Using the piles of a building demolished decades before as the foundation of a modern building

János Szendefy, EFERTE Ltd - Budapest; 2 BME Civil Eng Faculty, Dept. of Geotechnics and Eng. Geology, szendefy.janos@eferte.hu
Balázs Hübner, EFERTE Ltd - Budapest; 2 BME Civil Eng Faculty, Dept. of Geotechnics and Eng. Geology, hubner.balazs@eferte.hu
Ferenc Scheuring, HBM Soletanche Bachy – Budapest, scheuring.ferenc@hbm.hu
Attila Szepesházi, HBM Soletanche Bachy – Budapest, szepeshazi.attila@hbm.hu
Péter Turai, HBM Soletanche Bachy – Budapest, turai.peter@hbm.hu

KEYWORDS

re-use of piles, rigid inclusion, sustainability, carbon footprint

ABSTRACT

Budapest has been changing in the last few decades. The industrial areas built around the old city center were demolished or converted. In place of the old factories, exclusive office buildings or residential buildings have been built.

In the investigated area, where a printing house once stood, now an international developer is planning to build an exclusive office and residential complex of -1 floor + ground floor + 8 floors. The area was the former bank of the Danube river, so there are a few meters of peat below the surface at a depth of 4-5 m. The -1 level is an appropriate decision, since the building can be built above the groundwater level, and there is no need to use a D-wall retaining structure. However, with the high foundation level, there is also the need for a pile foundation because of the peat layers.

In almost half of the project area there are ~400 pcs of piles existing, about which there is no further information. By using a large number of old piles, foundation costs could be reduced by 30-45%. In addition to the economic benefits, there is also a technical interest in using the previous piles, since new piles cannot be designed without knowledge of the existing ones. By using the old piles, the carbon footprint of the construction of the new building could be significantly reduced. The schedule of the project's foundation works entails a significant risk if the contemporary piles are only uncovered during construction and they have to be dismantled. When taking into account a more environmentally-friendly approach, technical reasons and the economic concerns of the project, the use of the existing piles becomes necessary.

INTRODUCTION

A new mixed-function residential building is planned to be built in Budapest, Hungary. The building will have 1 basement level and 5 to 9 floors above ground level. The expected contact pressures at the foundation level range between ~30-230 kPa and organic soil was found under part of the building, therefore a deep foundation system was considered for the design.

The plot was used as a railway distribution center at the end of the 19th century and a printing press building built in the 1970s and 1980s, and was demolished in 2008. The foundation of the demolished press building was a reinforced concrete pile deep foundation. Its remains are still on the site as the piles could not have been removed.

During the preliminary design process the existing piles were seen as an opportunity, as these could be used as part of the foundation of the new investment. Therefore, an extensive investigation program was carried out on the site with excavations, pile integrity and bearing capacity tests. These actions are summarized in another conference paper, "Investigation program for the reuse of an existing pile foundation system in Budapest," and therefore only a short summary is given here to ease understanding of present subject.

Based on the results of the investigation program, a sustainability analysis is introduced in this paper about (1) a conventional piled-raft foundation solution by newly built CFA piles and (2) a rigid inclusion soil improvement solution using the existing old piles and the newly-built non-reinforced piles. The analysis focuses on material and fuel consumption and the carbon footprint of the different solutions, and it enumerates some crucial questions of the feasibility of soil improvement solutions by old piles.

PRELIMINARY SITE INVESTIGATION PROGRAMME

Site history was explored by researching databases available in Hungary. Old maps, bird's-eye view photographs (Figure 1) and historical texts were studied to have a comprehensive image of the plot. Luckily, the original foundation construction design from 1975 and 1977 was found as well, indicating 387 old piles in the design area.

The printing press building was demolished in 2008 but its pile foundation was only demolished down to 2-3m depth from present surface level. Altogether 34 piles were excavated and surveyed, which is approximately 10% of the total number, for pile diameter, position and length (Figure 1). Based on pile positions, the layout of old piles could be precisely positioned on a present-day geodetic map. The pile integrity tests were used to determine pile length as old drawings were not fully clear in this sense.

Schmidt-hammer tests were applied to estimate concrete strength and Young's modulus of the pile concrete. Average strength of 43,10MPa with standard deviation of 6,33 MPa was found, indicating C30/37 concrete strength according to MSZ EN 4798:2016+A1:2018. Two of the excavated piles were chosen for traditional static load tests (Figure 2). The outcome showed reasonably well correlation with present CPT based pile design practice in Hungary as studied in detail in our other paper.

Figure 1. – Airplane photograph of the Printing press (1996) and the excavation of piles (2022)

Figure 2. – Pile bearing capacity test frame (2022)

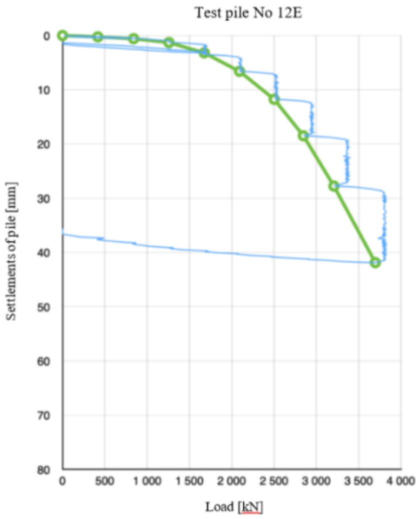

Figure 3. – Load-settlement curve of a chosen pile (2022)

FOUNDATION DESIGN OF NEW BUILDING

Organic soils were found in the eastern half of the site, which were below the proposed garage level, so a simple raft foundation was not an appropriate alternative. The use of piles became necessary for the foundation of the building. In the initial phase of the project, it was not intended to use the existing piles. However, this would have caused technical problems, as the new piles would have had to replace the existing piles in certain places, as shown in many examples in Figure 4a. The old piles cannot be completely removed, so the pile map would have required a lot of technical complications to design the foundation. In addition to the technical complications, it was also appropriate from an economic and environmental point of view to investigate the use of the existing piles, which we have done and presented here in another paper at the conference.

Two main concepts were sketched out in the design of the building's foundation, one being a combined-pile-raft-foundation (CPRF) and the other a rigid inclusion concept foundation.

The exploration of the existing piles and their usability was not completed until after the architectural concepts had been developed, and therefore the design did not take into account the need to match the superstructure to the existing piles. Consequently, in the case of CPRF, where piles are to be placed under piers and bracing walls essentially, there are many former piles which cannot be used as they fall on the centre of the field. A possible pile allocation picture of CPRF is shown in Figure 4a. In this case, those piles that fall on a previous pile or are within 1.5 m are considered suitable for use, but existing piles in other locations are not considered. In the western part of the building, where no organic soils were found it was calculated that the raft base would also take loads, while in the eastern part, covered with organic soils, the piles were dimensioned so that the slab would only carry its own weight and the parked cars.

The piles were basically continuous flight auger (CFA) 60 cm piles, but CFA 80 cm piles were also required in the western part. A technical problem with this version is that the reinforcement of the existing piles is not known, so the existing piles were only considered as being connected to the building by the tie-in reinforcement. The reinforcement of the new piles was going down to the bottom of the piles in accordance with the stresses and MSZ EN 1997-1 standard specifications. A total of 6204 m of new piles have been designed under the building, which will result in 2320 m3 of concrete being used. The base slab at the piles will be 1m thick, but may be thinned to 60 cm between the head piles. The amount of concrete in the base plate has not been taken into account in the carbon footprint calculation.

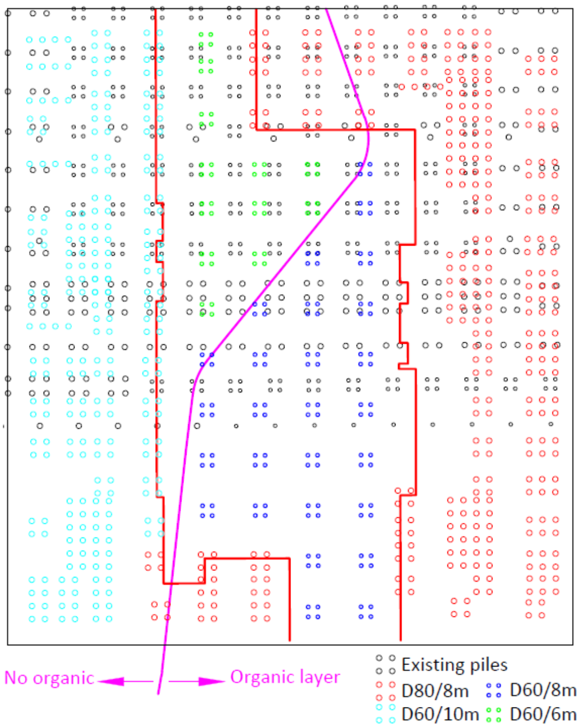

Figure 4a. Piles position in the CPRF foundation

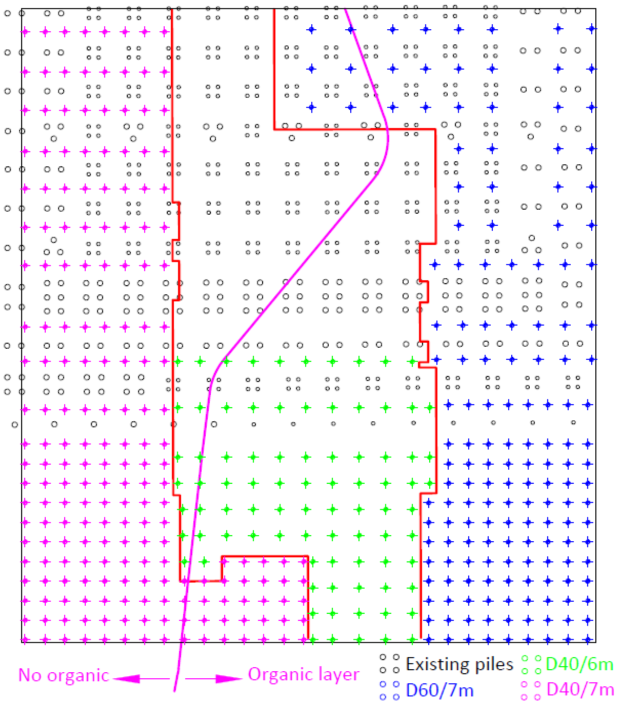

Figure 4b. Piles position in the rigid inclusion foundation

The existing piles did not fit the geometry of the structure, so the general contribution of existing piles in the grid layout can help to make the best use of them. The reinforcement of the existing piles was not known, so taking it into account would have created technical uncertainty, and a solution was considered that would eliminate these problems. In the case of the rigid inclusion foundation system, concrete piles are considered as rigid soil reinforcement elements providing general support to the raft. The foundation method used for silos, a uniformly loaded structure, was tried under the building loaded at individual points. Fortunately, due to the large load-bearing printing press building that previously stood here, there were a large number of pile groups relatively close together, so that by placing a small number of additional piles, a nearly uniform grid spacing pile pattern could be obtained.

In this way, all of the existing 393 pieces of piles were actively involved in the load bearing. In principle, there was no need for such a large load capacity as that of the existing piles and the additional piles, but the 90 cm economical thickness of the raft design made the use of new piles in places necessary, i.e., a thinner raft requires tighter pile spacing. The pile distribution pattern for the rigid inclusion foundation is shown in Figure 4b. In the southern part of the building, where there are no old piles, a 3 x 3 m grid spacing was used under the high load, multi-story western and eastern wings, while a 4 x 4 m grid spacing was used in the central, lower load part. With new piles placed between the existing piles, for the northern part of the building a 3 x 3 m grid spacing could be created. As with the CPRF, the entire weight of the building in the eastern part, which also contained organic material, was borne by the load-bearing capacity of the piles, so larger diameter CFA 60cm piles were used, while in the non-organic parts, the use of CFA 40 cm piles with a much more favorable concrete usage was sufficient. In the central, less heavily loaded section, where no organic soil is present, it was not necessary to install new piles due to the small pile loads.

By making efficient use of existing piles, circa half the amount, only 3206 lm of new piles was required, which, due to the predominantly smaller 40cm diameter, required only 590 m3 of concrete. As there were no piles directly under the piers, the thickness of the raft had to be increased by an average of 10 cm, which resulted in 850 m3 additional concrete used in the base slab compared to the CRPF. However, in total, ~40% less concrete is used for the rigid inclusion foundation, as 1440m3 of concrete is required for the piles and the difference in the volume of the raft due to the thicker base plate, compared to 2320 m3. This concrete saving not only results in an economic benefit but also in a significant carbon footprint reduction. Another environmental benefit is that the rigid inclusion foundation does not require reinforcement in the piles, so the large amount of steel saved also resulted in a significant carbon footprint reduction.

SUSTATINABILITY ANALYSIS

In practice, the decision between a piled-raft and rigid inclusion solution could be made by cost and time analysis considering the execution of the earth works, piles and the raft, as well. In some case the slightly different settlement behavior of the two solutions could have some influence on the upper structure, which could be considered, as well. Fortunately, sustainability aspects have started to become more and more important for investors and contractors. Therefore, its deeper consideration has started to be part of the analysis and proper methodologies need to be found.

At HBM Soletanche Bachy, following corporate group objectives, measurable sustainability targets have been defined in 2022 to reduce the carbon footprint of activities, reduce and reuse waste related to execution works, and to preserve the natural environment. At present stage, carbon footprint calculation standards are set and ongoing activities are monitored on a monthly frequency. More and more projects have a sustainability focus to analyze carbon and waste reduction possibilities. The analysis of the introduced project is presented here.

CO2 FOOTPRINT CALCULATION METHODOLOGY

Due to the increasing need of CO2 footprint analysis, CO2 emission calculation standard methodology was defined at HBM Soletanche Bachy in early 2022. Carbon footprint is calculated for materials (Scope 3 in sustainability terminology) and it is considered to be about ~95% of overall carbon emissions in the deep foundation industry. Therefore Scope 1 & 2 emissions (mainly fuel, energy and water consumption) are considered to be 5% of calculated material emission.

As a key subject for material CO2 footprint calculation, credible emission factors for different materials were defined in the lack of local standards or guides. The EFFC carbon calculator publication, corporate guides and information from local suppliers were collected and compared to define HBM Soletanche Bachy CO2 emission standard for carbon footprint reporting in the absence of official local standards. As only minor deviation of emission data from different sources was found, Table 1 was accepted as a first version. As an experience of the research, most of the parties (authorities, material suppliers, research institutes, etc.) have just made their first steps to provide credible and authorized data, therefore refinement of these data is expected in the upcoming years. It is expected that all parties are going to provide official, verified environmental data sheets to have a common understanding on CO2 emission methodology.

Table 1. – Emission factors of the materials (HBM Soletanche Bachy internal standard)

Material	**Type**	**Emission factor**
		kgCO2e/ton
Concrete	CEM I	670
	CEM II A	590
	CEM II B	480
	CEM III A	360
	CEM III B	220
Steel	New	2 211
	Re-used (70% local avg.)	938

CO2 FOOTPRINT REDUCTION – COMPARISON OF ALTERNATIVES

As the previous section implies, the key engineering opportunities in CO2 emission reduction are the optimization of concrete and steel quantities and the application of low carbon concrete. The optimization of quantities is a clear design question and sustainability considerations can accelerate the application of less cement consuming soil improvement techniques instead of traditional reinforced concrete piling solutions which are covered by design codes in more details. The application of low carbon concrete is more of a procurement subject and depends more on the local supplier possibilities. However, deep foundation contractors are responsible for increasing the need of such materials and therefore motivating concrete suppliers and to cooperate in testing of new recipes for foundation purposes.

Comparison of the above introduced foundation solutions are shown here. Foundation methods were compared according to different aspects, like functionality, durability, cost or construction lead time, but the role of “green” is increasing in the construction industry. To measure the sustainability performance of different solutions, two major aspects were analyzed: carbon dioxide equivalent of construction emissions and waste production in execution phase. However, the analysis cannot proceed with confirming a winning foundation option without mentioning the cost analysis as well.

Firstly, the CO2 footprint was calculated for both foundation methods according to the above-described method. The application of traditional and low-carbon concrete has been considered (according to Soletanche Bachy terminology, concrete with less than 200kgCO2e/m3 is nominated as low-carbon):

- traditional concrete with an average emission factor of 220kgCO2e/m3 as per internal statistics of HBM Soletanche Bachy for 2022.
- low carbon concrete with CEMIII/B with an emission factor of 130kgCO2/m3, a recipe that has been successfully applied in other local piling projects by HBM Soletanche Bachy in 2022.

Table 2. shows the volume of CO2 emissions including concrete and steel for the two alternative foundation solutions with different types of concrete used. As Table 2 shows, a design concept can result in a significant 60-70% reduction in CO2 emission as steel is a significant (54%) proportion of the overall emission and cement needed for the rigid inclusion is lower compared to traditional CFA piles.

Table 2. – Calculated total CO2 emissions (concrete and steel) of alternative solutions

	PILED RAFT 2320 m3 concrete (tonCO2e)	**RIGID INCLUSION 1440 m3 concrete** (tonCO2e)	REDUCTION BY DESIGN ALTERNATIVE
TRADITIONAL NORMAL CONCRETE	561	383	-32%
LOW CO2 CONCRETE - CEM III B	473	329	-30%
REDUCTION BY CONCRETE MIX	-16%	-14%	-41%

The optimization of concrete recipe can have a significant positive influence on CO2 emission as well, as shown in Figure 5 where you can see the comparison of carbon footprint of concrete mixtures of the two examined solutions. Hopefully, engineered concrete and new innovations will provide further improvement possibilities in the upcoming years.

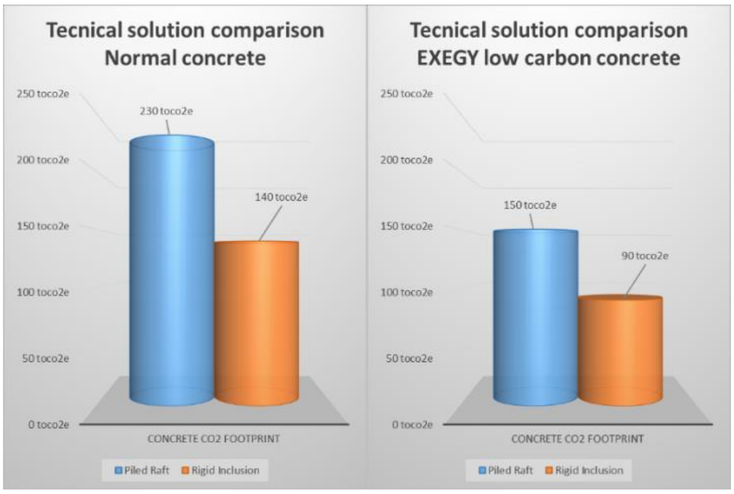

Figure 5. –CO2 emission of concrete material for the analyzed alternatives

WASTE & FUEL REDUCTION

Table 3 and Figure 6 indicate an approximation of waste production and fuel consumption of the two design alternatives. The rigid inclusion solution shows somewhat less waste material, however a significant difference could be found by the application of displacement piling which was found to be unfeasible in present geotechnical conditions. However, the potential on-site utilization of the construction material of the drilling spoil and concrete debris is a potential geotechnical design challenge. Historically such solutions would have been discarded considering quality and costs exclusively. However, considering sustainability, on-site re-use of such heterogenous, non-controlled material could be profitable. Additional in-situ testing and geotechnical design supervision would be necessary.

Table 3. – The comparison of the produced waste/by-products of the alternative solutions

	QUANTITY (m3)	
	Piled Raft	**Rigid Inclusion**
Bored soil	4600	4100
Fresh concrete spoil	100	250
Chiseled concrete debris	330	0
SUM	**5030**	**4350**

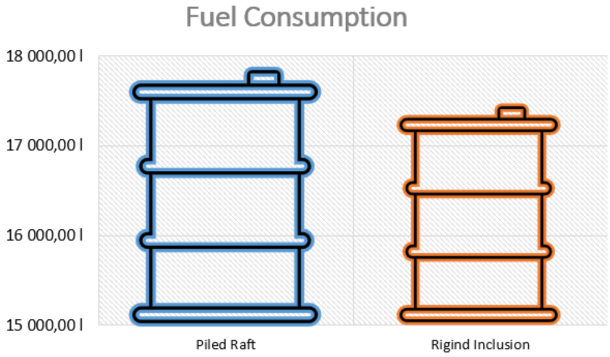

Figure 6. – Comparison of fuel consumption of alternative solutions

As both alternatives can be realized by piling rigs, there are no reasonable differences in fuel consumption. However, as rigid inclusion needs no steel cage installation, the application crane and vibrator can be avoided. Hopefully electric piling rigs will appear in the market and a significant reduction of such enormous fuel needs can be reached.

COST ANALYSIS

Even if sustainability and economical aspects are more and more in line with each other, the latter aspect is still the deterministic one. Any foundation concept developed with the objective to reduce waste quantity, optimize working hours or apply reused materials is generally the most cost-effective option. The fundamental components of foundation costs are time dependent (personnel, rigs, site organization) and material costs with the breakdown around 50-50% in similar piling projects.

The rigid inclusion solution has slightly lower machinery and labor costs, as steel cage installation is not necessary. At the same time, dependent costs can be reduced too because a higher production rate can be reached. In addition, pile trimming is not needed. This results in reduction of safety risks and amount of waste material too. The reasonable difference of costs is the result of the savings of the steel cage. Finally, the analysis shows that the cost of the rigid inclusion solution is only based on the two-thirds of piled raft option calculated on local market prices in 2022 December.

SUMMARY

In the case of investments in downtowns or industrial areas, it is expected that new buildings will replace existing ones. The demolition of the foundations of an old building is a technically complex and costly task. Integrating existing foundations into the new foundation system is environmentally conscious and additionally it can save time and money. The labour and energy required to demolish the foundations of an old building and the waste of demolished materials creates unnecessary environmental pollution. The preparation of a new foundation also consumes significant raw materials and energy, which also creates an additional environmental burden.

Although more engineering work is likely to be required during the design phase to ensure that the structure and the new foundation system are designed to fit in well with the foundations of the previous structure, the final result can provide a significantly more environmentally friendly solution. In the case of the building in this study, the pile foundations of the building remain on the site. The piles were initially seen as a technical problem and an additional cost for the investor, but at the end of the design process this was reversed, and an environmentally friendly and cost-saving solution was found. This required challenging measuring and analyses of the existing piles, but this helped to identify 393 pieces of piles with approximately 5000 m length, which reduces the necessary length of the new piles to approximately 3000 m, saving ~1000 m3 concrete to build in.

During the detailed analysis of the foundation system, several alternative solutions were considered, but the rigid inclusion foundation technology appeared to be the most technically, environmentally and cost-effective. The rigid inclusion technology is less sensitive to the geometry of the load, making the previous piles more integrable into the foundation system of the new building. Another advantage of the technology is that no reinforcement is required in the piles, which can result in significant CO2 emission reductions for the project. Thanks to this, it is possible to reduce CO2 emissions in the construction of the foundation by ~30%, while the costs can be decreased by circa 0,5 million euros in the foundation.

Although the presented investment can be considered as a pilot project in Hungary and therefore raised technical and legal issues during the design phase, it can serve as a good example for future investments. The technical issues include the examination of the properties of the existing piles and their integration into the new foundation system. Also related to the old piles is a contractual problem between the investor and the contractor that raises warranty issues. Nevertheless, the environmental objective that can be achieved, which is to reduce waste and CO2 emissions while reducing the use of raw materials, is considered a necessary direction for the future.