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ANALYSIS AND ECONOMICAL DESIGN OF TRANSMISSION LINE TOWERS OF DIFFERENT CONFIGURATIONS SUBJECTED TO WIND LOAD

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ABSTRACT

Transmission Line Towers represent approximately 28 to 42 percent of the cost of the transmission line. The growing demand for electrical energy can be met more economically through developing exceptional mild weight configurations of transmission line towers. I the present work, an attempt have been made to make the transmission line price effective through converting the geometry (form) and behavior (type) of transmission line structure. The main objective of our study is to design a 220 KV single Circuit Transmission Line carrying rectangular Base Self supporting Towers, which optimize the present geometry, such a suspension towers is replaced by Triangular Base Self supporting Tower. Then, the structural behavior of existing tower is studied with the aid of developing rectangular Base Guyed Mast. Excel programs are developed together with AutoCAD for configuring towers and calculating loading. By using STAAD.pro, evaluation of each of those 3 towers has been executed in a three dimensional systems. Then, the tower members are designed as ISA angle sections. For optimizing any member phase, the whole wind load computations must be repeated, simultaneously the analysis and again the design. Hence, three successive iterations had been carried out earlier arriving at the inexpensive designs of square base and triangular base self supporting towers and the square form guyed mast. Then all the3 towers are compared and analyzed.

Key words: Line Tower, STAAD.Pro, Transmission line.

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1. INTRODUCTION

1.1. Brief Introduction of Present Power Status

India is a hugely populated country and the electric power supply need of the population creates requirement of a huge transmission and distribution system. Also, the disposition of the number one resources for electrical generation viz., coal, hydro capacity, is quite uneven, thus, again adding to the transmission requirements. Transmission line is an integrated system which includes conductor subsystem, ground wire subsystem and one subsystem for every category of support structure. Mechanical support of transmission line constitutes an enormous portion of the price of the line and that they play an important role in the reliable power transmission. They're designed and built in wide variety of shapes, types, sizes, configurations and materials. The supporting structure types used in transmission lines usually fall into one of the three categories: lattice, pole and guyed. The supports of EHV transmission lines are generally metallic lattice towers. The price of towers constitutes about 28 to 42 percentage of the price of transmission line and subsequently top-quality tower layout will convey in great savings. The selection of an optimum outline together with proper type of bracing system contributes to a huge quantity in developing an economical design of transmission line tower. The height of tower is constant by using the consumer and the structural designer has the project of designing the overall configuration, and member and joint info. The tower behaves like a single cantilever freely self-supporting structure fixed at its base while guyed mast is a shape pin connected to its foundation and braced with guys or other elements. It's seen that guyed towers are price effective while there may be enough corridor rights of way available and the land price is not at top rate. The goal of every designer is to design the excellent systems due to the practical restrictions this has been carried out through intuition, enjoy and repeated trials, experience and repeated trials, a process that has worked well.

1.2. Objectives

In layout of tower for weight optimization below mentioned basic parameters are constrained on the basis for electrical necessities

1. Base Width
2. Height of the Tower
3. Outline of the Tower

Keeping in mind the above necessities, an attempt has been made to make the transmission line greater price effective with the aid of optimizing the geometry and behavior of transmission line structure.

This has been achieved as consistent with the suggestions of Power Grid corp. of India lit. Following the IS Codes and CBIP Manuals with the latest ongoing worldwide research.

2. ANALYSIS OF TOWER

Earlier, transmission towers have been designed with manual calculations based on 2 dimensional stress analysis / stress diagram procedure which is more time taking process. The designer has the limitations to try out several permutation and combinations of tower geometry. Later on, the highly sophisticated software had been developed to automate calculation of member forces based on 3 dimensional finite element analysis / stiffness matrix evaluation. Such software finds out vital member force for a number of loading situations and a variety of possible tower combinations, giving very accurate results. Availability of such software have accomplished exceptional assist to designers to understand pressure distribution and afford to them ample time to concentrate on fine tuning design aspects and at the same time undertake the repetitive calculation and optimization. STAAD Pro 2005 is the software used in our work for analysis purpose.

2.1. Design Calculations

2.1.1. Area of segment (Ae)

$A_{e\,1}$ = 22.0 m^2 (For trapezoidal section),
$A_{e\,2}$ = 21.0 m^2 (For rectangular section),
$A_{e\,3}$ = 1.760 m^2(For peak triangle)
$A_{e\,4}$ = 13.60 m^2 (For 6 cross arm)

2.1.2. Calculation of cable load

Unit Load of the cable = $3/4\ D^2 \times \rho = 0.0240$ KN/m

1. The basic wind speed in Hyderabad is 44.0 m/sec.

2. The probability factor k_1 is taken as 1.070.

3. The Terrain, height and structure size factor k_2 is varying at different levels of the tower and is taken from IS code as follows:

k_2 at 16m height = 0.9480
k_2 at 20m height = 0.980
k_2 at 24m height = 1.000
k_2 at 28m height = 1.020
k_2 at 30m height = 1.030

4. The Topography factor k_3 is assumed to be 1 for plain terrain of Hyderabad

2.1.3. Calculation of wind load

The design wind speed is calculated as:

Vz = Vb X k_1 X k_2 X k_3
Vz at 16.0m = 44.0 ×1.070 × 0.880 ×1 = 41.430 m/sec
Vz at 20.0m = 44.0 × 1.070 × 0.980 × 1= 46.140 m/sec
Vz at 24.0m = 44.0 × 1.070 × 1.0 × 1 = 47.080 m/sec
Vzat 28.0m = 44.0 × 1.070 × 1.020 × 1= 48.020 m/sec
Vzat 30.0m = 44.0 × 1.070 × 1.030 × 1= 48.490 m/sec

2.1.4 Calculation of Design Wind Pressure

pz= 0.60 Vz^2
pz at 16.0 m = 0.60 × (47.670) 2=1363.460 N/m^2
pz at 20.0 m = 0.60 × (49.280) 2 = 1457.110 N/m^2
pz at 24.0 m = 0.60 × (50.290) 2 = 1517.450 N/m^2
pz at 28.0 m = 0.60 × (51.290) 2 = 1578.390 N/m^2
pz at 30 m= 0.6 × (51.79)2 = 1609.32 N/m^2

2.1.5. Design wind force

$F = Cf \times Ae \times pz \times \varphi$

F at 16.0 m=3.20 × 44.0 × 1363.460 × 0.220 = 42.230 KN

F at 28.0 m=3.20 × 34.50 × 1363.460 × 0.220 = 42.230 KN

F at 28.0 m=3.20 × 34.50 × 1609.320 × 0.260 = 43.3060KN

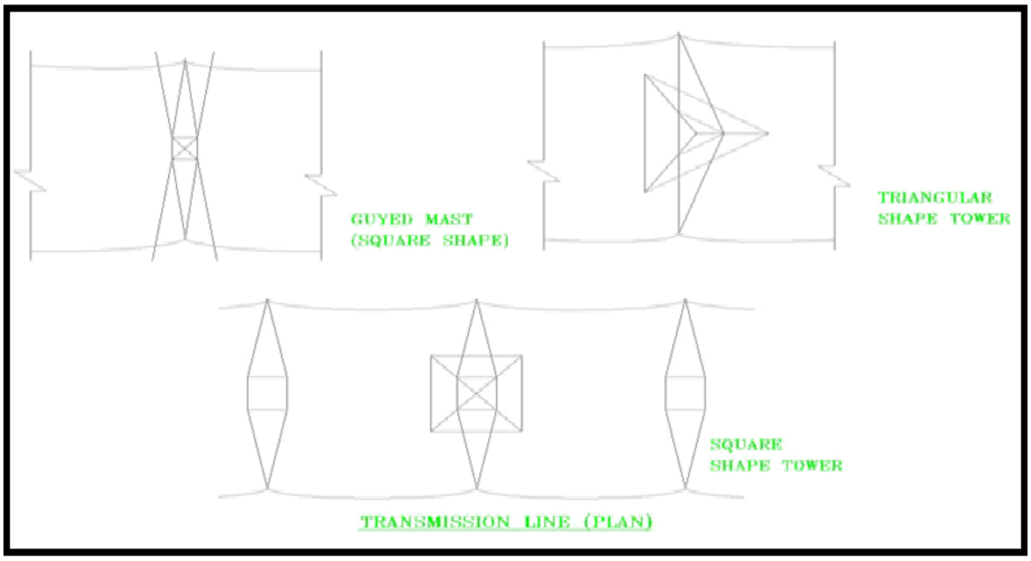


Figure 1 Transmission line plan

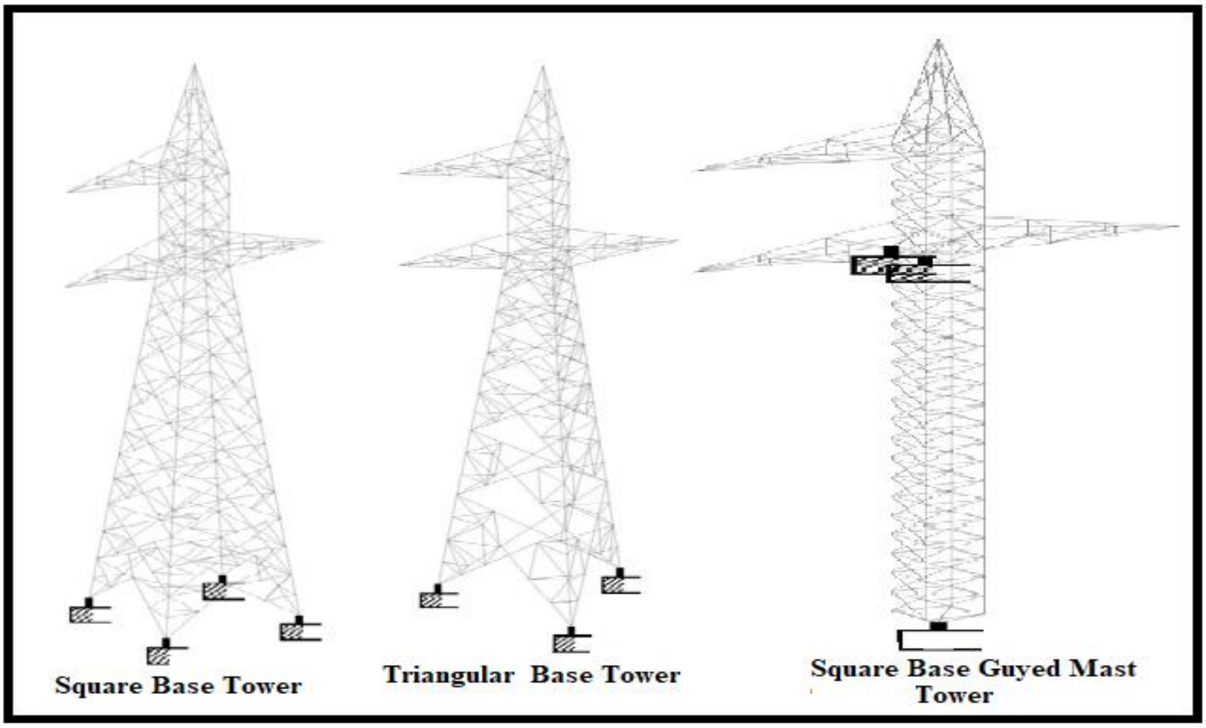
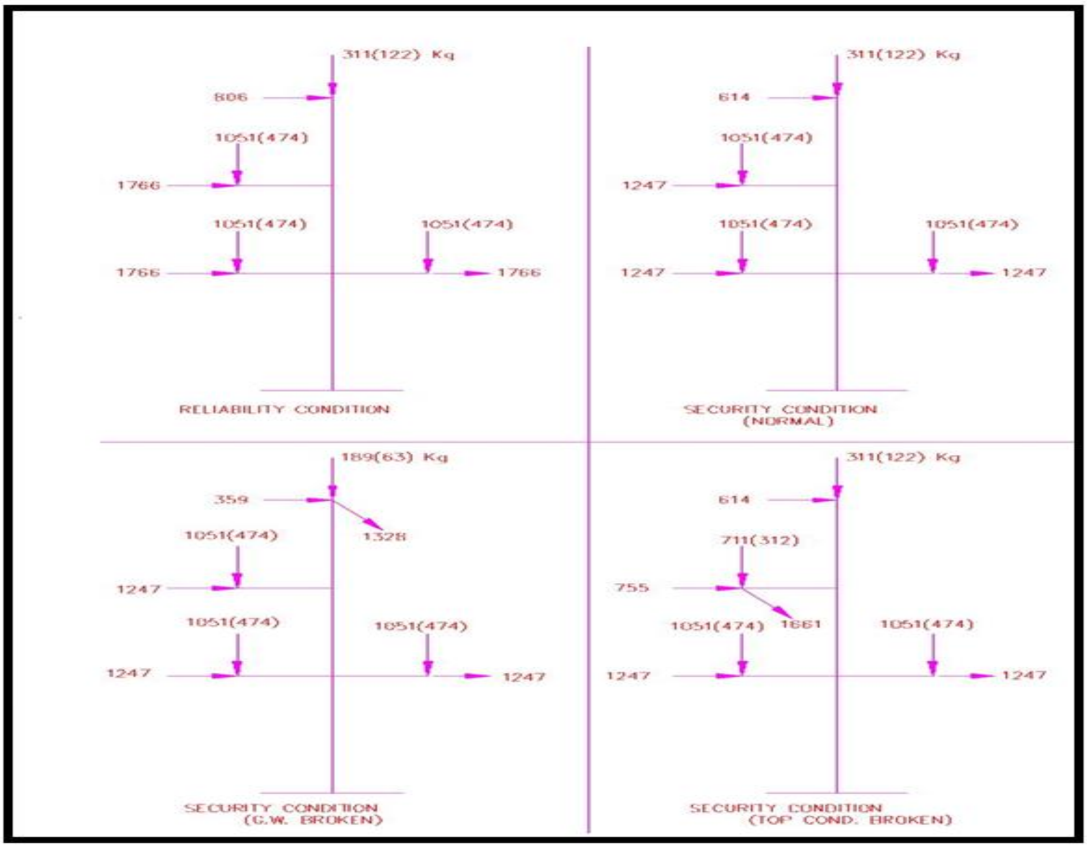
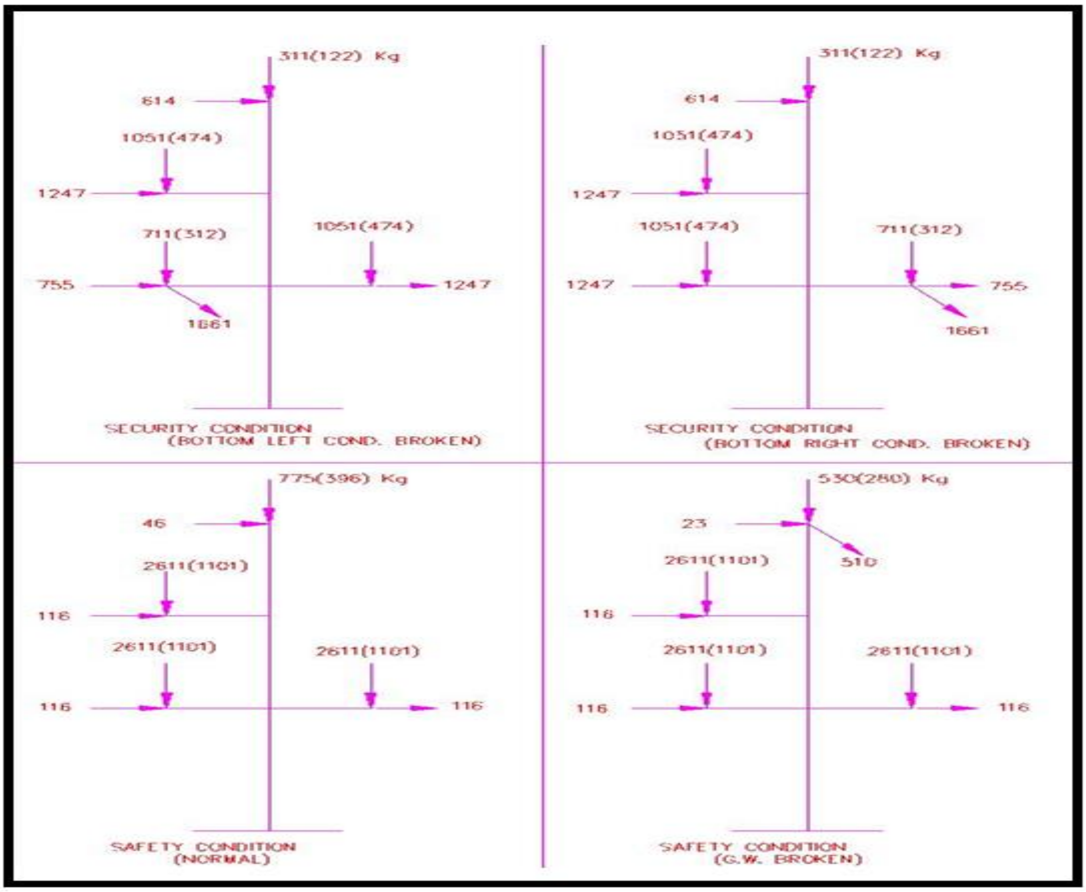


Figure 2 Tower Analysis using STAAD. Pro 2015


311(122) Kg
806
1051(474)
1766
1051(474)
1051(474)
1766
1766
RELIABILITY CONDITION
311(122) Kg
614
1051(474)
1247
1051(474)
1051(474)
1247
1247
SECURITY CONDITION
(NORMAL)
189(63) Kg
359
1328
1051(474)
1247
1051(474)
1051(474)
1247
1247
SECURITY CONDITION
(G.W. BROKEN)
311(122) Kg
614
711(312)
755
1051(474)
1661
1051(474)
1247
1247
SECURITY CONDITION
(TOP COND. BROKEN)


311(122) Kg
614
1051(474)
1247
711(312)
1051(474)
755
1247
1661
SECURITY CONDITION
(BOTTOM LEFT COND. BROKEN)
311(122) Kg
614
1051(474)
1247
1051(474)
711(312)
1247
755
1661
SECURITY CONDITION
(BOTTOM RIGHT COND. BROKEN)
775(396) Kg
46
2611(1101)
116
2611(1101)
2611(1101)
116
116
SAFETY CONDITION
(NORMAL)
530(280) Kg
23
2611(1101)
510
116
2611(1101)
2611(1101)
116
116
SAFETY CONDITION
(G.W. BROKEN)

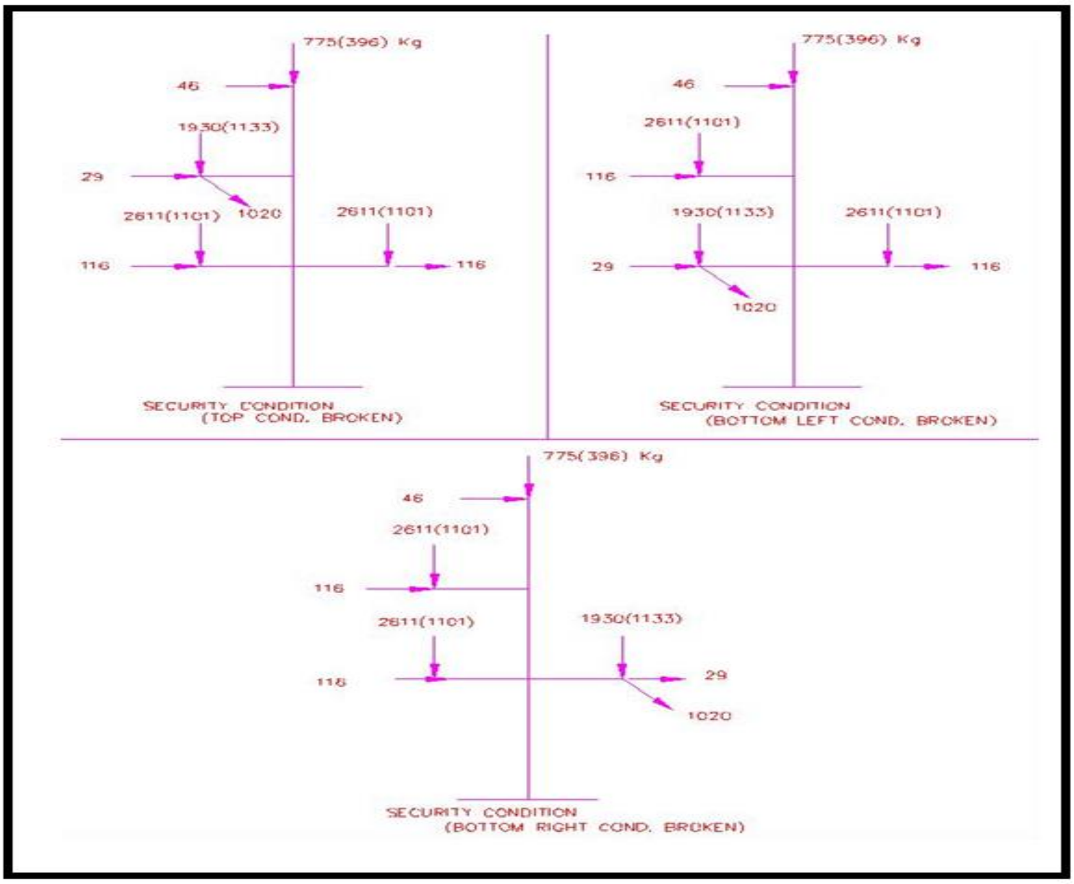


Figure 3 Loading Tree

Table 1 Wind Loading on Tower

Height (m) / Wind (kg)	Square Tower	Triangular Tower	Guyed Mast
0	292	306	129
8.91	-	-	279
10.5	475	-	-
12.14	-	461	-
18.9	243	210	195
20.2	118	111	101
24.1	127	119	108
25.4	107	101	89
29.1	122	118	103
Total	5571	5353	3708
No.of Exposed Memb.	180	195	174

Table 2 Maximum Force in the Cross Arm

Maximum Force in the Cross Arm (Kg)						
	Guyed Mast		Triangular Tower		Square Tower	
Panel	Compressive Load	Tensile Load	Compressive Load	Tensile Load	Compressive Load	Tensile Load
Lower	6268	4307	4969	3645	4651	2912
Upper	6767	4478	5463	2312	5111	2675
Upper Member						
Lower	1320	4801	1037	5418	669	4410
Upper	631	4064	825	5729	276	4150

Table 3 Maximum Force in the Leg Member

	Maximum Force in the Leg Member (Kg)					
Sl No.	**Guyed Mast**		**Triangular Tower**		**Square Tower**	
	Compressive	**Tensile**	**Compressive**	**Tensile**	**Compressive**	**Tensile**
0	3981	1160	-	-	-	-
1	2492	977	31175	28247	22945	20716
2	2661	1292	28469	25907	22033	20028
3	2839	1610	24726	22324	20560	18698
4	3013	1927	21430	19246	18306	16723
5	3188	2244	18355	16182	16536	15028
6	3362	2560	13826	11874	14242	12936
7	3535	2876	-	--	12892	11542
8	3708	3191	-	-	10604	9490
9	3884	3503	-	-	-	-
10	4608	3308	-	-	-	-
11	5335	3055	-	-	-	-
12	6063	2799	-	-	-	-
13	6792	2674	-	-	-	-
14	7522	3924	-	-	-	-
15	8255	4172	-	-	-	-
16	8990	4916	-	-	-	-
17	9736	5655	-	-	-	-
18	10463	6381	-	-	-	-
19	11302	7148	-	-	-	-
20	8498	12350	9999	8343	7950	5454
21	9013	1178	-	-	-	-
22	7853	8864	7455	6799	6755	6231
23	6556	7116	6206	4982	5509	4979
24	6638	5412	6935	4606	5090	3348
25	4008	3359	4660	2684	3322	2628
26	5256	4955	4641	3 537	3553	3459

Table 4 Deflection of Towers

Deflection of Towers			
Ht. (m)	**Square Tower (mm)**	**Triangular Tower (mm)**	**Guyed Mast (mm)**
0	0	0	0
18.9	85	71	8
20.2	98	90	14.5
24.1	142	129	60
25.4	157	142	76

3. DESIGN OF TOWERS

The tower is designed using limit load concept by utilizing probabilistic method of approach and hence summed in the Table 5 and 6.

Table 5 Design of Leg Member

Design of the Leg Member									
	Guyed mast			**Triangular Tower**			**Square Tower**		
S. No.	**Angle Section**	**Effective** Length (cm)	**F.O. S.**	**Angle Section**	**Effective** Length (cm)	**F.O.S.**	**Angle Section**	**Effective** Length (cm)	**F.O.S.**
0	(ISA 65X65X05)	87	3.4						
1	(ISA 65X65X05)	99	5.1	(ISA100X100X08)	129	1.1	(ISA 90X90X08)	110	1.3
2	(ISA 65X65X05)	99	5.1	(ISA100X100X08)	127	1.2	(ISA 90X90X08)	155	1.2
3	(ISA 65X65X05)	99	4.5	(ISA 90X90X08)	107	1.3	(ISA 90X90X08)	140	1.4
4	(ISA 65X65X05)	99	4.3	(ISA 90X90X08)	130	1.4	(ISA 90X90X06)	125	1.2
5	(ISA 65X65X05)	99	4.1	(ISA 90X90X06)	110	1.3	(ISA 90X90X06)	135	1.3
6	(ISA 65X65X05)	99	3.8	(ISA 75X75X06)	105	1.3	(ISA75X75X06)	110	1.3
7	(ISA 65X65X05)	99	3.6	-	-	-	(ISA75X75X06)	95	1.5
8	(ISA 65X65X05)	99	3.5	-	-	-	(ISA75X75X06)	160	1.3
9	(ISA 65X65X05)	99	3.3	-	-	-	-	-	-
10	(ISA 65X65X05)	99	2.8	-	-	-	-	-	-
11	(ISA 65X65X05)	99	2.4	-	-	-	-	-	-
12	(ISA 65X65X05)	99	2.1	-	-	-	-	-	-
13	(ISA 65X65X05)	99	1.9	-	-	-	-	-	-
14	(ISA 65X65X05)	99	1.7	-	-	-	-	-	-
15	(ISA 65X65X05)	99	1.6	-	-	-	-	-	-
16	(ISA 65X65X05)	99	1.4	-	-	-	-	-	-
17	(ISA 65X65X05)	99	1.3	-	-	-	-	-	-
18	(ISA 65X65X05)	99	6.3	-	-	-	-	-	-
19	(ISA 65X65X05)	99	1.1	-	-	-	-	-	-
20	(ISA 65X65X05)	130	1.3	(ISA75X75X06)	130	1.7	(ISA 65X65X05)	130	1.3
21	(ISA 65X65X05)	97	1.4	-	-	-	-	-	-
22	(ISA 65X65X05)	98	1.6	(ISA 65X65X05)	130	1.4	(ISA 65X65X05)	137	1.6
23	(ISA 65X65X05)	98	2	(ISA 65X65X05)	130	1.7	(ISA 65X65X05)	127	2
24	(ISA 65X65X05)	98	2	(ISA 65X65X05)	130	1.5	(ISA 65X65X05)	127	2.1
25	(ISA 65X65X05)	131	2.6	(ISA 65X65X05)	133	2.2	(ISA 65X65X05)	132	3.2
26	(ISA 65X65X05)	151	1.7	(ISA 65X65X05)	153	1.9	(ISA 65X65X05)	152	2.5

Table 6 Design of Cross Arm

Design of Cross Arm									
Panel	**Guyed Mast**			**Triangular Tower**			**Square Tower**		
	Angle Sect.	**Effectiv Length**	**F.O.S.**	**Angle Sect.**	**Effective Length**	**F.O.S.**	**Angle Sect.**	**Effective Length**	**F.O.S.**
LOWER MEMBER									
Lower	(ISA75X75X06)	136	2.4	(ISA75X75X06)	164	2.6	(ISA75X75X06)	123	3.4
				(ISA65X65X05)	120	4.7			
Upper	(ISA75X75X06)	136	2.2	(ISA75X75X06)	164	2.4	(ISA75X75X06)	123	3.1
				(ISA65X65X05)	120	4.3			
UPPER MEMBER									
Lower	(ISA50X50X04)	143	1.4	(ISA50X50X04)	143	1	(ISA50X50X04)	130	1.5
Upper	(ISA50X50X04)	154	1.4	(ISA50X50X04)	128	1	(ISA50X50X04)	146	1.6

4. CONCLUSIONS

Least weight of the tower implies greatest economy in the transmission line costs. Our research work has guided us to the following conclusions:

- Configuration of towers has revealed that all the three towers are having the same height but different base width.
- Loading including reliability, security and safety conditions have been kept same for all the three towers.
- Wind loading is calculated for each tower and has lead to following results:

Tower Type	**Total Wind Load (Kg)**
Square Tower	5571
Triangular Tower	5353
Guyed Mast	3708

- Analysis of Towers as a 3-D space structure with STAADPRO 2004 is showing Maximum Axial Compressive Force In Leg Member of the Lowest Panel (Panel one).

Tower Type	**Maximum Force (Kg)**
Square Tower	22945
Triangular Tower	31175
Guyed Mast	11302

- Design has been done with super most thought of conserving every Kg of steel possible within the limitations of the specifications by developing excel programs After performing three iterations, the economic design of towers has lead to the following conclusion:

Tower Type	**Tower Self Weight (Kg)**
Square Tower	2775
Triangular Tower	2519
Guyed Mast	1666

Thus, using Triangular Base Self Supporting Tower will bring a saving of 9.23% in the weight of structural steel and using Square Base Guyed Mast will lead to saving of 39.96% in the structural steel (excluding guy ropes), which is directly the cost saving in each tower or the structural optimization of transmission line.

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