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UNDERGROUND FACILITIES IN LOESS

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ABSTRACT

The underground facilities in loess in Bulgaria have a long history. The loess represents one of the best studied geological formations, its stratigraphic and engineering geological properties being well explored. It is characterized by a thick aeration zone, reaching up to 80-100 m. After the depth of 3-4 m from the surface, low humidity and constant temperature (15-16^0) are maintained in it. The composition of sandy and silty loess, is dominated by quartz, while the clayey fraction contains high amount of Ca^{2+}, which determines the relatively low hydrophilicity. Moreover, loess is easily excavated, keeps vertical slopes and unsupported arches. Loess with natural water content possesses satisfactory strength and bearing capacity. The main disadvantage is its collapsibility, which can be overcome. The paper considers the experience of exploitation of different underground facilities and the damages observed in it. Under the circumstances of the emerging shortage of inexpensive energy, it might be useful to carry out more detailed geotechnical and geotechnological investigations for the wider utilization of loess for underground construction.

INTRODUCTION

The construction of underground dwellings in loess in Bulgaria is known as early as in the antiquity, continued during the Middle Ages till present days. These are the near surface dwellings, sepulchres, temples, various economic premises, taverns, hiding-places, etc.

The near surface dwellings in loess were known from Thracian times – they were mentioned in the geography of Strabon (63 B.C. – 19 A.C.) and had been constructed ever since then till present days according to the evidence of voyagers, historians, geographers and geologists (Gunchev, 1934). Numerous underground facilities were built in loess in the towns in the Middle Ages, and especially in the Rousse city at the Danube River, their structures being discovered all the time during excavation works.

At present tens of millions Chinese live in underground dwellings built in the biggest loess plateau in the world along the course of the Yangtze River, where loess thickness reaches up to 250 m. Many kilometers of tunnel headings have been passed through it and whole settlements have been built there. Large volumes of underground facilities in loess (mainly wine-cellars) have been constructed in the town of Sandomir in Poland.
In the loess and glacier deposits along the Mississippi River valley there is also significant experience in the construction of near surface buildings and different underground facilities.

The near surface and underground facilities in loess and in similar soils are dry and constant temperature is kept in them. This is a serious advantage under the conditions of typical continental climate with hot summers and cold winters.

It is expected that in future the interest in underground construction will increase. One of the reasons for this is the decreasing area of terrains that might be used for construction – in the next decades 10-15 % of the land will be urbanized or occupied by highways, roads, railroads, airports, etc.

Parallel to the indisputable advantages, the modern underground construction requires significant capital investments, which depend except on the type and purpose of the facilities, also on the geological, engineering geological and especially on the hydrogeological conditions. Loess offers a number of advantages in this respect compared to the other soils.

The present paper considers the loess sediments, which cover a great part of the Danubian plain in Bulgaria from the viewpoint of the conditions in them for underground construction. Analysis is made of their geological structure and composition, physical and mechanical parameters, hydrogeological and other conditions, as well as the existing experience in the construction and functioning of near surface and underground facilities in loess.

LOESS IN THE DANUBIAN PLAIN

Distribution and Thickness of Loess

Bulgarian loess is of Aeolian origin and covers a territory of 12 000 km^2 in North Bulgaria. Its thickness near the Danube River, where the best conditions for underground construction exist, is 50 m and reaches 80-100 m at some places (Fig. 1). The section is the increase of the clayey content from the middle of the loess horizons towards the fossil soils.

The clayey fraction in the soils grows at the expense of the silty one. The clayey content in the loess soils is 5-10 %, in the fossil soils Fs_1, Fs_2, Fs_3 and Fs_4 – up to 30 %, in Fs_5, Fs_6 and Fs_7 it increases to 40 %, and in the red clays of the pedocomplex (RC it reaches up to 50 %

The highest content of the sandy fraction is in the middle of the loess horizons and it decreases towards the fossil soils. Due to the more intensive development of pedogenesis, the sandy fraction decreases in the fossil soils. The pedocomplex (RC) also exhibits lower sandy content.

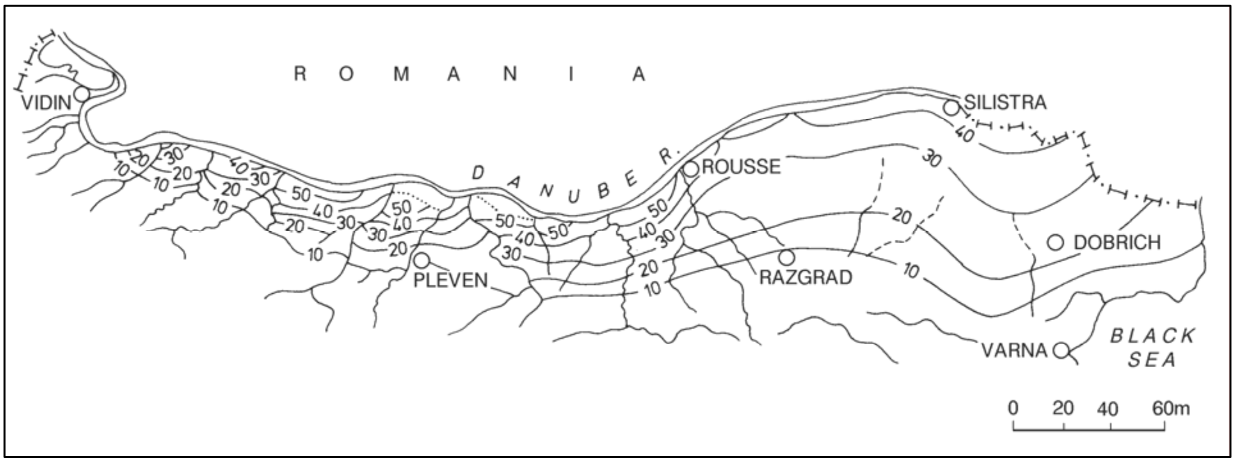

Fig. 1. Thickness of the loess in the Danubian plain (Minkov, 1968)

Grain Size Distribution and Lithofacial Varieties

According to Minkov (1968), depending on the clayey fraction content (< 0.005 mm) the following loess types are distinguished: loess-like sand – up to 5 %; sandy loess – 5-10 %; typical loess – 10-20 %; clayey loess – 20-30 % and loess-like clay – 30-40 %. Usually the loess-like sand occupies a strip close to the Danube River and the loess-like clay – the most distant regions from the river in southern direction.

Eight loess horizons have been established in the loess complex, separated by 7 fossil soils (Evlogiev, 2006).

The alteration of the grain-size distribution with depth is illustrated with data from a borehole near the Luybenovo village, Svishtov district, situated at a distance of 12.5 km to the south of the Danube River (Fig. 2). The main regularity of

A change in the proportion between the grain-size fractions is also observed in the direction from north to south. For example, along the profile line Gigen village – Pisarevo village, Pleven district (Fig. 3), the clayey fraction in L_1 increases from 12 to 37 %, and in L_2 - from 6-7 to 30 % with increasing the distance from the Danube River. Close to the Danube River L_2 is more sandy (35 %) with respect to L_1 (26 %), and the sandy fraction in both horizons diminishes to the south reaching 10-12 %.

The minerals from the hydromica group (mainly illite) predominate in the clayey fraction, followed by the minerals of the smectite group. Smectite is dominant in the fossil soils. The sorption capacity of loess is most often within the range from 5 to 15 mg/equ of a 100 g sample. The sorption capacity increases from sandy loess to loess-like clay with increasing the distance from the Danube River. The sorption complex of the clayey fraction is saturated with Ca^{2+}, which diminishes its plasticity and hydrophilicity.

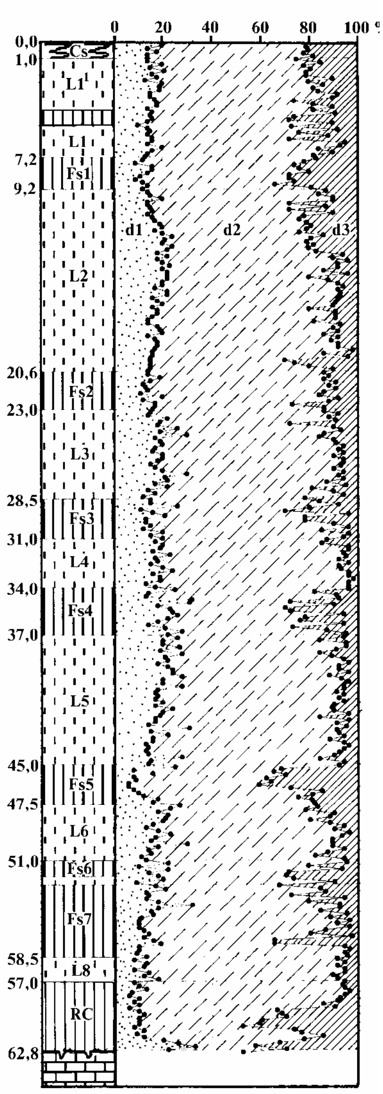

Fig. 2. Typical changes in the grain-size distribution of loess with depth (borehole near the Lyubenovo village, Svishtov district).
L – loess horizon; Fs – fossil soil; Cs – contemporary soil; RC – red loess-like clays; d_1 – fraction 0.1-0.05 mm (sand); d_2 – fraction 0.05-0.005 mm (silt); d_3 – fraction <0.005 mm (clay)

This is a favorable specific feature from the viewpoint of underground construction. The most important loess varieties in this case – the sandy and typical loess, contain more than 60-70 % of quartz, which is favorable for the low water retention capacity of loess (natural moisture content w = 10-17 %). The carbonates in these two varieties are 15-17 %. The greater part of them is in dispersed state and are contained in the clayey fraction.

Loess exhibits neutral or slightly alkaline reaction (pH=6-7), low sulphate content and no corrosion aggressiveness towards concrete and metals, which are used in underground construction.

Most generally, with respect to the considered problem, loess is characterized by favorable grain-size and mineral composition. The loess horizons L_1 and L_2, which are usually embedded at a depth of 12-15 m from the surface, offer good conditions. The silty and sandy fractions are prevalent in them; the hydrophilic clayey fraction is in small amount, which is one of the prerequisites for the formation of favorable moist environment, facilitating the water isolation works of the structures.

Loess Stratigraphy

The loess stratigraphy in North Bulgaria has been elucidated by detailed investigations of geomorphology, lithology and by means of paleomagnetic and geochronological dating (Evlogiev, 2006). As already mentioned, 7 fossil soils and 8 loess horizons are distinguished in the loess.

Fossil soils. Their presence is one of the most essential features of loess. The loess on the Pliocene denudation surface (PDS) in Central North Bulgaria contains the full set of seven well expressed fossil soils and a pedocomplex, situated beneath them. In the rest part of the Danubian plain and on the other geomorphologic forms the fossil soil number is smaller. After their formation they were subjected to diagenetic processes but regardless of this fact they had preserved many of their diagnostic features. They are best expressed in the 5-10 km strip parallel to the Danube River. In the southern part of the loess province the fossil soils are merged or do not have well exhibited loess horizons between them (Fig. 3).

The fossil soils have a small thickness – 1-2 m and regardless of their higher clayey and humus content do not cause problems in underground construction, especially in the thick loess massifs close to the Danube River, where their percentage share in the profile is lower and the typical soil properties are not so expressed.

Loess horizons. The full profile of the loess complex consists of 8 loess horizons (Fig. 2 and Fig. 3), which are numbered in downward direction as L_1, L_2, L_3, L_4, L_5, L_6, L_7 and L_8. A fossil soil is formed on top of each loess horizon – on top of L_1 is formed the contemporary soil Cs, on top of L_2 – Fs_1, on L_3 – Fs_2, on L_4 – Fs_3, on L_5 – Fs_4, on L_6 – Fs_5, on L_7 – Fs_6, on L_8 – Fs_7. The red clays (RC) of the pedocomplex, with which the loess section on ODS is started, are formed on thin loess accumulates that have been entirely soilized in consequence.

The number of the loess horizons on the river terraces diminishes from six on terrace T_6, to one on terrace T_1.

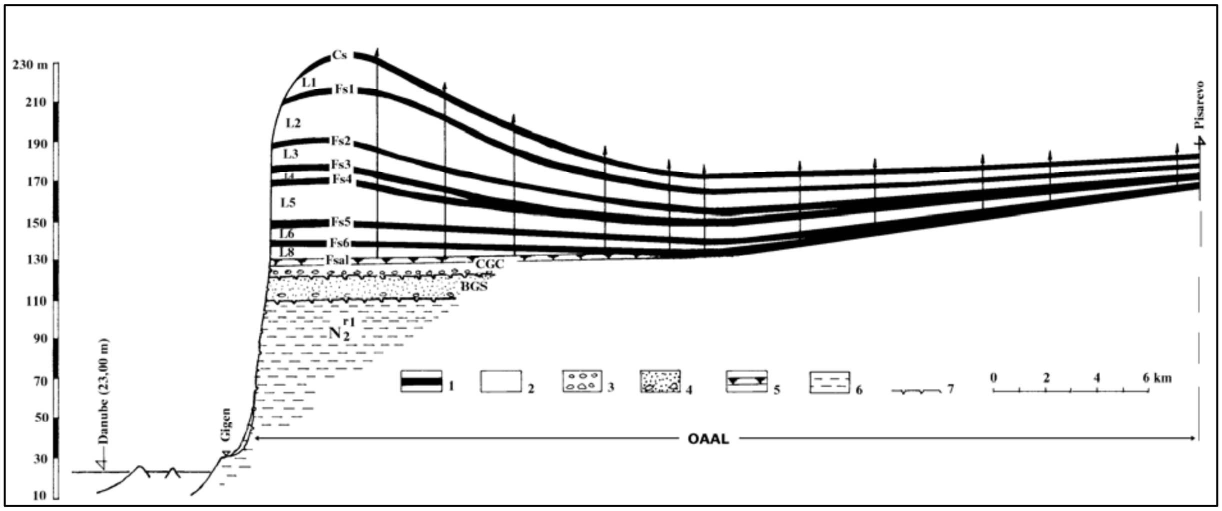

Fig. 3. Loess profile in Northwest Bulgaria (Minkov, 1970)
1 – fossil (Fs) and contemporary (Cs) soils; 2 – loess horizons (L); 3 – covering gravels and clays (CGC);
4 – basal gravels and sands (BGS); 5 – fossil soil developed on alluvium (Fs_{al}); 6 – Lower Romanian clays (N_2^{r1});
7 – abrasion surface; OAAL – old abrasion-accumulative level

The loess horizons L_1, L_2 and L_5 are most widely spread and have the biggest thickness. The other horizons are well developed along the Danube River. In the southern part of the loess area they become thinner and gradually disappear.

In conclusion, it has to be mentioned that loess stratigraphy and lithology are known in details and represent a good scientific basis for the engineering geological explorations and investigations in connection with the construction of underground facilities.

BASIC GEOTECHNICAL PROPERTIES OF LOESS

Sandy and typical loess have low dry density ρ_d, on the average 1.42 g/cm^3 and 1.39 g/cm^3 respectively. They possess high porosity n = 47-52 % and this is one of the prerequisites for their collapsibility under overburden when moistened. This property has a negative effect for the underground structures, especially in urbanized territories.

The compression laboratory modulus for the close to the surface part of the typical loess for normal moisture content is M_2 = 7.0-10.0 MPa and the plate modulus – E_0 = 13.0-15.0 MPa. The bearing capacity is R_0=0.15-0.17 MPa. E_0 increases with depth and, for example, its value at the depth of 15 m is E_0=19.0-20.0 MPa. The modulus of elasticity of loess is E = 40.0-60.0 MPa and its coefficient of Poisson is μ = 0.3. The parameters of the shear strength for natural moisture content (w) vary from $\varphi = 27\text{-}30^0$ and c = 0.010-0.016 MPa for the sandy varieties to $\varphi = 22\text{-}24^0$ and c = 0.020-0.025 MPa for the clayey ones. A typical feature of loess is that it holds temporary a vertical slopes and unsupported vault in underground workings. The high slopes of loess have vertical cleavage and wedge-like lamellae collapse from them during earthquakes.

An advantage of loess from geotechnological viewpoint is that it is easily excavated and the soil does not stick to the machines and instruments.

It is known that loess exhibits the feature of collapsibility. According to the Bulgarian norms two types of collapsibility are distinguished: of the I type – with a size of total deformation under geological burden when moistened s_{col} <5.0 cm, and of the II type – s_{col} >5.0 cm. Practically, the loess of the I type collapses only under the effect of the additional loading of the facilities, and the loess of the II type collapses except from the this loading also due to its own weight. The most suitable massifs for building underground structures, i.e. these situated close to the Danube River, represent a base of the II type, which may collapse under its own weight if uncontrolled moistening is allowed without taking the necessary measures.

To avoid the collapse hazard and increase the bearing capacity of the soil base or the strength of the surrounding massif as well as to protect against water the underground facilities, methods for strengthening, compacting and insulating are applied that have been practically acknowledged. The most suitable of them are silicate grouting, polymer injection, jet grouting, stabilizing by means of injection micropiles (rout piles), applying hydraulic insulation based on geocomposites, etc.

Silicatization (i.e. sodium silicate injection) in case of normal moisture content is realized according to the one-solution method, the loess sorption complex being used as the coagulating reagent of sodium metasilicate. In case of higher moisture content, the so-called gas silicatization, consisting in simultaneous injection of sodium metasilicate and carbon dioxide (CO_2), is very effective.

The water isolation of underground dwellings in the state of Iowa is successfully performed by injection of polymer solutions in the backfill embankments around their walls. The jet grouting technology is very effective for loess due to its easy dilution and active interaction with Portland cement. The diameter of the strengthened soil around the injection borehole may reach up to 3m. The soil-cement mixture acquires high strength (up to 8.0 MPa) due to the silicate composition of loess and its slightly alkaline reaction.

The injection rout piles are used successfully for strengthening the foundations of buildings affected by loess collapse. They are built mainly from the cellars, i.e. under restricted conditions and may be applied for stabilizing the foundations or walls of underground structures affected or endangered by collapse.

Geomembranes and geocomposites may be used as an element of the hydraulic insulation of underground facilities.

The seismic intensity of the loess terrains in North Bulgaria is I = VII-VIII degree according to the MSK scale for seismic coefficient Ks = 0.10-0.15.

The measured values of V_s in loess with natural moisture content in the city of Rousse are most often within the interval of 250-350 m/s, and these of V_p are from 350 to 740 m/s. The velocities in the Lower Cretaceous limestones, embedded under the loess, are V_p from 2800 to 1480 m/s and V_s from 4300 to 2300 m/s depending on the karstification degree of the limestones.

The available data show that the underground structures suffer less damage during earthquakes than the structures situated on the ground surface. This refers both to archaeological sites and for the galleries built in the course of the last hundred years.

The hydrogeological conditions in loess are favorable for underground construction. It possesses one of the thickest aeration zones in Bulgaria, which reaches up to 80-100 m in vicinity of the Danube River. For this reason loess represents an interest for underground storage and disposal of hazardous wastes.

The Darcy's coefficient of loess is most often within the range from 2.0 m/24h (for sandy loess) to 0.2 m/24h (for clayey loess).

The loess massif is incised and drained by the river valleys and in Dobrudzha – by dry ravines. Water saturated horizons are formed in its lowest part – above the red clays and as temporary perched aquifers above $Fs_{3,4}$. According to Minkov (1968) the water from precipitation permeates in sandy and typical loess to a depth of 3-5 m. In this zone the moisture content fluctuates during the climatic seasons depending on precipitation quantity. The so-called "dead horizon" is situated underneath, in which small changes are observed in the water content under conditions without technogenic impacts, and that is of great interest for underground construction. The temperature in this zone is kept constant – about 14-16^{o}C.

Under natural conditions the water movement in the depth of loess occurs in unsaturated medium by means of infiltration or diffusion – from the more thick water envelopes of the particles to the more thin ones.

EXPERIENCE FROM UNDERGROUND FACILITIES IN LOESS

In the course of millennia underground structures in loess had been subjected to the influence of seasonal climatic fluctuations and human interference. For this reason they provide valuable information for the future underground construction. Further on a description will be given for some facilities built in Bulgaria, their structure and the available data for their performance.

Near Surface Dwellings

These dwellings had existed in the loess province since the antiquity till the 30-ies of the last century. In North Bulgaria there were thousands of them in the end of the XIX and the beginning of the XX century (Gunchev, 1934). These structures represented premises situated entirely in excavations with a depth of up to 3-4 m, only their roof being above the terrain (Photo 1). The access to them was realized via several steps. In the bigger houses there was a type of hall after the entrance with doors leading to the rooms for cooking, eating, repose and storage. The premises with economic functions were adjacent to the dwellings and were also dug in the terrain. Life was concentrated around the hearth. The
The conditioning system maintains economically constant temperature both in summer and winter. The amplitude of the annual temperature fluctuations in this state reaches up to 50^{o}C and its maintenance in the above-the-surface houses within the range from 20 to 22^{o}C requires considerable costs.

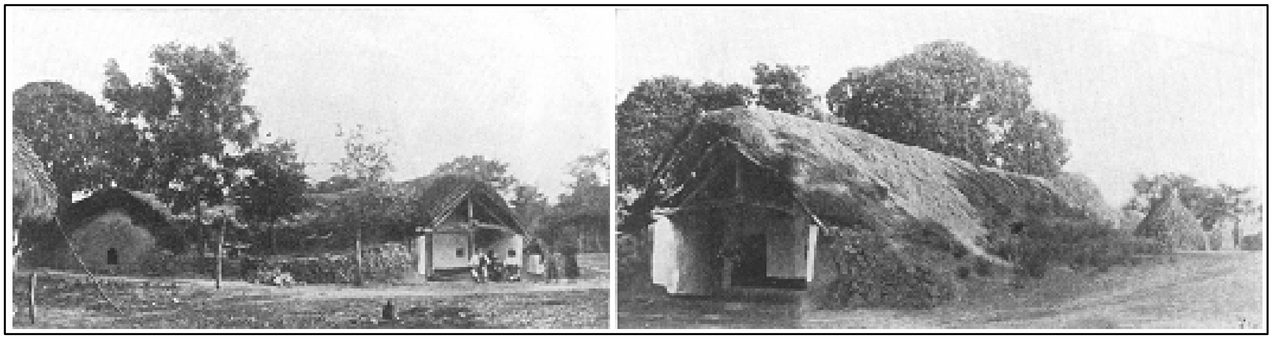

Photo 1. Front and side view of an undersurface house (Gunchev, 1934)

chimney rose above the roof or was built beyond the building outlines. The roof structure was made of wood. A loess layer with thickness of 0.5-1.0 m was spread on top of it for thermal isulation. The roof ends of the smaller dwellings rest on the natural soil. The roof elements of the bigger houses are supported by wooden columns aligned along the external walls and inside the premises.

The Czech scientist Irechek describes in his travel notes the near surface dwellings as spacious, dry and clean houses, cool in summer and warm in winter. Similar evidence is provided by the researchers, who visited the Chinese settlements dug in loess slopes.

The old near surface dwellings had no sewerage and water supply and of course they did not meet the sanitary requirements of modern society. Since the beginning of the XX century their number decreased and in the 30-ies they were abandoned and replaced by structures on the terrain surface. However, their advantages were not forgotten – hundreds of rural buildings in loess have deep cellars, sometimes on two floors, in which food products, wine and fruits are being stored.

The buildings in underground floors in loess, which are successfully functioning in Iowa, the USA, may be considered as the continuation of a millennium-long construction tradition. The disadvantages of the old near surface houses are overcome by modern insulation, climatic installation, water supply and sewerage networks. Only the roof with the rooms on the top floor is situated above the surface (Photo 2)

Photo 2. Contemporary nearsurface house in the town of Ames, Iowa.

<u>Thracian Tumuli with Sepulchre Chambers and the Gallery in Pliska</u>

The oldest inhabitants of the Bulgarian lands were the Thracians. In the loess province there are tens of Thracian tumuli left from their times (built between III – II millennia B.C. and III century A.C.). Semi-dug-in sepulchre chambers and stone tombs are found in part of them. The chambers and sepulchres are covered by 5-8 m well compacted soil and may be considered as shallowly situated underground facilities. The geotechnical properties of the mounds (Gergova et al., 2005), the earthquake consequences (Gergova et al., 1995) and the possibilities of using the experience from them for evaluating the safety of near-surface repositories for hazardous wastes have been investigated. The most important evidence from this experience is that the well drained loess base as well as the loess embankment on the semi-dug-in facility have ensured such humid and thermal environment that the bas-reliefs of soft limestone (the famous caryatides in the tumuli of Sveshtari, Northeast Bulgaria), the coal-drawn frescos and the metal objects have been preserved after 24 centuries of climatic and earthquake impacts. These facts may be the basis for conclusions related to the long-term stability of the underground facilities in loess.

Under the town of Pliska – the first Bulgarian capital on the Balkans, a gallery (total length of about 500 m) was built in the VII-VIII century in loess. It was used for the movement of people, including beyond the fortress walls. Its roof is found at a depth of 2.0-2.5 m from the surface, the width is 1.0 m and the height – 1.80-2.20 m. The gallery was dug from the surface with excavation width of 2.5-3.0 m. After lining with planks, the gallery was covered with compacted soil. Long sections of it are preserved till the present days.

Underground Facilities in the Rousse City

The relatively highest amount of underground facilities, which are also the deepest ones, are found in the Rousse City. The town was founded by the Romans 2000 years ago and was known as Sextaginta Prista. The oldest underground structures date back to this period.

The town is situated on river terraces, formed on limestones (Aptian), marls (Albian) and disperse soils (Miocene, Pliocene). On top of them follows alluvium, covered by loess with a thickness from 8 to 40 m (Fig. 4).

Almost the whole town is built on loess of the II type, collapsible under geological burden and moistening. The thickness of the collapsible zone is from 12 to 15-18 m. Loess of I type is established only on terrace T_1, with a thickness of the collapsible zone of 5-6 m.

The greater part of the underground facilities represent deep galleries passed through the loess of the terraces T_3 and T_4, mainly in the third loess horizon (L_3) and not so often in the second fossil soil (Fs_2), i.e. in the non-collapsible part of the loess profile or in the lowest part of the collapsible zone. For this reason they have not been seriously affected by collapse due to loess own weight.
The more shallowly situated hiding places, dug-in houses and churches, as well as all the rest underground infrastructure of the town of Rousse fall within the upper part of the collapsible zone. Loess collapse is a permanent hazard for the facilities, especially in the central part of the town.

During the Middle Ages underground storage spaces were built from the basement floors of the houses or from the terrain surface. They were used also for secret and hiding places. Part of these coverts is passable even now and may be used for civil purposes.

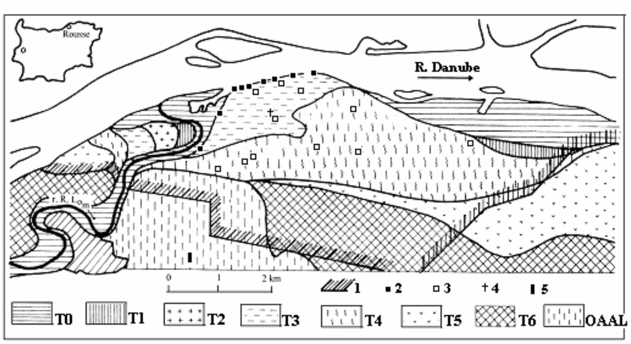

Fig.4. Engineering geological map of the town of Rousse T_0 – flood terraces. Water level at a depth of 2 m; T_1 – first-loess terrace. Water level from 7 to 9 m. Collapsible zone - 5-6 m; T_2 – second loess terrace - water level at 12-15 m. Collapsible zone - 12-13 m; T_3 – second loess terrace. The water level is in the limestones. Collapsible zone – up to 12 m; T_4 – fourth loess terrace. Water level is in the limestones. Collapsible zone - 12-13 m to 15 m; T_5 – fifth loess terrace. Water level in the limestones. Collapsible zone - 18 m; T_6 – sixth loess terrace. Water level in the Pliocene clays and sands. Collapsible zone- 15 m; OAAL – old abrasion-accumulative level. Water level in the Pliocene sediments and in the karst limestones. Collapsible zone 15 m; Other designations: 1 – boundaries of the town of Rousse; 2 – underground galleries with an entrance from the slope on the side of the Danube River; 3 – underground galleries in the central part of the town with a step-like entrance; 4 – the "Sv. Troitsa" church; 5 – Levent fortification; raster T_1 – loess terrains with collapsibility of the I type; raster T_2, T_3, T_4, T_5, T_6 and OAAL – loess terrains with collapsibility of the II type.

The hiding places begin from a depth of 3 to 6 m. Usually they have one gallery with two entrances, situated on the terrain or in the cellars. A staircase starts from the entrance and leads to the gallery. The galleries themselves are 50 m long, 1.5 to 2.5 m wide and 1.8-2.5 m high.

The older galleries were built with no stabilization and lining. They have vertical walls and vault ceilings. Later on the galleries were strengthened by rectangular frames of oval-shaped beams, which were lined with boards. Some of them are with brick or stone masonry or alternation of both, forming vertical walls and a cylindrical vault. In the beginning of 1941 the building of modern antiaviation shelters was launched.

One group of shelters is situated along the Danubian bank with entrances in the base of the loess slopes (Fig. 5).

The entrance and the main galleries are horizontal. The entrance galleries are short and with broken lines in plan, 1.0-1.8 m wide and 2.0-2.2 m high. The main galleries are 3.8-5.5 m wide and 2.2-2.5 m high. Their walls and vaults are built of reinforced concrete or of bricks masonry, floor cover is made of bricks on sand substrate. The walls rest on strip concrete foundations with at a depth of 0.4-0.6 m under the floor, their width being equal to that of the walls. The shelters are built at a depth of 15 m under built-up terrains, streets with water and sewerage systems (WSS) and other communications. They are situated in the non-collapsible loess zone or at the boundary between collapsible and non-collapsible loess. The loess slopes above the entrances are in stable state. Their surface is grass-covered and afforested and this protects them against erosion. For this reason the shelters are well preserved with small exceptions.

Another group of shelters is found in the central part of the town (Fig. 4). They are accessed from the surface. The entrance galleries are with steps.

Usually one shelter has two or three entrances. The shelter itself represents a horizontal gallery, which is situated at a depth from 12 to 15 m. In plan they have a broken or polygonal outline. Their width is 2.5-4.5 m and their height is 2.2-3.0 m. Their length is from 40-60 to 200 m. The walls are vertical and the ceiling is usually a cylindrical vault. The lining is 0.4-0.6 m thick and is made of reinforced concrete or brick masonry. The foundations under the walls are of the strip type and are laid at a depth of 0.5-0.7 m under the floor. Their width is 0.6 m. The floor cover is made usually of concrete with a thickness of 0.1 m.

After WWII most of these shelters were rearranged and additionally equipped. Single parts of them are under existing, most often subsequently built capital buildings and facilities, but the greater number are under contemporary boulevards, streets and parks in the densely built central part of the town with its entire underground infrastructure – water supply, sewerage, heating installations from TPP, etc.

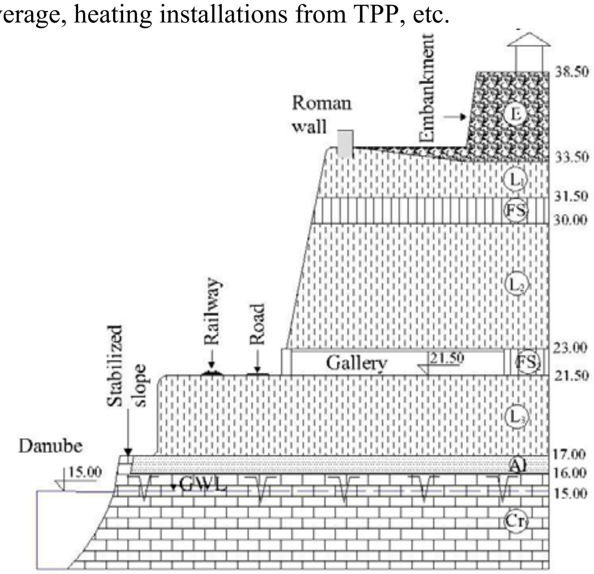

Fig. 5. Underground gallery in Rousse with an entrance in the slope base; L – loess; FS – fossil soil; Al – alluvium of gravels and sands; Cr_1 – Lower Cretaceous limestones.

This group of shelters is built in non-collapsible loess sediments. Some of them have suffered certain deformations due to over moistening the loess above the vault as a result of WSS communication accidents. However, the greater part of the shelters are dry and constant temperature of about 15-16^{0}C is maintained in them.

There is an idea for transforming one of the biggest shelters, situated in the central part of the town, into a natural science museum.

The semi-dug-in "St. Troitsa" cathedral temple is situated in the central part of Rousse. In plan it represents a three-nave basilica dug-in to 3.5 m from the surface. The church was built in 1632 (Photo 3). It was situated in the suburbs of the medieval town. At that time Bulgaria was under Turkish domination, which imposed restrictions on the height of Christian churches above the surface.

During the construction of the temple catacombs were discovered and a part of them were incorporated in it. The catacombs were built for secret worships of the first Christians (IV-V century). In 1764 and 1797 the temple was reconstructed and paintings were made on the walls and on the domes. After the liberation from Turkish reign, the chapel, central dome, belfry and stone staircase were built in 1884.

Photo 3. View of the "St. Troitsa" near surface church in the town of Rousse

The "St. Anastasii" temple in the village of Poroishte, Razgrad district, is also a near surface structure in loess and has survived the strong earthquakes that occurred during its long years of existence.

The analysis of the state of the underground facilities existed in the town of Rousse (Evstatiev et all. 1997) arrives at the next main conclusions:

- The deep underground galleries, situated at the boundary between collapsible and non-collapsible loess are in stable equilibrium under conditions of normal moisture content;

- When moistened however, loess aggravates its strength properties and bearing capacity. Its modulus of total deformation may be reduced up to three times, the cohesion – up to two times, and the angle of internal friction – from 5 to 30 times. In this way loess is transformed into a plastic material flowing even without additional loading. From the moment of starting the collapse, loess weight together with the weight of the building at the surface are applied on the underground facility. For a 13-14 m thick collapsible zone, the loading on the gallery vault reaches up to 0.22 MPa. Usually the vault is capable to bear this load but deformations in the structure occur due to the irregular settlement of the strip foundations, which bear the gallery walls. For the mentioned load on the vault the contact stresses under the foundations reach up to 0.5 MPa. The soil base settles irregularly under such a big load up to 20 cm. Vertical cracks (opened to 15-20 mm) appear in the wall lining on the place of sharp change in the settlement size, which attenuate in the vault reaching 0.1 mm.

- Due to the vertical overloading in the vault lock, 0.1-0.2 mm opened cracks are formed along the gallery length. Similar cracks are established between the walls and vault toes but their origin is due to horizontal overloading. In case of bigger cracks in the structure, conditions emerge for loess flowing in the gallery.

- Local swellings are formed on the lining without disturbing its integrity due to the hydrostatic pressure of plastic loess on the galleries. Most often the swellings are typical for the arches between the vault lock and toes as well as for the gallery walls.

- The deformations in the deep underground facilities affect also the structures built on top of them. They are deformed due to the settlement of loess in the active zone of the foundations, the collapse of loess between the building foundations and the underground facility and due to settlement of the latter.

The described type of deformations occurs in a restricted number of underground facilities, the deformations of the WSS network being also restricted and sporadic.

The underground facilities for civil purposes - semi-passable sewerage collectors from the XVII-XIX centuries, storehouses, refrigerating chambers, etc., are built in the topmost part of the collapsible zone. As in the case of the deep underground facilities, they are in good exploitation status under conditions of normal moisture content of loess around and under them. However, under conditions of emergency moistening serious deformations take place in them, which affect the structures on the surface too.

The described experience from the operation of under ground facilities in loess in built-up urban territories provides the ground for the conclusion that when they are built in the collapsible zone, measures have to be undertaken for avoiding the hazard of loess collapse.

POSSIBILITIES FOR THE CONSTRUCTION OF NEARSURFACE RADWASTE REPOSITORIES IN LOESS

Stefanov et al., (1984) Evstatiev et al. (1998) and Antonov (2002) have investigated the loess as a host medium for a radioactive waste repository.

The main conclusion from these investigations is that the construction of a LILW repository of the near surface or tunnel type in loess is possible. This is a facility with dry humidity regime and it itself will not provoke the hazard of moistening and collapse of loess. Loess possesses a thick aeration zone, sorption qualities and retention capacity with respect to radionuclide migration. Temporary repositories for unconditioned solid and liquid wastes have been functioning for more than two decades on loess at the NPP site without groundwater pollution.

CONCLUSIONS

Loess in the proximity of the Danube River, where are situated the biggest towns in the Bulgarian Danubian plain offers good possibilities for underground construction due to its thick aeration zone and deeply situated groundwater. Quartz is predominant in its mineral composition and the clayey fraction contains high amounts of dispersed $CaCO_3$. The sorption complex of the clayey minerals (mainly from the illite type) has high Ca^{2+} content. For this reason the well aerated porous structure of loess is not hydrophilic and its natural moisture content is low.

Loess is characterized by good physical and mechanical parameters under conditions of natural moisture content. It is easily excavated and retains temporary unsupported slopes and vaults. Its most unfavorable quality is the susceptibility to collapse under geological burden and additional loading after water saturation, which would be a threat for the stability of underground facilities, when they are built in the collapsible zone. This hazard may be avoided by appropriate situation of these structures in the massif and by using the method of loess improvement.

The long-years of experience accumulated during the functioning of underground facilities in China, the USA, Poland and Bulgaria provides a serous evidence for the suitability of loess for this type of structures. These are the nearsurface dwellings, old temples, galleries for economic and military purposes, storehouses, etc., some of them being utilized unsupported in the course of centuries. The underground facilities in loess in Bulgaria have been subjected to the impact of tens of strong earthquakes in the past without serious damages.

With the constant rising of energy prices, the buildings with underground storeys in loess possess the advantage of the maintained permanent temperature and humidity. This is proved by the functioning of the Chinese dwellings in loess slopes, the residential buildings with underground storeys in the state of Iowa, the underground enterprises in the town of Sandomir in Poland and by the rural buildings with deep, often two-storey cellars in Bulgaria.

The explorations carried out prove that loess offers good possibilities for the construction of near surface repositories for radioactive wastes. The radionuclide migration to the aquifer horizon in the loess base is practically impossible with the existing thick aeration zone and 5-6 m thick embankment above the repository.

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