The Investigation of Technical Conditions in Several Public School Buildings in Tirana

Architecture and Design

Kewords: soil-structure interaction, ultimate limit state, serviceability, structural damages

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Abstract

This paper deals with the investigation of technical conditions in several public school buildings in Tirana. 30 schools have been investigated and 12 of them have been found with considerable structural damages, affecting the functionality and serviceability of the building itself. In the paper are enhanced those damages connected with the geotechnical aspects of the structure. The most frequent identified concern was the lack of a comprehensive and complete study of the soil-structure interaction, leading to direct and indirect damages in the building structure. Causes and influential geotechnical issues affecting the building performance are elaborated and discussed, in order to demonstrate how these factors can cause the occurrence of serviceability and ultimate limit state. At the end some recommendations and discussions are made in order to improve existing situation and to prevent the occurrence of similar cases.

1. Introduction

This study is regarding to the public school buildings in Tirana, due to the enhanced importance of the city in country level. The studied buildings belong to the category of special importance buildings, according to KTP [4] [5] [6] and during the last 22 years there have been much damages to school buildings. We considered 30 public school buildings and 12 of them resulted in considerable structural damages influencing its functionality. In order to analyze the causes of the occurred damages, we enhanced on soil structure interaction (SSI) issues. This issue deals with several problems connected to the damages occurred in the buildings. Mostly, some problems related to foundations are discussed and also the diagnoses of problems and their causes (during the design or construction phases) and at the end examples of partial and total damages are shown. The study combines the theoretical conclusions with the specific discussed examples and even more with the scientific argumentation of the causes and influencing geotechnical factors, related to the miss functionality of the building. We think that the above issues make this material important and valuable for the designers and other professionals dealing with similar buildings. At the end recommendations are shown in order to avoid similar problems in the future. Damages can be due to: possible mistakes in the design phase, ground properties of the terrain, ground water, river floods, landslides, heavy rains, fire, earthquakes, use of un standardized building materials, bad construction quality, etc. In our case, the causes of damages are some phenomena related to soil behavior and their parameters.

2. Analysis of technical conditions in public school buildings in Tirana

In our study it is enhanced the importance of technical standards of design and construction KTP [5] of school buildings and even more to those related to foundation design. From the survey it can be concluded that most of the buildings are based on shallow foundations. Since these foundations are the source of more than 32% of the damages, it was decided to analyze and then to give recommendations regarding this type of foundations.

It was evidenced the lack of consulting with KTP in three phases:

- In the design phase
- In the construction phase
- In the utilization phase
- During the design phase it was identified the following:

a. Wrong calculation of loading on structure, resulting in wrong dimensioning of structural elements and in wrong prediction of reinforcement.
b. The neglect of possible deformations that can occur due to several reasons, such as: atmospheric agents, temperature change. This can bring to cracks to the ground during the summer and heave during the winter, resulting in damages to the foundations.
c. The neglect of possible landslides nearby the building.
d. The lack of a full and complete geologic survey report, resulting in future damages of the building.
e. Water actions, which can cause: settlements in silts, long terming deformations in clays, decrease of unit weight of the soil (increase of active zone and also of settlements).
f. Slide of all the school building due to the slide of the ground under the object.

Fig. 1 Damage of the school due to a sliding plane not evidenced before

This can happen due to:

- the presence of a sliding plane not evidenced before
- the decrease of soil resisting parameters in the sliding plane because of rain waters
- seismic shaking
- the construction of a new building on the same slope of the existing school that makes the slope unstable

During the construction phase it was identified the following:

a. the usage of an inappropriate concrete class
b. the production of the concrete in construction site not according to the recommendations
c. low quality of reinforcement arrangement and welding
d. the used quantity of reinforcement not according to the required from the design phase
e. the usage of an inappropriate steel class and quality
f. damages in the structure during the construction phase due to changes in the last moment in order to create space for the implementation of electric and hydraulic pipelines

During the utilization phase it was identified the following:

a. technical mistakes during reconstruction of the building and changing the loading conditions
b. changes on the loading type of the buildings

3. Analysis of the causes of foundation damages in public school buildings

In order to analyze the foundation damage causes, despite the literature, the following issues are discussed:

- Foundation settlement
  From the survey done in school buildings, those based on clay soils have undergone to unpredicted settlements, causing characteristic cracks in the building. This phenomenon has happened in shallow foundations which were not positioned on the appropriate depth. During drought time clay soil shrink and in this way cracks are created and during rain time the cracks are filled with water and the soil swell. These vertical movements of the ground cause damages and cracks in the foundations.

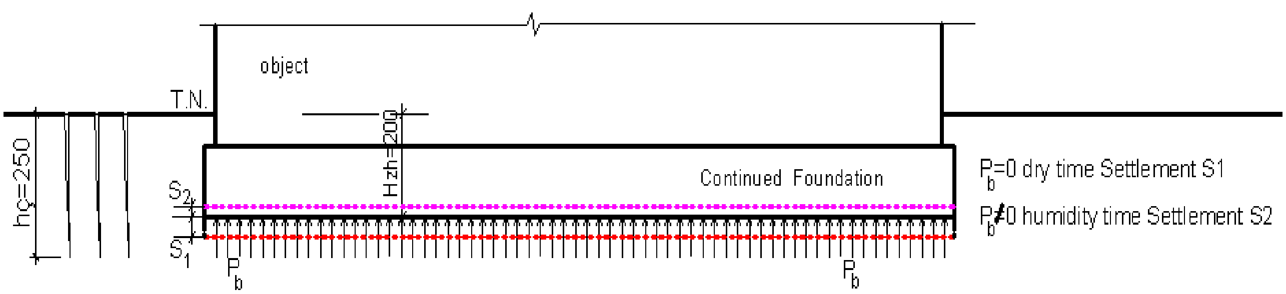


Fig 2 Foundation settlements during drought and rain time

- Little slides of the ground accompanied with horizontal and vertical displacements.

This has leaded to diagonal cracks in shallow continuous foundations and also similar cracks in buildings walls. The absence of drainage systems around the buildings has lead to the increase of water pressures.

- The placement of the foundation in a soil layer with weak properties or in an artificial layer and without drainage.
- Uneven settlements of the building due to different loading rates.
- Uneven settlements due to the presence of very compressible soil layers.
- Settlements above the permissible values due to the creation of plastic zones under the foundation.

4. Considering the soil structure interaction in the stability of school buildings

Considering the soil structure interaction (SSI) insures a normal functionality of the building. The most delicate point on this regard is the foundation, which coordinate the work of the structure and basement, two media with very different parameters. In order to insure a good interaction between the structure and the basement we have to know very well the characteristics of the structure (especially the sensitivity towards differential settlements) and also the properties of the basement. According to the sensitivity against differential settlement [1] the public school buildings belong to the III category (sensitive to differential settlement).

Regarding the basement characteristics, we have to know:

- its physical properties
- soil classification and type
- compressibility parameters
- infiltration parameters
- resisting parameters

According to these properties we can chose the calculating model of the basement. SSI can be considered for static and dynamic load conditions. In our case only static loading was considered. In order to ensure SSI the following should be calculated:

- consolidation settlements and time of settlements
- hydrodynamic pressure
- critical stresses (which can put the foundation out of stability)
- the stability of specific points of basement
- bearing capacity of the basement
- stability of natural and artificial slopes
- lateral soil pressures, etc.

In the following, we are considering a case where the neglecting of SSI has caused damages to the structure. Firstly, the design of the foundations for the school in Farke was done without a detailed geological study. From the available geological study we have γ=18.50KN/m3; γ_0=27 KN/m3; W=26.50 %; W_S=28.80 %; W_P=24.20 %; [σ]=150kPa. With this data was done the calculation of the foundations of the building. The load in the foundation for 1ml is N=9105daN. The area of the foundation (by taking its width 1m) for this load is:

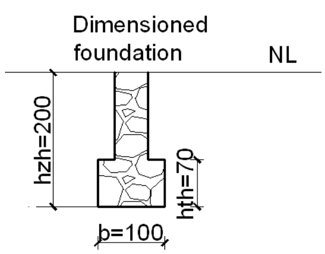
$$A_{th} = \frac{N}{[\sigma] - \gamma H_{zh}} = \frac{9105}{15000 - 2000 \cdot 2} = 0.89m \quad (1)$$

The height of the foundation is:

$$h_{th} = \frac{b - bm}{2tg\alpha_{kuf}} = \frac{100 - 25}{2tg31^0} = 62.5cm \quad (2)$$

The height of the foundation was chosen 0.7m. During the functionality of the buildings there have been cracks in the foundation and also in the wall. Most probably, these damages are due to the lack of the study of basement. In order to prove this we have to check:

- the foundation settlement according to the soil layers compressibility
- the foundation deflection according to its settlements
- the stability of special points of the basement and the formation of plastic zones (by checking tangential stresses)



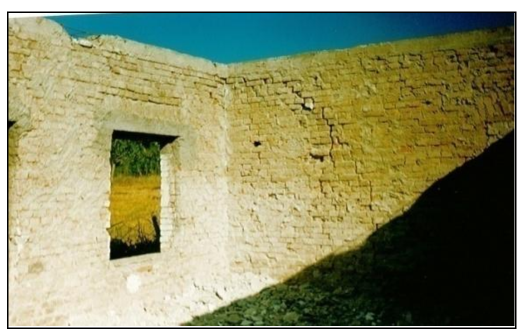


Fig 3 and 4 The dimensions of existing foundation (left) and wall cracks after 18 years of function (right).

Firstly, it was required a new geologic study in order to determine more exactly the parameters of soil layers.

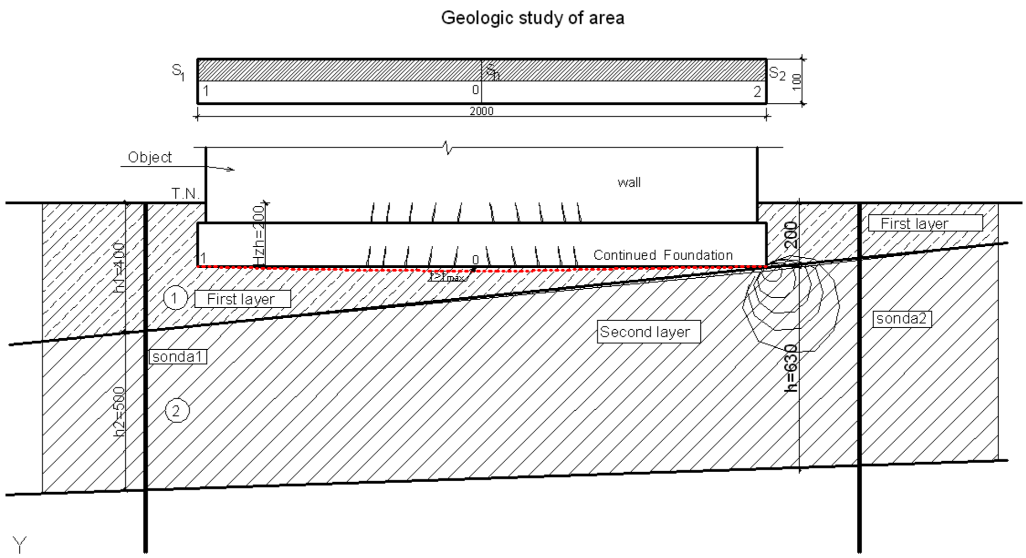


Fig 5. Geologic study of the area

According to this study [7], [8], the first soil layer has this properties: γ=19.40KN/m^3; γ_0=27KN/m^3; Wn=27.8 %; W_S=40.6 %; Wp=23.4 %; ε=0.72; G=0.9; $\alpha_{1\text{-}3}$=0.042cm^2/kg; φ=21^o; [σ]=220kPa; E=0.9 10^4 kPa; C=22 kPa and the second layer: γ=18.50KN/m^3; γ_0=26.80KN/m^3; Wn=26.9 %; W_S=28.5 %; Wp=24.2 %; Ip=4.3; ε=0.8; G=0.9; $\alpha_{1\text{-}3}$=0.042cm^2/kg; φ=24^o; [σ]=150kPa; E=0.5 10^4 kPa; C=5 kPa.

The foundation settlement is calculated as below:

- Settlement:

$$S = \sum_{0}^{Ha} \sigma_{mes} h_i a_0 \qquad (3)$$

where $a_0 = \dfrac{\beta}{E}$; β =0.4 for clays and β =0.7 for sandy clays.

- Stresses:

$$\sigma_z = 2 \cdot k_c \cdot P \qquad (4)$$

Table 1 Calculation of stresses for point 1 of the foundation $\sigma_z;\sigma_T;\sigma_{mes}$

z	β=z/b	Kc [2]	σ_z	σ_T	σ_{mes}
0	0	0,25	75	38,8	74,85
0,1	0,2	0,249	74,7	40,7	74,01
0,2	0,4	0,244	73,3	42,7	71,78
0,3	0,6	0,234	70,26	44,6	68,13
0,4	0,8	0,22	66,01	46,6	49,74
1,3	2,6	0,111	33,48	64	31,54
1,5	3	0,098	29,6	67,9	26,17
2	4	0,075	22,74	77,6	19,91
2,5	5	0,061	18,3	86,9	17,05
3	6	0,051	15,8	96,15	

After the calculation the settlement results $S_1 = 67.21 \cdot 10^{-4} m$

Table 2 Calculation of stresses for point 0 of the foundation $\sigma_z;\sigma_T;\sigma_{mes}$

z	β=z/b	Ko [2]	σ_z	σ_T	σ_{mes}
0	0	1	150	38,8	147
0,25	0,25	0,96	144	43,65	133,5
0,5	0,5	0,82	123	48,75	112,85
0,75	0,75	0,68	102,7	53,35	92,6
1	1	0,55	82,5	58,2	71,02
1,5	1,5	0,39	59,55	67,45	52,87
2	2	0,31	46,2	76,7	42,52
2,5	2,5	0,26	38,85	85,95	35,17
3	3	0,21	31,5	95,2	30
3,5	3,5	0,19	28,5	104,5	27
4	4	0,17	25,5	113,7	24
4,5	4,5	0,15	22,5	123	

After the calculation the settlement result $S_0 = 251.7 \cdot 10^{-4} m$

Table 3 Calculation of stresses for point 2 of the foundation $\sigma_z;\sigma_T;\sigma_{mes}$ **.**

z	β=z/b	Kc [2]	σz	σT	σmes
0	0	0,25	75	38,8	74,85
0,1	0,2	0,249	74,7	40,7	74,01
0,2	0,4	0,244	73,3	42,5	71,78
0,3	0,6	0,234	70,26	44,35	68,13
0,4	0,8	0,22	66,01	46,2	49,74
1,3	2,6	0,111	33,48	62,85	31,54
1,5	3	0,098	29,6	66,55	26,17
2	4	0,075	22,74	75,8	19,91
2,5	5	0,061	18,3	85,05	17,05
3	6	0,051	15,8	94,3	

*After the calculation the settlemen*t result $S_2 = 156.11 \cdot 10^{-4} m$.The maximal foundation deflection is calculated [1],: $f_{\max} \le [f]$

$$f_{max} = \frac{S_1 + 2S_0 + S_2}{2} = 363.36 \cdot 10^{-4} m \qquad (5)$$

And the allowable deflection is:

$$[f] = 0.0013 \cdot l = 0.0013 \cdot 20 = 0.026m \qquad (6)$$

So, the condition is not full filled and due to this we will have cracks in the foundation and also in the above walls.

The stability of some points on the vertical line from the foundation edge was checked. For example, for the point A in the depth z=0,2m below the foundation basement we have [2]:

- The angle of view is:

$$tg\alpha_1 = \frac{b}{z} = \frac{1}{0.2} = 5 \qquad \alpha_1^{rad} = \frac{\pi \cdot \alpha_1}{180^0} = 1.37rad \qquad \alpha_1 = 78.69^0$$

- The principal stresses in point A are [3]:

$$\sigma_1 = \frac{P}{\pi}(\alpha_{rad} + \sin\alpha) = \frac{150}{3.14}(1.37 + \sin 78.69^0) = 110.04\text{kPa}$$

$$\sigma_2 = \frac{P}{\pi}(\alpha_{rad} - \sin\alpha) = \frac{150}{3.14}(1.37 - \sin 78.69^0) = 20.87\text{kPa} \quad \tau_n = \tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = 44.58\text{kPa}$$

$$\tau_{rez} = \sigma_n \text{tg}\varphi_2 + c_2 = 65.45 \cdot \text{tg}24^0 + 5 = 30.91\text{kPa}$$

$$\tau_{rez} \prec \tau_n = \tau_{max}$$

The point A results as instable, so we continue with other points in different depths from the foundation basement. The results are presented in Table 4 and the stresses diagrams are in Figure 6.

Table 4 Calculation of stresses

Point	z	α°	α[radian]	τmax	τrez	FS
A	0,2	78,69	1,37	44,58	30,91	0,69336025
B	0,4	68,19	1,18	44,34	27,44	0,61885431
C	0,6	59,03	1,02	40,94	24,41	0,5962384
D	0,8	51,34	0,89	37,28	21,89	0,58717811
E	1	45	0,785	33,77	19,8	0,58631922
F	1,4	35,5	0,61	27,72	16,69	0,60209235

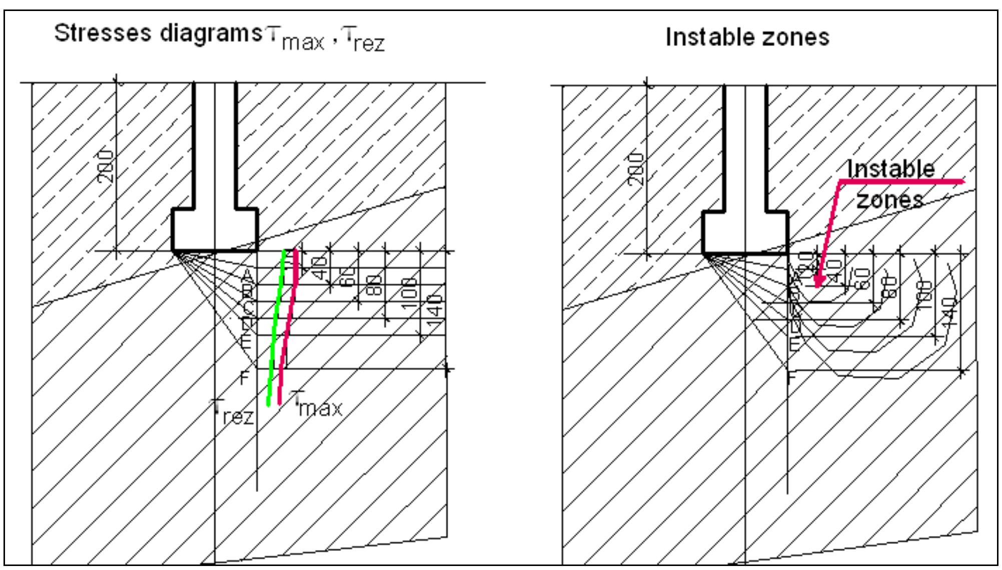


Fig. 6 and 7 Stresses diagrams (left) and instable zones (right).

According to the above calculations and to the Fig. 7 we can see that we have lose of stability in the zone 1.8m below the foundation basement. This is another reason of the damages on the foundation and walls.

5. Conclusions and recommendations

The following conclusions and recommendations can be achieved:

- A detailed geological and geotechnical must be prepared for every design.
- During the design process the SSI for static conditions has to be taken into account.
- In the geotechnical problematic zones the SSI has to be considered also for dynamic conditions.
- The cause of all structural damages has to be firstly checked in the foundations.

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