Collapsible soil properties research

Recherche sur les propriétés du sol

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ABSTRACT: Because of complex regional engineering-geological prospecting and the following generalisation, research came up with the following; mainly collapsible soils represent lower quaternary wind deposits, loess loams. Quaternary soils are notable for the variability of physical properties, complexity and diversity of mechanical characters. Therefore, collapsible soils were chosen as a target of the following research. Mountainous area around Almaty city taken as an experimental zone. The underground water of 40 meters deep is untapped in this region. However, laboratory tests reveal characteristics of loam as following: density – 15-16 kN/m3; porosity – e > 0.9 and minor mechanical properties. The value of the total settlement is 8.8 – 73.51 cm. According to the complex seismic zoning map, Almaty city and neighbour areas are adjacent to seismic district Ш-В-2. Section of given area represent in massive highly porous loess loam rested on gravel. According to seismic properties, following soil has the third category, because of high porosity coefficient (e > 0.9). Preliminary retaining wall design reveals that all northern slope prone to landslide. According to physical properties in full saturation stage, the most unfavourable against slope stability is collapsible loam.

RÉSUMÉ: La cause de la complicité de la prospection de génie-géologique régional et on suivant la généralisation, les recherches conclus le suivant; Principalement les sols pliables représentent plus faibles dépôts éoliens quaternaires, loams lœss. Sols quaternaires sont remarquables pour la variabilité des propriétés physiques, la complexité et la diversité des caractères mécaniques. Par conséquent, les sols pliables sont choisis comme cible de la présente recherche. La région montagneuse autour de la ville d'Almaty est prise comme zone expérimentale. L'eau souterraine de 40 mètres de profondeur est inexploitée dans cette région. Cependant, les tests au laboratoire révèlent des caractéristiques de loam comme suit: Densité - 15-16 kN / m3; porosité - e> 0,9 et propriétés mécaniques mineures. La valeur du tassement total est de 8,8 - 73,51 cm. Selon le plan complexe de zonage sismique, la ville d'Almaty et les zones voisines sont adjacentes au district sismique Ш-В-2. Une section de la zone donnée représente un massif limon loess très poreux reposé sur du gravier. Selon les propriétés sismiques, le sol suivant a une troisième catégorie, en raison du coefficient de porosité élevé (e> 0,9).La conception préliminaire du mur de soutènement révèle que tous les pentes du nord sont prédisposées aux glissements de terrain. Selon les propriétés physiques au stade de saturation complète, la plus défavorable contre la stabilité des pentes est le loam pliable.

KEYWORDS: Collapsible soil, Retaining wall, PLAXIS 2D, Case study, Slope stability

1 INTRODUCTION

Considered area for the slope stress-strain analysis located in Almaty region at the foothills of Alatau. Surface level fluctuates within +910.000 to +985.835 meters above sea level; therefore, the difference in elevation is 69.835 meter. A geologic-lithological formation mainly includes lower quaternary aeolian deposits. It is loess collapsible loams (QI) and upper quaternary alluvial-proalluvial deposits (arQIII), which subsequently represented by top soil (QIV), loam soil and cobble soil. Brownish loam soil (QI) 21 meter deep is collapsible below that is not. Loam soil penetrated down to 40 meters (Zhakulin, 2015). Cobble soil with sand inclusions observed on North side and have following structure: pebbles 10-15%, cobble 50-55%, gravel 10-15%, and crushed stone 15-20%.

On the 11th May of 2016, there was a landslide on the eastern side of mountain Mokhnatka with approximately 700 cubic meters of soil. 220 cubic meters deposited on the Medeo – Shymbulak road. Collapsible loessial soils are prone to landslide due to full or partial water saturation under significant design parameters degradation (cohesion, an angle of internal friction and stress-strain modulus). It is necessary to analyse stress-strain slope state formed by collapsible soils for slope stability prediction. For the slope's stress-strain state analysis simulation, the two-dimensional problem in elasto-plastic, conditions with numerical techniques was set.

2 DEFECTS ANALYSIS OF RETAINING WALL

In the aftermath of various tests - slope, reinforced concrete retaining wall and storm water drainage system reveal numerous defects, predominantly, during the design stage and reinforcing the slope with geosynthetics. Following inaccuracies lead to the thread of motorway security breach. Slope subjected to atmospheric and storm water precipitations during the year. Discovered defects point to unacceptable cracks and inclination of retaining wall along the road (Figure 1).

Figure 1. Slope view at wintertime

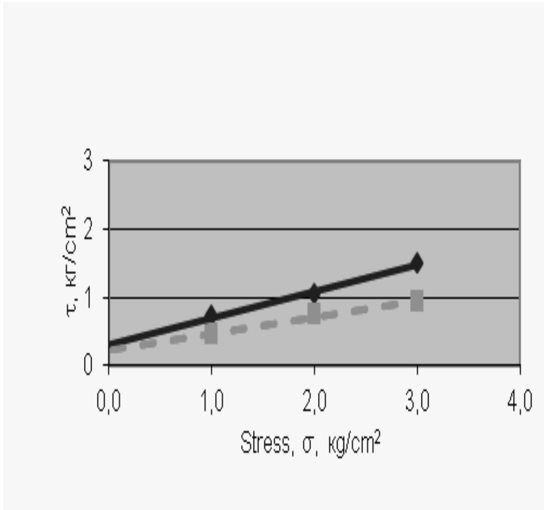

Figure 2. Graphics of strength parameters identification before and after water saturation.

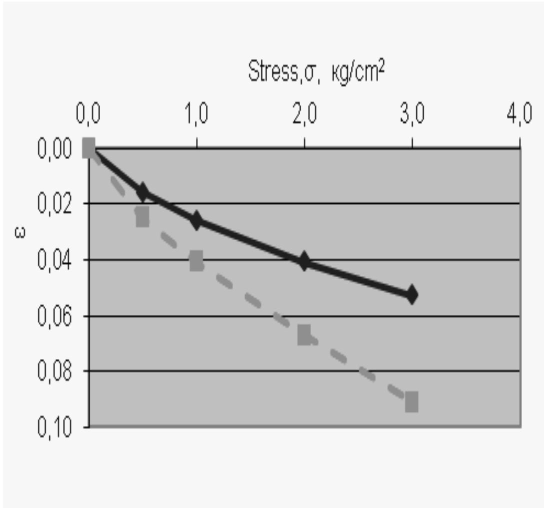

Figure 3. Graphics of deformational soil properties before and after water saturation.

3 SOIL PROPERTIES

According to the investigation, following physical-geological phenomena observed on south regions of Kazakhstan: rainwash, gullying, settlement, seismic activity. Slope formed from loam soils with following properties: brownish colour, from hard to low plasticity, carbonized, up to a depth of 15.5-21.0 m collapsible. Physical-mechanical properties given in Table 1. Underground water is untapped at depth of 40.0 m. However, laboratory tests state following characteristics: density – 15-16 kN/m3; porosity – e>0.9 with low mechanical properties. According to compression tests, loam under the water saturation perform collapsible properties. Moreover, strength characteristics drop down to 50% (Figure 2). Initial settlement pressure deviates from 0.028 until 0.361 MPa (0.112). Coefficient of relative settlement under unit pressure of 0.05 MPa fluctuates within 0.001 to 0.056 MPa (0.014); under unit pressure of 0.1 MPa range is 0.001-0.064 MPa (0.023); under unit pressure of 0.2 MPa range is 0.001-0.105 MPa (0.406); under unit pressure of 0.3 MPa range is 0.019-0.113 MPa (0.059) (Figure 3). Calculations represent a value of total settlement is 8.8-73.51 cm. It is the Second type of soil against the collapsibility. According to a complex seismic map of Almaty piedmont region and adjacent ones, investigation site located in seismic region "Ш-В-2" (upper piedmont step). Elevation of this step represented by thick mass (40 to 80 m) of highly porous loess loams rested on cobble. Subsequent to the analysis of seismic properties of soil they belong to the third category, because of high porosity (e>0.9) coefficients.

Table 1. Physical mechanical properties of soils.

Designation	Units	Initial	Design
I_p	-	0.080	-
W	-	0.170	-
γ	g/cm^3	1.50-1.60	-
γ_s	g/cm^3	2.70	-
γ_d	g/cm^3	1.47	-
e	-	0.84 – 1.1	-
S_r	-	0.55-0.61	1.0
I_L	-	-0.25	-
c	KPa	35	21
φ	degree	22	16
E	MPa	15	4.9

4. STRESS-STRAIN CONDITION OF SLOPE

During stress-strain analysis of slope, stability interacting with retaining wall collapsible soil behaviour investigated. Herewith, slope's collapsible soils are characterised by physical-mechanical properties variability (porosity reduction, deformation modulus, cohesion, the internal angle of friction); stress condition change, due to relocation after saturation and strain tensor change, due to elastoplastic and viscoplastic deformations propagation (Maslov N.N. 1982, Malyshev M.V. 1994). Target stress state occurs under saturation process in collapsible soil, which differs from initial one. The problem was set in the elastoplastic environment using the Coulomb-Prandtl model. It has an elastic behaviour of the environment at a stress below the yield point, and equivoluminar plastic flow at stress at the yield point. Coulomb formula describes the stress at the yield point (Morgenstern, N.R. & Price, V.E. 1967, Terzaghi, K. and Peck R. B. 1967):

$$\sigma_{\max} = S + \lambda \sigma_{\min} \qquad (1)$$

where $\lambda = \cot^2(\pi/4 - \phi/2)$ – passive pressure coefficient; $S = 2\,C\cot(\pi/4 - \phi/2)$ – uniaxial compressive strength; σ_{max}, σ_{min} – maximum and minimum primary stresses.

At the region of yield criterion:

$$\sigma_{min} = -T, \qquad (2)$$

where T – tensile strength is taken as $C/5$.

After the rupture propagation under stress $\sigma = - C/5$ further tensile strength analysis taken as zero ($T=0$). The elasto-plastic solution obtained by the finite element analysis and initial stress method using Newton-Raphson iteration approach with constant stiffness matrix. However, with alternating load vector replenished during iteration process by "initial stresses" in plastic elements. Tolerance in FEM consists of discretization error, conditional object substitution with an infinite number of degrees of freedom of the model with a finite number of degrees of freedom, and rounding errors in performing computations in software (Brinkgreve R.B.J. et al. 1997, Fadeyev A.B. 1987, Paramonov V.N. 2012). Because of numerical analysis for the designated problem, we obtained: (Figure 4. Calculation scheme) distortion of finite element mesh (Figure 5), horizontal and general deformation of the slope under design characteristics change of collapsible soils (Figure 6 and 7), and the isolines of maximum shear stress (Figure 8) and the trajectory of collapsible soil movement (Figure 9) under stress-strain state modification of the slope on the retaining wall.

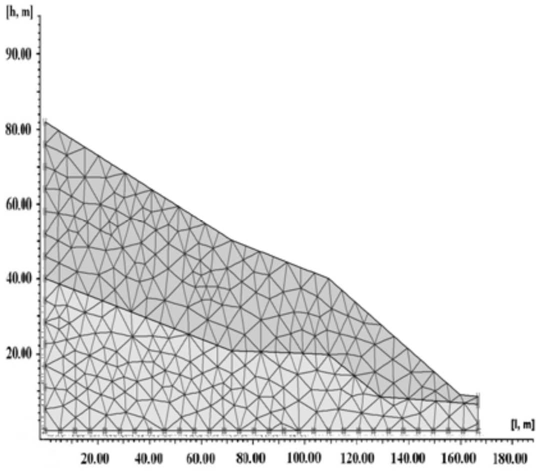

Figure 4. Calculation scheme

Result analysis of numerical solution for modelling the interaction of slope and retaining wall shows that the most dangerous development of maximum horizontal deformation at the wall is due to shear deformations. The range of shear deformations covers large areas in slope. Collapsible soils settle under its own weight during water saturation, which leads to an initial value of cohesion, the angle of internal friction and soil modulus degradation, due to stress-strain states change. The path of collapsible soil particles under the stress-strain state modification perform that movement of the soil particles takes place on the border in between the collapsible loam and non-collapsible loam. Calculations show that the retaining wall at the slope is not stable and the soil sliding occurs in the range of collapsible soil presence.

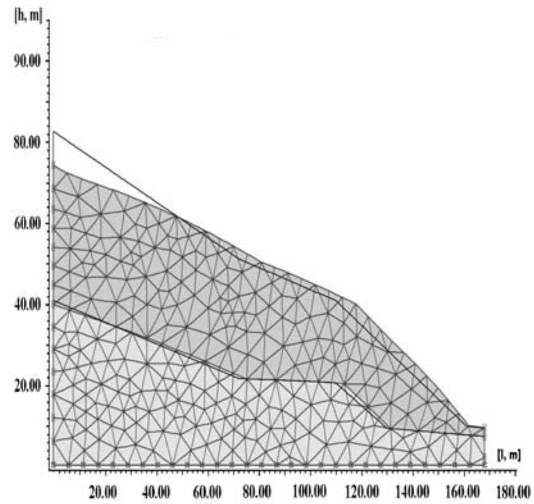

Figure 5. Deformed mesh

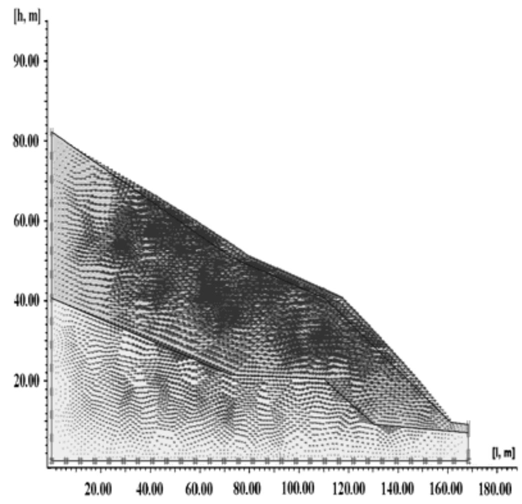

Figure 6. Horizontal displacements (U_x)

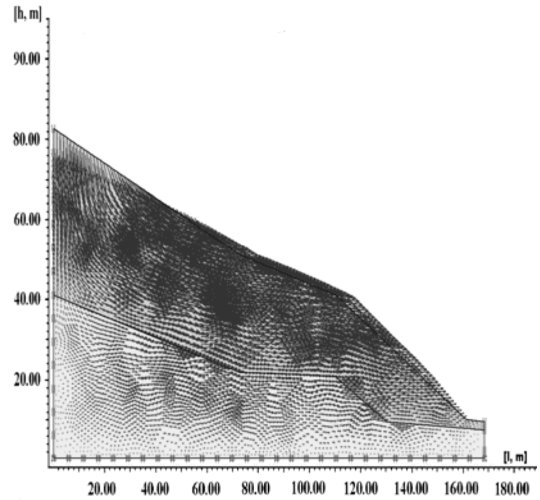

Figure 7. Total displacements (U_{tot})

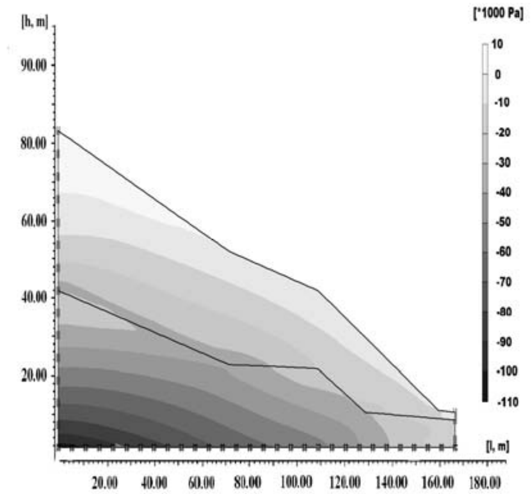

Figure 8.Horizontal total stresses

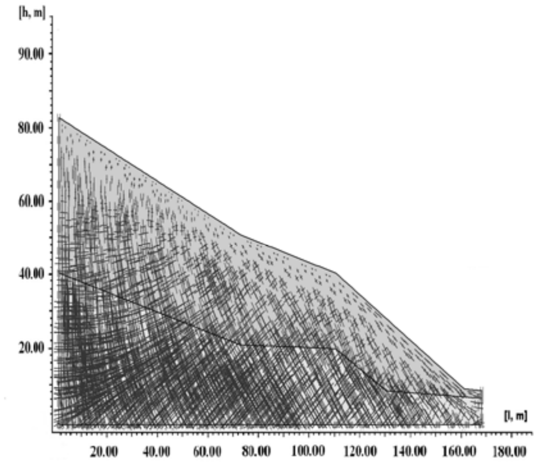

Figure 9. Total stresses (Extreme total principal stress)

5 CONCLUSIONS

Lower quaternary aeonian deposits, represented by loess-like loam (Q_I) is a part of the geological and lithological structures. As the result of experimental tests, reinforced concrete retaining wall and drainage system survey, numerous defects that were committed in the process of design and construction revealed. In return, this damage involves a threat to the safe operation of the road and facilities.
According to the results of compression tests, loam that lies 15.5-21.0 m deep under saturation exhibits collapsible soil properties. The initial subsidence pressure varies from 0.028 to 0.361 MPa (0.112). Calculations show that the total value of the settlement is 8.8-73.51 cm.
Retaining wall stability design carried out by numerical approach reveal that slope under saturation prone to landslide. Results of numerical analysis during the interaction of slope and retaining wall modelling show that the most dangerous development of critical horizontal deformation at the face of retaining wall due to shear deformations at the slope.

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