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CASE STUDY REGARDING EVALUATION AND CONSOLIDATION OF BUILDINGS INFRASTRUCTURE

M. SOLONARU[1] M. BUDESCU[1] I. LUNGU[2]
D. OANEA (FEDIUC)[1]

Abstract: *Rehabilitation solutions in terms of increasing the footing dimensions and foundation depth can be established by correlating the present soil parameters with the new loading conditions. Following the Eurocodes provisions, the evaluation of the geotechnical conditions of the existing buildings, results in stronger restrictions than the ones of previous norms. The paper presents a case study on correlating increased footings with natural soil conditions while rehabilitation regards the entire building.*

Key words: *geotechnical evaluation, infrastructure of buildings, soil parameters.*

1. Introduction

The assessment of the technical condition of existing buildings is performed when it presents a significant degree of damage due to external factors that endanger the safety of operation, when changing the beneficiary or if required by the builder structural changes, additions or disposal of storey, or changes of the destination of the building. In any of these cases, it may be necessary structural rehabilitation of the building, in order to meet the requirements of strength and stability of the existing structural assembly.

The present paper aims, through a case study, to evaluate the need for infrastructure interventions when changing the destination of the building, introducing an additional level and retrofitting the superstructure. As a consequence of failure to fulfill resistance restrictions, strengthening solutions for shallow foundations are analyzed in order to increase the bearing capacity for taking over new loads, either by enhancing the width of the foundation, or the foundation depth or simultaneously by both.

2. Geotechnical assessment outcomes for the building infrastructure

In this case study, the infrastructure of a building consisting of continuous foundations under the walls is subjected to analysis. In terms of original technical design, the existing infrastructure, has met safety threshold. Initial data used to assess the bearing capacity of the foundation is:

[1] Department of Structural Mechanics, Faculty of Civil Engineering and Building Services of Iasi.
[2] Department of Transportation Infrastructure and Foundations, Faculty of Civil Engineering and Building Services of Iasi.

- Permanent load, P=450 kN;
- Variable load, Q=150 kN;
- Width of foundation, B=3 m;
- Depth of foundation, D_f=1.40 m;
- Characteristics for the first layer of soil where the active zone is forming: bulk weight of the soil, γ_1=18kN/m3, internal friction angle, Φ_1=15˚, cohesion, c_1=12kPa and the height of the layer, H_1=2.90m.

Thus, the bearing capacity checking relation [3], [5] is as follows:

$$Q \leq m \cdot R \quad (1)$$

Where,
Q – Design load on the foundation soil, derived from the most unfavorable group actions;
m – Coefficient for working conditions;
R – Bearing capacity / design resistance of the foundation soil.

$$Q(=700.8kN) \leq m \cdot R(=723.816kN)$$

Although safety is achieved at the level of the footing, the superstructure presents degradations and therefore for comparison purposes, the geotechnical assessment is performed in current conditions, based on Eurocodes design rules, according to the design approach GEO as an ultimate limit state. Requirement that must be fulfilled [2], [4] is:

$$V_d \leq R_d \quad (2)$$

Where,
V_d – Design value of the vertical load or normal component of resultant of the actions applied to the base of foundation;
R_d – Design value of the resistance against action.

Calculation at ultimate limit state GEO [4] is performed based on the three design approaches that differ through applying of partial safety factors for actions, materials/ soil and resistances. Since the second design approach leads to intermediate values, for this case study, the values of the first (which has two combinations of calculation AC_1C_1 and AC_1C_2) and the third design approaches (AC_3) will be compared. The values involved for checking the relation of the bearing capacity for each design approach are:
- First design approach, combination one, with the notation AC_1C_1: V_d=968.58 kN; R_d=820.774 kN – relation (2) unfulfilled.
- First design approach, second combination, with the notation AC_1C_2: V_d=745.8 kN; R_d=565.194 kN – relation (2) unfulfilled.
- Third design approach, with the notation AC_3: V_d=968.58 kN; R_d=565.194 kN – relation (2) unfulfilled.

By evaluating the infrastructure under the current conditions, lack of safety is observed, as the criterion is not achieved in any of the design approaches. It is recommended to redo the geotechnical study, which reveals the effect in time of the compaction under load over the strength parameters of the soil.

The new values for the soil resistance parameters are: Φ=18˚ and c=18kPa. The results after re-evaluating the building infrastructure are the following:
AC_1C_1: V_d=968.58 kN; R_d=1329 kN – relation (2) fulfilled;
AC_1C_2: V_d=745.8 kN; R_d=866.011 kN – relation (2) fulfilled;
AC_3: V_d=968.58 kN; R_d=866.011 kN – relation (2) unfulfilled.

It is noted an increase of the resistance design values, but not sufficient for the third design approach. Thus, taking into account the unfulfilled safety criterion under initial load conditions and the new loads that will follow from adding a storey, the change of the building destination and the rehabilitation of the superstructure, the strengthening of the foundation is imposed.

3. Technical solutions for the geotechnical rehabilitation of the foundation

Structural rehabilitation of the

infrastructure by increasing the width of footing is one of the most common technological methods for getting an intake of bearing capacity, although to a limited extent. The new data involved in the calculations in this phase is: the permanent load from strengthening the superstructure, P_c=200kN, permanent load by adding a storey, P_s=250kN, variable load from the change of the building destination, Q_{sd}=50kN, and the characteristics of the second soil layer that will be included in the active area (internal friction angle, Φ_2=18˚, cohesion, c_2=12kPa and the bulk weight, γ_2=20kN/m^3).

According to contribution brought through the variation of the foundation depth and the increased foundation dimensions, the ratios between the resistance values and the design values of the load transmitted to the foundation (Rd/Vd) are graphically represented for each the design approach according to Eurocode 7.

Figure 1 shows the effect of increasing the foundation width. The area above the horizontal line from the unit value level represents the safety area of the strengthened foundation fulfilled for each design approach.

It is noted that simultaneously, the three approaches only satisfy the condition of safety at a width of 5.60m, thus the use of this technical solutions in the geotechnical rehabilitation being irrational. Figure 2 shows the effect of increasing the depth of foundation. As in the previous case, the area above the horizontal line from the unit value level represents the safety area of reinforced foundation.

Looking at graph it can be observed that the safety threshold is attained simultaneously for all the three approaches for a value of 4.30m for the depth of foundation, a value that can only be justified only if the beneficiary requires that a basement should be added at the existing construction.

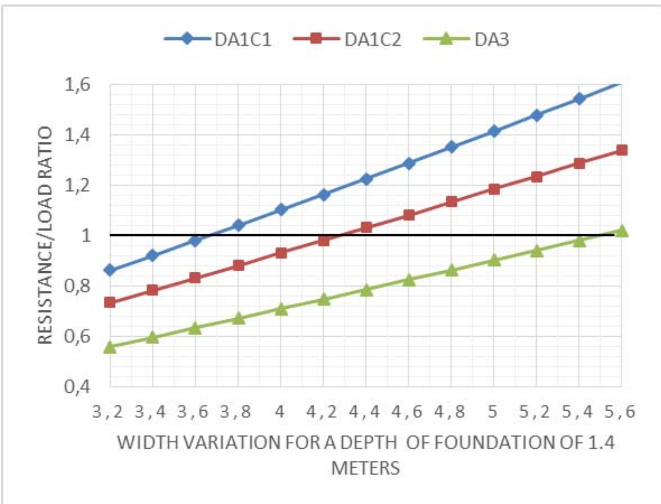

Fig. 1. *Consolidation of the foundation by increasing the foundation width*

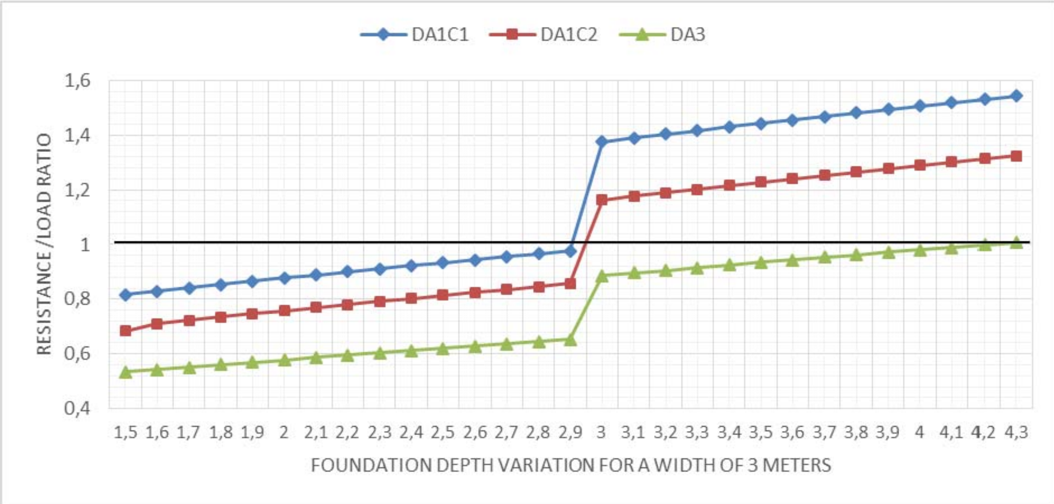

Fig. 2. *Consolidation of the foundation by increasing the foundation depth*

The rehabilitation solution of the foundation, both by increasing the width and depth of foundation, with the results deducted by calculation is presented below. Tables 1-3 summarize the results of the ratios between the design values of resistance and design values of the loads transmitted to the foundation per meter (Rd /Vd) for all possible combinations of the values of the foundation width (horizontal direction) and of the depth of foundation (vertical direction). The ranges for these values are of 3.20m-5.60m for the width of foundation and of 1.50m-3.60m for the foundation depth. The maximum extreme values of these structural dimensions (5.60m and 3.60m) are the first values that exceed the safety threshold in the most restrictive design approach.

In order of appearance, the tables correspond to the first design approach with the two possible combinations and to the third design approach.

The area in the tables with values fulfilling the safety criterion is separated from the ones not fulfilling it through a diagonally thicker line.

Values marked by yellow represents all the values that do not satisfy the condition of resistance for first approach, first combination; similarly, values marked with red do not satisfy the safety criterion for the second combination from the first design approach and values marked with blue do not verify the criterion for the third design approach.

The gray boxes of the tables with solid values include the first values that satisfy the condition of bearing capacity for all design approaches at the same time. The strengthening solution can be achieved by choosing any value below the thicker line, which separates the safety area and the uncertainty area, this value being corresponding to a pair of values for a width (B) and a depth of foundation (Df).

DA1C1	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	B
1.5	0.876	0.936	0.9959	1.056	1.118	1.179	1.2406	1.3025	1.3656	1.4289	1.492	1.557	**1.621**	
1.6	0.889	0.949	1.0088	1.07	1.131	1.192	1.2542	1.3166	1.3793	1.4425	1.505	**1.569**	1.634	
1.7	0.902	0.962	1.0222	1.083	1.144	1.206	1.2681	1.3303	1.3929	1.4559	1.519	1.583	1.647	
1.8	0.914	0.974	1.0348	1.096	1.157	1.219	1.2805	1.3432	1.4061	1.4687	1.532	1.596	1.659	
1.9	0.926	0.987	1.0472	1.109	1.17	1.232	1.294	1.3565	1.4193	1.4816	1.545	1.609	1.672	
2	0.938	0.999	1.0601	1.122	1.183	1.245	1.3072	1.3696	1.4315	1.4943	**1.56**	1.62	1.684	
2.1	0.95	1.011	1.0722	1.134	1.196	1.258	1.3197	1.3818	1.4441	1.5073	1.569	1.633	1.696	
2.2	0.962	1.023	1.0841	1.146	1.208	1.27	1.3319	1.3945	1.4567	1.5195	1.581	1.644	1.707	
2.3	0.973	1.035	1.0965	1.159	1.221	1.282	1.3445	1.4064	1.4688	1.5307	1.593	1.656	1.719	
2.4	0.985	1.047	1.1086	1.171	1.232	1.294	1.3565	1.4186	1.4809	**1.543**	1.606	1.667	1.73	
2.5	0.996	1.058	1.1201	1.182	1.244	1.307	1.3688	1.4301	1.4926	1.5547	1.617	1.679	1.74	**Rd/Vd**
2.6	1.007	1.069	1.132	1.194	1.256	1.318	1.3802	1.4419	1.5044	1.5661	1.628	1.69	1.751	
2.7	1.018	1.081	1.1432	1.206	1.268	1.33	1.3916	1.4538	1.5152	1.5774	1.639	1.701	1.762	
2.8	1.029	1.092	1.1542	1.217	1.279	1.341	1.4033	1.4653	**1.527**	1.5881	1.65	1.711	1.773	
2.9	1.04	1.103	1.1657	1.228	1.29	1.352	1.4144	1.4761	1.5376	1.599	1.66	1.722	1.783	
3	1.465	1.555	**1.645**	**1.73**	**1.822**	**1.91**	**2**	**2.089**	2.1771	2.2659	2.354	2.442	2.53	
3.1	1.479	**1.57**	1.6585	1.747	1.837	1.926	2.0148	2.1032	2.1918	2.2796	2.368	2.456	2.543	
3.2	1.493	1.583	1.6732	1.762	1.851	1.941	2.0289	2.117	2.2047	2.2932	2.381	2.467	2.554	
3.3	1.507	1.597	1.6868	1.777	1.865	1.954	2.0428	2.1305	2.2184	2.3054	2.393	2.48	2.566	
3.4	1.52	1.611	1.7003	1.79	1.879	1.968	2.056	2.1439	2.2314	2.3185	2.406	2.492	2.578	
3.5	1.534	1.624	1.7145	1.804	1.892	1.981	2.0695	2.1571	2.2448	2.3314	2.418	2.504	2.59	
3.6	**1.547**	1.638	1.7276	1.818	1.906	1.995	2.0828	2.1696	2.2573	2.3441	2.43	2.516	2.601	
Df	**Rd/Vd**													DA1C1

The degree of meeting the ULS condition for the variation of B and D_f according to DA_1C_1
Table 1

DA1C2	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	B
1.5	0.748	0.797	0.8465	0.896	0.946	0.997	1.047	1.0973	1.1485	1.2	1.252	1.303	**1.354**	
1.6	0.76	0.81	0.8598	0.91	0.96	1.011	1.0609	1.1114	1.1637	1.2145	1.265	**1.317**	1.369	
1.7	0.773	0.823	0.873	0.923	0.974	1.025	1.0746	1.1261	1.177	1.2287	1.28	1.332	1.384	
1.8	0.785	0.836	0.8853	0.937	0.987	1.038	1.0889	1.1398	1.1917	1.2427	1.294	1.346	1.397	
1.9	0.797	0.848	0.8988	0.95	1.001	1.051	1.1021	1.1533	1.2052	1.2565	1.308	1.36	1.411	
2	0.809	0.86	0.9107	0.963	1.013	1.065	1.116	1.1673	1.2187	1.27	**1.32**	1.373	1.424	
2.1	0.821	0.872	0.9239	0.975	1.026	1.077	1.1288	1.1803	1.2318	1.2833	1.335	1.386	1.438	
2.2	0.832	0.884	0.9363	0.988	1.039	1.09	1.1422	1.1932	1.2456	1.2963	1.347	1.399	1.45	
2.3	0.844	0.896	0.9478	0.999	1.051	1.103	1.1547	1.2065	1.2575	1.3092	1.361	1.412	1.464	
2.4	0.856	0.908	0.9605	1.012	1.064	1.116	1.1677	1.2189	1.2709	**1.322**	1.373	1.424	1.475	
2.5	0.867	0.919	0.9717	1.024	1.076	1.128	1.1798	1.2312	1.2831	1.3342	1.386	1.437	1.488	**Rd/Vd**
2.6	0.878	0.931	0.9834	1.036	1.088	1.14	1.1916	1.244	1.2945	1.3465	1.398	1.449	1.5	
2.7	0.889	0.942	0.995	1.048	1.1	1.152	1.2042	1.2558	1.3073	1.3585	1.41	1.461	1.511	
2.8	0.9	0.953	1.0064	1.059	1.111	1.164	1.2157	1.2675	**1.319**	1.3703	1.422	1.473	1.523	
2.9	0.91	0.964	1.017	1.071	1.123	1.176	1.2278	1.2797	1.3313	1.382	1.433	1.484	1.534	
3	1.237	1.31	**1.384**	**1.46**	**1.529**	**1.6**	**1.673**	**1.744**	1.8154	1.8868	1.958	2.027	2.098	
3.1	1.25	**1.324**	1.3978	1.471	1.543	1.616	1.688	1.759	1.8299	1.9008	1.971	2.041	2.111	
3.2	1.264	1.338	1.4123	1.485	1.558	1.629	1.7016	1.7733	1.8437	1.9145	1.985	2.055	2.125	
3.3	1.277	1.352	1.4256	1.498	1.571	1.643	1.7162	1.7874	1.8578	1.9287	1.998	2.068	2.137	
3.4	1.291	1.365	1.4388	1.512	1.585	1.657	1.7294	1.8013	1.8711	1.942	2.013	2.081	2.15	
3.5	1.303	1.378	1.4521	1.526	1.598	1.671	1.7425	1.8144	1.8848	1.9551	2.025	2.094	2.164	
3.6	**1.316**	1.391	1.465	1.539	1.612	1.684	1.7565	1.8279	1.8978	1.9686	2.039	2.106	2.176	
Df	**Rd/Vd**													DA1C2

The degree of meeting the ULS condition for the variation of B and D_f according to DA_1C_2
Table 2

DA3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	B
1.5	0.571	0.608	0.6462	0.684	0.722	0.76	0.7981	0.8367	0.8759	0.9147	0.954	0.993	**1.032**	
1.6	0.58	0.619	0.6557	0.694	0.732	0.77	0.809	0.8477	0.8866	0.9256	0.964	**1.003**	1.043	
1.7	0.59	0.628	0.6661	0.704	0.743	0.781	0.8196	0.8586	0.8971	0.9363	0.975	1.014	1.054	
1.8	0.599	0.637	0.6754	0.714	0.753	0.791	0.8296	0.8688	0.9075	0.9463	0.986	1.025	1.064	
1.9	0.608	0.647	0.6851	0.724	0.763	0.801	0.8399	0.8788	0.9182	0.9567	0.996	1.035	1.074	
2	0.617	0.656	0.6945	0.734	0.772	0.811	0.85	0.8891	0.9277	0.9668	**1.01**	1.045	1.084	
2.1	0.626	0.665	0.704	0.743	0.782	0.821	0.86	0.8988	0.9376	0.9768	1.016	1.055	1.093	
2.2	0.635	0.674	0.7133	0.753	0.792	0.831	0.8693	0.9083	0.9478	0.9866	1.025	1.064	1.103	
2.3	0.643	0.683	0.7224	0.761	0.801	0.84	0.879	0.9182	0.9568	0.9958	1.035	1.074	1.113	
2.4	0.652	0.692	0.7315	0.771	0.81	0.849	0.8885	0.9274	0.9666	**1.005**	1.044	1.083	1.122	
2.5	0.661	0.701	0.7399	0.779	0.819	0.859	0.8979	0.9364	0.9758	1.0146	1.054	1.092	1.131	**Rd/Vd**
2.6	0.669	0.709	0.7492	0.789	0.828	0.867	0.9067	0.9459	0.9849	1.0238	1.062	1.101	1.139	
2.7	0.677	0.717	0.7574	0.798	0.837	0.877	0.9158	0.9551	0.9938	1.0328	1.072	1.11	1.148	
2.8	0.685	0.726	0.766	0.806	0.846	0.886	0.9248	0.9638	**1.003**	1.0411	1.08	1.119	1.157	
2.9	0.693	0.734	0.7744	0.815	0.854	0.894	0.9336	0.9728	1.0117	1.0499	1.088	1.127	1.165	
3	0.942	0.998	**1.053**	**1.11**	**1.163**	**1.22**	**1.272**	**1.326**	1.3794	1.4333	1.487	1.539	1.593	
3.1	0.952	**1.008**	1.0634	1.119	1.174	1.228	1.2826	1.3364	1.3901	1.4437	1.497	1.55	1.603	
3.2	0.962	1.018	1.0742	1.129	1.184	1.239	1.2933	1.3469	1.4004	1.454	1.507	1.56	1.612	
3.3	0.972	1.028	1.0842	1.14	1.194	1.249	1.3038	1.3572	1.4107	1.4639	1.517	1.57	1.622	
3.4	0.982	1.038	1.0941	1.149	1.204	1.259	1.3135	1.3675	1.4207	1.4739	1.527	1.579	1.631	
3.5	0.991	1.048	1.104	1.16	1.214	1.27	1.3237	1.377	1.4308	1.4837	1.536	1.589	1.64	
3.6	**1.001**	1.058	1.1137	1.17	1.225	1.279	1.3338	1.3869	1.4405	1.4938	1.546	1.598	1.65	
Df							**Rd/Vd**							**DA3**

The degree of meeting the ULS condition for the variation of B and D_f according to DA_3

Table 3

4. Conclusions

The objective of this paper is to analyze the possibilities of intervention over the infrastructure of a building proposed for rehabilitation of the superstructure, the addition of a storey and the change of its destination, in order to obtain structural safety in operation and to satisfy the demands of the beneficiary.

After the calculation analysis, increasing the width of foundation proves to be irrational through the excessive values resulted and enhancing the depth of foundation is justifiable only in case of adding a basement to the existing structure.

The optimal solution recommends enhancing both the width and the depth of the foundation. The third design approach dictates the strengthening solution, being the most restrictive in the case study.

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