Designing a drilled pile foundation in a dual system structure

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Abstract. Drilled pile foundations that have been set in hard soil are generally used for buildings with shear walls. By nature, a drilled pile foundation can withstand moments because of the drilled pile's dimensions and the amount of reinforcement installed. This study presents a structural analysis of a 10-story building supported by a dual system structure to meet earthquake requirements. The results show that, by using a dual system, the earthquake requirements (natural period, modal, story shear, story drift, and P-Delta) are met. Other results show that the base shear force of the shear wall has a value of 58.76% for the X-direction and 63.72% for the Y-direction. The base shear force value of the frame is 41.23% for the X-direction and 36.27% for the Y-direction. Therefore, the requirements of the dual system are met because the resisted base shear force of the frame is higher than 25%. The dual system provides a normal force value of 24.32% for the shear wall, while the frame carries 75.67%. The bearing capacity of the drilled pile with a safety factor = 2.5 is 162 tons for a diameter of 50 cm, 214 tons for a diameter of 60 cm, 340 tons for a diameter of 80 cm, 493 tons for a diameter of 100 cm, 672 tons for a diameter of 120 cm, and 993 tons for a diameter of 150 cm. The result of the pile driving analyzer test values for a 120 cm diameter range from 988 to 1,232 tons.

1 Introduction

A dual system structure combines a shear wall frame and a shear wall placed in an elevator shaft [1–3] as shown in Fig. 1 and Fig. 2. The structural dual system design, which combines the frame with shear wall, must meet a 25% base shear resist by frame requirement [4]. An illustration of the displacement in the shear wall and frame can be found in Fig. 3. A dual system structure is used to satisfy the structural analysis requirements for a complicated structure using, for example, a slender column in an irregularly shaped building [5–7]. In buildings where the load is also large, it is necessary to use a foundation that reaches hard ground to ensure a large bearing capacity. A foundation that reaches hard soil is a type of deep foundation known as a pile foundation [8]. Drilled pile foundation dimensions are large, and sufficient reinforcement is installed that enables it to withstand the moment using just a single pile.

The case study in this research is a 10-story building with a dual system structure using a single drilled pile. In this case, soil data was obtained from hard sandy soil at a depth of 18 m, where the SPT value reached 32. The strength of the soil decreased again at a depth of 22 m where the SPT value reached 12; this was not a hard soil because the SPT value was less than 15. Accordingly, the depth for the drilled pile was calculated at 30 m, where the hard soil criteria were met with an SPT value of 22. The calculation of the bearing capacity of the drilled pile was compared with the three results of the pile driving analyzer (PDA) test for a diameter of 120 cm.

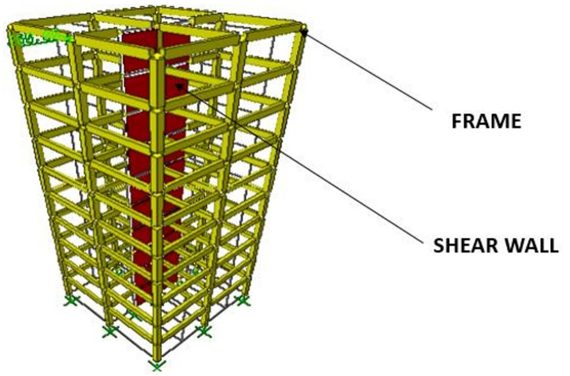

Fig. 1. The dual system structure [9].

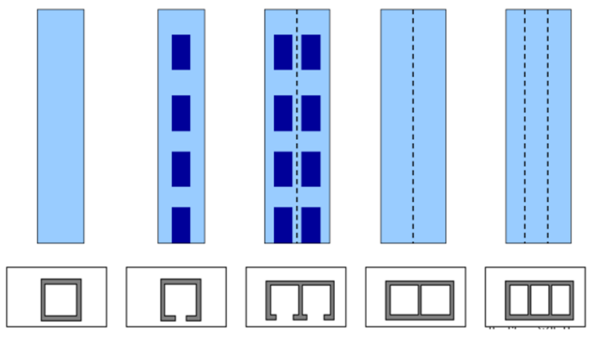

Fig. 2. Shear wall type on the elevator shaft [9].

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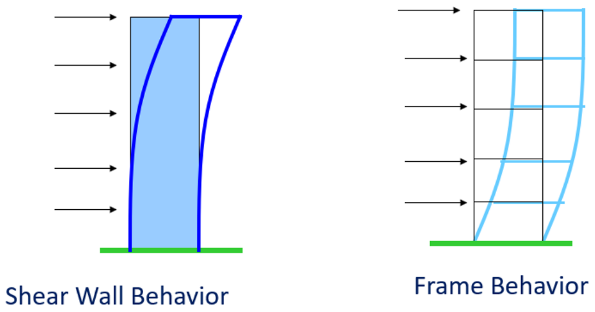


Fig. 3. Shear wall and frame behavior [9].

2 Analytical model

The building model in this study is a 10-story reinforced concrete building that adopts a dual system structure with a special moment-resisting frame system. The building model functions as an apartment. The building model structure is displayed in Jakarta City ($S_{DS} = 0.67g$, $S_{D1} = 0.63g$) with site class E [10]. The material property of the concrete f'c is 28 MPa and the steel reinforcement f_y is 420 MPa for all building elements. The building was modeled on the structure modeling software, SANSPRO V510 [11]. The building model is shown in Fig. 1 and Table 1. There are several slender columns in this structure with lengths of 14 m and 10 m. The use of slender columns is permitted, provided all structural irregularities and penalties are met. To overcome the difference in stiffness, a shear wall is used that meets the code requirements; Fig. 2-4 presents the soil investigation test location and result.

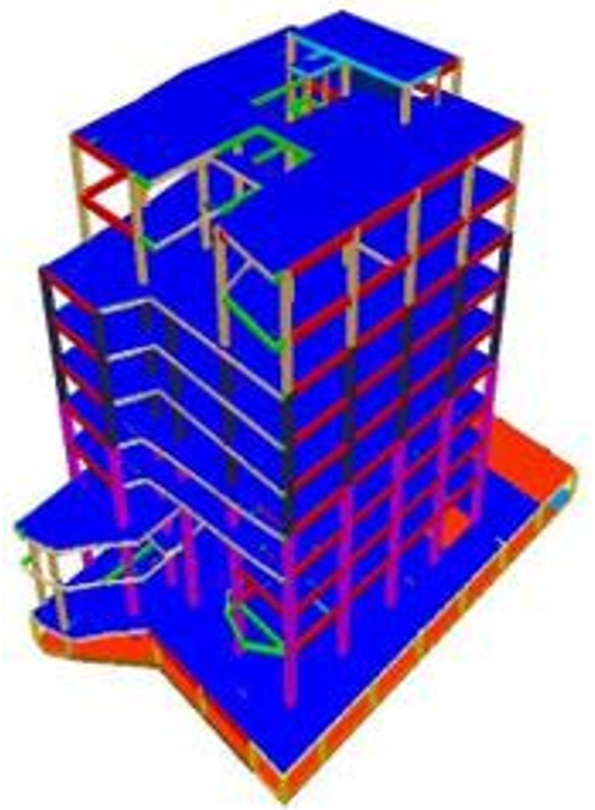


Fig. 4. The 3D building model.

Table 1. Building floor plan.

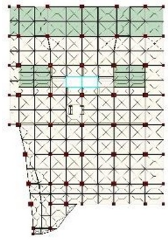
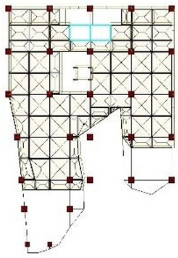
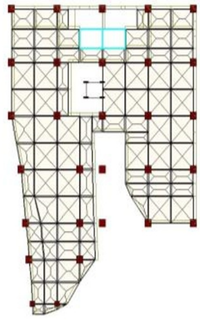
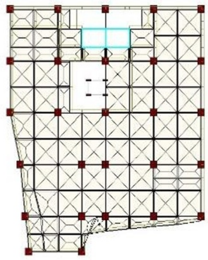
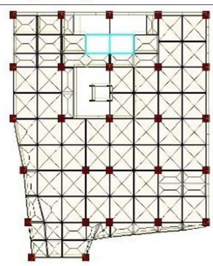
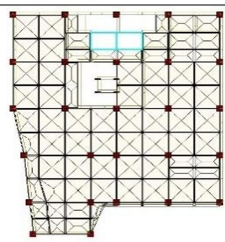
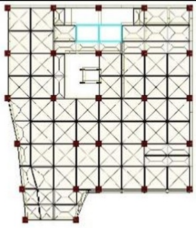
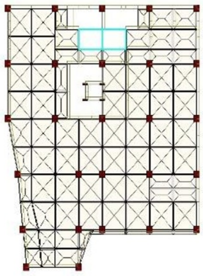
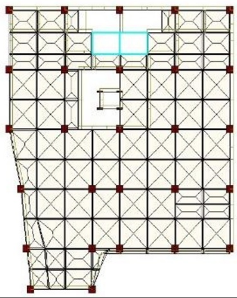
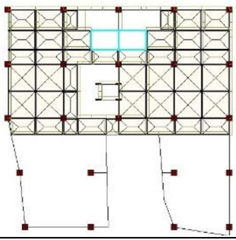
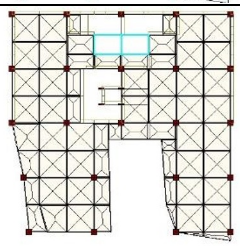
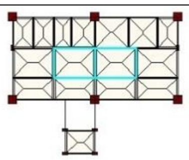
Floor	Plan
1st Plan	
2nd Plan	
3rd Plan	
4th Plan	
5th Plan	
5th Plan	
6th Plan	

Table 1 (continued). Building floor plan.

Floor	Plan
7th Plan	
8th Plan	
9th Plan	
10th Plan	
11th Plan	
12th Plan	

3 Results and discussion

The results of the dual system structure analysis are presented in the tables that follow. Table 2 shows the period in mode 1 (0.893), mode 2 (0.883), and mode 3 (0.591). The mass participation ratio is 86.47% in mode 1, 90.27% in mode 2, and 85.62% in mode 3. In the first analysis, the dynamic shear force is neither the same nor higher than 100% static shear force. After correcting with an updated scale factor of 1.1 for the X-direction and 1.1 for the Y-direction, the dynamic shear force reflects the required value. Story drift and force delta effect are also satisfied.

Table 2. Seismic requirement parameters.

Parameter	X-direction	Y-Direction
Period (T)	0.893	0.883
Mass Participation Ratio (%)	86.47	90.27
Static Base Shear, Vs (Kg)	246,764	422,229
Dynamic Base Shear, Vs (Kg)	271,440	464,452
Base Shear Requirement	Satisfied	Satisfied
Story Drift	Satisfied	Satisfied
P-Delta Effect	Satisfied	Satisfied

Tables 3-4 show that the shear wall has a base shear force value of 58.76% for the X-direction and 63.72% for the Y-direction. The frame gives the base shear force value of 41.23% for the X-direction and 36.28% for the Y-direction. Therefore, the requirements of the dual system structure are met because the frame has a resisted base shear force higher than 25%. The dual system structure provides a normal force value of 24.32% for the shear wall, while the frame carries 75.67%. For normal forces, the shear wall accepts less than the frame, but for shear forces, the shear wall accepts more than the frame.

Table 3. Shear wall frame base shear ratio.

System Structure	Spec X	Spec Y	Spec X	Spec Y
	Vx,max	Vz,max	Ratio	Ratio
	(kg)	(kg)	(%)	(%)
Shear Wall	1030777.2	933622.5	58.77	63.72
Frame	723250.7	531558.2	41.23	36.28
SW+Frame	1754027.9	1465180.7	54.49	45.51

Table 4. Shear wall frame normal force ratio.

System Structure	N_{max}	Ratio
	(kg)	(%)
Shear Wall	4823510.80	24.33
Frame	15005667.60	75.67
SW+Frame	19829178.40	

The bearing capacity of the drilled pile with a safety factor (SF) = 2.5 is 162 tons for a diameter of 50 cm, 214 tons for a diameter of 60 cm, 340 tons for a diameter of 80 cm, 493 tons for a diameter of 100 cm, 672 tons for a diameter of 120 cm, and 993 tons for a diameter of

150 cm as shown in Table 5. The foundation was calculated by reaction force and foundation capacity as shown in Fig. 5-6, and Table 6. The shear forces can be calculated for the column nodes because the lateral forces are received equally by all drilled pile or for each column node.

Table 5. Bearing capacity calculation.

Diameter	$Q_{all.\ compression}$ (ton)			$Q_{all.\ tension}$	$Q_{all.\ shear}$
m	**SF =2**	**SF =2,5**	**SF =3**	**ton**	**ton**
0.4	145	116	97	58	7
0.5	202	162	135	81	10
0.6	268	214	179	107	13
0.8	425	340	283	170	20
1	616	493	411	246	30
1.2	840	672	560	336	40
1.5	1241	993	827	496	60

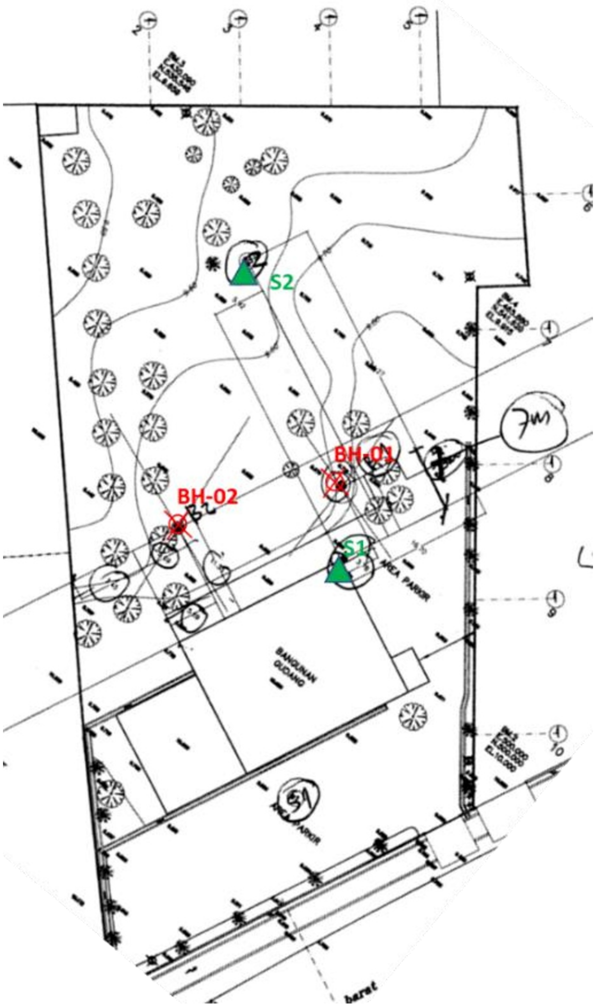


Fig. 5. Soil test location on the project site.

Using an SF = 2 for the test pile, the bearing capacity of the drilled pile is calculated to be 840 tons for a diameter of 120 cm as shown in Table 5. The result of the PDA test shows a bearing capacity ranging between 988 and 1239 tons for a diameter of 120 cm, where an SF = 2 is shown in Table 7 and Fig. 7. The location of PDA test shown in Fig. 8-9.

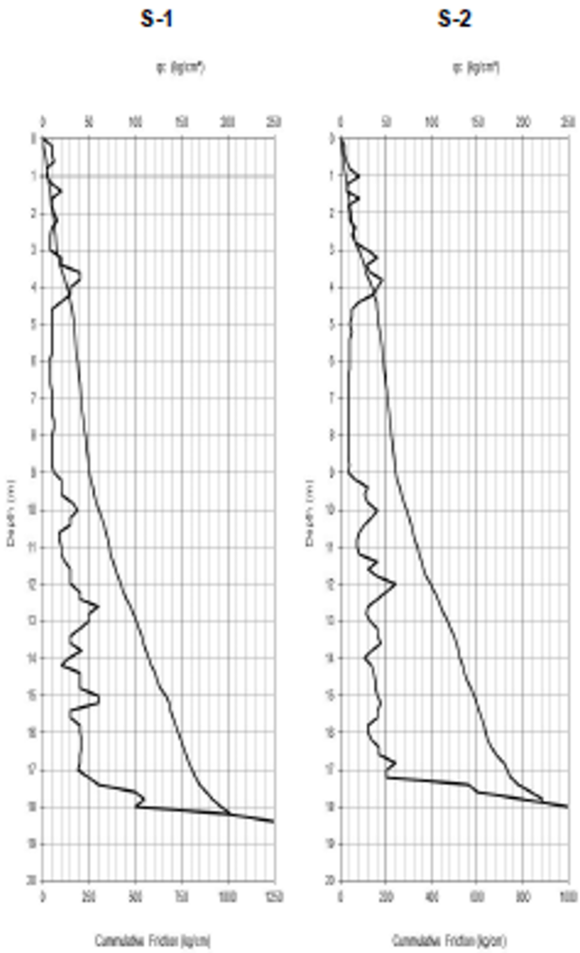


Fig. 6. Cone penetration test report.

Table 6. Foundation design detail.

Node Id	Type of EQ Resisting Structure	Type of Group Pile	Diameter (cm)	Length of Pile (m)
129	SW	P6A	150	30
130	SW	P6A	150	30
131	SW	P6A	150	30
132	SW	P6A	150	30
133	SW	P6A	150	30
134	SW	P6A	150	30
1	Frame	P2	60	30
3	Frame	P2	60	30
40	Frame	P3	80	30
4	Frame	P1	50	30
19	Frame	P1	50	30
20	Frame	P1	50	30
35	Frame	P1	50	30
41	Frame	P4	100	30
5	Frame	P1	50	30
18	Frame	P4	100	30
21	Frame	P5	120	30
34	Frame	P4	100	30
42	Frame	P5	120	30
6	Frame	P1	50	30
17	Frame	P5	120	30
22	Frame	P5	120	30
33	Frame	P5	120	30
2	Frame	P5	120	30
7	Frame	P6	150	30
15	Frame	P5	120	30

Table 6 (continued). Foundation design detail.

Node Id	Type of EQ Resisting Structure	Type of Group Pile	Diameter (cm)	Length of Pile (m)
23	Frame	P6	150	30
32	Frame	P5	120	30
36	Frame	P5	120	30
8	Frame	P5	120	30
16	Frame	P4	100	30
24	Frame	P5	120	30
31	Frame	P5	120	30
37	Frame	P4	100	30
9	Frame	P5	120	30
14	Frame	P5	120	30
25	Frame	P5	120	30
30	Frame	P5	120	30
38	Frame	P1	50	30
29	Frame	P1	50	30
10	Frame	P1	50	30
26	Frame	P1	50	30
13	Frame	P1	50	30
39	Frame	P1	50	30
11	Frame	P1	50	30
12	Frame	P1	50	30
27	Frame	P1	50	30
28	Frame	P1	50	30
136	Frame	P1	50	30
137	Frame	P1	50	30
138	Frame	P1	50	30
135	Frame	P1	50	30
155	Frame	P1	50	30
163	Frame	P1	50	30
161	Frame	P1A	50	18
159	Frame	P1A	50	18
157	Frame	P1A	50	18
170	Frame	P1A	50	18
168	Frame	P1A	50	18
166	Frame	P1A	50	18
164	Frame	P1A	50	18
172	Frame	P1A	50	18
174	Frame	P1A	50	18
176	Frame	P1A	50	18
178	Frame	P1A	50	18
50	Frame	P3	80	30
52	Frame	P5	120	30
248	Frame	P1	50	18
51	Frame	P4	100	30
247	Frame	P1A	50	18
128	Frame	P1A	50	18
99	Frame	P1A	50	18
100	Frame	P1A	50	18
98	Frame	P1A	50	18
114	Frame	P1A	50	18
177	Frame	P1A	50	18

Table 7. The PDA test summaries for a diameter of 1.2 m.

No. Test	Pile Length (m)	CAPWAP (Ton)		
		Total Pile Resistance	Friction Capacity	End-Bearing Capacity
BP24	27.9	1008	830	178
BP54	28.0	1239	1115	123
BP62	27.9	988	845	143

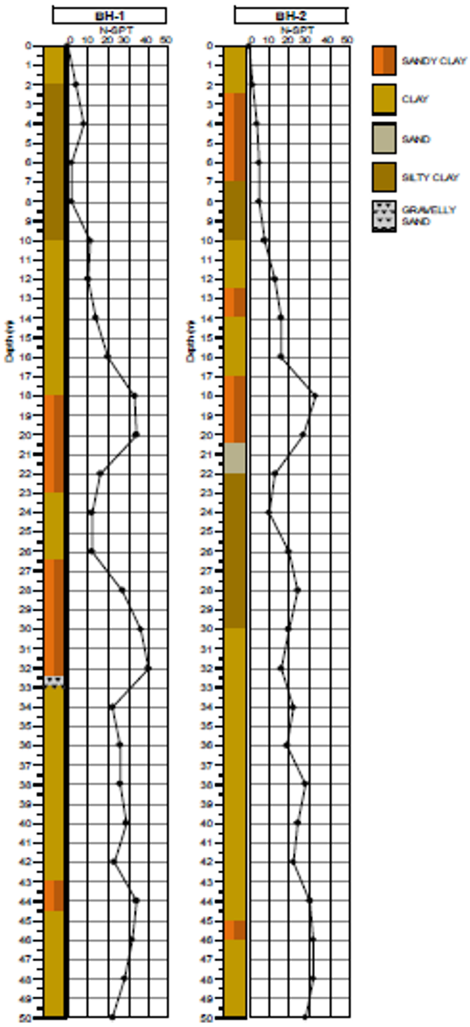


Fig. 7. The SPT boring report.

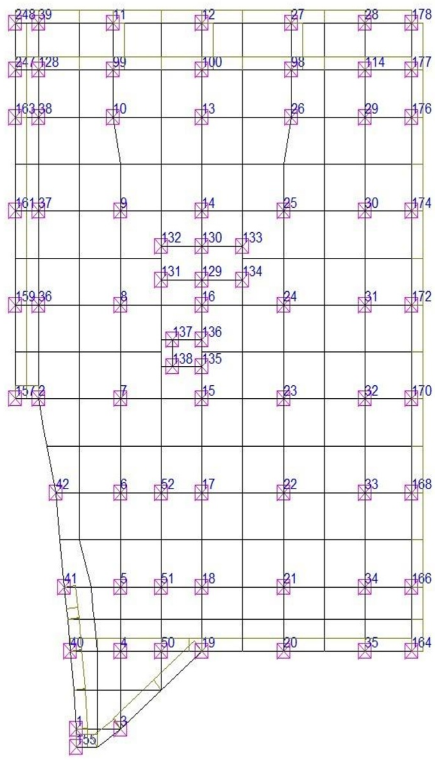


Fig. 8. Id node reaction.

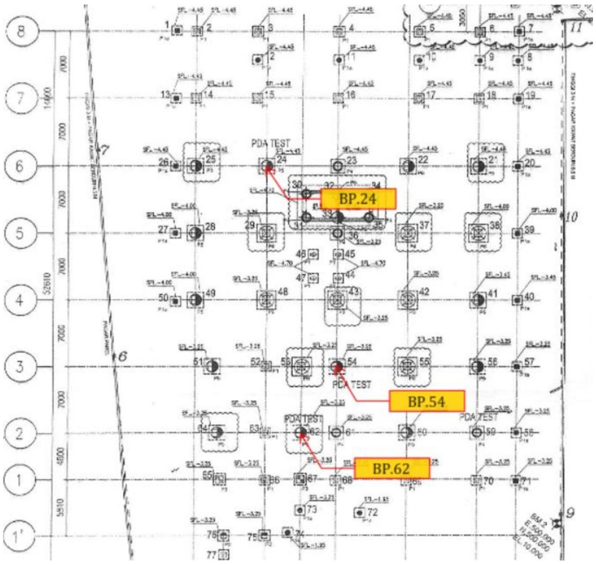


Fig. 9. The location of the PDA test.

4 Conclusion

This study shows that using a dual system structure, the requirements for the duration of vibration, mass participation, the ratio of dynamic and static base shear, story drift, and P-Delta effects are met. The shear wall has a base shear force value of 58.76% for the X-direction and 63.72% for the Y-direction. The frame has a base shear force value of 41.23% for the X-direction and 36.27% for the Y-direction. Therefore, the requirements of the dual system structure are met because the frame has a resisted base shear force higher than 25%. The dual system provides a normal force value of 24.32% for the shear wall, while the frame carries 75.67%. The bearing capacity of the drilled pile with an SF = 2.5 is 162 tons for a diameter of 50 cm, 214 tons for a diameter of 60 cm, 340 tons for a diameter of 80 cm, 493 tons for a diameter of 100 cm, 672 tons for a diameter of 120 cm, and 993 tons for a diameter of 150 cm. The result of the PDA test shows a bearing capacity for a diameter of 120 cm at a range between 988 to 1239 tons.

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