Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(12) (2023) 969-972
DOI: 10.22060/ceej.2022.21533.7754

Numerical Simulation of Pile Group Behavior by Proposed Optimum Mix Design of Plastic Concrete

M. Taghdisi Ali [1], M. Khabazian [2*], S. M. Sajjadi Attar [3]

[1] Khorramshahr University of Marine Science and Technology, Khorramshahr, Iran

[2] Faculty member of Islamic Azad University of Bojnourd, Bojnourd, Iran

[3] Montazeri College of Mashhad, Mashhad, Iran

ABSTRACT: Plastic concrete is a type of concrete that usually has high ductility and low permeability and it can be used in the construction of tangential piles in excavations that have a high groundwater level. In many cases, the project conditions for using plastic concrete with a proper mixing plan are not considered. The aim of this research is to present the optimal mixing plan in terms of mechanical and economic characteristics for plastic concrete piles. For this purpose, five different mix designs were considered for plastic concrete and the properties were evaluated. Finally, the group of tangential piles, including structural and plastic concrete piles with strut, was simulated in the vicinity of the deep excavation and the deformation and flow rate passing through the excavation wall were investigated. In the two-dimensional simulation, it is not possible to consider the characteristics of the plastic concrete pile in the modeling plane and check the deformation of the excavation wall between struts. For this reason, the simulation was done three-dimensionally. Results showed that if the groundwater level is kept constant, water infiltration into the project area is very low due to the very low permeability of plastic concrete piles and the subsidence and deformation created at the top of the piles as well as the swelling of the excavation bed is less than when the groundwater level is lowered. Also, by increasing the permeability of plastic concrete piles and soil, the flow rate through the excavation wall increases.

Review History:

Received: Jun. 26, 2022
Revised: Aug. 14, 2022
Accepted: Oct. 23, 2022
Available Online: Nov. 02, 2022

Keywords:

Plastic concrete
Optimum mix design
Numerical simulation
Permeability
Pile

1- Introduction

Plastic concrete is formable concrete that is obtained from the combination of water, cement, sand, and bentonite [1]. The purpose of using this type of concrete in many researches [2-5] is to reduce water seepage and facilitate drilling. Due to the use of bentonite in plastic concrete, this type of concrete usually has more ductility and less permeability than normal concrete. Many past researches have investigated the mixing plan of plastic concrete and the effect of the amount of each component on its properties on the properties of concrete. Zhang et al. [6] studied the ratio of water to bentonite and the amount of clay in plastic concrete. Results showed that by increasing of clay, the modulus of elasticity of plastic concrete decreases. International Committee for Large Dams [7] has made proposals for plastic concrete. According to the opinion of that committee, in order for plastic concrete to have good plasticity, there is no need for high compressive strength. They [7] suggested that the amount of cement consumed be between 100 and 200 kg per cubic meter, the amount of bentonite consumed be between 30 and 80 kg per cubic meter. The volume of granular materials should be about 50% of the total volume of concrete and their amount should be between 1300 and 1500 kg per cubic meter. The permeability of plastic concrete made of bentonite is acceptable between 10^{-8} and 10^{-7} m/s.

2- Experimental tests of plastic concrete

In order to evaluate the properties of plastic concrete, five different mixing designs were considered, in the first one, light sand was used and, in the others, bentonite was used. In the second and third mixing plan, dry bentonite was used and in the fourth and fifth mixing plan, wet (processed) bentonite was used to make plastic concrete. It should be noted that for the processing of wet bentonite, bentonite was stirred for 24 hours after mixing with the required water, and then it was used in the preparation of plastic concrete. The purpose of choosing five plastic concrete mixing plans is to compare the physical and mechanical characteristics of the samples made with dry and wet bentonite and also to compare their characteristics with plastic concrete obtained from light sand. For this purpose, the amount of cement used in all the samples was equal to 150 kg/m^3. All five mixing plans were chosen in such a way that the slump of the samples was close to each other. It should be noted that the first mixing plan, which is prepared using light sand, has the lowest cost and time required for preparation. Meanwhile, in the fourth and fifth mixing plans, due to the bentonite processing time of at least 24 hours, the cost of equipment and manpower as well

*Corresponding author's email: Masoud.khabazian@iau.ac.ir

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Table 1. Specifications of 5 mix designs of plastic concrete

Mix design No.	Bentonite (kg/m^3)	Light sand (kg/m^3)	Water (lit/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)
1	0	169.57	216	943.7	759.4
2	55	0	282.47	882.41	795.05
3	35	0	275.56	901.8	801
4	55	0	355.37	1052.37	411.88
5	35	0	304.82	853.75	764.35

Table 2. Test results of 5 mix designs of plastic concrete

Mix design No.	7 days Compressive strength (kg/cm^2)	28 days Compressive strength (kg/cm^2)	28 days Elasticity modulus (kg/cm^2)	28 days Tensile strength (kg/cm^2)	Permeability (cm/s)
1	28	43.2	6700	4.11	4.08e-6
2	15	32.1	5000	3.05	1.41e-7
3	18.9	34.1	5200	4.21	1.53e-7
4	11.3	23.5	2200	2.44	1.34e-7
5	15.7	30.3	4200	3.53	1.42e-7

as more time is spent. Examining the cost of making samples showed that the cost of producing plastic concrete with the fourth mixing plan is about 35% higher than the production of plastic concrete with the first mixing plan. Table 1 shows the specifications of five plastic concrete mixing designs. Table 2 shows the test results of all five mixing designs.

3- Pile group simulation

In order to investigate the practical properties of plastic concrete, the retaining wall of a project located in the city of Mashhad with a depth of 31 meters was simulated in three dimensions. For this purpose, 3D Plaxis 2020 software was used. For simulation, the finite element method, hardening soil behavior model and consolidation analysis were used. The retaining wall implemented in the mentioned project includes piles tangent to each other and struts. The piles with a diameter of one meter are divided into structural piles (made of ordinary reinforced concrete) and plastic concrete piles (made of plastic concrete). The plastic concrete mixing plan in the plastic concrete piles implemented in the project is the same as the fourth mixing plan. The underground water level at the beginning of the project was at a depth of 25 meters. Due to the fact that the depth of the excavation in the mentioned project is equal to 31 meters, it was possible for water to enter the project. According to what happened in the implementation, 10 stages were considered for simulation. To reduce the computational cost, a part of the project with dimensions of 10 × 16.8 meters was simulated.

The simulations were performed in two modes. In the first case, the retaining wall implemented in the target project was simulated. Due to the fact that in the implementation of the plastic concrete pile of the project, the fourth mixing design has been used, the permeability and resistance characteristics of the plastic concrete pile of the fourth mixing design (28-day compressive strength, 28-day tensile strength, modulus of elasticity and permeability) in the simulation was used. In the second mode of simulation, a new program was proposed. For this purpose, the specifications of the first plastic concrete mixing design (which has the highest compressive and tensile strength and modulus of elasticity as well as the lowest production cost) should be used for plastic concrete piles. Also, in this case, the underground water level is kept constant at the same depth of 25 meters to reduce the occurrence of consolidation settlements that can cause heavy damages to the nearby structures. Results showed that by keeping the underground water level constant and using plastic concrete piles, according to the first mixing design, it is possible to reduce about 15% of the maximum deformation of the excavation wall, 12% of the maximum settlement of the excavation wall, and 25% of the swelling of the excavated floor. In addition, the cost of plastic concrete made from the first mixing plan is 35% less than the cost of plastic concrete made from the fourth mixing plan.

In order to investigate the effect of plastic concrete pile permeability, six analyzes were performed. Results showed that the permeability of the plastic concrete pile has little effect on the settlement and deformation of the excavation. By increasing the permeability of the plastic concrete pile, the flow through the wall and the swelling of the excavated floor increases. One of the factors affecting the flow through the excavation wall is the permeability of the soil behind the wall. To investigate this factor, the soil permeability was considered different from the depth of 29 to 32 meters. By increasing soil permeability, the flow rate passing through the wall increases.

4- Conclusions

To determine plastic concrete with the best mixing plan, five different mixing plans were considered. In the first mixing plan, light sand was used, in the second and third, dry bentonite was used, and in the fourth and fifth, processed wet bentonite was used. The results showed that the first mixing design has the highest compressive strength, tensile strength, modulus of elasticity and lowest cost.

Tangential pile group including structural piles and plastic concrete piles with struts in the vicinity of the deep excavation was simulated in three dimensional. The simulation results showed that if the underground water level is kept constant and the first mixing plan is used, compared to the case where the underground water level is reduced by 10 meters and the fourth plan is used for plastic concrete, the maximum deformation of the excavation wall, the maximum settlement of and the swelling of the excavated floor is reduced. The effect of plastic concrete pile permeability was investigated. Results showed that the permeability of the plastic concrete pile has little effect on the settlement and deformation of the wall. By increasing the permeability of the plastic concrete, the flow rate passing through the excavation wall increases. The effect of soil permeability behind the excavation wall on the flow rate of the flow was investigated. Results showed that by increasing soil permeability, the flow rate passing through the wall increases.

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HOW TO CITE THIS ARTICLE

M. Taghdisi Ali, M. Khabazian, S. M. Sajjadi Attar, Numerical Simulation of Pile Group Behavior by Proposed Optimum Mix Design of Plastic Concrete, Amirkabir J. Civil Eng., 54(12) (2023) 969-972.

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