley, the most effective one from a feasibility point of view, and in addition, its construction may improve the environmental conditions in the area.

An almost completely finalized technical design is available, so probably a more detailed Environmental Impact Assessment will be needed (will be amended, respectively) to indicate the requirements of environmental scientists regarding designs for execution.

References

Abe, K. and Noguchi, S. (1983). Revision of magnitudes of large shallow earthquakes, 1897- 1912, *Physics of the Earth and planetary intenors*, 33(1):1—11.

Ambraseys, N. N. (2001). The Kresna earthquake of 1904 in Bulgaria. *Annals of Geophysics,* 44(1):95-117.

Bayliss, T. J. and Burton, P. W. (2007). A new earthquake catalogue for Bulgaria and the conterminous Balkan high hazard region. *Natural Hazards and Earth System Science,* 7(3):345-359. https://hal.archives-ouvertes.fr/hal-00299430/.

Christoskov, L. and Grigorova, E. (1968). Energetic and space-time characteristics of the destructive earthquakes in Bulgaria after 1900. *Bulletin Institute of Geophysics, Sofia,* 12:79-107.

Dineva, S., Batllo, J., Mihaylov, D., and Van Eck, T. (2002). Source parameters of four strong earthquakes in Bulgaria and Portugal at the beginning of the 20th century. *Journal of seismology,* 6(1):99—123.

Gutenberg, B. and Richter, C. (1954). *Seismicity of the Earth and Associated Phenomena.* Princeton University Press. 310 p.

Meyer, B., Armijo, R., and Dimitrov, D. (2002). Active faulting in SW Bulgaria: possible surface rupture of the 1904 Struma earthquakes. *Geophysical Journal International,* 148(2):246-255.

Kojumdjieva, E. I. Nikolov, P. Nedjalkov, A. Busev. Stratigraphy of the Neogene in Sandanski Graben,12.31982.62-81

Milovanov, I. Petrov, V. Valev, A. Marinova, I. Klimov, D. Sinyovsky, M. Ichev, S. Pristavova, E. Ilieva, B. Banushev. *Explanatory note to the Geological Map of the Republic of Bulgaria in scale 1:50 000. Map sheet K- 34-70-G (Vaksevo)* Consortium Geocomplex, 2009.

Milovanov, I. Petrov, V. Valev, A. Marinova, I. Klimov, D. Sinyovsky, M. Ichev, S. Pristavova, E. Ilieva, B. Banushev. *Explanatory note to the Geological Map of the Republic of Bulgaria in scale 1:50 000. Map sheet K-34-82-G (Berovo) and K-34-83-V (Kresna).* Consortium Geocomplex, 2009.

Pacheco, J. F. and Sykes, L. R. (1992). Seismic moment catalog of large shallow earthquakes, 1900 to 1989. *Bulletin of the Seismological Society of America,* 82(3):1306-1349.

Papadimitriou, E., Karakostas, V., TYanos, M., Ranguelov, B., and Gospodinov, D. (2007). Static stress changes associated with normal faulting earthquakes in the South Balkan area. *International Journal of Earth Sciences*, 96(5):911-924.

Pavlides, S. and Caputo, R. (2004). Magnitude versus faults' surface parameters: quantitative relationships from the aegcan region. Tectonophysics, 380(3): 159-188.

Zagorchev, I. Neogene fluviolacustrine systems in the northern PeriAegian Region – Geolocica Balcanica, 32.2-4:2002

2008 Sichuan earthquake (2024) Wikipedia. Available at: https://en.wikipedia.org/wiki/2008_Sichuan_earthquake (Accessed: 31 July 2024).