Construction Efficiency Analysis of Ultra-deep Underground Diaphragm Wall in High Altitude Area

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Abstract. Due to the special geographical location, geological conditions and construction conditions of the project in Tibet, there are often problems in the construction of ultra-deep underground diaphragm wall, which lead to the current preparation regulations, cost standards and supporting quotas can not be fully applied. It is necessary to carry out research on the construction efficiency of underground diaphragm wall in Tibet. To provide reference materials for the construction and economic analysis of the ultra-deep underground diaphragm wall in the later hydropower project. This paper takes a project in Xizang Province as the research object, through the analysis of the quota consumption and actual construction consumption of grab bucket and hydraulic slot milling machine, the construction efficiency of groove forming machinery under different formation conditions and groove depth is obtained, the rationality of the extension of the quota depth coefficient is verified, and the construction efficiency of the groove forming equipment is analyzed. It provides certain reference and reference for the construction and investment preparation of ultra-deep underground diaphragm wall in the later period of high altitude area.

Keywords: high altitude, ultra-deep, underground diaphragm wall, construction efficiency, rated consumption.

1 Introduction

Tibet Autonomous Region is located in the border area of southwest China. It is an important national energy reserve base with large hydropower reserves. It is often characterized by complex topographic and geological conditions, deep covering layer, joint and fissure development, etc. The natural foundation can not meet the engineering requirements, and needs foundation treatment. The construction of underground diaphragm wall can improve the bearing capacity and stability of the foundation, improve and strengthen the anti-seepage performance and the overall stability of the structure itself. It has the characteristics of high efficiency, short construction period, reliable quality, small vibration during construction, good anti-seepage performance, large wall stiffness, etc., and is widely used in the construction of hydropower engineering foundation and foundation treatment engineering. Because the construction of underground diaphragm wall is relatively complicated and the construction cost is high, different

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scholars have analyzed and studied the construction technology [1~2], work efficiency and related costs [3~6] of underground diaphragm wall in complex geological conditions. In recent years, among the underground diaphragm wall construction projects of key hydropower projects undertaken by our company, Underground diaphragm wall cost of Jiacha hydropower station accounts for about 65%[7] of the total cost of cofferdam. Hard beam package hydropower station, Luding hydropower station and other underground diaphragm wall cost accounts for about 20% of the dam section cost, withing the 14th Five-Year plan of Tibet hydropower project development, underground diaphragm wall cost accounts for the proportion of foundation treatment engineering construction costs will be more and more larger. Due to the special geographical location, geological conditions and construction conditions of hydropower construction projects in Tibet, there are often characteristics of ultra-deep underground diaphragm wall construction, resulting in the current preparation regulations, cost standards and supporting quotas can not be fully applied. Therefore, it is necessary to carry out the research on the construction efficiency of underground diaphragm wall in Tibet, so as to provide reference materials for the construction and economic analysis of ultra-deep underground continuous wall in later hydropower projects.

2 Overview

The underground diaphragm wall construction machinery can be selected according to the formation condition, wall structure type and equipment performance, etc. The equipment usually used includes impact drill, impact reverse circulation drill, grab bucket, two drill and one grab, hydraulic milling groove and other methods[8]. At present, all kinds of equipment are more mature in engineering, and different equipment combinations[9~11]can be used when necessary. At present, the "hydropower construction engineering budget quota" (2007) stipulates the formation quota consumption, wall thickness and slot depth of different construction machinery, and the work content includes the preparation of mud, hole making, slag discharging, hole clearing, slurry changing, record and other processes[12]. In addition to the impact reverse circulation drill is not suitable for viscous soil, other equipment are suitable for the construction of different strata, but the corresponding construction efficiency is slightly different.The characteristics and applicability of the construction machinery in the quota are detailed in Table 1.

Table 1. The Construction mechanical characteristics and the applicability of quota

Serial number	Construction machinery	Suitable strata	Scope of application	Job content
1	Percussion drill	Clay, powder, sand, gravel, egg, drift, soft rock, low strength hard rock	The wall thickness is 0.6m-1.4m, and the depth of the slot is within 80m.	Preparation of mud, hole making, slag discharging, hole cleaning,

Serial number	Construction machinery	Suitable strata	Scope of application	Job content
				slurry changing and record.
2	Shock the reverse circulation rig	Powder, sand, gravel, egg, drift, soft rock, low strength hard rock	The wall thickness is 0.6m-1.4m, and the depth of the slot is within 80m.	Preparation of mud, hole making, slag discharging, hole cleaning, slurry changing and record.
3	Grab bucket	Sticky, powder, sand, gravel, egg, drift, soft rock, low strength hard rock	The wall thickness is 0.6m-1.2m, and the depth of the slot is within 60m.	Preparation of mud, hole making, slag discharge, hole cleaning, slurry change, record.
4	Two drill and one catch	Goo, powder, sand, gravel, egg, drift, soft rock, low strength hard rock	The wall thickness is 0.6m-1.4m, and the depth of the slot is within 80m.	Preparation of mud, hole making, slag discharging, hole cleaning, slurry changing and record.
5	Hydraulic slot milling groove	Clay, powder, sand, gravel, egg, bleach, soft rock, low strength hard rock, concrete	The wall thickness is 0.8m-1.0m, and the depth of the slot is within 60m.	Preparation of mud, hole making, slag discharge, hole cleaning, slurry change, record.

3 Analysis of research and results

3.1 Slot depth factor

The elevation of a project in Xizang Province is about 3000m. The stratum is composed of viscous soil, silt, fine sand, medium coarse sand, gravel and drifter, etc. The foundation is treated by underground continuous wall. The wall thickness is 1.2m, the hole depth is about 115m, and the construction is made by grab bucket and hydraulic slot milling machine. According to the "Hydropower Construction Engineering Budget Quota" (2007), the hydraulic slot milling machine and the grab only agreed on the adjustment coefficient of the fixed consumption of the underground continuous wall construction within 60m depth and 1.0m wall thickness, as detailed in the summary table of the adjustment coefficient of the groove machinery quota in Table 2.

Table 2. Summary table of quota adjustment coefficient in Construction machinery

Serial number	Construction machinery	Elevation coefficient of 3000m	Wall thickness coefficient			Depth coefficient				
			0.8 m	1.0 m	1.2 m	≤40m	40~50m	50~60m	60~70m	70~80m
1	Grab Bucket	1.35	1.00	1.20	1.25	1.00	1.1	1.25	--	--
2	Two drill and one catch	1.35	1.00	1.20	1.25	1.00	1.00	1.1	1.25	1.5
3	Hydraulic slot milling machine	1.35	1.00	1.20	--	1.00	1.00	1.1	--	--

Because the groove quota of the hydraulic milling machine does not include the wall thickness coefficient of 1.2m wall thickness, it can be treated with reference to the wall thickness coefficient of 1.25 in the grab quota.

The construction depth coefficient of the underground continuous wall in the depth range of 60 to 80m of the hydraulic groove machine can be counted by reference to the two drill and one grab quota, but there is no agreement or reference for the depth coefficient above 80m. Analysis of the depth coefficient in the range of 40~80m for two drills and one grasp shows that every 10m increase in slot depth, the depth coefficient increases by 0.1, 0.15 and 0.25, respectively, and there is no strong regularity. In order to deduce the depth coefficient in the range of 80~120m, consider the effect of elevation coefficient, wall thickness coefficient and stage coefficient superimposed in addition to the depth coefficient of the project. If the depth coefficient is increased too much, the unit price will be too high, or deviate from the actual situation of the project. Therefore, considering the range of 80~120m, every 10m increase in depth, the depth coefficient is calculated as 0.25 increase. The analysis table of groove depth coefficient of hydraulic slot milling machine is shown in Table 3.

Table 3. Analysis table of depth coefficient in hydraulic slot milling machine groove

Slot depth	≤50m	50~60 m	60~70 m	70~80 m	80~90 m	90~100 m	100~110 m	110~120 m
Depth coefficient	1.00	1.10	1.25	1.50	1.75	2.00	2.25	2.50

3.2 Establishment Situation

3.2.1 Grooving process. The trauching engineering quantity of the underground diaphragm wall is measured by the designed wall area (m2) and calculated[2] by multiplying the length of the trauting axis by the average wall body.

$$A = L \times H \tag{1}$$

Wherein: A is the cutoff wall or calculating the wall (water interception) area of the groove section, m^2; L is the axis length, m; H is the average wall depth, m.

Taking 10 slot segments of the project as the research object, the odd-numbered slot segment (1#, 3#, 5#, 7#, 9#) adopts grab bucket construction in the upper 25m range, and adopts hydraulic slot milling machine in the lower 25m ~115m range, of which 90~115m range is the bedrock layer; Even number slot segment (2#, 4#, 6#, 8#, 10#) adopts hydraulic slot milling machine construction, of which 90~115m range is the bedrock layer.

3.2.2 Odd number slot segments.

According to the construction machinery, stratum depth, strata type and strata scale of the odd number slot segments, combined with the adjustment coefficient of the quota on wall thickness, elevation, stage and depth, the rated consumption of the odd number slot segments is obtained, as shown in Table 4.

Table 4. Analysis table of rated consumption in odd number slot segments

Construction Machinery	stratum Depth	Strata Type	Strata scale	Original rated con-sumpti-on (hours /100 m^2)	Wall thicken-ss Coeffici-ent	Elevati-on coef-fici-ent	Stage co-effi-cient	Depth coeffici-ent	Adjusted rated con-sump-tion (hours /100 m^2)	Compre-hensive rated Consum-ption (hours /100 m^2)	Groo-ving Area (m^2)
Grab bucket	0~25 m	Drifters	8%	171.67	1.25	1.35	1.05	1.00	304.17	71.88	701.25
		cobble	16%	46.81	1.25	1.35	1.05	1.00	82.94		
		Gravel	8%	22.89	1.25	1.35	1.05	1.00	40.55		
		Medium coarse sand	68%	25.75	1.25	1.35	1.05	1.00	45.62		
Hydraulic slot milling machine	25~90 m	Medium coarse sand	68%	8.28	1.25	1.35	1.05	1.75	25.67	25.57	1823.25
		Silt	15%	6.87	1.25	1.35	1.05	1.75	21.30		
		Clay	17%	9.36	1.25	1.35	1.05	1.75	29.02		
Hydraulic slot milling machine	90~115m	Bedrock	100%	33.58	1.25	1.35	1.05	2.00	118.99	119.00	701.25

As shown in the table above that the comprehensive rated consumption of the construction section of the grab bucket (0~25m) is 71.88 hours /100 m^2. The comprehensive rated consumption of the construction section of the hydraulic slot milling machine (25~90m) is 25.57 hours /100 m^2, and the comprehensive rated consumption of the construction section of the hydraulic slot milling machine (90~115m) is 119.00 hours /100 m^2.

3.2.3 Even number slot segments.

According to the construction machinery, stratum depth, strata type and strata scale of the odd number slot segments, combined with the adjustment coefficient of the quota on wall thickness, elevation, stage and depth, the rated consumption of the even number slot segments is obtained, as shown in Table 5.

Table 5. Analysis table of rated consumption in even number slot segments

Construction machinery	Formation depth	Strata Type	Strata scale	Original rated consumption (hours /100 m^2)	Wall thickness Coefficient	Elevation coefficient	Stage coefficient	Depth coefficient	Adjusted rated consumption (hours /100 m^2)	Comprehensive rated Consumption (hours /100 m^2)	Grooving area (m^2)
Hydraulic slot milling machine	0~90 m	Drifters	2%	82.40	1.25	1.35	1.05	1.75	255.50	31.21	1084.50
		Pebbles	4%	17.55	1.25	1.35	1.05	1.75	54.42		
		Gravel	2%	10.30	1.25	1.35	1.05	1.75	31.94		
		Medium coarse sand	68%	8.28	1.25	1.35	1.05	1.75	25.67		
		Silt	11%	6.87	1.25	1.35	1.05	1.75	21.30		
		Clay	12%	9.36	1.25	1.35	1.05	1.75	29.02		
Hydraulic slot milling machine	90~115 m	Bedrock	100%	33.58	1.25	1.35	1.05	2.00	119.00	119.00	301.25

As shown in the table above that the comprehensive rated consumption of hydraulic slot milling machine (0~90m) construction section is 31.21 hours /100 m^2. The comprehensive rated consumption of the construction section of the hydraulic slot milling machine (90~115m) is 119.00 hours /100 m^2.

$$\text{Comprehensive rated consumption } = \Sigma \frac{\text{Comprehensive rated consumption N}}{\text{Grooving Area N}} \times \text{Grooving Area} \tag{2}$$

Combined with the odd slot segment, even slot segment of the quota consumption situation, according to different construction machinery, formation depth and slot area, the calculation of 10 slot segment of the comprehensive quota consumption of 54.25 hours /100m^2,as shown in Table 6.

Table 6. Analysis table of comprehensive rated consumption in construction groove

Slot segment	Construction machinery	Formation depth	Rated consumption (hours /100 m^2)	Grooving area (m^2)
Odd slot segments	Grab bucket	0~25m	71.88	701.25
	Hydraulic slot milling machine	25~90m	25.57	1823.25
	Hydraulic slot milling machine	90~115m	119.00	701.25
Even slot segments	Hydraulic slot milling machine	0~90m	31.21	1084.50
	Hydraulic slot milling machine	90~115m	119.00	301.25
Composite Values			54.25	

3.3 Project implementation

Combined with the engineering data of the project implementation stage, the man-hour consumption of the project is analyzed. The man-hour consumption in the implementation stage includes production, mechanical failure, slot repair, inclination measurement and hole cleaning time. Effective working time refers to the man-hour consumption under normal load, based reduction under load, unavoidable no-load work and unavoidable interruption time. Idle waiting time and mechanical failure time are not effective working time and should be deducted in the man-hour consumption analysis.

$$\text{Actual Consumption } = \frac{\text{Effective working time}}{\text{Grooving Area}} \times 100 \tag{3}$$

3.3.1 Odd number slot segments.

According to the actual consumption and slot area of different slots in the project implementation process, the effective working time was analyzed, and the actual consumption of the grab construction section (within 25m), the hydraulic slot milling machine construction section (25~90m) and the hydraulic slot milling machine construction section (90~115m) was statistically obtained, and compared with the fixed consumption, as shown in Table 7.

Table 7. Actual consumption of odd number slot segments.

Strata	Slot number	Time consumption (hours)							Slot area (m^2)	Effective working time (hours)	Actual Consumption (hour /100 ㎡)	Fixed consumption (hour /100 ㎡)
		Production	Breakdown	Fixing the groove	wait	Slope measurement	Hole clean-ing	total				
Grab bucket (within 25m)	1 #	33.00	3.00					36.00	140.25	33.00		
	3 #	35.00	8.00		17.00			60.00	140.25	35.00		
	5 #	127.50	1.00	14.50	17.50	7.50		168.00	140.25	149.50	64.46	71.88
	7 #	87.00	3.50	9.50	25.00			125.00	140.25	96.50		
	9 #	81.00	33.00	51.00	16.00	6.00		187.00	140.25	138.00		
Magnitude of change												- 10.32%
Hydraulic slot milling machine (25~90m)	1 #	92.51	19.00	12.00	9.50			133.01	364.65	104.51		
	3 #	81.74	9.00	24.00	15.00	6.50		136.24	364.65	112.24		
	5 #	57.25	2.00	24.00	0.50	3.00		86.75	364.65	84.25	27.11	25.57
	7 #	93.20		15.00	11.00	6.00	2.00	127.20	364.65	116.20		
	9 #	69.59	11.00	5.00	14.50	2.50		102.59	364.65	77.09		
Magnitude of change												6.03%
Hydraulic slot milling machine (90~115m)	1 #	135.73	18.13	19.00	15.00	4.50		192.36	140.25	159.23		
	3 #	98.32	4.00	7.00	1.58	2.00	3.00	115.90	140.25	110.32		
	5 #	92.61	8.77	0.78		1.00	1.00	104.16	140.25	95.39	89.85	119.00
	7 #	116.35	15.00	8.00		4.30	5.00	148.65	140.25	133.65		
	9 #	121.15	19.16	5.33	4.50	3.00	2.00	155.14	140.25	131.48		
Magnitude of change												24.50%
Total									3225.75	1576.36	48.87	

As shown in the table above that the actual consumption of the construction section of the grab (0~25m) is 64.46 hours /100m^2, which is lower than the comprehensive fixed consumption of 71.88 hours /100m^2, a decrease of 10.32%; The actual consumption of the hydraulic slot milling machine (25~90m) construction section is 27.11 hours /100m^2, which is higher than the comprehensive quota consumption of 25.57 hours /100m^2, an increase of 6.03%; The actual consumption of hydraulic slot milling machine (90~115m) in the construction section is 89.85 hours /100m^2, which is lower than the comprehensive fixed consumption of 119.00 hours /100m^2, down 24.50%.

3.3.2 Even number slot segments.

According to the actual consumption and slot area of different slots in the project implementation process, the effective working time was analyzed, and the actual consumption of the grab construction section (within 25m) and the hydraulic slot milling machine construction section (25~90m) was statistically obtained, and compared with the fixed consumption, as shown in Table 8.

Table 8. Actual consumption of even number slot segments.

Strata	Slot number	Time consumption (hours)							Slot area (m^2)	Effective working time (hours)	Actual consu-ption (hours/100 ㎡)	Fixed consumption (hours/100 ㎡)
		Production	Breakdown	Fixing the groove	wait	Slope measurement	Hole cleaning	Total				
Hydraulic slot milling machine (0 to 90m)	2 #	91.73	16.00	11.00		1.50		120.23	216.90	104.23		
	4 #	119.42	17.00	18.50	11.00	6.00	2.00	173.92	216.90	145.92		
	6 #	147.27	25.92	4.00	3.50	4.00	2.00	186.69	216.90	157.27	59.62	31.21
	8 #	129.47	8.00	2.00		3.00		142.47	216.90	134.47		
	10 #	102.65	26.50			2.00		131.15	216.90	104.65		
Magnitude of change												91.03%
Hydraulic slot milling machine (90 to 115m)	2 #	47.60	4.00	1.17		1.50	3.67	57.93	60.25	53.93		
	4 #	49.93				1.00	5.00	55.93	60.25	55.93		
	6 #	48.91				1.00	3.00	52.91	60.25	52.91	91.61	119.00
	8 #	47.00	6.00			2.00	6.00	61.00	60.25	55.00		
	10 #	56.21	39.63			1.00	1.00	97.84	60.25	58.21		
Magnitude of change												- 23.02%
Total									1385.75	922.52	66.57	

As shown in the table above that the actual consumption of the hydraulic slot milling machine (0~90m) construction section is 59.62 hours /100m^2, higher than the fixed consumption of 31.21 hours /100m^2, an increase of 91.03%; The actual consumption of the construction section of the hydraulic slot milling machine (90~115m) is 91.61 hours /100m^2, which is lower than the fixed consumption of 119.00 hours /100m^2, a decrease of 23.02%.

3.3.3 Analysis of hourly consumption of integrated platform. Summing up the grooving area and effective working time of 10 construction grooves, the actual consumption and comprehensive actual consumption of the construction grooves of grab&hydraulic groove milling machine and the construction grooves of hydraulic groove milling machine are obtained, as shown in Table 9.Among them, the actual consumption of grab& hydraulic slot milling machine construction groove segment is 48.87 hours /100m^2, the actual consumption of hydraulic slot milling machine construction groove segment is 66.57 hours /100m^2, and the comprehensive actual consumption is 54.19 hours /100m^2. The comprehensive quota consumption is 54.25 hours /100m^2, the two are basically equivalent.

Table 9. Comprehensive consumption analysis

Serial number	Slot segment	Grooving Area (m^2)	Effective working time (hours)	Actual consumption (hours/100 m^2)
1	Grab&hydraulic slot mill	3225.75	1576.36	48.87
2	Hydraulic slot milling machine	1385.75	922.52	66.57
3	Total	4611.50	2498.88	54.19

3.4 Conclusions

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) When the unit price of the hydraulic slot milling machine is prepared, in the range of the groove depth 80~120m, the depth increases by 10m, and the depth coefficient increases by 0.25 is basically appropriate. In the actual construction, the consumption of the integrated platform is 54.19 hours /100m^2, and the comprehensive quota consumption is 54.25 hours /100m^2, the two are basically equivalent.

(2) The actual consumption of the grab bucket in the (0~25m) construction section and the hydraulic slot milling machine in the (90~115m) construction section, accounting for the quota consumption ratio of 89.68% and 76.99%, respectively, the construction efficiency is higher.

(3) The actual consumption of the hydraulic slot milling machine in the (0~90m) construction section increased by 91.03% compared with the fixed consumption. Compared with the actual consumption of the grab bucket in the construction section (0~25m), the consumption decreased by 10.32% compared with the norm; The actual consumption of the hydraulic slot milling machine in the construction section of (25~90m), the increase of 6.03% compared with the fixed consumption, it can be seen that the construction efficiency of the hydraulic slot milling machine is low in the upper 25m range, and the adaptability of the upper stratum with more drifts, eggs and gravel content is poor.

(4) This paper mainly analyzes the hourly consumption of trouging machinery for underground continuous wall construction of a project in Xizang Province. Specific to other engineering projects, there may be great differences due to different geological conditions, project elevation, construction schemes, etc. Therefore, the construction efficiency of ultra-deep underground continuous wall construction in high-altitude areas needs to be further analyzed and studied in combination with the actual situation of the project.

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