ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

Optimization of Distribution Poles for Medium Voltage Power Distribution Network in Sri Lanka

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Abstract:- Medium Voltage power distribution network in Sri Lanka accommodates different types of reinforced concrete and pre stressed poles. Sri Lanka is an environmentally diversified country of having a wide range of environmental conditions such as muddy, salty, hard soil, extreme windy, mountain terrain, etc. Hence, the selection of the optimum pole for a typical application in a particular environmental condition is in question due to forgone technical and economic advantage of different pole types on each other.

There was a necessity to develop a comprehensive method in order to select the most suitable pole type for a particular location. This effort is to develop an algorithm for selecting the best matched pole for typical site condition where user is allowed to select all the input parameters such as soil type, conductor, line profile, deviation angle, possibility of fixing stays or struts, provisions on mounting different transformer types, cross arm, insulator type, DDLO etc. This paper describes in detail the comprehensive algorithm, theory and assumptions used in formulating a pole optimization scheme in the Design Unit of the Ceylon Electricity Board.

Keywords:- *Power Distribution, Medium Voltage Network, Pole Stability, Transformer Mounting, Soil Bearing Capacity, Overturning Safety Factor.*

I. INTRODUCTION

The main electricity provider in Sri Lanka, Ceylon Electricity Board generates, transmits and distributes electricity power for domestic users as well as bulk consumers. The technical procedures and strategies taken to transmit power from generation upto consumers should be very precise in order to maintain the power quality to an acceptable level. Most importantly, the power distribution to all over the country should be strictly monitored and well organized to serve the country with an uninterrupted power supply with least power losses.

In this ground, medium voltage power distribution network serves as the backbone of the power distribution network in Sti Lanka. Moreover, this medium voltage power distribution system is the interconnection between low voltage power network and high voltage power network. Hence, medium voltage power distribution network should operate with a quality electrical supply ensuring safety and reliability throughout the whole time providing electrical supply to the all types of consumers at an affordable cost [1].

The strong performance of the medium voltage power distribution system decides the successful operation of the distribution network including general load growth, periodic demands and forecasted load developments. So, infrastructure systems required to distribute power in the medium voltage distribution system plays an important role which facilitates power flow without deteriorating the service quality.

Among the various kinds of materials, accessories and equipment used to construct medium voltage power distribution networks, power distribution poles are the most vital material that deserved great attention during selection procedures as well as in construction and erection. Most importantly maintaining statutory electrical clearances stipulated in [2] - [3] and ensuring the stability of the distribution pole with exerted bending moments due to acting loads on the poles are the two foremost concerns when selecting the most suitable pole type for a specific medium voltage line construction.

Due to the environmentally diversified nature of Sri Lanka, it is in high priority to have an appropriate analysis method to select pole types that facilitates the stabilized operation conditions in the presence of different types of geographical features such as soil types, vertical road angles, horizontal road angles, wind pressure etc. In addition, the excess load impacts cause due to other materials and accessories on the pole may limit a pole from being utilized in a specific medium voltage line construction work.

So, this algorithm facilitates to accommodate all the geographical features and other impacts from relevant materials and accessories to find the most suitable pole type for the application. In order to have a precise outcome it is required to investigate the site and decide the applicable factors that could affect the stabilization of the pole in both geographical aspect as well as line arrangement.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

II. LITERATURE REVIEW

➢ *Pole Types used in CEB Distribution Network*

The pole selection analysis comprises both the reinforced concrete poles and pre stressed concrete poles. The designed working load of the poles depend on several characteristics of concrete mixture and steel used to pole construction as indicated in Table 1 and Table 2 for RC poles and PS poles respectively [4] – [5].

Table 1 Characteristics Related to RC Poles

Characteristics Related to Reinforced Concrete Poles	Values
Concrete strength	25 N/mm^2
Steel strength of main reinforcement	450 N/mm^2
Steel strength of stirrups	250 N/mm^2
Maximum size of aggregate	20 mm
Minimum cover for all reinforcement	25 mm

Table 2 Characteristics Related to PS Poles

Characteristics Related to Pre-Stressed Poles	Values
Concrete strength	40 N/mm^2
Secondary steel reinforcement strength	450 N/mm^2
Stirrups and web reinforcement strength	250 N/mm^2
Maximum size of aggregate	15 mm
Minimum cover for all reinforcement	20 mm
Minimum spacing between pre-stressed tendons	20mm
Minimum spacing between secondary steel	25 mm

Conductors and line support accessories have a calculated designed working load. So, in order to provide allowance for deterioration due to unseen defects from metal fatigue, abrasion, corrosion, a factor of safety of 2.5 has been considered according to the [2]. The transverse load for any type of pole is considered to be acting on a point below 0.6m from top of the pole and buried length of one sixth of pole height is considered for the analysis [6].

Table 3 Dimensions of Poles used in CEB

Pole Type	Pole Weight (kg)	Pole Designed Working Load (kg)	Pole Height (m)	Pole Embedded Depth (m)	Bottom Broader Face Width (m)	Bottom Narrow Face Width (m)	Top Broader Face Width (m)	Top Narrow Face Width (m)
8.3m-100kg	610	100	8.3	1.38	0.290	0.142	0.142	0.142
8.3m-500kg	1100	500	8.3	1.38	0.350	0.200	0.200	0.200
9m-115kg	710	115	9.0	1.50	0.279	0.152	0.152	0.152
9m-500kg	1542	500	9.0	1.50	0.530	0.300	0.150	0.120
10m-225kg	858	225	10.0	1.67	0.340	0.130	0.210	0.130
10m-300kg	1010	300	10.0	1.67	0.343	0.178	0.152	0.152
11m-350kg	950	350	11.0	1.83	0.450	0.300	0.165	0.160
11m-500kg	1100	500	11.0	1.83	0.500	0.300	0.165	0.160
11m-850kg	1400	850	11.0	1.83	0.670	0.350	0.165	0.160
11m-1200kg	1600	1200	11.0	1.83	0.700	0.400	0.165	0.160
13m-500kg	1450	500	13.0	2.17	0.550	0.300	0.175	0.175
13m-850kg	1900	850	13.0	2.17	0.700	0.370	0.175	0.175
13m-1200kg	2305	1200	13.0	2.17	0.750	0.450	0.175	0.175

➢ *Wind Pressure Profile*

CEB monitored the wind data in Puttalam and central highlands also in 1999-2002 collecting data from 8 sites with anemometers installed at 10m, 20m and 40m [7]. Based on the outcome of these monitoring programs, an average wind pressure of 0.575 kN/m^2 has been considered for the calculations to address the possible occurrence of highest wind speed in Sri Lanka, 110km/h.

➢ *Soil Types in Sri Lanka*

As Sri Lanka is a highly diversified country with different environmental conditions and geometrical features, 4 different soil types are considered for the analysis such that, loose sand (soft clay), loose coarse sand (firm clay), loose sandy gravel (stiff clay) and compact sandy gravel (very stiff clay).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

➢ *Transformer Types used in CEB*

Medium voltage power distribution network in Sri Lanka utilizes 14 different capacity transformers in 11kV and 33kV distribution networks. Analysis facilitates to check the possibility of mounting these transformers in a specific pole as selected by the user and on the contrary, it is possible to find out the best match of pole to mount a specific transformer.

III. METHODOLOGY

The analysis accommodates several common parameters on stability calculation such as transformer clearance from pole edge, man weight, concrete density, foundation concrete block diameter, stay wire working tension, safety factor for MV conductors at minimum temperature, safety factor for MV conductors at every day temperature, stay fixing height from pole top, strut fixing height from pole top, gravitational force, Multiplication factor of wind pressure for circular surfaces and overturning safety factor. However, with the electrical clearance values to be maintained based on statutory regulations under Sri Lanka Electricity Act and geometrical features in the field, stay or strut fixing heights might differ and user is allowed to change these common parameters according to applicable values according to the specific filed requirements.

The pole selection and optimizing algorithm is depicted in the Figure 1.

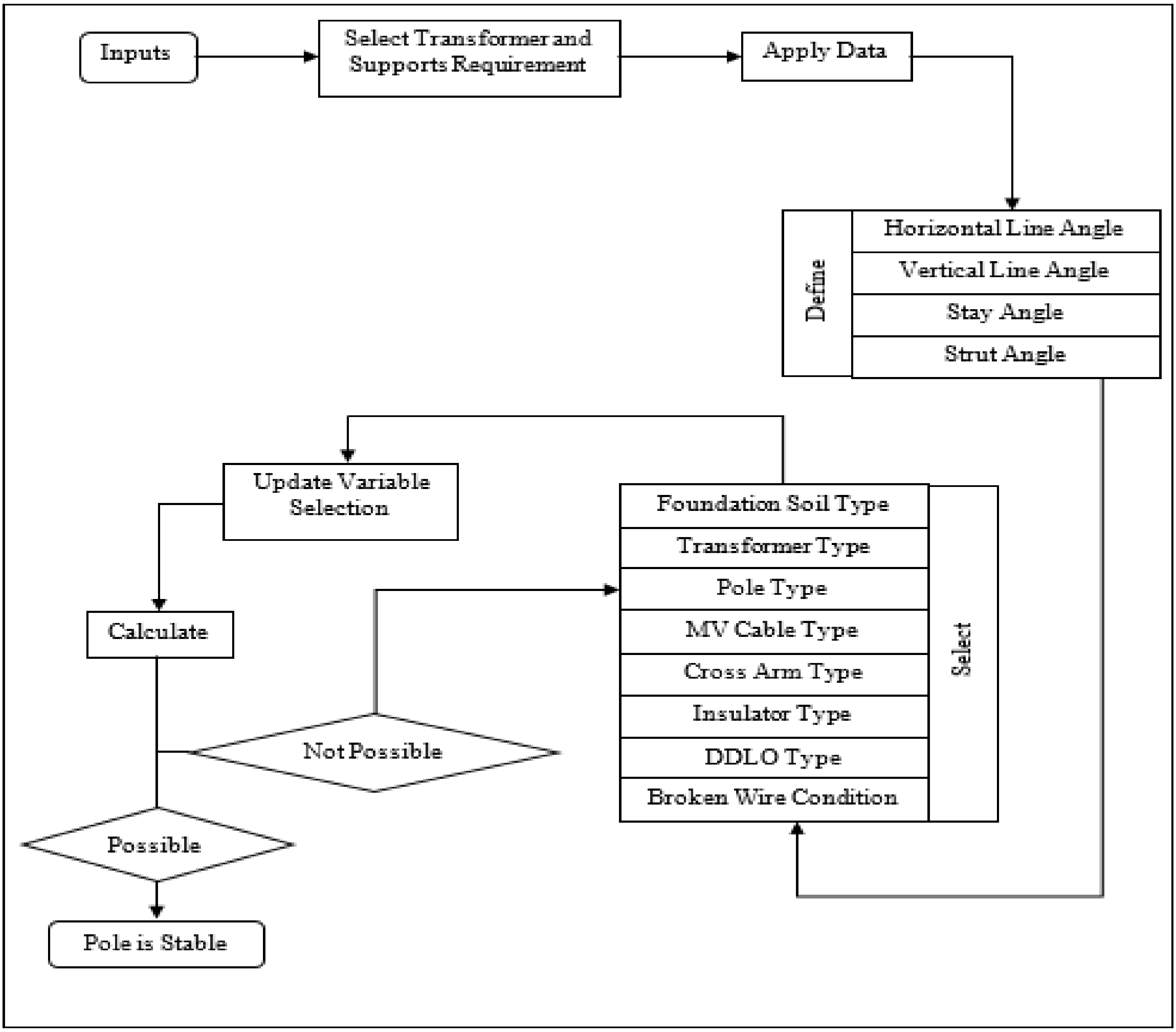

Fig 1 Flow Chart of the Analysis

This algorithm facilitates the user to identify whether the considered pole type is suitable for the construction or not. If it is not suitable, then user has to change the pole type with a higher working load and recalculate the results to find out the possible pole type which satisfies the field requirement

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

IV. POLE SELECTION ANALYSIS

The common parameters used for the analysis is given in Table 4. All these parameters have been calculated and decided with reference to existing CEB material specifications [8] – [9], manuals and current CEB practice in the field.

Table 4 Common Parameters for the Analysis

Symbol	Parameter	Value
w	Wind pressure	0.578 kN/m^2
cl_tx	Transformer clearance	0.45 m
man	Man weight	1.4709825 kN
d_con	Concrete density	23 kN/m^3
dia_con	Concrete block diameter	1.2 m
t_stay	Stay wire working tension	24.64 kN
sf_7C	Safety factor @ 7C	2.5
sf_ed	Safety factor @ every day temperature	4.5
h_stay	Stay fixing height from top of pole	2 m
h_strut	Struct fixing height from top of pole	2 m
g	Gravitational force	9.80655 N/kg
f	Multiplication factor for insulators/DDLOs	1.9
otsf	Overturning safety factor	1.5

Values for variables in the analysis shall be selected with a proper attention and close monitoring of the selected field. After having a proper investigation and clear geometrical and technical view of the location, it is required to input the horizontal and vertical line angles to the analysis where horizontal and vertical angles should be limited to a maximum value of 120^0 and 30^0 respectively. Stay and strut angles should be entered limiting to a maximum of 45^0, but mostly, the angle of stay or strut with respect to vertical axis is kept at 30^0 as much as possible due to the limited space around the site area.

This algorithm will analyze 13 types of concrete poles. Based on the concrete densities and other parameters listed in Table 1 and Table 2 these poles have different working load values. It is assumed that the working load is acting on the pole at a point of 0.6m down from the pole top while 100% of working load can be withstand in the transverse direction and only 25% of working load is applicable to the longitudinal load. These different portions of acting working loads are subjected to CEB specifications on poles.

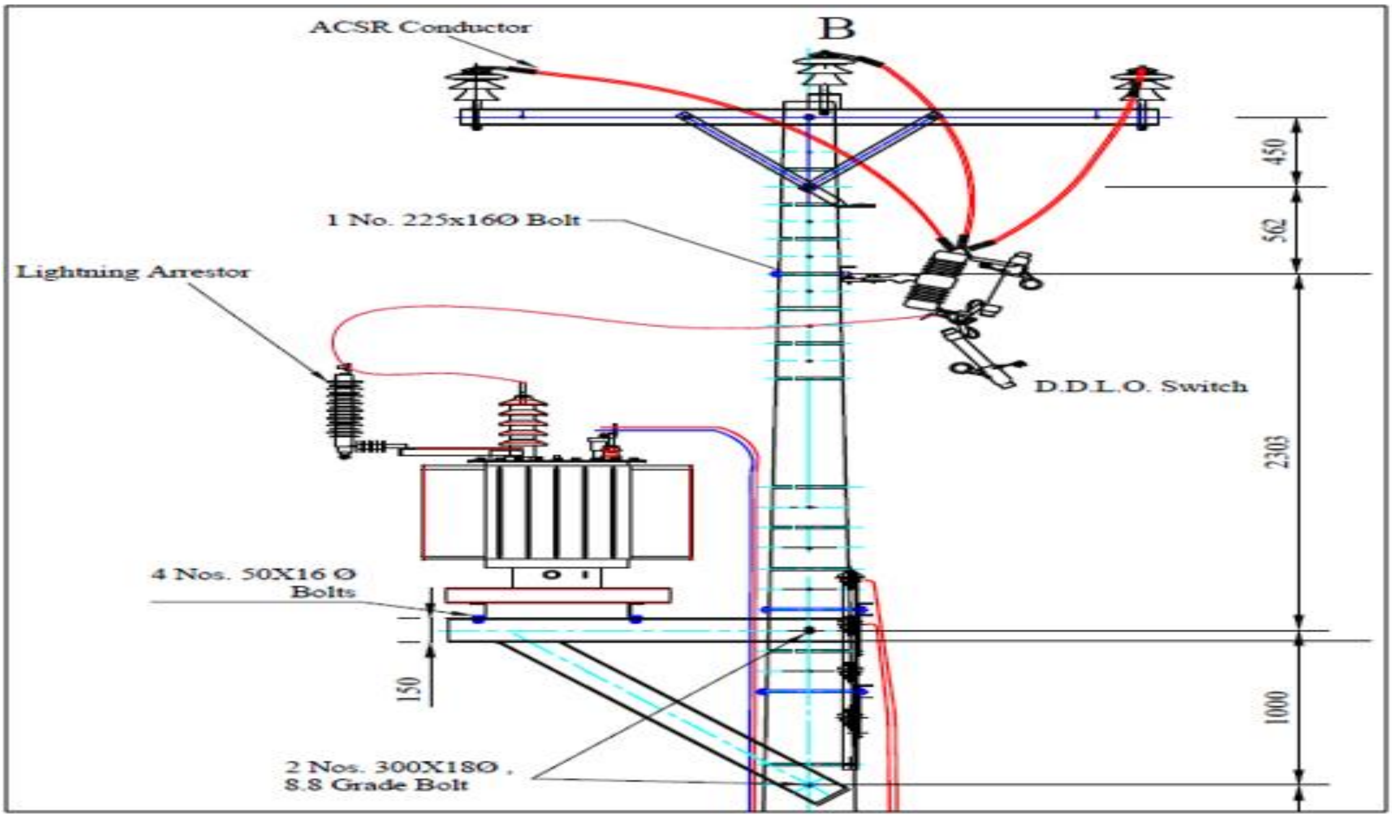

Fig 2 Single Pole Transformer Mounting on 11m Pole

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

V. TRANSVERSE AND LONGITUDINAL BENDING MOMENTS

Mostly, the transformer is mounted in the rare side of the pole in medium voltage distribution system in Ceylon Electricity Board. As narrow side of the pole is kept parallelly to the road when pole erection, rare side is the best location to mount a transformer as a pole can withstand 100% working load in that direction. Longitudinal bending moment is calculated in the direction of along the road. The bending moments applied on the pole from other accessories and equipment have been calculated in the transverse and longitudinal directions including bending moments from pole itself and other accessories such as insulators, cross arms, DDLOs, cables. All the bending moments exerted due to wind pressure on the accessories as well as self-weight. In addition, tension of the cables also exerted a bending moment on the pole and taken for the calculation.

Self-withstand bending moment values of a pole in transverse and longitudinal directions depends on its designed working load and safety factors. So, applicable total bending moments in both directions from pole and other accessories should be less than the maximum bending moments of the pole in the same directions. This is the foremost necessity to be fulfilled to check the pole stability for bending moments.

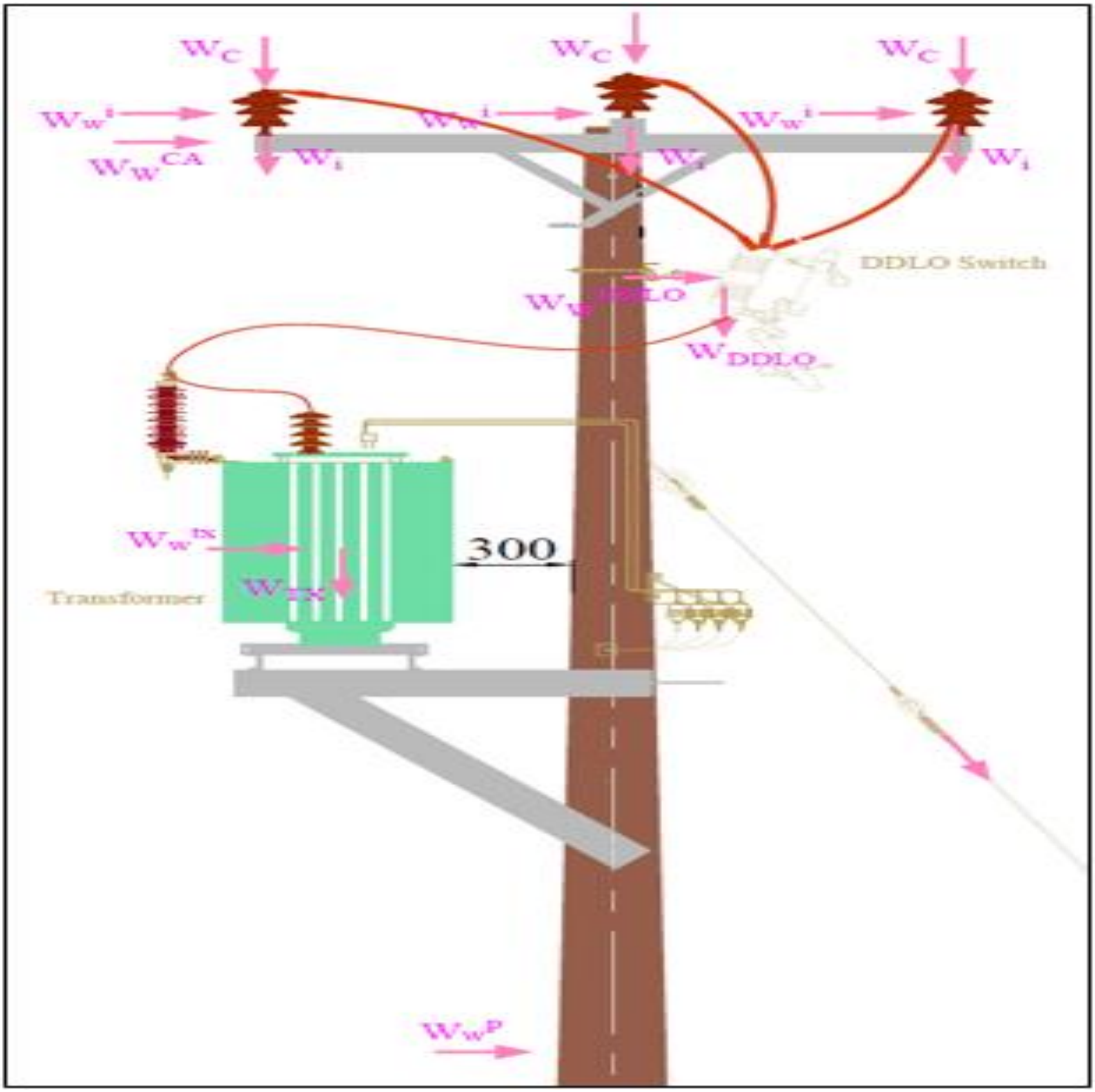

Fig 3 Bending Moment Components in Transverse Direction

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

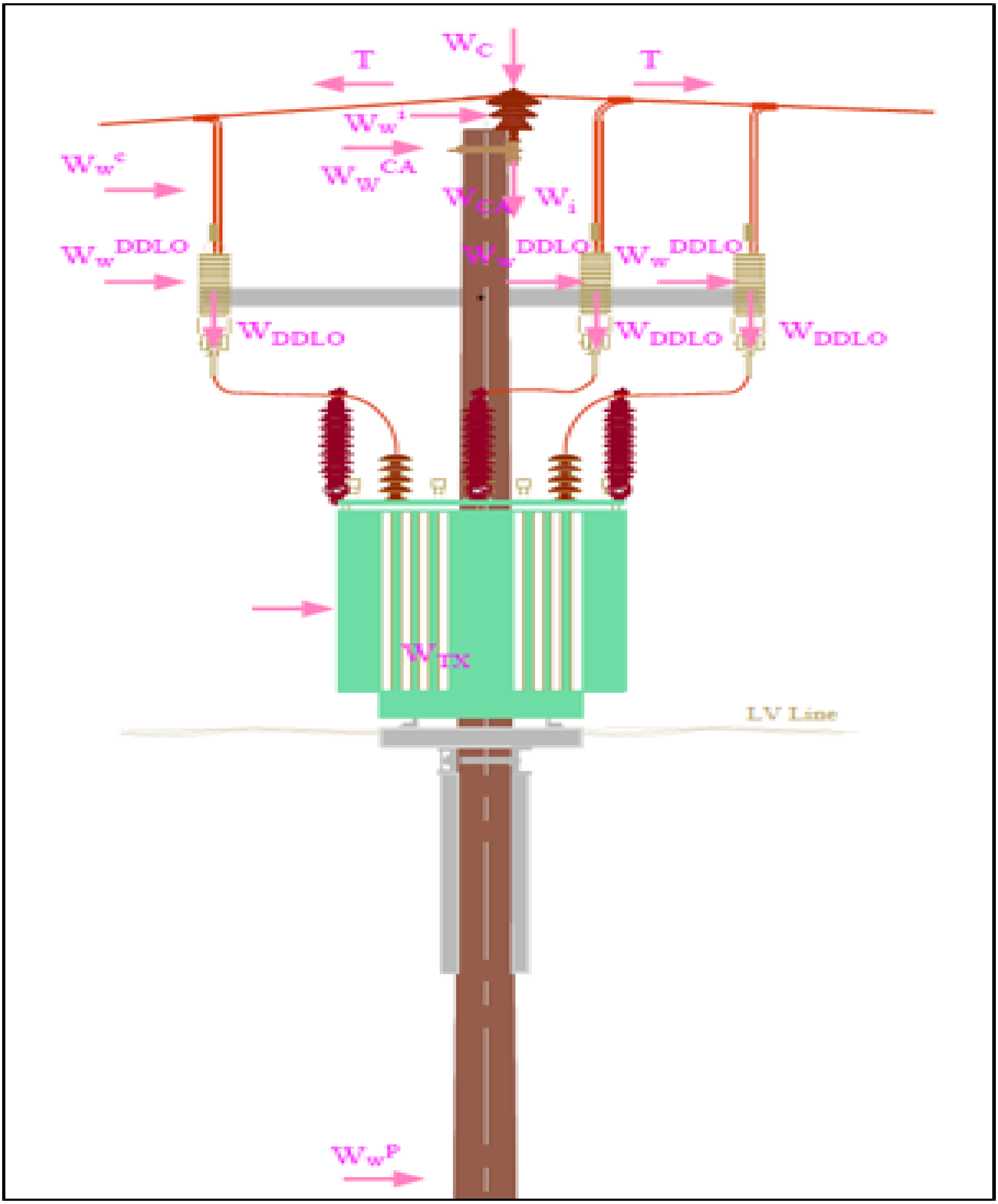

Fig 4 Bending Moment Components in Longitudinal Direction

➢ *Requirement of Stays or Struts*

When pole cannot withstand the applicable bending moments from its designed working load, the next step should be the analysis of using stays or struts. In this case, the excess bending moment beyond the maximum bending moments shall be borne by stay or strut.

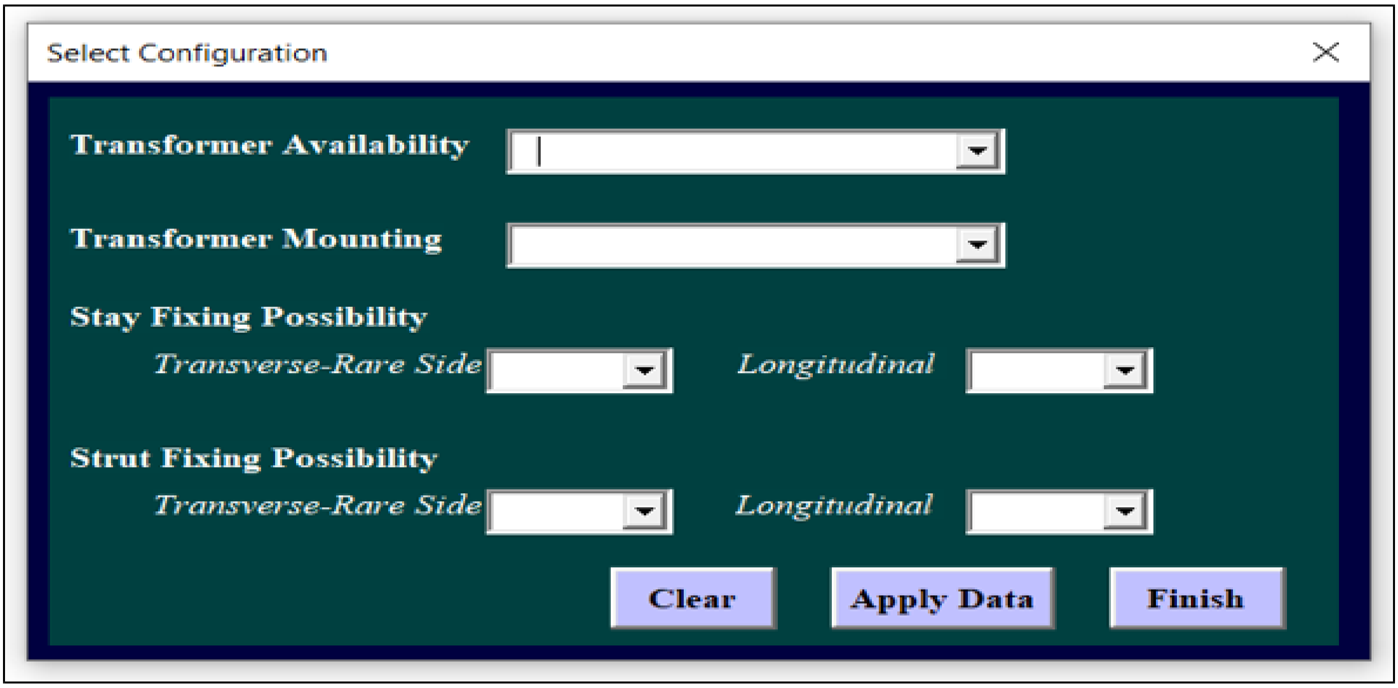

Fig 5 Data Input UI for Fixing Arrangements

In this analysis, it is possible to input what fixing method is possible based on the site conditions in both directions. So, with this input parameters, the algorithm will calculate the stay or strut requirement to cancel out excess bending moment. However, this analysis allows to use maximum of 2 stays or struts as supports due to constraints in the field such as aesthetic appearance and available space.

➢ *Applicability of Soil Pressure and Resisting Moments*

Pressure arisen due to total vertical load including concrete foundation block should be less than the bearing capacity of field soil type. Also, resisting moment exerted on the pole is the combination of resisting moment from soil and concrete foundation which has 1.2m diameter [10].

➢ *Impact from Overturning Safety Factor*

Overturning safety factor depends on total resisting moment and applicable bending moment. This algorithm allows a minimum 1.5 of overturning safety factor. The final outcome of the analysis is totally depending on four criteria such that, overturning safety factors in longitudinal and transverse directions, pressure exerted by total vertical load including weight of concrete block and total number of stays or struts as mentioned below.

VI. RESULTS

This sample calculation has been carried out considering mounting a transformer too on the pole for better analysis. However, it is possible to find out the stability of any pole without transformer where it has been facilitated to select whether a transformer is to be mounted on the pole or not using the UI given under Figure 5. In this case it is required to select “Transformer Availability” as “No” and “Transformer Mounting” as “Not Applicable”.

➢ *Configuration 1: Mounting of 33kV/250kVA Transformer on 10m/300kg Pole*

Table 5 Configuration Parameters

Parameter	**Value**
Horizontal line angle	0^0
Vertical line angle	0^0
Stay Fixing angle	30^0
Strut fixing angle	30^0
Soil type	Very stiff clay (Compact sandy gravel)
Transformer type	3kV/250kVA transformer
Pole type	10m/300kg pole
Conductor type	Racoon (ACSR)
Cross arm type	33kV cross arm
Insulator type	33kV pin insulator
DDLO type	33kV DDLO
Cable configuration	All cable sections are ideal. No any broken part.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

In addition, transformer shall be mounted on the rare side (outward direction-opposite to road side). Both stays and struts can be fixed in the transverse direction-rare side. Only stays can be fixed in the longitudinal direction.

Total applicable bending moments in both transverse and longitudinal directions are higher than the maximum bending moments that the 10m/300kg pole can withstands. So, the analysis shown that supporting accessories are required for both directions, and that could be either stays or struts. However according to the configuration parameters entered at the beginning as shown in Figure 5 using user interface, the most applicable way is to fix one strut in transverse direction and one stay in longitudinal direction. So, the first two criteria have been met through the analysis.

The third criterion, checking for resisting moments also accepted according to the results where total pressure exerted on the soil is lesser than the bearing capacity of soil which is 300 kN/m^2. The overturning safety factors are 1.4 and 3.4 for transverse and longitudinal directions respectively. So, fourth criterion is violated in the transverse direction and hence the pole is not stable with this configuration due to not satisfying all four criteria in the analysis.

So, in the process of finding a suitable pole for mounting, the next available pole shall be selected and outcome is given in Figure 6.

Designed Values			
Bending Moments			
Transverse Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
TBM-W_{tx}	Transformer Weight	12.7338	kNm
TBM-W_w^{tx}	Wind Pressure on Tx	7.9809	kNm
TBM-W_w^{CA}	Wind Pressure on CA	0.0054	kNm
TBM-W_i	Insulator Weight	0.0123	kNm
TBM-W_w^{i}	Wind Pressure on Insulator	0.3821	kNm
TBM-W_w^{P}	Wind Pressure on Pole	0.4822	kNm
TBM-W_{DDLO}	DDLO Weight	0.1259	kNm
TBM-W_w^{DDLO}	Wind Pressure on DDLO	0.7007	kNm
TBM-W_w^{C}	Wind Pressure on Cable	7.3710	kNm
TBM-W_c	Cable Weight	0.0129	kNm
TBM-T	Cable Tension	0.0000	kNm
BM_{Trans}	**Total Transverse BM**	**29.8070**	**kNm**
Longitudinal Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
LBM-W_w^{tx}	Wind Pressure on Tx	5.9313	kNm
LBM-W_{CA}	Cross Arm Weight	0.0284	kNm
LBM-W_w^{CA}	Wind Pressure on CA	1.0945	kNm
LBM-W_i	Insulator Weight	0.0371	kNm
LBM-W_w^{i}	Wind Pressure on Insulator	0.6033	kNm
LBM-W_w^{P}	Wind Pressure on Pole	0.6971	kNm
LBM-W_{DDLO}	DDLO Weight	0.0152	kNm
LBM-W_w^{DDLO}	Wind Pressure on DDLO	0.4437	kNm
LBM-W_c	Cable Weight	3.9243	kNm
LBM-T	Cable Tension	0.0000	kNm
BM_{Long}	**Total Longitudinal BM**	**12.7750**	**kNm**
BM_{Stay}	**Bending Moment of Stay**	**78.0881**	**kNm**
BM_{Strut}	**Bending Moment of Strut**	**9.3196**	**kNm**
B_{TMax}	BM_{Trans}^{Max}	22.7512	kNm
B_{LMax}	BM_{Long}^{Max}	5.6878	kNm
Dir_TBM	Transverse BM Direction	Outward-Rare Side	N/A
Req_StayT	Requirement of Stay / Strut - Transverse	Yes	N/A
Req_StayL	Requirement of Stay / Strut - Longitudinal	Yes	N/A
N_StayT	No of Stays Required - Transverse	0	Nos.
N_StrutT	No of Struts Required - Transverse	1	Nos.
N_StayL	No of Stays Required - Longitudinal	1	Nos.
N_StrutL	No of Struts Required - Longitudinal	0	Nos.
Tot_Stay	Total No of Stays	1	Nos.
Tot_Strut	Total No of Struts	1	Nos.
TVL	Total Vertical Load	46.3685	kN
W_CB	Concrete Block Weight	43.3540	kN
P_CB	Pressure with concrete block	79.3001	kN/m^2
RM_Soil	RM by Soil	17.7778	kNm
RM_Con	RM by Concrete	26.0124	kNm
RM_Tot	Total Resisting Moment	43.7902	kNm
OTSF_T	Overturning Safety Factor-Transverse	1.4691	N/A
OTSF_L	Overturning Safety Factor-Longitudinal	3.4278	N/A
Pos_TM	Possibility of Mounting Transformer	Not Possible	N/A
Calculate			

Fig 6 Sample Calculation for 33kV/250kVA Transformer on 10m/300kg Pole

➢ *Configuration 2: Mounting of 33kV/250kVA Transformer on 11m/350kg Pole*

Configuration parameters for the analysis are same as in **Configuration 1**. Only the pole has been changed to check the most suitable pole to mount the 33kV/250kVA transformer because 10m/300kg pole cannot withstand with the loads from transformer and other accessories.

- Pole type: 11m/350kg pole
- Cable configuration: All cable sections are ideal. No any broken part.

In addition, transformer shall be mounted on the rare side (outward direction-opposite to road side). Both stays and struts can be fixed in the transverse direction-rare side. Only stays can be fixed in the longitudinal direction.

From these analysis results it is possible to mount the 33kV/250kVA transformer on a 11m/350kg pole. However, the main restriction to this configuration is the soil type. For **Configuration 1** and **Configuration 2**, very stiff clay (Compact sandy gravel) type been selected. The analysis results when soil type is changed to a low bearing capacity is shown in Figure 8 under **Configuration 3**.

Designed Values			
Bending Moments			
Transverse Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
$TBM\text{-}W_{tr}$	Transformer Weight	12.7338	kNm
$TBM\text{-}W_w^{tr}$	Wind Pressure on Tx	7.9809	kNm
$TBM\text{-}W_w^{CA}$	Wind Pressure on CA	0.0059	kNm
$TBM\text{-}W_i$	Insulator Weight	0.0123	kNm
$TBM\text{-}W_w^{i}$	Wind Pressure on Insulator	0.4198	kNm
$TBM\text{-}W_w^{P}$	Wind Pressure on Pole	0.7241	kNm
$TBM\text{-}W_{DDLO}$	DDLO Weight	0.1288	kNm
$TBM\text{-}W_w^{DDLO}$	Wind Pressure on DDLO	0.7803	kNm
$TBM\text{-}W_w^{C}$	Wind Pressure on Cable	8.0909	kNm
$TBM\text{-}W_c$	Cable Weight	0.0129	kNm
TBM-T	Cable Tension	0.0000	kNm
BM_{Trans}	**Total Transverse BM**	**30.8896**	**kNm**
Longitudinal Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
$LBM\text{-}W_w^{tr}$	Wind Pressure on Tx	5.9313	kNm
$LBM\text{-}W_{CA}$	Cross Arm Weight	0.0295	kNm
$LBM\text{-}W_w^{CA}$	Wind Pressure on CA	1.2053	kNm
$LBM\text{-}W_i$	Insulator Weight	0.0386	kNm
$LBM\text{-}W_w^{i}$	Wind Pressure on Insulator	0.6629	kNm
$LBM\text{-}W_w^{P}$	Wind Pressure on Pole	1.1038	kNm
$LBM\text{-}W_{DDLO}$	DDLO Weight	0.0152	kNm
$LBM\text{-}W_w^{DDLO}$	Wind Pressure on DDLO	0.4942	kNm
$LBM\text{-}W_c$	Cable Weight	3.9243	kNm
LBM-T	Cable Tension	0.0000	kNm
BM_{Long}	**Total Longitudinal BM**	**13.4051**	**kNm**
BM_{Stay}	**Bending Moment of Stay**	**88.3256**	**kNm**
BM_{Strut}	**Bending Moment of Strut**	**12.3035**	**kNm**
B_{TMax}	BM_{Trans}^{Max}	29.4033	kNm
B_{LMax}	BM_{Long}^{Max}	7.3508	kNm
Dir_TBM	Transverse BM Direction	Outward-Rare Side	N/A
Req_StayT	Requirement of Stay / Strut - Transverse	Yes	N/A
Req_StayL	Requirement of Stay / Strut - Longitudinal	Yes	N/A
N_StayT	No of Stays Required - Transverse	0	Nos.
N_StrutT	No of Struts Required - Transverse	1	Nos.
N_StayL	No of Stays Required - Longitudinal	1	Nos.
N_StrutL	No of Struts Required - Longitudinal	0	Nos.
Tot_Stay	Total No of Stays	1	Nos.
Tot_Strut	Total No of Struts	1	Nos.
TVL	Total Vertical Load	45.2897	kN
W_CB	Concrete Block Weight	47.6894	kN
P_CB	Pressure with concrete block	82.1785	kN/m^2
RM_Soil	RM by Soil	23.6622	kNm
RM_Con	RM by Concrete	28.6136	kNm
RM_Tot	Total Resisting Moment	52.2758	kNm
OTSF_T	Overturning Safety Factor-Transverse	1.6923	N/A
OTSF_L	Overturning Safety Factor-Longitudinal	3.8997	N/A
Pos_TM	Possibility of Mounting Transformer	**Possible**	N/A
Calculate			

Fig 7 Sample Calculation for 33kV/250kVA Transformer on 11m/350kg Pole (Compact Sandy Gravel)

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

➢ *Configuration 3: Mounting of 33kV/250kVA Transformer on 11m/350kg Pole in Loose Sandy Gravel*

All the parameters and conditions are same as **Configuration 2** except soil type. Soil type is set to loose sandy gravel.

Designed Values			
Bending Moments			
Transverse Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
TBM-W_{tx}	Transformer Weight	12.7338	kNm
TBM-W_w^{tx}	Wind Pressure on Tx	7.9809	kNm
TBM-W_w^{CA}	Wind Pressure on CA	0.0059	kNm
TBM-W_i	Insulator Weight	0.0123	kNm
TBM-W_w^{I}	Wind Pressure on Insulator	0.4198	kNm
TBM-W_w^{P}	Wind Pressure on Pole	0.7241	kNm
TBM-W_{DDLO}	DDLO Weight	0.1288	kNm
TBM-W_w^{DDLO}	Wind Pressure on DDLO	0.7803	kNm
TBM-W_w^{C}	Wind Pressure on Cable	8.0909	kNm
TBM-W_c	Cable Weight	0.0129	kNm
TBM-T	Cable Tension	0.0000	kNm
BM_{Trans}	**Total Transverse BM**	**30.8896**	**kNm**
Longitudinal Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
LBM-W_w^{tx}	Wind Pressure on Tx	5.9313	kNm
LBM-W_{CA}	Cross Arm Weight	0.0295	kNm
LBM-W_w^{CA}	Wind Pressure on CA	1.2053	kNm
LBM-W_i	Insulator Weight	0.0386	kNm
LBM-W_w^{I}	Wind Pressure on Insulator	0.6629	kNm
LBM-W_w^{P}	Wind Pressure on Pole	1.1038	kNm
LBM-W_{DDLO}	DDLO Weight	0.0152	kNm
LBM-W_w^{DDLO}	Wind Pressure on DDLO	0.4942	kNm
LBM-W_c	Cable Weight	3.9243	kNm
LBM-T	Cable Tension	0.0000	kNm
BM_{Long}	**Total Longitudinal BM**	**13.4051**	**kNm**
BM_{Stay}	**Bending Moment of Stay**	**88.3256**	**kNm**
BM_{Strut}	**Bending Moment of Strut**	**12.3035**	**kNm**
B_{TMax}	BM_{Trans}^{Max}	29.4033	kNm
B_{LMax}	BM_{Long}^{Max}	7.3508	kNm
Dir_TBM	Transverse BM Direction	Outward-Rare Side	N/A
Req_StayT	Requirement of Stay / Strut - Transverse	Yes	N/A
Req_StayL	Requirement of Stay / Strut - Longitudinal	Yes	N/A
N_StayT	No of Stays Required - Transverse	0	Nos.
N_StrutT	No of Struts Required - Transverse	1	Nos.
N_StayL	No of Stays Required - Longitudinal	1	Nos.
N_StrutL	No of Struts Required - Longitudinal	0	Nos.
Tot_Stay	Total No of Stays	1	Nos.
Tot_Strut	Total No of Struts	1	Nos.
TVL	Total Vertical Load	45.2897	kN
W_CB	Concrete Block Weight	47.6894	kN
P_CB	Pressure with concrete block	82.1785	kN/m^2
RM_Soil	RM by Soil	23.6622	kNm
RM_Con	RM by Concrete	28.6136	kNm
RM_Tot	Total Resisting Moment	52.2758	kNm
OTSF_T	Overturning Safety Factor-Transverse	1.6923	N/A
OTSF_L	Overturning Safety Factor-Longitudinal	3.8997	N/A
Pos_TM	Possibility of Mounting Transformer	Possible	N/A
Calculate			

Fig 8 Sample Calculation for 33kV/250kVA Transformer on 11m/350kg Pole (Loose Sandy Gravel)

In this configuration with a different soil type also, the pole can still withstand the load. The next configuration gives the results for same configuration with loose coarse sand which has a lower bearing capacity than loose sandy gravel.

➢ *Configuration 4: Mounting of 33kV/250kVA Transformer on 11m/350kg Pole in Loose Coarse Sand*

Designed Values			
Bending Moments			
Transverse Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
$TBM\text{-}W_{tx}$	Transformer Weight	12.7338	kNm
$TBM\text{-}W_w^{tx}$	Wind Pressure on Tx	7.9809	kNm
$TBM\text{-}W_w^{CA}$	Wind Pressure on CA	0.0059	kNm
$TBM\text{-}W_i$	Insulator Weight	0.0123	kNm
$TBM\text{-}W_w^i$	Wind Pressure on Insulator	0.4198	kNm
$TBM\text{-}W_w^P$	Wind Pressure on Pole	0.7241	kNm
$TBM\text{-}W_{DDLO}$	DDLO Weight	0.1288	kNm
$TBM\text{-}W_w^{DDLO}$	Wind Pressure on DDLO	0.7803	kNm
$TBM\text{-}W_w^C$	Wind Pressure on Cable	8.0909	kNm
$TBM\text{-}W_c$	Cable Weight	0.0129	kNm
TBM-T	Cable Tension	0.0000	kNm
BM_{Trans}	**Total Transverse BM**	**30.8896**	**kNm**
Longitudinal Bending Moments (kNm)			
Parameter	**Description**	**Value**	**Units**
$LBM\text{-}W_w^{tx}$	Wind Pressure on Tx	5.9313	kNm
$LBM\text{-}W_{CA}$	Cross Arm Weight	0.0295	kNm
$LBM\text{-}W_w^{CA}$	Wind Pressure on CA	1.2053	kNm
$LBM\text{-}W_i$	Insulator Weight	0.0386	kNm
$LBM\text{-}W_w^i$	Wind Pressure on Insulator	0.6629	kNm
$LBM\text{-}W_w^P$	Wind Pressure on Pole	1.1038	kNm
$LBM\text{-}W_{DDLO}$	DDLO Weight	0.0152	kNm
$LBM\text{-}W_w^{DDLO}$	Wind Pressure on DDLO	0.4942	kNm
$LBM\text{-}W_c$	Cable Weight	3.9243	kNm
LBM-T	Cable Tension	0.0000	kNm
BM_{Long}	**Total Longitudinal BM**	**13.4051**	**kNm**
BM_{Stay}	**Bending Moment of Stay**	**88.3256**	**kNm**
BM_{Strut}	**Bending Moment of Strut**	**12.3035**	**kNm**
B_{TMax}	BM_{Trans}^{Max}	29.4033	kNm
B_{LMax}	BM_{Long}^{Max}	7.3508	kNm
Dir_TBM	Transverse BM Direction	Outward-Rare Side	N/A
Req_StayT	Requirement of Stay / Strut - Transverse	Yes	N/A
Req_StayL	Requirement of Stay / Strut - Longitudinal	Yes	N/A
N_StayT	No of Stays Required - Transverse	0	Nos.
N_StrutT	No of Struts Required - Transverse	1	Nos.
N_StayL	No of Stays Required - Longitudinal	1	Nos.
N_StrutL	No of Struts Required - Longitudinal	0	Nos.
Tot_Stay	Total No of Stays	1	Nos.
Tot_Strut	Total No of Struts	1	Nos.
TVL	Total Vertical Load	45.2897	kN
W_CB	Concrete Block Weight	47.6894	kN
P_CB	Pressure with concrete block	82.1785	kN/m²
RM_Soil	RM by Soil	20.9509	kNm
RM_Con	RM by Concrete	28.6136	kNm
RM_Tot	Total Resisting Moment	49.5646	kNm
OTSF_T	Overturning Safety Factor-Transverse	1.6046	N/A
OTSF_L	Overturning Safety Factor-Longitudinal	3.6974	N/A
Pos_TM	Possibility of Mounting Transformer	Not Possible	N/A
Calculate			

Fig 9 Sample Calculation for 33kV/250kVA Transformer on 11m/350kg Pole (Loose Coarse Sand)

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24JUN212

VII. DISCUSSION

According to the pole loading analysis results summarized here, one of the main parameters that decides the pole stability is the soil type of the filed. When bearing capacity of the soil type is increasing, the stability of the pole erected in that specific soil is also high. These results are for Racoon conductor which has a cable weight of 0.00319kN/m. However, with the Racoon MV cable, pole is stable only for poles which have a height higher than 10m. Also, the designed working load should be higher than 300kg to bare the loads resulted from other line accessories.

This analysis can be used to check out the pole stability in any line configuration in medium voltage power distribution network where all the applicable parameters and variables can be set according to the site geometry and arrangements. So, according to the analysis, 10m/300kg pole is stable for same parameters under Configuration 1 without a transformer for both very stiff clay (Compact sandy gravel) and stiff clay (Loose sandy gravel). Stability cannot be expected when soil type is loose coarse sand or loose sand where bearing capacities are 75kN/m^2 and 25kN/m^2 respectively.

When cable type is changed to Lynx which has a higher cable weight of 0.00826 kN/m, with same parameters in Configuration 1 without transformer, the 10m/300kg pole is stable. But it is not possible to mount a 33kV/250kV transformer on the pole as it is not in stable condition with the transformer. However, even without the transformer, pole is stable only for compact sandy gravel and loose sandy gravel soil types. With compact sandy gravel, the maximum capacity transformer, the 10m/300kg pole can withstand is 33kV/160kVA.

VIII. CONCLUSION

This analysis facilitates the user to decide on the compatibility of pole configuration according to site requirement. The most important factors concerned in this analysis are possibility of fixing stays and struts in the field, transformer mounting direction, horizontal and vertical lines angles. Apart from that, this analysis can be used in each and every case of pole erecting situation by changing the common parameters as well.

This analysis depicts that, bending moment from accessories is just one factor that decides the pole stability. Apart from that, it is in the highest importance to contemplate on bearing pressure, resisting moments and overturning conditions because in some cases just due to a change only in soil type makes the final outcome opposite. So, it is very vital to carefully select the variables and parameters for the analysis after proper inspection of the site.

The reliable operation of medium voltage power distribution network is one of the main concerns in Ceylon Electricity Board services because it directly affects on day-to-day work life of domestic consumers, bulk consumers and maintenance / operation cost. The existing network of medium voltage power distribution does not refer any analyzer to find out the most suitable pole type for the construction purpose. This tool can be further utilized in order to determine the behavior of existing poles of the medium voltage network. Specially, for any pole in danger due to new installation, soil erosion, water logging, etc. Finally, we are in the process of developing a Mobile App for smart phones for easier usage at sites.

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