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Diamond Shape Monopole

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ABSTRACT

Electric transmission is the process by which large amounts of electricity produced at power plants is transported over long distances for eventual use by consumers. Usually steel lattice towers and monopoles are used to transmit the electric power. In these towers three different cross arms one above another are provided for one circuit and requires more height with large footprint. In developed cities it is very difficult to get the clearance for height and area for transmission line tower.

A new diamond shape monopole as electric transmission line structure has been developed to carry the load in efficient way for restrictive height of pole. This paper demonstrate the design of geometry of cross arm and diamond shape monopole.

INTRODUCTION

Transmission line supporting structures have to carry the heavy transmission conductor at a sufficient safe height from ground. In addition to that all towers have to sustain all kinds of natural calamities. So transmission tower designing is an important engineering job where two basic engineering concepts, civil and electrical engineering concepts are equally applicable.

Because of the steadily growing use of electricity, new generating facilities and transmission lines are required to meet that demand and maintain a reliable power system. And in developed cities it is very difficult to get the clearance for height and area for transmission line tower. Therefore it becomes necessary to have such kind of transmission line supporting structures which requires less footprint and have less height.

Currently following two types of transmission line supporting structures are in use:

1) Lattice tower:

A lattice tower is a framework construction made of galvanized steel or aluminium sections and used for power lines of all voltages. These are the most common type for high-voltage transmission lines. These are usually assembled at the site.

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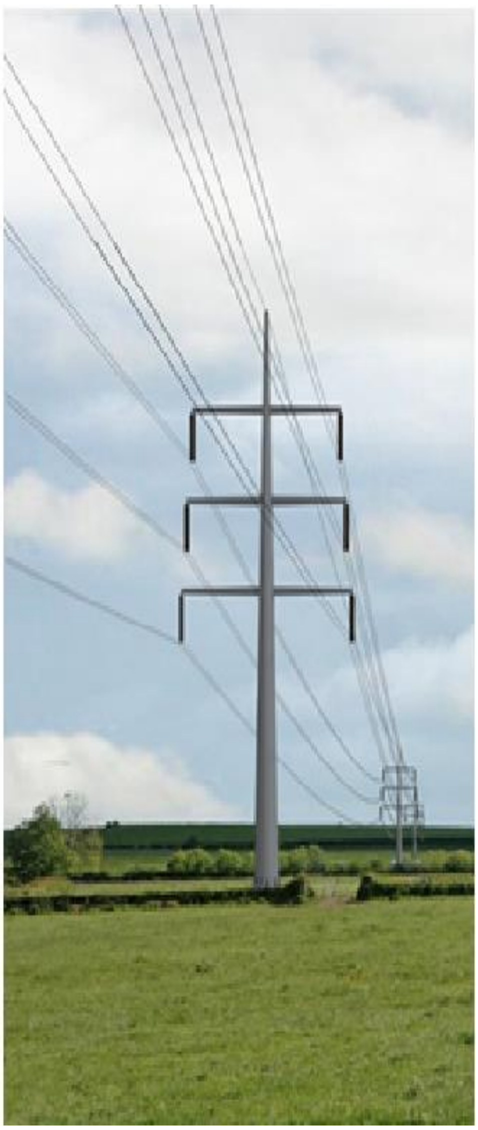
2) Monopoles:

A monopole is a long, slender and tapered structure used to support transmission line. These can be of wood, tubular steel and concrete.

Wood poles can be used for low voltage line up to 30kV and are not common in use. Tubular steel poles are generally assembled at the factory and placed on the right-of-way afterward and can be used for power lines of voltages up to 500kV. Concrete structures as pole can also be used for transmission and distribution systems at a range of 25kv to 230-345kv.

Above mentioned different types of Transmission line structures are shown in *Figure1*

Lattice Tower



Monopole

Figure 1

DIAMOND SHAPE MONOPOLE

Diamond Shape Monopole is a transmission line monopole with cross-arms having diamond shape geometry and fabricated from uniformly tapered hollow diamond shape steel sections & pivoted type insulated cross arms. The key characteristic of new diamond shape monopole is the geometry of cross arm and strategically placement of three conductors of one circuit on single cross arm. These can be fabricated in factory and placed on the right-of-way afterwards. These can be fabricated into segments of 12m length. The minimum thickness of material used is usually 6mm.

Trigger for design of Diamond Shape Monopole

In order to meet the growing demand, upgradation of existing transmission lines and construction of new transmission lines are under implementation, and towers which are presently used for carrying the transmission lines require large footprint, and are tall structure with considerable height. Moreover, it is a known reality about the state of developed cities that it is indeed very difficult to get the clearance for transmission line towers of great height and requiring large footprint area. In view of foregoing, it becomes a need of the hour to have a structure that would overcome the limitations of state-of-the-art transmission line towers as described above.

Development of Philosophy

A study has been done for different type of structures with different geometry to reduce the height and footprint of tower. It has been finalized to use monopole as transmission line structure as it requires less footprint compared to the area of lattice tower, but the problem of height still persists because both lattice tower and monopole has three different cross-arms (one above the other as shown in figure 1) for conductors of single phase. To reduce the height of tower we studied different type of cross-arm geometries and finalized to have single cross-arm for one phase with diamond shape arrangement for attaching conductors. This arrangement resulted in approximately 20 % reduction in height and approximately 50 % reduction in footprint (above ground) of transmission line structure.

GEOMETRY OF DIAMOND SHAPE MONOPOLE

The factors governing the geometry of diamond shape monopole are as follows:

1) Minimum permissible ground clearance-

From safety considerations, along the route of the transmission line clearances above open countries, roads, rivers, railway tracks, tele-communication lines, other power lines, etc. up to conductor needs to be maintained. The minimum ground clearance for diamond shape monopole as per I.E. rules is maintained up to bottom conductor attachment.

2) Maximum sag of Lowermost Conductor-

The size and type of conductor, wind and climatic conditions of the region and span length determine the conductor sag. The maximum sag for conductor span occurs at the maximum temperature and still wind conditions. In snow regions, the maximum sag may occur even at $0^{o}C$ with conductors loaded with ice in still wind conditions. This maximum value of sag for conductor is also considered while deciding the height of monopole.

3) Spacing of conductors-

The spacing of conductors is determined by the conductor swinging, size of conductor, length & configuration of the insulator string (to which conductor is attached), swing of insulator string and electrical clearance required for conductor from the live point. This plays the major role in deciding the geometry of cross-arm. Based on the above mentioned parameters the geometry of cross-arm of diamond shape monopole is finalized which is different than the cross-arm arrangement of regular monopole. By placing the conductors in diamond shape with pivoted type insulated cross-arms, the height reduction of tower is achieved.

4) Vertical clearance between ground wire and top conductor-

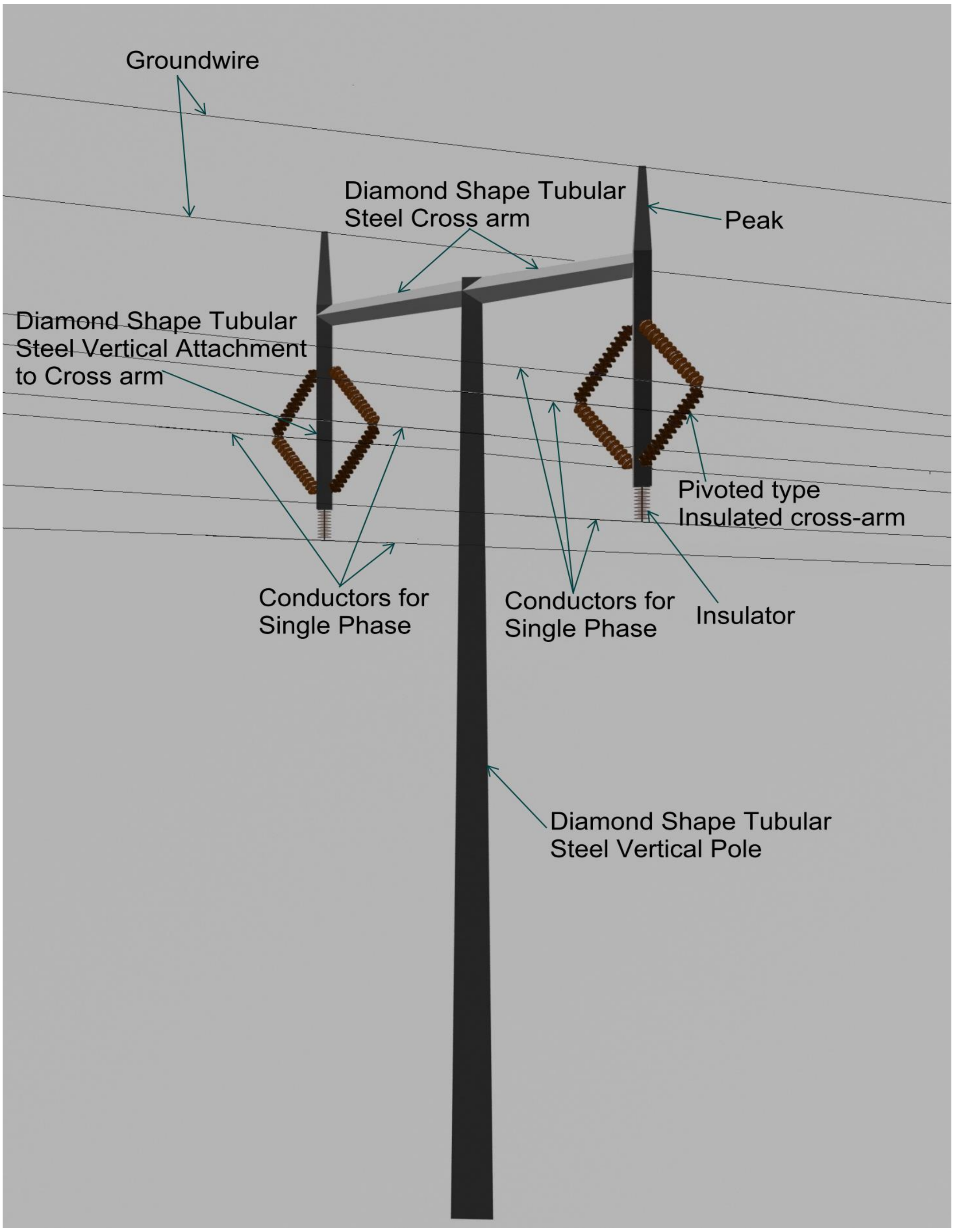
This is governed by the angle of shielding i.e. the angle which the line joining the ground wire and the outermost conductor makes with the vertical, required for the interruption of lightning strokes at the ground and the minimum mid span clearance between the ground wire and the top conductor. Based on this the height of peak is provided.

Above mentioned parameters are considered while designing the geometry of diamond shape monopole. These parameters are considered as per IE rules.

STRUCTURE CONFIGURATION

Diamond shape monopole consists of following components. These components are shown in figure 2.

1) Vertical pole – for supporting cross arm having uniformly tapered hollow diamond shape steel section.
2) Cross-arms – horizontal member having uniformly tapered hollow diamond shape steel section.
3) Vertical attachment to cross-arm – vertical member attached below to cross-arm having hollow diamond shape steel section.
4) Insulated cross-arms – V shaped insulated cross-arm, rigid ends of insulated cross-arm are attached to the top and bottom points of vertical attachment of steel cross-arm and conductor is attached to the pivoted end of insulated cross-arm.
5) Insulator – vertical insulator attached to the bottom point of vertical attachment of cross-arm.
6) Peak- vertical member provided above both the cross arms to support ground wire.



Diamond Shape Monopole
Figure 2

LOADS ON DIAMOND SHAPE MONOPOLE

Transmission lines are subjected to various loads during their lifetime. These loads

are classified into three distinct categories, namely,
a) Climatic loads -- related to the reliability requirements (This is considered to be a normal condition).
b) Failure containment loads - related to security requirements (This is considered to be a broken wire condition).
c) Construction and maintenance loads – related to safety requirements.

Climatic Loads

The wind pressure in the region where transmission line has to be constructed has a definite impact. The region may be experiencing snow fall or no snow fall. Thus, there are three categories as under:
a. Wind Loads (Non-Snowy Regions).
b. Wind Loads with Ice (Snowy Regions).
c. Wind loads without Ice (Snowy Regions).
Transmission lines in snowy regions will be subjected to additional vertical loads due to the weight of snow on conductor and tower. The sag and tension calculations will have to be done with and without snow.

Failure containment loads

During the normal operation of the line, the monopole has a balanced tension on both the sides. When one or more wires break off, there will be Unbalanced Longitudinal loads and Torsional Loads. Monopoles should have inherent strength for resisting the longitudinal and torsional loads resulting from breakage of specified number of conductors and/or groundwire. The Broken wire loads shall depend upon the angle of deviation of the line through the monopole. During the calculations, the maximum deviation angle shall be considered.

Failure of items such as earth wires broken in the same span, Insulators, hardware joints etc. as well as failure of major components such as monopoles, foundations and conductors may result in cascading condition. In order to prevent the cascading failures angle monopoles shall be checked for anti-cascading loads for all conductors. The failure due to cascading is more likely in the hilly region as there are large differences in elevation. Cascade tripping can also take place when large scale inundation takes place along the line along with hail storm.

Construction and maintenance loads

As an important and essential requirement, Construction and maintenance Practices should be regulated to eliminate unnecessary and temporary loads which would otherwise demand expensive permanent strengthening of Monopoles. However, there are bound to be some additional loads due to lifting of gadgets and eccentricity. The chances of such extra loads are more during construction than that during maintenance. Construction loads include weight of ropes, pulleys, component of various pulling loads, man and tower material etc. Maintenance loads include the weight of maintenance tools-tackles, man, pulleys etc.

Nature of Loads

Loads are calculated on the structures in three directions: vertical, transverse, and longitudinal. The transverse load is perpendicular to the line and the longitudinal loads act parallel to the line.

Transverse Loads – Reliability Condition (Normal Condition)

Wind load is a major component of total loading on monopole. The wind velocity varies for different parts of country and basic wind velocity are indicated on the map of India in IS 875. After that design wind pressure is calculated based on terrain, structure height and reliability level. Design wind pressure calculation is explained in detail in IS 802-Part1-Section1. Loads imposed on tower due to action of wind are calculated under the following climatic criteria:
Criterion-I - Every day temperature and design wind pressure.
Criterion-II - Minimum temperature with 36% of design wind pressure.

Transverse loads in reliability condition has following components:

1) Wind Load on Conductor/Ground-wire

The load due to wind on each conductor and ground wire, F_w applied at supporting point normal to the line shall be determined by the following expression:

$$F_w, = P_d \times C_{dc} \times L \times d \times G_c \qquad (1)$$

Where,
P_d = Design wind pressure in N/m^2
C_{dc} = Drag Coefficient which is 1.0 for conductor and 1.2 for ground wire
L = Wind span in meters, being sum of half the span on either side of supporting point
d = Diameter of conductor /groundwire in meters
G_c = Gust response factor, which takes into account the turbulence of the wind and the dynamic response of the conductor.
Values of Gc for three terrain categories and different heights of the conductor/ ground wire above ground Level are given in Table 1. The average height will be taken up to the clamping point of top conductor/ground wire on monopole less two-third the sag at minimum temperature and no wind.

2) Wind Load on insulator strings

Wind load on insulator strings shall be determined from the attachment point to the centre-line of the conductor in case of suspension monopole and up to the end of clamp in case of tension monopole, in the direction of wind as follows:-

$$F_w, = P_d \times C_{di} \times A_i \times G_i \qquad (2)$$

Where,
P_d = Design wind pressure in N/m^2
C_{dc} = Drag Coefficient, to be taken as 1.2
A_i = 50 percent of the area of insulator string projected on a plane which is parallel to the longitudinal axis of the string
G_i = Gust response factor, peculiar to the ground roughness and depends on the height of insulator attachment point above ground. Values of G_i for the three terrain categories are given in Table 2.

Table 1 Values of Gust Response Factor G_c for Conductor /Ground wire

Terrain Category	Height above Ground (meter)	Values of G_c for Ruling Span of, in m						
		Upto 200	300	400	500	600	700	800 and above
1	Upto 10	1.70	1.65	1.60	1.56	1.53	1.50	1.47
	20	1.90	1.87	1.83	1.79	1.75	1.70	1.66
	40	2.10	2.04	2.00	1.95	1.90	1.85	1.80
	60	2.24	2.18	2.12	2.07	2.02	1.96	1.90
	80	2.35	2.25	2.18	2.13	2.10	2.06	2.03
2	Upto 10	1.83	1.78	1.73	1.69	1.65	1.60	1.55
	20	2.12	2.04	1.95	1.88	1.84	1.80	1.80
	40	2.34	2.27	2.20	2.13	2.08	2.05	2.02
	60	2.55	2.46	2.37	2.28	2.23	2.20	2.17
	80	2.69	2.56	2.48	2.41	2.36	2.32	2.28
3	Upto 10	2.05	1.98	1.93	1.88	1.83	1.77	1.73
	20	2.44	2.35	2.25	2.15	2.10	2.06	2.03
	40	2.76	2.67	2.58	2.49	2.42	2.38	2.34
	60	2.97	2.87	2.77	2.67	2.60	2.56	2.52
	80	3.19	3.04	2.93	2.85	2.78	2.73	2.69
NOTE - Intermediate values may be linearly interpolated.								

Table 2 Values of Gust Response Factor G_i for Insulators

Height above Ground (meter)	Values of Gi for Terrain categories		
	1	2	3
Upto 10	1.70	1.92	2.55
20	1.85	2.20	2.82
30	1.96	2.30	2.98
40	2.07	2.40	3.12
50	2.13	2.48	3.24
60	2.20	2.55	3.34
70	2.26	2.63	3.46
80	2.31	2.69	3.58
NOTE - Intermediate values may be linearly interpolated.			

3) Wind Load on monopole

Then wind load on the structure is calculated based on terrain, location, structure height, reliability level, wind gust, drag coefficient and structure shape as per IS 875.

4) Transverse Load from Horizontal Component of Mechanical Tension of conductor and Ground wire due to wind (Deviation Load)

This load acts on the tower as component of Mechanical tension of conductor / ground-wire.

$$F_{wd} = 2 \times T \times \sin \phi/2 \qquad (3)$$

Where,
F_{wd} = Load in Newtons
T = Maximum Tension of conductor and ground wire at everyday temperature and 100% of full wind Pressure or at minimum temperature and 36% of full wind pressure whichever is more stringent.
ϕ = Angle of Deviation

Transverse Loads – Security Condition (Normal Condition)

Suspension Monopoles should not be designed for transverse loads due to wind action on tower structure, conductors, ground wires and insulators. On these monopoles transverse loads due to line deviation shall be based on component of mechanical tension of conductors and ground wires corresponding to everyday temperature and nil wind condition. For broken wire the component shall be corresponding to 50% of mechanical tension of conductor and 100% of mechanical tension of ground wire at everyday temperature and nil wind.

Tension and Dead end Monopoles should be designed for transverse loads due to wind action on monopole, ground wires and insulators as mentioned earlier. 60% wind span shall be considered for broken wire and 100% for intact wire.

Transverse Load During Construction and Maintenance – Safety

1) Normal condition – Suspension, Tension and Dead End Monopoles

Transverse loads due to wind action on monopole, conductors, ground wires and insulators shall be taken as nil. Transverse loads due to mechanical tension of conductor or ground wires at everyday temperature and nil wind on account of line deviation shall be considered as follows:

$$TM = 2 \times T1 \times \sin \phi/2 \qquad (4)$$

Where,
TM = Load in Newtons
T1 = Tension in Newtons of conductor/ground wire at everyday temperature and nil wind.
ϕ = Angle of deviation of the line.

2) Broken wire Condition – Suspension, Tension and Dead End Monopole

Transverse loads due to wind action on monopole, conductors, ground wire, insulators shall be taken as nil. Transverse load due to mechanical tension of conductor or ground wire at everyday temperature and nil wind on account of line deviation shall be considered as follows:-

$$TM = 2 \times T1 \times \sin \phi/2 \quad (4)$$

Where,
TM = Load in Newtons
T1 = 50% of tension in Newtons of conductor and 100% of tension of ground wire at everyday temperature and nil wind for and 100% for angle and dead end monopole for both conductor and ground wire
ϕ = Angle of deviation of the monopole

Vertical Loads - Reliability Condition

Loads due to weight of tower, each conductor and ground wire based on appropriate weight span, weight of insulator strings and accessories.

Vertical Loads - Security Condition

Loads due to weight of each conductor or ground wire based on appropriate weight span, weight span, weight of insulator strings and accessories taking broken wire condition where the load due to weight of broken conductor / ground wire shall be considered as 60% of weight span and self-weight of monopole.

Vertical Loads during Construction and Maintenance – Safety Condition

Same as Clause above multiplied by overload factor of 2. Load of 1500 N shall be considered acting at each cross arm tip as a provision for weight of line man with tools. Load of 3500 N at cross arm tip to be considered for cross-arm design up to 220 KV and 5000 N for 400KV and higher voltages. The cross arms of tension towers shall also be designed for the following construction loads:

1) For twin bundle conductor 10000 N load at a minimum distance of 600 mm from the tip of cross-arm.
2) For multi bundle conductor 20000 N load at a minimum distance of 1000 mm from the tip of cross-arm.

Longitudinal Loads - Reliability Condition

Longitudinal loads for Suspension and Tension monopoles shall be taken as nil. Longitudinal loads which might be caused on tension towers by adjacent spans of unequal lengths shall be neglected.

Longitudinal loads for Dead End monopoles shall be considered corresponding to mechanical tension of conductors and ground wires for criteria specified in Transverse Loads – Reliability Condition.

Longitudinal Loads – Security Condition

For suspension monopoles the longitudinal load corresponding to 50 % of the mechanical tension of conductor and 100% of mechanical tension of ground wire shall be considered under everyday temperature and no wind pressure for broken wire only.

For tension monopoles horizontal loads in longitudinal direction due to mechanical tension of conductors and ground wire shall be taken for loading criteria specified in specified in Transverse Loads – Reliability Condition for broken wire. For intact wires these loads shall be considered as nil.

For Dead End monopoles horizontal loads in longitudinal direction due to mechanical tension of conductors and ground wire shall be taken for loading criteria specified in transverse Loads – Reliability Condition for intact wires; however for broken wires these shall be taken as nil.

Longitudinal Loads during Construction and Maintenance – Safety Condition

In normal Condition for suspension and tension monopoles these loads shall be taken as nil.

In normal Condition for dead end monopoles these loads shall be considered as corresponding to mechanical tension of conductor/ground wire at every day temperature and nil wind. Longitudinal loads due to unequal spans may be neglected.

Longitudinal loads during construction simulating broken wire condition will be based on stringing of one earth wire or one complete phase of sub-conductors at one time.

In broken wire conditions longitudinal loads during stringing on suspension monopole should be normally imposed only by the passing restriction imposed during pushing of the running block through the Sheave. It will apply only on one complete phase of sub-conductors or One Earth wire. It will be taken as 10,000 N per Sub-conductor or 5,000 N per Earth wire.

Angle monopoles used as dead end during stringing simulating broken wire condition shall be capable of resisting longitudinal loads resulting from load equal to twice the sagging tension (sagging tension is 50 per cent of the tension at everyday temperature and no wind) for one earth wire or one complete phase sub-conductors which is in process of Stringing. At other earth wire or conductor attachment points for which stringing has been completed, loads equal to 1.5 times the sagging tension will be considered. However, the structure will be strengthened by installing temporary guys to neutralize the unbalanced longitudinal tension. These guys shall be anchored as far away as possible to minimize vertical load.

Anti-Cascading Checks

All angle monopoles shall be checked for the following anti-cascading conditions with all conductors and GW intact only on one side of the monopole.

1) Transverse Loads - These loads shall be taken under no wind condition.
2) Vertical Loads - These loads shall be the weight of conductor/ground wire intact only on one side of tower, weight of insulator strings and accessories.
3) Longitudinal Loads - These loads shall be the pull of conductor/ ground wire at everyday temperature and no wind applied simultaneously at all points on side with zero degree line deviation.

Broken Wire Condition

1) Single Circuit Tower - Any one phase of ground wire broken, whichever is more stringent for a particular member
2) Double, Triple and Quadruple Circuit Towers
   Suspension Towers - Any one phase or ground-wire broken whichever is more

stringent for a particular member.
Small and Medium Angle Towers - Any two phases broken on the same side and same span or any one phase and one ground wire broke on the same side and same whichever combination is more stringent for a particularmember.
Large Angle/Dead End Towers - Any three phases broken on the same side same span or any two phases and one ground wire broken on the same side same span whichever is more stringent for a particular member.

Broken Limb Condition For ‘V’ Insulator String

For ‘V’ Insulator strings, in normal condition one limb broken case shall be considered. In such a case the transverse and vertical loads shall be transferred to outer limb attachment point.

DESIGN OF DIAMOND SHAPE MONOPOLE

These poles are flexible structures and may undergo relatively large lateral deflections under design loads. A secondary moment (or P − Delta effect) will develop in the poles due to the lateral deflections at the load points. This secondary moment can be a significant percent of the total moment. In addition, large deflections of poles can affect the magnitude and direction of loads caused by the line tension and stringing operations. Therefore, the effects of pole deflections should be included in the analysis and design of single and multi-pole transmission structures.

To properly analyse and design the tubular pole transmission structures, usually nonlinear finite element computer programs are used. These computer programs allow efficient evaluation of pole structures considering geometric and/or material nonlinearities. There are several popular computer software programs available to design tubular poles like, PLS-pole.

The loadings calculated by method as mentioned above are provided as input in PLS-pole software. PLS-POLE does both linear and nonlinear analyses. Nonlinear analysis allows to see P-Delta effects, to detect instabilities, and to perform accurate buckling checks. After calculation of forces and moments in different members of monopole software compares them against code capacities. The ASCE/SEI 48-11 (previously ASCE manual 72) is used to check steel poles and tubular steel elements. The Manual provides detailed design criteria including allowable stresses for pole masts and connections and stability considerations for global and local buckling. It also defines the requirements for fabrication, erection, load testing, and quality assurance. To prevent excessive deflection effects, the lateral deflection under factored loads is usually limited to 5 to 10% of the pole height. For more stringent design and if line passes through congested areas then the deflection limit can be reduced but this will increase the section of monopole.

As this monopole has square cross-section having thin material, special considerations must be given to the calculation of member section properties and assessment of local buckling. To ensure that member can reach yielding on its extreme fiber under combined axial and bending compression, local buckling must be prevented. This can be met by limiting the width to thickness ratio or providing

Table 3 Comparison of results achieved for tower and diamond shape monopole

	Lattice tower	**Diamond shape Monopole**
Type of tower	220kV two circuit dead end	220kV two circuit dead end
Span between two towers	300 m	300 m
Height of tower	35.9 m	29.5 m
Base of tower structure	5.2 m	1.25 m
Base of tower with pedestal	6.2 m	2 m

stiffeners on all sides of pole member. Therefore, sides of the pole is checked as thin walled member as per IS 801.

MATERIAL FOR DIAMOND SHAPE MONOPOLE

Special considerations should be given in the selection of the pole materials where poles are to be subjected to subzero temperatures. To mitigate potential brittle fracture, use of steel with good impact toughness in the longitudinal direction of the pole is necessary. The general requirements relating to the supply of the material shall be as per IS 1387.

Poles shall be well-finished, clean and free from harmful surface defects. Ends of the poles shall be cut square. Poles shall be straight (finished pole shall not be out of straightness by more than 1/600 of its length), smooth and cylindrical. The welded joints shall be of good quality, free from scale, surface defects, cracks, etc.

The monopole material, when analysed in accordance with IS 228 (Part III) and IS 228 (Part IX), shall not show sulphur and phosphorus contents of more than 0·06% each.

Corrosion protection must be considered for steel poles. Selection of a specific coating or use of weathering steel depends on weather exposure, past experience, appearance, and economics. The poles can be coated with black bituminous paint conforming to IS 158 throughout, internally and externally, up to the level which goes inside the earth. The remaining portion of the exterior shall be painted with one coat of red oxide primer as specified in IS 2074. Weathering steel is best suited for environments involving proper wetting and drying cycles. When weathering steel is used, poles should also be detailed to provide good drainage and avoid water retention. Also, poles should either be sealed or well ventilated to assure the proper protection of the interior surface of the pole. Alternatively, tubular poles over the entire length can be hot-dip galvanized.

COMPARISON BETWEEN DIAMOND SHAPE MONOPOLE AND REGULAR TOWER

Type of transmission line supporting structure considered for comparison between tower and diamond shape monopole is 220kV two circuit dead end for 300m span. The regular tower is designed with the help of Staad.Pro Software and Diamond Shape Monopole is designed with the help of PLS-Pole Software. The comparison of results achieved for tower and diamond shape monopole are tabulated below:

CONCLUSION

The proposed diamond shaped monopole helps to overcome the critical drawbacks of more height and footprint requirement associated with conventional lattice towers. In diamond shape monopole the three conductors of one circuit are placed on single cross arm in diamond geometry with the help of pivoted type insulated cross arm, which results in approximately 20 % reduction in height and approximately 50 % reduction in footprint (above ground) of pole if compared with conventional lattice structure.

In addition, diamond shaped monopole offers numerous other advantages. For example, owing to a considerable reduction in overall height of the transmission line supporting structure, it is possible and convenient to use the present diamond shaped monopole structure in vicinity of aerodromes where height of the tower is restricted and when proposed transmission line crosses existing transmission line tower in perpendicular direction. Moreover, the dangers of faults associated with lightning will be reduced due to reduction in the height of the structure. As well as, the erection of this monopole is easy, takes less time for fabrication because it has square sections which can be made from four different plates and no special machinery is required to bend plates. Also fabrication of this monopole can be done at the factory and placed at sites afterward.

REFERENCES

Journal articles:
Fang, S.J.; Roy, S. and Kramer, J. (1999), “Transmission Structures", *CRC Press LLC,* Boca Raton.

Standards:
1) ASCE/SEI 48-05 (2006), “Design of Steel Transmission Pole Structures”, American Society of Civil Engineers, New York
2) IS 800 (1984), “Code of Practice for General Construction in Steel”, *Indian Standard Institution*, New Delhi.
3) IS 801 (1975), “Code of Practice for Use of Cold-Formed Light Gauge Steel Structural Members in General Building Construction”, *Indian Standard Institution*,

New Delhi.

4) IS 802 (Part I/Set 1) (1995), “Code of Practice for Use of Structural Steel in Overhead Transmission Line Towers”, *Indian Standard Institution*, New Delhi.
5) IS 2713 (1980), “Code of Practice for Specification for Tubular Steel Poles for Overhead Power Lines”, *Indian Standard Institution*, New Delhi.
6) “PLS-Pole Manual”
7) Publication no. 268 (1993), “Transmission Line Manual”, *Central Board of Irrigation and Power*, New Delhi.