Structural Optimization of Flood Control Screw Piles: A Review

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Abstract. This paper discusses the importance of research on flood control piling equipment, and lists the existing domestic flood control piling equipment. The research status of screw piles at home and abroad in recent ten years is summarized from three aspects: bearing capacity, installation torque, stress and strain of soil. This paper introduces some optimization methods closely related to screw piles, such as evolutionary algorithm, neural network, numerical simulation optimization method, and makes a comparative analysis of the optimization methods that can be adopted for the screw pile. At last several directions which need to be further studied in the future are put forward.

Keywords: screw piles; optimization algorithm; numerical simulation; pile driving; flood control.

1. Introduction

There are many rivers and lakes in China, and the total amount of water conservancy projects built on that is huge. Some shortcomings in design, construction, maintenance of water conservancy projects will lead to various kinds of dangers in flood season. Common dangers include overflow, wave washout, bank crack and collapse.\textsuperscript{[1]} piles and its supporting pile drivers are essential for flood control emergency, which can be mainly used for embankment reinforcement, curtain hanging to plug loophole, barrier setting in fissure, ship and cable hanging operation and so on.

At present, there are mainly the following methods for flood control piles: manpower hammer piles, mechanical hammer piles and mechanized sink screw metal piles. However, the manpower hammering piles need high labor intensity, but pile sinking speed still slow and waste serious of human resources; mechanical hammering piles are difficult to display in flood disaster areas, and it is easy to cause secondary disasters such as cracks and collapses on the dam.\textsuperscript{[2]}

The research results of the existing flood control pile machines mainly include: ZJ100A type flood control pile driver\textsuperscript{[3]} adopts the principle of impact pile sinking, which has the advantages of flexible maneuverability and convenient operation, but the hitting noise is very large. DZF-120 portable flood control pile driver\textsuperscript{[4]} sink piles by periodic impact due to vibration. The main engine and power device are separated from each other, and are connected by a transmission flexible shaft, which makes the operation of pile driver more complicated. The anti-mite and rescue screw pile\textsuperscript{[5]} has the advantages of high efficiency, low vibration and noise, no secondary hazard and corrosion resistance, and is a new direction worth investing energy and time.

Based on the structural optimization of flood control screw piles, this paper summarizes the research status related to screw piles, and combines various optimization design methods to explore the feasible design scheme of screw pile structure, so that the screw piles can better meet the actual working conditions of flood control and rescue.
2. Research on Screw Piles at Home and Abroad

The researches on flood control piles and their associated machines at home and abroad are not too much, but domestic and foreign scholars have already had a lot of understanding of the characteristics of screw piles in pile foundation engineering, including the installation torque, bearing capacity and group pile effect of screw piles. Therefore, we can refer the study of screw piles used in pile foundation engineering to solve the problem of structural optimization of flood control screw piles. For the study of screw piles, different scholars tend to apply different research methods, which can be roughly divided into theoretical analysis, numerical simulation, indoor model test and field test research. In the following, the research of screw piles by previous scholars will be summarized from three aspects: bearing capacity, installation torque and stress and strain on soil.

2.1. Research on Bearing Capacity of Screw Piles

The role of the screw pile is generally subjected to compression or tension. Therefore, the bearing capacity must be considered in the design process of the screw pile. A large number of experts and scholars have analyzed the screw pile from the perspective of bearing capacity. The systematic research of screw steel piles abroad began in 1950s, and the research of bearing capacity of screw steel piles have made great progress in the past ten years. M. Hesham El Naggar et al. [7-8] began to study the monotonic and cyclic characteristics of screw pile foundation system in 2007, developed a new type of screw pile foundation system suitable for seismic transformation of existing foundation and new structure, and conducted some static and dynamic load tests about it. Mohammed Sakr et al. [9-10] carried out full-scale pile load tests using single pile and double screw piles, and studied the performance of single pile and double screw pile under axial compression, tension and lateral loads. Amy B. Cerato et al. [11] compared the uplift prediction methods used in screw pile design as well as discussed the effects of long-term dynamic loads and water level fluctuations on the performance of screw piles used as the foundation of small wind tower stay cables. Hamed Niroumand et al. [12] carried out laboratory tests of small-scale models with sand paving technique and measured uplift load and uplift displacement. Yong-Seone KIM et al. [13] compared the laboratory model tests of pre-drilled screw piles and smooth surface piles with different diameters, pitches and screws, and then combined with the finite element method to find appropriate parameters of screw pile mainly based on ultimate bearing capacity. Adnan Anwar Malik et al. [14] carried out laboratory model tests on pile loads and straight piles, and tested the displacement of piles and the stress changes of soils. The results show that screw piles in similar pile shaft diameter showed higher end bearing capacity than straight piles. Lisa n. Wheeler et al. [15] proposed the use of screw pile to reduce the displacement of railway track and play a role in strengthening the foundation of railway track, at the end conducted experiments for nearly a year, showing that the effect of screw pile on foundation reinforcement is obvious. Although the research on domestic screw piles started later, due to the large number of applications of pile foundation engineering in China, domestic scholars have already accumulated a lot of research on the bearing capacity of screw piles. In recent ten years, the research direction of domestic scholars tends to be more and more diversified, and there are many researches on specific engineering practical problems. Dong Tianwen et al. [16] systematically conducted theoretical and experimental research on screw steel pile. Through the theoretical analysis, the failure mode of the screw pile foundation and the calculation method of the bearing capacity of the screw steel pile are proposed, and the influence of several geometric parameters of the pile on the bearing capacity of the pile is analyzed by model test and field test. Wang Zhao et al. [17] summarized the application of screw steel pile manufacture of screw pile, conducted structural design, and carried out anchoring and field drawing tests on anchor rods with different soil penetration depth, overlying soil thickness, standing time and whether grouting. Liu Jiankun et al. [18] investigated the photovoltaic support screw pile, through the tension and compression test, the pile type parameters (blade spacing, number of blade paths, blade diameter, pile length, etc.) of the screw steel pile and its ultimate pullout resistance. The relationship between the compressive bearing capacity is studied, and the recommended values of the pile parameters are given combined with test results. Zhou Yang [19] compared the bearing characteristics of variable-section threaded piles with ordinary threaded straight piles and ordinary cylindrical smooth piles by laboratory
model test and finite element method, and analyzed the influence of pitch, varied-section and thickness of screw blade on the bearing capacity of threaded pile.

2.2. Research on Screw Piles about Installation Torque
The flood control screw pile requires that the pile body should reduce the torque as much as possible on the basis of meeting the bearing capacity requirements, so that the supporting pile-sinking equipment can be more simple and efficient, and easy to carry. Since the installation and settlement of the screw pile in the pile foundation engineering can be equipped with sufficient power, there is generally no need to worry that the pile cannot provide sufficient torque and pressure, so there is relatively little research on the pure installation torque of the screw pile. However, many scholars have found that there is a certain relationship between the installation torque and the bearing capacity after the pile is installed, so that a lot of researches have been carried out on that. El Naggar et al. [20-21] tested the installation torque and bearing capacity of screw piles, compared and obtained the torque bearing relationship applicable to large-diameter screw piles, and conducted finite element analysis to study the ultimate load criterion and load transfer mechanism of screw piles. Nelson Aoki [22] theoretically analyzed the relationship between the installation torque and uplift capacity of deep screw pile in sand layer, verified the correctness of this expression through centrifugal and direct shear interface tests, and finally compared the torque correlation factor calculated in different literatures. Mohammed Sakr [23] also presented a theoretical model developed to estimate the torsional resistance of cohesionless soils, and verified the theoretical torque model using some installation records. In order to study axial capacity and end installation torque of piles in cohesive soils, Zhengyang Guo et al. [24] conducted field tests on full-size screw piles and established a theoretical model of end installation torque. Umair Khan and Sumi Siddiqua [25] continue to study the relationship between the installation torque and bearing capacity of screw piles, focusing their research on the settlement of ultimate load and laying a foundation for the wide application of screw piles.

2.3. Analysis of Soil Stress and Strain by Screw Piles and Pile Group
The The dams need flood control and rescue operations are generally fragile, and it is very likely to cause secondary damages to the dam during pile installation. Therefore, it is necessary to consider the influence of the soil structure during the process of sinking piles into the soil. Many studies have been done on soil stress and strain analysis at home and abroad, but most of the tests are complicated and the equipment is expensive. CC HIRD et al. [26] carried out a model test of screw piles in beds of transparent synthetic soil simulating clay. Reflected particles were mixed into the clay, and the soil displacement could be recorded under laser irradiation, at the end vertical axis of the screw axis was measured by particle image velocimetry. This method can reveal the real mechanism of soil deformation around the screw pile by comparing and analyzing the deformation field under the influence of different pullout forces. Hamed Niroumand et al. [12] analyzed the measurement of drawing load and vertical displacement, and studied the failure mechanism of soil. In the rescue process, the flood-prevention screw pile generally needs a lot of piles to sink into a certain area at the same time, so group pile analysis is also very necessary. There are many researches on pile group theory in pile foundation engineering: Dong Tianwen and Zheng Yingren [28] Based on a lot of theories established a bearing capacity function of pile group foundation, and the concept of ultimate load criterion and safety reserve factor of group pile foundation is proposed. C.C. Mendoza et al. [29] extended the knowledge of shear mechanism, stress generated, displacement field and the contribution of supporting raft to the overall system performance by combining finite element analysis with field test. Bushra s. Albusoda et al. [30] studied 36 kinds of screw pile group models embedded in expansive soil, which was formed by four piles arranged in a square way.

2.4. Research on Soil Replacement Screw Piles
Although the soli displacement screw piles are only used to squeeze soil and drilling, ultimately what created bearing force is the concrete which have been poured in the hole after drilled, the interaction between soil and drill bit during drill the hole has a high reference significance for the pile installation modeling of flood control screw piles.
T. Pucker [27] conducted numerical simulation of screw pile installation process based on Coupled Eulerian–Lagrangian approach, analyzed the influence of different ratios between the rotational and the penetration velocity, and verified the numerical model with experimental data of others. A. Krasin [31] conducted experiments and numerical simulation on the interaction between screw pile and non-cohesive foundation in the process of compression load transfer. Deng Yibing et al. [32-34] conducted discrete element analysis based on PFC software on the pile installation process of soil displacement screw piles, and compared it with indoor model test and field test to verify the effectiveness of numerical simulation. Different parameters of screw piles are taken for finite element analysis and indoor model test analysis, which provided a basis for optimal design of screw pile's drill bit. The influence of rotation speed ratio on the pore formation characteristics of loose and dense soil was analyzed by means of macroscopic model test and microscopic digital image analysis.

3. Research on Optimization Method of Screw Pile Structure

The structure of screw pile is mainly composed of central cylindrical pile and screw blades, so the structural optimization of screw pile is based on the interaction between cylindrical pile and soil and the parameter optimization of screw blade. The optimization methods commonly used in mechanical design include tabu-search algorithm, simulated annealing algorithm, genetic algorithm, ant colony optimization algorithm, artificial neural network, Lagrange relaxation algorithm and so on. In the published literature, four methods are mainly used for pile optimization and screw optimization: fmincon function optimization method, evolutionary algorithm, neural network, numerical simulation combined with experimental.

3.1. Fmincon Function Optimization Method

Fmincon function is widely used in various fields because it can directly call the command of the mathematical calculation software MATLAB after building the model, which is convenient and simple to use. Ma Aili [35] and Xue Zixuan [36] respectively constructed the mathematical model of screw cutter optimal design for vertical rotary-cultivated ditcher. Zhang Chengxin et al. [37] established the mass objective function of the helix and calculated the optimal solution of the mathematical model by using the fmincon function. Wu Yinliang et al. [38] used fmincon function to optimize the plane layout, spacing, anchoring depth and section shape of the pile, which has many references for the layout of the flood control screw piles.

3.2. Evolutionary Algorithm

Evolutionary algorithms cover a wide range, including genetic algorithm, ant algorithm [39], particle swarm optimization, harmony search algorithm [40] and so on. At home and abroad, there are many examples of applying evolutionary algorithms to the optimization of screws. Cristina Teixeira [41] adopted multi-objective ant colony optimization algorithm (MOACO) to deal with the twin-screw configuration problem, and compared the performance with the existing multi-objective evolutionary algorithm and two-stage local search algorithm. Ching-chi Hsu et al. [42] adopted genetic algorithm for multi-objective optimization in the investigation of bone screws to study the optimal design of bending strength and bone holding power. Chian-her Lee et al. [43] established a three-dimensional numerical model of locking compression plate femoral fracture in order to find the optimal number and position of locking compression plate screws, and used particle swarm optimization algorithm based on simulation to determine the position and number of screws. Kyunguk Na et al. [44] on the basis of predicting the bearing capacity of screw piles, optimized the components of screw piles and adopted harmony search algorithm to minimize the material cost of screw piles. Li Xiaohuo and other scholars used evolutionary algorithms to optimize the structural parameters of the shearer auger drill and drum, the optimization variables were the drill pipe inner diameter, blade screw angle, blade height, blade thickness, blade pitch and motor speed: hybrid algorithm based on genetic algorithm and ant algorithm (GAAA) on the coal productivity and conveying efficiency optimization [45]; Evolutionary algorithm based on strength pareto evolutionary algorithm (SPEA) optimizes
transportation productivity, machine quality and energy consumption \cite{46}. The improved genetic algorithm was used to carry out multi-objective optimization design for the conveying power, secondary crushing rate, coal conveying quantity and drill pipe quality of the screw coal drilling and mining machine \cite{47}. Qin Dagong \cite{48} used particle swarm optimization algorithm and annealing algorithm to optimize the cutting performance of shearer drum. With the increasing maturity of the evolutionary algorithm to solve multi-objective optimization problems \cite{49}, the evolutionary algorithm plays an increasingly important role in the screw optimization problem. Therefore, the optimization problem of flood control screw piles needs further study of evolutionary algorithm in the future. The optimization objectives of flood control and emergency spiral pile include the quality of spiral pile, driving torque and bearing capacity. For the problem of four optimization targets, there are many classic second-generation multi-objective optimization algorithms, such as SPEA-II, PAES-II, NSGA-II, which have good optimization effect. These algorithms have many successful cases in engineering optimization, among which NSGA-II is the most widely used.

3.3. Artificial Neural Network

The neural network is mainly used to predict the bearing capacity of pile, and can also be used for inverse prediction of soil parameters \cite{50}, multi-objective optimization \cite{51} and other problems, so it has a wide range of applications. Neural networks are suitable for nonlinear systems and can be used for systems that are difficult to be described by mathematical expressions, but the neural network needs a large amount of data to perform the operation.

Irshad Ahmad et al. \cite{52} established six artificial neural network models for predicting various response parameters of soil pile interaction. F. PooyaNejad \cite{53} established a neural network model to predict pile settlement according to standard penetration test (SPT) data. Mansour Mosallanezhad \cite{54} used competitive algorithm (ICA) to train, test and optimize the artificial neural network, and the ICA-ANN model established has a good prediction effect on the ultimate bearing capacity of screw piles. Hossein Moayedi \cite{55} used classical support vector machine and its two variants, namely, normalized generalized proximal support vector machine and double support vector machine, adaptive neural fuzzy inference system and genetic programming, to model and predict the friction resistance of clay foundation piles. H. I. PARK et al. \cite{56} introduced the application of ANN in dynamic load test of pile foundation, predicted pile tip resistance and pile body resistance, and measured these values accordingly. FatehniaMilad \cite{57} established a model to predict the bearing capacity by using the data of the last meter hammer strike times of 100 driven piles, the basic properties of surrounding soil, pile geometry and friction Angle of pile and soil, etc., combined with the artificial neural network. Then, using genetic algorithm program and linear regression method, the influence equations of plate number, soil parameters and pile geometry on pile bearing capacity are established. Xu Lina \cite{50} used the combination of finite element and experiment to analyze the bearing characteristics of large-diameter pile foundation, and applied the BP neural network to back-analyze soil parameters.

3.4. Numerical Simulation Combined with Experimental

When using numerical simulation to optimize parameters, relevant verification tests are usually designed to verify the accuracy of numerical simulation optimization solutions. Ma Aili \cite{35} and Xue Zixuan \cite{36} respectively carried out numerical simulation of soil cutting with screw cutting ditcher based on ANSYS/ls-dyna, which was used to calculate the maximum power of soil cutting. Wang Shaowei et al. \cite{58} established a simulation model for optimization of structural parameters of tooth cutter by using response surface analysis method and EDEM software, and obtained the structural parameters of ditcher through optimization. Gao Wening et al. \cite{59} used orthogonal experiments to optimize the deep burial rate of corn straw, the power consumption of furrow cutting and the maximum deviation of unit linear driving. Sebastian lobo-guerrero et al. \cite{60} used discrete element method to analyze and visualize the influence of pile type on the permeability resistance of driving pile to crushing particles. Hong-bin Xiao et al. \cite{61} analyzed the interaction between pile and soil in expansive land by numerical simulation. NuoDuan et al. \cite{62} used discrete element method to study the effect of foundation pile installation.
3.5. Other Optimization Methods

Michal Lisicki et al. \cite{63} applied Bayesian optimization method to optimize the design and operation of Archimedes screw turbine (AST), so as to maximize the total return rate of specific devices. KyeongEop Kang \cite{64} used response surface method to optimize the pretreatment parameters when designing the double-screw extruder, and evaluated the pretreatment effect through relevant tests.

4. Conclusions and Prospects

This paper discusses the importance of flood control and emergency rescue, enumerates some existing pile driving equipment for flood control and emergency rescue, summarizes and analyzes the research status of spiral pile used in pile foundation engineering, and explores the optimization methods related to spiral pile. Through the summary of the problems related to the optimization of screw pile structure parameters, it is found that the optimization of screw pile in the future exploration should pay attention to the following aspects:

- At present, there is little research on the theory of spiral pile sinking, so it is necessary to fully learn from the mature pile-soil interaction mechanism, combine the pile-soil friction theory, comprehensively consider the parameters of spiral pile and soil, and make the theoretical model of spiral pile sinking into soil more conform to the actual situation. When the theoretical model and bearing capacity model of screw pile installation are established, each component of the theoretical model is verified by combining the test and finite element method. For example, the pile head is isolated to test its installation torque, and the pressure required for pile installation is tested after removing screw blades of the screw pile, so as to test and modify the theoretical model.

- When using finite element model simulation, especially when using existing commercial software, such as ANSYS, to do screw pile installation and load analysis, there is some gap between the pile-soil interaction model used and the actual pile installation process, so the simulation results may not very consistent with the actual degree. Therefore, it is necessary to combine the finite element method with others, such as: study the dynamic contact of piles and soil by combining the finite element method and boundary element method, and investigate the coupling of finite element method and smooth particle method. In this way, part of operational errors which are difficult to overcome by the finite element method can be corrected.

- In the optimization design of flood control and emergency helical pile, the optimization objective of screw pile can be extended from the single objective optimization of installation torque of screw pile to multiple objectives optimization: mass of screw pile, installation torque, bearing capacity, etc. The second-generation multi-objective optimization algorithm such as the widely used NSGA-II, can be used to calculate the theoretical model of screw pile installation and bearing capacity. Under certain soil parameters, an optimal set of structural parameters of screw pile is obtained.

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