IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 4 Ver. II (Jul- Aug. 2014), PP 07-15
www.iosrjournals.org

A New Vision for Design of Steel Transmission Line Structures by Reliability Method

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Abstract: *A reliability design method for statically determinate and indeterminate steel transmission lines towers and poles is presented. The method is in a Load and Resistance Factor Design (LRFD) format. The nominal load and resistance values for design are obtained from the mean values of probability distribution functions describing wind speed, radial ice thickness and yield stress. The load and resistance involving the coefficient of variation of the above variables and a target reliability index. Several cases demonstrate that use of the equations results in steel line having an actual reliability index nearly equal to the target reliability index.*

Probability of failure calculations by the methods of numerical integration and the design point method are discussed. The mathematical relationship between probability of failure and the reliability index is explained.

The analysis and design by computer program, using reliability method gives more safety and economical results.

Keywords*: Steel Transmission Structure, Reliability, Design.*

I. Introduction:

One motive for examining the design of steel utility truss is to seed a balance between initial costs and failure costs. A simplified graphical representation of this concept is shown.[1]

The concept of structural design has been undergoing radical changes in philosophy in the last several years. A large amount of research and development in this area has been and is being concentrated on the application of concepts of reliability analysis to design. Major research efforts have been conducted for several construction materials [1,2,3], and have resulted in proposals for alternate reliability-based (often called probability- based design methodology).

The development of new concepts for design, involving some form of reliability assessment has resulted largely because of the better control of safety and economy they promise to provide.

. The specific research objective was to develop an improved design method which would result in structures being consistently closer to the optimum reliability level than possible using current methods,, while retaining the simplicity and low expense of use necessary for a practical design method.

. Similarly in reliability design or the distributions of R and S may be driven forwards or backwards to adjust α.

Conventional design can lead to under designed (failure prone) or over designed (expensive) structures.

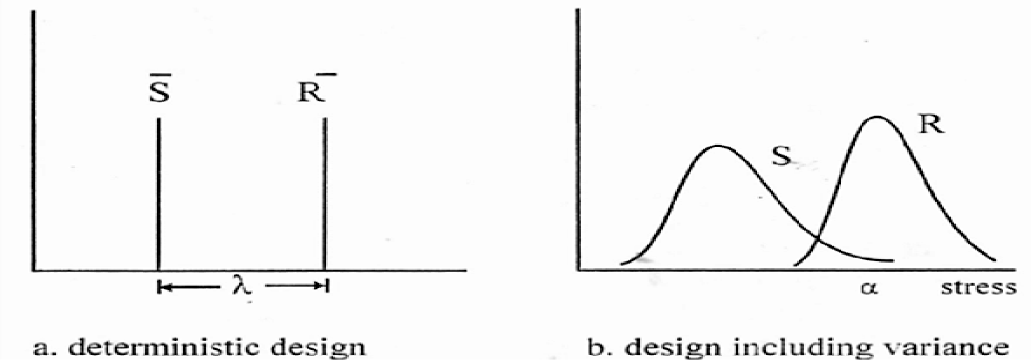


Figure (1.1). Comparison of deterministic design and designIncluding variance.

1.1Steps of Solution:

- Study the design parameters covering the design(loads, resistance) to concepts of reliability.
- Study the mathematical of structural analysis of steeltransmission line towers.
- Study methods of calculation probability of failure including but-up of computer program.
- Determination the probability — based values for parameters covering the design (new proposed method).

1.2Load and Resistance Factor Design:

The uncertainty of structural performance due to variable loads and resistance can be compensated for designing with decreased values of resistance and increased loads. Loads or load effects can be increased, and resistance can be decreased, by applying load and resistance factors, respectively, to the nominal values of loads and resistance. A general design equation, with a summation for multiple loads, is written symbolically as:

$$\phi R > A\ (\Sigma \gamma_i P_i) \qquad \text{………………………(1)}$$

Where γ is a load factor usually greater than unity,
$\emptyset$ is a resistance factor less than unity,
R is structural resistance however one chooses to quantify it,
P_i are generalized loads, and
A is the analysis that converts loads to load effects with dimensions comatible to those of R.

II. Problem Study

Equation(1) is a design equation expressed in load and resistance factor design (LRFD) format see figure (1 and 2). The problem of assigning values to $\emptyset$ and γ illustrates another major difference between conventional and reliability design. Load and resistance factors for conventional design have historically been ignored in favor of using factors of safety based on the judgment and past experience of members of professional engineering society committees. Reliability design on the other hand, uses the logical approach of basing the parameters of equation (1) ($\emptyset$, γ, R, P) on the probability distributions of the load and resistance variables associated with the structure to be designed. figure (3)

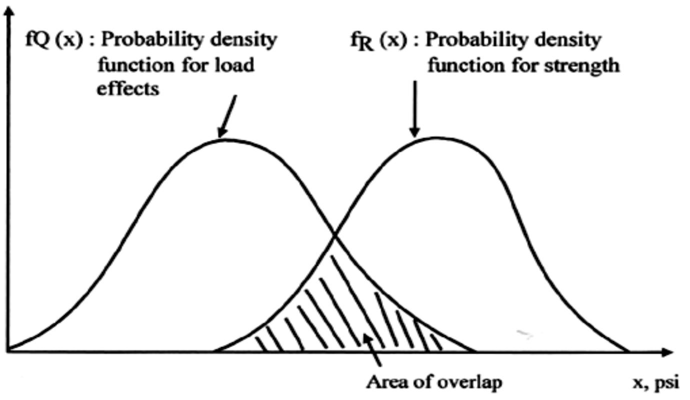


Figure (1)

Figure 1.7a. Structural Reliabliity Diagram for Load Effects Q and Resistance R Model

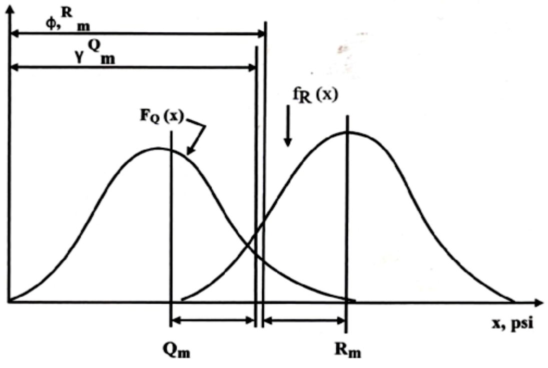


Figure (2) b Load and resistance factor design format

$$\phi R_m \geq \gamma Q_m$$

Where ϕ = resistance factor,

R_m = mean resistance,

γ = load factor , and

Φ_m= mean load effects

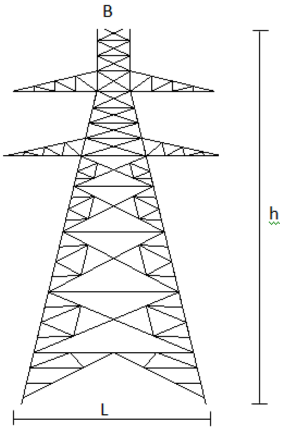


figure (3): The steel transmission tower

2.1 Loading conditions

To maximize stresses in tower members and loadings on foundations. The following loading combinations should be investigated.

Intact loading case:

1. Maximum transverse, maximum vertical.
2. Maximum transverse, minimum vertical.
3. Maximum transverse conductor, minimum transverse OHGA, minimum vertical.
4. Maximum transverse conductor, minimum transverse OGHA, minimum vertical.
5. Combination of vertical loads (max. and min) to obtain vertical torsion (spans iced and bare).
6. Broken Wire (or other longitudinal) Loading. Taking maximum longitudinal and vertical and minimum for the point from (1 -5) above.

2.2 Analysis of the Study Problem (deterministic design):

Generally, the program assumes or the engineer inputs either assumed member sizes or areas of members into the three-dimensional elastic analysis program after the forces are distributed based on satisfying statics and the stiffness matrix, the members are sized. It the size of the members now selected vary considerably from the original assumed sizes, a reanalysis should be conducted to determine the extent to which the load distribution has changed, if at all, deterministic design for tower S60 is shown below:

It would appear that a “catch 22” can and does exist in some areas of the tower, for inatance, let us assume that we have a crossarm where the hanger and main corssarm members can take tension and compression. Let us also assume that only a longitudinal load is applied.

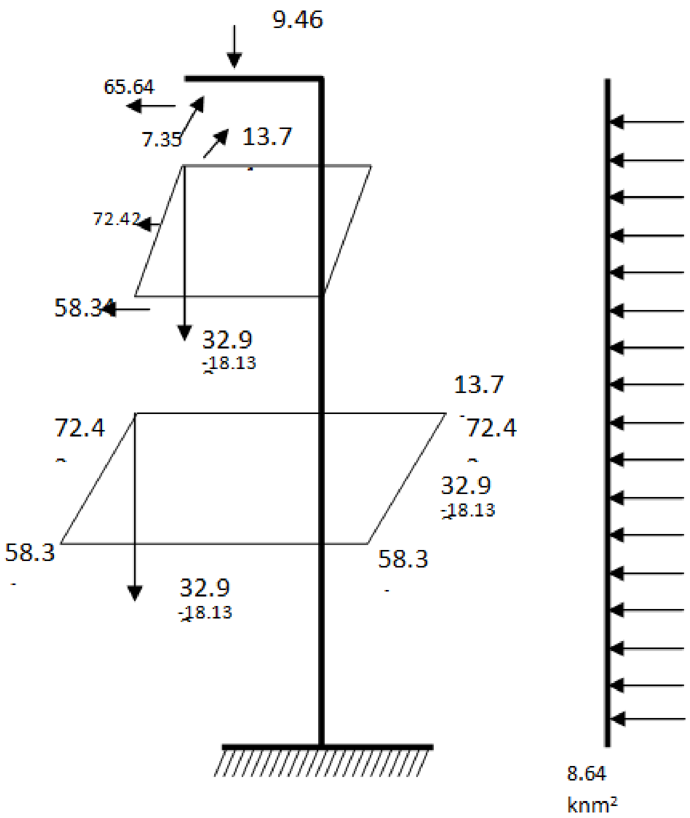
Thus, in this study failure is assumed to occur when either of the events below occur:

1. The maximum plastic bending stress along the tower or pole exceeds the modulus of plasticity (MOP) of the tower or pole.
2. The maximum bending deflection along the tower or pole an arbitrarily defined allowable limit.
3. The range of safety against overturning limit is less than the factor of safety by second moment method.

III. Computer Program

(Tower member Design, Analysis, and Reliability) is a FORTRAN language computer program written by Folse.developed and new built-up done by the authorsto solve the problem.

Program is additionally capable of performing reliability analyses by either numerical integration or the design point method. The input requirements for these computations include the summary statistic and distribution type for each random variable affecting the structure to be analyzed. For steel poles and tower member design by reliability the random variables which must be described are wind, ice, and yield stress. The program can additionally accept variable modulus of elasticity data which are necessary for the analysis of tower member design by reliability.



Loading cases for tower type one (S60) from experience of Sudanese work in the field of design of transmission line towers, table (1)

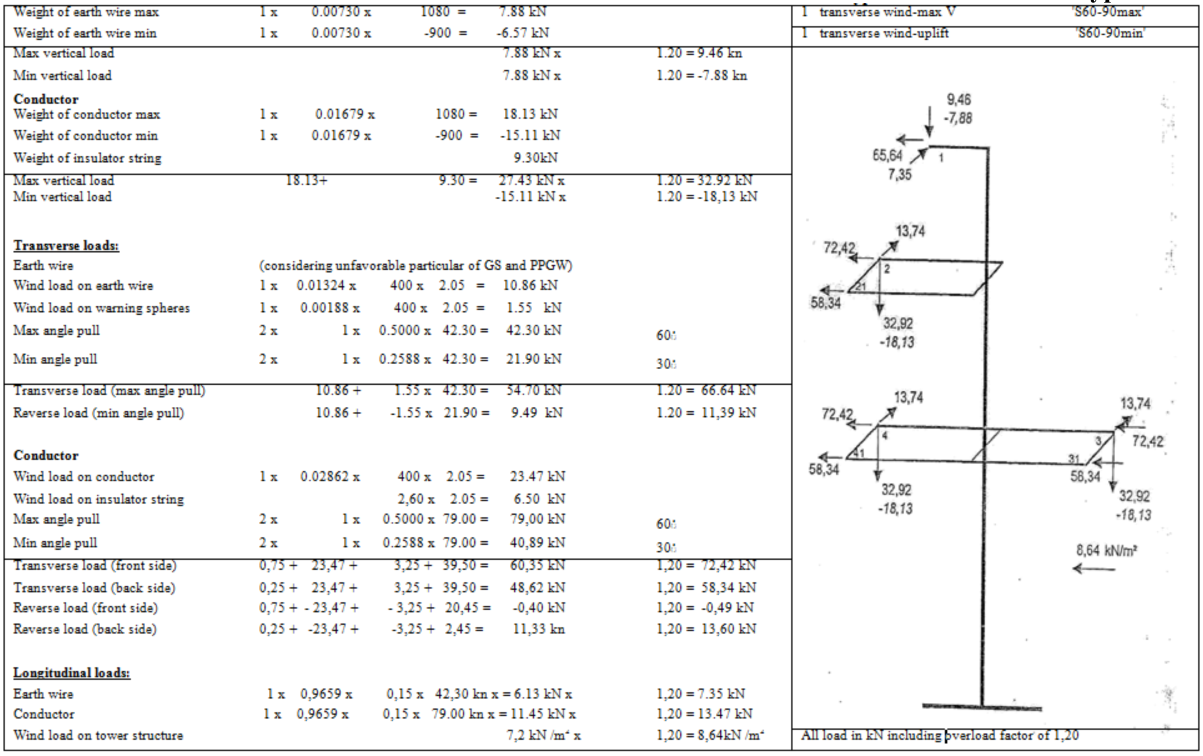
No	Name		Line angle	vertical loads	Wind direction	Unbalanced load
1.	Transverse Wind-max V	'S60_90max'	60	Max	90	
2.	Transverse Wind-uplift	'S60_90min'	60	Min	90	
3.	Wind at 45ȯ.maxV	'S60_45max'	60	Max	45	
4.	Wind at 45ȯ.upliftV	'S60_45min'	60	Min	45	
5.	Reverse Wind-max V	'S60_270max'	30	Max	270	
6.	Reverse Wind-uplift V	'S60_270min'	30	Min	270	
7.	Earthwire+ Top conductor broken –max V	'S60_EWTC90max'	60	Max	90	Earthwire+top conductor (left side)
8.	Earthwire + Top conductor broken –uplift	'S60_EWTC90min'	60	Min	90	Earthwire+top conductor (left side)
9.	Earthwire + Middle conductor broken –max V	'S60_EWMC90max'	60	Max	90	Earthwire+middle conductor (right side)
10.	Earthwire + Middle conductor broken –uplift	'S60_EWMC90min'	60	Min	90	Earthwire+middle conductor (right side)
11.	Earthwire + Bottom conductor broken –max V	'S60_EWBC90max'	60	Max	90	Earthwire+bottom conductor (lift side)
12.	Earthwire + Bottom conductor broken –uplift	'S60_EWBC90min'	60	Min	90	Earthwire+bottom conductor (lift side)
13.	Top conductor+ Bottom Conductor broken –max V	'S60_TCBC90max'	60	Max	90	Top+ bottom conductor (left side)
14.	Top conductor+ Bottom Conductor broken –uplift	'S60_TCBC90min'	60	Min	90	Top+ bottom conductor (left side)
15.	Earthwire+ Top Conductor broken –max V-rev.Wind	'S60_EWTC270max'	30	Max	270	Earthwire+top conductor (left side)
16.	Earthwire+ Top Conductor broken –uplift-rev.Wind	'S60_EWTC270min'	30	Min	270	Earthwire+top conductor (left side)
17.	Earthwire+ Middle Conductor broken –max V-rev.Wind	'S60_EWMC270max'	30	Max	270	Earthwire+middle conductor (right side)
18.	Earthwire+ Middle Conductor broken –uplift-rev.Wind	'S60_EWMC270min'	30	Min	270	Earthwire+middle conductor (right side)
19.	Earthwire+ Bottom Conductor	'S60_EWBC270max'	30	Max	270	Earthwire+bottom

	broken –max V-rev.Wind					conductor (lift side)
20.	Earthwire+ Bottom Conductor broken –uplift-rev.Wind	'S60_EWBC270min'	30	Min	270	Earthwire+bottom conductor (lift side)
21.	Top Conductor + Bottom Conductor broken –max V-rev.Wind	'S60_TCBC270max'	30	Max	270	Top+ bottom conductor (left side)
22.	Top Conductor + Bottom Conductor broken –uplift -rev.Wind	'S60_TCBC270min'	30	Min	270	Top+ bottom conductor (left side)
23.	Cascade condition-max V	'S60_casc_max'	60	Max	-	
24.	Cascade condition-uplift V	'S60_casc_min'	60	Min	-	
25.	Temporary terminal condition	'S60_temp'	60	Max		
26.	Maintenance condition (left side)	'S60_maint_left'	-	3 ×normal		
27.	Maintenance condition	'S60_maint'	-	3 ×normal		
28.	Wind on tower (with ovedoad factor for tower weight)	'S60_wind_max'	-	-	180	
29.	Wind on tower (without overload factor for tower weight)	'S60_wind_min'	-	-	180	

Table (2): Most Critical loading cases number (1 and 2)

Earth and wire

Tower Type S60



Weight of earth wire max 1 x 0.00730 x 1080 = 7.88 kN
Weight of earth wire min 1 x 0.00730 x -900 = -6.57 kN
Max vertical load 7.88 kN x 1.20 = 9.46 kn
Min vertical load 7.88 kN x 1.20 = -7.88 kn

Conductor
Weight of conductor max 1 x 0.01679 x 1080 = 18.13 kN
Weight of conductor min 1 x 0.01679 x -900 = -15.11 kN
Weight of insulator string 9.30kN
Max vertical load 18.13+ 9.30 = 27.43 kN x 1.20 = 32.92 kN
Min vertical load -15.11 kN x 1.20 = -18,13 kN

Transverse loads:
Earth wire (considering unfavorable particular of GS and PPGW)
Wind load on earth wire 1 x 0.01324 x 400 x 2.05 = 10.86 kN
Wind load on warning spheres 1 x 0.00188 x 400 x 2.05 = 1.55 kN
Max angle pull 2 x 1 x 0.5000 x 42.30 = 42.30 kN 60
Min angle pull 2 x 1 x 0.2588 x 42.30 = 21.90 kN 30
Transverse load (max angle pull) 10.86 + 1.55 x 42.30 = 54.70 kN 1.20 = 66.64 kN
Reverse load (min angle pull) 10.86 + -1.55 x 21.90 = 9.49 kN 1.20 = 11,39 kN

Conductor
Wind load on conductor 1 x 0.02862 x 400 x 2.05 = 23.47 kN
Wind load on insulator string 2,60 x 2.05 = 6.50 kN
Max angle pull 2 x 1 x 0.5000 x 79.00 = 79,00 kN 60
Min angle pull 2 x 1 x 0.2588 x 79.00 = 40,89 kN 30
Transverse load (front side) 0,75 + 23,47 + 3,25 + 39,50 = 60,35 kN 1,20 = 72,42 kN
Transverse load (back side) 0,25 + 23,47 + 3,25 + 39,50 = 48,62 kN 1,20 = 58,34 kN
Reverse load (front side) 0,75 + - 23,47 + - 3,25 + 20,45 = -0,40 kN 1,20 = -0,49 kN
Reverse load (back side) 0,25 + -23,47 + -3,25 + 2,45 = 11,33 kn 1,20 = 13,60 kN

Longitudinal loads:
Earth wire 1 x 0,9659 x 0,15 x 42,30 kn x = 6.13 kN x 1,20 = 7.35 kN
Conductor 1 x 0,9659 x 0,15 x 79.00 kn x = 11.45 kN x 1,20 = 13.47 kN
Wind load on tower structure 7,2 kN /m² x 1,20 = 8,64kN /m²

1 transverse wind-max V 'S60-90max'
1 transverse wind-uplift 'S60-90min'

All load in kN including overload factor of 1,20

IV. Proposed analysis and design by reliability

The design above show the determinist design of tower how can analyses by using many methods,

The proposed method proved a level of control over design of frame. the control of this design enables engineers to make the proper decisions when considered by the balance between structural survival and cost. The essential elements of this method include:

1) Use of LRFD equation.
2) Probability based design values of dead load, live load, and wind load.

Beam and column models of resistance (MOR) and models of elasticity (MOE).

3) The specification of target reliability index.

4.1 Calculation of probability of failure:

To calculate probability of failure one need to understand the meaning of failure

Failure will occur when the demand exceeds the capacity by referring to the performance function of mathematically as the event when $y < 0$ thus

Probability of (failure) = P (Y < 0) ………………….. (2)

Since y is a normal random variable we can calculate this

4.2 Limit state Function:

Table (3) Limit state function (data for load resistance factor design)

Distribution	Coefficient	Mean factor	
R log normal	VR = 13%	$\lambda R = 1.1$	1.11
D normal	VD = 10%	$\lambda_D = 1.05$	1.25
L Gmble I	VL = 25%	$\lambda L = 1.0$	1.02
W I	VW = 25%	$\lambda W = 1.01$	1.02

V. Reliability-Based Design of Transmission Towers Under Loads and Wind (proposed design)

Using equ. (3)

$$\emptyset Rn \geq \alpha_{\circ} D_n + \alpha L + \alpha_W w$$

Where:

Rn resistance , D dead load , L live load , W wind load , Φ reduced factor

Extrem type (Gbmle (1))

$$\alpha = \sqrt{\frac{\pi 2}{b\sigma_L^2}} = \frac{\pi}{\sqrt{6}(v_L \mu_L)} = \frac{5.13}{\mu L} = \frac{1.710}{\mu_D}$$

$$U = \mu L \frac{0.577}{a} = 3\mu D - \frac{0.5772}{1.710/\mu D} = 2.66\,\mu D$$

Then

Fl (1*) = exp (– exp (– α (1 * – U)))

fL (1*) = α (exp (–a (1* –u))) exp (– exp (–a (1 – u)))

Substituting I* $= 3\mu_D$ for the first iteration we get

Fl = (I*) = 0.5706 Fl (I*) = $\frac{0.5474}{\mu_D}$ …………………………….(4)

Thus the equivalent parameter of L, or $\sigma_L^e = 0.5474$, $\mu_L^e = 2.872\mu_D$

Determine (G):

$$G_1 = -\frac{\partial g}{\partial_R}\sigma_R^e = -\sigma_R^e$$

$$G_2 = -\frac{\partial g}{\partial_R}\sigma_D \quad Design\ po\,\text{int} = +\sigma_R^2 = V_o\mu_D$$

$$G_3 = -\frac{\partial g}{\partial_R}\sigma_D = +\sigma_R^e \qquad \text{……(5.19)}$$

$$G_3 = -\frac{\partial g}{\partial_R}\sigma_L^E \quad Design\ po\,\text{int} = +\sigma_R^e$$

$$\sigma_R^2 = r^* VR = 4\mu(0.13) = 0.52\,\mu D$$

$$\mu_R^e = r^* \;(1 - \ln(r^* + Ln(\mu R))) \qquad \text{......(5.20)}$$

$$= r^* \;(1 - \ln(\frac{r^*}{\mu R})) = 4\mu D[1 - \ln\left(\tfrac{4\mu D}{4\mu D}\right)]$$

$$\mu_R^e = 4\mu D$$

$$Where$$

σ = Standarddeviation

$\mu_R = Mean$

$$\{\alpha\} = \frac{\rho(G)}{\sqrt{(G^T(\rho)(G))}} \qquad \text{.................................(5)}$$

Case (1):

$$\alpha i \begin{array}{ll} \alpha_R & (-0.5832) \\ \alpha_D & (-0.1122) \\ \alpha_L & (-0.8045) \\ \alpha_W & (-0.8045) \end{array} \Rightarrow \begin{array}{llll} Z_D^+ = & \alpha_D\beta = & 0.1122(3) = & 0.3366 \\ Z_L^+ = & \alpha_L\beta = & 0.8045(3) = & 2.414 \\ Z_W^+ = & \alpha_W\beta = & 0.80115(3) = & 2.414 \\ & & & \end{array}$$

Case (2):

$$\alpha i \begin{array}{ll} \alpha_R & (-0.5832) \\ \alpha_D & (-0.1122) \\ \alpha_L & (-0.8045) \\ \alpha_W & (-0.8045) \end{array} \Rightarrow \begin{array}{llll} Z_D^+ = & \alpha_D\beta = & 0.1122(2.38) = & 0.267 \\ Z_L^+ = & \alpha_L\beta = & 0.8045(2.38) = & 1.9147 \\ Z_W^+ = & \alpha_W\beta = & 0.80115(2.38) = & 1.9147 \\ & & & \end{array}$$

5.1 Determine corresponding design point method:

$$d^* = \mu D + Z_D^* \sigma_D^* = \mu_D\;(1 + Z_D^+ V_D) = case1 = 1.034\mu_D \quad case2 = 1.0267$$

$$I^* = \mu_l^e + Z_D^* \sigma_D^* = 2.872\mu_D + 2.414(0.717\mu_D) = case1 = 4.604\mu_D$$

$$case(2) = \qquad // \qquad 1.91471 \quad // \qquad = case2 = 4.243\;\mu_D$$

R* = d* + I* ....(6)

$$\mu R = \frac{r^*}{1 + \alpha_R\beta \;\; V_R}$$

$$\mu R = \frac{5.638\,\mu_D}{1 + (0.5832)(3)\,(9132.38)} = 7.298\mu_D \;\; case1$$

$$case2 \qquad // \qquad 2.38 \qquad = 6.87932\mu_D$$

5.9 Reduced factor:

$$\phi = \frac{r^*}{R_n} = \frac{r^A}{\mu_R / \lambda_R} = \lambda_R \frac{r^A}{\mu_R} = 1.1 \frac{5.638\ \mu D}{7.429\ \mu D} = 0.8498$$

$$From\ \ table\ \ (3) \qquad \gamma_D = \lambda_D \frac{d^*}{\mu_D} = 1.05 \frac{1.02\ \mu_D}{\mu_D} = 1.0710$$

$$\lambda = \qquad \gamma_L = \lambda_L \frac{I^*}{\mu L} = (1.0) \frac{4.604\ \mu D}{3\mu D} = 1.534667$$

$$\lambda = \qquad \gamma_w = \lambda_L \frac{I^*}{\mu_W} = (1.01) \frac{4.6.04\ \mu_D}{3\mu_D} = 1.5500$$

$$\phi RN \geq \gamma_D D_n + \alpha_L L_n + \alpha_w W_n$$

$$((0.8498)R_n \geq (1.071)\ D_n + (1.53467)\ L_n + (1.55)w_n) \qquad \text{……….(7)}$$

Equation (7) is the result of work depend on critical loading condition and it give safety and economical design, the factor’s is ruled to give ideal solution of the equation and all relations between loads are present in its critical condition to be solved in load resistance format. Wright hand give loads combinations and left hand give the reduction factor and resistance while lead to final solution.

Result and comparisons using equation (7) are shown in table (4)

Table (4): Results and comparison between α i, β target and β index and reduction factor (Ø) and γ i factors for **Equation (7)**

Trial No.	X dead load (cov)	α live load (cov)	α wind (cov)	α Resistance (cov)	Target β	β index	Mean factory				Resistant Rn		Load			Reduction factor (Ø)	Dead load factor (γ_d)	Live load factor (γ_L)	wind load factor (γ_w)
							λ_R	λ_w	λ_d	λ_1	Steel	Conc	Dn	Ln	Wn				
1.	0.112 (0.1)	0.55 (0.0125)	0.55 (0.25)	-0.55 (0.13)	3	1.726 not good	1.1	1.01	1.05	1	**5.4 kip/m2**	4.35	0.6 kip/m	0.5	0.45	0.86405	1.0853	1.4125	1.36578
2.	09112 (0.1)	0.8 (0.25)	0.8 (0.25)	-0.3832 (0.13)	3	3.003 good	1.1	1.01	1.05	1	**65.3 Kip/ft**	78.3	1.5	0.750.55	0.55	.0.84981	1.08534	1.600	1.5475
3.	0.5 (0.1)	0.75 (0.25)	0.75 (0.25)	-0.583 (0.13)	3	1.896 not good	1.1	1.01	1.05	1	**55 kip/lt**	7414.3	0.61	0.22	0.67	0.84981	1.2075	1.56250	1.51079
4.	0.3 (0.1)	0.65 (0.25)	0.65 (0.25)	-0.65 (0.13)	3	1.785	1.1	1.01	1.05	1	**55 kip/lt**	7414.3	0.61	0.22	0.67	0.82115	1.1445	1.4875	1.43827
5.	0.1122 (0.1)	0.55 (0.25)	0.55 (0.25)	-0.55 (0.13)	3	1.726	1.1	1.01	1.05	1	**51.4 kip/lt**	4.33	0.68	0.67	0.53	0.86405	1.08528	1.4125	1.36576

VI. Discussions:

The solution proposed by the authors has been compared with the ASCE-LRFD nd the korean-ASD and it was found that the solution was in godd agreement with these codes. Alengthy discussion regarding that has been given in reference (8).

VII. Conclusions:

1. This study consisted of the development of new vision for design of steel transmission line structures towrs and poles by reliability taking in consideriton many situation of loads effects and resistance by material of

pole and towers and this development give the designer great control over probability of failure of structure used in transission line resolution of problems arising in the course of the development that a conversion by transmission line structure designers from current methods to a probability-based approach is both reasonable and beneficial.

2. The current method is characterised by over simplified load model and structural analysis and utilizes nominal loads and structural properties and safety factors which are difficult to relate to structural reliability. Therefore improved load models and structural analysis techniques were done for calculating the probability of failure of structure and factors were selected to complete the solution of design in good way.
3. The current methods of selecting factor design (LRFD) resulting structal relability to increase design control of reliability with good way to satisfy economy and safty.

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