Economic Benefit Analysis of Mechanized Construction of Digging Pile Foundation in Mountainous Areas of Typical Overhead Transmission Lines in Fujian Province

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ABSTRACT. The foundation construction of overhead transmission lines in mountainous areas is the key and difficult point of the whole process of mechanized construction. Digging pile foundation is one of the most commonly foundation types. The economic benefit analysis of mechanical digging pile foundation is an important prerequisite for mechanized construction. Based on the characteristics of typical transmission lines in Fujian Province, this paper discusses the changing cost of mechanical digging pile foundation, and uses the single variable method to analyze the impact of human transport distance, road width, engineering quantity and geological conditions on the economic benefits of mechanized construction. The results show that the changes of engineering quantity and human transport distance have a great impact on the cost of mechanized construction. When the human transport distance of 110kV transmission line is less than 39m, and distance of 220kV transmission line is less than 39m, and distance of 500kV project is less than 214m, The mechanized construction is more economic than that of manual construction; The width of road construction has little impact on the cost of mechanized construction, and the impact of geological conditions on economic benefits increases with the increase of voltage level.

Keywords: pile foundation; labor transportation distance; mechanized construction; manual construction; Road width; Material quantities; geological conditions.

1 Introduction

The mechanized construction of the foundation of overhead transmission lines in mountainous areas is a key and difficult point in mechanized construction [1,2]. Pile foundation is one of the most commonly foundation [3-5], which is widely used in 110kV-500kV transmission lines in Fujian province. Mechanical pile foundation and manual pile foundation are quite different in road construction, foundation excavation

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and environmental conservation measures. Therefore, economic benefit analysis of mechanical pile foundation is an important prerequisite for mechanized construction.

Some relevant research have conducted on the economic analysis of mechanized construction. Yu Honghai [6] analyze risk points one by one through analysis and enumeration, and the countermeasures are proposed to ensure that the construction safety risks are fully controlled. Tan Wentao [7] consider multiple types of factors affecting the formulation and selection of design scheme, and implement targeted control measures for different factors, so as to realize the optimization of transmission line design scheme. good application effect during the project construction, which is helpful to guide the high-quality development of power design industry in the new era, and provide technical support for the disposal of power transmission and transformation project residual soil [8.9].

To sum up, there are few studies on the impact analysis of the economic benefits of mechanical pile foundation in mountain area. This article analyzes the impact of road construction length, road width, engineering quantity, and geological conditions on the economic benefits of mechanized construction based on the characteristics of typical project in Fujian province. It has important guiding significance for the design of mechanical piles in mountain area.

2 Difference cost between mechanized construction and manual construction

2.1 The increased cost of mechanized construction

The increased costs of mechanical pile foundation mainly include: cost of equipment access roads, environmental conservation costs, and mechanical excavation costs of earthwork.

(1) Cost of equipment access road

The factors that affect the cost of road construction include the length and width of the access road. The length of the access road depends on the transportation distance and the road tortuosity coefficient. The road width depends on the equipment walking width.

The construction equipment for mechanical pile foundation in mountain area is rotary drilling rig. According to market research, the main drilling rig series include the electric construction KR series, XCMG XR series and Sany SR series. Different types of drilling rigs with similar excavation capacity are selected for comparison, as shown in Table 1.

Table 1. Functional parameters of drilling rig on different series

Drilling rig model	Maximum drilling diameter (m)	Drilling depth(m)	Total weight(T)	Walking width(m)
electric construction KR110D	2.0	20	32	2.6
XCMG -XR200L	1.6	20	38	2.8
Sany SR155	1.5	42	48	3.5

It is shown that the equipment of KR110D has an optimal drilling capacity, and its walking width and total weight are smaller than those of XR200L and SR155. The maximum drilling depth of KR110D is 20m, which meets the design requirements. Considering factors such as environmental protection, compensation, equipment miniaturization, and application, the electric construction drilling rig KR110D was selected as the construction equipment for sensitivity analysis. The width of the road construction is 3.6m.

In terms of new road construction, the roadbed shaping cost is RMB 6.26 [10] per m^2. Considering the characteristics of the mountainous areas in Fujian province, part of roads require excavation with an volume of $3m^3/m$, and an estimated unit price of about RMB 50 per m^3. The calculation is based on 40% of the mechanical access roads requiring excavation.

In terms of road widening, the unit price is calculated as half of the new road construction.

(2) Environmental conservation costs for construction roads

To ensure the stability of construction roads and slopes nearby the road, environmental conservation measures need to be set up, including topsoil stripping, topsoil recovery, and vegetation restoration. Based on previous construction experience of transmission line, the topsoil stripping fee is RMB 4 per m^3, the topsoil recovery fee is RMB 22 per m^3, the vegetation restoration fee is RMB 2 per m^2. The thickness of topsoil stripping is considered to be 0.2m.

(3) Mechanical excavation cost for earthwork and stonework

The excavation of earthwork and stonework mainly includes pit of pile foundation. The cost of excavation in the pit can refer to Section 2.5 of the quota [10] for “the mechanical excavation cost”.

2.2 Reduced costs of mechanized construction

The reduced costs of mechanized construction mainly include: labor transportation costs and costs caused by changes in engineering quantities.

(1)Reduction in labor transportation costs

Mechanized construction requires the construction of roads, and materials can be transported by car to the tower site, which can reduce the cost of labor transportation compared to manual construction. The engineering materials need to be transported include concrete, steel, insulators, and hardware. Due to the small relatively weight, the impact of hardware and insulators on costs is not considered.

(2)Reduction of engineering quantity

In order to ensure the safety of the operators when excavating the foundation, the retaining wall shall be set when the pile foundation is constructed manually. If mechanized construction is used for excavation, it can reduce the quantity of retaining wall.

3 Analysis of Factors Influencing the Economic Benefits of Mechanized construction

By comparing the differences in costs between mechanized construction and manual construction, it can be seen that the main influencing factors for the economic benefits of mechanized construction include road construction length, road construction width, material engineering quantity, and geological conditions.

The length of road construction is related to labor transportation distance and tortuosity coefficient, and the tortuosity coefficient is determined to be 1.4 based on typical conditions in Fujian province.

The width of road construction is mainly related to the width of the equipment's walking state. Considering the safety of the equipment's walking statue, the width of road construction is taken as the equipment's walking width plus 1m.

The quantity of material engineering is related to factors such as voltage level, meteorological conditions, parameters of conductor etc. Taking typical 110kV, 220kV, and 500kV overhead transmission line projects in Fujian province as examples, the main material engineering quantities are detailed in Table 2.

Table 2. the Typical quantities of different voltage transmission line

Voltage classification	Weight of tower(t)	Quantity of concrete(m^3)	Diameter and length(m)	quantity of retaining wall. (m^3)
110kV	15	30	1.2/6.6	6
220kV	30	55	1.4/9	11
500kV	45	80	1.6/10	16

The geological conditions affect the cost of mechanical excavation of piles. Considering that the quota [10] does not involve the quota for mechanical excavation of rocks, hard plastic clay is selected for the geological conditions.

4 Economic analysis of labor transportation distance factors

4.1 Typical project of 110kV transmission line

Considering the transportation conditions in Fujian province, the cost will be calculated based on 70% of new roads construction and 30% of road widening. The geological conditions of the mechanical excavation foundation will be considered based on hard plastic clay.

The range of labor transportation distance is between 100m and 800m, with a step of 100m. Calculating the costs of labor transportation, car transportation, wall protection reduction, mechanical excavation, road construction and environmental conservation measures with different distance, which are shown in Tables 3 to 4 and Figure 1.

Table 3. Reduced cost of mechanized construction of 110kV transmission line with different distance

labor transportation distance(m)	Length of road construction (m)	Cost of labor transportation (RMB*10000)	Cost of car transportation (RMB*10000)	The reduced cost of retain wall (RMB*10000)	Reduced cost of mechanized construction (RMB*10000)
100	130	0.16	0.27	1.8	1.68
200	260	0.32	0.28	1.8	1.84
300	390	0.48	0.28	1.8	2.00
400	520	0.63	0.28	1.8	2.16
500	650	0.79	0.28	1.8	2.31
600	780	0.95	0.28	1.8	2.47
700	910	1.11	0.28	1.8	2.63
800	1040	1.27	0.28	1.8	2.78

Table 4. Increased cost of mechanized construction of 110kV transmission line with different distance

labor transportation distance(m)	Length of road construction (m)	Cost of mechanized excavation (RMB*10000)	Increased cost of road construction (RMB*10000)	Increased cost of environmental conservation (RMB*10000)	Increased cost of mechanized construction (RMB*10000)
100	130	1.06	1.03	0.34	2.43
200	260	1.06	2.06	0.67	3.79
300	390	1.06	3.09	1.01	5.16
400	520	1.06	4.12	1.35	6.53
500	650	1.06	5.15	1.68	7.89
600	780	1.06	6.17	2.02	9.26
700	910	1.06	7.20	2.36	10.62
800	1040	1.06	8.23	2.70	11.99

From Table 3, it can be seen that when the labor transportation distance is small, the calculated cost of car transportation is higher than that of labor transportation. However, as the human transportation distance increases, the cost of labor transportation is higher than that of car transportation. The main reason is that car transportation includes the cost of entry and exit of transportation. According to Table 4, with the labor transportation distance exceeds 100m, the road construction cost accounts for the highest proportion of the total increased cost of mechanized construction.

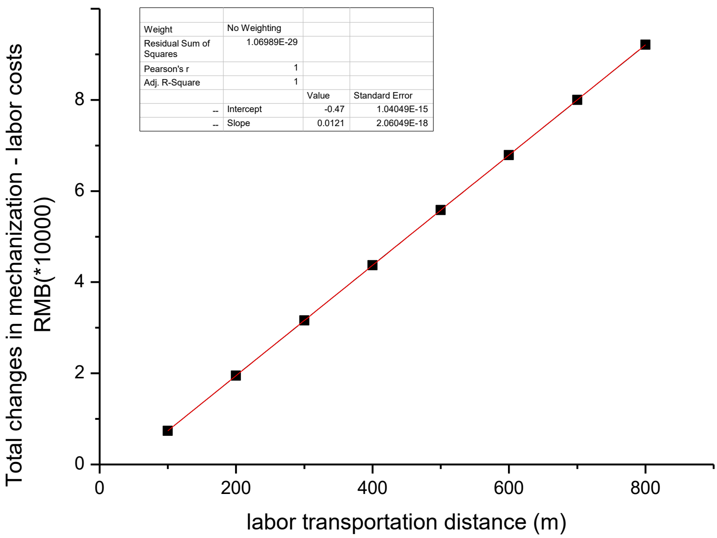

Fig. 1. The relationship between the increasing of cost and distance on 110kV transmission line

From Figure 1, it can be seen that the mechanization construction cost of a typical 110kV transmission line project increases linearly with the increase of labor transportation distance. When the labor transportation distance is less than 39m, the mechanized construction cost is lower than the manual construction cost.

4.2 Typical project of 220kV transmission line

Based on the typical engineering quantities of 220kV in Table 2, calculate the cost changes of mechanized construction under different labor transportation distance conditions, as shown in Table 5 and Figure 2.

Table 5. Increased cost of mechanized construction of 220kV transmission line

labor transportation distance(m)	Length of road construction (m)	Reduced cost of mechanized construction (RMB*10000)	Increased cost of mechanized construction (RMB*10000)	Difference of mechanized construction and manual construction (RMB*10000)
100	130	3.08	3.00	-0.08
200	260	3.37	4.36	0.99
300	390	3.67	5.73	2.06
400	520	3.96	7.09	3.14
500	650	4.25	8.46	4.21
600	780	4.55	9.83	5.28
700	910	4.84	11.19	6.35
800	1040	5.13	12.56	7.43

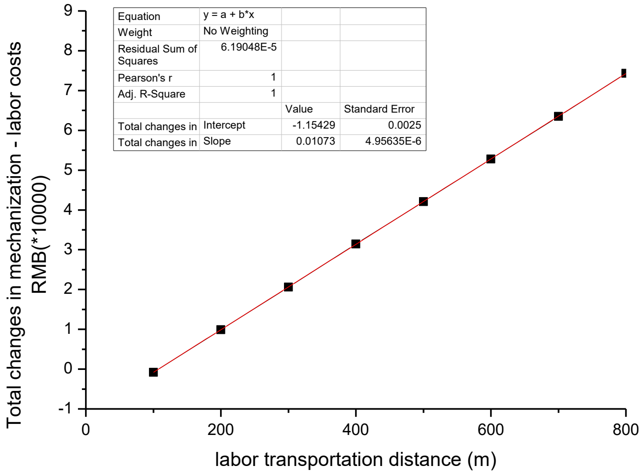

Fig. 2. The relationship between the increasing of cost and distance on 220kV transmission line

The increased cost of mechanized pile on 220kV transmission line is not much different from that of 110kV, but the reduced cost is higher than that of 110kV line, which is mainly due to the larger amount of material quantity of 220kV transmission line, and the larger reduction of retain wall cost and labor transportation cost.

As shown in Figure 2, when the labor transportation distance is 115m, mechanized construction is the same as manual construction. Compared to Figure 1, it can be seen that the slope of the relationship curve of 220kV transmission line is less than that of 110kV.

4.3 Typical project of 500kV transmission line

The cost changes of mechanized construction for typical 500kV transmission line are detailed in Table 6 and Figure 3.

Table 6. Increased cost of mechanized construction of 500kV transmission line

labor transportation distance(m)	Length of road construction (m)	Reduced cost of mechanized construction (RMB*10000)	Increased cost of mechanized construction (RMB*10000)	Difference of mechanized construction and manual construction (RMB*10000)
100	130	4.48	3.42	-1.06
200	260	4.91	4.79	-0.12
300	390	5.33	6.15	0.82
400	520	5.76	7.52	1.76
500	650	6.19	8.89	2.69
600	780	6.62	10.25	3.63
700	910	7.05	11.62	4.57
800	1040	7.48	12.98	5.50

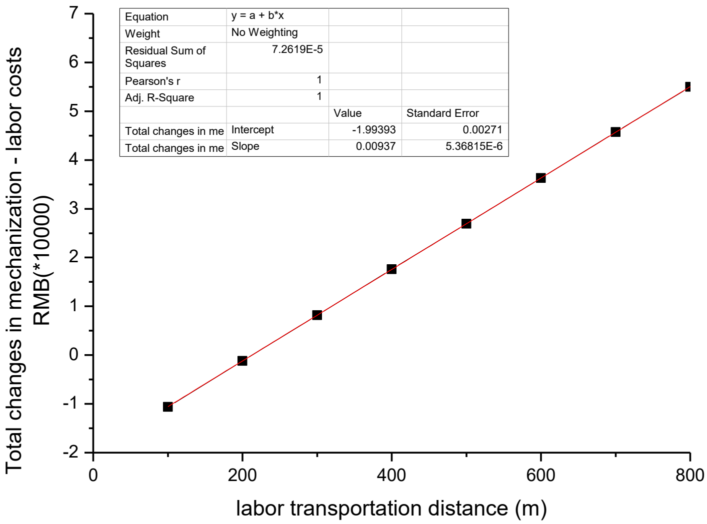

Fig. 3. The relationship between the increasing of cost and distance on 500kV transmission line

As shown in Figure 3, when the labor transportation distance is 214m, mechanized construction is the same as manual construction. Comparing with Figures 1 and 2, it can be seen that the slope of the relationship curve of 500kV transmission lines is less than those of 220kV and 110kV transmission lines.

It can be seen from the above analysis that with the increase of voltage level and the increase of quantity of material, the economic advantages of mechanized construction of pile foundation become more effective. With the increase of labor transportation, the economic disadvantages become more obviously.

5 Economic Analysis of Road Construction Width factor

The width of road construction affects the cost of road construction and corresponding environment conservation measures. Based on the walking width of existing construction equipment, this paper chose 2.5m, 3m, 3.5m, and 4.0m road widths and 500m labor transportation distance to analysis the influence. Hard plastic clay geological conditions is selected for economic analysis, as shown in Table 7.

Table 7. Increased proportion of mechanized construction costs for different road widths

road widths (m)	Road construction costs (RMB*10000)	Cost of environmental conservation(RMB*10000)	total(RMB*10000)	The ratio of environmental conservation cost on 110kV	The ratio of environmental conservation cost on 220kV	The ratio of environmental conservation cost on 500kV
2.50	4.76	1.17	5.93	0.84	0.78	0.73
3.00	4.94	1.40	6.34	0.85	0.79	0.75
3.50	5.11	1.64	6.75	0.86	0.80	0.76
4.00	5.28	1.87	7.16	0.87	0.81	0.77

From Table 7, it can be seen that road construction and environmental conservation cost account for a significant proportion in the cost of mechanized construction. With changes in the amount of the 0.5m, it affects about 1% of mechanized construction costs. But considering factors such as slope stability of road construction on mountainous areas, it is recommended to use small equipment for mechanized foundation construction.

6 Economic analysis of material quantity factor

Selecting a labor transportation distance of 500m and a road width of 3.6m, there are 8 sets of material quantities to be analyzed for the impact of quantities on the cost of mechanized construction. The values of the 8 groups of material quantities are shown in Table 8, and the changes in mechanized construction costs are shown in Table 9.

Table 8. Eight groups of typical quantities

Group	Weight of tower(t)	Quantity of concrete(m^3)	Diameter and length(m)	quantity of retaining wall. (m^3)
1	15	30	1.2/6.6	6
2	30	55	1.4/9	11
3	45	80	1.6/10	16
4	60	96	1.6/12	16
5	75	120	1.8/12	24
6	90	144	2.0/12	28.8
7	105	168	2.0/13	33.6
8	120	192	2.2/13	38.4

Table 9. Change of mechanized construction cost with different material quantity

labor transportation distance(m)	Length of road construction (m)	Reduced cost of mechanized construction (RMB*10000)	Increased cost of mechanized construction (RMB*10000)	Difference of mechanized construction and manual construction (RMB*10000)
1	500	2.31	7.89	5.58
2	500	4.25	8.46	4.21
3	500	6.19	8.89	2.69
4	500	6.45	9.30	2.85
5	500	9.33	9.37	0.04
6	500	11.19	9.60	-1.59
7	500	13.06	9.60	-3.45
8	500	14.92	9.60	-5.32

From Table 9, it can be seen that as the amount of material engineering increases, the cost of mechanized construction gradually decreases, and the advantages of mechanization gradually become obviously. In the fifth group of material quantities, the cost of mechanized construction is basically the same as the cost of manual construction.

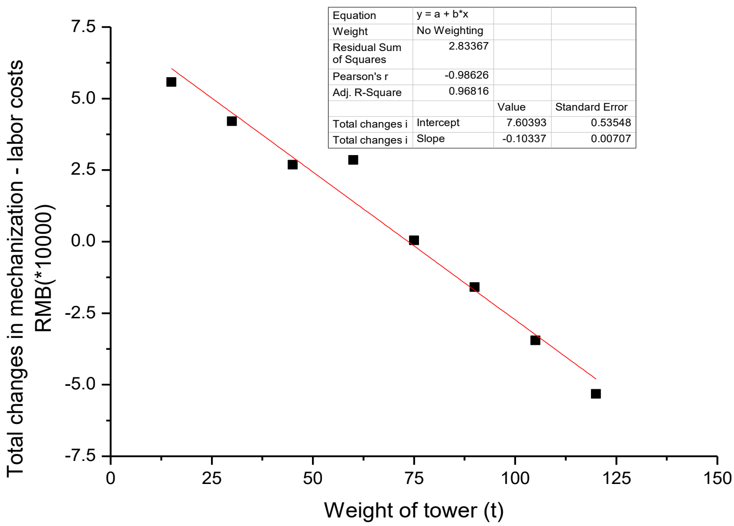

Fig. 4. The relationship between the cost of mechanization minus labor and the material quantity

From Figure 4, it can be seen that as the amount of tower weight increases, the difference between mechanized construction and manual construction continues to decrease. When the weight of the iron tower is 76 tons, the cost of mechanized construction and manual construction remains the same. The slope of the cost change caused by the amount of tower weight is 0.103, indicating that this factor has a greater economic impact on the mechanized piles.

7 Economic analysis of geological factor

Selecting a 500m labor transportation distance and a 2.6m road width for typical engineering quantities shown on Tab2, this chapter analyze the difference in drilling costs between hard plastic clay and loose sandy rock. The difference have been referred to Table 10 for details.

Table 10. Change of mechanized construction cost with different material quantity

Soil types with different voltage levels	Cost of mechanized excavation(RMB*10000)	Increased cost of mechanized construction (RMB*10000)	Increased costs due to changes in soil type (RMB*10000)	Proportion of increased cost (%)
110kV hard plastic clay	1.06	7.89	0.76	8.75%
110kV loose sandy rock	1.82	8.65		
220kV loose sandy rock	1.63	8.46	1.19	12.29%
220kV loose sandy rock	2.82	9.65		
500kV hard plastic clay	2.06	8.89	2.24	20.10%
500kV loose sandy rock	4.29	11.12		

From Table 10, it can be seen that as the voltage level increases, the proportion of cost changes caused by geological factors is higher. The main reason is that the higher the voltage level, the larger the amount of earthwork excavation, and the higher the cost of mechanical excavation. if the geology is rock, the geological factors will have a greater impact on the economic benefits of mechanized construction of pile foundation.

8 Conclusion

Pile foundation for overhead transmission lines in mountainous areas is one of the most commonly foundation types, and the economic benefit analysis of mechanical pile foundation is an important prerequisite for carrying out mechanized construction. This paper analyzes the difference between mechanical piles and manual pile, and analyzes the impact of labor transportation distance, construction width, material quantities and geological conditions on the economic benefit of mechanical piles, and draws the following conclusions:

(1) The labor transportation distance has a significant impact on the economic efficiency of mechanical pile. For a typical 110kV project in Fujian province, when the labor transportation distance is less than 39m, mechanized construction has advantages over manual construction. The typical 220kV project has advantages in mechanized construction over manual construction when the labor transportation distance is less than 115m. The proposed 500kV typical project has advantages in mechanized construction over manual construction when the labor transportation distance is less than 214m. With the increase of voltage level, the advantages of mechanized construction of excavation piles become increasingly apparent.

(2) The width of road construction has little impact on the cost of mechanized construction. Taking the 500m labor transportation distance as an example, the change in 0.5m road width accounts for about 1% of the increase in the entire mechanized construction cost. Due to factors such as slope stability of road construction in mountainous areas, it is recommended to use small equipment for mechanized construction.

(3) The amount of material quantity has a significant impact on mechanized construction cost. Taking the 500m labor transportation distance as an example, as the amount of tower weight increases, the advantages of mechanized construction become more apparent. When the weight of the tower is 76 tons, the cost of mechanized construction is equal to that of manual construction. The slope of the change in mechanized construction cost caused by the weight of tower is 0.103, which has a significant impact on the economic efficiency of mechanization.

(4) As the voltage level increases, the proportion of geological factors in the increased cost of mechanized construction increases. If the geological conditions are rock, the geological factors have a greater impact on the economic benefits of mechanized construction.

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