GEOTEHNIČKI UZROCI OŠTEĆENJA DOMA NARODNE SKUPŠTINE U BEOGRADU

GEOTECHNICAL CAUSES OF DAMAGES FOR THE PARLIAMENT BUIDLING IN BELGRADE

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1 UVOD

Dom Narodne skupštine Republike Srbije u ul. Trg Nikole Pašića br. 13 u Beogradu, slika 1, ima ozbiljna oštećenja pojedinih delova konstrukcije, slika 2, koja su nastala na objektu tokom više od 70 godina njegovog korišćenja. Pored toga, ovaj monumentalni objekat više ne zadovoljava savremene propise u pogledu otpornosti na dejstvo zemljotresa [7]. Radi iznalaženja trajnog rešenja

1 INTRODUCTION

The Parliament building of the Republic of Serbia, that is located at Nikola Pasic Square 13 in Belgrade, Fig.1, has serious damages on the certain parts of structures, which occured at the construction in more than 70 years of its use, Fig.2. In addition, this monumental building in this moment fails to satisfy actual codes related to the resistance to the effects of

Slika 1. Dom Narodne Skupštine Republike Srbije na Trgu Nikole Pašića 13 u Beogradu
Figure 1.The Parliament building Republic of Serbia at Nikola Pasic Square 13 in Belgrade

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problema sleganja i problema dugoročne dinamičke stabilnosti i statičke održivosti konstruktivnog sistema objekta, bilo je potrebno definisanje geotehničkih uslova i interakcije sistema teren-objekat. Zbog toga su na predmetnoj lokaciji izvedena detaljna geotehnička istraživanja.

earthquakes [7]. In order to find permanent solutions to the problem of long-term subsidence and problems of dynamic stability and structural viability of the building structural system, it was necessary to define the geotechnical conditions and interactions between construction and foundation soil. Therefore, detailed geotechnical and geophysical field investigations and laboratory tests were performed.

Slika 2. Oštećenja u Domu Narodne skupštine
Figure 2. Damages in the Parliament building

2 GEOTEHNIČKA ISTRAŽIVANJA TERENA

Radi definisanja inženjerskogeoloških svojstava terena, kao područja međusobnog uticaja prirodne litogenetske konstrukcije i objekta, izvedena su sledeća terenska istraživanja i laboratorijska ispitivanja [2], tj:

– Inženjerskogeološko rekognosciranje površine terena sa ekspertskim pregledom zgrade, susednih objekata i saobraćajnica;

– Istražno bušenje 6 istražnih bušotina, dubine 19 do 38m, ukupne dužine bušenja 140.5m, sa detaljnim inženjerskogeološkim kartiranjem jezgra istražnih bušotina;

2 GEOTECHNICAL INVESTIGATIONS

– In order to define the geological and geotechnical properties of soil, as well as zone of interaction between building and underlying soil, detailed field investigations and laboratory tests were carried out [2], i.e:

– Engineering geological visual on-site inspection of the terrain surface with expert's observation of the Parliament building, adjacent buildings and pavements;

– Exploration boring of six bore holes, 19 to 38m depth, boring a total length of 140.5m, with the detailed description core drilling from various strata;

– Opiti standardne penetracije, izvedeni u 2 istražne bušotine: B-2 i B-4; ukupno je izvedeno 11 opita standardne penetracije (5 opita u bušotini B-2 i 6 opita u bušotini B-4), pri čemu su, opitima obuhvaćene sve izdvojene litološke sredine;

– Istražno iskopavanje 2 istražne jame, do dubine fundiranja, sa detaljnim inženjerskogeološkim kartiranjem iskopa: jedne sa spoljne, zapadne strane objekta, J-1, a druge u okviru gabarita objekta u njegovom jugoistočnom atrijumu;

– Ugradnja pijezometara i merenje nivoa podzemnih voda, u dve istražne bušotine B-5 i B-6, sa dužinom pijezometarske konstrukcije od po 12m;

– Refrakciona seizmička ispitivanja na površini terena, duž 2 profila i u bušotinama,

– Seizmički karotaž istražne bušotine B-1,

– Laboratorijska geomehanička ispitivanja 18 neporemećenih uzoraka tla iz svih izdvojenih litoloških članova, na kojima je izvedeno 18 identifikaciono klasifikacionih opita, 16 opita edometarske stišljivosti, 8 opita direktnog smicanja i 16 opita jednoaksijalne čvrstoće na pritisak;

– Laboratorijska geohemijska ispitivanja uzoraka podzemne vode.

Položaji istražnih bušotina i istražnih jama prikazani su na slici 3.

Detaljna geotehnička istraživanja su izvedena u julu i avgustu 2010. godine (Rudarsko-geološki fakultet Univerziteta u Beogradu, 2010).

Istražno bušenje, ugradnja i razrada pijezometara i opiti standardne penetracije izvedeni su od strane „Kosovoprojekta«, d.o.o., a pod nadzorom Rudarsko-geološkog fakulteta.

Istražna iskopavanja temelja izveo je »Kosbet« iz Beograda.

Terenska i laboratorijska geofizička ispitivanja poverena su »NIS« – Servisu za geofiziku. Interpretaciju rezultata geofizičkih ispitivanja i formiranje geofizičkog modela za seizmičku mikroreonizaciju terena je uradio Seizmološki zavod Srbije.

Laboratorijska geomehanička ispitivanja uzoraka tla izvedena su u Laboratoriji za mehaniku tla Rudarsko-geološkog fakulteta.

Laboratorijska geohemijska ispitivanja uzoraka podzemne vode su urađena u Zavodu za javno zdravlje RS.

Na osnovu rezultata istraživanja, od strane Rudarsko-geološkog fakulteta Univerziteta u Beogradu, utvrđena su inženjerskogeološka svojstva terena i, u skladu sa tim, definisani geotehnički uslovi za izvođenje sanacionih mera koje bi trebalo da obezbede dugoročnu stabilnost objekta.

Rešenje problema sleganja i problema dugoročne dinamičke stabilnosti i statičke održivosti konstruktivnog sistema zgrade povereno je Građevinskom fakultetu Univerziteta u Beogradu koji je, u ovoj fazi rada, definisao idejno rešenje sanacije konstrukcije Doma Narodne skupštine u Beogradu.

3 GEOTEHNIČKA SVOJSTVA TERENA

Objekat se nalazi na platou između Bulevara Kralja Aleksandra i ulica: Vlajkovićeve, Kosovske i Takovske u Beogradu. Površina istražnog prostora iznosi približno 240 x 135 m, odnosno $\cong$ 3.24 ha.

– Standard Penetration Tests, performed in two boreholes: B-2 and B-4, a total 11 standard penetration tests were carried out (5 tests in the borehole B-2 and 6 tests in the borehole B-4), in all existing layers of the soil;

– Excavation 2 trial pits to a depth of foundation, with the detailed engineering geological description of excavated soil: one was outside, on the western side of the building, J-1, and the other was inside the building, J-2, in its atrium;

– Installation of piezometer tubes and recording groundwater levels, in two boreholes B-5 and B- 6, the length of the each piezometric construction was 12m;

– Refractive seismic testing on the surface, along the two profiles and in the boreholes B-1 and B-3,

– Seismic well logging in the borehole B-1,

– Laboratory soil testing on 18 undisturbed soil samples extracted from all lithologic layers, 18 soil classification tests, 16 oedometar compressibility tests, 8 direct shear tests and 16 unconfined compression tests;

– Laboratory geochemical testing of groundwater.

Locations of boreholes and trial pits are presented in the Figure 3.

Detailed geotechnical investigations were carried out by Faculty of Mining and Geology, University of Belgrade, in July and August 2010.

Exploration boring, installation and development of piezometers and standard penetration tests were carried out by the "Kosovoprojekt" Ltd, under the supervision of Faculty of Mining and Geology.

The trial pits were carried out by "Kosbet" from Belgrade.

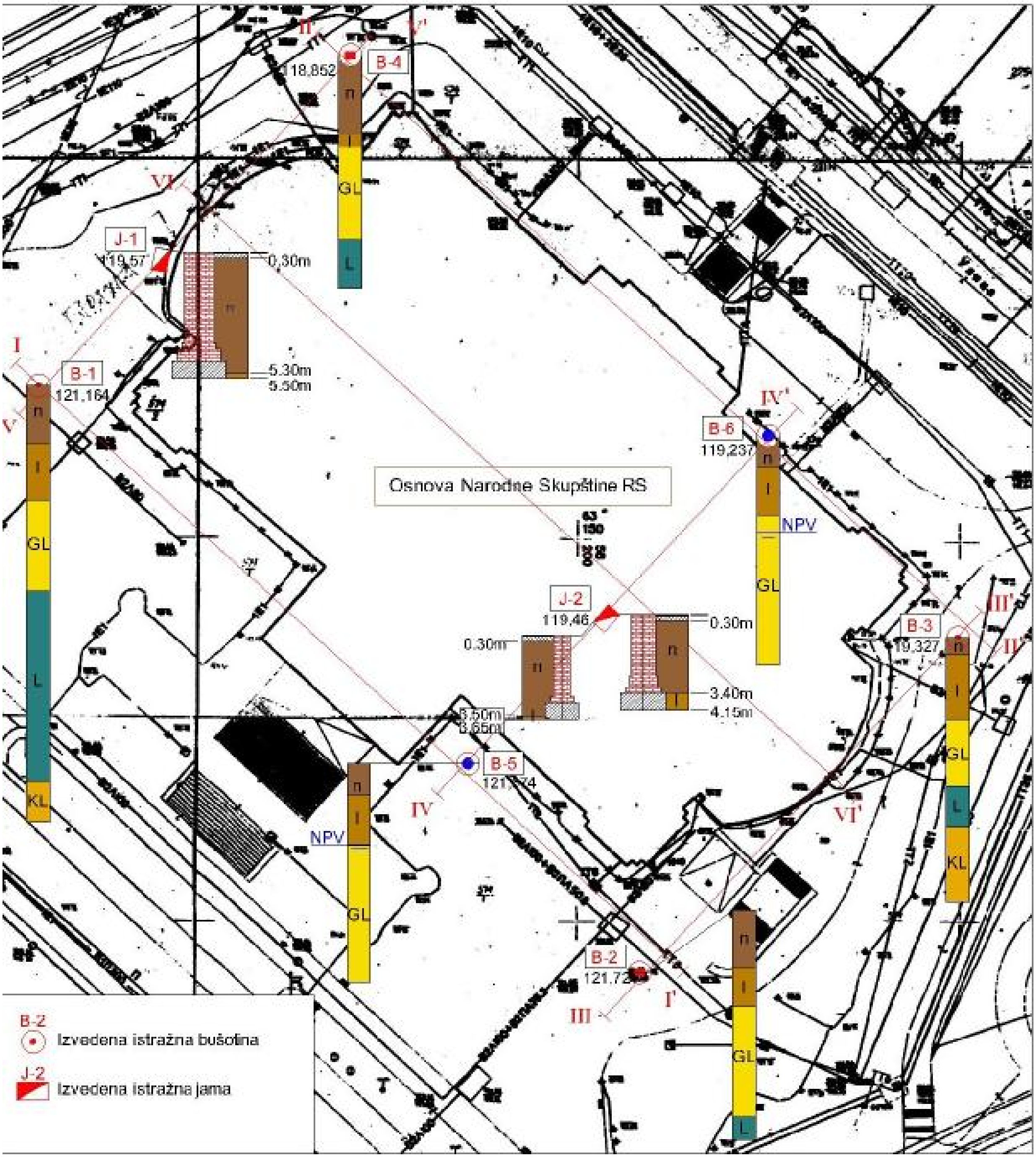
Field and laboratory geophysical tests were performed by "NIS" - Geophysical Service. Interpretation of the results of geophysical analyses and setting up geophysical models for the formation seismic microreonisation of the site area were performed by Seismological Institute of Serbia. Laboratory geomechanical testing of soil samples was performed at the Laboratory for Soil Mechanics at the Faculty of Mining and Geology. Geochemical laboratory testing of groundwater was conducted in the Department of Public Health of the Republic of Serbia.

On the basis of results of detailed investigations, performed and controlled by the Faculty of Mining and Geology, University of Belgrade, engineering geological properties of the terrain site were determined. Accordingly, geotechnical conditions for the remedial measures that should provide long-term structural stability of the Parliament building were defined.

The solution for the problems of long-term subsidence, dynamic stability and sustainability of static structural system of the building was proposed by Faculty of Civil Engineering, University in Belgrade. The conceptual design of the rehabilitation of the structure for the Parliament building in Belgrade was defined at this stage of the work.

3 GEOTECHNICAL PROPERTIES OF THE TERRAIN SITE

The Parliament building of the Republic of Serbia is located on the plateau between the Boulevard of King Alexander and Vlajkoviceva, Takovska and Kosovska streets in Belgrade. The exploratory area is approximately 240 x 135 m or 3.24 ha.



Slika 3. Položaj istražnih bušotina i jama
Figure 3. Locations of boreholes and trial pits

U morfološkom smislu, istražni prostor predstavlja deo padine koja se od Terazija spušta ka Dunavu sa kotama, u intervalu, od približno 122 mnv kod Bulevara Kralja Aleksandra do 115 mnv u području Kosovske ulice.

U geološkoj građi terena, do dubine istraživanja, učestvuju: savremene veštačke tvorevine (nasip), prašinasti sedimenti kvartarne starosti, lesne naslage i

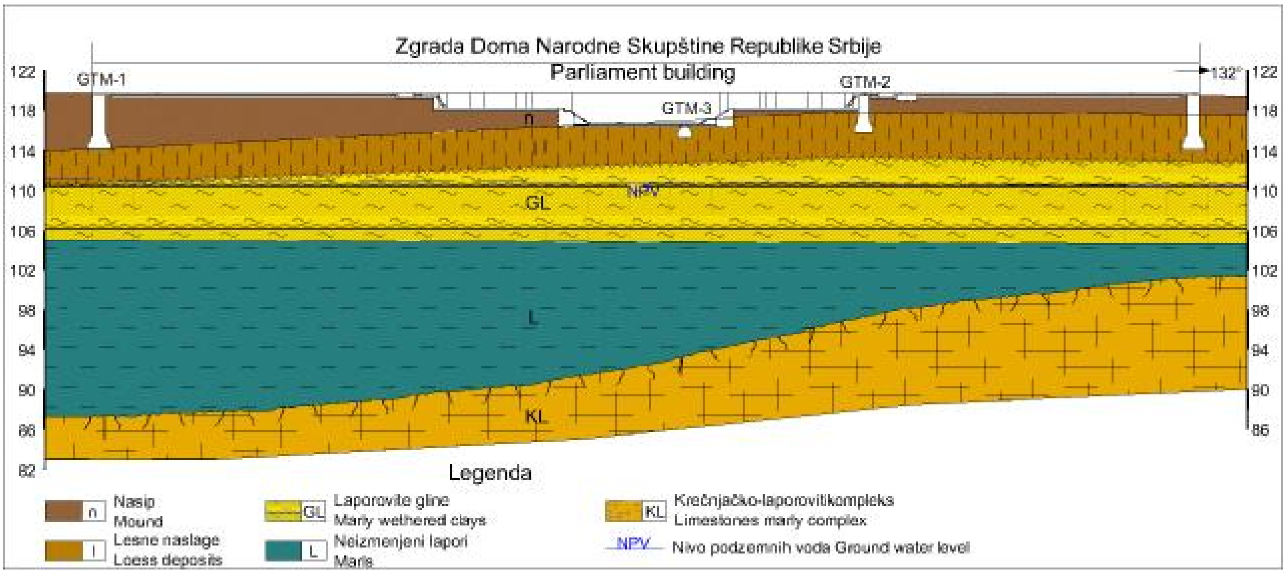
Morphologically, the site is a part of the slope that falls from plateau Terazije to the river Danube with elevations in the range of approximately 122 m above sea level near the Boulevard of King Alexander to the altitude of 115 m in the Kosovska street.

To the depth of investigations, the geological structure of the terrain consists of contemporary artificial deposits, mound, silty sediments of Quaternary loess laporovite gline, glinoviti lapori i krečnjaci tercijarne starosti, slika 4.

Teren je, u gornjem delu, izgrađen od nasipa (n) promenljive debljine 1.5 - 6.9m (izvan gabarita objekta), u čijoj su podlozi stišljive i na promenu vlažnosti, osetljive, lesne naslage (l) debljine 1.1m u bušotini B-4, do 5.6m u bušotini B-3. Od dubine 6.6 - 10.0m od površine, teren izgrađuju prekonsolidovani glinovito-laporoviti sedimenti: laporovite gline GL, promenljive debljine, od 5.4m u bušotini B-1 do 13.0m u bušotini B-6 i lapori L, takođe promenljive debljine, od 3.5m u bušotini B-3 do ≈19.0m u bušotini B-1, ispod kojih se nalazi tercijarni krečnjak K, neutvrđene debljine. Najmanja dubina na kojoj se krečnjak pojavljuje je 16.5m od površine terena, na koti ≈ 103m, u bušotini B-3.

deposits and Tertiary marly clays, clayey marls and limestones, Figure 4.

The terrain, in the upper part, is built of unconsolidated and heterogeneous mound, variable thickness of 1.5 - 6.9m (outside of the building), which is underlying by compressible and the change in moisture sensitive, loess deposits (l) of thickness 1.1m, in the borehole B-4, and 5.6m in the borehole B-3. In the depths of 6.6 - 10.0m from the ground surface, there are overconsolidated clayey-marly sediments: marly clay, GL, variable thickness of 5.4m in the borehole B-1 to 13.0m in the borehole B-6 and marls, L, also of variable thickness from 3.5m in the borehole B-3 to ≈ 19.0m in the borehole B-1. Tertiary limestones K, undetermined thickness, is under clays and marls. The minimum depth at which the limeston appears is 16.5m from the ground surface, at level of ≈ 103m, in the borehole B-3.



Slika 4. Geotehnički presek terena
Figure 4. Geotechnical cross-section of terrain

Podzemna vode nije konstatovana u bušotinama B-1, B-2 i B-3. U ostalim bušotinama je, u vreme bušenja (juli 2010.god.), izmeren nivo podzemne vode na promenljivim dubinama: 7.10m od površine terena, u bušotini B-4, do 8.40m od površine terena, u bušotini B-6. Nakon dvomesečnog osmatranja, nivo podzemne vode se nalazio na dubini ≈ 9.50m od površine terena. Maksimalni nivo podzemne vode je moguć u dubljim delovima lesnih naslaga i u zoni veće izdeljenosti laporovitih glina. Generalno, ovaj nivo prati nagib površine terena i nalazi se na dubini 7.0-9.0m od površine terena [2].

Fundiranje objekta, najvećim delom, izvedeno je u lesnim naslagama, osim za manji deo temelja ispod jugoistočnog dela objekta, prema Bulevaru Kralja Aleksandra, čije se temeljne spojnice nalaze na kontaktu lesnih naslaga i laporovitih glina.

U prijemu i prenošenju opterećenja od objekta učestvuju kvartarne lesne naslage i tercijarne laporovite gline i to:

– Lesne naslage (l), prašinasto-glinovite, promenljive debljine od 1.5 do 3.8m i

Groundwater was not observed in boreholes B-1, B-2 and B-3. In other boreholes, in the time of investigations (July of 2010.), groundwater level was measured at variable depths: 7.10m from the ground surface in borehole B-4, up to 8.40m from the ground surface in borehole B-6. After two months of observation, the level of the underground water was located at a depth ≈ 9.50m from the ground surface. The maximum level of groundwater may be located in the deeper parts of the loess deposits and in the zone of higher fragmentation marly clay. Generally, this level follows the slope of the ground surface and is located at a depth of 7.0-9.0m under the ground surface [2].

Foundation strips, for the most part of the Parliament building, are placed in the loess deposits, except for a small part of the ground beneath the southeastern part of the building, towards Boulevard King Alexander, where the footing level is in the contact of loess deposit and marly clay.

The loading from the building is transmitted to the Quaternary loess deposits and Tertiary marly clays as follows:

– Loess deposits (l), silty clays, CI, of variable

– Ispucale laporovite gline kore raspadanja (GL) promenljive debljine od 6.6 do više od 13.0m.

Nestišljivu podlogu, bedrock, predstavljaju tercijarni lapori, na dubini od 13.0 do više od 20.0m.

U Tabeli 1 su prikazani najvažniji parametri temeljnog tla merodavni za geostatičke proračune.

thickness from 1.5 to 3.8m

– Marly clays (GL) of weathering zone, CH, of variable thickness of 6.6 to more than 13.0m

Incompressible layer, bedrock, consists of Tertiary marls at a depth of more than 13.0 to 20.0m.

Table 1 presents the most important parameters of the foundation soil for the reliable geostatic analyses.

Tabela 1. Merodavni parametri tla za geostatičke proračune
Table 1. Reprezentative parameters of soils for geostatical analyses

Oznaka i debljina sloja u gabaritu objekta Mark and thickness of the soil beneath the building (m)		Zaprem. težina tla Unight weight of the soil γ/• '(kN/m^3)	Ugao unutrašnjeg trenja Shear resistance angle φ(^{0})	Kohezija Cohesion c (kPa)	Modul stišljivosti Modul of compressibility Ms (kPa)	Tlo Soil
n	1.5-5.30	19.0	-	-	-	-
I	1.2-3.8	18.2 10	25	10	8000 3500	Loess natural wet Wet loess
GL	6.6-13.0	19.3	23	15	8500	Fissured clay

4 TEHNIČKI PODACI O OBJEKTU

Dom Narodne skupštine je jedan od najvećih i najlepših spomenika kulture u Srbiji iz prve polovine 20. veka. Objekat je izgrađen u baroknom stilu, sa zidovima od opeke obloženim fonolitom i veštačkim kamenom. Objekat je nepravilnog, približno pravougaonog oblika, u osnovi površine ≈ 55 x 110 m. Visina objekta sa kupolom je ≈44 m.

Sastoji se od centralne zone i dva bočna krila, u kojima su smešteni atrijumi. Objekat ima podrum, suteren, prizemlje, dva sprata, potkrovlje i kupole. U konstruktivnom smislu, to je krut zidani objekat koji je fundiran na temeljnim trakama. Međuspratne konstrukcije su armiranobetonske ploče ojačane rebrima. Objekat nema dilatacionih razdelnica. Raskošni holovi i plenumske sale se visinski protežu na dve etaže, tako da su u ovim zonama formirani značajni otvori kroz međuspratne konstrukcije. Pored toga, prostrane vertikalne komunikacije – stepeništa, koja se nalaze u centralnoj zoni objekta, takođe formiraju otvore kroz međuspratne konstrukcije. Sve ovo značajno narušava integritet i jedinstvo objekta kao celine i bitno umanjuje njegovu krutost u ravni međuspratnih konstrukcija, što je posebno opasno kada je objekat izložen seizmičkim uticajima.

Izgradnja objekta je započeta u avgustu 1907.god. Do prvih deformacija na objektu došlo je još u toku građenja, 1909.god., usled čega su radovi na izgradnji objekta obustavljeni sve do 1911.god. Od 1911. do 1912.god. vršena je rekonstrukcija objekta i nakon toga je nastavljena izgradnja, ali je zbog istorijskih dešavanja zgrada završena tek 1937.god.

4 TECHNICAL DATA OF THE PARLIAMENT BUILDING

The Parliament building is one of the biggest and the most beautiful cultural monuments in Serbia from the first half of the 20th century. The building was built in Baroque style, with brick walls that are covered with clinkstone and artificial stone. The building has an irregular, roughly rectangular shape, with basic area of ≈ 55 x 110 m. The height of the building with the dome is ≈ 44 m.

It consists of a central zone and two side wings, where the atriums are located. The building has a cellar, basement, ground floor, two floors, attic and dome. Structurally, it is a rigid masonry construction that is founded on the strip foundations. The floors are reinforced concrete slabs that are reinforced with ribs. The building lacks expansion joints. Luxurious lobbies and plenum halls extend to the height of two stories, so significant openings are formed through the ceiling in these zones. Also, the large vertical communications (the stairs) that are located in the central zone of the building, create the openings through the floors. All these openings significantly reduce the integrity and unity of this object as a compact structure and greatly reduce its stiffness in the level of the floors. It is particularly dangerous in the case when the building is subjected to seismic effects.

Construction of the building began in August 1907.year. The first deformations and displacements of the object occurred in 1909, so the construction works were suspended until 1911.

Slika 5. Utvrđivanje dimenzija temelja u jami J-1
Figure 5. Measuring foundation dimensions in trial pit J-1

Slika 6. Uzimanje uzorka tla ispod temelja u jami J-1
Figure 6. Sample extracting from trial pit J-1

Originalan građevinski projekat nije sačuvan, a prema našim terenskim istraživanjima, objekat je fundiran na betonskim temeljnim trakama, sa visinom betonske stope 75 cm, promenljive širine i na promenljivoj dubini fundiranja, slike 5 i 6:

– T_1, spoljna temeljna traka (u istražnoj jami J-1 u zapadnom delu objekta, širina temelja B_1=2.30m, na dubini fundiranja 5.50m od površine trotoara kota 119.57m, $D_{fmin}=D_f$=5.50m ;

– T_2, unutrašnja podužna temeljna traka (u istražnoj jami J-2, u jugoistočnom atrijumu), širina temelja B_2=1.95m na dubini fundiranja 4.15m od površine trotoara (kota119.46m, D_{fmin}=2.41m);

– T_3, unutrašnji poprečni temelj (u istražnoj jami J-2 u jugoistočnom atrijumu), širina temelja B_3=1.45m na dubini fundiranja 3.65m od površine trotoara (kota119.57m, D_{fmin}=1.41m).

Analiza opterećenja, dobijena od inženjera statičara, pokazala je da su izračunata opterećenja u rasponu: 236 do 298 kPa za stalno opterećenje i 9.20-16.0 kPa za korisno opterećenje, što dovodi do prosečnog opterećenja σ=267 kPa za stalno i dodatnih 12 kPa za korisno opterećenje, tako da je ukupni srednji napon koji temeljne trake prenose na tlo σ_{sr}= 280 kPa.

The building was reconstructed from 1911 to 1912, but due to the following historical events construction was finally completed in 1937.

The original building design was not saved, and according to our field exploration, the building is founded on concrete strip foundations, Figure 5 and 6, with a height of 75 cm and with variable widths of the footing and depths of the foundations:

– T_1, the external footing strip (the excavated trial pit J-1 in the western part of the building) has a width of B_1=2.30m and it is founded at a depth of 5.50m below the surface of the pavement (level 119.57m, Df_{min} = minimum depth of foundation = 5.50m).

– T_2, the internal longitudinal footing strip (the excavated trial pit J-2 in the southeast atrium) has a width of B_2=1.95m and it is founded at a depth of 4.15m below the surface of the pavement (level 119.46m, Df_{min} = minimum depth of foundation = 2.41m).

– T_3, the internal cross footing strip (the excavated trial pit J-2 in the southeast atrium) has a width of B_3=1.45m and it is founded at a depth of 3.65m below the surface of the pavement (level 119.57m, Df_{min} = minimum depth of foundation = 1.41m).

Analysis of the loading, obtained from the structural

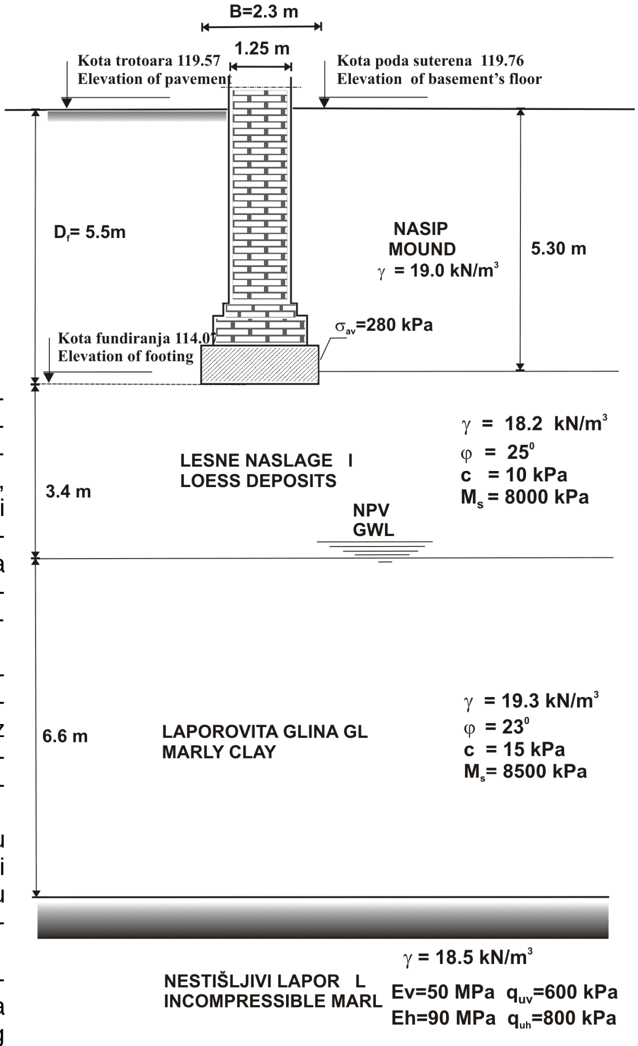
5 GEOSTATIČKI PRORAČUNI

Proračuni graničnih opterećenja su urađeni za utvrđene geotehničke modele terena GMT-1, slika 7, GMT-2, slika 8 i GTM-3, slika 9, kao i za različite moguće kombinacije širina temelja i dubina fundiranja, kao i za uslove prirodno vlažnog tla i provlaženog tla.

Granično vertikalno centrično opterećenje temelja sračunato je po postupku iz Pravilnika o tehničkim normativima za temeljenje građevinskih objekata.

Faktor sigurnosti F_s u pogledu dozvoljene nosivosti temeljnog tla je dobijen u odnosu na prosečno opterećenje σ_{sr}=280kPa.

Izvršene su analize graničnih opterećenja i faktora sigurnosti u pogledu opšteg loma, za sve, terenskim radovima utvrđene, širine temelja i dubine fundiranja.



Slika 7. Geotehnički model terena GMT 1
Figure 7. Geotechnical model of terrain GMT 1

engineer, showed that the calculated load range is: 236 - 298 kPA for permanent load and 9.20 – 16.0 kPa for imposed load, resulting in an average load σ = 267 kPa for a permanent and 12 kPa for imposed load, so the total average load of the concrete strips, that is transferred to the ground is σ ≈ 280 kPa.

5 GEOSTATIC ANALYSES

Bearing capacity analyses were performed for the different combinations of width of strip footings and depth of foundations, The analyses were performed for pervious defined geotechnical models of terrain GMT-1, Figure 7, GMT-2, Figure 8 and GMT-3, Figure 9, as well as in naturally wet soil conditions and in soil with increasing moisture.

The ultimate vertical centric bearing capacity of the foundation soil was calculated according to Serbian technical codes for foundation of buildings.

The safety factor, F_S for allowable bearing capacity of foundation soil was determined in relation to the average load σ_{av} = 280 kPa.

Bearing capacity analyses were performe and safety fac tors were calculated for all field conditions and for all widths of footings and depths of foundation which were identified by trial pits.

Na osnovu izvršenih analiza može se zaključiti da su faktori sigurnosti, u sadašnjim uslovima (tlo je u gabaritu objekta konsolidovano usled opterećenja od objekta, kao i usled težine nasutog tla) veći od 2.5 za sve temelje, tako da nosivost temeljnog tla nije dovedena u pitanje [3].

Sleganje temelja je sračunato za srednji neto kontaktni napon σ_{zo}=250 kPa i širine temelja B_1=2.30m, B_2=1.95m i B_3=1.45m, uz uvažavanje odgovarajućeg geotehničkog modela terena.

Proračuni sleganja temelja su vršeni za centričnu tačku temelja, a date su i veličine prosečnih sleganja temelja. Veličine sleganja pod objektom određene su konvencionalnom metodom [1]. Raspodela napona u temeljnom tlu određena je metodom Štajnbrenera.

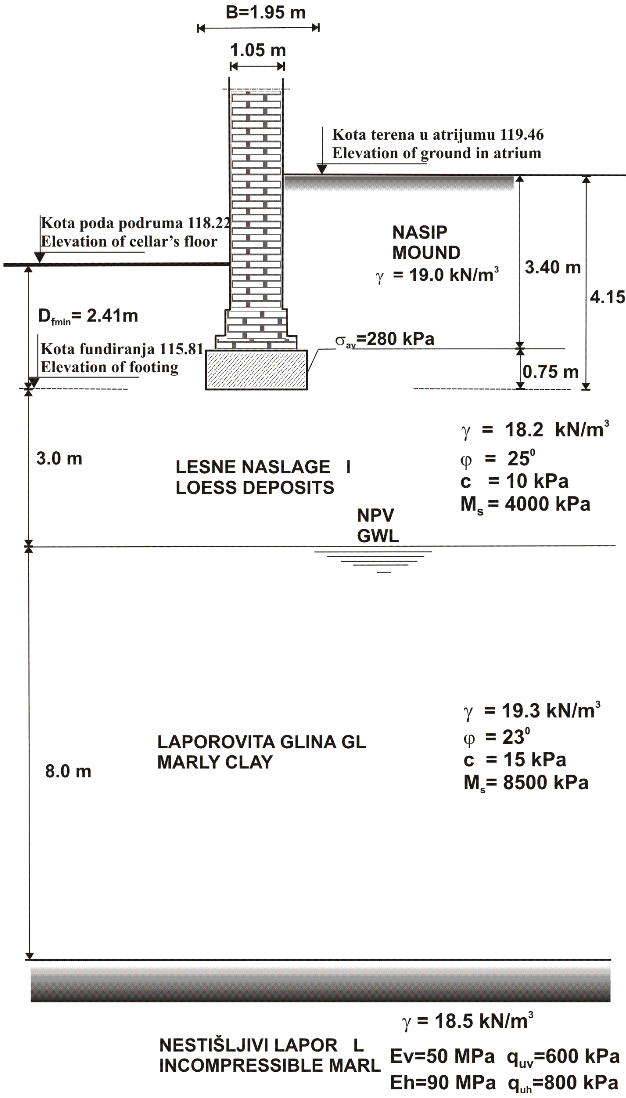
U Tabeli 2 su prikazane veličine maksimalnih i prosečnih sleganja za različite temelje i geotehničke modele terena.

Thus, it can be concluded that the factors of safety, under the present conditions (the soil is consolidated beneath the foundations due to the load of the building and weight of the buried soil) are higher than 2.5 for all footing strips, so that bearing capacity of foundation soil is not compromised [3].

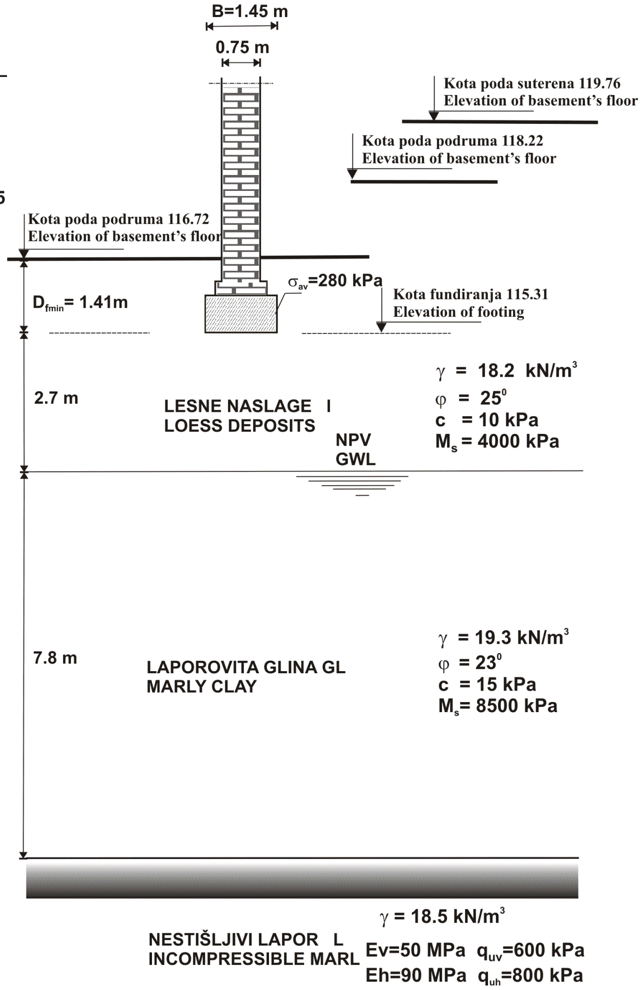
Footing settlements were calculated for the average net contact pressure σ_{avn} = 250 kPa and strip widths of B_1= 2.30m, B_2=1.95m and B_3 = 1.45m, taking into account appropriate geotechnical model of the terrain.

Settlement analyses were performed for the centric point, but the average values of the settlement were also calculated. The settlement values of building were determined by the conventional method [1]. The distribution of stresses under the foundation strips was determined by the Steinbrenner's method.

The maximum and average values of settlement for different footing strips and different geotechnical terrain models are presented in Table 2.



Slika 8. Geotehnički model terena GMT 2
Figure 8. Geotechnical model of terrain GMT 2



Slika 9. Geotehnički model terena GMT 3
Figure 9. Geotechnical model of terrain GMT 3

Analiza rezultata sleganja pokazuje da su se, samo usled opterećenja od objekta, temelji slegli u proseku za 9 -14cm. Ovim sleganjima od opterećenja objektom, svakako treba dodati i sleganja usled provlažavanja temeljnog tla, koja su u ovakvim inženjerskogeološkim sredinama i kod starih objekata neizbežna i koja, u našem slučaju, iznose i do 8.0 cm [4].

U vezi sa tim treba reći da su, prema Skemptonu i MekDonaldu, za ovakvu vrstu temelja, dozvoljena ukupna sleganja 6.5cm, a dozvoljena diferencijalna sleganja 4.0 cm [9].

Maksimalna sleganja su pretrpeli temelji koji se nalaze u središnjem delu zgrade, ispod glavnog stepeništa, gde su debljine lesnih naslaga najveće (≈ 3.0m), a gde njihovi moduli stišljivosti, istovremeno, imaju najniže vrednosti (≈ 3500 kPa u J-2).

Analysis of the results shows that the foundation settlements sank in average 9-14cm only due to the loading of the building. Sinking of the foundation soil due to the increase of soil moisture should be added as well [4]. That settlements are, in loess deposits and in the old buildings environment, almost inevitable. For the loess deposits the settlement due to the increase of the soil moisture could be additionally 8 cm.

Thus, according to Skempton and MacDonald (1956) the allowable total settlements for this type of foundation are 6.5 cm and allowable differential settlements are 4.0 cm [9].

Maximum sustained settlements arised in the central part of the building, underneath the main staircase, where the thickness of loess deposits is the largest (≈ 3.0m), and where their moduli of compressibility, at the same time, have the lowest value (≈ 3500 kPa in the J-2).

Tabela 2. Rezultati proračuna sleganja temeljnih traka
Table 2. Results of the foundation settlement analyses

Geotehnički model terena (Geotechnical model of terrain)	Širina temeljne trake (Width of footing strip) B (m)	Debljina i modul stišljivosti sloja (Thickness and moduli of compressibility) H (m)^Ms (kPa)	Neto prosečno kontaktno opterećenje (Net average contact pressure) • av $_n$ (kPa)	Najveće sleganje (Maximum settlement) s (cm)	Prosečno sleganje (Average settlement) s (cm)
GMT_1	2.30	*I* 3.40 ^ 8 000 *LG* 6.60 ^ 8 500	250	11.5	9.2
GMT_2	1.95	*I* 3.00 ^ 4 000 *LG* 8.00 ^ 8 500	250	17.5	14.0
GMT_3	1.45	*I* 2.80 ^ 4 000 *LG* 7.80 ^ 8 500	250	14.1	11.3
T_1 u preseku (T_1 in section) VI-VI’	2.30	*I* 1.20 ^ 8 000 *LG* 8.20 ^ 8 500	250	11.4	9.1
T_4 u preseku (T_4 in section) IV-IV’	2.30	*LG* 11.60 ^8 500	250	12.1	9.7
T_5 u preseku (T_5 in section) IV-IV’	1.95	*I* 2.00 ^ 4 000 *LG* 12.00 ^ 8 500	250	16.1	12.9
T_6 u preseku (T_6 in section) IV-IV’	2.30	*I* 2.00 ^ 8 000	250	12.7	10.1

Za potrebu ove analize formiran je model na bazi metode konačnih elemenata, i to primenom domaćeg softverskog paketa Tower 6. Detaljniji prikaz numeričkog modela prikazan je u Idejnom rešenju, autorizovanom programu i projektnom zadatku sanacije konstrukcije Doma Narodne skupštine u Beogradu, urađenom 2010. godine od strane Građevinskog Fakulteta Univerziteta u Beogradu [6].

Svi armiranobetonski elementi konstrukcije modelirani su sadašnjom markom betona MB20. Zapreminska težina zidova od opeke je 1700 kg/m^3. Modul elastičnosti zidanog zida određen je prema evropskim standardima EC 6 za proračun zidanih konstrukcija i tako je dobijena vrednost E=4835MPa. Tlo ispod temeljne konstrukcije modelirano je posebnim konačnim elementima čije su karakteristike određene na osnovu vrednosti koeficijenta vertikalne reakcije tla. Ova vrednost određena je saglasno EC 7, na osnovu prethodno izračunatih sleganja temelja, Tabela 2 i usvojeno je da iznosi k=2650 kN/m^3.

Ovim proračunima dobijene su veličine sleganja ≈10.0-11.0 cm, što se dobro slaže sa veličinama sleganja dobijenim konvencionalnom metodom.

Ovim je potvrđeno da je model konstrukcije dobro napravljen [5]. Tako ovaj model može biti iskorišćen u daljoj analizi postojećeg stanja na konstrukciji, a pruža mogućnost i za proračun konstrukcije tokom eventualne sanacije objekta.

Ovde je potrebno istaći da se, uvođenjem adekvatnih modula elastičnosti za opeku, program Tower 6 može da koristi i za proračun zidanih građevina. Ovo predstavlja proširenje programa, što može da bude vrlo značajno, jer u Beogradu postoje mnoge zidane građevine koje imaju brojna oštećenja i zahtevaju primenu sanacionih mera.

For the purpose of the analysis in this paper, the numerical model is created on the basis of finite element method, using the domestic software package Tower 6. Detailed overview of the numerical model is given in Conceptual design, authorized program and project task for the rehabilitation of the structure for the Parliament building in Belgrade. This report was done by the Faculty of Civil Engineering, University in Belgrade in 2010 [6].

All reinforced concrete structural elements are calculated with concrete grade MB20. Volume weight of brick walls is 1700 kg/m^3. Modulus of elasticity of brick wall was determined according to European standards for design of masonry structures (EC6) and it is obtained E = 4835MPa. The foundation soil is modeled by a special finite elements whose characteristics are determined by the value of the modulus of subgrade reaction. This value is determined according to EC 7, Table 2, on the basis of the calculated settlements, and has been adopted k_s = 2650 kN/m3.

The settlement values determined by finite element analysis are ≈10.0-11.0 cm, which corresponds to the values obtained by conventional method.

This confirms that the model of this structure is well made and it can be used in further numerical analysis of the current state of this structure. Thus, the calculation of the structure during the possible rehabilitation can be performed.

It should be noted that taking into consideration equivalent values of modulus elasticity for brick walls, the software package Tower 6 can be also used for the calculation of masonry structures. This extension of this software can be very useful, because there are many masonry buildings in Belgrade which have structural damages and should be rehabilitated.

Sleganja terena na koti fundiranja, koja su nastala od opterećenja objekta su veća od dozvoljenih i konstruktivni sistem objekta, svojim elastičnim kapacitetom nije mogao da ih prihvati i podnese bez oštećenja. Samim tim, u zonama gde je bila iscrpljena nosivost konstrukcije, pojavila su se oštećenja koja su se manifestovala kao prsline, pukotine i slični diskontinuiteti na samom objektu, slika 2.

Posebno treba naglasiti negativan uticaj raskvašavanja lesnih naslaga ispod temelja koje dovodi do dodatnih sleganja objekta. Ovo izaziva ugaonu rotaciju delova objekta, oko mesta provlažavanja, koja je znatno veća od dozvoljene, a što neizbežno dovodi do novih oštećenja objekta. Ovo je karakteristično za mnoge stare zgrade u Beogradu.

Rezultati seizmičke mikrorejonizacije pokazali su da objekat treba računati sa koeficijentom seizmičnosti Ks=0.05 (VIII seizmička zona) usvajajući prvu kategoriju objekta i drugu kategoriju tla. Izmereni periodi oscilovanja su: u podužnom pravcu 0.792 sec, a u poprečnom pravcu 0.890 sec [8].

Prema rezultatima seizmičkih proračuna, maksimalna horizontalna pomeranja vrha objekta – kupole, usled dejstva zemljotresa iznose: u podužnom pravcu 8.90 cm, a u poprečnom pravcu 7.40cm [6].

I pored uočenih oštećenja i nedostataka, objekat je u funkciji, služi nameni i koristi se bez većih problema. Da bi se ovakvo stanje zadržalo i u narednom periodu, neophodno je preduzeti mere i intervencije, kako na konstruktivnom sistemu objekta, tako i na temeljnoj konstrukciji. Preduzete mere i intervencije bi trebalo da spreče dalje širenje oštećenja i sačuvaju integritet čitavog objekta.

Zato su, s obzirom na geotehničku problematiku, razmatrana varijantna rešenja mera sanacije: ojačanjem temeljne konstrukcije mikrošipovima, dijafragmama ili kombinacijom dijafragmi i mikrošipova.

Primenom sistema mikrošipova sprečila bi se dalja sleganja, ali se ne bi uvećala sposobnost objekta da primi horizontalne sile od seizmičkih sila. Osim toga, naknadno raskvašavanje lesnih naslaga, u zoni fundiranja objekta, moglo bi da umanji nosivost mikrošipova, a samim tim i omogući dalji razvoj sleganja objekta.

Sanacija temeljne konstrukcije sistemom dijafragmi obezbedila bi i dinamičku stabilnost objekta i njegovu bezbednost u pogledu oscilacija nivoa podzemnih voda. Međutim, zbog izrazite razuđenosti objekta, ne može se efikasno prići svim bitnim zonama unutar samog objekta.

Zbog toga je predloženo da se sanacija temeljne konstrukcije izvede kombinovanjem mikrošipova i dijafragmi sa pratećim adekvatnim intervencijama na konstruktivnom sistemu objekta (Građevinski fakultet Univerziteta u Beogradu, 2010).

Ground settlements at a footing level, arising from the building load and increase of soil moisture are larger than allowable values. Thus, the building structural system with its elastic capacity was not able to accept and submit these settlements without damages. Therefore, in places where construction capacity was exhausted, appeared the damages that were manifested as cracks, crevices and similar discontinuities on the some parts of construction, Fig. 2.

The negative impact of later soil moisture increasing on loess deposits underlying the foundation should be emphasized as well. It produces subsequent subsidence of the building. Additional settlements lead to the angular rotations of some parts of the building around the site of the increase of soil moisture which were significantly higher than the allowable values, and inevitably cause the additional damage of the building [5]. It characterizes many old buildings in Belgrade.

Results of performed investigations of the seismic microzoning showed that the seismic coefficient is Ks = 0.05 (seismic zone VIII) by adopting the first category for building and the second category for soil. The measured periods of oscillations are: in the longitudinal direction 0.792 sec and 0.890 sec in the transverse direction [8].

According to the results of seismic calculations, the maximum horizontal displacements due earthquake to the top of the dome are: in the longitudinal direction 8.90 cm and 7.40cm in the transverse direction [6].

Despite the observed damages and deficiencies, the Parliament building is in operation. It serves to its purpose and it is in use without any problems. To retain this status in the future, it is necessary to take action and intervention to the building construction system as well as to the foundation structure. These actions and interventions should prevent further spread of damages and should preserve the integrity of the whole building. Therefore, from the geotechnical point of view, some solutions of remedial measures are considered: strengthening of foundation structure with micropiles, diaphragms, or with combination of micropiles and diaphragms.

Applying the system of micropiles would prevent additional settlements, but it would not increase the ability of structure to receive the horizontal seismic forces. Besides, subsequent leaching of loess deposits in the foundation soil could reduce the bearing capacity of micropiles. This would cause additional settlements of the building.

Rehabilitation of foundation structure using diaphragms would produce the dynamic stability of the structure as well as its safety in regard to the fluctuations of groundwater levels. However, due to exceptional indentation of the building, it is not possible to make diaphragms in all relevant areas within the object.

Therefore, it was proposed that rehabilitation of the foundation system can be performed using the suitable combination of micropiles and diaphragms, with additional appropriate interventions in the building structure system (Faculty of Civil Engineering, University in Belgrade, 2010).

6 ZAKLJUČAK

Zbog uočenih oštećenja na zgradi Doma Narodne Skupštine Republike Srbije u Beogradu, a i ugrožene dugoročne dinamičke stabilnosti objekta, izvedena su detaljna geotehnička istraživanja terena. Ova istraživanja izveo je Rudarsko-geološki fakultet Univerziteta u Beogradu, 2010.god.

U prijemu i prenošenju opterećenja od objekta učestvuju kvartarne lesne naslage debljine od 1.5 do 3.8m i tercijarne ispucale laporovite gline kore raspadanja promenljive debljine od 6.60 do više od 13.0m. Nestišljivu podlogu, bedrock, predstavljaju tercijarni lapori, koji se nalaze na dubini od 13.0 do više od 20.0m.

Objekat je, u konstruktivnom smislu, krut zidani objekat, fundiran na betonskim temeljnim trakama, promenljive širine, od 1.45m do 2.30m, i na promenljivoj dubini fundiranja, od 1.41m do 5.50m

Izvršene analize graničnih opterećenja i faktora sigurnosti u pogledu opšteg loma tla, za sve, terenskim radovima utvrđene, širine temelja i dubine fundiranja, pokazuju da su faktori sigurnosti, u sadašnjim uslovima veći od 2.5 za sve temelje.

Analiza rezultata sleganja pokazuje da su se, samo usled opterećenja od objekta, $\sigma_{sr} \approx 280$ kPa, temelji slegli u proseku za 9 -14cm. Ovim sleganjima od opterećenja objektom, svakako treba dodati i sleganja usled provlažavanja temeljnog tla, koja su u ovakvim inženjerskogeološkim sredinama i kod starih objekata, neizbežna. Ukupna sleganja terena su veća od dozvoljenih i konstruktivni sistem objekta nije mogao da ih prihvati i podnese bez oštećenja. Samim tim, u zonama gde je bila iscrpljena nosivost konstrukcije, pojavila su se oštećenja koja su se manifestovala kao prsline, pukotine i slični diskontinuiteti na samom objektu. Posebno treba naglasiti negativan uticaj raskvašavanja lesnih naslaga ispod temelja koje dovodi do dodatnih sleganja objekta.

Prema rezultatima seizmičkih proračuna, maksimalna horizontalna pomeranja vrha objekta-kupole, usled dejstva zemljotresa iznose: u podužnom pravcu 8.90 cm, a u poprečnom pravcu 7.40cm.

Radi obezbeđivanja statičke i dinamičke stabilnosti objekta, razmatrana su varijantna rešenja mera sanacije: ojačanjem temeljne konstrukcije mikrošipovima, dijafragmama ili kombinacijom dijafragmi i mikrošipova. Zaključeno je da bi se kombinovanjem mikrošipova i dijafragmi, sa pratećim adekvatnim intervencijama na konstruktivnom sistemu objekta, trajno rešili problemi sleganja i problemi dugoročne dinamičke stabilnosti i statičke održivosti konstruktivnog sistema objekta.

6 CONCLUSION

The observed damages and deficiencies over the Parliament building Republic of Serbia in Belgrade, as well as the endangered long-term structural dynamic stability of the building and public safety, caused the need to carry out detailed geotechnical explorations. These investigations were performed by the Faculty of Mining and Geology, University of Belgrade.

On the basis of these investigations it was concluded that the loading from the building is transmitted to Quaternary loess deposits of thickness from 1.5 to 3.8m and to Tertiary marly clays of weathering zone with variable thickness from 6.60 to more than 13.0m. Incompressible layer, bedrock, consists of Tertiary marls, at a depth of more than 13.0 to 20.0m.

Structurally, the building is a rigid masonry construction that is founded on the strip foundations, with variable widths of footing, from 1.45m to 2.30m and with variable depths of foundation, from 1.41m to 5.50m.

The bearing capacity analyses confirmed that, for all geotechnical models of terrain and for all foundation strips, safety factors with respect to the general failure of soil are higher than 2.5.

Due to total average load $\sigma_{av} \approx 280$ kPa, settlements were 9-14cm. For these settlement values, due to the loading of the building, it has to be added the settlement (sinking) of the foundation soil due to the increase of the soil moisture. It is almost inevitable for these deposits and beneath the very old buildings. Thus, the total ground subsidence is higher than allowable and the building structural system was not able to accept and bear it without damages. Therefore, the damages that were manifested as cracks, crevices and similar discontinuities at the building appeared in parts where the construction capacity was exhausted. It should be emphasized that there is the negative impact of increased moisture of the loess deposits under the foundation that leads to the additional subsidence of the building.

According to the results of seismic calculations, the maximum horizontal displacements of the top of the dome, due to the earthquake, are as follows: in the longitudinal direction is 8.90 cm and 7.40cm in the transversal direction.

In order to provide static and dynamic stability of the building, some solutions for the remedial measures were considered: strengthening foundation structure by micropiles, diaphragms, or a with combination of micropiles and diaphragms. It was concluded that the combination of micropiles and diaphragms, with additional appropriate interventions in the building construction system, will solve problems of permanent subsidence and problems of dynamic stability as well as long-term sustainability of the building structure system.

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REZIME

GEOTEHNIČKI UZROCI OŠTEĆENJA DOMA NARODNE SKUPŠTINE U BEOGRADU

Gordana HADZI-NIKOVIĆ
Slobodan ĆORIĆ
Stanko ĆORIĆ

Dom Narodne skupštine je jedan od najznačajnijih spomenika kulture u Srbiji iz prve polovine dvadesetog veka. Na njemu su uočena brojna oštećenja i u cilju njegove sanacije bilo je neophodno izvođenje detaljnih geotehničkih istraživanja koja je izvršio Rudarsko-geološki fakultet Univerziteta u Beogradu. Ovim istraživanjima definisana su geotehnička svojstva terena u zoni njegove interakcije sa objektom, a određena su i sleganja temelja i nosivost temeljnog tla. Utvrđeno je da su stvarna opterećenja temelja manja od dozvoljenih, ali da su sleganja temelja višestruko veća od dopuštenih i da je to glavni uzrok oštećenja objekta. Ova sleganja su određena konvencionalnom metodom i metodom konačnih elemenata i dobijeni su slični rezultati. Osim toga, analizom sa konačnim elementima, utvrđeno je i da objekat ne zadovoljava uslove stabilnosti u slučaju dejstva zemljotresa. Stoga su, u saradnji sa projektantom sanacije objekta, predložene sanacione mere koje sa geotehničkog aspekta trajno rešavaju probleme kako statičke tako i dinamičke stabilnosti Doma Narodne skupštine u Beogradu.

Ključne reči: oštećenja konstrukcije, geotehnička istraživanja, nosivost tla, sleganja temelja, geotehnički model, statička i dinamička stabilnost, geotehničke mere sanacije.

SUMMARY

GEOTECHNICAL CAUSES OF DAMAGES FOR THE PARLIAMENT BUIDLING IN BELGRADE

Gordana HADZI-NIKOVIC
Slobodan CORIC
Stanko CORIC

The Parliament building of the Republic of Serbia is one of the biggest and most beautiful cultural monuments in Serbia from the first half of 20th century. Right now, there are numerous structural damages over the building. In order to define remedial measures for rehabilitation of the Parliament building, it was necessary to carry out detailed geotechnical investigations. These investigations were performed by the Faculty of Mining and Geology, University in Belgrade. Thus, geotechnical properties of the terrain in a zone of its interaction with the building were defined according to the obtained results. The bearing capacity of foundation soil and settlements of footings were calculated, too. These analyses showed that the existing footings loads values are less than allowable values, but the settlements of footings are much larger than it is allowable, and it is a main reason of the structural damages over the building. The settlements were determined by two methods: conventional and finite element. The obtained values are very close. In addition, by the finite element analysis it was concluded that the building has no resistance to the effects of earthquakes. Remedial measures were proposed on the basis of these results, and in cooperation with engineers responsible for rehabilitation of the structure. These measures permanently solve the problems related to the static and dynamic stability of the Parliament building from the geotechnical point of view.

Key words: structural damages, geotechnical investigations, bearing capacity, footing settlement, geotechnical model, static and dynamic stability, remedial geotechnical measures.