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# Analytical Study of Using Fiber-Reinforced Concrete Pile Foundation for Renewable Energy Storage

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**ABSTRACT**

Compressed Air Energy Storage (CAES) is actively being used for compression and storage of surplus energy and further release for later use. This technology which is commonly used for large-scale storage of energy, can also be operated at a small scale. In pursuing the idea of small-scale energy storage, one will face the issue of high storage pressure and temperature which leads to the complicated loading condition. The previous analytical study has shown significant circular tension stress that exceeds the capacity of normal strength concrete. Therefore, the concrete with higher tensile strength is required, such as fiber-reinforced concrete. This paper presents a preliminary analytical study of performance of fiber-reinforced concrete pile foundation subjected to high CAES pressure.

## 1. INTRODUCTION

Nowadays there exist numerous ways of storing renewable energy, and one of them is Compressed Air Energy Storage (CAES). This method involves converting the electricity generated through renewable energy into compressed air by pressurizing the storage tank (ESA, 2017). The energy is then extracted from the reservoir for further generation of electricity. The CAES is commonly used for the large-scale storage, whereas this paper investigates the possibility of applying this technology into the small-scale structures such as the residential buildings. The proposed model for energy storage involves storing the energy generated from the solar panels connected to the residential building in the pile foundation, i.e. hollow sections inside the circular piles. The limited storage provided by the piles will lead to significant increase of storage pressure. The high air pressure in combination with vertical loading from superstructure will cause the pile foundation to undergo complicated loading condition and therefore, might threaten the structural and geotechnical safety. Given the high internal pressure from energy storage, it is predicted that the pile foundation will undergo significant circular tensile loading. Therefore, this paper will investigate the feasibility of using the fiber reinforced concrete (FRC), which is known for comparatively high tensile strength, as the material for pile foundation (Mathew et al., 2015).

## 2. BACKGROUND

### *2.1 CAES technology*

The energy is proposed to be stored through compressed air as shown on the thermodynamic cycle in Fig. 1.

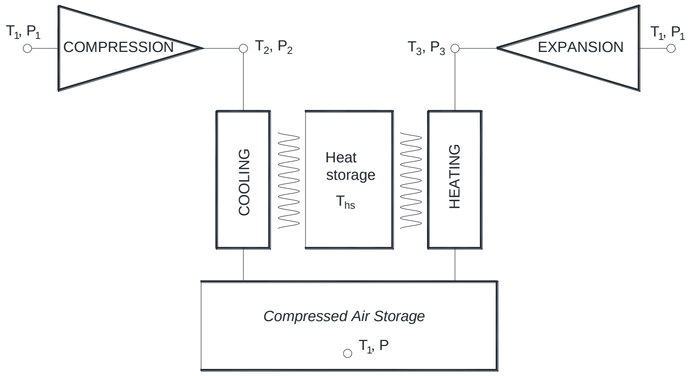


Fig. 1. CAES thermodynamic cycle schematic

This thermodynamic cycle represents advanced-adiabatic process which involves compressing air, extracting the heat from it, storing compressed air, which is followed by expanding of the re-heated air for further use (ESA, 2017).

The variations of pressure inside the compressed air storage section are shown in the Fig. 2 (Tulebekova et al., 2017). As it can be seen from the graph, the maximum storage pressure is 8 MPa which far exceeds the tensile strength of the normal weight concrete. Therefore, the alternative material with high tensile strength is required, such as fiber-reinforced concrete.

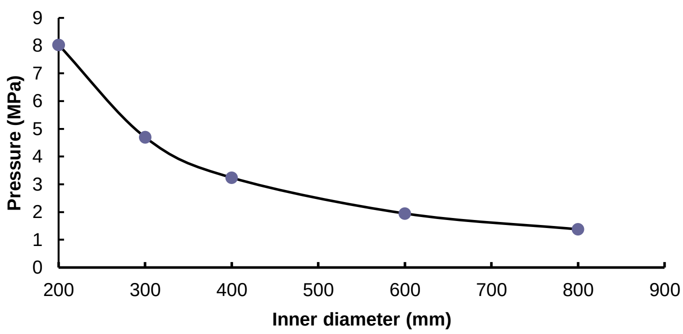


Fig. 2. Maximum pressure for various inner diameter

### *2.2 Fiber reinforced concrete*

The available experimental data on the fiber reinforced concrete has been applied for the modeling of pile foundation. The graphs in Fig. 3 show the performance of the high-performance fibre-reinforced concrete with reinforcement made of steel fibres (Hassan et al., 2012).

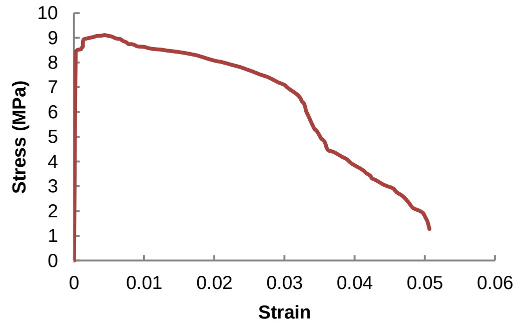


Fig. 3a. Tensile stress-strain graph

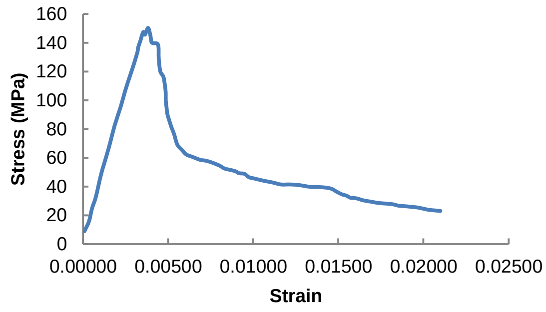


Fig. 3b. Compressive stress-strain graph

The summary of direct tensile and compressive tests is shown below:

Table 1. Properties of fiber reinforced concrete

| Property | Value | |
|---|---|---|
| Maximum compressive strength | 150.56 | MPa |
| Maximum tensile strength | 9.07 | MPa |
| Steel fiber content | 2 | % |
| Elastic modulus | 45.55 | GPa |

This experimental data is going to be used for modeling the fiber reinforced concrete material in the finite element software.

## 4. ANALYTICAL STUDY

The modelling and analysis of the pile foundation has been performed using the finite element software ABAQUS. In this study the homogeneous material model has been applied. The properties of the fibre-reinforced concrete have been input by using concrete damaged plasticity option in ABAQUS.

Circular pile cross section dimensions are as follows: $r_i$=100mm (inner radius), $r_o$=500mm (outer radius), $P_a$=8.02MPa (applied pressure). $P_a$ has been applied uniformly at the inner surface of the circular pile. Since the length of the pile is large compared to the pile cross-section, the plain strain model has been applied in the simulations to allow for 2-dimensional modelling. Fig. 4 shows the finite element model with constraints and loads applied.

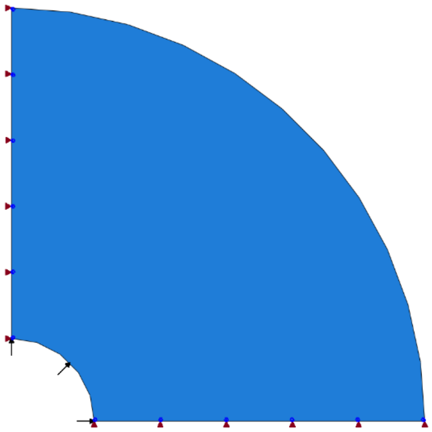

Fig. 4. Finite element model of the pile with constraints and loads

The results of the simulation have shown that the fiber reinforced concrete model was able to withstand the applied pressure on the inner surface of the pile. Fig. 5 shows the circular stress distribution in the pile cross-section. As it can be seen from the graph, the stress is mainly concentrated at the inner part of the pile, with largest stress value of 7.19 MPa.

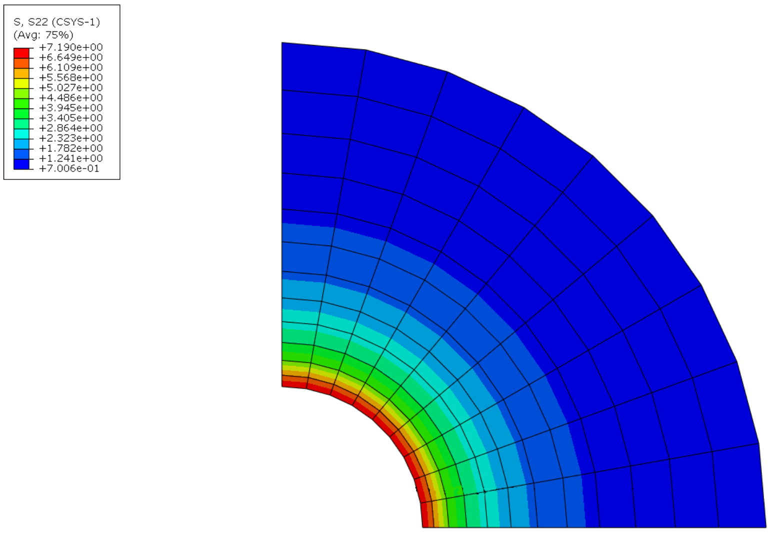


Fig. 5. Circular stress inside the pile section

The values for the stress and strain distribution are shown in the Fig. 6. Since the cracking strain $\varepsilon_c$=0.000229, and the maximum strain achieved during the simulation is $\varepsilon$=0.000187, the cracking of the material in the model has not taken place.

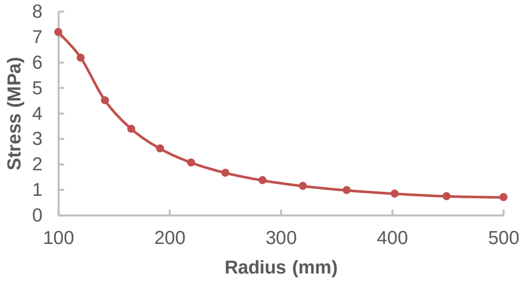


Fig. 6a. Circular stress distribution in pile

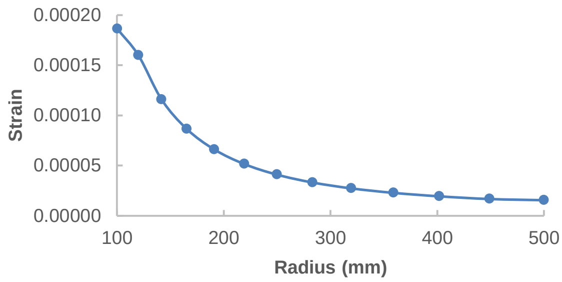


Fig. 6b. circular strain distribution in pile

As it can be seen from these preliminary results, the fiber-reinforced concrete has the capacity to resist high tensile loading from the high air pressure without cracking in the material.

## 3. CONCLUSIONS

This paper explored the possibility of using the fiber reinforced concrete as the material for the circular pile foundation, which is used as the energy storage for CAES technology. It has been determined, that the applied pressure from energy storage exceeds the tensile strength of normal weight concrete. Therefore, fiber-reinforced concrete, which is known for higher tensile strength, is considered in this paper. The preliminary analytical model has been built in the finite element software to evaluate the performance of the fiber reinforced concrete. The result has shown that the model is able to withstand the applied CAES pressure. The future work will involve a more comprehensive analysis of the model, including experimental setup and the calibration of the model.

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