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Time- Cost Benefit Analysis for Anchor Type Foundation in Transmission Towers

[1]M.Harikrishnan,[2]R.Balagopal.

[1]M-E CEM, Jerusalem College of Engineering, Chennai, Project Student CSIR-SERC.
[2]Scientist,CSIR-Structural Engineering Research Centre,Taramani,Chennai- 600113
hariagem@gmail.com,bala@serc.res.in

***Abstract*- Transmission line tower (TL) are used in electric power transmission from grid to consumer to support high voltage conductors. In this paper attempt has been made to find the time-cost benefit analysis for various types of transmission tower foundations. A 400-kV double circuit TL tower is chosen for the present study. Analytical studies are carried out using FEMAP with NX Nastran, a nonlinear finite element analysis software. The tower is modelled using two dimensional beam elements for leg, bracings & redundant members. Static analysis has been carried out for critical load case conditions such as reliability, right ground wire broken, right top conductor broken, right middle conductor broken, right bottom conductor broken conditions. The maximum foundation forces such as uplift, down thrust and shear forces are determined. Hard anchor and prestressed rock anchor type foundations were designed in accordance with IS-456:2000, IS-800:2007, IS-802:2006, IS 10270:2003 codal provisions. A comparative study based on time cost benefit analysis for the foundations such as hard anchor and prestressed rock anchor has been worked out.**

I. Introduction

In every country, developed and developing, the electric power consumption has continued to raise and the rate of growth been greater in developing countries. This in turn has led to the increase in the number of power station and capacities and constituent increase in the power transmission line from the generating stations to the load centers and also considerable increase in the size of transmission towers. Due to the increase in power transmission capacity the size of foundations for the transmission line tower is increased. The foundation for the transmission line towers cost about 20-35 % of the total cost of the transmission line project. An optimum design of the transmission line tower foundation can therefore result in substantial saving in economy. Thus great responsibility thus rests on the transmission line engineer, who has to prepare not only economical but also reliable design.

It is a challenging task to build TL towers especially in hilly terrain, where the type of soil encountered will be hard rock. The maximum complexity arise on TL tower foundation which are to be laid on hilly terrain when compared to the normal type of foundations such as isolated , grillage or raft type of foundations.

II. Need For The Study

Selection of the best type of foundation for TL tower is very important to prevent the failure of towers. The hard anchor and prestressed rock anchor type of foundations are generally adopted for foundations in normal and hilly terrain. In the present study a comparative study between these two types of foundations is carried out to help the design engineers to adopt the most economical type of foundation.

The cost of construction for isolated, grillage or raft foundation in hilly terrain is costly. Proper planning and scheduling is very much important in order to predict the cost and the time required to carry out these type of foundations. In this paper an attempt has been made to analyze the time cost benefit for hard rock anchor and prestressed rock anchor foundation. This can save considerable amount of time and economy in the laying of transmission tower foundation.

III. Analytical Investigation

A 400kV-double circuit TL tower is taken for the present study. FEMAP with NX Nastran a nonlinear finite element analysis software is used for the analysis of the tower. Static analysis has been carried out for critical load case conditions such as reliability, right ground wire broken, right top conductor broken, right middle conductor broken, right bottom conductor broken conditions. The maximum uplift, down thrust and shear loads is identified from the above analysis.

All the legs, bracings, redundant and cross arm members are modelled using two node beam elements. The constraints are given as fixed support at the base of the tower. All the two node beam elements were assigned with the respective material properties such as mild steel or high tensile steel. The section properties depending upon the capacities for the tower were assigned respectively to all the 2-node beam elements and static analysis was carried out for the modelled tower for the above mentioned load cases.

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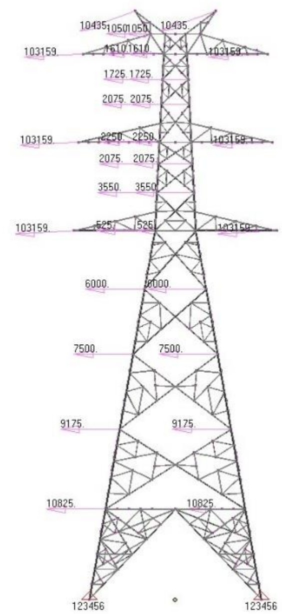
The results of the analysis for the various load cases are tabulated in Table 1. The maximum loads are arrived by comparing the analysis report for the various load case conditions as mentioned above and the foundations are designed accordingly. The deformed and un-deformed FE model of the tower for the reliability load case condition which yields the maximum uplift force is shown in the Fig1 (a) &1(b) respectively. The summary of the foundation forces arrived from the analysis is shown in Table-1.

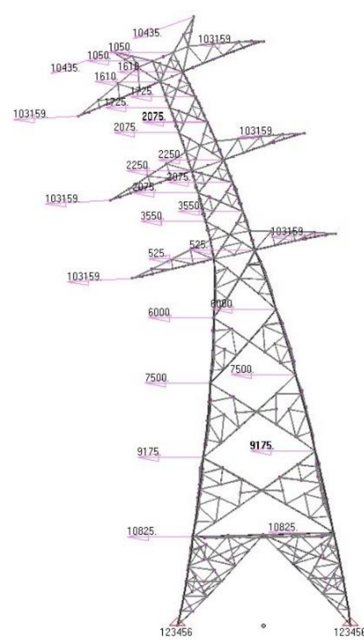
Table I. SUMMARY OF FOUNDATION FORCES

Loading Conditions	Legs	Uplift (N)	Down thrust(N)	Shear(N)
Reliability	1	1119790	197653	222632
	2	1230676(M)	219486	244287
	3	1122559	198255	223358
	4	1227734	218883	243802
Right Ground Wire Broken	1	911045	158746	185288
	2	647744	114720	138511
	3	730427	129651	150327
	4	816796	147937	165474
Right Top Conductor Broken	1	1076839	168799	231069
	2	485705	72559.8	126078
	3	831122	160931	151375
	4	570448	123561	104818
Right Bottom Conductor Broken	1	126275	220317 (M)	270422 (M)
	2	810226	124103	190255
	3	543050	115987	87176.4
	4	420985	78590.7	65486.5

Note: (M) indicates the maximum force in the respective category.



(a)



(b)

Fig 1(a), 1(b). Un-deformed & deformed model of 400kV D/C Tower - Reliability Condition

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IV. Foundation Design

The soil data taken in the study is for a hilly terrain category. The same soil data is taken for the purpose of both the foundation design and the comparative study is done.

- Unit weight of dry soil – 1440 kg/m^3
- Unit weight of wet soil – 940 kg/m^3
- Limit bearing capacity (wet) – 27350 kg/cm^2
- Limit bearing capacity (dry) –13765 kg/cm^2

A. Hard Rock Anchor Foundation

Since there is no specified Indian Standard Codal provision for the design of this type of foundations, CBIP Manual Technical report No: 268 was referred for this type of foundation design. First the bearing capacity of the hilly terrain considered is checked for the resistance against the maximum uplift forces arrived from the static analysis for both normal and broken wire conditions. Then the most economical diameter of the anchor rods, grade of steel and the depth of the drill hole required in order to drive the anchor rods is arrived by checking the anchor rods against bending, uplift resisted by a single anchor and the uplift resisted by the cement concrete grout for the anchor. Working bond stress between rock and concrete in order to find the resistance is found out by equation.

$$P = \pi d l \tau \text{ ……………….. (1)}$$

Where,

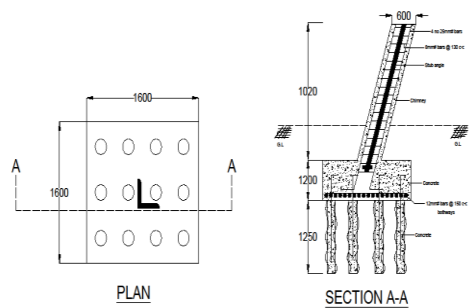
P = Anchor force (N)

d = diameter of the pile (mm)

l = length of the anchor rod (mm)

τ = working bond stress between concrete grout and rock (N/mm^2)

A plain cement concrete mat slab not less that 1000mm thick (as per CBIP Manual Technical Report: 268) is generally considered for this type of foundation and the anchor rods are extended form the top of the drilled whole till the middle of the mat slab. The tower is embedded into the mat slab with the help of cleat and a plain concrete chimney is built above the mat slab. This resulted in increased depth of the mat slab in order to prevent the tower failing due to heavy shear and the sliding forces acting on the hard anchor foundation. The consumption of concrete is increased in resulting in uneconomical design. This issue is addressed here by providing a reinforced mat slab instead of the plain cement concrete mat slab and also reinforcing the chimney above the mat slab which will result in reduced size of the mat slab and chimney ultimately gaining economic benefits. The reinforced concrete mat slab is checked for safety against deflection and sliding. Reinforcement is provided in both tension and compression faces of the mat slab. The chimney is also checked for resistance against uprooting of the embedded stub for the maximum shear forces take from the analysis results of the TL tower. A detailed drawing of the designed foundation is shown in Fig2.



Note: All dimensions are in mm.

Fig 2. Plan, Section of Hard Anchor Foundation (Non-Prestressed)

B. Prestressed Rock Anchor Foundation

IS-10270: 1982 Indian Standard guidelines for design and construction of prestressed rock anchors were followed for this type of foundation design. In here the soil stratum is checked for the bearing capacity at first. In this foundation design the anchor rods are prestressed driving into the drilled whole. DYWYDAG prestressed rock anchor manual (DYWYDAG a company which provides solution for foundation construction and mining solution) is referred and the suitable grade of steel, type of anchor required depending upon the uplift resisting capacity of the anchor for the maximum uplift got from the TL tower analysis is selected for design. The Indian Standards IS 10270: 1982 do not specify any provision of reinforced concrete mat and reinforced concrete chimney above the rock anchor. But in order to resist the failure of the tower due to uprooting of the stub, a reinforced concrete mat and a chimney similar to hard anchor foundation is designed and provide.

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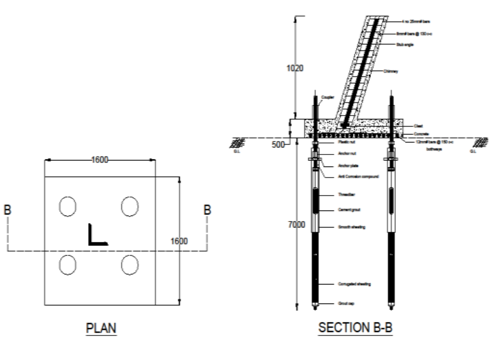
The checks such as check for bending and sliding for the mat slab and resistance check against uprooting of the stub for the chimney is also done. The working bond stress between the concrete and rock is determined in a similar manner as that of the hard rock foundation. In here the depth of the reinforced concrete mat slab is designed in an economical manner in order to transfer the loads from the tower to the rock anchor and also to enhance the prestressing process. The rock anchor rods are extended out of the reinforced concrete mat and prestressing of the anchor rods are done with the help of couplers selected from DYWYDAG coupler manual. This results in reduced depth of the mat slab. The chimney is designed for reinforcement and checked for resistance against uprooting of the stub and the reinforced concrete mat slab is designed and checked for sliding and bending in a similar manner as hard rock foundation. A detailed design of this foundation is shown in Fig 3 below.



Note: All dimensions are in mm.

Fig 3. Plan, Section of Rock Anchor Foundation (Prestressed)

V. TIME-COST BENEFIT ANALYSIS

Since the foundations design adopted for the hard anchor and prestressed rock anchor foundation differs from the conventional method checks not only pertaining to the design capacity and stability of the foundation to withstand the tower is needed but also a study on the most economical design on the basis of time required to execute the foundation in site and the cost involved in the foundation execution is to be analyzed. This will give a clear idea about the most economical type of foundation to be adopted for the hilly terrain.

The time-cost benefit analysis is done for the hard anchor vs. prestressed rock anchor foundation with the help of MS-Project software. For this comparative study individual tasks involved in designing and construction of the above mentioned foundations are considered. The resources in terms of time required for the execution of these foundation in site are arrived from field study done in TTRS (Tower Testing Research Station Chennai). The cost of the materials used for the time-cost benefit analysis were arrived from DSR-2012 (Delhi Schedule of Rates Handbook - 2012).

In the MS-Project software tasks were created and the time duration required for each task is specified. Resources in terms of cost and manpower is allocated for each and every task. The critical paths, slack in the project are calculated and the total project time and total cost involved for every foundation type is arrived. The tasks, their respective durations, cost involved and the resources allocated are shown in the Fig 4 & 5 below.

Hard Anchor

	Task Name	Cost	Duration
0	msproj11	₹475,568.75	9.78 days
1	1 Design of Transmission Tower	₹60,000.00	3 days
2	1.1 Analysis and Design	₹20,000.00	1 day
3	1.2 Structural Drawings	₹20,000.00	1 day
4	1.3 Proofing and correction	₹20,000.00	1 day
5	2 Site Preperation	₹2,682.00	1 day
6	2.1 Cleaning the site surface	₹2,232.00	4 hrs
7	2.2 Preparing the site	₹450.00	4 hrs
8	3 Laying out Foundation	₹412,886.75	6.33 days
9	3.1 Marking	₹62.50	1 hr
10	3.2 Excavating hard rock(blasting)	₹16,000.00	16 hrs
11	3.3 Drilling bores	₹12,480.00	1 day
12	3.4 Anchoring & Grouting Preperat	₹40,000.00	4 hrs
13	3.5 Inserting anchors	₹252,000.00	5 hrs
14	3.6 Grouting	₹5,495.00	3 hrs
15	3.7 Laying out PCC for bed	₹24,574.20	2 hrs
16	3.8 Reinforcement for mat	₹9,337.50	4 hrs
17	3.9 Shuttering for mat	₹2,640.00	2 hrs
18	3.10 Concretig for mat	₹30,717.75	5 hrs
19	3.11 Formwork for chimney	₹6,435.00	6 hrs
20	3.12 Reinforcement for chimney	₹2,801.25	1 day
21	3.13 Concrete for chimney	₹6,143.55	1 day
22	3.14 Refilling	₹4,200.00	6 hrs

Rock Anchor

	Task Name	Cost	Duration
0	msproj11	₹403,458.40	6.89 days
1	1 Design of Transmission Tower	₹60,000.00	3 days
2	1.1 Analysis and Design	₹20,000.00	1 day
3	1.2 Structural Drawings	₹20,000.00	1 day
4	1.3 Proofing and correction	₹20,000.00	1 day
5	2 Site Preperation	₹2,682.00	1 day
6	2.1 Cleaning the site surface	₹2,232.00	4 hrs
7	2.2 Preparing the site	₹450.00	4 hrs
8	3 Laying out Foundation	₹340,776.40	5.22 days
9	3.1 Marking	₹62.00	1 hr
10	3.2 Drilling bores	₹22,400.00	10 hrs
11	3.3 Anchoring & Grouting Preperation	₹40,000.00	4 hrs
12	3.4 Inserting anchors	₹235,200.00	5 hrs
13	3.5 Grouting	₹5,495.00	3 hrs
14	3.6 Reinforcement for mat	₹3,112.50	4 hrs
15	3.7 Shuttering for mat	₹2,640.00	2 hrs
16	3.8 Concretig for mat	₹12,287.10	4 hrs
17	3.9 Formwork for chimney	₹6,435.00	6 hrs
18	3.10 Reinforcement for chimney	₹2,801.25	4 hrs
19	3.11 Concrete for chimney	₹6,143.55	4 hrs
20	3.12 Refilling & Finishing	₹4,200.00	6 hrs

Note: The variations in the time and cost for the foundations are highlighted

Fig 4. Task comparison for hard anchor & rock anchor foundation

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RESOURCE SHEET

	Resource Name	Type	Std. Rate	Group
1	Concrete	Material	₹ 6,143.55	cum
2	Reinforcement	Material	₹ 62.25	kg
3	Bar bending	Work	₹ 562.50/day	
4	Labour	Work	₹ 337.50/day	
5	Formwork	Material	₹ 330.00	sqm
6	Site Clearance	Material	₹ 62.00	sqm
7	Planning	Cost		
8	Transportation	Cost		
9	Survey & Marking	Work	₹ 337.50/day	
10	Drilling	Material	₹ 800.00	m
11	Blasting Excavation	Work	₹ 1,000.00/hr	
12	Excavation	Work	₹ 700.00/hr	
13	Grouting for concrete	Material	₹ 350.00	m
14	Anchors & Accessories	Material	₹ 8,400.00	m

Fig 5. Common resources allocated for both foundations

While computing the total time of the project the slacks in the time duration of the project the critical paths in the project were taken into account. The critical tasks which takes up the maximum time of completion within the project in both the foundations projects are listed in Table 2 below

Table 2 Critical tasks in the project

Critical tasks in Hard Anchor Foundation	Critical tasks in Prestressed Rock Anchor foundation
Excavating hard rock	Marking
Drilling bores	Drilling bores
Anchoring & Grouting Preparation	Anchoring & Grouting Preparation
Concreting for PCC	Reinforcement in mat and chimney
Reinforcement in mat and chimney	Formwork for chimney
Formwork for chimney	Concreting for chimney
Concreting for chimney	Refilling
Refilling	-

From the above analysis the time and cost for the project is compared and is presented in the form of bar chart in Fig 6 &7 respectively.

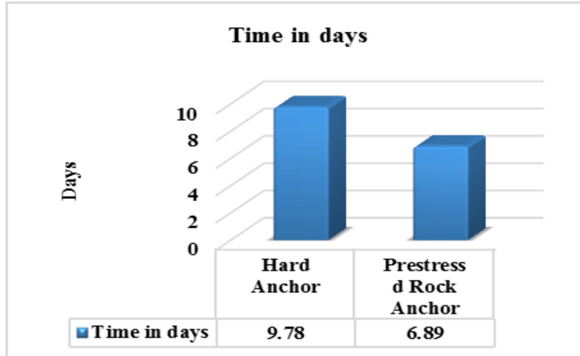

Fig 6. Project completion time comparison.

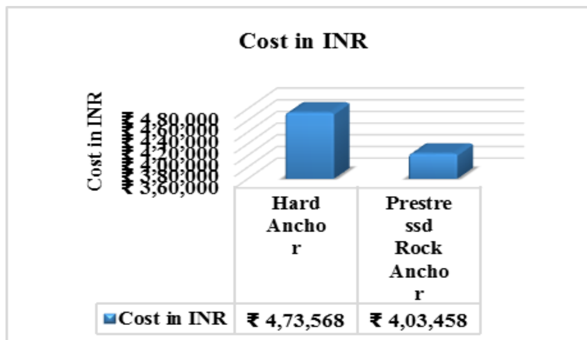

Fig 7. Foundation cost comparison

VI. CONCLUSIONS

Based on the above comparative study the following conclusions are drawn.

- The project completion time for prestressed rock anchor type of foundation was found to be 30% earlier when compared to hard anchor foundation.
- The overall cost of the prestressed rock anchor foundation was found to be 15% less when compared with hard anchor type foundation.
- The time-cost benefit analysis shows that the prestressed rock anchor design is more economical and time saving when compared to that of a conventional rock anchor system.
- Additional specifications such as the provision of reinforced mat slab and reinforced concrete chimney in the hard anchor and the rock anchor system proves to resist the TL tower from failure due to foundation but the prestressed rock anchor system is found to give much more economic benefits and also the time of execution is also less when compared to hard anchor foundation.

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