SSRG International Journal of Mechanical Engineering
ISSN: 2348–8360 / https://doi.org/10.14445/23488360/IJME-V10I6P103

Volume 10 Issue 6, 15-19, June 2023
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Original Article

Optimize the Parameters of the Barrette Grab Bucket based on the Objective Function of Minimizing the Tensile Stress of the Smallest Crawler Crane

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Received: 26 April 2023 Revised: 04 June 2023 Accepted: 15 June 2023 Published: 29 June 2023

***Abstract** - The barrette grab bucket is one of the important devices used in the construction of foundations for bridges and high-rise buildings. The productivity, quality, and construction cost of the pile holes depend on various parameters, such as the shape and size of the excavation bucket, the assembly position of the components on the excavation bucket, and the crawler crane serving the bucket. This article studies the influence of the position of the components on the excavation bucket on the tension force of the crawler crane based on the dynamic analysis of the barrette grab bucket during the excavation process. This helps determine the reasonable parameters of the barrette grab bucket according to the objective function of the minimum tension force of the crawler crane, providing a basis for selecting crawler cranes with appropriate lifting capacity to reduce construction costs.*

***Keywords** - The shape of the barrette grab bucket, The size of the digging bucket, The dynamic analysis of the barrette grab bucket, The reasonable parameters of the barrette grab bucket, and the minimum tension force of the crawler crane.*

1. Introduction

The barrette pile construction equipment is one of the commonly used devices in foundation construction, and there have been numerous in-depth studies on this type of equipment. These studies include research on the digging forces acting on the excavation bucket during the design and optimization of the bucket shape [5], [9], [10], [13]; investigation of the appropriate weight of the working unit for different soil and rock conditions [5]; optimization of the excavation bucket design based on dynamic analysis and dynamic force analysis during the start and end of the digging process [11]; determination of reasonable parameters for the excavation bucket during the extraction process [3]; optimization of the bucket structure based on trajectory and limiting digging force [2]; application of genetic algorithms for excavation bucket optimization [12]; design and testing of new type and traditional type grab buckets, and comparison of their working efficiency [1]; study of the quantity and position of bucket teeth for effective digging cycles [4]; application of finite element method to determine digging force and digging resistance when changing the inclination angle of bucket teeth [15]; study of the tension force of the lifting cable of the grab bucket through sensors installed on the winches of the crawler crane [7]; theoretical and practical investigation of digging force and digging resistance of the excavation bucket to determine the percentage difference between theoretical calculations and actual measurements [8]. However, there is no existing research on the optimization of parameters of the barrette grab bucket based on the objective function of minimizing the tension force of the crawler crane. This paper focuses on studying this issue.

2. Contents

2.1. Determine the Tension Force of the Closing Cable for the Digging Bucket

The structural diagrams of the barrette grab bucket are presented in Figure 1 and Figure 2.

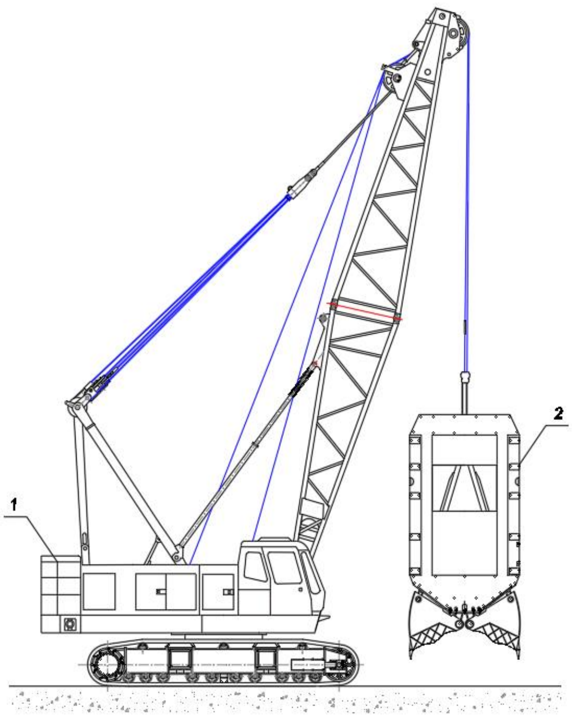

Fig. 1 The structure of the barrette grab bucket mounted on a crawler crane

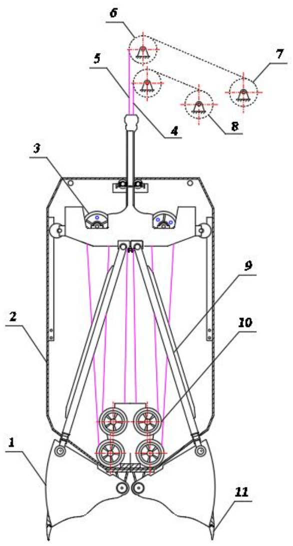

Fig. 2 The structure of the barrette grab the bucket

According to Figure 1: 1- Crawler crane, 2- Barrette grab bucket.

According to Figure 2: 1- Digging bucket, 2- Bucket body, 3- Upper pulley assembly, 4- Lifting cable, 5- Digging bucket closing cable, 6- Guide pulley of the crawler crane; 7,8- Winch assembly of the crawler crane, 9- Push bar, 10- Lower pulley assembly, 11- Cutting teeth.

The diagram of the forces acting on the digging bucket during the soil-digging process is presented in Figure 3.

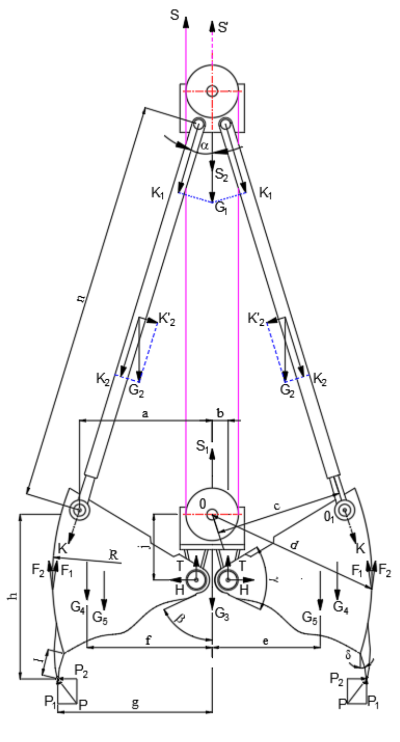

Fig. 3 The diagram of the forces acting on the digging bucket during the soil-digging process

According to Figure 3: S - Force in the digging bucket closing cable; S' - Force in the barrette grab bucket lifting cable; S_1 and S_2 - Combined forces of the cable branches;

G_1, G_2, G_3, G_4, G_5 - Weight of the upper pulley assembly, the push bar, the bucket body and lower pulley assembly, the digging bucket, and the soil inside the digging bucket;

H, T - Reaction forces at the digging bucket mounting joint; K_1, K_2, K - Forces on the push bar; F_1, F_2 - Frictional forces between the soil and the digging bucket; P_1, P_2 - Normal resistance force and tangential resistance force of the soil acting on the cutting teeth; R - Radius of the digging bucket; a, b, c, d, e, f, g, h, j, l, n – Dimensions are indicated in figure 3; β, γ, α, δ - Structural angles are shown in figure 3.

According to document [14]:

- The normal resistance force P_1 can be calculated as follows:

$$P_1 = \psi . P_2 \tag{1}$$

Where: Ψ- Dependent coefficient; P_2 - Tangential resistance force, N.

- The tangential resistance force P_2 can be calculated as follows:

$$P_2 = \mu . B . \tau \tag{2}$$

Where: μ - Coefficient of the soil resistance force, N/m^2; B - The width of the cutting edge, calculated as the width of the digging bucket, m; τ - The thickness of the cutting edge generated by the bucket teeth, m.

- The thickness of the cutting edge can be calculated as follows:

$$\tau = l . \cos\delta \tag{3}$$

Where: l- The length of the cutting teeth, m; δ - The front cutting angle of the bucket teeth, degree.

- The frictional force between the outer wall of bucket F_1 and the soil and the frictional force between the inner wall of bucket F_2 and the soil during the soil digging and compaction process can be determined as follows:

$$F = F_1 + F_2 = G_5 . \varepsilon + (G_1 + G_2 + G_3 + G_4) . \varepsilon \tag{4}$$

Where: ε - Coefficient of friction between the soil and the digging bucket

- The tension force of the digging bucket closing cable:

$$S = \frac{S_1}{m.\eta_p} \Rightarrow \quad S_1 = S.m.\eta_p \quad \text{and: } S_2 = S_1 - S = S.(m.\eta_p - 1) \tag{5}$$

- The force acting on the push bar:

$$K = K_1 + K_2 = (\frac{S_2+G_1}{2} + G_2).cos\alpha \quad (6)$$

By substituting equation (5) into equation (6), we obtain:

$$K = \frac{1}{2}[G_1 + 2G_2 + S.(m.\eta - 1)].cos\alpha \quad (7)$$

On the other hand:
Calculating the moment with point 0, we obtain:

$$K = \frac{H.j + T.b + P_1.g + P_2.h + (F_1 + F_2).d - G_4.f - G_5.e}{c} \quad (8)$$

To determine the forces H and T and project the forces K, G_3, G_4, G_5, H, T, S_1, F_1, F_2, P_1, and P_2 along the vertical and horizontal directions and calculate the moment at point 0_1, we obtain:

$$\begin{cases} H = -(P_2 + K.\sin\alpha) \\ T = \frac{G_3}{2} + G_4 + G_5 + K.\cos\alpha - P_1 - (F_1 + F_2) - \frac{S_1}{2} \end{cases} \quad (9)$$

Given that the value of K in equations (7) and (8) is equal, and substituting the values of the parameters from equations (1), (2), (3), (4), (5), (9) into equations (7) and (8), we obtain:

$$S = \frac{2b.[\frac{G_3}{2}+G_4+G_5-\psi.\mu.B.l.\cos\delta-(G_1+G_2+G_3+G_4+G_5).\varepsilon] + b.(G_1+2G_2).(\cos\alpha)^2+2\mu.B.l.\cos\delta.(g.\psi+h)+2[(G_1+G_2+G_3+G_4+G_5).d-G_4.f-G_5.e] - 2j.\mu.B.l.\cos\delta-(G_1+2G_2).(c+j.\sin\alpha).\cos\alpha}{(m.\eta-1).[(c+j.\sin\alpha).\cos\alpha-b.(\cos\alpha)^2]+b.m.\eta} \quad (10)$$

This article uses the parameters of the commonly used barrette grab bucket type LTN-1000, which has the following specifications: The dimensions (m): a=0,428; b=0,051; c=0,413; d=0,554; e=0,348; f=0,404; g=0,498; h=0,531; j =0,212; n=1,304. The angles (degree): β=65; γ=56; α=16; δ=15. The weights (N): G_1=23400; G_2=9360; G_3=63180; G_4=10530; G_5=3300. The parameters of the digging bucket (m): R=0,8; B=1,0; l=0,2. The other parameters: m = 6, Ψ =0,25, ε=0,5, μ = 30. 10^4 N/m^2.

Substituting the given parameters into equation (10), we obtain the tension force of the digging bucket closing cable during digging, S = 45412,4 N.

2.2. Optimize the Parameters of the Barrette Grab Bucket Based on the Objective Function of Minimizing the Tensile Stress of the Smallest Crawler Crane

According to equation (10), given the soil type and the parameters: a, d, e, f; g, h, n, β, γ, α, δ, G_1, G_2, G_3, G_4, G_5, R, B, l, m, Ψ, the objective function only depends on the parameters j, b, c. Therefore, the optimization problem can be formulated as follows: When expressing the tension force function S as S = f(x_i) with $x_i \in R^n$, where (x_1= j; x_2= b; x_3= c). Find the minimum value (min) of the function f(x_i) corresponding to $x_i \in R^n$, where (x_1= j; x_2= b; x_3= c). This should satisfy the given condition that the amount of excavated soil remains constant after each digging cycle, along with the specified constraints: $j_{min} < j < j_{max}$; $b_{min} < b < b_{max}$ and $c_{min} < c < c_{max}$ with: j_{min} = 0,15 m; j_{max} = 0,3 m; b_{min} = 0,02 m; b_{max} = 0,08 m; c_{min} = 0,3 m < c_{max} = 0,5 m.

To solve this problem, the author used the Taguchi algorithm and the Minitab simulation software, resulting in the following outcomes:

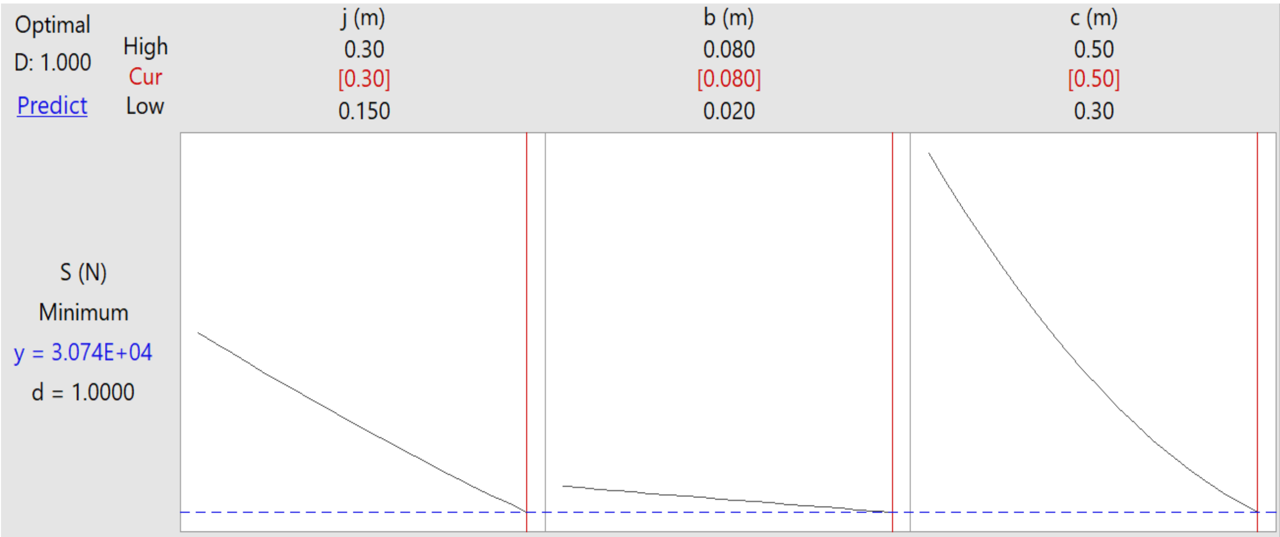

Fig. 4 Optimization of the tension force S with respect to the variables j, b, c.

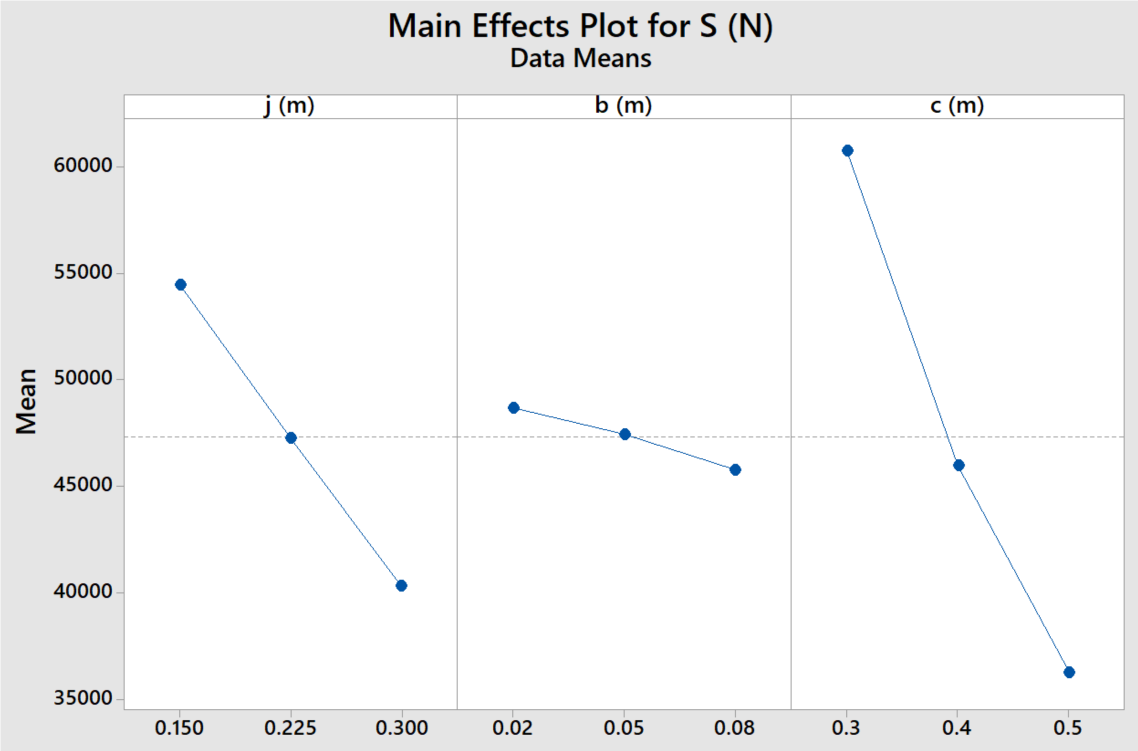

Fig. 5 Influence level of variables j, b, c on the tension force S

3. Discussion

- The minimum tension force S = S_{min} = 30740 N is achieved at the values j = 0.3 m, b = 0.08 m, c = 0.5 m (Figure 4).
- The influence level of the variables j, b, and c on S varies (Figure 5). From the graph, it can be observed that variable c has the steepest slope, indicating the highest influence on S, while variable b has the least impact on S.
- If the barrette grab bucket is designed according to the values j = 0.3 m, b = 0.08 m, c = 0.5 m, the tension force S will be approximately 68% of the LTN-1000 barrette grab bucket currently in use.

4. Conclusion

By selecting appropriate values for j, b, and c during the design and manufacturing of the barrette grab bucket, it is possible to choose a type of crawler crane with a lower lifting capacity for the bucket. It can lead to cost savings in terms of the investment required for the crawler crane and reduced construction costs. By matching the hoisting capacity of the crawler crane to the specific requirements of the barrette grab bucket, the overall project expenses can be optimized.

Acknowledgment

This research is funded by the University of Transport and Communications (UTC) under grant number T2023-CK-003.

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