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OPTIMAL COST OF SLOPE STABILIZATION WITH RETAINING WALL

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ABSTRACT: Optimal cost calculation is important to know the most economical wall type used in construction projects due to many types of ground retaining walls. The types of soil retaining walls often used in Indonesia are gravity, cantilever, and sheet pile. The selection of the soil retaining wall type is based on two factors: stability and cost. The purpose of this study is to compare the cost of gravity retaining walls, cantilevers, and sheet piles based on optimal dimensions. Optimal dimension calculation uses the Solver program in the Microsoft Excel application. Furthermore, cost calculations are carried out with material data, equipment, and labor wages based on the unit price of Padang City in 2021. The sheet pile retaining wall used is a type of corrugated sheet pile wall from PT. Jaya Sentrikon. From the results of the study, it is known that gravity retaining walls are the most efficient compared to cantilever and sheet pile retaining walls, but gravity is not safe for heights more than 7 m because it does not meet the requirements of internal stability. The cost of cantilever retaining walls is less expensive than sheet pile walls at a height of 8-14 m.

Keywords: Optimal Cost, Gravity, Cantilever and Sheet pile

1. INTRODUCTION

A ground retaining wall is a construction used to provide soil stability. Ground retaining walls serve to prevent landslide-indicated soil mass [1]. Ground retaining walls that are often used in construction projects are gravity, cantilevers, and sheet piles.

According to Hakam, the gravitational ground retaining wall should be limited to stone pairs of 6 m and cantilevers over 12 m [1]. Gravity walls are not safe to hold high ground whereas cantilevers can hold soil up to 8 m [2]. Cantilevered sheet pile walls are not recommended for high ground where the value of H (high sheet pile above ground) should be 3-5 m [3]. The stability of the cantilevered sheet pile depends on the length of the sheet pile erection [4].

Retaining wall planning should be safe and economical [5]. The type of retaining wall used must be safe against external and internal stability therefore it must also consider the cost factor.

Gravity retaining walls are more efficient than cantilever walls at a ground level of up to 6 m [6-8]. Gravity walls are more economical in terms of cost, concrete, and reinforcement requirements than cantilever and counterfort walls at a height of 6 m [9].

Cantilever walls are more cost-effective for a height of 9 m [10]. The optimal cantilever retaining wall is the most cost-effective solution compared to other types of retaining walls [11]. Based on the research of Perwira et.al, the cost of optimized cantilever retaining walls is more efficient than concrete sheet piles and cantilevered walls without optimization [12]. According to Alexiou et.al, cantilever walls are more cost-effective than gravity and counterfort walls at a height of 4 m where the gravity wall used is a concrete wall [13]. This is also supported by Donkada's statement which states that cantilever walls are more cost-effective than counterfort and relieving platforms [11].

The types of sheet pile retaining walls are steel, concrete, and wood sheet piles [14]. The sheet pile that is often used is steel sheet pile and concrete sheet pile. Retaining walls of concrete sheet piles are more economical than steel sheet piles [15]. Therefore concrete sheet pile walls are used more than steel. Based on several studies, sheet pile retaining walls are more cost-effective than secant pile walls [16]. Based on the research of Gestarindo et.al, concrete sheet pile retaining walls are more cost-effective than cantilever walls [17]. Sheet pile walls can be an alternative to gravity walls for a ground height of 6 m [18].

The construction of retaining walls must be well planned to avoid collapse. In addition, the construction of retaining walls must be carried out efficiently so that there is no waste, such as the research of Yuliet et.al, who researched over-designed concrete sheet pile retaining walls [19].

Therefore, this study is to compare the cost of gravity retaining walls, cantilevers, and sheet piles based on the optimal dimensions, making it easier for planners to determine the type of retaining wall to be used.

2. RESEARCH SIGNIFICANCE

The results of this study provide new information and analysis to obtain the optimal design of gravity retaining walls, cantilevers, and sheet piles using the Microsoft Excel solver. Microsoft excel solver can perform many iterations directly without manual trial and error. With the optimal design, the possibility of construction failure can be minimized. This research can be used as a guide for planners before planning the construction of retaining walls so that there is no waste such as the construction of over-designed concrete sheet piles in Pariaman. So that it is known the type of retaining wall that is effectively used.

3. OPTIMIZATION METHOD

Optimization of retaining walls uses a linear program. A linear program is a mathematical model developed by George B. Dantzig in 1947. Linear programming aims to solve the problems by minimizing and maximizing an object function by various constraints [20]. A linear program is applied to determine the optimal design of retaining walls. The optimal design of retaining walls has minimal weight and cost that still allows the constraints. Therefore to get the optimal design, a method called the optimization method is needed. To save time and ease in designing, the optimization process requires an application, namely Microsoft Excel and the Solver feature in Microsoft Excel.

The data needed in the optimization are objective function, design variables, and constraints. The objective function illustrates the purpose of a linear program. The objective function example is the minimum volume of the retaining walls. Design variable is the amount in the design of a structure whose value changes or remains (fixed parameters) during the optimization process to obtain the minimum volume where the magnitude is the dimension of the retaining wall, while the constraint is data that limits the purpose for still meet the requirements, the limiting data is the value of the safety factor of the retaining wall [21].

4. METHODOLOGY

This study uses Microsoft Excel for calculating the optimal dimensions and the cost of the retaining walls. The methodology of this study is divided into several stages, namely the calculation of the optimal dimensions, the cost calculations, and comparisons of cost for retaining walls.

The calculation of the optimal dimensions uses the solver optimization program in the Microsoft Excel application. The calculation of the retaining wall formula is made on a Microsoft excel worksheet. This calculation consists of dimensions, volume, external and internal safety factors, After obtaining the calculation framework, optimization is carried out with a solver so that the optimal dimensions of the retaining wall are obtained.

Cost calculation is carried out with data of the prices of the materials, the equipment, and the labor wages based on the work unit price of the City of Padang in 2021. The analysis of sheet pile cost uses a price list from PT Jaya Sentrikon with the type of sheet pile retaining wall used is Corrugated Sheet pile Wall from PT. Jaya Sentrikon located in the city of Padang.

Furthermore, a comparison of gravity retaining walls, cantilevers, and sheet piles is effective and efficient for use at each height.

5. OPTIMIZATION OF RETAINING WALL

In this study, three types of retaining walls were used, specifically gravity, cantilever, and sheet pile. The limitations of this research are as follows:

- The original soil and the backfill behind the retaining wall were sandy soil.
- In the stability analysis, the only static load is accounted
- An earthquake load was excluded
- Earth pressure was calculated using Rankine's theory.

The soil and material parameter data used are as follows:

Table 1 Specification of materials

Parameter	Value	Unit
Unit Weight (γ)	1,45	ton/m^3
The angle of internal friction (ϕ)	29,31	^{o}
Cohesion (c)	0	ton/m^3

Table 2 Specification of materials

Parameter	Value	Unit
Stone Unit Weight (γ)	2,2	ton/m^3
Concrete Unit Weight (γ)	2,4	ton/m^3
Mortar press strength	50	kg/cm^2
Concrete Strength (fc)	20	Mpa
Steel Yield Strength (fy)	240	Mpa

5.1 Gravity Retaining Wall

The calculations use the Microsoft Excel application by compiling the calculation formulation for external stability and internal stability. Next, to determine the exact dimensions for each height, use the Solver feature in Microsoft Excel.

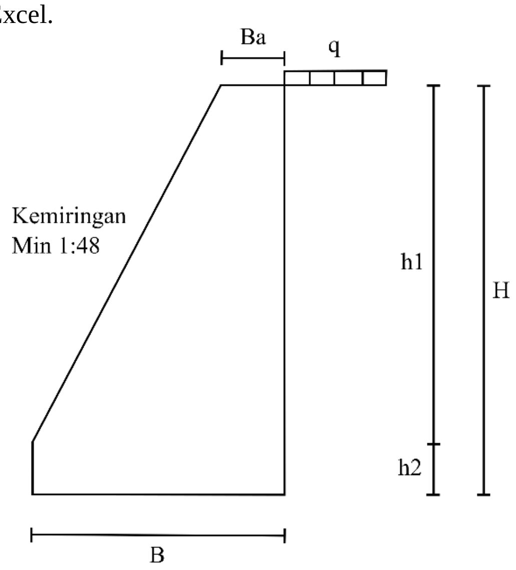

Fig.1 Gravity wall geometry

Optimization Data :

- Objective Function : Volume
- Design variable : B, Ba dan h2
- Constraint

Table 3 Constraint

Variable	Minimum	Maximum
B	0,5 H	0,7 H
Ba	0,3	H/12
H2	H/8	H/6

Table 4 Constraint of external and internal stability

Constraint	Minimum	Maximum
External		
SF Overturning	2	-
SF Sliding	1,5	-
SF Soil Bearing Capacity	3	-
Internal		
σ pressure stress	-	66 ton/m^2
Σ tensile stress	-	10 ton/m^2
σ sliding	-	12 ton/m^2

Source: PBI 1971[22]

From the destination data, the volume is obtained which will be used to calculate the cost of retaining the wall. Components in the calculation of costs are labor consisting of ordinary workers, artisans, and a foreman. The second component was the material consisting of river stone, cement, and sand. The third component is equipment consisting of a concrete mixer, water tanker, and auxiliary equipment. Cost calculation is based on the work unit price of Padang in 2021.

5.2 Cantilever Retaining Wall

The calculation of the cantilever retaining wall is the same as that for the gravity wall, namely by compiling a formulation for calculating external and internal stability using Microsoft Excel.

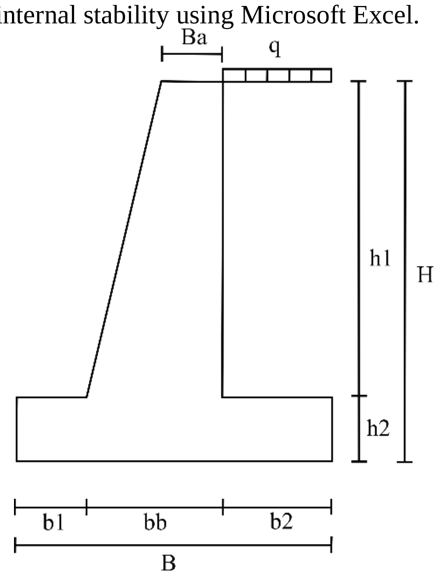

Fig.2 Cantilever wall geometry

Optimization Data :

- Objective Function : Volume
- Design variable : B, Ba, b1,b2,bb,h2
- Constraint

Table 5 Constraint

Variable	Minimum	Maximum
B	0,4 H	0,7 H
Ba	0,3	-
h2	H/12	H/10
b1	B/3	-
bb	0,1 H	-
b2	B-(b1+bb)	-

Table 6 Constraint of external and internal stability

Constraint	Minimum	Maximum
External		
SF Overturning	2	-
SF Sliding	1,5	-
SF Soil Bearing Capacity	3	-
Internal		
σ pressure stress	-	269,28 ton/m^2
Σ tensile stress	-	20,56 ton/m^2
σ sliding	-	24,56 ton/m^2

Source: PBI 1971[22]

Optimization of cantilever retaining walls results in optimal dimensions and optimal volume of retaining walls. The cost of calculation is carried out with the work component, namely the workforce consisting of ordinary workers, artisans, and foremen. The cost of the work is based on the work unit price of Padang in 2021.

5.3 Sheet Pile Retaining Wall

The optimization for sheet pile retaining walls was different from the process for the gravity and cantilever walls.

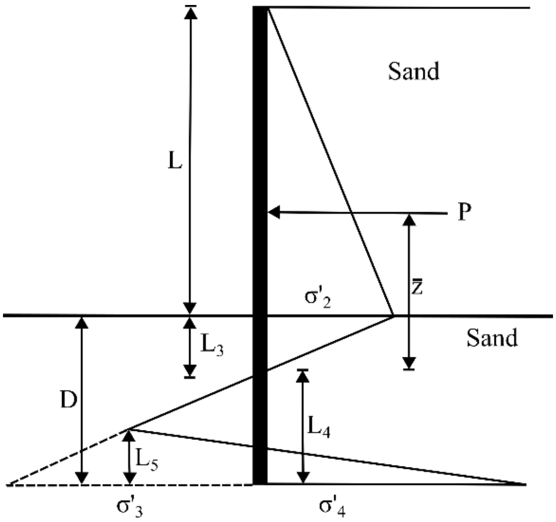

Fig. 3 Sheetpile geometry

Optimization Data :

- Objective Function : Mmaks
- Design variable : L4
- Constraint : L4=0

Sheet pile calculation refers to *Principle Of Foundation Engineering Eighth Edition*, Braja M. Das [23].

From the result of optimizing sheet pile walls, the total length of sheet pile required is obtained. Furthermore, the cost calculation is carried out with the work component, namely the workforce consisting of workers, builders, and foremen. Material components consist of a conca rete sheet pile, steel plate, and welding wire. Equipment components consist of the trailer, crane 1, crane 2, a welding set, a pile driver hammer, and tools.

6 RESULT AND DISCUSSION

6.1 Optimal Cost of Gravity Retaining Wall

The optimal cost of the gravity retaining wall is calculated based on the optimal dimensions of the solver optimization results. The gravity wall meets the requirements of internal and external stability up to a height of 7 m. The following is the optimal cost of the gravity retaining wall.

Table 7 Dimension and optimal cost of gravity wall

Height (H)	Wall Height (h1)	Foot Width (B)	Wall Top Width (Ba)	Foot Thickness (h2)	Volume (V)	Cost for 1m³ Retaining Wall (Rp)	Total Cost of Gravity (Rp)	PPN 10%	Total Cost (Rp)
a	b	c	d	e	f	g	h = (f x g)	i	j = (h + i)
4	3,33	2,38	0,30	0,67	6,06	699.631	4.242.924	424.292	4.667.216
5	4,17	2,82	0,30	0,83	8,85	754.631	6.679.614	667.961	7.347.575
6	5,00	3,26	0,30	1,00	12,15	754.631	9.166.371	916.637	10.083.008
7	5,83	3,69	0,30	1,17	15,95	754.631	12.036.726	1.203.673	13.240.398
8	6,67	4,13	0,30	1,33	20,26	754.631	15.290.698	1.529.070	16.819.768
9	7,50	4,56	0,30	1,50	25,08	754.631	18.928.276	1.892.828	20.821.104
10	8,33	5,00	0,30	1,67	30,42	809.631	24.625.052	2.462.505	27.087.557
11	9,21	5,50	0,30	1,79	36,54	809.631	29.586.438	2.958.644	32.545.082
12	10,09	6,00	0,30	1,91	43,23	809.631	34.999.762	3.499.976	38.499.738

The calculation of the optimal cost of the gravity wall consists of the cost of material, labor, and equipment, the cost calculation is carried out for 1m3 of the gravity wall, then multiplied by the total volume to obtain the total cost of the gravity wall.

Based on table 7, gravity retaining walls are safe to use up to a height of 7 m. For a height of more than 7 m, the internal safety figure does not meet the requirements. The cost of a gravity wall for 1 m^3 is different for each height. For a height of 4 m, the price for 1 m3 is Rp. 699,631,-so the total cost is Rp. 4,667,216,- and for a height of 7 m, the cost for 1 m3 is Rp. 754,631,- so the total cost is Rp. 13,240,398,-

Table 8 Optimal dimension of cantilever wall

Height (H)	Wall Height (h1)	Volume (V)	Foot Width (B)	Wall Top Width (Ba)	Foot Thickness (h2)	Width of Heel Slab (b1)	Width of Toe Slab (b2)	The thickness of the Stem Wall (bb)
a	b	c	d	e	f	g	h	i
4,00	3,60	3,41	2,80	0,60	0,40	0,93	1,19	0,67
5,00	4,50	3,89	3,50	0,43	0,50	1,17	1,81	0,52
6,00	5,40	4,96	4,20	0,30	0,60	1,40	2,20	0,60
7,00	6,37	6,26	4,90	0,30	0,63	1,63	2,57	0,70
8,00	7,33	7,75	5,57	0,30	0,67	1,86	2,92	0,80
9,00	8,25	9,59	6,18	0,30	0,75	2,06	3,22	0,90
10,00	9,17	11,62	6,79	0,30	0,83	2,26	3,53	1,00
11,00	10,08	13,84	7,40	0,30	0,92	2,47	3,83	1,10
12,00	11,00	16,26	8,01	0,30	1,00	2,67	4,14	1,20
13,00	11,92	18,87	8,61	0,30	1,08	2,87	4,44	1,30
14,00	12,83	21,67	9,22	0,30	1,17	3,07	4,75	1,40
15,00	13,75	24,66	9,83	0,30	1,25	3,28	5,05	1,50

Table 9 Optimal cost of cantilever wall

Concrete Volume (m³)	Concrete Cost (Rp)	Total Concrete Cost (Rp)	Steel Weight (Kg)	Reinforcement Cost for 1 Kg (Rp)	Total reinforcement (Rp)	Total Cost for Cantilever (Rp)	PPN 10%	Total Cost (Rp)
j	k	l = (j x k)	m	n	o = (m x n)	p = (l + o)	q	r = (p + q)
3,00	1.701.499	5.111.906	408	22.931	9.351.661	14.463.567	1.446.357	15.909.923
3,44	1.715.929	5.906.958	443	22.931	10.165.999	16.072.957	1.607.296	17.680.253
4,34	1.689.107	7.331.911	621	22.931	14.246.345	21.578.256	2.157.826	23.736.082
5,57	1.689.107	9.414.308	685	22.931	15.708.591	25.122.899	2.512.290	27.635.189
6,91	1.674.256	11.577.405	834	22.931	19.127.287	30.704.691	3.070.469	33.775.161
8,69	1.655.790	14.392.525	894	22.931	20.503.519	34.896.044	3.489.604	38.385.649
10,36	1.641.572	17.005.697	1.257	22.931	28.831.658	45.837.355	4.583.735	50.421.090
12,39	1.629.533	20.191.770	1.449	22.931	33.226.032	53.417.803	5.341.780	58.759.583
14,72	1.619.207	23.838.488	1.534	22.931	35.180.445	59.018.933	5.901.893	64.920.826
17,25	1.610.253	27.771.298	1.619	22.931	37.134.858	64.906.156	6.490.616	71.396.771
19,80	1.602.414	31.729.079	1.868	22.931	42.827.084	74.556.163	7.455.616	82.011.779
22,71	1.595.495	36.235.436	1.953	22.931	44.781.497	81.016.933	8.101.693	89.118.626

Cantilever retaining walls based on the calculation of the optimal dimensions are safe to use up to a height of 12 m, and a height of 13–15 m does not meet the requirements. The calculation of the optimal cost of cantilever walls consists of the volume of concrete, reinforcement, labor, and equipment.

Based on Table 9, for a height of 4 m, the total cost of concrete is Rp. 5.111.906,- with the cost of reinforcement being Rp. 9.351.661,-, so that the total cost of the cantilever height of 4 m is 15.909.923,-. The price of reinforcement in Padang City for 1 kg is Rp. 22,931,-.

6.2 Optimal Cost of Cantilever Retaining Wall

The optimal cost of the cantilever retaining wall is obtained from the optimal dimensions that meet the requirements for external and internal stability as shown in Table 8.

6.3 Optimal Cost of Sheet Pile Retaining Wall

The optimal cost of the sheet pile retaining wall is calculated for 1 m. Optimal cost of the sheet pile retaining wall in Table 10

Table 10 Optimal cost of the sheet pile wall

Sheet Pile Length (m)	Sheet Pile Type	Sheet Pile Cost for 1m' (Rp)	Total Cost of Sheet Pile (Rp)	Capping Beam Cost (Rp)	Total Cost (Rp)	PPN 10%	Total Cost (Rp)
a	b	c	d = (a x c)	f	g = (d + e + f)	h	i = (g + h)
7	W-325-A-1000	2.491.148	17.438.033	1.333.429	18.771.462	1.877.146	20.648.608
8	W-325-A-1000	2.465.920	19.727.357	1.333.429	21.060.786	2.106.079	23.166.865
9	W-350-A-1000	2.623.425	23.610.822	1.319.255	24.930.077	2.493.008	27.423.085
10	W-400-B-1000	2.912.301	29.123.012	1.301.705	30.424.717	3.042.472	33.467.189
11	W-500-A-1000	3.503.573	38.539.306	1.605.646	40.144.952	4.014.495	44.159.447
12	W-600-A-1000	3.861.379	46.336.542	1.583.912	47.920.454	4.792.045	52.712.500
13	W-600-A-1000	3.925.496	51.031.448	1.583.912	52.615.360	5.261.536	57.876.896
14	W-600-B-1000	4.132.075	57.849.054	1.583.912	59.432.966	5.943.297	65.376.263
15	-	-	-		-	-	-

The type of sheet pile retaining wall is a corrugated sheet pile wall from PT Jaya Sentrikon with a length of 7 m – 14 m.

The calculation of sheet pile wall cost consists of sheet pile cost and capping beam cost. Based on Table 10 for a sheet pile length of 7 m, the sheet pile cost is Rp. 17.438.033, - and capping beam cost is Rp. 1.333.429, - so the total cost is Rp. 20,648,608,-

6.4 Comparison of the Optimal Cost of Gravity, Cantilever and Sheet Pile Retaining Wall

Comparison of the optimal cost of gravity, cantilevers, and sheet pile walls by taking into account the cost of material, labor, and equipment based on the Padang City Work Unit Price in 2021 and based on the sheet pile prices from PT Jaya Sentrikon.

Table 11 Comparison of the optimal cost of the gravity, cantilever, and sheet pile wall

Height	Cost					
	H1	Gravity	H1	Cantilever	L	Sheet Pile
4	3,33	4.667.216	3,60	15.909.923	-	-
5	4,17	7.347.575	4,50	17.680.253	-	-
6	5,00	10.083.008	5,40	23.736.082	-	-
7	5,83	13.240.398	6,37	27.635.189	2,90	20.648.608
8	6,67	16.819.768	7,33	33.775.161	3,00	23.166.865
9	7,50	20.821.104	8,25	38.385.649	3,50	27.423.085
10	8,33	27.087.557	9,17	50.421.090	4,00	33.467.189
11	9,21	32.545.082	10,08	58.759.583	4,50	44.159.447
12	10,09	38.499.738	11,00	64.920.826	5,00	52.712.500
13	-	-	11,92	71.396.771	5,20	57.876.896
14	-	-	12,83	82.011.779	5,50	65.376.263
15	-	-	13,75	89.118.626		-

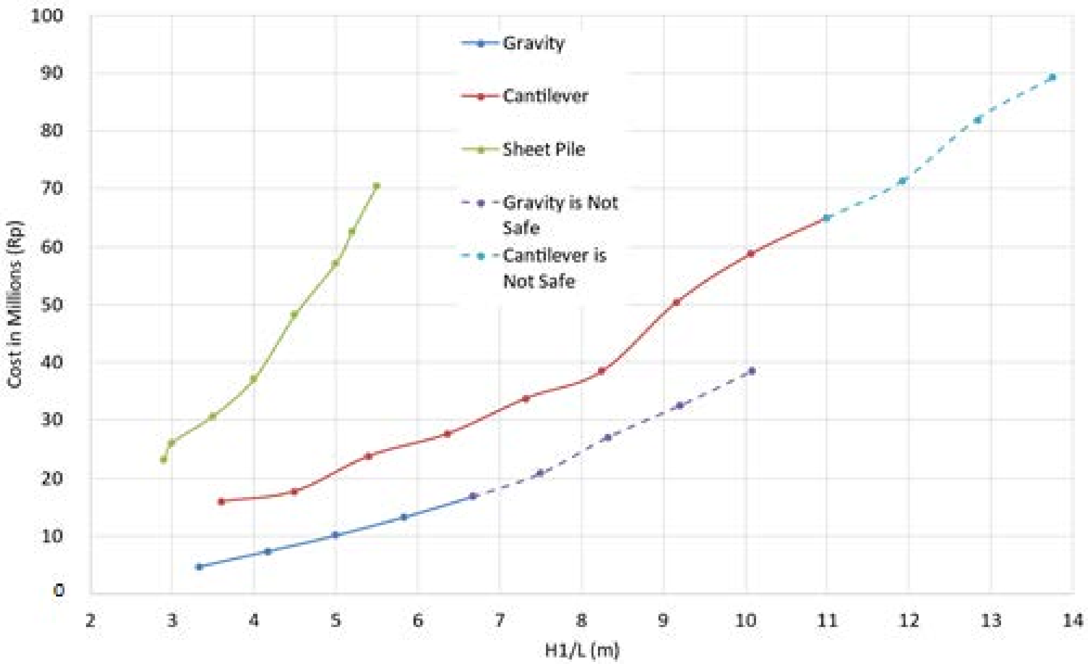

Fig. 4 Comparison of the optimal cost of gravity wall, cantilever, and sheet pile

The heights of the retaining walls compared are h1, and L. h1 and L are the heights of the unembedded retaining walls. Based on Fig. 4, gravity retaining walls are more cost-effective than cantilevers and sheet piles, but gravity walls are not safe to use for heights over 7 m because they do not meet internal stability requirements. At the height of 8–14 m, cantilever retaining walls are more efficient than sheet piles, but cantilevers do not meet internal stability at the height of 13–14 m.

7 CONCLUSION

The various types of retaining walls available make it difficult for the planners to determine which one to be used. The types of retaining walls that are often used in Indonesia are the gravity walls, the cantilevers, and the sheet piles. The selection of retaining wall types must be based on two things, namely the stability and the cost of the retaining walls.

Based on the results of this study, it was found that the gravity retaining walls are more cost-effective than the cantilever walls and the sheet piles but the gravity walls can only be used for heights of up to 7 m. For a height of 8 m – 14m, cantilever walls are more efficient than sheet pile walls.

8 ACKNOWLEDGMENT

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