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Note from the Editor

Welcome to Volume 26, Edition 2 of *Civil Engineering Dimension* (CED). As we begin another exciting edition filled with insightful research and innovations in civil engineering, I would like to take a moment to celebrate a significant achievement within our community.

We are immensely proud to share that our esteemed editor, Professor Benjamin Lumantarna, has been awarded the prestigious HAKI Achievement Award 2024. This accolade, presented by the *Himpunan Ahli Konstruksi Indonesia* (HAKI) during their annual meeting in August, is a well-deserved recognition of Professor Lumantarna's exemplary achievements and continuous contributions to the civil engineering profession and the Indonesian construction industries.

Prof. Benjamin Lumantarna, Recipient of the 2024 HAKI Achievement Award

Professor Lumantarna has been at the helm of CED for many years, guiding the journal with his visionary leadership, editorial expertise, and passion for advancing civil engineering knowledge. His commitment to both academia and industry has left an indelible mark, making him a highly respected figure in the field.

We are honored to work alongside such a distinguished individual whose achievements inspire the next generation of civil engineers. On behalf of the editorial team and all contributors to this edition, we extend our heartfelt congratulations to Professor Lumantarna on this outstanding accomplishment.

We hope this issue continues to inform and inspire, as we strive to uphold the standards of excellence that Professor Lumantarna embodies.

Happy reading!

Warm regards,
Prof. Djwantoro Hardjito, Ph.D
Editor in Chief
Civil Engineering Dimension

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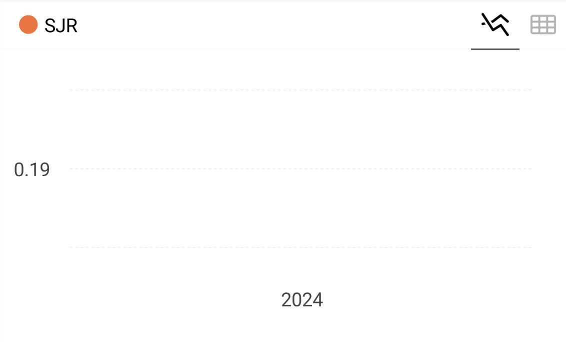

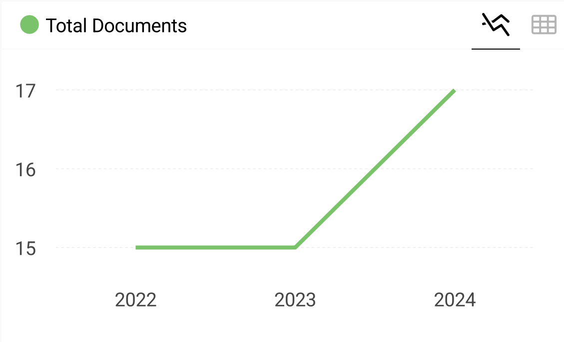

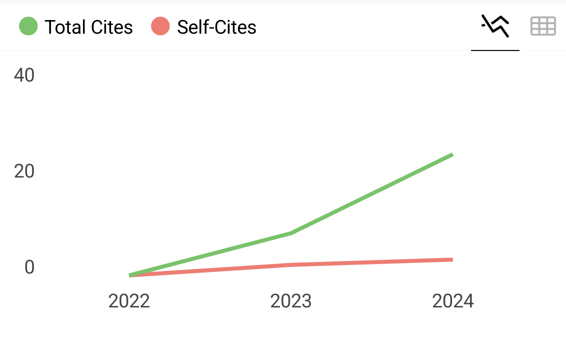

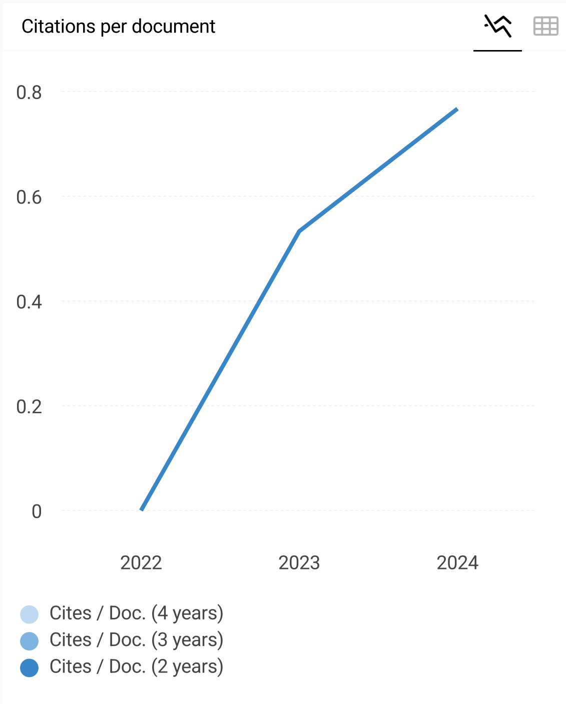

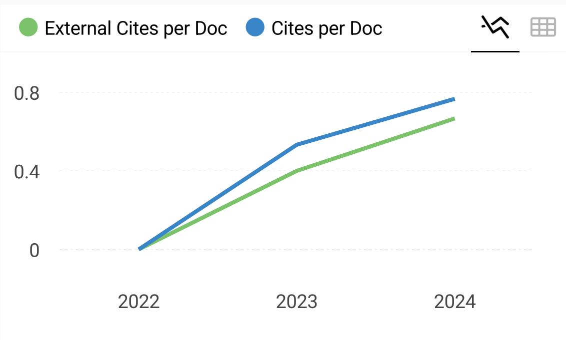

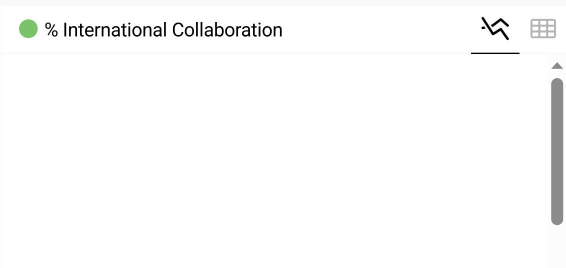

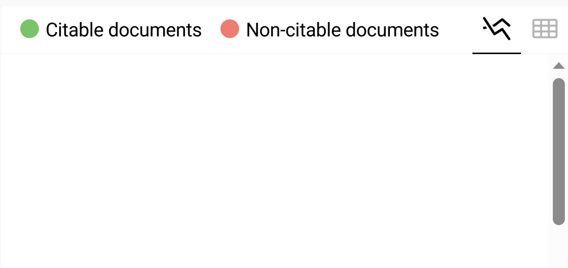

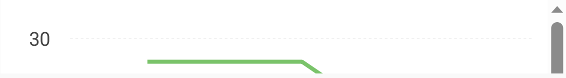

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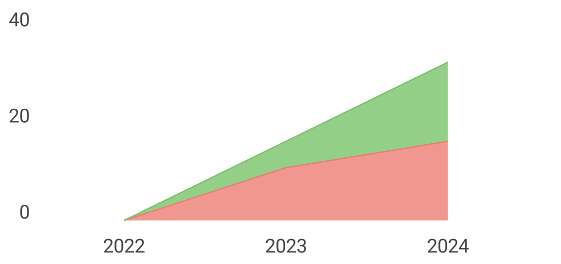

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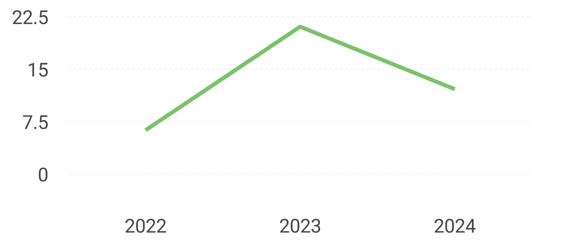

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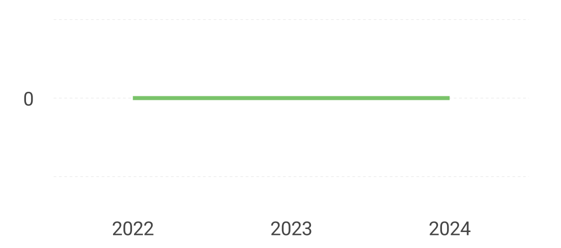

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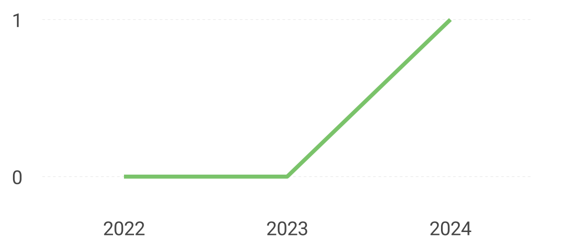

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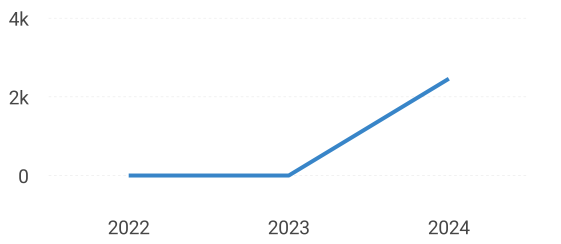

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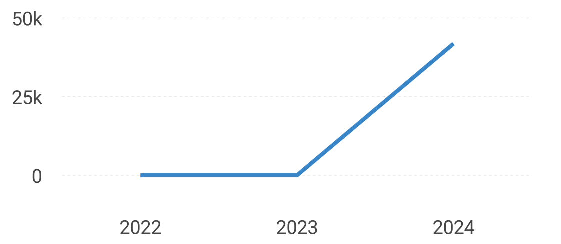

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Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method

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Abstract

This paper presents the optimization work to obtain the most economical of counterfort retaining wall structure with shear key attached at its base using metaheuristic method. The metaheuristic algorithm is a global optimization method that can be used to find the optimum solution of complex problems. In this research, optimization is carried out using the Particle Swarm Optimization (PSO) and Symbiotic Organisms Search (SOS) methods. This research utilizes a retaining wall sitting on stiff clay layer subjected to ten (10) m of granular soil of backfill. The scope of the study is limited to the material cost, that consists of the cost of concrete and reinforcement bars, of the counterfort retaining wall with shear key. The results show that the SOS algorithm resulted a lower cost and relatively faster in obtaining optimum retaining wall design compared to that of the PSO algorithm.

Introduction

A retaining wall is a structure to withstand lateral active pressure of soil or water [1]. A retaining wall consists of vertical section, commonly known as a stem, and a base slab. There is a specific element beneath the base slab called a shear key, which enhances the stability of the retaining wall to anticipate lateral force by utilizing passive pressure below the base slab arising from the active lateral pressure of the soil [2].

In general, the dimension and reinforcement of the cantilever wall (stem) increases with the increase of its bending moment generated due to lateral pressure of soil. The generated bending moment in the stem can be reduced by employing counterforts (a vertical walls or slabs) that connect the stem and the base slab of the retaining wall. In other words, counterforts play an important role in restraining tensile/horizontal force developed in the stem of the retaining wall [3].

Studies on the optimization of retaining wall can be found in several publications. Kalemci et al. [2] developed a tool using Grey Wolf algorithm to determine the optimum design of cantilever wall with shear key to increase its horizontal capacity. The retaining walls with a 3m and 4.5m height of stem were designed to retain embankment consisting of both cohesive and non-cohesive soils. The optimization process of the two metaheuristic algorithms proceeded for 30 runs, where each run iterated 1000 times. It is stated that the results of the optimization of cantilever wall with shear key, developed using Grey Wolf algorithm, agree with other published results using different algorithms. Öztürk et al. [4] developed an application using Teaching-Learning Based Optimization (TLBO) and Jaya algorithms to obtain the optimum cost of a 10-m height counterfort retaining wall with shear key, which is built in cohesive soil. It is stated that the TLBO algorithm exhibits better performance compared to the Jaya algorithm.

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This research employs metaheuristic approach to optimize a counterfort retaining wall with a shear key subjected to gravity and seismic loads, which meets all existing constraints while considering safety requirements, and producing cost-effective solutions. Two metaheuristic algorithms, namely Particle Swarm Optimization (PSO) and Symbiotic Organisms Search (SOS), are utilized in this study. Both algorithms operate using a penalty function method to control the existing constraints during the design process, thereby achieving optimal and economical results while still satisfying safety requirements.

The PSO algorithm is inspired by natural conditions about food chains, such as the social behavior of a group of birds or insects looking for food. The concept is to mimic the social interaction between individuals in the group to find the optimal solution to the optimization problem. PSO is computationally efficient because it requires only a few computing resources to work, so the number of iterations used to produce optimal results is relatively small and fast [5].

The SOS algorithm uses mutualism, commensalism, and parasitism strategies to simulate interactions in a relationship. SOS uses simple mathematical operations, and can achieve efficient and effective optimization without the need to determine parameter tuning like other algorithms so that its performance stability is higher [6]. SOS is also proven to be able to solve optimization for continuous and non-linear problems on simple to complex problems, so these are the advantages of SOS.

Previously, the PSO algorithm has successfully aided in the optimization processes within the field of civil engineering, such as the estimation of the shear strength of reinforced concrete walls using support vector regression that optimized with the PSO and Harris Hawks algorithms [7]. In addition, the optimization of special concentrically braced steel frame structures was conducted using metaheuristic methods based on the Indonesian National Standards SNI 1729:2020 and SNI 7860:2020 [8].

Meanwhile, the SOS algorithm has also successfully contributed to solving optimization cases in the field of civil engineering. For example, it was applied in the optimization of multi-constraint frames under free vibration and transient behavior [9]. Additionally, it was used in optimizing the scheduling duration of housing projects using the line of balance method and metaheuristic methods with consideration for resource leveling [10].

The objective of this research is to provide alternative designs for a robust and economical counterfort retaining wall with shear key, in a relatively short of time. In addition, the seismic load is considered in this research.

Method

Cantilever retaining walls are designed to withstand all the loads that include gravity load and lateral load generated by soil pressure. The design of retaining wall is determined by several variables such as geometry/dimension, load and reinforcement, and geotechnical condition that meet structural safety requirements. Counterfort retaining wall with shear key is a modification of a cantilever retaining wall to reduce the thickness of the stem and increase its horizontal stability. In other words, counterfort is beneficial for very high retaining walls (10-12 m) since it reduces the shear and bending moment at the stem [11].

The optimization process of counterfort retaining wall with shear key in this research is carried out using metaheuristic method. In general, the optimization includes several aspects such as optimal shape, maximizing structural stability, minimizing bending moment, and optimizing the slope angle. The optimization process requires information that include variables, constraints, and objective functions. The solution that obtained from the optimization is in the form of variables, which represent the most economical retaining wall design.

The design variables used in the optimization process is presented in Figure 1. The range of design variables is limited by the upper and lower bounds, which are the maximum and minimum values of the design variables to be randomized. The ranges of the geometrical variables are based upon the recommendation given by SNI 8460:2017 [12]. A range of reinforcement area is applied to reduce the search field and improve the possibility of finding the optimal solution. By using both ranges of values recommended by SNI 8460:2017 [12] for the geometrical variables and a range of values for the reinforcement area, it will ensure that the optimal solution lies in these ranges. Constraints are used to ensure that the design results of the optimization process fall into the specified specifications. Table 1 shows the upper and lower bounds used in the design process. The constraints used in the optimization process can be seen in Table 2.

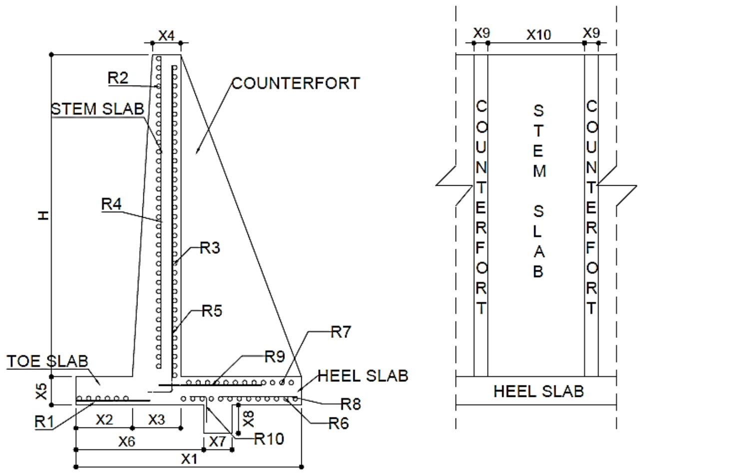

Figure 1. Modeling of Counterfort Retaining Wall with Shear Key

Descriptions:

X_1 = total base width [m]
X_2 = toe projection width [m]
X_3 = stem thickness at bottom[m]
X_4 = stem thickness at top [m]
X_5 = base slab thickness [m]
X_6 = distance of the front shear key from the front of toe slab [m]
X_7 = width of the base shear key [m]
X_8 = height of the base shear key[m]
X_9 = counterfort thickness [m]
X_{10} = Distance between counterforts [m]
R_1 = area of the horizontal reinforcement of the toe, per unit length of the wall [mm^2]
R_2 = area of the horizontal field reinforcement of the stem, per unit length of the wall [mm^2]
R_3 = area of the horizontal support reinforcement of the stem, per unit length of the wall [mm^2]
R_4 =area of the vertical field reinforcement of the stem, per unit length of the wall [mm^2]
R_5 = area of the vertical support reinforcement of the stem, per unit length of the wall [mm^2]
R_6 = area of the horizontal field reinforcement of the heel, per unit length of the wall [mm^2]
R_7 = area of the horizontal support reinforcement of the heel, per unit length of the wall [mm^2]
R_8 = area of the vertical field reinforcement of the heel, per unit length of the wall [mm^2]
R_9 = area of the vertical support reinforcement of the heel, per unit length of the wall [mm^2]
R_{10} = area of reinforcement of the shear key, per unit length of the wall [mm^2]

Table 1. Upper Bound and Lower Bound

Parameter	Lower Bounds	Upper Bounds
X_1 (m)	$0.4H$	$0.7H$
X_2 (m)	$0.4H/3$	$0.7H/3$
X_3 (m)	$\frac{H+48X_4}{48}$	$0.1H$
X_4 (m)	0.3	$0.1H$
X_5 (m)	$H/12$	$H/10$
X_6 (m)	0	$X_1 - X_7$
X_7 (m)	0	0.5
X_8 (m)	0	0.5
X_9 (m)	0.2	0.2
X_{10} (m)	$0.3H$	$10H$
R_1 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_2 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_3 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_4 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_5 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_6 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_7 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_8 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_9 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_{10} (mm^2)	235.62 (3D10)	28,148.67 (35D32)

Note: H is the height of the stem

Table 2. Constraints and Failure Mode

Constraint	Requirement	Description
$g_1(x)$	Safety against overturning	$\frac{SF_{O\ design}}{SF_O} \leq 1$
$g_2(x)$	Safety against lateral shear	$\frac{SF_{S\ design}}{SF_S} \leq 1$
$g_3(x)$	Safety against bearing capacity	$\frac{SF_{B\ design}}{SF_B} \leq 1$
$g_4(x)$	Safety against earthquake-induced overturning	$\frac{SF_{OE\ design}}{SF_{OE}} \leq 1$
$g_5(x)$	Safety against earthquake-induced lateral shear	$\frac{SF_{SE\ design}}{SF_{SE}} \leq 1$
$g_6(x)$	Safety against earthquake-induced bearing capacity	$\frac{SF_{BE\ design}}{SF_{BE}} \leq 1$
$g_7(x)$	Base slab uplifted	$q_{min} \geq 0$
$g_8(x)$	Toe moment	$\frac{M_d}{M_n} \leq 1$
$g_{[9-12]}(x)$	Stem Moment	$\frac{M_d}{M_n} \leq 1$
$g_{[13-16]}(x)$	Heel Slab Moment	$\frac{M_d}{M_n} \leq 1$
$g_{[13-16]}(x)$	Heel Slab Moment	$\frac{M_d}{M_n} \leq 1$
$g_{17}(x)$	Shear toe	$\frac{V_d}{V_n} \leq 1$
$g_{[18,19]}(x)$	Stem shear	$\frac{V_d}{V_n} \leq 1$
$g_{[19,20]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21-29]}(x)$	Minimum reinforcement	$\frac{A_{s\ min}}{A_s} \leq 1$
$g_{[30-38]}(x)$	Maximum reinforcement	$\frac{A_{s\ max}}{A_s} \geq 1$
$g_{39}(x)$	Development length of horizontal reinforcement of the toe	$\frac{l_d}{X_1 - X_2 - c_c} \leq 1$
$g_{40}(x)$	Development length of the vertical support reinforcement of stem	$\frac{l_d}{X_5 - c_c} \leq 1$
$g_{41}(x)$	Development length of the vertical support reinforcement of the heel	$\frac{l_d}{X_1 - X_2 - X_3 - c_c} \leq 1$
$g_{42}(x)$	Development length of reinforcement of the shear key	$\frac{l_d}{X_5 - 2 \times c_c} \leq 1$

Where:
$SF_{O\ design}$ = overturning safety factor limit given by SNI 8460:2017 [12]
SF_O = overturning safety factor
$SF_{S\ design}$ = sliding safety factor limit given by SNI 8460:2017 [12]
SF_S = overturning safety factor
$SF_{B\ design}$ = bearing safety factor limit given by SNI 8460:2017 [12]
SF_B = bearing safety factor
$SF_{OE\ design}$ = overturning safety factor limit with earthquake load given by SNI 8460:2017 [12]
SF_{OE} = overturning safety factor limit with earthquake load
$SF_{SE\ design}$ = sliding safety factor limit with earthquake load given by SNI 8460:2017 [12]
SF_{SE} = sliding safety factor limit with earthquake load
$SF_{BE\ design}$ = bearing safety factor limit with earthquake load given by SNI 8460:2017 [12]
SF_{BE} = bearing safety factor limit with earthquake load
q_{min} = minimum soil reaction [kN/m]

M_d = driving moment [kNm]
M_n = nominal moment capacity [kNm]
V_d = driving shear [kN]
V_n = nominal shear capacity [kN]
$A_{s\,min}$ = maximum reinforcement area [mm^2]
$A_{s\,max}$ = maximum reinforcement area [mm^2]
A_s = reinforcement area [mm^2]
l_d = required development length [mm]
X_1 = total base width [mm]
X_2 = toe projection width [mm]
X_3 = stem thickness at the bottom[mm]
X_5 = base slab thickness [mm]
c_c = concrete cover [mm]

The boundaries used in this study refer to Geotechnical specification SNI 8460:2017 [12], Structural Concrete for Building specifications SNI 2847:2019 [13], and Rankine Theory for calculating the lateral earth pressure on the wall.

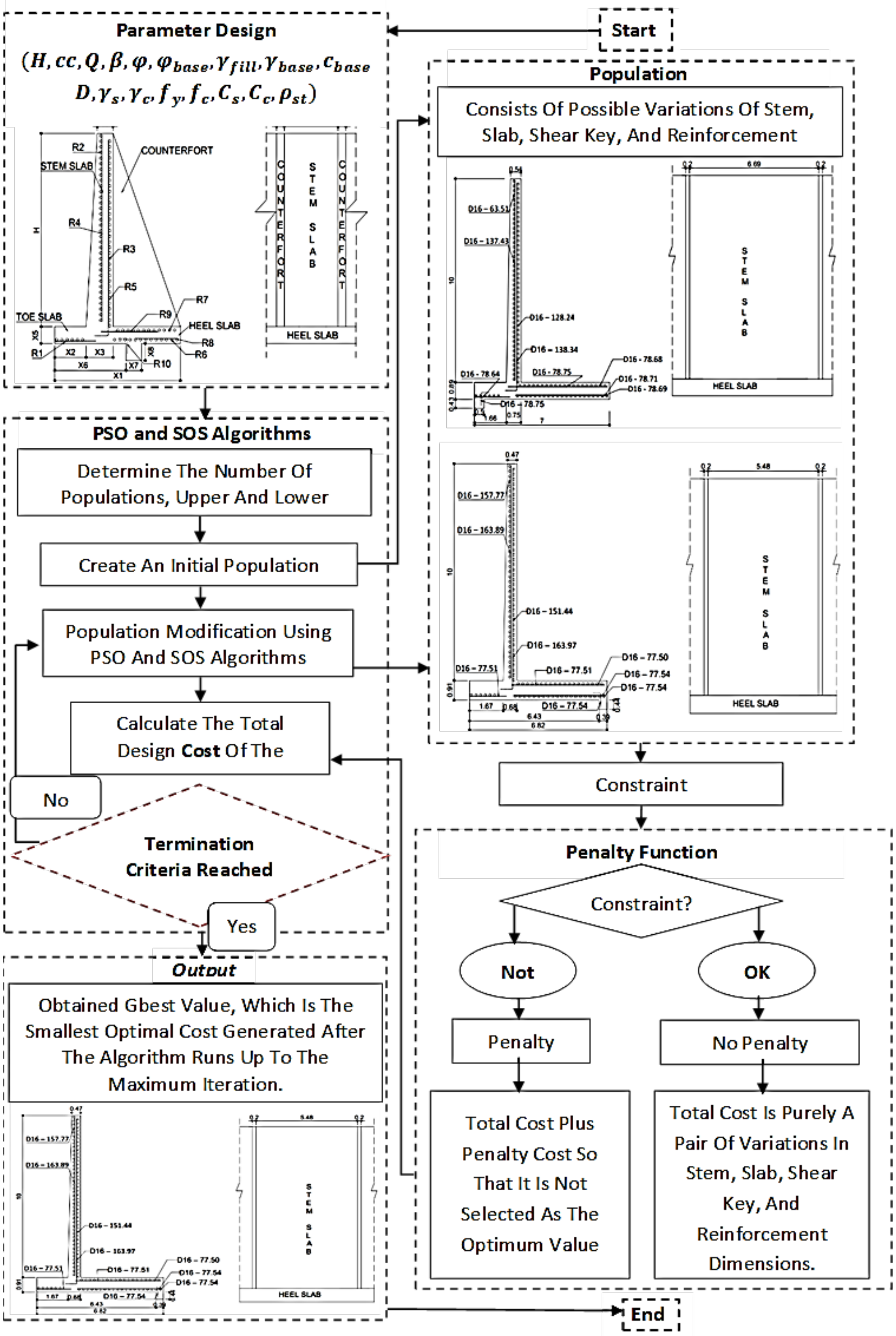

Figure 2. Flow Chart the Optimization of Counterfort Retaining Wall with Shear Key

Formulation that describes a value of the goal of the optimization process, which is called objective function, in this study is the cost optimization, as presented in Equation 1.

$$f_{obj} = V_c C_c + w_s C_s \tag{1}$$

Where:

V_c = concrete volume per unit length of the wall length $[m^3]$
C_c = concrete material cost per unit volume $[Rp/m^3]$
w_s = mass of steel reinforcement used per unit length of the wall $[kg]$
C_s = steel material cost per unit mass $[Rp/kg]$

The optimization process, namely PSO and SOS, in this research was developed using MATLAB R2019b. The algorithm performs iteration until the result meets all the specified constraints. If the results do not meet the constraints, the algorithm will provide a penalty function. Initially, the PSO and SOS algorithms execute the input data, then work using random variables to obtain a result that meets the constraints. The iteration process stops when the number of iterations set in the input parameter is reached. Details of the optimization process is presented in Figure 2.

Results and Discussion

PSO and SOS algorithms require initial settings in the form of inputting several parameter values. The setting parameters used include particle weight (w) that set at 0.5 and constant c_1 and c_2 are both set at 2. The soil parameters used for the base consist internal friction angle (ϕ_{base}) of 0°, density (γ_{base}) of 18.5 kN/m^3, and cohesion (cB) of 125 kPa. For the retained soil, the input internal friction angle (f) is 36°, soil density (γ_{fill}) was 17.5 kN/m^3, and the cohesion (cF) is 0 kPa. Meanwhile, the groundwater level in this study is not taken into account. Other input parameters are presented in Table 3.

Table 3. Input Parameters for Counterfort Retaining Wall Case Study with Shear Key

Input Parameter	Symbol	Input Value
Stem height (m)	H	10
Concrete Cover (cm)	cc	7
Surcharge Load (kPa)	Q	20
Backfill Slope (°)	B	10
Backfill Soil Friction Angle (°)	ϕ	36
Base Soil Friction Angle (°)	ϕ_{base}	0
Backfill Soil Unit Weight (kN/m^3)	γ_{fill}	17.5
Base Soil Unit Weight (kN/m^3)	γ_{base}	18.5
Base Soil Cohesion (kPa)	cB	125
Backfill Soil Cohesion (kPa)	cF	0
Depth of Soil in Front of Wall	D	0.5
Steel Unit Weight (kN/m^3)	γ_s	78.5
Concrete Unit Weight (kN/m^3)	γ_c	23.5
Steel Yield Strength (MPa)	f_y	400
Concrete Compressive Strength (MPa)	f_c	25

The optimization results, in the form of the final cost, for the both algorithms of SOS and PSO obtained after thirty (30) runs are summarized in Table 4.

Table 4. The Best Results of Optimization of Counterfort Retaining Wall Structure with Shear Key

Subject	PSO (Rp)	SOS (Rp)
Best (Rp/m^1)	24,525,850.19	23,956,617.73
Worst (Rp/m^1)	35,912,845.30	25,831,324.00
Median (Rp/m^1)	26,974,742.70	24,405,457.67
Average (Rp/m^1)	26,898,545.24	24,436,104.20
Std. Deviation (Rp/m^1)	2,136,661.22	503,180.24
Coeff. Variation (%)	7.94%	2.06%

Table 5 shows the detail comparison of the optimization results of the counterfort retaining wall structure with shear keys design, obtained from the PSO and SOS algorithms process.

Table 5. The Detail Comparison of Optimization Results Obtained from the PSO and SOS Algorithms.

Variabel	PSO (Best)	SOS (Best)
X1	7.00	6.82
X2	1.66	1.67
X3	0.75	0.68
X4	0.54	0.47
X5	0.89	0.91
X6	0.00	6.43
X7	0.50	0.39
X8	0.43	0.44
X9	0.20	0.20
X10	6.69	5.48
R1	2556.86 (D16 – 78.64)	2593.98 (D16 – 77.51)
R2	3166.03 (D16 – 63.51)	1274.41 (D16 – 157.77)
R3	1567.90 (D16 – 128.24)	1327.63 (D16 – 151.44)
R4	1462.98 (D16 – 137.43)	1226.81 (D16 – 163.89)
R5	1453.42 (D16 – 138.34)	1226.21 (D16 – 163.97)
R6	2555.04 (D16 – 78.69)	2593.09 (D16 – 77.54)
R7	2555.35 (D16 –78.68)	2594.46 (D16 – 77.50)
R8	2554.35 (D16 – 78.71)	2593.09 (D16 – 77.54)
R9	2553.08 (D16 – 78.75)	2594.00 (D16 – 77.51)
R10	2553.01 (D16 – 78.75)	2593.09 (D16 – 77.54)

The results show that SOS algorithm exhibits coefficient of variation of 2.06% compared to that of 7.49 resulted from PSO. In other words, the SOS algorithm exhibits better performance in the process of optimizing the counterfort retaining wall structure with shear keys, compared to that of PSO algorithm. The most optimal result of the design performed by PSO and SOS algorithms is presented in Figure 3 and Figure 4, respectively.

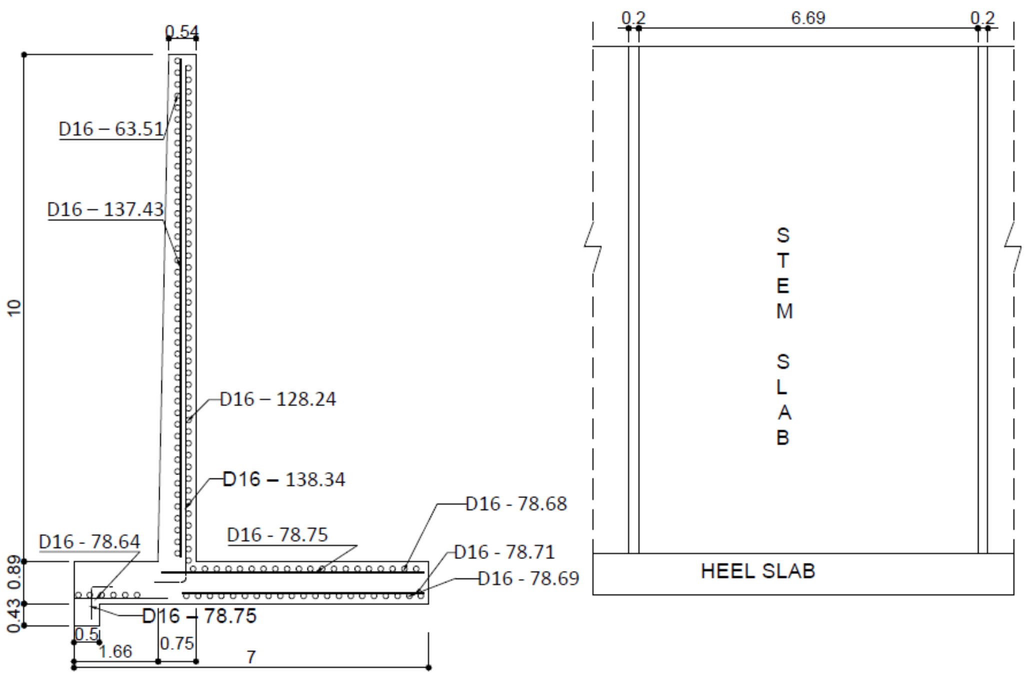

Figure 3. Retaining Wall Structure Design based on PSO Algorithm

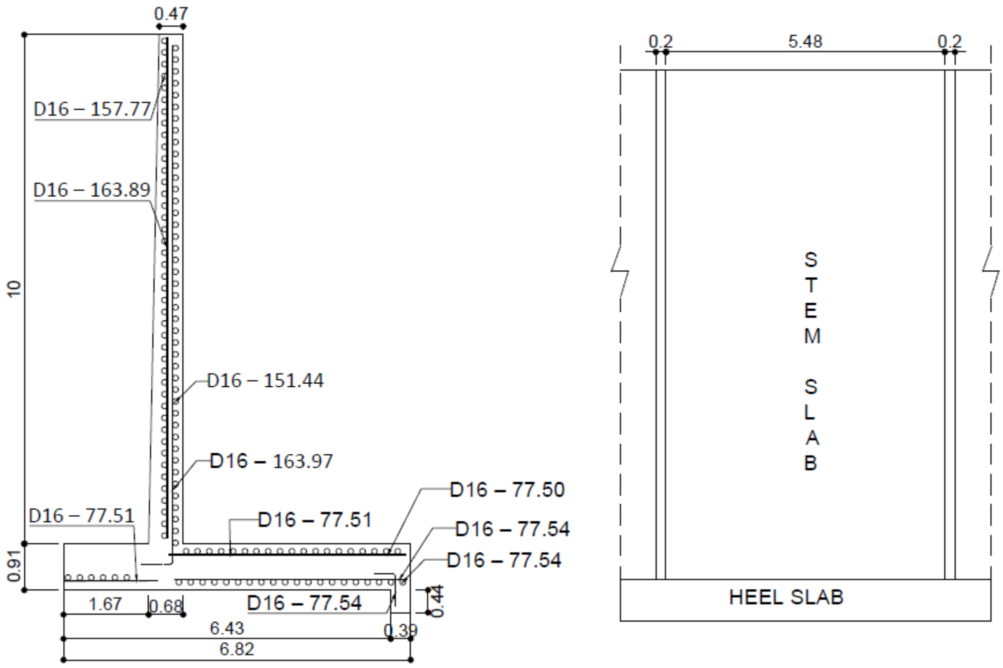

Figure 4. Retaining Wall Structure Design based on Cost SOS Algorithm

Figure 5 shows the rate of convergence of both algorithms on the optimization of the counterfort retaining wall structure with shear keys using input parameters presented in Table 3.

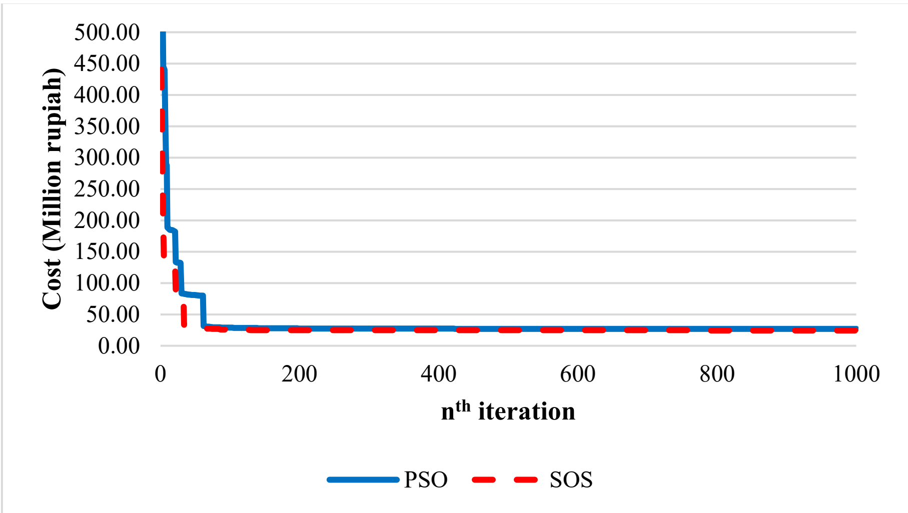

Figure 5. Convergence Graph of Median Run Results in the Case of Counterfort Retaining Wall with Shear Key

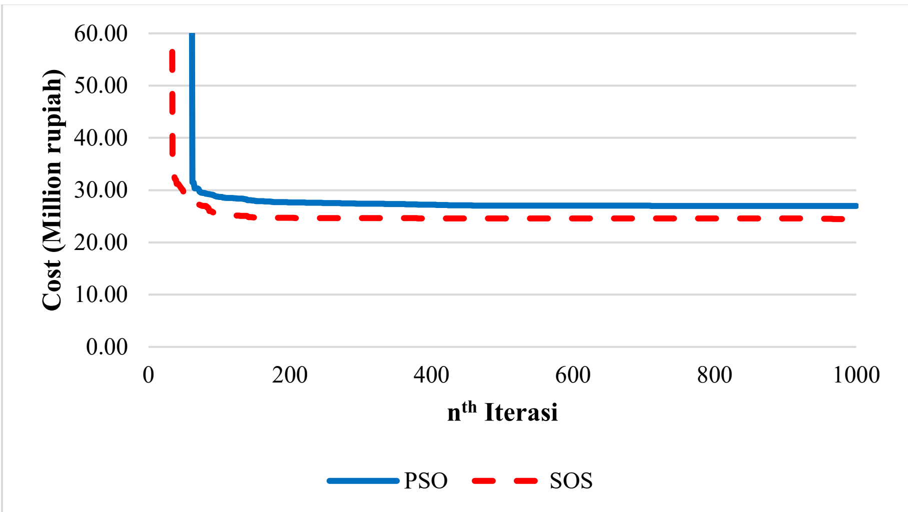

Figure 6. The Convergence Process of PSO and SOS Algorithms to Achieve the Most Optimal Costs

It can be seen in Figure 5 that the rate of convergence of the SOS algorithm is faster than that of PSO, where the lowest cost (or the best result) can be achieved in smaller number of iteration.

Figure 6 shows the rate of convergence process of the two algorithms. The curve generated from the SOS algorithm almost constant from about 300^{th} iteration compared to that generated based on the PSO algorithm, which still decreasing up to 1000^{th} iteration. Based on the results presented in Figure 5 and Figure 6, it can be stated that in this research, the SOS algorithm is faster than that of the PSO algorithm.

Conclusions

Based on the results of the analysis, it can be concluded that the metaheuristic method using the SOS algorithm produces the most optimum result in terms of the material cost of the counterfort retaining wall with shear key. In addition, the SOS algorithm is relatively faster in achieving the optimum result (as indicated by the rate of convergence) compared to the PSO algorithm.

References

1. Khuzaifah, E., Studi tentang Dinding Penahan (Retaining Wall), *Swara Patra: Majalah Ilmiah PPSDM Migas*, *9*(1), 2019, pp. 7–18, Accessed: Jul. 25, 2023. [Online]. Available: http://ejurnal.ppsdmmigas.esdm.go.id/sp/index.php/swarapatra/article/view/189
2. Kalemci, E.N., İkizler, S.B., Dede, T., and Angın, Z., Design of Reinforced Concrete Cantilever Retaining Wall using Grey Wolf Optimization Algorithm, *Structures*, *23*, 2020, pp. 245–253, doi: 10.1016/j.istruc.2019.09.013.
3. Fardilla, H., Perencanaan Dinding Penahan Sebagai Alternatif Pencegah Bahaya Longsor pada Konstruksi Pangkal Jembatan, *Journal Rekayasa Sipil dan Desain (JRSDD)*, 2018, [Online]. Available: http://digilib.unila.ac.id/30392/11/SKRIPSI%20TANPA%20BAB%20PEMBAHASAN.pdf
4. Öztürk, H.T., Dede, T., and Türker, E., Optimum Design of Reinforced Concrete Counterfort Retaining Walls using TLBO, Jaya Algorithm, *Structures*, *25*, 2020, pp. 285–296, doi: 10.1016/j.istruc.2020.03.020.
5. Khajehzadeh, M., Taha, M.R., El-Shafie, A., and Eslami, M., Modified Particle Swarm Optimization for Optimum Design of Spread Footing and Retaining Wall, *Journal of Zhejiang University: Science A*, *12*(6), 2011, pp. 415–427, doi: 10.1631/jzus.A1000252.
6. Cheng, M.Y., Prayogo, D., and Tran, D.H., Optimizing Multiple-resources Leveling in Multiple Projects using Discrete Symbiotic Organisms Search, *Journal of Computing in Civil Engineering*, *30*(3), 2016, doi: 10.1061/(asce)cp.1943-5487.0000512.
7. Parsa, P. and Naderpour, H., Shear Strength Estimation of Reinforced Concrete Walls using Support Vector Regression Improved by Teaching-learning-based Optimization, Particle Swarm Optimization, and Harris Hawks Optimization Algorithms, *Journal of Building Engineering*, *44*, 2021, p. 102593, doi: 10.1016/j.jobe.2021.102593.
8. Prayogo, D., Santoso, H., Budiman, F., and Jason, M., Layout, Topology, and Size Optimization of Steel Frame Design using Metaheuristic Algorithms: A Comparative Study, *Civil Engineering Dimension*, *24*(1), 2022, pp. 31–37, doi: 10.9744/ced.24.1.31-37.
9. Nguyen-Van, S., Nguyen, K.T., Dang, K.D., Nguyen, N.T.T., Lee, S., and Lieu, Q.X., An Evolutionary Symbiotic Organisms Search for Multiconstraint Truss Optimization under Free Vibration and Transient Behavior, *Advances in Engineering Software*, *160*, 2021, p. 103045, doi: 10.1016/j.advengsoft.2021.103045.
10. Husada, V.N. and Tanara, A.C., *Optimasi Durasi Penjadwalan Proyek Perumahan X menggunakan Metode Line of Balance dan Metode Metaheuristik dengan Memperhatikan Resource Leveling*, Undergraduate Thesis, Petra Christian University, 2022. Accessed: Sep. 17, 2023. [Online]. Available: https://dewey.petra.ac.id/digital/view/55660
11. Clayton, C.R.I., Woods, R.I., Bond, A.J., and Milititsky, J., *Earth Pressure and Earth Retaining Structures*, 3rd ed., CRC Press, 2013.
12. Badan Standardisasi Nasional, *SNI, 8460:2017: Persyaratan Perancangan Geoteknik*, 2017.
13. Badan Standardisasi Nasional, *SNI, 2847:2019: Persyaratan Beton Struktural untuk Bangunan Gedung dan Penjelasan*, 2019.

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Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method

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Abstract

This paper presents the optimization work to obtain the most economical of counterfort retaining wall structure with shear key attached at its base using metaheuristic method. The metaheuristic algorithm is a global optimization method that can be used to find the optimum solution of complex problems. In this research, optimization is carried out using the Particle Swarm Optimization (PSO) and Symbiotic Organisms Search (SOS) methods. This research utilizes a retaining wall sitting on stiff clay layer subjected to ten (10) m of granular soil of backfill. The scope of the study is limited to the material cost, that consists of the cost of concrete and reinforcement bars, of the counterfort retaining wall with shear key. The results show that the SOS algorithm resulted a lower cost and relatively faster in obtaining optimum retaining wall design compared to that of the PSO algorithm.

Introduction

A retaining wall is a structure to withstand lateral active pressure of soil or water [1]. A retaining wall consists of vertical section, commonly known as a stem, and a base slab. There is a specific element beneath the base slab called a shear key, which enhances the stability of the retaining wall to anticipate lateral force by utilizing passive pressure below the base slab arising from the active lateral pressure of the soil [2].

In general, the dimension and reinforcement of the cantilever wall (stem) increases with the increase of its bending moment generated due to lateral pressure of soil. The generated bending moment in the stem can be reduced by employing counterforts (a vertical walls or slabs) that connect the stem and the base slab of the retaining wall. In other words, counterforts play an important role in restraining tensile/horizontal force developed in the stem of the retaining wall [3].

Studies on the optimization of retaining wall can be found in several publications. Kalemci et al. [2] developed a tool using Grey Wolf algorithm to determine the optimum design of cantilever wall with shear key to increase its horizontal capacity. The retaining walls with a 3m and 4.5m height of stem were designed to retain embankment consisting of both cohesive and non-cohesive soils. The optimization process of the two metaheuristic algorithms proceeded for 30 runs, where each run iterated 1000 times. It is stated that the results of the optimization of cantilever wall with shear key, developed using Grey Wolf algorithm agree with other published results using different algorithms. Öztürk et al. [4] developed an application using Teaching-Learning Based Optimization (TLBO) and Jaya algorithms to obtain the optimum cost of a 10-m height counterfort retaining wall with shear key, which is built in cohesive soil. It is stated that the TLBO algorithm exhibits better performance compared to the Jaya algorithm.

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This research employes metaheuristic approach to optimize a counterfort retaining wall with a shear key subjected to gravity and seismic loads, which meets all existing constraints while considering safety requirements, and producing cost-effective solutions. Two metaheuristic algorithms, namely Particle Swarm Optimization (PSO) and Symbiotic Organisms Search (SOS), are utilized in this study. Both algorithms operate using a penalty function method to control the existing constraints during the design process, thereby achieving optimal and economical results while still satisfying safety requirements.

The PSO algorithm is inspired by natural conditions about food chains, such as the social behavior of a group of birds or insects looking for food. The concept is to mimic the social interaction between individuals in the group to find the optimal solution to the optimization problem. PSO is computationally efficient because it requires only a few computing resources to work, so the number of iterations used to produce optimal results is relatively small and fast [5].

The SOS algorithm uses mutualism, commensalism, and parasitism strategies to simulate interactions in a relationship. SOS uses simple mathematical operations, and can achieve efficient and effective optimization without the need to determine parameter tuning like other algorithms so that its performance stability is higher [6]. SOS is also proven to be able to solve optimization for continuous and non-linear problems on simple to complex problems, so these are the advantages of SOS.

Previously, the PSO algorithm has successfully aided in the optimization processes within the field of civil engineering, such as the estimation of the shear strength of reinforced concrete walls using support vector regression that optimized with the PSO and Harris Hawks algorithms [7]. In addition, the optimization of special concentrically braced steel frame structures was conducted using metaheuristic methods based on the Indonesian National Standards SNI 1729:2020 and SNI 7860:2020 [8].

Meanwhile, the SOS algorithm has also successfully contributed to solving optimization cases in the field of civil engineering. For example, it was applied in the optimization of multi-constraint frames under free vibration and transient behavior [9]. Additionally, it was used in optimizing the scheduling duration of housing projects using the line of balance method and metaheuristic methods with consideration for resource leveling [10].

The objective of this research is to provide alternative designs for a robust and economical counterfort retaining wall with shear key, in a relatively short of time. In addition, the seismic load is considered in this research.

Method

Cantilever retaining walls are designed to withstand all the loads that include gravity load and lateral load generated by soil pressure. The design of retaining wall is determined by several variables such as geometry/dimension, load and reinforcement, and geotechnical condition that meet structural safety requirements. Counterfort retaining wall with shear key is a modification of a cantilever retaining wall to reduce the thickness of the stem and increase its horizontal stability. In other words, counterfort is beneficial for very high retaining walls (10-12 m) since it reduces the shear and bending moment at the stem [11].

The optimization process of counterfort retaining wall with shear key in this research is carried out using metaheuristic method. In general, the optimization includes several aspects such as optimal shape, maximizing structural stability, minimizing bending moment, and optimizing the slope angle. The optimization process requires information that include variables, constraints, and objective functions. The solution that obtained from the optimization is in the form of variables, which represent the most economical retaining wall design.

The design variables used in the optimization process is presented in Figure 1. The range of design variables is limited by the upper and lower bounds, which are the maximum and minimum values of the design variables to be randomized. The ranges of the geometrical variables are based upon the recommendation given by SNI 8460:2017 [12]. A range of reinforcement area is applied to reduce the search field and improve the possibility of finding the optimal solution. By using both ranges of values recommended by SNI 8460:2017 [12] for the geometrical variables and a range of values for the reinforcement area, it will ensure that the optimal solution lies in these ranges. Constraints are used to ensure that the design results of the optimization process fall into the specified specifications. Table 1 shows the upper and lower bounds used in the design process. The constraints used in the optimization process can be seen in Table 2.

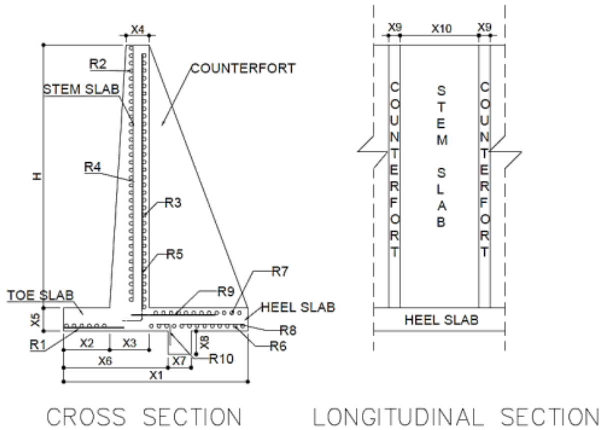

Figure 1. Modeling of Counterfort Retaining Wall with Shear Key

Descriptions:

X_1 = total base width [m]
X_2 = toe projection width [m]
X_3 = stem thickness at bottom [m]
X_4 = stem thickness at top [m]
X_5 = base slab thickness [m]
X_6 = distance of the front shear key from the front of toe slab [m]
X_7 = width of the base shear key [m]
X_8 = height of the base shear key [m]
X_9 = counterfort thickness [m]
X_{10} = Distance between counterforts [m]
R_1 = area of the horizontal reinforcement of the toe, per unit length of the wall [mm^2]
R_2 = area of the horizontal field reinforcement of the stem, per unit length of the wall [mm^2]
R_3 = area of the horizontal support reinforcement of the stem, per unit length of the wall [mm^2]
R_4 =area of the vertical field reinforcement of the stem, per unit length of the wall [mm^2]
R_5 = area of the vertical support reinforcement of the stem, per unit length of the wall [mm^2]
R_6 = area of the horizontal field reinforcement of the heel, per unit length of the wall [mm^2]
R_7 = area of the horizontal support reinforcement of the heel, per unit length of the wall [mm^2]
R_8 = area of the vertical field reinforcement of the heel, per unit length of the wall [mm^2]
R_9 = area of the vertical support reinforcement of the heel, per unit length of the wall [mm^2]
R_{10} = area of reinforcement of the shear key, per unit length of the wall [mm^2]

Table 1. Upper Bound and Lower Bound

Parameter	Lower Bounds	Upper Bounds
X_1 (m)	$0.4H$	$0.7H$
X_2 (m)	$0.4H/3$	$0.7H/3$
X_3 (m)	$\frac{H+48X_4}{48}$	$0.1H$
X_4 (m)	0.3	$0.1H$
X_5 (m)	$H/12$	$H/10$
X_6 (m)	0	$X_1 - X_7$
X_7 (m)	0	0.5
X_8 (m)	0	0.5
X_9 (m)	0.2	0.2
X_{10} (m)	$0.3H$	$10H$
R_1 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_2 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_3 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_4 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_5 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_6 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_7 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_8 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_9 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_{10} (mm^2)	235.62 (3D10)	28,148.67 (35D32)

Note: H is the height of the stem

Table 2. Constraints and Failure Mode

Constraint	Requirement	Description
$g_1(x)$	Safety against overturning	$\frac{SF_{O\ design}}{SF_O} \leq 1$
$g_2(x)$	Safety against lateral shear	$\frac{SF_{S\ design}}{SF_S} \leq 1$
$g_3(x)$	Safety against bearing capacity	$\frac{SF_{B\ design}}{SF_B} \leq 1$
$g_4(x)$	Safety against earthquake-induced overturning	$\frac{SF_{OE\ design}}{SF_{OE}} \leq 1$
$g_5(x)$	Safety against earthquake-induced lateral shear	$\frac{SF_{SE\ design}}{SF_{SE}} \leq 1$
$g_6(x)$	Safety against earthquake-induced bearing capacity	$\frac{SF_{BE\ design}}{SF_{BE}} \leq 1$
$g_7(x)$	Base slab uplifted	$q_{min} \geq 0$
$g_8(x)$	Toe moment	$\frac{M_d}{M_n} \leq 1$
$g_{[9-12]}(x)$	Stem Moment	$\frac{M_d}{M_n} \leq 1$
$g_{[13-16]}(x)$	Heel Slab Moment	$\frac{M_d}{M_n} \leq 1$
$g_{[13-16]}(x)$	Heel Slab Moment	$\frac{M_d}{M_n} \leq 1$
$g_{17}(x)$	Shear toe	$\frac{V_d}{V_n} \leq 1$
$g_{[18,19]}(x)$	Stem shear	$\frac{V_d}{V_n} \leq 1$
$g_{[19,20]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21-29]}(x)$	Minimum reinforcement	$\frac{A_{s\ min}}{A_s} \leq 1$
$g_{[30-38]}(x)$	Maximum reinforcement	$\frac{A_{s\ max}}{A_s} \geq 1$
$g_{39}(x)$	Development length of horizontal reinforcement of the toe	$\frac{l_d}{X_1 - X_2 - c_c} \leq 1$
$g_{40}(x)$	Development length of the vertical support reinforcement of stem	$\frac{l_d}{X_5 - c_c} \leq 1$
$g_{41}(x)$	Development length of the vertical support reinforcement of the heel	$\frac{l_d}{X_1 - X_2 - X_3 - c_c} \leq 1$
$g_{42}(x)$	Development length of reinforcement of the shear key	$\frac{l_d}{X_5 - 2 \times c_c} \leq 1$

Where:

$SF_{O\ design}$ = overturning safety factor limit given by SNI 8460:2017 [12]
SF_O = overturning safety factor
$SF_{S\ design}$ = sliding safety factor limit given by SNI 8460:2017 [12]
SF_S = overturning safety factor
$SF_{B\ design}$ = bearing safety factor limit given by SNI 8460:2017 [12]
SF_B = bearing safety factor
$SF_{OE\ design}$ = overturning safety factor limit with earthquake load given by SNI 8460:2017 [12]
SF_{OE} = overturning safety factor limit with earthquake load
$SF_{SE\ design}$ = sliding safety factor limit with earthquake load given by SNI 8460:2017 [12]
SF_{SE} = sliding safety factor limit with earthquake load
$SF_{BE\ design}$ = bearing safety factor limit with earthquake load given by SNI 8460:2017 [12]
SF_{BE} = bearing safety factor limit with earthquake load
q_{min} = minimum soil reaction [kN/m]

M_d = driving moment [kNm]
M_n = nominal moment capacity [kNm]
V_d = driving shear [kN]
V_n = nominal shear capacity [kN]
$A_{s\,min}$ = maximum reinforcement area [mm^2]
$A_{s\,max}$ = maximum reinforcement area [mm^2]
A_s = reinforcement area [mm^2]
l_d = required development length [mm]
X_1 = total base width [mm]
X_2 = toe projection width [mm]
X_3 = stem thickness at the bottom[mm]
X_5 = base slab thickness [mm]
c_c = concrete cover [mm]

The boundaries used in this study refer to Geotechnical specification SNI 8460:2017 [12], Structural Concrete for Building specifications SNI 2847:2019 [13], and Rankine Theory for calculating the lateral earth pressure on the wall.

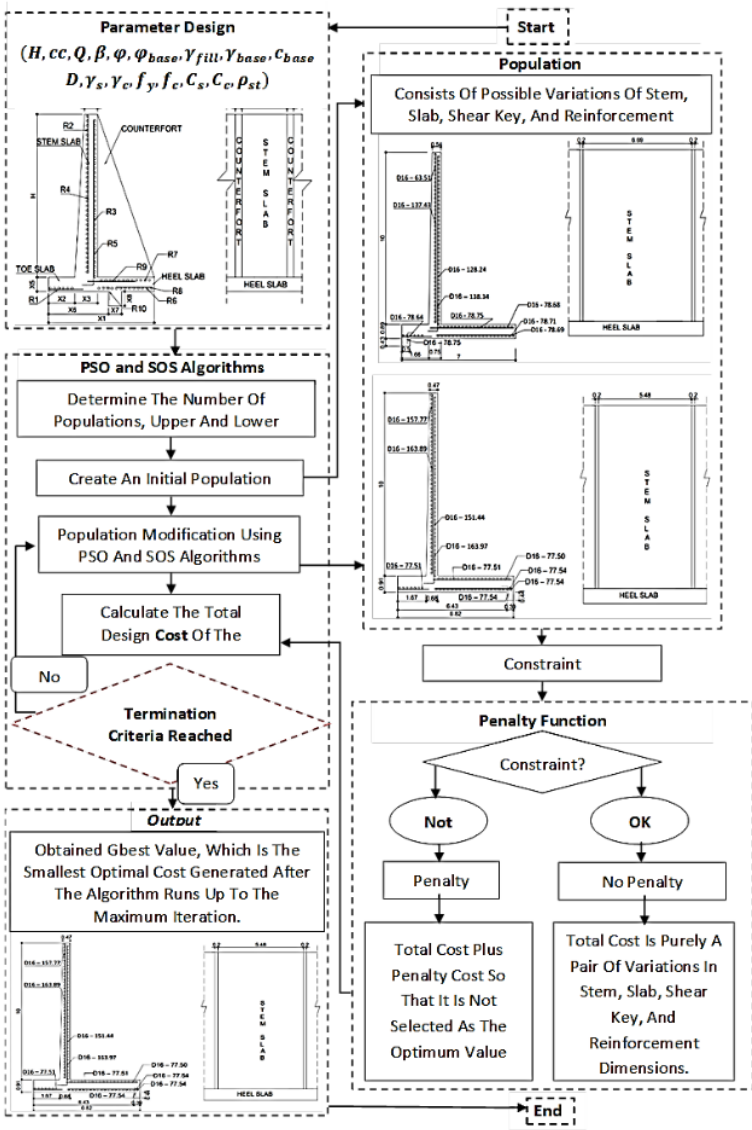

Figure 2. Flow Chart the Optimization of Counterfort Retaining Wall with Shear Key

Formulation that describes a value of the goal of the optimization process, which is called objective function, in this study is the cost optimization, as presented in Equation 1.

$$f_{obj} = V_c C_c + w_s C_s \quad (1)$$

Where:
V_c = concrete volume per unit length of the wall length $[m^3]$
C_c = concrete material cost per unit volume $[Rp/m^3]$
w_s = mass of steel reinforcement used per unit length of the wall $[kg]$
C_s = steel material cost per unit mass $[Rp/kg]$

The optimization process, namely PSO and SOS, in this research was developed using MATLAB R2019b. The algorithm performs iteration until the result meets all the specified constraints. If the results do not meet the constraints, the algorithm will provide a penalty function. Initially, the PSO and SOS algorithms execute the input data, then work using random variables to obtain a result that meets the constraints. The iteration process stops when the number of iterations set in the input parameter is reached. Details of the optimization process is presented in Figure 2.

Results and Discussion

PSO and SOS algorithms require initial settings in the form of inputting several parameter values. The setting parameters used include particle weight (w) that set at 0.5 and constant c_1 and c_2 are both set at 2. The soil parameters used for the base consist internal friction angle (ϕ_{base}) of 0°, density (γ_{base}) of 18.5 kN/m^3, and cohesion (cB) of 125 kPa. For the retained soil, the input internal friction angle (f) is 36°, soil density (γ_{fill}) was 17.5 kN/m^3, and the cohesion (cF) is 0 kPa. Meanwhile, the groundwater level in this study is not taken into account. Other input parameters are presented in Table 3.

Table 3. Input Parameters for Counterfort Retaining Wall Case Study with Shear Key

Input Parameter	Symbol	Input Value
Stem height (m)	H	10
Concrete Cover (cm)	cc	7
Surcharge Load (kPa)	Q	20
Backfill Slope (°)	B	10
Backfill Soil Friction Angle (°)	ϕ	36
Base Soil Friction Angle (°)	ϕ_{base}	0
Backfill Soil Unit Weight (kN/m^3)	γ_{fill}	17.5
Base Soil Unit Weight (kN/m^3)	γ_{base}	18.5
Base Soil Cohesion (kPa)	cB	125
Backfill Soil Cohesion (kPa)	cF	0
Depth of Soil in Front of Wall	D	0.5
Steel Unit Weight (kN/m^3)	γ_s	78.5
Concrete Unit Weight (kN/m^3)	γ_c	23.5
Steel Yield Strength (MPa)	f_y	400
Concrete Compressive Strength (MPa)	f_c	25

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Table 5 shows the detail comparison of the optimization results of the counterfort retaining wall structure with shear keys design, obtained from the PSO and SOS algorithms process.

Table 5. The Detail Comparison of Optimization Results Obtained from the PSO and SOS Algorithms.

Variabel	PSO (Best)	SOS (Best)
X1	7.00	6.82
X2	1.66	1.67
X3	0.75	0.68
X4	0.54	0.47
X5	0.89	0.91
X6	0.00	6.43
X7	0.50	0.39
X8	0.43	0.44
X9	0.20	0.20
X10	6.69	5.48
R1	2556.86 (D16 – 78.64)	2593.98 (D16 – 77.51)
R2	3166.03 (D16 – 63.51)	1274.41 (D16 – 157.77)
R3	1567.90 (D16 – 128.24)	1327.63 (D16 – 151.44)
R4	1462.98 (D16 – 137.43)	1226.81 (D16 – 163.89)
R5	1453.42 (D16 – 138.34)	1226.21 (D16 – 163.97)
R6	2555.04 (D16 – 78.69)	2593.09 (D16 – 77.54)
R7	2555.35 (D16 –78.68)	2594.46 (D16 – 77.50)
R8	2554.35 (D16 – 78.71)	2593.09 (D16 – 77.54)
R9	2553.08 (D16 – 78.75)	2594.00 (D16 – 77.51)
R10	2553.01 (D16 – 78.75)	2593.09 (D16 – 77.54)

The results show that SOS algorithm exhibits coefficient of variation of 2.06% compared to that of 7.49 resulted from PSO. In other words, the SOS algorithm exhibits better performance in the process of optimizing the counterfort retaining wall structure with shear keys, compared to that of PSO algorithm. The most optimal result of the design performed by PSO and SOS algorithms is presented in Figure 3 and Figure 4, respectively.

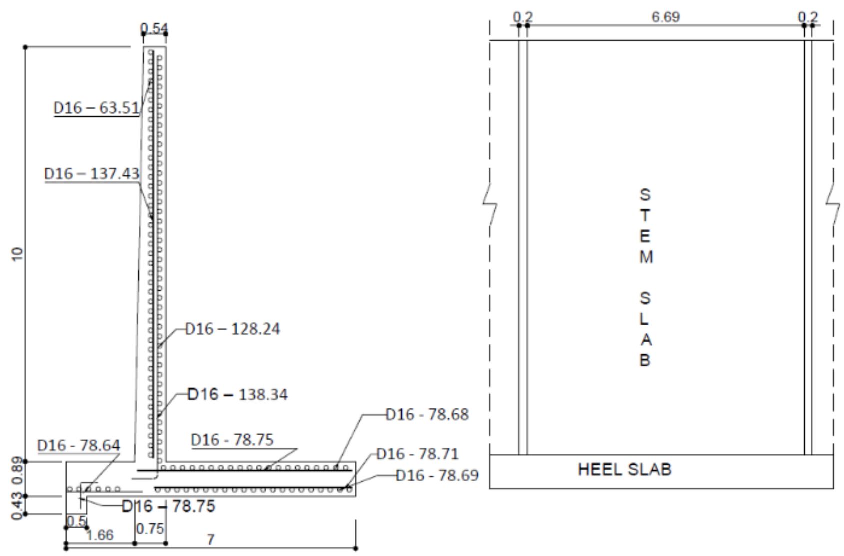

Figure 3. Retaining Wall Structure Design based on PSO Algorithm

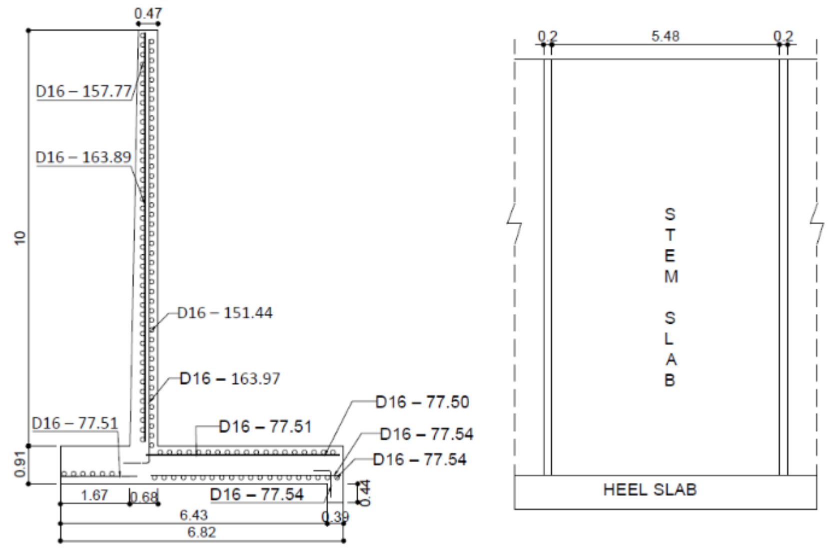

Figure 4. Retaining Wall Structure Design based on Cost SOS Algorithm

Figure 5 shows the rate of convergence of both algorithms on the optimization of the counterfort retaining wall structure with shear keys using input parameters presented in Table 3.

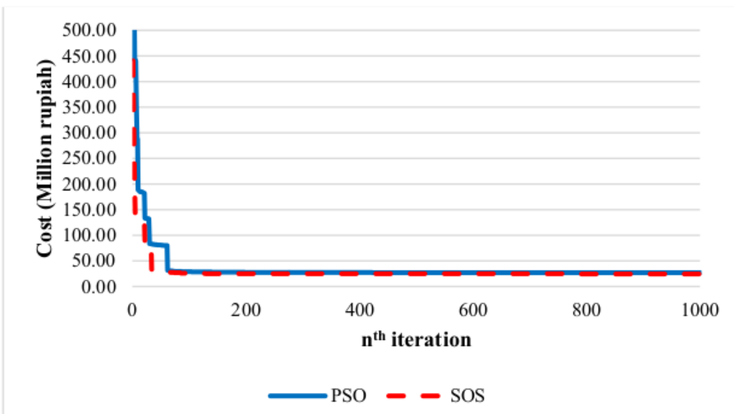

Figure 5. Convergence Graph of Median Run Results in the Case of Counterfort Retaining Wall with Shear Key

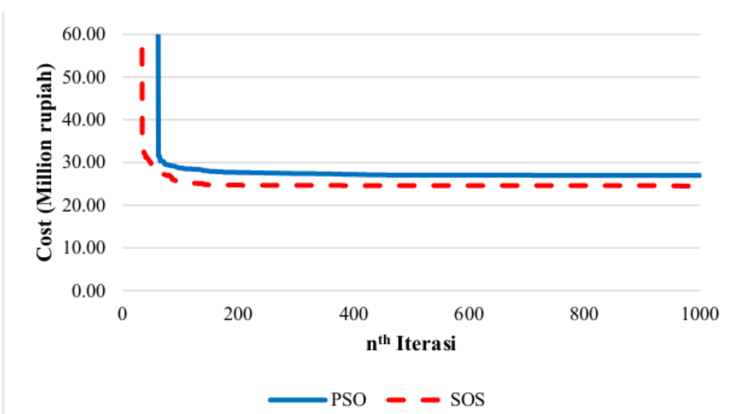

Figure 6. The Convergence Process of PSO and SOS Algorithms to Achieve the Most Optimal Costs

It can be seen in Figure 5 that the rate of convergence of the SOS algorithm is faster than that of PSO, where the lowest cost (or the best result) can be achieved in smaller number of iteration.

Figure 6 shows the rate of convergence process of the two algorithms. The curve generated from the SOS algorithm almost constant from about 300th iteration compared to that generated based on the PSO algorithm, which still decreasing up to 1000th iteration. Based on the results presented in Figure 5 and Figure 6, it can be stated that in this research, the SOS algorithm is faster than that of the PSO algorithm.

Conclusions

10

Based on the results of the analysis, it can be concluded that the metaheuristic method using the SOS algorithm produces the most optimum result in terms of the material cost of the counterfort retaining wall with shear key. In addition, the SOS algorithm is relatively faster in achieving the optimum result (as indicated by the rate of convergence) compared to the PSO algorithm.

References

1. Khuzaifah, E., Studi tentang Dinding Penahan (Retaining Wall), *Swara Patra: Majalah Ilmiah PPSDM Migas*, *9*(1), 2019, pp. 7–18, Accessed: Jul. 25, 2023. [Online]. Available: http://ejurnal.ppsdmmigas.esdm.go.id/sp/index.php/swarapatra/article/view/189
2. Kalemci, E.N., İkizler, S.B., Dede, T., and Angın, Z., Design of Reinforced Concrete Cantilever Retaining Wall using Grey Wolf Optimization Algorithm, *Structures*, *23*, 2020, pp. 245–253, doi: 10.1016/j.istruc.2019.09.013.
3. Fardilla, H., Perencanaan Dinding Penahan Sebagai Alternatif Pencegah Bahaya Longsor pada Konstruksi Pangkal Jembatan, *Journal Rekayasa Sipil dan Desain (JRSDD)*, 2018, [Online]. Available: http://digilib.unila.ac.id/30392/11/SKRIPSI%20TANPA%20BAB%20PEMBAHASAN.pdf
4. Öztürk, H.T., Dede, T., and Türker, E., Optimum Design of Reinforced Concrete Counterfort Retaining Walls using TLBO, Jaya Algorithm, *Structures*, *25*, 2020, pp. 285–296, doi: 10.1016/j.istruc.2020.03.020.
5. Khajehzadeh, M., Taha, M.R., El-Shafie, A., and Eslami, M., Modified Particle Swarm Optimization for Optimum Design of Spread Footing and Retaining Wall, *Journal of Zhejiang University: Science A*, *12*(6), 2011, pp. 415–427, doi: 10.1631/jzus.A1000252.
6. Cheng, M.Y., Prayogo, D., and Tran, D.H., Optimizing Multiple-resources Leveling in Multiple Projects using Discrete Symbiotic Organisms Search, *Journal of Computing in Civil Engineering*, *30*(3), 2016, doi: 10.1061/(asce)cp.1943-5487.0000512.
7. Parsa, P. and Naderpour, H., Shear Strength Estimation of Reinforced Concrete Walls using Support Vector Regression Improved by Teaching-learning-based Optimization, Particle Swarm Optimization, and Harris Hawks Optimization Algorithms, *Journal of Building Engineering*, *44*, 2021, p. 102593, doi: 10.1016/j.jobe.2021.102593.
8. Prayogo, D., Santoso, H., Budiman, F., and Jason, M., Layout, Topology, and Size Optimization of Steel Frame Design using Metaheuristic Algorithms: A Comparative Study, *Civil Engineering Dimension*, *24*(1), 2022, pp. 31–37, doi: 10.9744/ced.24.1.31-37.
9. Nguyen-Van, S., Nguyen, K.T., Dang, K.D., Nguyen, N.T.T., Lee, S., and Lieu, Q.X., An Evolutionary Symbiotic Organisms Search for Multiconstraint Truss Optimization under Free Vibration and Transient Behavior, *Advances in Engineering Software*, *160*, 2021, p. 103045, doi: 10.1016/j.advengsoft.2021.103045.
10. Husada, V.N. and Tanara, A.C., *Optimasi Durasi Penjadwalan Proyek Perumahan X menggunakan Metode Line of Balance dan Metode Metaheuristik dengan Memperhatikan Resource Leveling*, Undergraduate Thesis, Petra Christian University, 2022. Accessed: Sep. 17, 2023. [Online]. Available: https://dewey.petra.ac.id/digital/view/55660
11. Clayton, C.R.I., Woods, R.I., Bond, A.J., and Milititsky, J., *Earth Pressure and Earth Retaining Structures*, 3rd ed., CRC Press, 2013.
12. Badan Standardisasi Nasional, *SNI, 8460:2017: Persyaratan Perancangan Geoteknik*, 2017.
13. Badan Standardisasi Nasional, *SNI, 2847:2019: Persyaratan Beton Struktural untuk Bangunan Gedung dan Penjelasan*, 2019.

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Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method

Budi, G.S., Chandra, J.G., Ongkowardhana, B.S., and Husada, W.*

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To: Bryan Ongko <bryanongko29@gmail.com>, Glenn <b11200070@john.petra.ac.id>, Gogot <gogot@petra.ac.id>, Willy <willy.husada@petra.ac.id>

Bryan Ongko, Glenn, Gogot, Willy:

We have reached a decision regarding your submission to Civil Engineering Dimension, "The Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method".

Our decision is to request minor revisions to your manuscript.

Please revise your manuscript according to the reviewer's comments. Additionally, we kindly request that you provide a one-on-one feedback reply addressing the reviewer's comments.

We look forward to receiving your revised manuscript.

Best regards,

Editor

Reviewer A:

Comments:

1. The main idea of the paper is clear that optimization processes were used to obtain best results of RC retaining wall design.
2. However, it should be improved by noticing these following comments/suggestions/questions:
a. If variable description below Fig.1 is meant as note of the figure, there are still many variables which are not illustrated in the figure, starting from X9.
b. Use of consistent definition is encouraged. For example, please compare definitions of variables R3 and R5.
c. How were the range of the variables chosen? How do you know if optimum design result will be obtained by using the design variables in this range?
d. Notations in Constraint, and Description of Table 2 should be defined somewhere in the text.
e. How does the algorithm know if the cost from the current iteration is the lowest? That it will stop and will not go to the next iteration.
f. Please improve Figure 2. Details are in the commented text.
g. In Figures 3 and 4, there are horizontal layers of reinforcement without vertical reinforcement. Is that the case?

Recommendation: Revisions Required

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Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method

Budi, G. S [1]., Chandra, J. G., Ongkowardhana, B. S., Husada, W.

Civil Engineering Department, Faculty of Civil Engineering and Planning, Petra Christian University, Jl. Siwalankerto 121-131, Surabaya 60236, Indonesia

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Abstract:

A retaining wall is a relatively rigid wall used to retain lateral load generated by a different elevation of soil and to anticipate an embankment from sliding. Retaining walls can be classified into several types, one of which is a retaining wall with counterfort and shear key to increase its capacity against horizontal load. This paper presents the optimization work to obtain the most economical of counterfort retaining wall structure with shear key attached at its base, without sacrificing its stability, using metaheuristic method. The metaheuristic algorithm is a global optimization method that can be used to find the optimum solution of complex problems. In this research, optimization is carried out using the Particle Swarm Optimization (PSO) and Symbiotic Organisms Search (SOS) methods. This research utilizes a retaining wall sitting on stiff clay layer subjected to ten (10) m of granular soil of backfill. The scope of the study is limited to the material cost, that consists of the cost of concrete and reinforcement bars, of the counterfort retaining wall with shear key. The results show that the SOS algorithm resulted a lower cost and relatively faster in obtaining optimum retaining wall design compared to that of the PSO algorithm.

Keywords: retaining wall, counterfort, shear key, optimization, metaheuristic, PSO, SOS

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Introduction

A retaining wall is a structure to withstand lateral active pressure of soil or water [1]. A retaining wall consists of vertical section, commonly known as a stem, and a base slab. There is a specific element beneath the base slab called a shear key, which enhances the stability of the retaining wall to anticipate lateral force by utilizing passive pressure below the base slab arising from the active lateral pressure of the soil [2].

In general, the dimension and reinforcement of the cantilever wall (stem) increases with the increase of its bending moment generated due to lateral pressure of soil. The generated bending moment in the stem can be reduced by employing counterforts (a vertical walls or slabs) that connect the stem and the base slab of the retaining wall. In other words, counterforts play an important role in restraining tensile/horizontal force developed in the stem of the retaining wall [3].

Studies regarding optimization of retaining wall can be found in several publications. Kalemci et al [4] developed a tool using Greywolf algorithm to determine the optimum design of cantilever wall with shear key to increase its horizontal capacity. The retaining walls with a 3m and 4.5m height of stem were designed to retain embankment, that consists of both cohesive and non-cohesive soils. The optimization process of the two metaheuristic algorithms proceeded for 30 runs, where each run iterated 1000 times. It is stated that the results of the optimization of cantilever wall with shear key, which is developed using Greywolf algorithm, agree with other published results using different algorithms. Öztürk et al. [5] developed application using Teaching Learning Based Optimization (TLBO) and Jaya algorithms to obtain the optimum cost of a 10-m height counterfort retaining wall with shear key, which is built in cohesive soil. It is stated that the TLBO algorithm exhibits better performance compared to that of Jaya algorithm.

This research employes metaheuristic approach to optimize a counterfort retaining wall with a shear key subjected to gravity and seismic loads, which meets all existing constraints while considering safety requirements, and producing cost-effective solutions. Two metaheuristic algorithms, namely Particle Swarm Optimization (PSO) and Symbiotic Organisms Search (SOS), are utilized in this study. Both algorithms operate using a penalty function method to control the existing constraints during the design process, thereby achieving optimal and economical results while still satisfying safety requirements.

The PSO algorithm is inspired by natural conditions about food chains, such as the social behavior of a group of birds or insects looking for food. The concept is to mimic the social interaction between individuals in the group to find the optimal solution to the optimization problem. PSO is computationally efficient because it requires only a few computing resources to work, so the number of iterations used to produce optimal results is relatively small and fast [6].

The SOS algorithm uses mutualism, commensalism, and parasitism strategies to simulate interactions in a relationship. SOS uses simple mathematical operations, and can achieve efficient and effective optimization without the need to determine parameter tuning like other algorithms so that its performance stability is higher [7]. SOS is also proven to be able to solve optimization for continuous and non-linear problems on simple to complex problems, so these are the advantages of SOS.

Previously, the PSO algorithm has successfully aided in the optimization processes within the field of civil engineering, such as the estimation of the shear strength of reinforced concrete walls using support vector regression that optimized with the PSO and Harris Hawks algorithms [8]. In addition, the optimization of special concentrically braced steel frame structures was conducted using metaheuristic methods based on the Indonesian National Standards SNI 1729:2020 and SNI 7860:2020 [9].

Meanwhile, the SOS algorithm has also successfully contributed to solving optimization cases in the field of civil engineering. For example, it was applied in the optimization of multi-constraint frames under free vibration and transient behavior [10]. Additionally, it was used in optimizing the scheduling duration of housing projects using the line of balance method and metaheuristic methods with consideration for resource leveling [11].

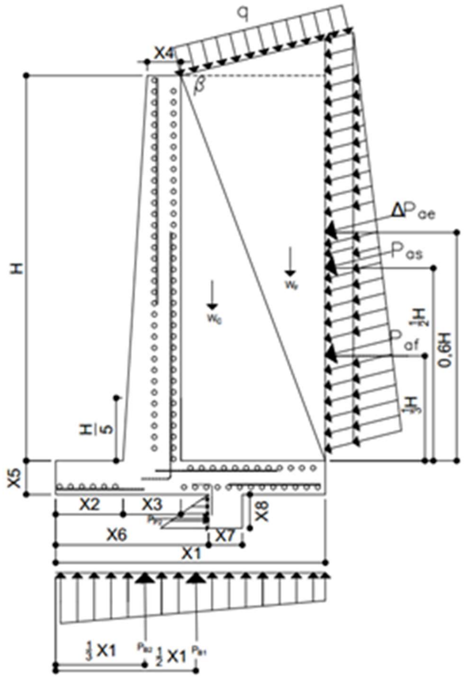
The objective of this research is to provide alternative designs for a robust and economical counterfort retaining wall with shear key, in a relatively short of time. In addition, the seismic load is considered in this research.

Research Method

Cantilever retaining walls are designed to withstand all the loads that include gravity load and lateral load generated by soil pressure. The design of retaining wall is determined by several variables such as geometry/dimension, load and reinforcement, and geotechnical condition that meet structural safety requirements. Counterfort retaining wall with shear key is a modification of a cantilever retaining wall to reduce the thickness of the stem and increase its horizontal stability. In other words, counterfort is beneficial for very high retaining walls (10-12 m) since it reduces the shear and bending moment at the stem [12].

The optimization process of counterfort retaining wall with shear key in this research is carried out using metaheuristic method. In general, the optimization includes several aspects such as optimal shape, maximizing structural stability, minimizing bending moment, and optimizing the slope angle. The optimization process requires information that include variables, constraints, and objective functions. The solution that obtained from the optimization is in the form of variables, which represent the most economical retaining wall design.

The design variables used in the optimization process is presented in Figure 1.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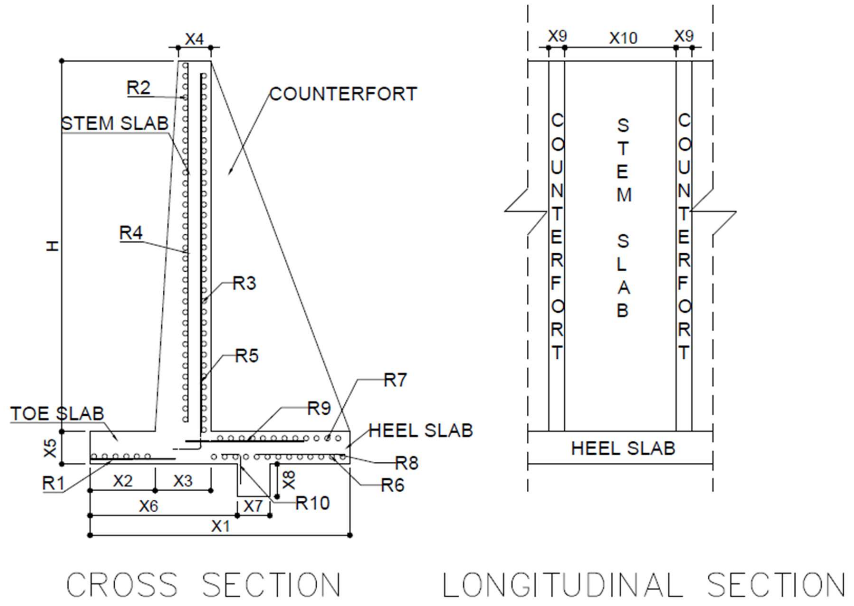
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S T E M S L A B
C O U N T E R F O R T
HEEL SLAB
CROSS SECTION
LONGITUDINAL SECTION

Fig. 1. Modeling of Counterfort Retaining Wall with Shear Key.

Descriptions:

X_1 = total base width [m]

X_2 = toe projection width [m]

X_3 = stem thickness at bottom[m]

X_4 = stem thickness at top [m]

X_5 = base slab thickness [m]

X_6 = distance of the front shear key from the front of toe slab [m]

X_7 = width of the base shear key [m]

X_8 = height of the base shear key[m]

X_9 = counterfort thickness [m]

X_{10} = Distance between counterforts [m]

R_1 = area of the horizontal reinforcement of the toe, per unit length of the wall [mm^2]

R_2 = area of the horizontal field reinforcement of the stem, per unit length of the wall [mm^2]

R_3 = area of the horizontal support reinforcement of the stem, per unit length of the wall [mm^2]

R_4 =area of the vertical field reinforcement of the stem, per unit length of the wall [mm^2]

R_5 = area of the vertical support reinforcement of the stem, per unit length of the wall [mm^2]

R_6 = area of the horizontal field reinforcement of the heel, per unit length of the wall [mm^2]

R_7 = area of the horizontal support reinforcement of the heel, per unit length of the wall [mm^2]

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Area of horizontal reinforcement of stem --> like definition of R5

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R_8 = area of the vertical field reinforcement of the heel, per unit length of the wall [mm^2]

R_9 = area of the vertical support reinforcement of the heel, per unit length of the wall [mm^2]

R_{10} = area of reinforcement of the shear key, per unit length of the wall [mm^2]

The range of design variables is limited by the upper and lower bounds, which are the maximum and minimum values of the design variables to be randomized. The ranges of the geometrical variables are based upon the recommendation given by SNI 8460:2017 [13]. A range of reinforcement area is applied to reduce the search field and improve the possibility of finding the optimal solution. By using both ranges of value recommended by SNI 8460:2017 [13] for the geometrical variables and a range of values for the reinforcement area, it will ensure that the optimal solution lies in these ranges.

Table 1 shows the upper and lower bounds used in the design process.

Table 1. Upper Bound and Lower Bound

Parameter	**Lower Bounds**	**Upper Bounds**
X_1 (m)	$0.4H$	$0.7H$
X_2 (m)	$0.4H/3$	$0.7H/3$
X_3 (m)	$\dfrac{H+48X_4}{48}$	$0.1H$
X_4 (m)	0.3	$0.1H$
X_5 (m)	$H/12$	$H/10$
X_6 (m)	0	$X_1 - X_7$
X_7 (m)	0	0.5
X_8 (m)	0	0.5
X_9 (m)	0.2	0.2
X_{10} (m)	$0.3H$	$10H$
R_1 (mm^2)	235.62 (3D10)	28,148.67 (35D32)

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How do you know if optimum design result will be obtained by using the design variables in this range.

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R_2 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_3 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_4 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_5 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_6 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_7 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_8 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_9 (mm^2)	235.62 (3D10)	28,148.67 (35D32)
R_{10} (mm^2)	235.62 (3D10)	28,148.67 (35D32)

Note: H is the height of the stem

Constraints are used to ensure that the design results of the optimization process fall into the specified specifications. The constraints used in the optimization process can be seen in Table 2.

Table 2. Constraints and Failure Mode

Constraint	**Requirement**	**Description**
$g_1(x)$	Safety against overturning	$\frac{SF_{O\ design}}{SF_O} \leq 1$
$g_2(x)$	Safety against lateral shear	$\frac{SF_{S\ design}}{SF_S} \leq 1$
$g_3(x)$	Safety against bearing capacity	$\frac{SF_{B\ design}}{SF_B} \leq 1$
$g_4(x)$	Safety against earthquake-induced overturning	$\frac{SF_{OE\ design}}{SF_{OE}} \leq 1$
$g_5(x)$	Safety against earthquake-induced lateral shear	$\frac{SF_{SE\ design}}{SF_{SE}} \leq 1$
$g_6(x)$	Safety against earthquake-induced bearing capacity	$\frac{SF_{BE\ design}}{SF_{BE}} \leq 1$
$g_7(x)$	Base slab uplifted	$q_{min} \geq 0$
$g_8(x)$	Toe moment	$\frac{M_d}{M_n} \leq 1$

$g_{[9-12]}(x)$	Stem Moment	$\frac{M_d}{M_n} \leq 1$
$g_{[13-16]}(x)$	Heel Slab Moment	$\frac{M_d}{M_n} \leq 1$
$g_{[13-16]}(x)$	Heel Slab Moment	$\frac{M_d}{M_n} \leq 1$
$g_{17}(x)$	Shear toe	$\frac{V_d}{V_n} \leq 1$
$g_{[18,19]}(x)$	Stem shear	$\frac{V_d}{V_n} \leq 1$
$g_{[19,20]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21]}(x)$	Slab heel shear	$\frac{V_d}{V_n} \leq 1$
$g_{[21-29]}(x)$	Minimum reinforcement	$\frac{A_{s\,min}}{A_s} \leq 1$
$g_{[30-38]}(x)$	Maximum reinforcement	$\frac{A_{s\,max}}{A_s} \geq 1$
$g_{39}(x)$	Development length of horizontal reinforcement of the toe	$\frac{l_d}{X_1 - X_2 - c_c} \leq 1$
$g_{40}(x)$	Development length of the vertical support reinforcement of stem	$\frac{l_d}{X_5 - c_c} \leq 1$
$g_{41}(x)$	Development length of the vertical support reinforcement of the heel	$\frac{l_d}{X_1 - X_2 - X_3 - c_c} \leq 1$
$g_{42}(x)$	Development length of reinforcement of the shear key	$\frac{l_d}{X_5 - 2 \times c_c} \leq 1$

Where :

$SF_{O\,design}$ = overturning safety factor limit given by SNI 8460:2017 [13]

SF_O = overturning safety factor

$SF_{S\,design}$ = sliding safety factor limit given by SNI 8460:2017 [13]

SF_S = overturning safety factor

$SF_{B\,design}$ = bearing safety factor limit given by SNI 8460:2017 [13]

SF_B = bearing safety factor

$SF_{OE\ design}$ = overturning safety factor limit with earthquake load given by SNI 8460:2017 [13]

SF_{OE} = overturning safety factor limit with earthquake load

$SF_{SE\ design}$ = sliding safety factor limit with earthquake load given by SNI 8460:2017 [13]

SF_{SE} = sliding safety factor limit with earthquake load

$SF_{BE\ design}$ = bearing safety factor limit with earthquake load given by SNI 8460:2017 [13]

SF_{BE} = bearing safety factor limit with earthquake load

q_{min} = minimum soil reaction [kN/m]

M_d = driving moment [kNm]

M_n = nominal moment capacity [kNm]

V_d = driving shear [kN]

V_n = nominal shear capacity [kN]

$A_{s\ min}$ = maximum reinforcement area [mm^2]

$A_{s\ max}$ = maximum reinforcement area [mm^2]

A_s = reinforcement area [mm^2]

l_d = required development length [mm]

X_1 = total base width [mm]

X_2 = toe projection width [mm]

X_3 = stem thickness at the bottom[mm]

X_5 = base slab thickness [mm]

c_c = concrete cover [mm]

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The boundaries used in this study refer to Geotechnical specification SNI 8460:2017 [13], Structural Concrete for Building specifications SNI 2847:2019 [14], and Rankine Theory for calculating the lateral earth pressure on the wall.

Commented [PP7]: Notations in Constraint, and Description of Table 2 should be defined somewhere in the text.

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Formulation that describes a value of the goal of the optimization process, which is called objective function, in this study is the cost optimization, as presented in Equation 1.

$$f_{obj} = V_c C_c + w_s C_s \quad (1)$$

Where :

V_c = concrete volume per unit length of the wall length $[m^3]$

C_c = concrete material cost per unit volume $[Rp/m^3]$

w_s = mass of steel reinforcement used per unit length of the wall $[kg]$

C_s = steel material cost per unit mass $[Rp/kg]$

The optimization process, namely PSO and SOS, in this research was developed using MATLAB R2019b. The algorithm performs iteration until the result meets all the specified constraints. If the results do not meet the constraints, the algorithm will provide a penalty function. Initially, the PSO and SOS algorithms execute the input data, then work using random variables to obtain a result that meets the constraints. The iteration process stops when the number of iterations set in the input parameter is reached. Details of the optimization process is presented in Figure 2.

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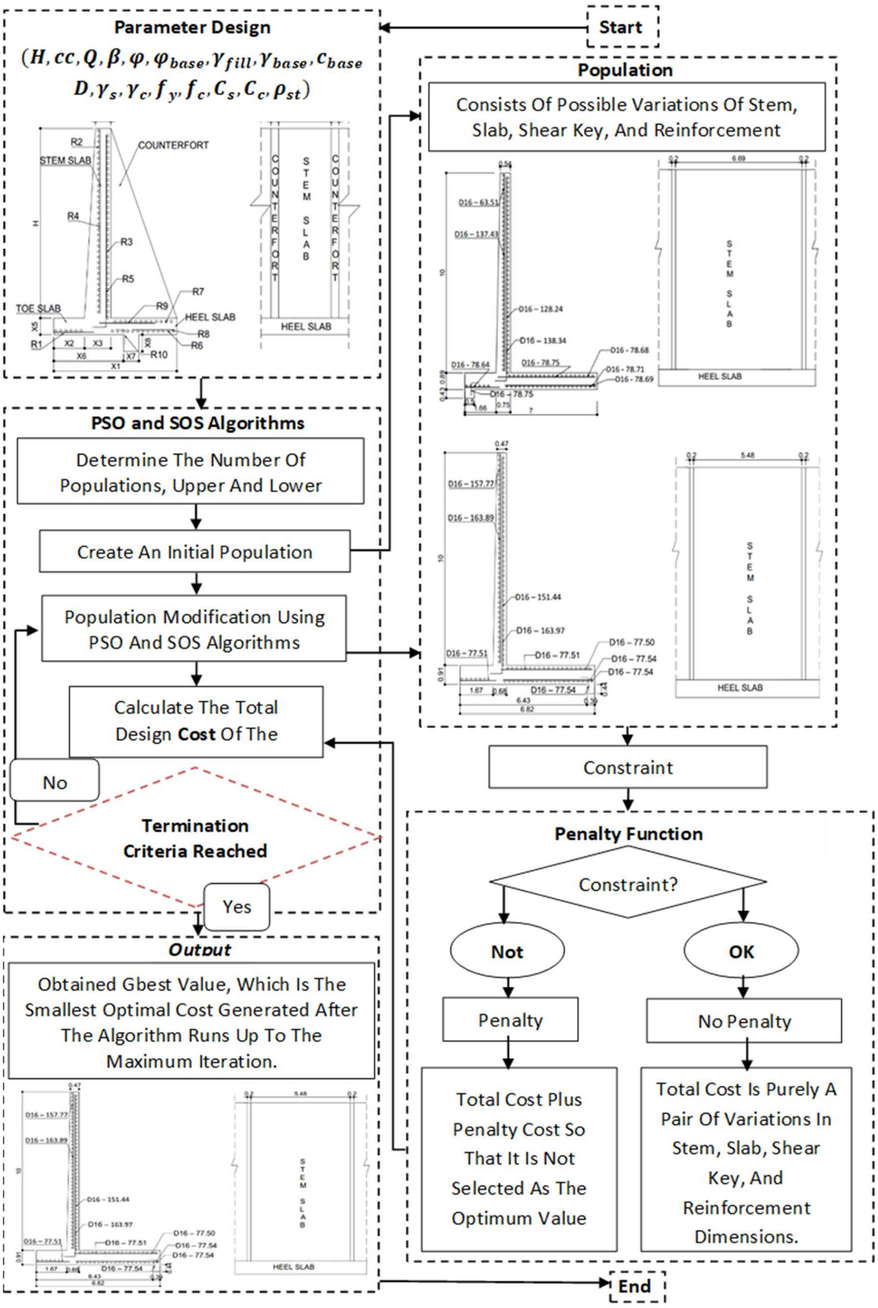

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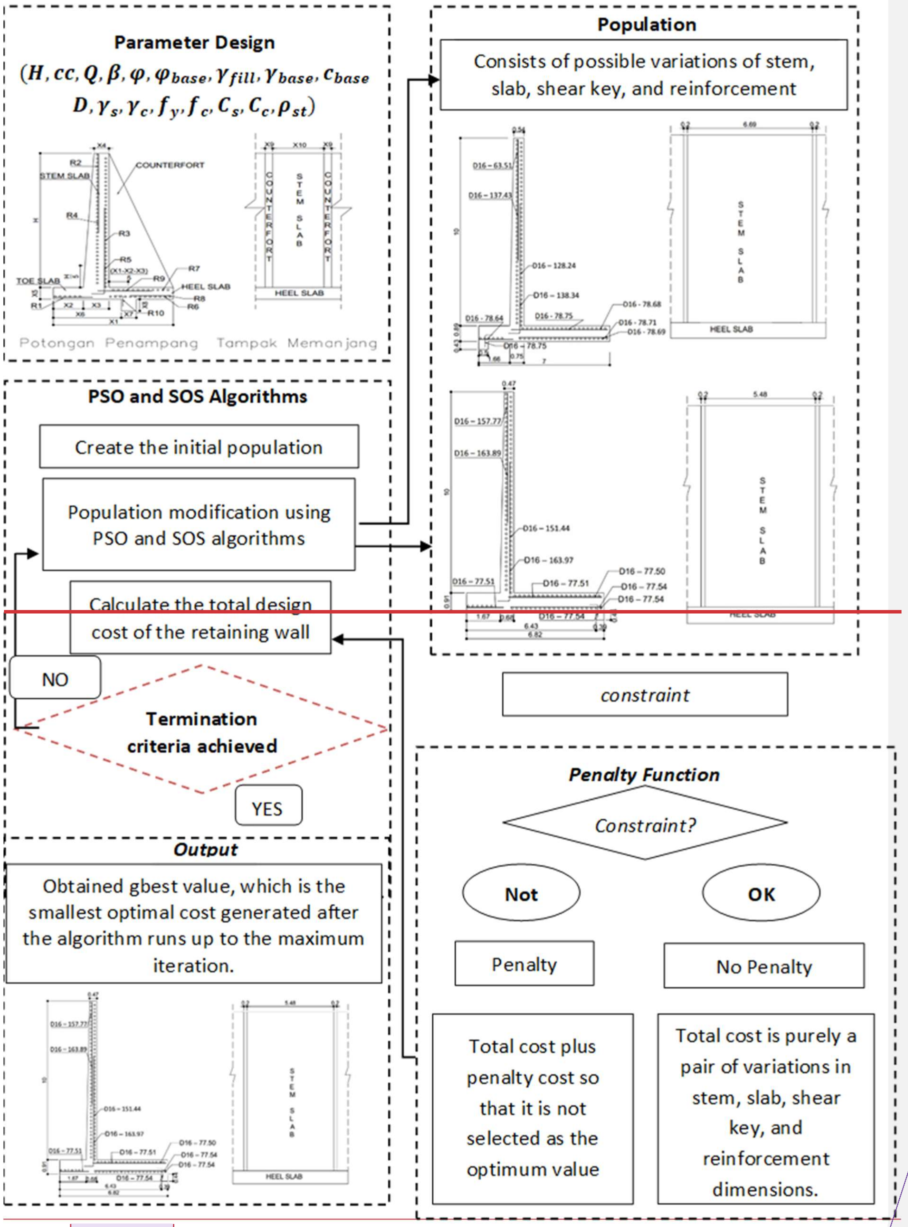
[1] email: gogot@petra.ac.id



Fig, 2. Flow chart The Optimization of Counterfort Retaining Wall with Shear Key

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Please use more standard form of Flowchart. For example, No "Start" nor "Finish" in the figure.

Please improve the clarity of the figure. Images of the wall are too small. Some arrows connecting processes are missing, for example, there is no connecting arrows after decisive process "Constraint?".

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Results and Discussion

PSO and SOS algorithms require initial settings in the form of inputting several parameter values. The setting parameters used include particle weight (w) that set at 0.5 and constant c_1 and c_2 are both set at 2. The soil parameters used for the base consist internal friction angle (ϕ base) of 0°, density (γbase) of 18.5 kN/m^3, and cohesion (cB) of 125 kPa. For the retained soil, the input internal friction angle (ϕ) is 36°, soil density (γfill) was 17.5 kN/m^3, and the cohesion (cF) is 0 kPa. Meanwhile, the groundwater level in this study is not taken into account. Other input parameters are presented in Table 3.

Commented [PP11]: How about the SOS?

If it does not require any, a sentence to inform just that is a good additional information.

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Table 3. Input Parameters for Counterfort Retaining Wall Case Study with Shear key

Input Parameter	Symbol	Input Value
Stem height (m)	*H*	10
Concrete Cover (cm)	*cc*	7
Surcharge Load (kPa)	*Q*	20
Backfill Slope (°)	Β	10
Backfill Soil Friction Angle (°)	ϕ	36
Base Soil Friction Angle (°)	ϕ_{base}	0
Backfill Soil Unit Weight (kN/m^3)	γ_{fill}	17.5
Base Soil Unit Weight (kN/m^3)	γ_{base}	18.5
Base Soil Cohesion (kPa)	cB	125
Backfill Soil Cohesion (kPa)	cF	0
Depth of Soil In Front of Wall	D	0.5
Steel Unit Weight (kN/m^3)	γ_s	78.5
Concrete Unit Weight (kN/m^3)	γ_c	23.5
Steel Yield Strength (MPa)	f_y	400
Concrete Compressive Strength (MPa)	f_c	25

The optimization results, in the form of the final cost, for the both algorithms of SOS and PSO obtained after thirty (30) runs are summarized in Table 4.

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Table 4. The Best Results of Optimization of Counterfort Retaining Wall Structure with Shear Key

Subject	**PSO (Rp)**	**SOS (Rp)**
Best (Rp/m^1)	24,525,850.19	23,956,617.73
Worst (Rp/m^1)	35,912,845.30	25,831,324.00
Median (Rp/m^1)	26,974,742.70	24,405,457.67
Average (Rp/m^1)	26,898,545.24	24,436,104.20
Std. Deviation (Rp/m^1)	2,136,661.22	503,180.24
Coeff.Variation (%)	7.94%	2.06%

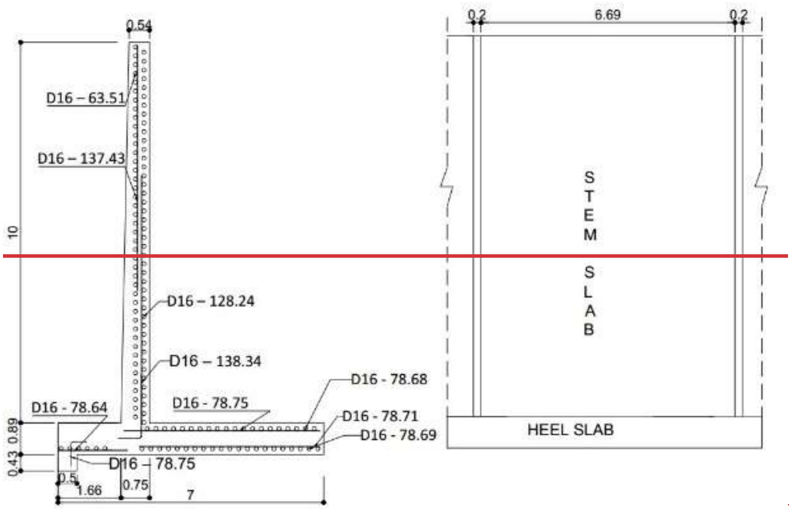
Table 5 shows the detail comparison of the optimization results of the counterfort retaining wall structure with shear keys design, obtained from the PSO and SOS algorithms process.

Table 5. The detail comparison of optimization results obtained from the PSO and SOS algorithms.

Variabel	**PSO (Best)**	**SOS (Best)**
X1	7.00	6.82
X2	1.66	1.67
X3	0.75	0.68
X4	0.54	0.47
X5	0.89	0.91
X6	0.00	6.43
X7	0.50	0.39
X8	0.43	0.44
X9	0.20	0.20
X10	6.69	5.48
R1	2556.86 (D16 – 78.64)	2593.98 (D16 – 77.51)
R2	3166.03 (D16 – 63.51)	1274.41 (D16 – 157.77)
R3	1567.90 (D16 – 128.24)	1327.63 (D16 – 151.44)
R4	1462.98 (D16 – 137.43)	1226.81 (D16 – 163.89)
R5	1453.42 (D16 – 138.34)	1226.21 (D16 – 163.97)
R6	2555.04 (D16 – 78.69)	2593.09 (D16 – 77.54)
R7	2555.35 (D16 –78.68)	2594.46 (D16 – 77.50)

R8	2554.35 (D16 – 78.71)	2593.09 (D16 – 77.54)
R9	2553.08 (D16 – 78.75)	2594.00 (D16 – 77.51)
R10	2553.01 (D16 – 78.75)	2593.09 (D16 – 77.54)

The results show that SOS algorithm exhibits coefficient of variation of 2.06% compared to that of 7.49 resulted from PSO. In other words, the SOS algorithm exhibits better performance in the process of optimizing the counterfort retaining wall structure with shear keys, compared to that of PSO algorithm. The most optimal result of the design performed by PSO and SOS algorithms is presented in Figure 3 and Figure 4, respectively.



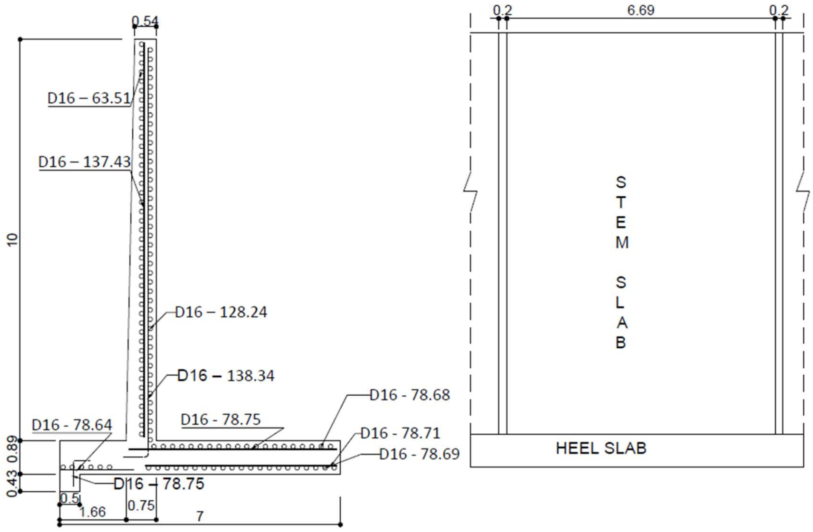
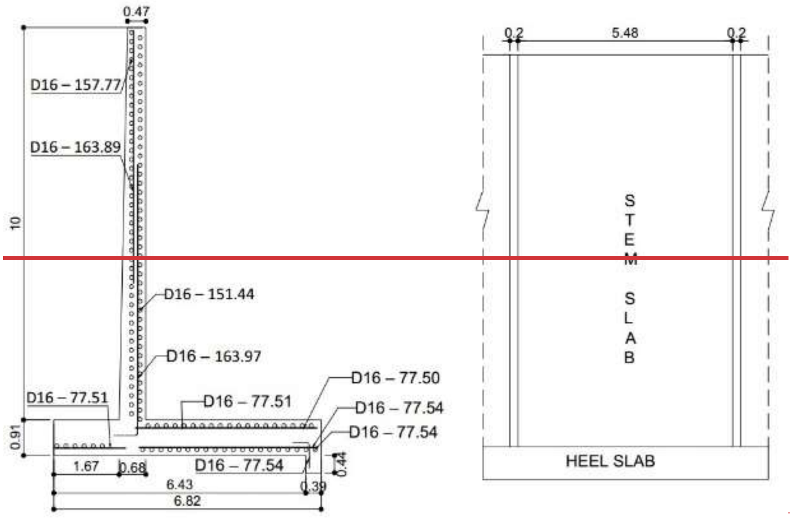


Fig. 3. Retaining Wall Structure Design based on PSO Algorithm



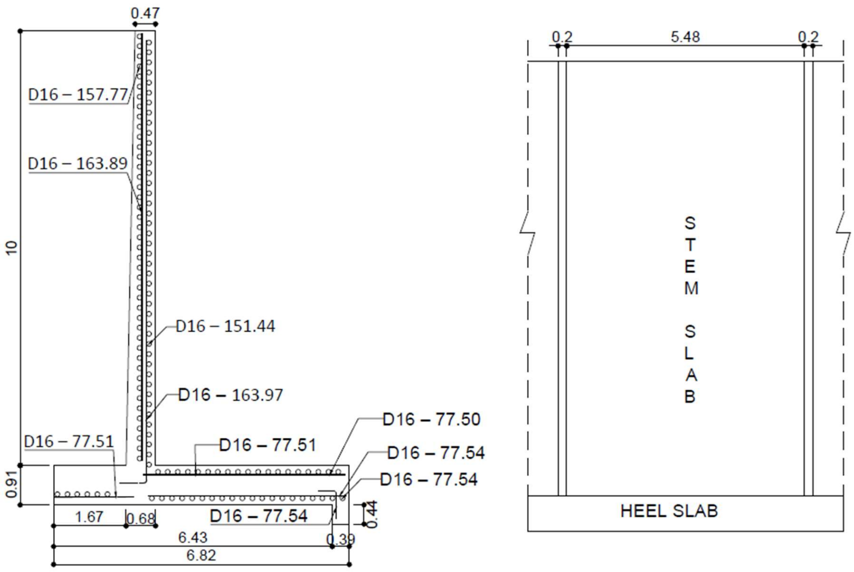


Fig. 4. Retaining Wall Structure Design based on Cost SOS Algorithm

Commented [PP13]: There are two layers of stem's horizontal reinforcement, but only one layer in vertical direction (at top and bottom part of the stem).

How is it possible in practice?

The same question applys to Fig.3.

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Figure 5 shows the rate of convergence of both algorithms on the optimization of the counterfort retaining wall structure with shear keys using input parameters presented in Table 3.

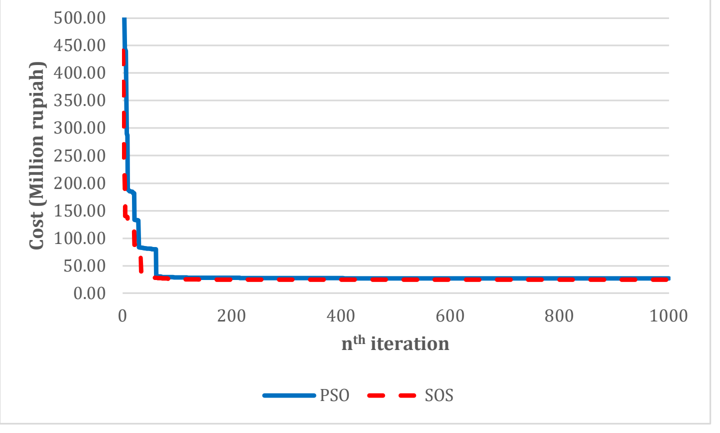

Fig. 5. Convergence Graph of Median Run Results in the Case of Counterfort Retaining Wall with Shear Key

It can be seen in Figure 5 that the rate of convergence of the SOS algorithm is faster than that of PSO, where the lowest cost (or the best result) can be achieved in smaller number of iteration.

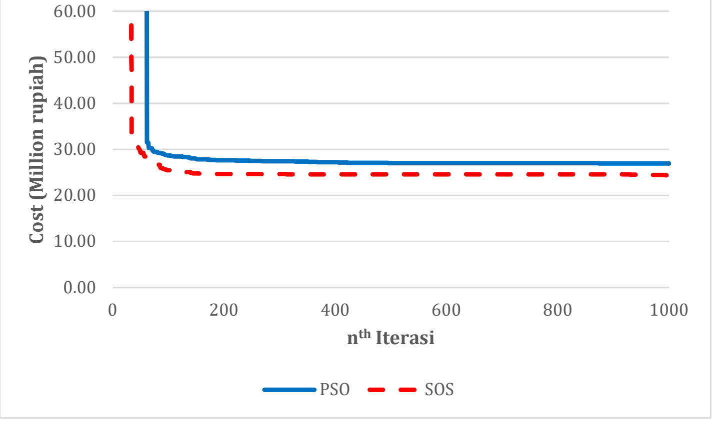

Fig. 6. The Convergence Process of PSO and SOS Algorithms to Achieve the Most Optimal Costs

Figure 6 shows the rate of convergence process of the two algorithms. The curve generated from the SOS algorithm almost constant from about 300th iteration compared to that generated based on the PSO algorithm, which still decreasing up to 1000th iteration. Based on the results presented in Figure 5 and Figure 6, it can be stated that in this research, the SOS algorithm is faster than that of the PSO algorithm.

Conclusions

Based on the results of the analysis, it can be concluded that the metaheuristic method using the SOS algorithm produces the most optimum result, in term of material cost of the counterfort retaining wall with shear key. In addition, the SOS algorithm is relatively faster to achieve the optimum result (indicated by the rate of convergence) compared to that of PSO algorithm.

Reference

1. E. Khuzaifah, "Studi tentang dinding penahan (retaining wall)," *Swara Patra : Majalah Ilmiah PPSDM Migas*, vol. 9, no. 1, pp. 7–18, 2019, Accessed: Jul. 25, 2023. [Online]. Available: http://ejurnal.ppsdmmigas.esdm.go.id/sp/index.php/swarapatra/article/view/189
2. E. N. Kalemci, S. B. İkizler, T. Dede, and Z. Angın, "Design of reinforced concrete cantilever retaining wall using Grey wolf optimization algorithm," *Structures*, vol. 23, pp. 245–253, Aug. 2020, doi: 10.1016/j.istruc.2019.09.013.
3. H. Fardilla, "Perencanaan dinding penahan sebagai alternatif pencegah bahaya longsor pada konstruksi pangkal jembatan," *Journal Rekayasa Sipil dan Desain (JRSDD)*, 2018, [Online]. Available: http://digilib.unila.ac.id/30392/11/SKRIPSI%20TANPA%20BAB%20PEMBAHASAN.pdf

4. E. N. Kalemci, S. B. İkizler, T. Dede, and Z. Angın, "Design of reinforced concrete cantilever retaining wall using Grey wolf optimization algorithm," *Structures*, vol. 23, pp. 245–253, Feb. 2020, doi: 10.1016/j.istruc.2019.09.013.

5. H. Tahsin Öztürk, T. Dede, and E. Türker, "Optimum design of reinforced concrete counterfort retaining walls using TLBO, Jaya algorithm," *Structures*, vol. 25, pp. 285–296, Jun. 2020, doi: 10.1016/j.istruc.2020.03.020.

6. M. Khajehzadeh, M. R. Taha, A. El-Shafie, and M. Eslami, "Modified particle swarm optimization for optimum design of spread footing and retaining wall," *Journal of Zhejiang University: Science A*, vol. 12, no. 6, pp. 415–427, Aug. 2011, doi: 10.1631/jzus.A1000252.

7. M.-Y. Cheng, D. Prayogo, and D.-H. Tran, "Optimizing multiple-resources leveling in multiple projects using discrete symbiotic organisms search," *Journal of Computing in Civil Engineering*, vol. 30, no. 3, Aug. 2016, doi: 10.1061/(asce)cp.1943-5487.0000512.

8. P. Parsa and H. Naderpour, "Shear strength estimation of reinforced concrete walls using support vector regression improved by teaching-learning-based optimization, particle swarm optimization, and harris hawks optimization algorithms," *Journal of Building Engineering*, vol. 44, p. 102593, 2021, doi: 10.1016/j.jobe.2021.102593.

9. D. Prayogo, H. Santoso, F. Budiman, and M. Jason, "Layout, topology, and size optimization of steel frame design using metaheuristic algorithms: A comparative study," *Civil Engineering Dimension*, vol. 24, no. 1, pp. 31–37, Apr. 2022, doi: 10.9744/ced.24.1.31-37.

10. S. Nguyen-Van, K. T. Nguyen, K. D. Dang, N. T. T. Nguyen, S. Lee, and Q. X. Lieu, "An evolutionary symbiotic organisms search for multiconstraint truss optimization

under free vibration and transient behavior," *Advances in Engineering Software*, vol. 160, p. 103045, 2021, doi: 10.1016/j.advengsoft.2021.103045.

11. V. N. Husada and A. C. Tanara, "Optimasi durasi penjadwalan proyek perumahan X menggunakan metode line of balance dan metode metaheuristik dengan memperhatikan resource leveling," 2022. Accessed: Sep. 17, 2023. [Online]. Available: https://dewey.petra.ac.id/digital/view/55660
12. C. R. I. Clayton, R. I. Woods, A. J. Bond, and J. Milititsky, *Earth pressure and earth retaining structures*, 3rd ed. CRC Press, 2013.
13. Badan Standardisasi Nasional, *SNI, 8460:2017: Persyaratan perancangan geoteknik*. 2017.
14. Badan Standardisasi Nasional, *SNI, 2847:2019: Persyaratan beton struktural untuk bangunan gedung dan penjelasan*. 2019.

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[ced] Editor Decision

Dr. Doddy Prayogo <prayogo@petra.ac.id> Tue, Jul 23, 2024 at 10:09 AM
To: Bryan Ongko <bryanongko29@gmail.com>, Glenn <b11200070@john.petra.ac.id>, Gogot <gogot@petra.ac.id>, Willy <willy.husada@petra.ac.id>

Bryan Ongko, Glenn, Gogot, Willy:

We have reached a decision regarding your submission to Civil Engineering Dimension, "The Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method".

We are pleased to inform you that your manuscript has been accepted for publication.

Thank you for your valuable contribution. We look forward to publishing your work in our journal.

Sincerely,
Editor

Reviewer A:

All comments have been accommodated in the revised version.

Recommendation: Accept Submission

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