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Loess Collapsibility Problem in Bulgaria

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Abstract

Loess and loess-like sediments occupy 13% of Bulgarian territory. Their collapsibility predetermined by existence of a great volume of macropores and non-water resistant particle binding substances causes serious problems in the construction activities. To avoid this unfavorable property a lot of research work is being carried out concerning loess origin, stratigraphy, lithology, engineering geological and soil mechanics properties. Loess thickness reaches up to 100 m and the total collapse under conditions of moistening and overburden pressure - up to 170 cm.

A specific characteristic of Bulgarian loess is its vertical and horizontal heterogeneity. In North Bulgaria the Aeolian loess covers a dynamic Pliocene relief and this is the prerequisite for the existence of many steppe limpits and other relief lowerings.

The silty fraction containing mainly quarts, feldspars and micas predominates in the grain size distribution of loess, reaching up to 80% in the most widely spread varieties. The quantity of the clayey fraction (<0.005 mm) is used as the basic criterion in loess classification according to granulometry. The sandy, silty, clayey type of loess and loess-like clay are distinguished.

The Russian classification of loess base has been adopted in Bulgaria, which differentiates two types according to the collapsibility after moistening and under overburden pressure.

In the case of First type loess base, moistening and additional load practically provoke the collapse of the building. The collapsibility of the Second type loess base is mainly due to the overburden (geological) load. The measures for elimination of the both type loess collapsibility (loaded and unloaded) are briefly discussed in the report.

Key words: loess, collapsibility, classifications

1. Introduction

The birthday date of the geological investigation of Bulgarian loess is 1836 and is connected with the name of Ami Boué. One hundred years after his pioneer report, G. Gunchev published the first scientific summary work concerning the loess properties [1]. In the next decades Bulgarian loess was thoroughly studied from the point of view of geology, engineering geology and soil mechanics, since considerable civil, industrial and melioration construction has been developed on it. On 13% of the national loess covered territory lives 30% of the Bulgarian population. In this region 80 municipalities are situated where are concentrated 20% of the industrial and civil construction and more than 30% of the melioration one. The "Kozloduy" Nuclear Power Plant, several thermal power plants as well as several high TV towers are also situated in this area.

The publishing of the monograph "Building Properties of the Bulgarian Loess Soils" treating the loess problem in the aspect of Soil Mechanics [2] was an important event in Bulgarian loess investigations. A set of geological and engineering geological maps of the loess formation in scale 1:500000 was published by Minkov and Stoilov in 1964. The monograph "The Loess in North Bulgaria" [3] is of a special significance for the development of the loess engineering geological aspect. A series of other authors have also contributed to the completion of the knowledge on Bulgarian loess. The total number of the Bulgarian publications on loess is about 250, including 5 monographs and some maps.

As a result of all this research work the stratigraphy, lithology, composition, structure, physical and mechanical parameters, collapsibility, settlement capacity and filtration properties of loess were studied. The suitable methods for the improvement of loess building properties were experimented and some of them applied in the foundation practice. This report presents briefly the current state of loess collapsibility researches in Bulgaria and summarizes the Bulgarian experience in the design and treatment of loess base for construction purposes.

2. General information about Bulgarian loess

The loess and loess-like sediments occupy 13 % of the territory of Bulgaria, i.e. about 14 000 km². The greatest part of them is distributed in the Danubian plain - about 12 000 km² (fig. 1). Here the loess is mainly of aeolian origin, the transfer of the silty material being from North and Northeast. There is a wide strip of loess-like clays situated to the South of the Danubian plain, which originate from weathered Lower Cretaceous marls. Loess-like sediments of alluvial origin are encountered in the big river terraces in South Bulgaria and along Black Sea sand dunes.



Fig. 1. Specific regions of the loess cover in North Bulgaria (by Minkov, 1968):

1-region with continuous cover (except on the flooded terraces and steep right side river banks); 2-region with episodically discontinuous cover; 3-region with discrete cover with Aeolian loess; 4-region with discrete cover with diluvial loess; 5-region with eluvial and diluvial clays; 6-transitional zone of the Fore-Balkan; 7-region of the Fore-Balkan with sporadic cover of diluvial loess-like deposits

The greatest loess thickness is along the Danube and varies from 40-50 up to 100 m. The thickness decreases in southern direction to several meters (fig. 2). It has been established by means of paleomagnetic methods that the beginning of loess accumulation in North Bulgaria dates back to the 0.82 Ma BP [4]. The geomorphologic conditions and climate changes during the Pleistocene exerted a substantial effect on the loess stratigraphy.

A characteristic feature of loess in North Bulgaria is the clearly expressed fossil soils separating the loess horizons. The greatest number of them is found on the plateaus and high river terraces where up to 7 fossil soils separate 8 loess horizons. The number of fossil soils diminishes from North to the South and they join in a single soil complex several meters thick in the most southern part of the loess province.

The silty fraction predominates in the grain size distribution of loess, reaching 80% in the most widely spread varieties. The quantity of the clayey fraction (< 0.005 mm) is used as the basic criterion in loess classification according to granulometry: loess-like sand and sandy loess - up to 10%; silty loess - up to 20%; clayey loess - up to 30%; loess-like clay - >30%. Loess has mainly quartz composition of the

sandy and silty fractions (>50%), a small quantity of heavy fractions (up to 3-4%) and a considerable quantity of finely dispersed clayey carbonate substance. Loess has a carbonate type of salinity and weak alkalinity.



Fig. 2. Thickness of the loess in North Bulgaria (by Minkov, 1968)

Silty loess shows the greatest collapsibility under overburden pressure and in irrigation canals without lining collapsibility reaches 170 cm. A large number of buildings and equipment in Bulgaria were damaged by this phenomenon (fig. 3).

According to approximate calculations, the damage from loess collapsibility during the period of three decades amounted to about \$150 million, which is a huge sum for a country as small as Bulgaria.





b.

Fig. 3. Fissures on the construction walls: a. Rousse town railway station building, b. administrative building in Rousse town

Loess soils are characterized by considerable water permeability. Loess-like sands have hydraulic coefficient k_f from 3 to 5 m/d (3.5 to 5.8 x10⁻⁵ m/s), sandy loess - 1.0-2.5 m/d (1.2 – 2.9 x10⁻⁵ m/s), silty loess - 0.25-0.35 m/d (2.9 – 4.1 x10⁻⁶ m/s), clayey loess - 0.18-0.20 m/d (2.1 – 2.3 x10⁻⁶ m/s) and loess-like clay - <0.10 m/d (<1.2 x10⁻⁶ m/s). Suffosion ruptures leading to deep funnel formation have been established during the operation of irrigation systems without concrete lining. A considerable rising of the ground water level has been observed which caused landslide activation on the edges of loess plateaus in consequence.

A characteristic specificity of Bulgarian loess is its vertical and horizontal heterogeneity. In North Bulgaria it is blown on over a dynamic Pliocene relief and this is the prerequisite for the existence of many steppe limpits and other relief lowerings, where loess is compacted and has lost its collapsibility properties [5]. Considerable changes in loess collapsibility are sometimes observed at small horizontal distances. This emphasizes the importance of the engineering geological investigations, which may lead to significant decrease of building costs and increase of its safety.

From the subsidence curve of more than 500 tests at a load of 3 kg/cm², the relative subsidence $(\delta_{np,3})$, the relative settlement before the subsidence $(\Delta h/h)$, the one dimentional compression modulus (M), and the total compression deformation = settlement+subsidence (S₃) are determined (tabl. 1).

The mentioned specific characteristics of loess soils brought the necessity of the development of series of state and departmental legislation documents, fixing the requirements for the design and construction. A detailed zoning has been made in the regions with intensive building, taking under consideration loess thickness and collapsibility and seismicity as well. This problem has been very satisfactorily solved for one of the largest Bulgarian cities - Rousse. An experimental station of the

Bulgarian Academy of Sciences performs loess investigations in the region. Specific loess studies were carried out for the Kozloduy Nuclear Power Plant, built up on improved collapsible loess. Now these studies are devoted to the possibilities of construction of the low- and intermediate level radioactive waste repository on the loess complex close to the Nuclear Plant. The investigations till that moment show that the researched area possesses both positive and negative properties for that purpose [6, 7].

Туре	Horison	γd	n	w	S₃	۱ _p	∆h/h	δ _{пр,3}	S ₃	М
		g/cm ³	%	%	%	%	%	%	%	kg/cm ²
Loess-like sand	I	1.44	46	9.0	25	3.6	5.8	2.0	7.8	135
Sandy loess	+	1.42	48	10.5	30	6.4	6.5	4.5	11.0	125
Silty loess	+	1.39	49	13.8	45	10.0	8.3	6.5	14.3	90
Clayey loess	+	1.47	48	19.0	55	17.0	8.5	7.0	15.5	55
Loess-like clay	+	1.55	43	22.0	70	23.0	7.0	2.0	9.0	65
Note: Each value is an arithmetical mean from 500 tests										

Table 1. Physical and mechanical parameters of Bulgarian loess varieties (by Minkov et al., 1977)

3. Loess base classification

The Russian division of the loess bases is accepted in Bulgaria, which classifies them depending on their collapsibility under overburden pressure, δ_n , into First type loess base (δ_n <5 cm) and Second type loess base (δ_n >5 cm). The First type collapses practically under additional load of the construction. Second type can collapse under the overburden pressure as well as under the additional construction pressure.

The collapsibility of First type loess base begins after a certain value of the additional pressure, which is greater than some critical stress $P_{i,coll}$ when loess collapse starts.

From the point of view of the collapse hazard under overburden pressure in one Second loess base three zones can be distinguished: lower uncollapsible zone, collapsible zone and upper uncollapsible zone. The lower uncollapsible zone had collapsed in the past under the overburden pressure of the top loess layer after moistening. The upper zone does not collapse since it has not a sufficiently big overburden pressure. However, it is collapsible under the additional load of the constructions on it. The collapsible zone under overburden pressure is situated between these two zones. Its thickness usually changes from 5 to 15 m and is characterized by great porosity and collapsibility.

The numerous investigations carried out in Bulgaria prove that δ_n cannot be established only by laboratory data [8, 9]. It has been recommended that the type of loess base should be determined by experimental wetting in situ. For this purpose data from irrigation construction are also used, a border being outlined between zones with and without collapsibility under overburden pressure in the irrigation systems.

On the basis of the experience, however, the identification of the loess base may be performed according to expert assessment, although not with 100% of security, taking under consideration laboratory data of collapsibility, loess thickness, porosity and moisture content. The data about the deformations of already built structures are also taken into account.

4. Main principles of design and treatment of loess soils

The existing methods of counteracting the collapsibility of constructions and water leakage can be divided into three big groups: construction measures, water isolation measures, and loess improvement methods.

The first group includes the various methods of reinforcing structures and pile foundations by means of which the loess is essentially traversed till the stable soil base has been reached. The second group includes the methods of preventing the access of water to the loess base. The third group comprises all methods whereby collapsibility and filtration are counteracted by a modification of the loess properties by way of compaction, stabilization, replacement or some other ways.

An analysis and classification of the loess improvement methods used in the world and particularly in Bulgaria has been made [10]. The methods are divided into 8 groups. In Bulgaria the most applicable decisions in that area are as follows.

Compaction by heavy tamping - the dynamic energy of a concrete tamper is used, the tamper being dropped by the outrigger jib of a scraper. Initially the weight of the tamper was 2.5-3 tons, but later it has been increased to 15-20 tons and the compaction effect has grown to 4 m [11].

Compaction by short pyramidal piles – it consists of driving into the loess of a concrete pile 3-4 m long with a cross section in the upper part 60 x 60 up to 70 x 70 cm and in the lower part most frequently 10 x 10 cm. A compaction zone is formed along the length of the pile, which bears most of the stresses.

Compaction by preliminary moistening – the natural susceptibility of loess to collapse after moistening due to overburden has been used. Usually moistening is applied to a shallow excavation where a constant water level is maintained in the course of several months until the collapse deformation fade out. Compaction could be accelerated by vertical sand drains, especially if water is fed into them under pressure.

Compaction by preliminary moistening and underwater explosions – this method is used in water irrigation and hydropower constructions. After preliminary moistening of the base as described in the previous paragraph, linear charges are placed on the bottom of the water basin. The explosions are set off with a water column usually more than 1.0 m high serving as a weight. The result is a faster and greater effect of compaction [12].

Compaction by preliminary moistening and deep explosions – loess is moistened with drain boreholes situated at a distance of 3-5 m from each other. A metal pipe with a widening in the lower part is sunk in additional borehole or in the drain boreholes, with 5-7 kg of explosive put in it. After the moistening of the loess, which does not continue until the complete saturation, the explosives placed in several boreholes are simultaneously set off. The powerful blast corresponding to a 12 degree MSK earthquake causes the loess texture to break and there is a quick collapse reaching up to 2 m. The method is very cost-effective and suitable in eliminating collapse. In Bulgaria it has been applied in highrise housing construction [13].

Stabilization using cement, lime and some waste materials – this method is most widely applied in road construction as well as in streets and farm grounds construction [12]. Stabilization is achieved by mixing the soil with binding materials or chemical reagents in special mixtures. Its application in water irrigation construction has been of a comparatively recent date. In Bulgaria, 20 balancing reservoirs have been built whose bottoms with a total area of 130 000 m² have an impermeable screen consisting of one or two soil-cement layers, each one 0.15 m thick and covered by a protective soil layer 0.15-0.20 m thick.

Injection of silicate grouts – as a result of injection of various chemical reagents, new cementing bonds are created and cohesion is considerable increased, collapsibility is eliminated and the bearing capacity is growing. In Bulgaria the method has been used for base stabilization of already existing old buildings - theater, schools etc.

Replacement with other soils – this group of improvement methods includes several techniques in which part of the collapsible surface layer directly under the foundation or in depth is excavated and replaced by compacted or stabilized loess or some other soil (clay cushion, sand cushion) or materials (soil-cement cushion). Soil-cement cushions have been widely used in foundation works on collapsible loess soils in Bulgaria. More than 90 buildings and other installations have been constructed on soil-cement cushions including a large nuclear power plant, industrial and power installations, high TV towers, and administrative buildings. The cushion is built using loess from the building site itself, mixed with 3-7% Portland cement and compacting in layers of 15-20 cm at optimal moisture content until the attainment of standard bulk density. The thickness of the cushion is usually 1-1.5 m and only in rare cases reaches or exceeds 3 m. It has a modulus of total deformation of 80-120 MPa and unlike the other cushions (soil and sand) has a capacity of redistributing the stresses transmitted to it by the foundations on a larger area [14, 15].

5. Future problems of loess investigations

Collapsing of the loess soils is one of the main components of the geological hazard in Bulgaria. In this connection, a huge amount of studies have been performed on the genesis, properties and methods of improvement. The main problems defined twenty years ago by the ones of the notable loess investigators in Bulgaria are still in actuality. In brief they could be summarize as:

1. Evolvement of the method best suited to defining the collapsibility of the soil type when the horizontal and vertical heterogeneity of the loess deposit is well expressed, thus lending a mosaic and multi layered character to the soil even within the bounds of a single construction site.

2. Elucidating the temperature-moisture regimen and stress state of the loess deposits in a natural and water-saturated state, especially when the underground space is to be used.

3. Establishment of the geotechnical properties of loess soils involved in the formation of the big landslides at the Danube River.

4. Forecasting of long-term changes of the moisture content, density and properties of the loess complex on large territories as a result of urbanization and irrigation.

5. Evolvement of suitable methods for the anti-collapsible treatment of the loess soils at the Danube River whose collapsible zone is 35-40 m thick.

6. Improving the methods of making engineering seismogeological characteristics of the ground and seismic micro-zoning of the loess terrain with higher seismic intensity, the existence of an interdependence between landslides, settlement and earthquake deformations.

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