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Bearing Capacity Analysis of Pile Foundation in Reservoir Construction

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Abstract – *The foundation was an important part of the structure. In foundation design, it was necessary to considered the foundation condition to be built must be able to support the load up to the allowable capacity. To determine a safe foundation requires analysis using several of static methods. This research was conducted to obtain a critical bearing capacity so that it can be used to determine a very safe foundation. In this study, analysis of the bearing capacity of pile foundations was calculate using the method of Briaud et al. (1985), Meyerhof (1956), Decourt (1982), Shioi & Fukui (1982) based on SPT N-value obtained from the field at borehole 1 (BH-01) and borehole 2 (BH-02). Based on the analytical result of the bearing capacity calculation of a pile foundation with a diameter of 0.35m on depth of 24m, The lowest of bearing capacity (critical value) used to determine the number of piles is the method of Briaud et al. (1985) was 90.55 tons at borehole 1 and 87.06 tons at borehole 2. This value was use as a guideline for determining the number of pile foundations used in reservoir construction design.*

Key words – *bearing capacity, static methods, pile foundation, reservoir, N-value, borehole*

I. PRELIMINARY

A foundation is the lowest part of a building that transfers the load of the building to the ground or stone below [1]. Pile foundations are used to support buildings when the hard soil layer is very deep. Pile foundations are also used to support buildings that resist upward lifting forces, especially in high-rise buildings which are affected by overturning forces due to wind loads and earthquake loads [2].

The design of the foundation needs to calculate the value of the working load and the bearing capacity of the local soil. If the ratio between the bearing capacities of the soil to the load is not taken into account, it has the potential to cause losses both in the form of cost efficiency and construction failures such as uneven settlement which can result in damage to the building.

The focus on this research was the analysis of the soil bearing capacity of the pile foundation in the reservoir building. Determining a safe foundation requires analysis using a variety of static methods. This research was conducted to obtain a critical load-bearing capacity so that it can be used to determine a very safe foundation.

A reservoir is a building structure with a large load because it has large dimensions with high-quality concrete and the heavy live load it receives, for this reason, an analysis of the bearing capacity of the foundation is needed, so that the reservoir construction can be carried out with the geological conditions in the planning area.

Standard Penetration Test (SPT) of soil investigation results from two boreholes at the Pekanbaru-Kampar reservoir construction project was used in this research.

The objectives of this study include knowing the load distribution at each point of the reservoir building foundation which will be calculated using the ETABS software and knowing the maximum load on the group pile configuration. This allowed the authors to determine the depth of soil that could accommodate the building load and determine the required foundation amount.

II. RELATED RESEARCH

Based on Hardiyatmo (2002), deep foundations are foundations that transfer building loads to hard soil or rocks relatively far from the ground surface. The foundation is classified as a deep foundation type if the ratio of the depth to the width of the foundation is greater than or equal to 4($D_f/B \geq 4$).

Yani (2021) has researched calculating the bearing capacity of piles in office buildings using Standard Penetration Test (SPT) and Cone Penetration Test (CPT) data using the Décourt-Quaresma (1982), Meyerhof (1956), Schmertmann (1975) and LCPC (1982) methods.

The aim of this study was to determine the value of the pile-bearing capacity using several methods to determine the safe condition of a building.

Based on the research that has been done with several methods, the results obtained are safe conditions using a pile diameter of 40 cm and 50 cm. For analytical results, to calculating the bearing capacity of the pile using LCPC (1982) method, Meyerhof (1956), and Schmertman (1975) with an accuracy rate of 67% - 101%.

III. RESEARCH METHODS

This research starts from a literature study then determines the research location for data collection. Determining the research location is a very important stage in research, because by setting the research location the objects and objectives have been determined so that it makes it easier to carry out the next steps. The location of the research was carried out in the project area of the Pekanbaru-Kampar regional SPAM in Kuala Village, Kec. Mining, Kampar Regency.

The soil parameter data used is the Standard Penetration Test (SPT) data which is the data for testing the bearing capacity of the soil directly at the location using bores, the SPT data used is SPT data from borehole 1 (BH-01) and borehole 2 (BH-02).

Structural analysis refers to SNI 1727-1989, as a reference in entering loading provisions on the building structure and SNI 03-1726-2002 Standards for Earthquake Resistance Planning for Building Structures as a reference for the magnitude of earthquake loads that occur on building structures.

Structural analysis is carried out to obtain the magnitude of the load at each foundation point such as axial load and lateral load on the foundation. In the analysis of the structure, the author uses the help of ETABS software.

In this study, the bearing capacity of pile foundations was calculated using the method of Briaud et al. (1985), Meyerhof (1956), Decourt (1982), Shioi & Fukui (1982) based on N-SPT data obtained from the field at borehole 1 (BH-01) and borehole 2 (BH-02). The results of bearing capacity using the method which have a critical or lower value compared to other methods, so that the parameters used to determine the pile foundation will be more critical and produce a safer pile foundation configuration. The method used in determining the bearing capacity of group piles is by using the Converse-Labarre Formula for calculate efficiency value of pile.

IV. RESULTS AND DISCUSSION

Analysis of Structure

Structural analysis of this building structure was performed using 3D structural modeling with ETABS software. Columns and beams are modeled as frame elements, slabs and stairs are modeled as shell elements. In seismic load analysis, the building structure is modeled as a shear structure with the floor as a rigid membrane. In this model, the mass of each building is concentrated at the center of gravity of the ground (lump mass model).

Structural analysis results are obtained as the magnitude of the internal force and support reaction force generated at each hinge reaction point, and this result are used to compare with the magnitude of the base support force obtained by SPT data. The reservoir is modeled with ETABS software.

Loads are based on the provisions of “Peraturan Pembebanan Indonesia Untuk Gedung (PPIUG) 1989” and “Standar Nasional Indonesia for Seismic Design of Buildings and Non-Buildings (SNI) 03-1726-2002”.

Correction of values from SPT data is made on site prior to determination of pile bearing capacity. These modifications are tool modifications, site procedure effects, and overload pressure modifications. Measurements of N-SPT1 from BH-01 are corrected for field method effects and are discussed below.

$$N'_{60} = \frac{(E_m + C_B + C_S + C_R)}{0{,}60} \times (\text{N-SPT}) \qquad (1)$$

Where,

N'_{60} = SPT N value corrected for field procedure

E_m = Hammer efficiency or energy correction factor

C_B = bore-hole diameter correction factor

C_S = sampler correction factor

C_R = rod length correction factor
N-SPT = N value data

Briaud et al. method

The soil bearing capacity results using the Briaud et al. method can be seen in the analysis of the N-SPT1 data from BH-01 below, the following is an example of a calculation at a depth of 20 meters with the soil type being silty fine sand.

a. End bearing (Q_b)

$$Q_b = f_b \times A_b \tag{2}$$

$$f_b = 19.7 \times (N'_{60})^{0,36} \times \sigma_r \text{ (Sand)} \tag{3}$$

Where,
N'_{60} = 73.33
D = 0.35 m
σ_r = 100 kN/m²
f_b = 9246.44 kN/m²
A_b = $\frac{1}{4}\pi \times D^2 = 0.096$ m²

The result of end bearing, (Q_b) = 889.16 kN

b. Skin friction (Q_s)

$$Q_s = f_s \times A_s \tag{4}$$

$$f_s = 0.224 \times (N'_{60})^{0,29} \times \sigma_r \text{ (Sand)} \tag{5}$$

Where,
N'_{60} = 73.33
D = 0.35 m
Li = 2 m
σ_r = 100 kN/m²
f_s = 77.84 kN/m²
A_s = $\pi \times d \times Li = 2.198$ m²
The result of skin friction, (Q_s) = 171.09 kN (local)

Skin friction resistance used for calculate the ultimate of bearing capacity of the cumulative Skin friction resistance is Q_s = 1436.44 kN

c. Ultimate of bearing capacity (Q_u)

$$Q_u = Q_b + Q_s - W_p \tag{6}$$

W_p = 20 m × 0.3 kN/m = 6 kN
Q_u = 889.16 kN + 1436.44 kN – 6 kN = 2319.61 kN

d. Allowable of bearing capacity (Q_{all})

$$Q_{all} = \frac{Q_u}{SF} \text{ with } \textit{safety factor} \text{ (SF)} = 3 \tag{7}$$

$Q_{all} = \frac{2319.61}{3}$ = 773.20 kN = 78.87 ton

Meyerhof method

The soil bearing capacity results using Meyerhof method can be seen in the analysis of the N-SPT1 data from BH-01 below, the following is an example of a calculation at a depth of 20 meters with the soil type being silty fine sand.

a. End bearing (Q_b)

$$Q_b = f_b \times A_b \tag{8}$$

$$f_b = 0.4 \times N'_b \times (L/D) \times \sigma_r \text{ (Sand)} \tag{9}$$

$$N'_b = \frac{N'_{60\ average}\ (10D\ top\ and\ 4D\ bottom\ from\ endbearing)}{number\ of\ points\ 10D\ top\ and\ 4D\ bottom\ from\ endbearing} \tag{10}$$

Where,

L = 2 m

D = 0.35 m

N'_b = 62.11

σ_r = 100 kN/m²

f_b = 14196.82 kN/m²

A_b = $\frac{1}{4}\pi \times D^2 = 0.096$ m²

The result of end bearing, (Q_b) = 1365.2 kN

b. Skin friction (Q_s)

$$Q_s = f_s \times A_s \tag{11}$$

$$f_s = \frac{1}{50} \times N'_b \times \sigma_r \text{ (Sand)} \tag{12}$$

Where,

D = 0.35 m

Li = 2 m

σ_r = 100 kN/m²

f_s = 216 kN/m²

A_s = $\pi \times d \times Li = 2.198$ m²

The result of skin friction, (Q_s) = 474.77 kN (local)

Skin friction resistance used for calculate the ultimate of bearing capacity of the cumulative Skin friction resistance is Q_s = 4232.952 kN

c. Ultimate of bearing capacity (Q_u)

$$Q_u = Q_b + Q_s - W_p \tag{13}$$

W_p = 20 m × 0.302 kN/m = 6.04 kN

Q_u = 1365.2 kN + 4232.952 kN – 6.04 kN = 2434.16 kN

d. Allowable of bearing capacity (Q_{all})

$$Q_{all} = \left(\frac{Q_b}{3} + \frac{Q_s}{5}\right) - W_p \tag{14}$$

$$Q_{all} = \left(\frac{1365.2\ kN}{3} + \frac{4232.952\ kN}{5}\right) - 6.04\ kN = 1283.54 kN = 130.921 ton$$

Decourt method

The soil bearing capacity results using Decourt method can be seen in the analysis of the N-SPT1 data from BH-01 below, the following is an example of a calculation at a depth of 20 meters with the soil type being silty fine sand.

a. End bearing (Q_b)

$$Q_b = f_b \times A_b \tag{15}$$

$$f_b = C \times N'_u \tag{16}$$

$$N'_u = \frac{N'_{60\ average}\ (4D\ top\ and\ 4D\ bottom\ from\ endbearing)}{number\ of\ points\ 4D\ top\ and\ 4D\ bottom\ from\ endbearing} \tag{17}$$

Where,

D = 0.35 m

C = 0.04 MPa(for sand)

N'_u = 63.59

f_b = 2543 kN/m^2

A_b = $\frac{1}{4}\pi \times D^2 = 0.096$ m^2

The result of end bearing, (Q_b) = 244.585 kN

b. Skin friction (Q_s)

$$Q_s = f_s \times A_s \tag{18}$$

$$f_s = \left(N'_{60} + 1\ {}^{ton}/_{m^2}\right)/3 \tag{19}$$

Where, f_s calculated from a depth of 18-20 meters

D = 0.35 m

Li = 2 m

N'_{60} = 73.33

f_s = 243.07 kN/m^2

A_s = $\pi \times d \times Li = 2.198$ m^2

The result of skin friction, (Q_s) = 534.27 kN (local)

Skin friction resistance used for calculate the ultimate of bearing capacity of the cumulative Skin friction resistance is Q_s = 4589.49 kN

c. Ultimate of bearing capacity (Q_u)

$$Q_u = Q_b + Q_s - W_p \tag{20}$$

W_p = 20 m × 2.96 kN/m = 59.216 kN

Q_u = 244.585 kN + 4589.49 kN – 59.216 kN = 4774.86 kN

d. Allowable of bearing capacity (Q_{all})

$$Q_{all} = \frac{Q_u}{SF} \text{ with } \textit{safety factor} \text{ (SF)} = 3 \tag{21}$$

$Q_{all} = \frac{4774.86}{3} = 1591.62$ kN ≈ 162.35 ton

Shioi & Fukui method

The soil bearing capacity results using Shioi & Fukui method can be seen in the analysis of the N-SPT1 data from BH-01 below, the following is an example of a calculation at a depth of 20 meters with the soil type being silty fine sand.

a. End bearing (Q_b)

$$Q_b = f_b \times A_b \tag{22}$$

$$f_b = C \times N'_b \tag{23}$$

$$N'_b = \frac{N'_{60\ average}\ (10D\ top\ and\ 4D\ bottom\ from\ endbearing)}{number\ of\ points\ 10D\ top\ and\ 4D\ bottom\ from\ endbearing} \quad (24)$$

Where,

D	= 0.35 m
C	= 0.3 MPa (for L/D > 5)
N'_b	= 62.11
f_b	= 18633.3 kN/m^2
A_b	= $\frac{1}{4}$ π × D^2 = 0.096 m^2

The result of end bearing, (Q_b) = 1791.83 kN

b. Skin friction (Q_s)

$$Q_s = f_s \times A_s \quad (25)$$

$$f_s = A + (B + N'_{60}) \quad (26)$$

Where, f_s calculated from a depth of 18-20 meters

A	= 0.2
D	= 0.35 m
Li	= 2 m
N'_{60}	= 73.33
B	= 2 (for granular soil)
f_s	= 139.71 kN/m^2
A_s	= π × d × Li = 2.198 m^2

The result of skin friction, (Q_s) = 307.087 kN (local)

Skin friction resistance used for calculate the ultimate of bearing capacity of the cumulative Skin friction resistance is Q_s = 2703.75 kN

c. Ultimate of bearing capacity (Q_u)

$$Q_u = Q_b + Q_s - W_p \quad (27)$$

W_p	= 20 m × 2.96 kN/m = 59.216 kN
Q_u	= 1791.83 kN + 2703.75 kN – 59.216 kN = 4436.35 kN

d. Allowable of bearing capacity (Q_{all})

$$Q_{all} = \frac{Q_u}{SF} \text{ with } \textit{safety factor} \text{ (SF) = 3} \quad (28)$$

$$Q_{all} = \frac{4436.35}{3} = 1478.78 \text{ kN} \approx 150.836 \text{ ton}$$

Comparison of Bearing Capacity from Several Methods

The following is a comparison of each soil bearing capacity from NSPT 1 data from BH-01 and NSPT 2 from BH-02 using several methods. Comparisons are made to obtain the most critical value that will be used to determine the number of piles to be used.

TABLE I
COMPARISON OF BEARING CAPACITY FROM N-SPT 1 DATA

Depth (m)	**Axial bearing capacity / Q_{all} (ton)**			
	Meyerhof	**Decourt**	**Briaud et al.**	**Shioi & Fukui**
0	0,00	0,00	0,00	4,10
2	10,88	11,08	21,77	56,36
4	21,92	25,67	25,53	95,13
6	64,17	34,34	35,98	116,39
8	83,66	53,54	43,49	138,05
10	103,67	72,19	49,79	157,74

12	123,54	96,54	58,86	165,82
14	132,93	121,78	65,59	167,26
16	134,19	132,78	64,80	167,69
18	136,90	143,18	69,89	178,62
20	148,86	162,35	78,87	196,35
22	164,86	178,81	83,07	216,48
24	184,54	197,33	90,55	241,13
26	209,31	226,01	101,03	266,90
28	233,56	253,98	107,48	247,89
30	221,32	279,93	113,93	228,89

TABLE II
COMPARISON OF BEARING CAPACITY FROM N-SPT 2 DATA

Depth (m)	**Axial bearing capacity / Q_{all} (ton)**			
	Meyerhof	**Decourt**	**Briaud et al**	**Shioi & Fukui**
0	0,00	0,00	0,00	0,61
2	2,27	2,11	12,21	10,73
4	12,67	7,81	18,12	35,59
6	42,76	15,01	30,67	57,30
8	65,13	27,15	38,16	84,32
10	87,63	42,59	47,34	111,26
12	104,56	61,73	55,89	130,67
14	110,73	74,64	58,91	133,77
16	111,53	81,20	60,76	130,25
18	119,50	90,43	67,28	138,08
20	130,92	104,39	74,98	150,84
22	145,40	115,28	78,69	165,22
24	165,60	129,36	87,06	188,11
26	186,92	152,02	97,54	213,36
28	209,97	169,22	101,47	236,49
30	196,53	188,82	110,11	217,48

The results of bearing capacity using the Briaud et al. method were chosen to determine the number of pile foundations because they have a critical or lower value compared to other methods, the method with the lowest value is chosen because the lowest number represents the results of the other methods, if the bearing capacity uses the with the lowest result being able to accept the load of the building above it, the bearing capacity with other methods with higher yields will also be able to accept the same load, so that the parameters used to determine the pile foundation will be more critical and produce a safer pile foundation configuration.

Foundation design

The foundation used is a concrete pile foundation using a precast spun pile. The Q_{all} value is used which is equivalent to the Q_{all} of the pile material is used to determine the depth of the pile. It is important not to damage the pile during driving, so that the planned depth can be reached.

It is planned that a solid pile foundation with JIS A 5335 specifications will use precast spun pile concrete with a diameter of 0.35 meters Type C, length of 7 meters, and weight of 1.06 tons.

The Q_{all} material of the pile is known to be 85.25 tons, so the pile depth is used at 24 m below the soil surface with a bearing capacity using the method of Briaud et al. which value is equivalent to the Q_{all} of the pile material, Q_{all} at a depth of 24 meters, namely 90.55 tons at Borehole 1 and 87.06 tons at Borehole 2.

To determine the number of piles at each point of the foundation based on the load acting on the foundation and the allowable bearing capacity of a single pile/Q_{all}. The results of calculating the number of piles can be seen in Table III and Table IV.

TABLE III
NUMBER OF PILES IN BOREHOLE 1

Point of foundation	Q_{all} (ton)	Load (ton)	Number of piles		Pile cap (PC)
1	90,55	56	0,6	Single pile	PC 1
2		39	0,4	Single pile	PC 2
3		190	2,1	group pile	PC 3
4		190	2,1	group pile	PC 3
5		139	1,5	group pile	PC 2
6		51	0,6	Single pile	PC 1
7		80	0,9	Single pile	PC 1
8		67	0,7	Single pile	PC 1
9		171	1,9	group pile	PC 2
10		35	0,4	Single pile	PC 1
11		60	0,7	Single pile	PC 1
12		34	0,4	Single pile	PC 1
13		287	3,2	group pile	PC 4
14		175	1,9	group pile	PC 2
15		138	1,5	group pile	PC 2
16		50	0,5	Single pile	PC 1

TABLE IV
NUMBER OF PILES IN BOREHOLE 2

Point of foundation	Q_{all} (ton)	Load (ton)	Number of piles		Pile cap (PC)
1	87,06	56	0,6	*Single pile*	PC 1
2		39	0,4	*Single pile*	PC 1
3		190	2,2	*group pile*	PC 3
4		190	2,2	*group pile*	PC 3
5		139	1,6	*group pile*	PC 2
6		51	0,6	*Single pile*	PC 1
7		80	0,9	*Single pile*	PC 1
8		67	0,8	*Single pile*	PC 1
9		171	2,0	*group pile*	PC 2
10		35	0,4	*Single pile*	PC 1
11		60	0,7	*Single pile*	PC 1
12		34	0,4	*Single pile*	PC 1
13		287	3,3	*group pile*	PC 4
14		175	2,0	*group pile*	PC 2
15		138	1,6	*group pile*	PC 2
16		50	0,6	*Single pile*	PC 1

After knowing the reaction forces at the joint, then looking for P_{max} reaction on the pile. Group piles are designed with a number of single piles (PC 1) and group pile with configurations pile cap 2 (PC 2), pile cap 3 (PC 3), and pile cap 4 (PC 4). Then grouping based on the number of piles to get the biggest load from each foundation and pile configuration.

The maximum load value of a single pile in a group of piles due to the combination of axial loads and moments can be seen in the Table V.

TABLE V
MAXIMUM LOAD VALUE OF SINGLE PILE IN A GROUP

Pile cap	n	Fz (kN)	Mx (kN.m)	My (kN.m)	xi	yi	Nx	Ny	$\sum X^2$	$\sum y^2$ (m^2)	P_{max} (kN)
PC 2	2	1712,6	1108,36	1209,49	0,6	0	2	1	0,72	0	1360,25
PC 3	3	-1866	959,182	1036,79	0,6	0,6	2	1	0,72	0,72	609,34
PC 4	4	2817,11	960,821	1055,23	0,44	0,44	2	2	0,7744	0,7744	1277

Analysis of Axial Bearing Capacity of Group Pile

Converse-Labarre formula is used to analyse the axial bearing capacity of group piles. The axial bearing capacity of group piles is affected by the efficiency of piles and the number of piles on the allowable bearing capacity of a single pile. The following is an example of a group pile bearing capacity calculation that analyses the results of the permissible axial bearing capacity of a single pile (PC1) obtained by Briaud et al.'s method. At a depth of 24 meters from N-SPT1 data in borehole 1 (BH-01).

TABLE VI
RESULTS OF ANALYSIS OF THE AXIAL BEARING CAPACITY OF GROUP PILE AT BH-01
(*BRIAUD ET AL*. METHOD)

SPT N value from BH-01									
Pile cap	Depth (m)	Number of piles / n	Number of row / m	Diameter / D (m)	Space of pile / S (m)	arc Tangen / Φ	Efficiency /Eg	Qall (kN)	Q_g (kN)
PC 2		1	2		1,2		0,73		1294,30
PC 3	24	2	3	0,35	1,2	16,26	0,66	887,73	1781,07
PC 4		2	2		1		0,57		2028,75

TABLE VII
RESULTS OF ANALYSIS OF THE AXIAL BEARING CAPACITY OF GROUP PILE AT BH-02
(*BRIAUD ET AL*. METHOD)

SPT N value from BH-02									
Pile cap	Depth (m)	Number of piles / n	Number of row / m	Diameter / D (m)	Space of pile / S (m)	arc Tangen / Φ	Efficiency /Eg	Qall (kN)	Q_g (kN)
PC 2		1	2		1,2		0,73		1244,44
PC 3	24	2	3	0,35	1,2	16,26	0,66	853,53	1712,45
PC 4		2	2		1		0,57		1950,59

V. CONCLUSION

Based on the results of analysis, conclusions can be drawn as follows:

1. The bearing capacity value of the pile foundation for reservoir construction is obtained from the calculation results on BH-1 using the method of Briaud et al. (1985) was 90.55 tons, Meyerhof (1956) was 184.54 tons, Decourt (1982) was 197.33 tons, Shioi & Fukui (1982) was 241.13 tons.
2. The bearing capacity values of the pile foundation for BH-02 are based on the method of Briaud et al. (1985) was 87.06 tons, Meyerhof (1956) was 165.60 tons, Decourt (1982) was 129.36 tons, and Shioi & Fukui (1982) was 188.11 tons.
3. The lowest of bearing capacity (critical value) used to determine the number of piles is the Briaud et al method of 90.55 tons at BH-01 and 87.06 tons at BH-02.
4. The value of the axial load formed as a result of structural analysis using ETABS software is 56 tons at joint 1, at joint 2 is 39 tons, joint 3 is 190 tons, joint 4 is 190 tons, joint 5 is 139 tons, joint 6 is 51 tons , joint 7 amounted to 80 tons, joint 8 amounted to 67 tons, joint 9 amounted to 171 tons, joint 10 amounted to 35 tons, joint 11 amounted to 60 tons, joint 12 amounted to 34 tons, joint 13 amounted to 287 tons, joint 14 amounted to 175 tons, joint 15 of 138 tons and at joint 16 of 50 tons.
5. The pile configuration used at the foundation point in Borehole 1 (BH-01) is pilecap 1 at a depth of 24 m as many as 8 points, pilecap 2 at a depth of 26 m as many as 5 points, pilecap 3 at a depth of 24 m as many as 2 points, and pilecap 4 at a depth of 24 m as much as 1 point.
6. The pile configuration used at the foundation point in Borehole 2 (BH-02) is pilecap 1 at a depth of 24 m as many as 9 points, pilecap 2 at a depth of 26 m as many as 4 points, pilecap 3 at a depth of 24 m as many as 2 points, and pilecap 4 at a depth of 24 m as much as 1 point.

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