Feasibility Study Stage of Mountain Highway Engineering Based on Empirical Analysis Method Estimation of Subgrade Engineering Quantity

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Abstract

In the feasibility study stage of highway engineering construction project, it is one of the bases for compiling investment estimation to reasonably estimate the quantity of subgrade works. Combined with years of practical work, this paper introduces the contents and compilation methods of subgrade works in the feasibility study stage of Highway Engineering in mountainous and hilly areas. Taking 11 specific projects as examples, this paper analyzes the specific application of empirical analysis method, and concludes that the empirical analysis method can be applied to the estimation of highway subgrade engineering quantity in mountainous areas in the feasibility study stage.

Keywords: *Subgrade engineering, subgrade earthwork, subgrade drainage, subgrade protection,*

I. Introduction

The feasibility study of highway construction project is a comprehensive study on the necessity, technical feasibility, economic rationality and implementation possibility of the project, which is the main basis for the decision-making of the construction project [1]. The investment estimation is an important part of the feasibility study report. It is one of the bases for the demonstration of technical feasibility, economic rationality and implementation possibility [2]. It is an important basis for decision-making of construction projects. Reasonable determination and control of project investment in feasibility study stage is an important work of construction project feasibility study [3].

The preparation of investment estimation is based on the design documents of the project, comprehensive understanding of the construction conditions of the project site, mastering various basic data, correctly quoting indicators, charging standards, labor unit price, material and equipment price, The work is carried out in accordance with the *Compilation Method for Investment Estimation of Highway Capital Construction Engineering* and *Estimation Index of Highway Engineering* implemented at the present stage, as well as the provisions in line with the current relevant national and industrial standards [4].

The reasonable estimation of engineering quantity in the stage of engineering feasibility study is the key work of feasibility study and the important basic data of investment estimation. The quantities of engineering feasibility study include: estimation of temporary works, subgrade works, pavement works, bridge and culvert works, tunnel works, crossing works, facilities along the line, greening and environmental protection works, other works, land use scale and demolition, etc [5].

The investment of subgrade, pavement and other projects in low-grade highway or high-grade highway with low proportion of bridges and tunnels occupies a large part in the investment estimation [6-9]. For example, for a class III Highway with subgrade width of 8.5m in hilly district, when the proportion of bridges and tunnels accounts for about 1% ~ 10%, the investment in subgrade accounts for about 50 ~ 75% of the construction and installation cost

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at the present stage of the project. Reasonable estimation of subgrade engineering quantity is one of the key works to determine and control engineering investment estimation.

The estimation of subgrade engineering quantity in the engineering feasibility study stage is reflected by the compilation of subgrade engineering quantity estimation table [10-12]. According to the relevant provisions of highway engineering implemented at this stage, the standardization promotion of engineering quantity estimation table in the engineering feasibility study stage is advocated, which is beneficial to improve the efficiency of cost document compilation. The standardization and standardization of cost documents is conducive to the whole process control of cost documents.

In the stage of engineering feasibility study, the standardization of quantity table of highway subgrade engineering in mountainous area needs to be studied systematically in combination with project characteristics, Compilation Rules of project cost, requirements of highway engineering estimation index and similar quantities of built projects.

II. Preparation of Subgrade Engineering Estimation Table

2.1 Contents of subgrade engineering in *Highway Engineering Estimation Index*

The compilation of subgrade quantity table in the stage of engineering feasibility study is mainly based on the contents and measurement rules of Subgrade Engineering in *Highway Engineering Estimation Index*. Firstly, it is necessary to be familiar with the subgrade engineering contents and measurement rules in *Highway Engineering Estimation Index*.

Highway Engineering Estimation Index subgrade engineering includes subgrade soil, stonework, drainage, protection engineering, special subgrade treatment and other projects.

2.2 Estimation method of subgrade quantity in feasibility study stage

The quantity of subgrade in the stage of engineering feasibility study can generally be determined by quantitative method and empirical estimation method.

2.2.1 Quantitative method

The quantitative method is to use computer program to calculate the quantity of excavated stonework through the design of subgrade cross section. Generally, the quantitative method is used to calculate the quantity of Subgrade Earthwork in the stage of preliminary design and construction drawing design. In the engineering feasibility study stage, the 1:10000 topographic map is used to interpret the plane, vertical plane, cross section and other basic data, and the read data are often different in the collection of basic data under different terrain conditions, such as plain micro hilly area and mountain heavy hilly area, so the workload of subgrade cross section design in the engineering feasibility study stage is often large. Therefore, in the stage of engineering feasibility study, the quantitative method is generally applicable to the projects with short route mileage and long engineering feasibility study period in plain and hilly terrain, and the quantity of earthwork after quantification is close to the actual situation.

In the feasibility study stage, the subgrade cross-section design should be used to quantify the quantity of Subgrade Earthwork, and the quantity of earthwork needed to recover to the original ground elevation after surface clearing and compaction before filling should be calculated, and the quantity of earthwork needed for ultra wide rolling should be increased.

For the filling section, the amount of earth and stone to be recovered to the original ground line after surface clearing and compaction before filling shall be increased, and the amount of earth and stone required for calculating super wide rolling shall be increased.

2.2.2 Empirical estimation method

The empirical estimation method is a commonly used method to estimate the engineering quantity in the engineering feasibility study stage. That is, based on the preliminary design, construction drawing design and other data of similar projects, the earthwork quantity of subgrade is estimated through the plan and longitudinal diagram in the engineering feasibility study stage.

The empirical estimation method is more suitable for projects with short study period and complex terrain in mountainous and hilly areas.

The empirical estimation method generally refers to the earthwork quantity of the built highway in the area where the project is located, and adopts the empirical value according to the earthwork quantity of the section (excavation quantity + filling quantity) subgrade, which can comprehensively consider the factors such as the earthwork quantity required for ultra wide rolling, surface clearing, compaction before filling and restoration to the original ground line.

III. Estimation of Subgrade Engineering Quantity based on Empirical Analysis Method

3.1 Subgrade soil and stone works

The following statistics part of the mountain highway preliminary design and construction drawing design of Subgrade Earthwork quantity. The quantity of Subgrade Earthwork can be estimated with reference to the following items, just as table 1 and table 2.

Table 1 Statistics of earthwork quantity of expressway subgrade in preliminary design of mountainous and hilly areas

Project name	Subgrade width (m)	Subgrade length (km)	Quantity of subgrade earthwork			
			Excavation	Fill	Total section	Average per kilometer
Baolu highway SJ1	25.5	8.033	2480197	507897	2988094	371977
Baolu highway SJ2	25.5	7.481	1835985	209399	3045384	407082
Tenhou highway	25.5	16.943	7064513	2200837	9265350	546854
Nanjing highway SJ1	25.5	17.8	5659039	3205965	8865004	498034
Nanjing highway SJ2	25.5	20.635	2846635	4870457	7717092	373981
Pingwen highway SJ1	24.5	21.394	3770227	2874171	6644398	310573
Suomeng highway SJ2	24.5	61.691	11783500	8018496	19801996	320987
Shihong highway	23	33.032	6049781	3598292	9648073	292083
Heguan highway	25.5	25.185	6464752	1942479	8407231	333819
Shanghe highway	25.5	38.004	9074244	2012989	11087233	291739
Daigong highway	24.5	30.305	7675717	4544784	12220501	403250
Baoshi highway	25.5	14.496	7297591	818020	8115611	559852
Xiangli highway SJ1	24.5	23.328	7845101	271171	8116272	347920

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Table 2 Statistics of earthwork quantity of Expressway Subgrade in construction drawing design of mountainous and hilly area

Project name	Subgrade width (m)	Subgrade length (km)	Quantity of subgrade earthwork			
			Excavation	Fill	Total section	Average per kilometer
Tenghou highway SJ1	25.5	17.348	7737569	1866121	9603690	553591
Nanjing highway SJ2	25.5	22.022	3922209	4422526	8344735	378927
Pingwen highway SJ1	24.5	23.422	3914979	2036677	5951656	254105
Dayong highway SJ2	25.5	22.459	5887706	3749324	9637030	429094

It can be seen from the above statistical table that the quantity of earthwork varies greatly due to the terrain conditions, characteristics, design depth and design ideas of each project.

The empirical estimation method of earthwork quantity in the stage of engineering feasibility study is generally based on the plane and vertical drawings provided. The earthwork quantity is estimated according to the average filling and excavation height in the vertical section, and then adjusted with the earthwork quantity of similar projects. For example, The K22 + 000-k23 + 000 section of an expressway west project is 1000m long and 33.0m wide. The subgrade is 731m long (excluding the bridge and tunnel length of 269M). It is estimated that the average filling length of this section is about 240m (K22 + 400-k22 + 540, K22+760-K22+780,K22 + 920-k23 + 000), the rest are excavation sections, with an average length of 491m, as shown in the vertical section. The average height of excavation is estimated as 9.0m, and that of filling is calculated as 5.0m. All of them are estimated as full fill or full cut.

The estimated volume of excavation is about 203274 cubic meters and that of filling is about 48600 cubic meters. When estimating the excavation and filling section, if most of the section is excavation section, the filling or half excavation and half filling on both sides of the bridge head should be considered as the estimated earthwork quantity of the filling section according to the plan.

3.2 Subgrade drainage works

Table 3 and table 4 show the quantity of subgrade drainage works in preliminary design and construction drawing design of some mountainous expressways. When estimating the quantity of subgrade drainage works, the estimated quantity can be adjusted according to the following items.

Table 3 Statistical table of Expressway Subgrade Drainage Engineering in preliminary design of mountainous and hilly areas

Project name	Subgrade width (m)	Subgrade length (km)	Quantity of subgrade drainage works (m^3)					
			Side ditch	Drainage ditch	Intercepting ditch	Chute	Total	Average per kilometer
Baolu highway SJ1	25.5	8.033	4937	2550	9428	379	17294	2153
Baolu highway SJ2	25.5	7.481	7210	5515	16339	4886	33950	4538
Tenhou highway	25.5	16.943	13751	10383	20039	4233	48406	2857

Nanjing highway SJ1	25.5	17.8	22421	6009	14266	4341	47037	2643
Nanjing highway SJ2	25.5	20.635	8680	12043	11178	3071	34972	1695
Pingwen highway SJ1	24.5	21.394	15071	26449	7449	2571	51540	2409
Suomeng highway SJ2	24.5	61.691	29777	32282	12116	2078	76253	1236
Shihong highway	23	33.032	27087	11240	8976	3308	50610	1532
heguan highway	25.5	25.185	20678	10902	17198	4123	52901	2100
Shanghe highway	25.5	38.004	32062	11502	29920	6529	80014	2105
Daigong highway	24.5	30.305	30127	23566	35909	9119	98721	3258
Baoshi highway	25.5	14.496	16514	1680	17223	3840	39257	2708
Xiangli highway SJ1	24.5	23.328	24223	1274	29166	10163	64826	2779

Table 4 Statistical table of Expressway Subgrade Drainage Engineering in preliminary design of mountainous and hilly areas

Project name	Subgrade width (m)	Subgrade length (km)	Quantity of subgrade drainage works (m^3)					
			Side ditch	Drainage ditch	Intercepting ditch	Chute	Total	Average per kilometer
Tenghou SJ1	25.5	17.348	14222	4942	17709	5661	42534	2452
Nanjing SJ2	25.5	22.022	9986	6616	11778	4108	32488	1475
Pingwen highway SJ1	24.5	23.422	14173	25420	7988	1425	49006	2092
Dayong highway SJ1	25.5	22.459	17026	10136	7719	6003	40885	1820

3.2.1 Side ditch

Side ditch refers to the longitudinal artificial ditch set outside the shoulder of the excavated subgrade and the foot of the low fill subgrade, which is used to collect the surface water of the highway pavement and drain the slope water of the slope above the road, quickly collect them and lead them into the smooth drainage channel.

Generally, the side ditch of high-grade highway adopts rectangular cover plate. If there are landscape requirements, the buried rectangular cover slab side ditch can be used. The trapezoidal side ditch or rectangular side ditch is generally used in the second, third and fourth class highways. The cover plate is made of precast concrete, and the side ditch can be made of cast-in-place concrete or mortar rubble.

It is suggested that the length of side ditch should be calculated according to the coefficient of 1.85-1.96 of the mileage of excavation section in the feasibility study stage. The estimated length of side ditch shall be checked with the length of embankment retaining wall in this section. The length of embankment retaining wall + side ditch in this section is less than or equal to 2 * subgrade length.

3.2.2 Drainage ditch

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The main purpose of drainage ditch is to divert water from various water sources within the scope of subgrade (such as side ditch, intercepting ditch, slope and ponding near subgrade) to culverts, bridges or natural ditches. The general farmland road section is set at one side of the fill slope toe, along with the side ditch drainage, guide fill slope chute, etc.

The drainage ditch is generally made of mortar rubble or cast-in-place concrete.

The estimated length of drainage ditch in the feasibility study stage of the project is as follows:
(1) Length of drainage ditch in filling section on both sides of farmland in flat terrain area: It is suggested that drainage ditches should be set on both sides of the filling section. The length is estimated according to the 1.90-2.0 coefficient of the filling section.
(2) Length of drainage ditch in filling section of mountain area and heavy hill area:
It is suggested to estimate the length of drainage ditch according to the coefficient of 0.9-1.2 of filling section. In the feasibility stage, the pavement area of Expressway and first-class highway is generally calculated according to the integral subgrade. Conventional down Lane pavement and hard shoulder pavement adopt the same pavement structure, and the earth shoulder is hardened. The area of driving road surface is generally fixed, and the width of 25.5m driving road surface is calculated as 2 * 3.75 * 2 = 15m. The shoulder area of driving road is calculated according to different road sections, and the curb area of the middle section is generally determined. Conventional down Lane pavement and hard shoulder pavement adopt the same pavement structure, and the earth shoulder is hardened. The area of driving road surface is generally fixed, and the width of 25.5m driving road surface is calculated as 2 * 3.75 * 2 = 15m. The shoulder area of driving road is calculated according to different road sections, and the curb area of the middle section is generally determined.

3.2.3 Intercepting ditch, slope platform drainage (intercepting) ditch
The intercepting ditch on the top of the cutting slope is also called the gutter. In order to intercept the water flowing to the subgrade on the slope, the ditch set outside the cutting slope is usually in the form of mortar rubble or cast-in-place concrete.

The platform intercepting ditch is generally divided into the intercepting ditch on the slope protection platform of the high fill section and the intercepting ditch on the broken platform of the cut slope.

(1) The length of intercepting ditch on the top of cutting slope is estimated as follows:
In the feasibility study stage, the length of intercepting ditch is estimated according to the plan and vertical map, the terrain along the line and the excavation height. Generally, only one side of intercepting ditch is considered. It is suggested that the length of the intercepting ditch on the top of the cutting slope can be estimated by the coefficient of 1.5-2.0 of the mileage length of the excavation section.
(2) Estimation of intercepting ditch length of platform:
In the stage of engineering feasibility study, the length of platform intercepting ditch is generally up to the platform intercepting ditch considering the broken platform in the excavation section. According to the plan and vertical plan, the terrain is along the line and the excavation height. It is suggested to estimate the length of platform intercepting ditch according to the coefficient of 1.5-2.0 of the length of side ditch.

3.2.4 Chute
The chute is generally set in the long section of the cut slope and fill slope to timely discharge the water flow from the intercepting ditch and platform intercepting ditch, and timely drain the pavement drainage and other slope drainage facilities. At the same time, it can also be used as a channel for slope maintenance. The length of chute can be estimated as 5% - 20% of the length of platform drain.

3.3 subgrade protection works

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The following statistics part of the mountain highway preliminary design and construction drawing design of subgrade protection engineering quantity. When estimating the quantity of subgrade protection works, the estimated quantity can be adjusted according to the following items, just as table 5 and table 6.

Table 5 Statistical table of highway subgrade retaining wall engineering in preliminary design of mountainous and hilly areas

Project name	Subgrade width (m)	Subgrade length (km)	Quantity of subgrade drainage works (m^3)	
			Total	Average per kilometer
Baolu highway SJ1	25.5	8.033	59002	7345
Baolu highway SJ2	25.5	7.481	80899	10814
Tenhou highway	25.5	16.943	51244	3025
Nanjing highway SJ1	25.5	17.8	81494	4578
Nanjing highway SJ2	25.5	20.635	161000	7802
Pingwen highway SJ1	24.5	21.394	135597	6338
Suomeng highway SJ2	24.5	61.691	338051	5480
Shihong highway	23	33.032	316867	9593
heguan highway	25.5	25.185	117164	4652
Shanghe highway	25.5	38.004	104970	2762
Daigong highway	24.5	30.305	186146	6142
Baoshi highway	25.5	14.496	46008	3174
Xiangli highway SJ1	24.5	23.328	114651	4915

Table 6 Statistical table of expressway subgrade retaining wall engineering for construction drawing design in mountainous and hilly areas

Project name	Subgrade width (m)	Subgrade length (km)	Quantity of subgrade drainage works (m^3)	
			Total	Average per kilometer
Tenghou SJ1	25.5	17.348	139477	8040
Nanjing SJ2	25.5	22.022	403622	18328
Pingwen highway SJ1	24.5	23.422	11862	506
Dayong highway SJ1	25.5	22.459	141760	6312

The budget of grass slope protection in the statistical table is included in the greening and environmental protection measures, but the number of grass slope protection is not included in the table.

When the quantities of subgrade drainage and retaining works are estimated, the quantities of both works should be summarized and checked. The total quantity of expressway is about 6000-10000 cubic meters per kilometer.

The area of roadside slope protection estimated in the engineering feasibility study is generally based on the plan and vertical plan. It is estimated according to the cut section and fill section in the estimation of earthwork quantity table. The slope area is estimated by filling section and excavation section respectively.

3.3.1 Slope area of fill section

In estimating the quantity of Subgrade Earthwork and subgrade drainage, the length of filling section has been estimated. The area of fill slope is calculated according to the average area, and the height factor of retaining wall can be deducted（ The fill area can be simplified as the following formula.

Fill slope area = slope length of average fill height * fill subgrade length * 2 * fill slope adjustment coefficient

The adjustment coefficient of fill slope and terrain condition are reduced or increased respectively.

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If retaining wall is considered to be set on both sides or one side of the fill, the adjustment coefficient of the fill slope is reduced according to the average height of the retaining wall. If one side is a filling area, the adjustment factor of one side should be increased

Grass planting slope protection can be estimated as 10-15% of the fill slope area, and the rest is skeleton slope protection.

3.3.2 Slope area of cut section
According to the length of excavation section and average excavation height, the slope area of excavation section is estimated. The excavation area can be calculated by the following formula.

Excavation slope area = slope length of average excavation height * excavation subgrade length * 2 * slope expansion coefficient

The slope expansion coefficient (1.0-2.5 is recommended) can be adjusted by referring to the terrain in the plan. It can be 1.0 in the case of gentle terrain, and 2.5 in the case of steep terrain and high excavation section. Generally it is between 1.2 and 2.0.

In general, the slope protection with anchor can be estimated as 20-30% of the total excavation area, and the anchor cable can be estimated as 15-25% of the total excavation area. The rest is the area of skeleton slope protection. When the geological conditions are relatively poor, the proportion of slope protection with anchor rod and anchor cable can be increased.

The number of active and passive protection nets should be estimated when the stone section is rich and the stone is broken. In the feasibility study stage of excavation section, it is not necessary to estimate the area of grass slope protection. Generally, the slope of the excavation section is 8.0 m high. Finally, the area of cut slope + area of fill slope is the protection area of subgrade protection slope.

IV. Conclusion

The main subgrade quantity in the feasibility study stage is mainly used empirical estimation method at present, which is applied to the feasibility study of most expressway projects in mountainous and heavy hill area of Yunnan Province, such as Mohin expressway, Yuchu Expressway and Chu Da expressway, and the effect is relatively significant. With the improvement of scientific and technological means, application promotion, the accuracy of basic data collection is improved and the estimation method of subgrade engineering quantity in the feasibility study stage is improved constantly, which can greatly improve the efficiency and quality of the preparation of the feasibility study.

References

[1] C.D.F. Rogers, A.M. Thomas, I. Jefferson, et al., “Carbon Dioxide Emissions due to Highway Subgrade Improvements,” Transportation Research Record, vol.2, no.2104, pp.80-87, 2009.
[2] A.L. Murmu, N. Dhole, A. Patel, et al., “Stabilisation of black cotton soil for subgrade application using fly ash geopolymer,” Road Materials And Pavement Design, vol.21, no.3, pp.867-885, 2020.
[3] A. Siukscius, V. Vorobjovas, A. Vaitkus, et al., “Long Term Behaviour of An Asphalt Pavement Structure Constructed on A Geogrid-Reinforced Subgrade over Soft Soils,” Road Materials And Pavement Design, vol.14, no.3, pp.384-404, 2019.
[4] J.H. Zhang, L. Ding, F. Li, et al., “Recycled aggregates from construction and demolition wastes as alternative filling materials for highway subgrades in China,” Journal of Cleaner Production, vol.255,

doi: org/10.1016/j.jclepro.2020.120223, 2020.

[5] T. Zhang, G.J. Cai, S.Y. Liu, "Application of Lignin-Stabilized Silty Soil in Highway Subgrade: A Macroscale Laboratory Study," Journal of Materials in Civil Engineering, vol.30, no.4, pp. 04018034, 2018.

[6] H. Liu, H. Liu, W. Ding, et al., "Dynamic Characteristics of the Rubber-Tailings Mixture Based on Dynamic Triaxial Test," Advances in Materials Science and Engineering, vol.2020, no.2, pp.1-10, 2020.

[7] S.Wang, X. Li, K. Ren, et al., "Experimental Research on Steel slag Stabilized Soil and its Application in Subgrade Engineering," Geotechnical and Geological Engineering, vol.38, no.12, pp.1-13, 2020.

[8] B. Xu, "Quality inspection method of layered compacted subgrade and engineering example analysis," E3S Web of Conferences, no.248, pp.03068, 2021.

[9] O. D. Afolayan, O. M. Olofinade, I. I. Akinwumi, "Use of some agricultural wastes to modify the engineering properties of subgrade soils: A review," Journal of Physics: Conference Series, vol.1378, no.2, pp.1-12, 2020.

[10] S. Dhar, M. Hussain, "Experimental Investigation on Strength and Bearing Capacity Improvement of a High Plasticity Clayey Subgrade Soil Using Lime," Key Engineering Materials, no.803, pp.13-25, 2019.

[11] X. Xing, L. Chen, Z. Yuan, et al., "An Improved Time-Series Model Considering Rheological Parameters for Surface Deformation Monitoring of Soft Clay Subgrade," Sensors, vol.19, no.14, pp.14-23, 2019.

[12] S. Zhou, B. Wang, Y. Shan, "Review of research on high-speed railway subgrade settlement in soft soil area," Railway Engineering Science, vol.28, no.1, pp.4-10, 2020.

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