RESEARCH REGARDING THE STABILITY OF A1 MOTORWAY IN THE LUGOJ-DEVA SECTION, LOT 2 KM: 27+620÷47+090

*Ileana PASCU**

Abstract: *This paper is part of a larger study and lays the foundation of my doctoral thesis. It presents the research carried out on the area where the motorway section will be founded and on the grounds included in the construction of this motorway. In order to determine the stability of the motorway, many laboratory tests had to be carried out, which then allowed to perform the stability calculations. All the results are based on modern methods of analysis and calculation that have been correlated with the standards required for such studies.*
Cuvinte cheie: motorway, geo-mechanical features, base land, grounds, stability

1. Introduction

The Deva-Lugoj motorway section is part of the A1 Motorway: Bucharest - Piteşti - Curtea de Argeş - Sibiu - Deva - Timişoara - Arad - Nădlac.

At present, it is partially carried out (Bucharest - Pitesti - 100%, Piteşti - Sibiu - in the process of bidding, Deva - Timişoara - partially carried out, Arad - Nădlac – entirely carried out).

The Romanian National Road Infrastructure Company, following the public tender procedures, has designated the Design and Execution of the Lot2 Motorway, km 27+620 - km 56+220, to an international concern, based on technical and economic criteria.

The length of the studied section represents 19.47 km, containing earthworks, art works, hydrological works of riverbed improvement, water collection and drainage, etc. For a good collaboration and execution control, the length was divided into the following sectors: A (km 27+620 ÷ km 32+330); B (km 32+330 ÷ km 37+681); C (km 37+681 ÷ km 42+695) and D (km 42+695 ÷ km 47+090) (fig.1).

Fig. 1. **Route of Lugoj-Deva motorway section, Lot 2**

2. General characteristics of the analysed section

The route of Deva – Lugoj motorway, Lot 2 crosses Becheiului Plain on the territory of Timiș County and Fragului Hills at the border between Timiș and Hunedoara counties and passes through the administrative territories of the following inhabited areas: Traian Vuia, Dumbrava, Făget, Margina (Nemeşti, Zorani), Costeiul de Sus and Coșevița.

On a *horizontal plane*, *the route* has the following features:

- The classification according to technical class I (in accordance to the Technical Norms regarding the establishment of the technical road class, approved by Order no. 46/1998 issued by the Ministry of Transport);
- The design speed for a class I technical road in the lowland area is 120 km/h and in the hill area is 100 km/h;
- The connection radii range from 720 m to 17,000m, which ensures the design speed of 120 km/h.

* *Ph.D stud.eng. University of Petroșani*

On a *vertical plan, the route* has the next features:
- The connection radii are in accordance with the normative PD 162-2002 *Normative on the design of extra-urban motorways* and TEM rules for motorways, ensuring a design speed of 120 km/h;
- On the whole route, the situation of declivities is as follows: (0-1) ‰ (87.06%) and (1-3) ‰ (12.94%).

Throughout the whole route analysed, there are flooded and marshy areas, where, during rainy seasons, floods can affect large areas on the surface, due to the low permeability of surface horizons.

Along the route, in all the sectors covered by this study, several types of works are executed, such as earthworks (excavations and embankments), art works (culverts, boxed structures, passages and bridges) and hydro-technical works (corrections and recalibrations of watercourses, consolidations and protections of the watercourses' banks, the creation of a protection for the gabions placed at the base of the abutments of the bridges over the water courses, and discharge works – collection of meteoric waters: open collector channels, gutters, discharge channels, drainage channels, catch pits with mineral oil separators and petroleum products and a tank).

The road structure considered has been dimensioned and verified under the freeze-thaw phenomenon, according to STAS 1709/1 and STAS 1709/2.

At present, the studied motorway section is executed in a proportion of 95%.

3. The geo-mechanical characteristics of the base terrain and of the soils used for the motorway construction

3.1. Geo-mechanical characteristics of the base terrain

In the present study, both field and laboratory geotechnical investigations have been carried out.

3.1.1. Geotechnical field investigations

➢ In sector A, there were executed:
- 18 drillings with depths between 6.00m and 25.00m,
- 2 dynamic cone penetrations made with super heavy dynamic penetrometer (DPSH -Type B)
- 4 dynamic cone penetrations made with light dynamic penetrometer (PDU)
- for alignment, 5 drillings (FA01 - FA05) with depths between 10.00 – 15.00 m
- for structures 3 drillings (FS01 - FS03) with depths between 15.00 – 20.0 m

➢ In sector B, there were executed:
- 15 drillings with depths between 6.00m and 25.00m
- 8 dynamic cone penetrations made with super heavy dynamic penetrometer (DPSH - Type B)
- for alignment: 6 drillings (FA06 - FA11) with depths between 10.00 – 20.00 m
- for structures: 3 drillings (FS04 - FS06) with depths of 20.00 m and, respectively, 35.00 m

➢ In sector C, there were executed:
- 21 drillings with depths between 6.00m and 25.00m
- 5 dynamic cone penetrations made with super heavy dynamic penetrometer (DPSH -Type B)
- for alignment: 5 drillings (FA12 - FA16) with depths between 10.00 – 20.00 m
- for structures: 6 drillings (FS07 - FS12) with depths of 15.00 m and 35.00 m, respectively

➢ In sector D, there were executed:
- 23 drillings with depths between 6.00m and 25.00m
- 4 dynamic cone penetrations with super heavy dynamic penetrometer (DPSH-Type B)
- for alignment: 8 drillings (FA17 - FA24) with depths between 10.00 - 20.00 m
- for structures: 8 drillings (FS04 - FS06) with depths between 10.00 – 35.00 m

Continuous samples have been taken from the drillings, alternately from 2 to 2 meters and/or at the change of layer, undisturbed soil samples and cores that were analysed in the laboratory according to the standards in force. If a water infiltration or hydrostatic level has been encountered during the drilling, this has been mentioned in the drilling report.

3.1.2. Laboratory tests

Laboratory analyses were carried out in accordance with the standards in force on disturbed (T), undisturbed (N) and core (C) samples. The laboratory analyses performed consisted in determining the following geo-mechanical characteristics: natural humidity, natural density, plasticity limit and consistency index, granulometric distribution, compressibility and consolidation in endometer, in natural and flooded samples, shear resistance by direct shear (CU, CD), uniaxial compression, free swelling, humus content, carbonate content, aggressive water analysis on concrete and metals.

3.1.3. Interpretation of results

Based on the results of the laboratory analyses and geotechnical investigations, the stratification encountered along Lugoj - Deva motorway, Lot 2 can be divided into horizons with similar physico-mechanical properties. The stratification was divided (lithological profile) as:

➢ ***Sector A***:
✓ Covering Formations:
Alluvial deposits
A1 horizon - consisting of cohesive soils: clays, dusty clays and dusty sandy clays.

A2 horizon - consisting of poorly cohesive soils: sandy dusts, sandy clayey dusts, clayey sands and dusty sands.

Diluvia / eluvia deposits

B1 horizon - consisting of cohesive soils: fat clays, clays, dusty clays and sandy clays.

B3 horizon - consisting of non-cohesive soils: gravels with sands, dusty sands with gravels, clayey sands with gravels.

- ✓ Base Formations :

C1 horizon - composed of cohesive soils: fat clays, clays and dusty clays with loamy appearance.

C2 horizon - composed of poorly cohesive soils: sandy dusts, dusty sands and rarely clayey dusts and sands.

- ***Sector B*:**
  - ✓ Covering Formations:

Alluvial deposits

A1 horizon - consisting of cohesive soils: fat clays, clays and dusty clays.

A2 horizon - consisting of poorly cohesive soils: sandy dusts, clayey dusts, dusts and dusty sands.

A3 horizon – consisting of non-cohesive soils: gravels and boulders with sandy dusts.

Diluvia / eluvia deposits

B1 horizon - consisting of cohesive soils: fat clays, clays, dusty clays and sandy clays.

B2 horizon - consisting up of poorly cohesive soils: sandy dusts, clayey sandy dusts, clayey dusts, dusty sands and clayey sands.

B3 horizon - consisting of non-cohesive soils: sands, gravels with sands, gravels with sands or dusty sands or clayey sands, dusty sands with gravels.

- ✓ Base Formations:

C1 horizon - composed of cohesive soils: fat clays, clays, dusty clays and sandy clays.

C2 horizon - composed of poorly cohesive soils: sandy dusts and dusty sands.

C3 horizon - is composed by non-cohesive soils: sands.

- ***Sector C*:**
  - ✓ Covering Formations:

Alluvial deposits

A1 horizon - consisting of cohesive soils: fat clays, clays and dusty clays.

A2 horizon - consisting of poorly cohesive soils: clayey dusts, sandy clayey dusts, sandy dusts, dusty sands and clayey sands.

A3 horizon – consisting of non-cohesive soils: sands, sands with gravels, gravels with sands, gravels with dusty sands.

Diluvia / eluvia deposits

B1 horizon - consisting of cohesive soils: fat clays, clays, dusty clays and rarely sandy clays.

B2 horizon - consisting up of poorly cohesive soils: sandy dusts, clayey sands and dusty sands.

B3 horizon - consisting of non-cohesive soils: sands, sands with gravels, gravels with sands and gravels with dusty sands.

- ✓ Base Formations:

C1 horizon - composed of cohesive soils: fat clays, clays, dusty clays.

C2 horizon - composed of poorly cohesive soils: clayey dusts, sandy dusts and dusty sands.

C3 horizon - is composed by non-cohesive soils: sands.

C4 horizon - is composed by loamy cohesive soils: fat clays, clays, dusty clays.

- ***Sector D*:**
  - ✓ Covering Formations:

Alluvial deposits

A1 horizon - consisting of cohesive soils: fat clays, clays, dusty clays and sandy clays.

A2 horizon - consisting of poorly cohesive soils: clayey dusts, sandy clayey dusts, sandy dusts, dusty sands and clayey sands.

A3 horizon – consisting of non-cohesive soils: sands, sands with gravels, gravels with sands, dusty sands with small gravels, gravels with dusty sand.

Diluvia / eluvia deposits

B1 horizon - consisting of cohesive soils: fat clays, clays, dusty clays and sandy clays.

B2 horizon - consisting of poorly cohesive soils: sandy dusts, clayey dusts, dusty sands and clayey sands and dust.

B3 horizon - consisting of non-cohesive soils: sands, gravels with sands and boulders.

- ✓ Base Formations:

C1 horizon - composed of cohesive soils: fat clays and clays.

C2 horizon - composed of poorly cohesive soils: sandy dusts, clayey sandy dusts, clayey dusts and dusty sands.

C3 horizon - is composed by non-cohesive soils: sands.

C4 horizon - is composed by loamy cohesive soils: fat clays, clays and dusty clays.

3.2. Geo-mechanical characteristics of the soils used in the construction

The construction of the motorway was made from local materials. The execution of an embankment involves the fulfilment of some technical conditions that take into account: the shape, size and ultimate deviation, the research of the material that is part of the embankments materialized by laboratory studies for the determination of their physical and mechanical characteristics, the establishment of the categories and types of terrains used in the execution of embankments.

In Romania, the soils used for embankment is classified into five groups (STAS 2914-88), namely coarse non-cohesive soils, medium and fine non-cohesive soils and cohesive soils.

As ***filling material*** of the embankments' body, it was used the material from the excavations required on the motorway's route. The material resulting from the excavations was classified mainly as cohesive material. As a consequence of the results obtained by the laboratory analysis (analysis of the physical-mechanical characteristics, freeze-thaw verification, internal friction angle, cohesion, etc.), they could be used for filling in the body of the motorway, meeting the normative requirements in force.

The geotechnical computation features adopted for the clayey materials for embankments are:

- Internal friction angle $\phi = 12°$
- Cohesion c = 25 kPa
- Volumetric weight $\gamma = 20$ kN/m^3

To complete the filling works, it was also necessary to provide material from borrow pits, appropriate local material.

For each type of material used in the body of the motorway, experimental polygons were executed.

The embankment of the motorway's body was executed in layers. In order to ensure a further safety of the stability of the embankments, the physical mechanical characteristics of some layers were improved by treating them with hydraulic binders.

Embankments' execution was realized in extra profile in order to achieve well compacted slopes, obtained by excavation with an inclination of 1: 1.5 (H/L).

4. Stability analysis

4.1. Establishment of calculation elements

These calculation elements aim at establishing the stability conditions (safety factors) for embankments and excavations and at determining the maximum value of embankments' consolidation (at the level of the road system and at the level of the base, at axis).

The calculation of the embankment structures involved the following steps:

- establishing the calculation values for geotechnical parameters based on the existing data, values resulting either from a statistical calculation of data grouped on homogeneous layers where the volume of information allowed this analysis, or by extrapolating data from similar sections filtered through the lens of the values recommended by standards;
- simplifying the lithology where the variations of the physical mechanical parameters were reduced and obtaining a simpler calculation in the end;
- analysing the stability using *the plan of deformation* model in the hypothesis of a perfectly plastic behaviour of the material, using the Mohr-Coulomb failure criterion;
- calculating the deformability of embankments by considering rheological phenomena.

The selection of the calculation profiles was done according to the geometry of the structures (the embankments and excavations with the highest height were chosen), to the land characteristics and the ground water level.

The basic data were the layers' description, the drilling reports, the in-situ and laboratory analyses, the monitoring of the piezometric level.

The values of the parameters in the embankments' analysis were taken as averages of the characteristics of the soils resulting from the excavations, but also taking into account their improvement due to compaction:

$\gamma = 20$kN/m^3; E = 24000kPa; $\nu = 0.35$; $\phi_k = 15°$; $c_k = 35$kPa; k = 1 x 10^{-7} cm/s.

In the embankments' stability analyses, for the parameters of the resistance to shear stress of the layers from natural land, the minimum values of laboratory results, X_{kinf}, determined on the regulation NP 122:2010, were used as characteristic values

4.2. Stability analysis

The method underlying the embankments' stability analysis is the Bishop limit equilibrium method. The calculation is automatic, using the SLOPE/W program - version 2007.

The stability analysis takes into account both the potential slip surfaces of circular shape and those of polygonal shape.

For each type of geometry of potential slip surfaces, after determining the surface with the lowest stability factor, the program runs a procedure to optimize it. Finally, a composite geometry surface can result, corresponding to the minimum stability factor, in cases when, in the natural land, there are layers with significant variations in shear stress resistance.

In order to define the potential slip surfaces of circular shape, a network of slip surfaces centres and a set of lines tangent to these are used, fig. 2.

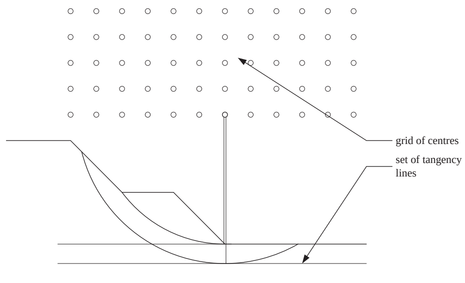

Fig. 2. **Choosing the potential slip surfaces**

There may be defined local slip surfaces for a part of the embankment or general slip surfaces for the entire cross-sectional profile studied, taking into account the presence of base rock or of some layers with poor mechanical characteristics that may influence the position of the critical slip surface.

To determine the critical slip surface (for which the safety factor to stability is minimal), all possible combinations of centres of slip surfaces and the lines tangential to them are analysed. The results are presented in the form of equal safety factor curves, the minimum safety factor corresponding to the critical slip surface being highlighted.

If the minimum safety factor value corresponds to a centre that is at the edge of the centre network, figure 3, this network will be extended until the minimum safety factor position is framed by higher safety factor curves, figure 4.

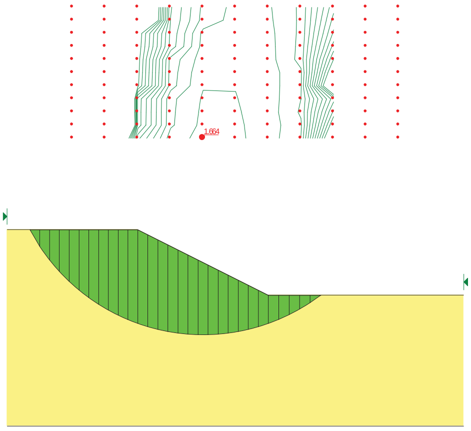

Fig.3. **Incorrectly positioned center network**

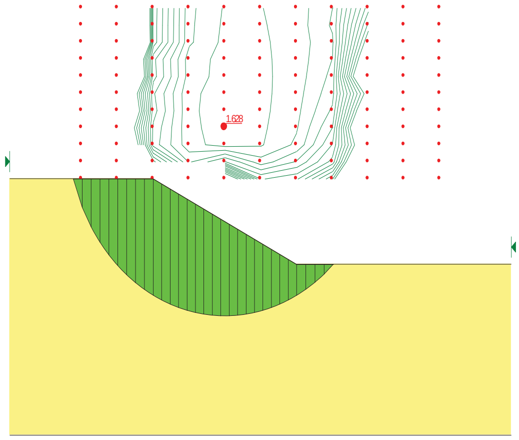

Fig.4. **Correctly positioned center network**

Polygonal surfaces are defined in the program with the help of two grids (networks). The line segment joining one point of the two grids forms the basis of the potential slip surfaces. The other two line segments, which form the edges of the surfaces, vary as inclination with an established step, having one end in the point network and the other at the intersection with the land line. In this way, polygonal surfaces are formed by three line segments. The potential slip surface, with the minimum stability factor, is correctly chosen when the ends of the middle segment (base of the surface) are not on the outline of the two points network (figs. 5 and 6).

At the end, the program has the option of optimizing the polygonal surface with the lowest stability factor, resulting in a composite geometry surface.

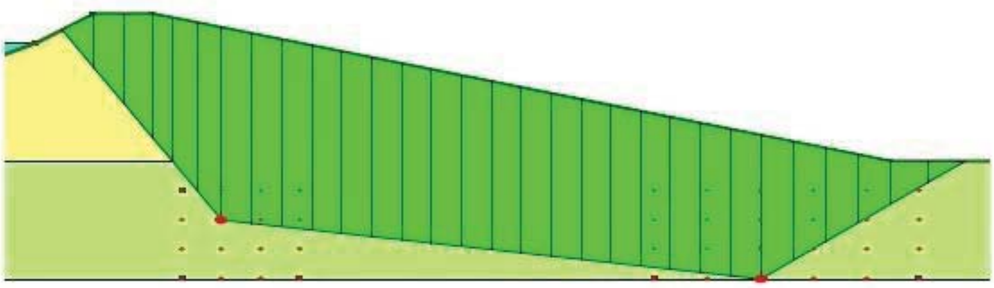

Fig. 5. **Incorrectly positioned point network**

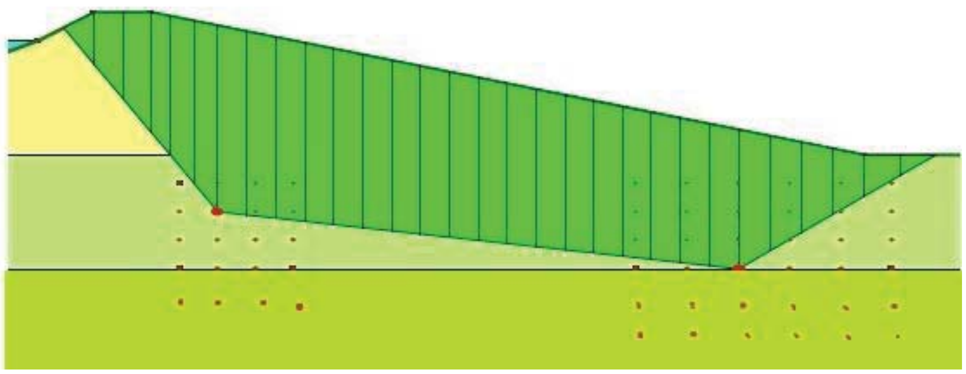

Fig.6. **Correctly positioned point network**

According to the provisions of the national annex to SR EN 1997-1/2004, in the ***static analysis***, the calculation approaches in Romania are Approach 1 and Approach 3, which are essential for the way in which the values for the calculation of actions, resistances and parameters resistance of the materials and partial coefficients will be chosen and used.

Thus, the calculation *Approach 1* allows the use of two groups and sets of partial coefficients to verify that it is not reached in any limit status (GEO and STR): excessive yield or deformation.

Grouping 1: A1 + M1 + R1

Grouping 2: A2 + M2 + R1

In this case, the partial coefficients apply to the actions and parameters of the resistance of the land. Grouping 1 is generally more severe in terms of the structural dimensioning of works in contact with land, while grouping 2 is more severe in terms of geotechnical characteristics. It turns out that grouping 2 (A2 + M2 + R1) is more unfavorable for the verification of the slopes' stability.

In the calculation *Approach 3*, according to NOTE 2 of SREN 1997-1: 2004, in the case of calculating slope stability or general stability, the actions applied to the land (e.g. structure, traffic) are treated as geotechnical actions, so that grouping sets of partial coefficients is: A2 + M2 + R3

In this approach, the partial coefficients are applied to the geotechnical actions and to the resistance parameters of the land.

Based on the values of the partial coefficients corresponding to the two calculation Approaches (1 and 3) and the corresponding sets in Tables A3, A4 and A14 of SREN 1997-1: 2004, it is observed that in the case of slopes' stability and general stability, Approach 1 - grouping 2 becomes identical to calculation Approach 3.

That is why, for problems regarding slopes' stability and general stability, the most unfavorable for the static analysis is Approach 1 - grouping 2.

In the ***dynamic analysis***, the partial coefficients for actions or actions' effects in the earthquake calculation are equal to the unit, according to SR EN1990 NA: 2006, section A1.3.2 and table NA A1.3.

Partial coefficients for earth parameters are specified in SR EN 1998-5/NA: 2007, at 3.1. It is noted that they are equal in value to those corresponding to the M2 set in SR EN 1997-1: 2004, as follows:

- according to Table A.4 in SR EN 1997-1, the values of partial safety coefficients for earth parameters (γ_M) - set M2 are:

$\gamma_Ø$ = 1.25 for the internal friction angle (applied to tgØ)

γ_{cu} = 1.4 for the not drained cohesion

- for the earthquake calculation, the national annex SR EN 1998-5/NA specifies in the note in point 3.1 the recommended values on the territory of Romania for the partial safety coefficients of the shear stress resistance parameters:

$\gamma_Ø$ = 1.25 for the internal friction angle (applied to tgØ)

γ_{cu} = 1.4 for not drained cohesion

Stability analyses were performed in dynamic conditions (earthquake with a_g = 0.12 g). The dynamic analysis is performed with the method of static equivalent forces, in the sense of considering a horizontal inertial force equivalent to the seismic demand.

According to section 2.4.7.3.1 of the SR EN 1997-1: 2004, for the land yield limit state (GEO), it is necessary to verify the fulfilment of the condition:

$E_d \leq R_d$,

where: E_d is the value of the action effect calculation (in our case, the mobilized shear stress resistance) and

R_d is the value of the resistance calculation (represented by the shear stress strength available), which results to an admissible stability factor $F_s^{admissible}$ = 1.00.

The verification condition being $F_s^{effective} \geq F_s^{admissibile}$ (condition which, if fulfilled in the earthquake analysis, is also fulfilled in the static analysis, because in the dynamic analysis, horizontal inertial forces with a destabilizing role also intervene, and the values of the partial safety coefficients of the earth parameters are the same (those corresponding to the M2 set according to Table A.4 of SR 1997-1: 2004 with those specified in section 3.1 of SR EN 1998-5: 2004/NA: 2007).

At the embankments, the traffic overload was considered in accordance with STAS 1545-89 and STAS 3221-86 (in force on 01-01-2014) as being equivalent to the pressure given by a layer of earth with a height of 1.30 m: q = 1.30 m x 20 kN/m^3 = 26 kPa.

Up to the height of 6.00 m, the embankments' slopes have a bank of 2:3. For embankments with a height higher than 6.00 m, the same inclination was maintained, but berms with a width of 3 m were built.

The groundwater level will be taken into account in the worst case scenario, based on the piezometric measurements performed.

5. Conclusions

The limited space did not allow for the detailed presentation of the stability calculations, which can be found in the biographical material belonging to the author of this paper.

It should be noted that the large number of data collected in the field, corroborated and supplemented with the laboratory ones required a laborious statistical processing. Given the importance of the objective under consideration, a choice of the final input data in the stability calculation, imposed a higher responsibility.

The calculation methodology of safety coefficients is not only a common one for such studies, but also a modern one, accepted by the European standards in force.

The results obtained reveal that both the stability of the base land and the structures that make up the motorway as a whole are admissible limits provided that all the auxiliary and protective works foreseen in the project are executed.

References

1. Pascu, Ileana
Stadiul actual al construcției autostrăzii A1 pe tronsonul Deva- Lugoj, Lot 2 (km 27+620m - 47+090m), Raport de cercetare nr. 1, Universitatea din Petroșani, 2016

2. Pascu, Ileana
Caracteristicile geomecanice ale terenului de bază şi ale pământurilor utilizate la construcția autostrăzii A1 pe tronsonul Deva- Lugoj, Lot 2 (km 27+620m - 47+090m) și stabilitatea structurii de rezistență a acesteia pe tronsonul analizat. Raport de cercetare nr.2, Universitatea din Petroșani, 2017

3. ***
SR EN 1997-1/2004

4. ***
SR EN 1998-5:2004/NA:2007

5. ***
STAS for determining geo-mechanical characteristics