Composite helical micro pile’s bearing capacity

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Abstract. It is proposed to use two options of piles’ bearing capacity calculation based on existing Russian codes. Calculation of pipe’s section for an axial load is proposed either. Results of these calculations are compared to the site tests made earlier. Comparison of test results with calculations makes clear that existing methods for helical piles calculation are too conservative. Calculated soil’s bearing strength is 6 times lower than test results. Calculation method of pipes’ FRP sections is proposed. Existing fiberglass section bears almost double of the soil’s capacity. Optimization is proposed. Research provides results of bearing strength installed to weak clay helical fiberglass micro pile. Pile was designed, produced and provided by Composite Group LLC. Pile is made with pultruded fiber reinforced polymer pipe and screw produced with cast iron. Screw is glued to the FRP pipe by epoxy. In addition rivets strengthen connection detail. This structure is stable for corrosion, ground electricity. FRP screw pile has small weight and high strength. All the benefits and disadvantages of the composite piles are described below.

Keywords: Fiberglass, Composite piles, FRP piles, Screw micro piles, Piles, Fiber reinforced polymer.

1 Introduction

Helical micro piles are often used for temporary building installations and infrastructure of road projects. It happened due to below benefits of this foundation type:
- Installation speed,
- Piles can be used several times that is very convenient for fast mobilization and demobilization of the temporary buildings,
- Helical micro piles are much cheaper than regular piles,
- Piles can be used at any kind of soils. It is very useful for Russia since most of the area is forests, water saturated areas, permafrost \cite{1–3} etc.

There are many patents for the bridges, ice breakers and other similar structures \cite{4–8}.

Commonly used steel piles have several disadvantages. Most critical of them is corrosion. Especially at the sea shore. Water and air dissolved at the soil and ground current immediately start own duty by electro chemical corroding the steel.
There are different alternatives to the steel piles[9]. Most efficient trend is substantiation to the fiber reinforced polymers within underground structures. FRP is widely used for the tanks and almost removed the concrete and steel. There are codes already developed for the pipelines. It is used for the road structures improvement [10]. Steel beams and reinforcement are already duplicated by FRP pultruded sections and bars. Fiberglass reinforcement was already incorporated into commonly used in East Europe local market FEA software named Lira.

One of the sample using advantages of the fiberglass can be a helical composite micro pile produced by Composite Group [11]. It is a helical pile made with the cast iron screw and fiberglass pultruded pipe.

Increase of new material use is due to significant benefits of the structures:
- Corrosion resistant material;
- High strength compared to the weight;
- Material is 3-4 times lighter than steel;
- It has lower thermal conductivity;
- Fiberglass is dielectric.

Latest item has significant benefit for the light weight steel thin walled structures described at the articles of Nazmeeva T.V., Rybakov V.A., Garifullin M.R. [12–14]. Absence of electrical contact to the ground is a vital point for the thin walled steel in order to avoid corrosion.

Other benefits of composite piles are long life, slow ageing and obsolescence, high strength (690 MPa) compared to the weight of the structure (1600 kg/m³).

These main benefits reduce a cost of transportation and installation due to light weight and cost of the maintenance. Maintenance is simple [15]. Piles do not require painting and primer coating. Installation does not require high skilled manpower and complicate equipment. Two workers are good enough.

Pearson Pilings is a one of the manufacturer producing piles with a fiberglass pipes’ diameter 203.2 – 600 mm. These piles are used for seashore wave breakers. Assumed life time is more than 100 years. They are corrosion resistant, have a Young Modulus 28GPa that is 13 GPa higher than a concrete [16]. Water absorption is less than 5%.

Another piles manufacturer CMI (UltraComposite) states the tension strength 165.4 MPa for diameter 457.2 mm [17].

| Parameter      | Fiberglass | PVC  | Wood (pine) | Aluminum | Steel |
|----------------|------------|------|-------------|----------|-------|
| Density, kg/cm³ | 1.6...1.9  | 1.3...1.43 | 0.3...0.7 | 2.64...2.8 | 7.7...7.9 |
Other benefit of the composite use compared to the rest materials is environmentally friendly. Some composites allow using recycled materials and especially plastics, that has an immediate positive impact for the environment.

Creative Composites manufacture the composite piles produced using pultrusion method. Recycled materials are 85% of the used materials. Stated life period is more than 75 years. Absence of chemicals washed out compared to the wood piles is very important for the use at the sea.

The following advantages are used for a sea shore:
- Absence of corrosion, material delamination and dilution as it happens for the steel, wood and concrete in the aggressive sea water.
- Recovery of the seashore ecology due to replace of impregnated wood that was discharging the chemicals to the surrounding water.
- Reduce of influence on the workers touching the impregnated wood piles.
- Minimal waste due to extended use period.

Guades [18] describes another advantage of the composite piles. It is an absence of additional chemicals application during maintenance period since anticorrosion and color are already incorporated into fiberglass structure. For example ultraviolet protection is made with ecofriendly black color adding.

It also affects the cost since life period is higher and no need to maintain the structures as it happens for wood or steel.

Beside many advantages there are conditions holding wide application. Iskander [19] has pointed out five key limitations:
- Initial cost of the manufacture is high (Figure 2).
- New materials’ parameters are taken conservatively. Hence require additional tests by long term load application at the field.
- Design should be verified considering the installation method. Rear use of these structures creates risks at the installation stage. Additional field tests are needed considering different load applications at various climate conditions.
Design codes’ absence limits the wide application by design companies. Piles developers are interested in the codes development. However they are mostly small companies without enough staff. Investments can be not enough or too risky.

Innovative structure requires additional tests since design companies responsible for structure’s stability like to use the regular materials. Deviation from the regular course will be compensated by additional measures such as field test and similar. Hence it will have a negative impact on a Project’s budget.

The relevance of the topic is obviously visible based on above. Piles made with fiberglass have huge potential. However knowledge about the structure and details is not enough. Several details of pipes connections, connection to the screw and others that would resist to the significant torsion moments are to be developed. Absence of details and legalized calculation methods holds the global application of FRP helical micro piles. Absence of large scale production does not allow decreasing the cost of structure.

2 Methods

2.1. Pile’s description.

The researchers deal with several tasks:

Helical screw and fiberglass pipe connection’s calculation. This place is the most important since resists to the soil during piles lowering. At the same time this detail is buried under the soil and invisible. It is almost impossible to control this place after installation. It can lead to the unpredictable situation.

To assess pile’s behavior within soft clays and argillite like clays [20].

There is a detail related to the potential delamination of composite pipes appearing during transfer of torsion load to the pile’s toe. Its’ behavior can be made starting from an existing code for calculations of three point bending and additional tests.

Delamination is researched by O’Keefe and Sirimanna [18] who was testing epoxy injected between the concrete core and fiberglass pipe. These injections allowed improving the cohesion and providing the dynamic resistance. It is relevant for the dynamic force provided by the driven equipment. Additional investigations are required in order to develop effective methods of increasing the composite pipes’ bearing capacity and controlling delamination.

Researchers Pando[15] and Valez [21] not just tested several composite piles but also incorporated improvements allowed to reduce the gap between investigations and full scale production. Valez [21] tested the work of fiberglass and carbon piles at the soft stabilized and non stabilized soils. His results have shown better adhesion and bearing capacity compared to the steel piles. But at the same time piles have shown higher deviation of the piles’ head.

Main disadvantage of these piles’ type is a cost of production. Composite piles just start appearing at the civil construction. Production shall find cheap solutions for their production [22]. However process of cost optimization is unavoidable [23].

At the same time starting cost of the composite structures will be recovered during maintenance. As it is explained at the article of Mohajerani and Zyka [24], life cycle of fiberglass piles SEAPILE manufactured by Bedford Technology’s is much longer compared to the wooden piles. After six years cost of maintenance will be equal to the cost of wooden piles. Hence composite piles become cheaper than alternaties [25].

Same problems are specified by Vasyutkin S.F. and Vasyutkin E.S. bringing attention to the imperfection of existing cost procedures at construction and tender procedures. Current procedures of materials and contractors do not consider life period of the structure and cost of the maintenance.

Composite piles produced by Composite Group [11] is a sample that can be implemented into mass market and compensate the disadvantages of steel helical micro piles. In case full scale production will be started main disadvantage of the initial cost also will be skipped.
Figure 3. Fiberglass helical pile.
Most important detail is a connection of fiberglass pipe and the screw. Two options of the details were already tested [26]. First is a screwed connection resisting to the shear. Second is epoxy glue connection. Glue connection has an advantage since pipe is not damaged by the screws at the pile’s most loaded part. Screw connection was already damaged during these tests. Torsion force at the damage was not recorder. Lowering equipment applied 5200 kg*m torsion moment.

It is necessary to determine the bearing capacity of the pile as it was reviewed by Sprince A. and Pakrastinsh, L. [27]. Pile structure has parameters listed in Table 2.

| Section | Dimensions | g, kg | γ, g/cm³ | E, GPa | R, MPa |
|---------|------------|-------|----------|--------|--------|
| Pipe    | l, mm      | 1300  | 99       | 91     | 2.64   | 1.7    | 17     | 200    |

Table 2. Geometric and mechanical characteristics of the pipe.
2.2. Pile structure’s bearing capacity.

Main pipe’s bearing capacity to be assessed. Euler equation and allowed strength calculation method used for steel structures to be applied.

Material’s parameters are specified in Table 2.

Axial load calculation to be provided. For the members with ultimate strength $R_{yn} \leq 440 \text{ N/mm}^2$ for axial tension or compression calculations to be made based on the Eq. (1):

$$\frac{N}{A_n R_y \gamma_c} \leq 1$$

(1)

Hence ultimate force to be applied to the pile’s fiberglass structure shall be:

$$N < A_n * R_y * \gamma_c$$

(2)

After we apply the data from the Table 2 ultimate axial force becomes

$N < 0.23864 \text{ MN} = 23,864 \text{ kg}$

Pile’s main part’s bearing capacity is good enough and even has a significant reserve. Comparison with soil’s bearing capacity is necessary. Structure’s optimization can be made based on the comparison. It is enough to minimize the structure in order to reduce the effect of main disadvantage of the material reflected at the high cost at the initial stage.

Calculation of lateral stability is not required since pipe is fully surrounded by the soil. However maximum length of the pipe to be calculated. Buckling resistance to be calculated for the same pipe 100mm diameter and 4 mm thickness.

Length factor to be taken between 1.0 and 0.7:

$$\mu = 1.0$$

$$\mu = 0.7$$

Screw that has 4 times higher diameter most probably will not let the base to be rotated. Hence lowest point can be considered as a rigid connection. However considering the soils to be soft as at earlier studies [28, 29] conservative factor $\mu = 1.0$ to be taken.

At the next iteration factor could be counted based on a below equation:
Efficient length $l_{ef} = \mu l = 1\ m$
Pipe’s slenderness $\lambda = l_{ef}/i = 100\ cm / 3.36\ cm = 29.75$
Ultimate slenderness $180-60\ \alpha$, where $\alpha = N / (\varphi ARy\gamma)$ will not exceed 1.
Than maximum length $l = 4.03\ m$

2.3. Soil’s bearing capacity
Nikolishin specifies steel helical piles’ average bearing strength based on experience. Hence pipe 108 mm dia should bear a load up to 5-7 ton. 89 mm up to 3-5 ton. Thinnest piles 73 mm dia can bear up to 3 ton of the vertical load.
Similar calculations of the soil’s bearing capacities to be made based on equations used for the piles calculations. Bearing capacities to be specified at the graph (Fig. 6). Main parameters of the soft clays to be taken from the test results [26], others from the works of Mirsayapov I.T. [30, 31]. Used parameters are specified in Table 3.

| Index | Name           | Parameters | $I_p$ | $W$ | $\rho$, t/m$^3$ | $e$ | $I_L$ | $\phi$,° | $c$, kg/cm$^2$ | $E_I$, kg/cm$^2$ |
|-------|----------------|------------|-------|-----|----------------|----|-------|-----------|----------------|-----------------|
| lg III| loamy soil     | $X_a$      | 0.04  | 0.38| 1.91           | 1.02| 1     | 7         | 0.07            | 70              |
|       |                | $X_I$      |       | -   | 1.91           | -   | -     | 6         | 0.05            |                 |
|       |                | $X_{II}$   |       | -   | 1.91           | -   | -     | 7         | 0.07            |                 |

Soil’s bearing capacity was calculated by using two same equations specified in the different codes. Hence only several factors are slightly different. $F_d = 1542.3\ kg$ and $F_d = 1922.9\ kg$.

It is already visible that calculated soil’s strength is significantly lower than specified by Nikolishin or received during piles’ test[26].

3. Results
Calculation results are provided at the comparison graph (Fig.6). Test results [26] are reflected at the graph as well. It shall be noted that piles did not reach the bearing strength during a test. Moreover, the results of bearing strength became more than 6 times higher compared to the calculated ones. This result repeats the statement of Zhelezkov about extremely high reserve of the end and shear bearing strengths specified at the existing codes. Helical piles calculation methods to be updated.
Fiber reinforced polymer pipe 100 mm diameter used by Composite Group has significant bearing strength’s reserve. As it is clearly visible from the graph (Fig. 6). Hence several values are calculated for the reduced pipes sections and are marked at the graph. After comparison with the test results it is visible that the pipe 60x4 is good enough for this type of the load. Meanwhile pipe’s section 60x4 is almost two times cheaper than 100x4.

4. Discussions

Fiber polymer plastics application for underground structures is relevant direction of the scientific researches. Development perspective was already recognized. It is confirmed by increased number of scientific researches, articles and conference reports published over last 10 years.

Fiber glass is environmentally friendly. They are resistant to corrosion. Material has enough strength, small thermal conductivity.

Additional investigations are required. Especially in terms of the materials long life cycle, potential influence on the environmental.

Massive use of fiber glass structures is limited by insufficient codes, not confirmed calculation methods, absence of FRP classification and insufficient experimental investigations.

Based on a test results described in the article of Kvitko A.V. [26] and own bearing capacity analysis it is clear that FRP pile produced with pultruded pipe 100x4mm and cast iron screw 400 mm diameter has significant reserve. Preliminary calculations show that this structure has fifteen times reserve compared to the applied codes and two times reserve compared to the actual tests. This fact requires additional investigation during the full scale experiments.

The main disadvantage linked to the high price can be overcome after structure’s optimization and start of full-scale production. In terms of cost FRP has even advantage compared to the regular structures if we consider a long-term investment.
Connection of the fiberglass pipe and cast iron screw to be researched at the next stages. Including theory search and additional tests. Below list of other details to be reviewed more carefully as well.

- Local compression of the pultruded pipe.
- Detailed check of the glue and adjust applicable calculation method.
- Pipe’s calculation for the torsion including delamination investigation.
- Finite element analysis of the connection details.
- Piles strength comparison with test results described at the article of Kvitko A.V. [26]
- Further development of the pile’s bearing strength determination method.
- Clarification method with regard to soft clays considering earlier researches [28, 29] and approach of considering piles as a vertical reinforcement elements [32–35].

5. Conclusion

Method of pile’s body load bearing strength calculation is proposed. Bearing strength calculation is similar to the equations used for the steel structures. Manufacturers such as Composite Group are used to consider similar methods combining with FEA software in order to get the designed strength of own structures.

Calculated bearing strength is compared to the field tests of same piles at the same soils. It is confirmed that proposed by Composite Group pile has a significant reserve of the pipe’s bearing strength. Pipe’s capacity reached during the test 115% higher value compared to calculated strength. Therefore, optimization is made. It is proposed within current article to reduce the pultruded pipe’s section to 60x4.

Reached optimization reduces the impact of the main problem of the initial cost. It will be partially resolved after the section reduction.

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