Limit Load Exemplary Analyses of Foundations Accidentally Placed on Sand Underlain by Peat Using Their Various Parameters

Łukasz Kaczmarek, Maria Grodzka-Łukaszewska, and Grzegorz Sinicyn

Abstract The interaction of underlying organic soils with buildings and infrastructure is an important aspect of environmental engineering. Especially since these soils have a particularly important role in the ecosystem, as well as because of the great variety of their mechanical and permeability characteristics. This limit load study concerns the hypothetical situation of accidental direct foundation of a building on a layer of sands under which are peats (and the unconfined groundwater table). The analyzed case is a common situation in the vicinity of rivers and lakes, especially in areas with high urban pressure. In the calculations, the finite element method (FEM) was used to model the strip foundation of a residential building in a plane strain approach. The peat parameters were derived from various literature analyses of different locations (specifically from Poland, Nederland, and Turkey,) to provide a range of possible soil failure load scenarios. This type of analysis identifies the most undesirable variant and gives an idea of the scale of the issue.

Keywords Organic soil · Building foundation · FEM · Shear strength · Stress state

1 Introduction

Environmental concerns on the one hand and urban pressures on the other cause interactions which, without analysis, result in ecological damage and engineering constructions. To achieve sustainable development, it is very important to carry out even preliminary analyses which enable crucial risks to be identified. One of such risks is the danger of exceeding the bearing capacity of the ground, or even too large settlements causing the inability to exploit. Based on the results of a pre-linear analysis it is possible to customize the following detailed studies (and optimize their financial costs of them).

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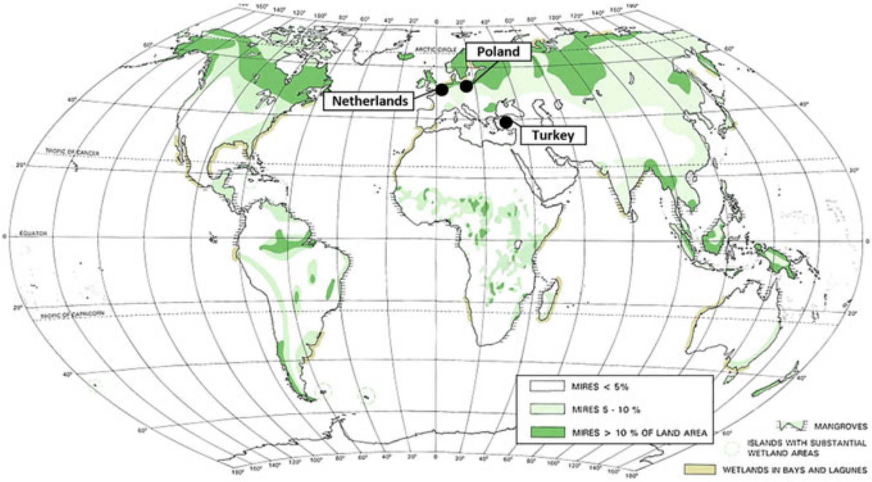

Fig. 1 Peats locations of used archival studies on the background of peatlands distribution (modified from [1])

An example of above would be housing buildings accidentally placed on weak peat soils. These soils are mostly located in wetlands, where there is also the problem of high groundwater table. Figure 1 shows area where peatland might be an issue in described context what gives some overview of the issue scale. This map shows selected peatland locations characterized in the literature (Poland, Netherlands, Turkey), which geotechnical parameters were used in this study to demonstrate the building foundations on peatlands failure loading hazards.

The objective of this limit load study by rough and non-sublime numerical calculations is to demonstrate the consequences of poorly designed or accidental foundations on peats.

2 Material Model

A model consisting of a direct foundation of a building on a layer of sands under which are peats (Fig. 2) was used to perform comparative numerical calculations. Below peat there are alluvial sands. The unconfined grondwater table is on the top surface of peat layer. Four variants of this model were considered, differing in parameters of 1 m peat layer. There were used 3 sets of peat parameters defined in 3 different publications referring to three different areas of analysis—Poland, the Netherlands and Turkey. The fourth variant concerned a model where in place of peat layer a layer of medium sands #1 was introduced. Thanks to this a reference point was obtained.

The analyzed study reflected one of the cases which occurred in the area adjacent to a lake and a small watercourse—i.e. construction of a building, where the foundation

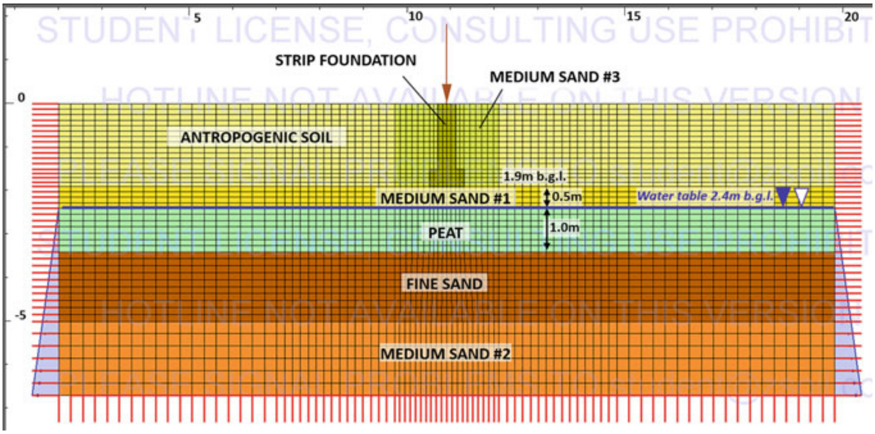

Fig. 2 Numerical model of analysed case study

level was located on sands below the layer of anthropogenic soils. As it turned out later, these sands were only 0.5 m thick, and under them there was a 1 m thick layer of peat. Thus, from the assumed not the worst ground conditions, it appeared that the building was located in complex conditions. This situation became the inspiration for this study, in order to illustrate the possible exceeding of the load-bearing capacity.

The model in the topic assumed a footing depth of 2.9 m below ground level, where the footing width was 0.8 m. In the footing excavation, the input of #3 medium sands was reconstructed.

Peats are soft organic soils, which geotechnical parameters are strongly varied, making difficult their characteristics, improvement or removing. For this reason, in this study three exemplary sets of peat parameters were selected (Table 1), which were used to carry out calculations of soil limit load in the situation of accidental direct foundation on peat. Their geotechnical parameters were derived from various studies in different locations (Poland, Netherland and Turkey) to provide a range of possible failure loading scenarios.

3 Methods

In the calculations, the finite element method (FEM) by Zsoil v.2018 software was used to model the strip foundation of a two-story residential building in a plane strain approach. That simplified limit load analysis of rigid footing problem has been done with use of Coulomb-Mohr model for soils (the yield criterion) and elastic model for foundation. The applied model is an elastic perfect plastic material model. The soil is regarded as an ideal elastic–plastic material and the associated flow law is adopted. The widely known set of parameters for the CM model contributes to the popularity of this type of preliminary analysis and estimation. The material models used were

Table 1 Materials parameters of geotechnical layers

No	Soil type		Bulk density, γ [kN/m^3]	Angle of internal friction, ϕ [°]	Cohesion, c [kPa]	Young's modulus, E [MPa]	Poisson ratio, υ [−]	Hydraulic conductivity, k [m/day]
1.1	Localization of exemplary peat characteristics	Poland [2, 3]	13.0	18.0	10.0	2.00'	0.37	5×10^{-4}
1.2		Netherland [4,*5]	11.0	25.0	1.4	1.34*	0.26	1.6×10^{-2}
1.3		Turkey [6, ^assumed]	11.4	16.2	1.6	2.75	0.30^	9×10^{-6}
2	Antropogenic soil		17.0	30.0	0.0	34	0.27	1
3	Medium sand #1		18.5	33.0	0.0	85	0.25	0.5
4	Fine Sand		19.0	31.0	0.0	55	0.30	0.1
5	Medium sand #2		20.0	33.5	0.0	95	0.23	0.4
6	Medium sand #3		20.0	34.0	0	100	0.24	0.45
7	Concrete		25.0	–	–	30,000	0.20	0

applied as a rough initial approach of limit analyses. For more detailed analyses it is necessary to use large deformation continuum approach (due to significant finite elements geometry changes; [5]). Moreover, in order to carry out complex bearing capacity and serviceability analysis, the mentioned model cannot be used due to its limitations. Then, dedicated models of soft soils are necessary [4, 7, 8].

The mesh of the analyzed problem contained 3698 regular 4-noded elements (mainly rectangles). In this FE model standard box-type solid boundary conditions were generated. The hydrostatic pressure distribution was applied along define flow boundaries on model sides (Fig. 2). It was done through the pressure head value with special seepage elements. The axial loaded rigid strip footing is related to interfaces.

The numerical calculations included excavation, insertion of the footing along with sand filling, and then application of the force. The force was increased gradually until the loading limit was exceeded. The analysis of the results focused on comparing the maximum loads applied to the footing model, the corresponding stress distributions in the soil medium (especially the stress values affecting the peat layer), and the resulting failure surface.

4 Results

The most important reaction of the subsoil to the new load application is the loss of bearing capacity or settlement in case of not exceeding it. Therefore, the basic deliverables of this study are values of limit loads—Table 2. The highest values of limit load correspond with the highest values of cohesiveness which are characteristic of chosen studied peats in Poland. These soils do not have the highest value of internal friction angle. The highest value of friction angle was found for soil from the Netherlands—the maximum force, in this case, was 34.5 kN per 1 m of footing lower than in the parameters variant of soil from Poland. The lowest parameters were characteristic for the selected soils from central Turkey. As a result of such values of shear strength parameters, the difference in limit load was about 50 kN per 1 m of footing. The obtained load capacity results were 4–5 times lower than in the case of the assumed profile, in which there would be no peats (presence of fine sands only).

The obtained values of limit load were determined by the distribution of effective additional stress at maximum load. At the level of peat top surface, in the case of soils from Poland, it was about 90 kPa. In the case of soils from the Netherlands

Table 2 Limit loads calculation results

No	Localization of peat parameters archival case study	Limit load, Q [kN]
1	Poland	199.7
2	Nederland	165.2
3	Turkey	153.7
4	No peat case (MSa #1 parameters instead)	786.8

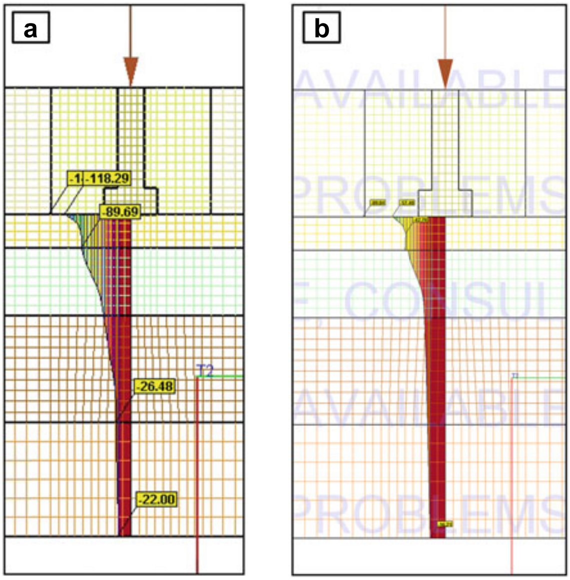

Fig. 3 Effective additional stress due to external limit loading in function of depth: **a** profile with geotechnical parameters of peat from Poland; **b** profile with geotechnical parameters of peat from Netherlands

and Turkey, the values of additional stress were over two times lower and equalled about 40 kPa (Fig. 3). On the receive bearing capacity of analysed soft soil, not only do soil strength properties have an impact, but also influence soil stiffness and their bulk density [5].

Analyzing the failure load results (Table 2) the load from the weight of the foundation itself was also taken into account (in the analyzed cases 53,2 kN of additional load). Thus, for example in case of peats from Turkey, where the lowest values of limit load were obtained, juxtaposing this value to the result of constant increase of axial force (100,5 kN per meter of footing), this load was approx. 50%.

The results confirm the key role of compressibility of peats (Fig. 5)—both from the physical perspective and further settlements as well as from the numerical perspective, where large deformations of finite elements occur (Fig. 4).

In this short paper, the immediate effects of exceeding or not exceeding the ultimate limit state are analysed, keeping in mind that in the case of organic soils (here peats) long-term settlements causing exceeding the serviceability limit state are a serious concern. In the case of a comprehensive analysis of the issue, calculations of short-term settlements as well as those developing in time are essential.

The described situation should be avoided by performing soil replacement or indirect foundation on a proper subsoil. However, if in case of residential buildings one can try to avoid the considered accidental foundation on peats (increasing reliable of ground investigation by drilling to several meters below the foundation level and

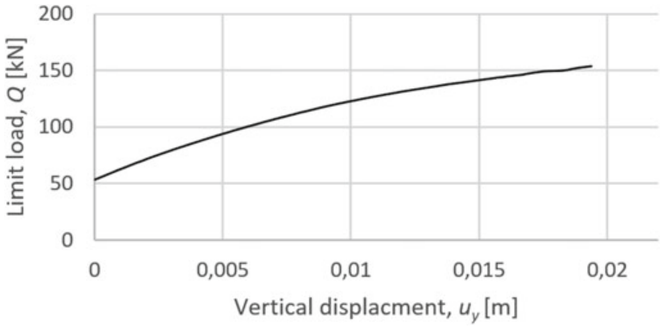

Fig. 4 Loading in Turkey peat parameters case

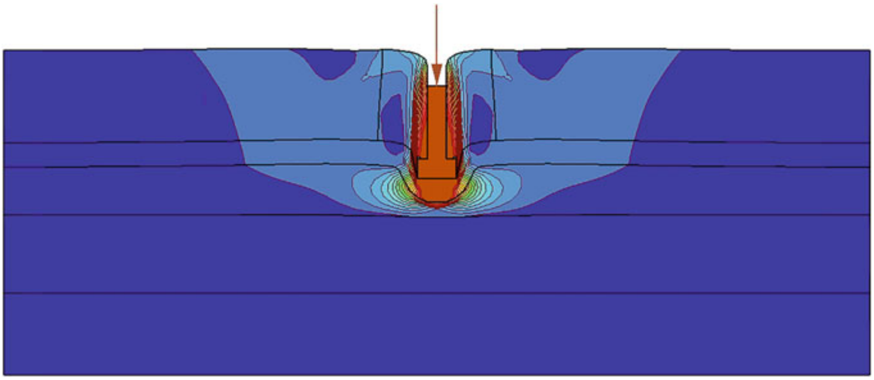

Fig. 5 Effect of soil displacement due to exceeding the ultimate state

choosing the optimal location), then for example in case of communication constructions of not too high rank, they can cause big difficulties in long-term exploitation. In case of realization of the investment and finding the problems caused by occurrence of peats, the main method of ground reinforcement are injections (associated with higher costs).

5 Conclusions

Peats are soft organic soils which geotechnical parameters are highly variable, making them difficult to strengthen and use in construction. In engineering practice in regions where organic soils such as peats may be present, it is worthwhile to carry out variant calculations of bearing capacity in case of unexpected occurrence of weak soils shallow under the layer of mineral soils. Therefore, it is very important to have a good knowledge of the strength, stiffness, and filtration characteristics of such soils up to several meters below the foundation level. The effect of bad-scenario situations maybe even 5 times lower limit loads of soil. In the case of full geotechnical engineering analyses of ultimate and serviceability limit states, they provide the possibility to adjust the proper reinforcement method for failure-free exploitation of building objects.

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