**ISBN** 978-93-84468-19-4
**Proceedings of International Conference on Transportation and Civil Engineering (ICTCE'15)**
*London, March 21-22, 2015, pp. 83-87*

# Use of Carbon Geomembrane for Foundations of Buildings in Poor Load-Bearing Foundation Soil

Ales Zibert[1], Stanislav Skrabl[2], and Andrej Ivanic[3]

[1, 2, 3]University of Maribor, Faculty of Civil Engineering, Smetanova 17, 2000 Maribor, Slovenia

**Abstract**: *In this paper we verified the usefulness of carbon geomembrane (woven carbon fiber) for the construction of facilities on the low bearing capacity foundation soils. The mechanical properties of the material were summarized by product MAPEI Mapewrape (wrap) BI-AX, which is primarily used for repairing of damaged concrete structures. We checked the serviceability limit states (SLS) with numerical calculations on a deformable and a non-deformable model of soils. We also checked the ultimate limit state (ULS) in accordance to applicable standards (EN 1997 - Eurocode 7). The results show a significant reduction in settlements and confirm the hypothesis of the effective use of carbon fiber fabric in the foundation soils.*

**Keywords:** *geomembranes, bearing capacity of soil, reinforced soil, carbon fibre, carbon fibre fabrics.*

## 1. Introduction

Ensuring appropriate ground resistance is one of the basic fields of geotechnical engineering. To ensure inadmissible settling of ground and foundation, as envisaged by the project, we have to anticipate and implement appropriate measures to avoid excessive relative settlements (Serviceability Limit State - SLS) and the collapse of the soil at the impacts that are smaller than the design values (Ultimate Limit State - ULS). Building roads in very compressible and low load-bearing ground is in geotechnical practice generally problematic due to excessive settlements, related to the long-term course of the primary consolidation, especially at bridging structures connecting embankments mostly with non-existent settlements and based on piles. In practice, we frequently approache to the application of different types of geotextile materials. Due to the excellent mechanical properties of carbon fiber fabrics available on the market, we explored the possibility of using them as a geomembranes. Usability was tested on a practical model, under which we also tested the difference between the numerical calculation on the undeformed and deformed model of the soil, ie. with and without taking into account the theory of large deformations in the program Plaxis 3D Tunnel. We want to prove a beneficial effect of used geomembranes on the reduction of the structure settlements, with the foundations built in poor load-bearing soils.

## 2. Characteristics of the Materials used in Numerical Calculations

We dealt with a system of three strip foundations on the inter-axle spacing of 10 m (Fig 1). The depth of foundation is 0.8 m below the ground level. Under individual strip foundation (width B = 2.0 m) the improvement of foundation soil with 0.6 m of tampon layer and a geomembrane of carbon fiber fabric is taken into account. The rest of the geometrical, geological and geomechanical data are shown in TABLE I.

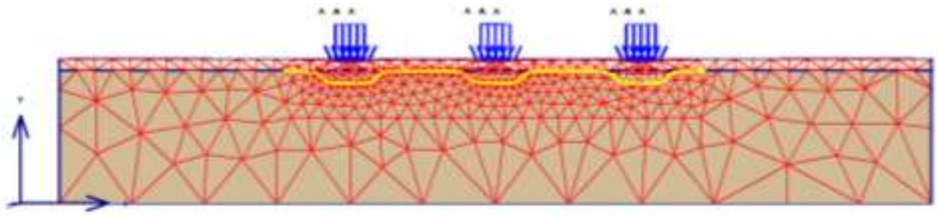

Fig 1: The system of three strip foundations

We used the mechanical properties of carbon fiber fabric of manufacturer MAPEI (type of fabric is Mapewrap C BI-AX 230) with the following characteristics required for input into Plaxis 3D Tunnel [1]:

- Fabric cross area per unit width: 64.2 $mm^2$/m';
- Tensile strength: 4800 MPa;
- Maximum load per unit width: 305 kN/m';
- Tensile modulus of elasticy: 230 GPa.

Carbon fiber fabric MapeWrap C BI-AX is basically intended to repair concrete structures and to improve the flexural and shear strength of concrete elements. Due to useful mechanical properties of carbon fiber fabric it was estimated that it would be suitable to carry the tensile stresses in poor foundation soils and would thus enable a faster process of improving the foundation soils and consequently faster construction of buildings.

TABLE I: Mechanical properties of soils

| Type of soil | clay (CL) | gravel (GP) | Silt | Concrete |
|---|---|---|---|---|
| Material model | Mohr-Coulomb | Mohr-Coulomb | Mohr-Coulomb | Elastic |
| Type of material | Drained | Drained | Drained | Drained |
| $\gamma$ [kN/$m^3$] | 18 | 20 | 18 | 25 |
| $k_x = k_y = k_z$ [m/day] | $1 \times 10^{-3}$ | 1 | 0.1 | 1 |
| E [kN/$m^2$] | $2 \times 10^3$ | $4 \times 10^4$ | $5 \times 10^3$ | $3 \times 10^7$ |
| $\nu$ [-] | 0.3 | 0.3 | 0.3 | 0.3 |
| c [kPa] | 3 | 5 | 3 | |
| $\varphi$ [°] | 15 | 35 | 25 | |
| $\psi$ [°] | 0 | 5 | 0 | |

Because we have assumed that the outer edges of geomembrane are coated with adhesive (eg. Epoxy) in order to increase adhesion between the fabric and the soil, this effect was taken into account so that the value of the adherency reduction factor, $R_{inter}$ was not reduced. For the geotextile the recommended value is between 0.9 - 0.6. In our case we retain an upper limit, the value of 1.0 [2].

## 3. Results and Analysis

In our numerical geomechanical analysis, a useful load of each strip foundations in the vertical direction V = 300 kN/m' is considered. An example of building the prefabricated facility where the vertical load increases linearly and reaches the full value within 42 days after the beginning of construction is also considered. An example of the foundation was analyzed with respect to the deformed and undeformed elasto-plastic Mohr-Coulomb model by finite element method in Plaxis 3D Tunnel.

If it is expected that the deformations of model will substantially affect the geometry of the structure it is necessary to take into account a large deformation theory. The advantage of taking into account large deformation theory is that the finite element mesh is updated continuously at each computational step. In some cases, the conventional small deformation analysis indicates significant change in geometry. By using the feature "Updated mesh" it is possible to take large deformations in Plaxis 3D Tunnel into account. Computational methods are based on the principle of Updated Lagrange formulation. In our case, we expect large settlements due to poor load-bearing of foundation soil, so we take into account the impact of large deformations in numerical calculations. [3]

Fig 2 shows graphs of vertical displacements of the edge and the middle strip foundation as a function of time for the first year of the construction, when it reaches about 90 % of consolidation settlements. The presented results indicate that the expected settlements determined by the undeformed model are practically inadmissible (about 80 cm), while in the case of reinforcement of soil with a geomembrane of carbon fiber fabric is still acceptable for the cases of building structures on a poor load-bearing foundation soil (about 28 cm). Fig 2 also shows the movements that assess the ultimate limit states, where the effects were increased by a partial factor $\gamma_Q = 1.3$ and reduced by a partial coefficient for the material properties of soils $\gamma_\phi = \gamma_c = 1.25$, when the maximum design loads were reached at time t = 43 days and at least 90 % of the completion of the primary consolidation (at time t = 370 days).

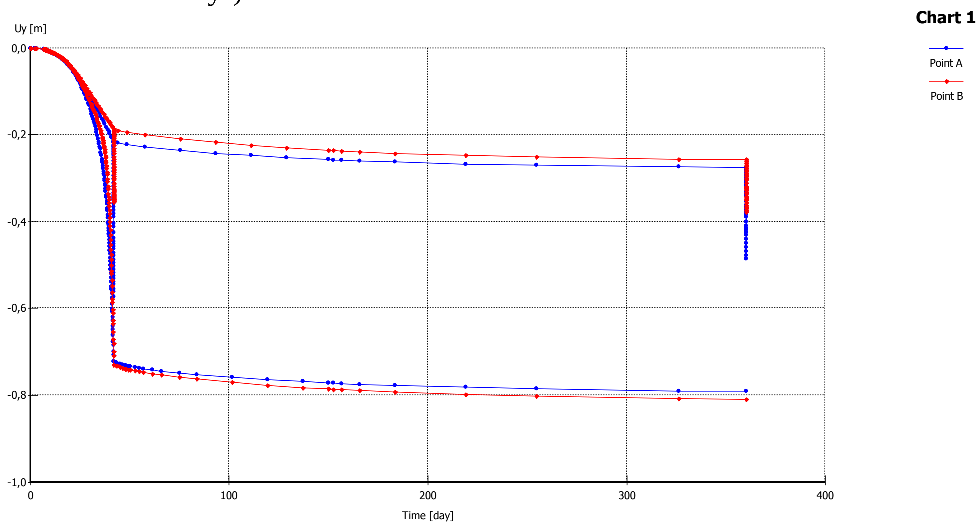


Fig 2: Vertical movement of the edge (point A) and central (point B) strip foundation as a function of time: a deformed model - the graph above, undeformed model - the graph below

In case of application undeformed model of soils equilibrium of analyzed elasto-plastic model for the ultimate limit states can no longer be established. It is interesting that in case of using the deformed model, the vertical displacement of the edge strip foundation is higher, but in case of using the undeformed model it is smaller in comparison with the displacement of the central foundation (Fig 2).

After finished consolidation the axial force in geomembrane, determined by the deformed elasto-plastic model reaches value $N_{max.} = 95.37$ kN/m', while with standard undeformed elasto-plastic model, the value of $N_{max.} = 84.68$ kN/m'. Due to the fact that the maximum allowable load per unit width of fabric is 305 kN/m' (determined from the manufacturer), we still have some reserve. In the first case we have the utilization of 31 % (ie. Factor of safety, FS = 3.2) and in the second, 27.8 % (ie. Factor of safety, FS = 3.6). In case of using the deformed model it can be seen that the geomembranes are loaded over the entire width, while in the case of undeformed model more significant values of axial forces are detected only under foundations (Fig 3). The consequence of this is a very different intensity of the displacements of foundations (Fig 2).

For determining the design allowable tensile strength of fabric it is necessary to take into account the influence of damage during installation, creep effect, chemical / biological degradation and any poor connections or contacts between the individual strips of the embedded fabric [4].

In case of installation of the carbon fibre fabric membrane, principal stress with depth rapidly declines (Fig 4). The effect of integrated geomembrane is in the fact that the additional loads are reallocated to a larger surface area. This effect is slightly larger in case of application of the deformed model, which is also reflected in the value of the maximum principal stress (Fig 4).

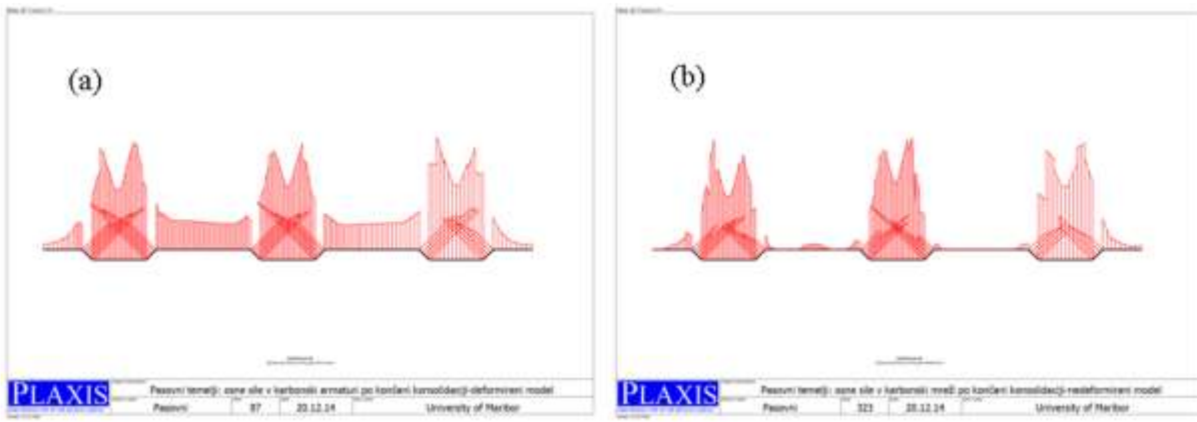


Fig 3: Axial forces in the carbon membrane after completed consolidation determined by deformed elasto-plastic model $N_{max.}$ = 95.37 kN/m' (a) and determined by standard undeformed elasto-plastic model $N_{max.}$ = 84.68 kN/m' (b)

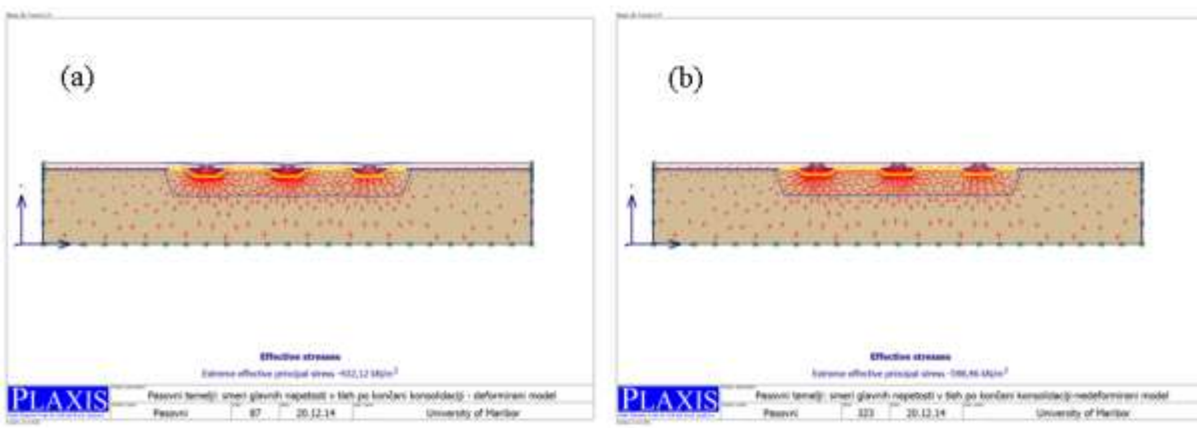


Fig 4: Trajectories of principal stresses in the soil after the end of consolidation determined by numerical analysis on the deformed elastic-plastic model $\sigma_{max.}$ = 432.12 kPa (a) and the undeformed elasto-plastic model $\sigma_{max.}$ = 598.46 kPa (b)

## 4. Conclusions and findings

The paper discusses the example of the foundations of the object at a very low bearing capacity foundation soils. In considered facility, we anticipate the implementation of reinforced concrete strip foundations and reinforcement of soil underneath with a tampon layer of 60 cm and a geomembrane of carbon fiber fabric on the entire area under foundations of the facility. Numerical analysis was performed with the program Plaxis 3D Tunnel, taking into account the deformed (Lagrange) and undeformed Mohr-Coulomb soil model with simultaneous calculation of hydrodynamic consolidation.

Analyses were performed for the serviceability limit states (SLS) and ultimate limit state (ULS), which was in the present case proved in accordance to current standards (EN 1997 - Eurocode 7), only by using the deformed elasto-plastic model of soil. Ultimate limit states could not be proved with usual undeformed Mohr-Coulomb model of the soil, in the present case.

In the analysis of serviceability of limit states it has been shown that the maximum settlements by using of carbon geomembrane on deformed model after the end of consolidation amount to 28 cm, and in the analysis by application of undeformed model being equal to 80 cm. In the case without the use of carbon membrane foundation it is not at all feasible.

Results of the analysis show that by a correspondingly shaped carbon membrane beneath the foundations it is possible to significantly increase distribution of vertical loads on foundation ground. This also significantly reduces settlements and increases the bearing capacity of soils. In the future, it would be necessary to carry out model testing in practice that can further prove or disprove the obtained numerical results.

## 5. References


[1] *Technical Data Sheet of MAPEI MAPEWRAP-C-BI-AX*, http://www.mapei.com/AE-EN/Products-for-Building/Carbon-and-glass-fibre-structural-reinforcement/MAPEWRAP-C-BI-AX

[2] *Structural elements and Interfaces*, https://noppa.aalto.fi/noppa/kurssi/rak-50.3149/materiaali/Rak-50_3149_e._l5-_structural_elements_and_interfaces.pdf

[3] *Plaxis 3D Reference manual*, http://www.plaxis.nl/files/files/3D2013-2-Reference.pdf

[4] Geosynthetic Institute, *GRI Standard Pratice, 2012, pp. 3-4*