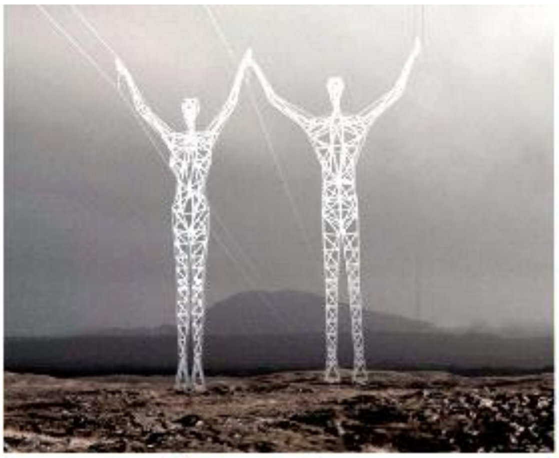
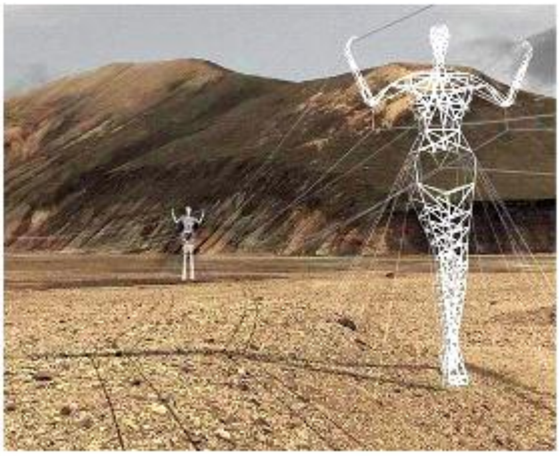
POWER CELL
Ministry of Power, Energy and Mineral Resources
Government of People's Republic of Bangladesh

FINAL REPORT

ON

CONSULTANCY SERVICES FOR TECHNICAL STUDY FOR INNOVATIVE DESIGNING OF GRID TRANSMISSION TOWER USING OPTIMUM AREA OF LAND

Submitted by

STEAG Energy Services India Pvt. Ltd.
in association with
N_Arc Consulting, India and
Technobin Engineering Services Limited, Bangladesh

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ABBREVIATIONS

AAAC	All Aluminum Alloy Conductor
ACSR	Aluminum Conductor Steel Reinforced
CG	Centre of Gravity
FL	Failure Limit
FOS	Factor of Safety
GoB	Government of Bangladesh
GTT	Grid Transmission Tower
HFL	Highest Flood Level
HTLS	High Temperature Low Sag
MVMCT	Multi-Voltage Multi-Circuit
OPGW	Optical Ground Wire
PGCB	Power Grid Company of Bangladesh
SBC	Safe Bearing Capacity
SPT	Standard Penetration Test
UBC	Ultimate Bearing Capacity

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

E-1 PROJECT BACKGROUND

Government of Bangladesh (GoB) is facing big challenge in getting sufficient land and right-of-way for transmission line corridor especially in urban areas. In this context, GoB intends to carry out a technical study for innovative designing of grid transmission towers by optimizing the footprint area.

Power Cell has appointed Steag Energy Services India Pvt. Ltd. to carry out the above mentioned study

E-2 OBJECTIVES OF THE STUDY

The following are the main objectives:

- To carry out innovative design of Grid Transmission Tower.
- To carry out various tower configuration analysis.
- Tower weight estimation.
- Cost analysis and span optimization.
- Optimization of tower footprint area.

E-3 APPROACH

Optimize the tower footing area of transmission tower in order to reduce the impact of land requirement aspect. This will be achieved based on design optimisation incorporating various innovative methods, within the existing standard requirement.

E-4 METHODOLOGY

The methodology adopted to carry out the assignment includes:

- Optimization of various types of Existing Towers
- Both double and four circuit towers have been considered for study
- All the required design basis have been collected from the utility
- Existing Design basis considered for optimization
- Optimization options have been studied
- Required optimization have been analyzed
- Primary Optimization have been done in Tower Base

E-5 INNOVATIVE OPTIONS CONSIDERED

The innovative ideas considered for optimizing the tower design are based on following modification aspects.

- Structural Modification
- Tower Configuration
- Tower design data / Loadings
- Electrical Parameters
- Material of tower & bolts and tower types
- Modifications in existing design criteria.
- Re-configuration of tower classification.

Each innovative options listed and techniques offered have been analysed for its impact on reducing the tower footing area. Out of these, only the technical feasible option have been taken up for further analysis.

Some of the possible options are as under:

1. Modification in base width of tower
2. Modification in peak
3. Modification in tower cross arm
4. Modification in tower cross arm
5. Use of high tensile low sag (HTLS) conductor
6. Use of higher material grade
7. Use of minimum member size
8. Use of higher section with different thickness
9. Modification in redundant pattern
10. Use of redundant members
11. Modification in bolts diameter
12. Modification in bolts material
13. Use of insulated cross arm
14. Use of different arrangements of insulated cross arm
15. Modification in tower design loadings, wind pressure and factor of safety (FOS)
16. Use of multi-voltage multi-circuit (MVMCT) tower
17. Modify the angle of suspension tower to 6 degree and re-configure the classification of towers based on the angle of line deviation.
18. Use of 8-legged tower.

E-6 ANALYSIS OF CANDIDATE TOWERS

Bangladesh Grid mainly comprises 132 kV, 230 kV and 400 kV network. For the purpose of study, double circuit and multi circuit towers have been considered for PLS analysis for each voltage level, however the significant reduction in footing area was observed only in 132 kV towers. The nomenclature of 132 kV double circuit and 132 kV multi circuit towers in PGCB parlance is 1QL and 1QT6 respectively.

E-6.1 Analysis of 1QL Suspension Tower

E-6.1.1 Innovation and Optimisation of 1QL Suspension Tower

The following innovation options were applied to the reference tower owing to that the significant reduction in tower base area and tower weight have been achieved successfully.

Table 0-1: Innovation and Optimisation of 1QL Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration ii. Alterations in tower Geometry - Modifications iii. Tower Slopes alterations	i. Modification in base width of tower, ii. Tower geometry, Leg member proposed straight. iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements, ii. Material of tower & bolts and tower types	i. Use of different size Bolts, 16mm & 24mm ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used. iii. Minimum Lattice/ redundant sections used. iv. Redundant members designed for 1.5 % force of supported members.	As per the discussion held with PGCB on 25th July 2023. The orginal design criteria of PGCB has been used.
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence, ii. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

E-6.1.2 Tower Base Optimization

The base width of the original tower is 7.5 m and at +9 m level as per slope base width would be 10.056 m. It means land area required is 10.056 m x 10.056 m i.e. 101.12. Therefore, the area required when tower with +9 m extension is installed on ground is 101.12 m^2.

It was observed that after applying the innovative measures during analysis, the tower base width at +9 m level remains same as normal tower level i.e. 7.5 m, which means that the area required for tower with +9 m will be (7.5 x 7.5) 56.25 m^2.

Table 0-2: Reduction in Tower base in 1QL Tower

Description	Original Tower	Innovated tower	Reduction
Tower Base width/ ROW-area	101.12m^2	56.25m^2	44%

The total weight of the 1QL tower post optimization works out to **11.6 tons which is about 16% less** than the original weight.

E-6.2 Analysis of 1QT6 Angle Tower

E-6.2.1 Innovation and Optimisation of 1QT6 Angle Tower

Following options were applied on 1QT6 tower that resulted in only reduction in tower base area whereas tower weight has increased significantly.

Table 0-3: Optimization Options for 1QT6 Angle Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Modification in base width of tower,	
	ii. Alterations in tower Geometry - Modifications	ii. Tower geometry, Leg member proposed straight.	
	iii. Tower Slopes alterations	iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	As per the discussion held with PGCB on 25th July 2023. The orginal design criteria of PGCB has been used
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used.	
		iii. Minimum Lattice/ redundant sections used.	
		iv. Redundant members designed for 1.5 % force of supported members.	
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence,	No Change, as per Bangladesh design code	
	ii. Tower design data / Loadings		
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

The outcome of the optimization is the reduced tower base area which is shown in table below:

Table 0-4: Reduction in Tower base in 1QT6 Tower

Description	Original Tower	Innovated tower	Reduction percentage
Tower Base width / ROW - area	179.5Sq.m	100Sq.m	44.3 %
Tower Weight	-	Approximate provided below	Approx. 8 T

The total weight of the 1QT6 tower post optimization works out to about **48 tons which is about 22% more** than the original weight.

E-6.3 Analysis of 2QL Suspension Type Tower

E-6.2.2 Innovation and Optimisation of 2QL Suspension Type Tower

Following options were applied on 2QL tower that resulted in only reduction in tower base area whereas tower weight has increased significantly.

Table 0-5: Optimization Options for 2QL Suspension Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Modification in base width of tower,	
	ii. Alterations in tower Geometry - Modifications	ii. Tower geometry, Leg member proposed straight.	
	iii. Tower Slopes alterations	iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	As per the discussion held with PGCB on 25th July 2023. The original design criteria of PGCB has been used
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used.	
		iii. Minimum Lattice/ redundant sections used.	
		iv. Redundant members designed for 1.5 % force of supported members.	
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence,	No Change, as per Bangladesh design code	
	ii. Tower design data / Loadings		
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

The outcome of the optimization was terminated due to unstable tower configuration, on analysis of this tower it was noticed that the tower structure becomes unstable on further optimisation.

E-6.4 Analysis of 2QT Angle Tower

E-6.2.3 Innovation and Optimisation of 2QT Angle Tower

Following options were applied on 2QT tower that resulted in only reduction in tower base area whereas tower weight has increased significantly.

Table 0-6: Optimization Options for 2QT Angle Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Modification in base width of tower,	
	ii. Alterations in tower Geometry - Modifications	ii. Tower geometry, Leg member proposed straight.	
	iii. Tower Slopes alterations	iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	As per the discussion held with PGCB on 25th July 2023. The original design criteria of PGCB has been used
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used.	
		iii. Minimum Lattice/ redundant sections used.	
		iv. Redundant members designed for 1.5 % force of supported members.	
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence,	No Change, as per Bangladesh design code	
	ii. Tower design data / Loadings		
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

The optimisation techniques were also applied to 2QT (D- Type / Dead End) Tower, the outcome of the optimization was terminated due the unstable tower configuration, on analysis of this tower it was noticed that the tower structure becomes unstable on further optimisation. Hence the original tower appears to be optimised.

E-6.5 Analysis of 2QL (80m/sec) Suspension Tower without change in base width

E-6.2.4 Innovation and Optimisation of 2QL Suspension Tower

Following options were applied on 2QL tower that resulted in only reduction in tower base area whereas tower weight have been achieved successfully.

Table 0-7: Optimization Options for 2QL Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Modification in base width of tower,	The tower structure has not been modified and the original tower has been considered for Innovation. No change in Base With or any other structural change made.
	ii.. Tower Slopes alterations	ii.. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	As per the discussion held with PGCB on 25th July 2023. The original design criteria of PGCB has been used
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used.	
		iii. Minimum Lattice/ redundant sections used.	
		iv. Redundant members designed for 1.5 % force of supported members.	
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence, ii. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

The total weight of the 2QL tower (normal) post optimization works out to 42.4 MT

The optimisation techniques were also applied to 2QL tower with wind speed of 80m/sec and the outcome of the optimization was successful. On analysis of this tower it was noticed that the tower structure is stable with enhanced wind speed under the optimised condition. Hence the original 2QL tower appears to be stable & optimised at 80m/sec.

E-6.6 Analysis of 4DL Suspension Tower

E-6.1.3 Innovation and Optimisation of 4DL Suspension Tower

The following innovation options were applied to the reference tower owing to that the significant reduction in tower base area and tower weight have been achieved successfully.

Table 0-8: Innovation and Optimisation of 4DL Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	iv. Structural / tower Configuration v. Alterations in tower Geometry - Modifications vi. Tower Slopes alterations	iv. Modification in base width of tower, v. Tower geometry, Leg member proposed straight. vi. Modification in cross arms, Cross arm length modified as per swing	

Category	Domain of modification	Preferred innovation options	Remarks
		angle.	
Category B	iii. Structural material improvements, iv. Material of tower & bolts and tower types	v. Use of different size Bolts, 16mm & 24mm vi. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used. vii. Minimum Lattice/ redundant sections used. viii. Redundant members designed for 1.5 % force of supported members.	As per the discussion held with PGCB on 25th July 2023. The original design criteria of PGCB has been used
Category C	ii. Structural Analysis methodology	ii. Slenderness ratio of redundant used upto its maximum limit.	
Category D	iii. Design criteria & design guideline adherence, iv. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	ii. Modifications in Electrical requirements	NA	
Category F	ii. Latest in the Transmission line practices.	NA	

E-6.1.4 Tower Base Optimization for 4 DL Tower

The base width of the original tower is 7.96 m and at +9 m level as per slope base width would be 10.664 m. It means land area required is 10.664 m x 10.664 m i.e. 113.72 m^2. Therefore, the area required when tower with +9 m extension is installed on ground is 113.72 m^2.

It was observed that after applying the innovative measures during analysis, the tower base width at +9 m level remains same as normal tower level i.e. 7.96 m, which means that the area required for tower with +9 m will be (7.96 x 7.96) 63.36 m^2.

Table 0-9: Reduction in Tower base in 4DL Tower

Description	Original Tower	Innovated tower	Reduction
Tower Basewidth/ ROW-area	113.72 m^2	63.36 m^2	44.3%

The total weight of the 4DL tower post optimization works out to **30.2 tons which is about 17% more** than the original weight.

E-6.7 Analysis of 132 KV Twin Grosbeek “ST” Suspension Tower

E-6.1.5 Innovation and Optimisation of ST Suspension Tower

The following innovation options were applied to the reference tower owing to that the significant reduction in tower base area and tower weight have been achieved successfully.

Table 0-10: Innovation and Optimisation of ST Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	vii. Structural / tower Configuration viii. Alterations in tower Geometry - Modifications ix. Tower Slopes alterations	vii. Modification in base width of tower, viii. Tower geometry, Leg member proposed straight. ix. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	v. Structural material improvements, vi. Material of tower & bolts and tower types	ix. Use of different size Bolts, 16mm & 24mm x. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used. xi. Minimum Lattice/ redundant sections used. xii. Redundant members designed for 1.5 % force of supported members.	As per the discussion held with PGCB on 25th July 2023. The original design criteria of PGCB has been used
Category C	iii. Structural Analysis methodology	iii. Slenderness ratio of redundant used upto its maximum limit.	
Category D	v. Design criteria & design guideline adherence, vi. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	iii. Modifications in Electrical requirements	NA	
Category F	iii. Latest in the Transmission line practices.	NA	

E-6.1.6 Tower Base Optimization for 132 KV ST Tower (Twin Conductor)

The base width of the basic tower is 6.43m and at 18.85m level as per slope base width would be 13.23 m. It means land area required is 13.23 m x 13.23 m i.e. 175.03m^2. Therefore, the area required when tower with +12 m body extension & 6.85m Leg extension is installed on ground is 175.03 m^2.

It was observed that after applying the innovative measures during analysis, the tower base width at 12 m body extension & 6.85m Leg extension m level remains same as basic tower level i.e. 6.43 m, which means that the area required for tower with 12 m body extension & 6.85m Leg extension m will be (6.43 x 6.43) 41.34 m^2.

Table 0-11: Reduction in Tower base in ST Tower

Description	Original Tower	Innovated tower	Reduction
Tower Basewidth/ ROW-area	175.03m^2	41.34m^2	76%

E-7 LEGAL ASPECTS OF TRANSMISSION LINE

Some of the legal aspects applicable to the transmission lines are as under:

- According to Section 14 of the Electricity Act 2018 ("Act") tower erection does not require any acquisition or lease of the land but rather uses a portion of land by exercising the Right of Way over the land under Section 13 of the Act, with appropriate compensation as prescribed by Law.
- . As per section 13 of the Electricity Act 2018, the licensee shall reserve the right of way over the land and the space above or underground thereof for the purpose of laying power supply lines or doing civil works under this Act
- If any trees, construction, or any structure is established near the Aerial Line which can interrupt Electricity Transmission or cause disturbance or create obstacles to the transmission or civil works, such structures, and trees shall be removed for the smooth operation of the civil work [Rule 8(6)].
- The Landowner can utilize the land below the Tower after the completion of such civil work without causing any harm or interruption of the Electric Transmission and the tower. However if the Licensee assumed that the usage of the land may cause harm or threat to such transmission, he can restrain the Landowner to use the Land below the Tower [Rule 10(6)].
- Section 12 stipulates the requirement of compensating the Land Owner for the Usage of Land as fixed by the Rule.

E-8 BARRIERS AND CONSTRAINTS

1. Implementation of Optimised Design in Existing Towers

Implementation of modification in the existing tower infrastructure requires meticulous planning and may lead to long line outages. Owing to that long duration outages will be difficult to manage with the current system demand.

2. Impact due to Tower Cost

Replacing lattice structure towers with mono pole structures to reduce the foot print area may not be financially viable proposition. As the cost of mono pole towers are much higher than the lattice structure towers.

3. Adoptability in Bangladesh Scenario

Currently locations of some of the towers and ROW of some transmission line (mainly in urban area) are heavily inhabited, which will create major barrier in adopting any modifications. Also in such area modifying the route in line with the S/S orientation will be a tough task to adopt.

4. Relevance w.r.t. existing practice

Some existing practices viz.

- doing agriculture under the tower,
- doing some other small temporary economic activities under the tower

Such practices can be considered as multipurpose use of land and supporting the economy in both ways. So in such cases impact of tower footing optimisation reduces, though it considerably reduces the compensation fees.

5. Modification in Established Code

Though it is ideal to implement the optimised design within the existing code, however some modifications in standard can make optimisation more impactful. Some factors, such as factor of safety, deviation optimisation (for angle tower) etc. can be revisited to achieve more optimised design.

6. Suitability of Line Route

The adoptability of MC/MVMC towers (which will considerably reduce tower footprint and ROW) depends mainly on alignment of long parallel transmission line. Such scenario may be remote in existing Bangladesh transmission infrastructure, as existing system does not have many long distance bulk transmission lines.

E-9 BENEFIT COST ANALYSIS

The benefit cost analysis for adopting the innovative design for 132 kV multi circuit transmission towers has been worked out and the results have been compiled in the table below:

Table 0-12: Benefit-Cost Analysis of Innovative GTT Design for 132 kV Transmission Line w.r.t. Multicircuit Tower (1QL)

1QL+9M (for each tower)	Existing	Innovative
Tower Weight (tonne)	13.880	11.600
Tower Cost* (million BDT)	1.25	1.04
Foundation Cost (million BDT)	1.56	1.87
Total Cost of Tower	2.81	2.92
Increase in tower cost (million BDT per GTT)		0.11
Total Route Length considered for Financial Analysis (based on the planned 132kV Line) (kilo-meters)		1,070
Total increase in GTT cost of Line (million BDT)		317.48
Saving in Compensation (million BDT)		530.00
Net Saving (million BDT)		441.84
Benefit-cost Ratio		3.36
** Reference Cost Data of steel (BDT/tonne)*		90,000

The analysis clearly brings out the net benefit of adopting the innovative GTT design for the multi circuit 132 kV transmission line. It is seen that for the proposed 1,070 km high voltage transmission line, a saving of BDT 441.84 million is possible. Moreover, the benefit-cost ratio is also very attractive at 3.36.

E-10 CONCLUSION AND RECOMMENDATION

The tower design optimization study clearly demonstrates that the footing area of transmission tower can be significantly reduced by adopting the innovative design options. The major economic benefit that can be derived by reducing the footing area is the reduction in compensation to the owner of the land which will have considerable impact on project cost optimisation.

The recommendations are as under:

- Adopt low footing area towers in the countryside whereas mono pole towers for city areas, where ROW and land availability problem is acute.
- Multi voltage multi circuit (MVMC) towers can be adopted around the substations.
- Routing of lines should be such that MVMC towers can be easily adopted. This can be done by creating a transmission line corridor.
- Extra high voltage of 765 kV must be adopted for long and bulk transmission lines.
- Temporary economic activities or multipurpose land use can take place under the conductor in urban areas.
- The optimisation effort can be initiated with planned 132kV network

1.0 INTRODUCTION

INTRODUCTION

1.1 PROJECT BACKGROUND

Bangladesh is a densely populated country and to supply electricity to its subject, a large transmission and distribution network has been constructed that consumes large swathes of land. Owing to this GoB is facing big challenge in getting land and right-of-way for transmission line corridor especially in urban areas. In this context, GoB intends to carry out a technical study for innovative designing of grid transmission towers by optimizing the footprint area. This study will not only help GoB in estimating the land requirement for the tower of various voltage levels but also help them to reduce the right-of-way requirement.

Power Cell has entrusted the above mentioned assignment to Steag Energy Services India Pvt. Ltd.

1.2 OBJECTIVES OF THE STUDY

The following are the main objectives:

- To carry out innovative design of Grid Transmission Tower.
- To carry out various tower configuration analysis.
- Tower weight estimation.
- Cost analysis and span optimization.
- Optimization of tower footprint area.

1.3 APPROACH

The general approach for undertaking the assignment will be to optimize the tower footing area of transmission towers in order to reduce the impact of land requirement aspect. This will be achieved based on design optimisation incorporating various innovative methods, within the existing standard requirement.

The approach includes the review of following aspects:

1.3.1 Structural Optimization

This will be achieved by reducing the mass of the existing transmission tower and optimize number of members and joints without adversely affecting qualitative criteria.

1.3.2 Electrical Aspects

Attempt will be made to optimize the vertical clearances between earth wire and top conductor.

1.3.3 Tower Configuration

Optimization of tower configuration will be done by reviewing the computation of conductor and ground wire sags and their permissible maximum working tensions under the critical wind pressure and temperature conditions.

Following points will be considered while designing the tower

- Minimum ground clearance of the lowest conductor point above the ground level.
- Length of the insulator string.
- Minimum clearance between conductors and between conductor and tower.
- Location of a ground wire with respect to outermost conductors.
- Mid span clearance for assessing the dynamic behaviour of the conductor and lightning protection of the power line.

1.3.4 Tower Material

The impact of change in material grade of various components of tower on the tower foot print area if any will be analysed and duly commented upon.

1.4 METHODOLOGY

The methodology to carry out the assignment will include:

- The optimization shall be done considering various types of Existing Towers
- Both double and four circuit towers shall be considered for study
- All the required design basis shall be collected from the utility
- Design basis shall be re-visited for optimization
- Optimization options shall be studied
- Required optimization shall be undertaken
- Primary Optimization will be done in Tower Base

Apart from this the following suggestions and practices of PGCB will also be considered while carrying out the study.

1. For wind zone BNBC data needs to be referred
2. To optimize the ROW, multi circuit tower must be proposed within 2 km around the substation
3. Presently, narrow base towers are being used by PGCB

4. In addition to double circuit towers, 230 kV and 132 kV multi circuit (four circuit) towers are being currently used by PGCB.
5. PGCB is using HTLS (high temperature low sag) conductors to reduce the sag
6. Some special towers viz. river crossing tower, section tower are also being used by PGCB
7. Presently, V-type insulator strings are being used by PGCB in recent 400 kV transmission lines.

1.4.1 Analyses of Transmission Tower through PLS Software

The following major steps for tower analyses will be considered:

- Step 1: Modelling of a Transmission Tower
- Step 2: Assigning Properties for a Transmission Tower
- Step 3: Assigning Supports to a Transmission Tower
- Step 4: Assigning Loads to a Transmission Tower
- Step 5: Assigning design properties
- Step 6: Analysis of a Transmission Tower

1.4.2 Application of furnished Data for Simulation Activities

A brief of various activities to be undertaken based on the furnished data is as under:

1.4.2.1 Details of Conductor Parameters

For calculation of conductor sag tension, wind area and wind load will be calculated on conductor for specified wind span.

1.4.2.2 Details of OPGW/ Earthwire Parameters

For calculation of OPGW / Earthwire sag tension, wind area and wind load will be calculated on OPGW / Earthwire also for specified wind span.

1.4.2.3 Details of Suspension Insulator, Tension Insulator, Jumper Suspension Insulator

These will be required for calculation of phase to phase clearance i.e. for vertical clearance and is also required for calculation of vertical weight, wind area and wind load on insulator.

1.4.2.4 Calculation of Swing Angle for Suspension Insulator, Jumper and Jumper Insulator

The swing angle will be calculated with the help of horizontal clearance of phase to phase that will help in deciding the cross-arm length.

1.4.2.5 Midspan Separation Calculation

The midspan separation will be calculated using vertical clearances of phase to earth wire / OPGW to work out the peak height and width of the tower.

1.4.2.6 Loading Calculation

Various loads acting on the tower like transverse load, vertical load and longitudinal load for each conductor/OPGW holding point in structure will be calculated using conductor / OPGW parameters, sag tension, wind span, weight span and details of insulator.

1.4.2.7 Codes /Standard

The applicable and relevant codes, standards, PGCB specifications and best international practices will be followed for calculation of above mentioned aspects of the tower design.

1.4.2.8 Geometry of Towers

Based on the inputs from specification and the vertical/horizontal clearance, midspan clearance etc worked out will firm up the geometry of towers at this stage. The pattern of bracings, pattern of secondary bracings will also be firmed up at this stage to make the geometry as the most optimized model.

1.4.2.9 Loading Trees

As per the above loading calculations, transverse load, vertical load and longitudinal loads are applied on tower geometry. Load cases will be considered depending upon reliability condition, security condition, safety & maintenance condition and also anti cascade condition as per respective codes and standards.

Depending upon the location of tower a matrix of acting loads will be developed. Generally the tower is subjected to following loads.

1. Dead load of tower
2. Dead load from conductors and other equipment
3. Load from ice, rime or wet snow on conductors and equipment
4. Ice load, etc. on the tower itself
5. Erection and maintenance loads
6. Wind load on tower
7. Wind load on conductors and equipment
8. Loads from conductor tensile forces
9. Damage forces
10. Earthquake forces

1.4.2.10 Tower Optimization

Tower optimization will be achieved by keeping the loading, height as well as reliability, safety and security condition same but different base width configuration like square base, triangular base or guyed mast base type.

1.4.2.11 Wind on tower calculation

Wind on tower structure is calculated as per the projected area of each member and applied on the tower structure. On the basis of above loads and wind loads on tower and conductor/OPGW points considering overload factor (as per respective code/specification), a loading tree chart will be prepared to summarize the applied load on structure.

1.4.2.12 Analysis of Tower

Tower design will be analyzed in the light of applicable loads and factors using **PLS tower software**. Optimization will be carried out at this stage to make the tower most economical and to maintain factor of safety. Each member will be designed to meet their maximum usage. Respective codes, standard and power grid manuals will be duly referred for designing each steel member by controlling their slenderness ratio.

1.4.2.13 Foundation Forces

After analysis of tower from reliability, security and safety point of view, foundation forces will be derived for ascertaining the foundation design.

Some of the design consideration to counter the foundation forces will be as under:

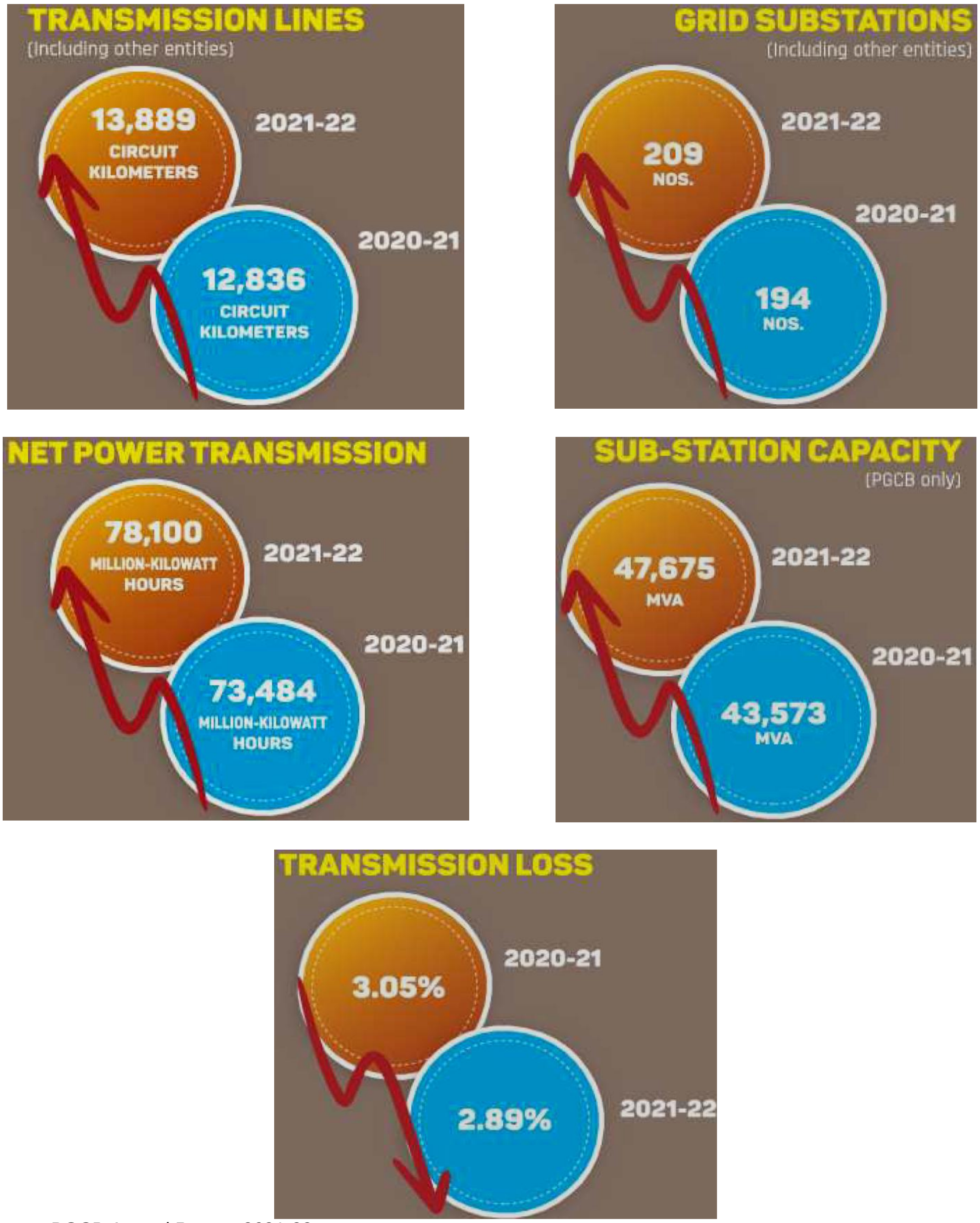
- To resist uplift load by the foundation and soil over footing
- For the thrust load or compression, size of the footing may be so chosen to satisfy within the allowable bearing capacity of the soil
- To resist the lateral force
- Settlement in soil is within allowable limit

2.0 TRANSMISSION SYSTEM IN BANGLADESH

2.1 SYSTEM DETAILS OF BANGLADESH GRID

The transmission system of Bangladesh comprises mainly three (3) voltage levels i.e. 132 kV, 230 kV and 400 kV. From the tables 2-1 and 2-2 below, it is evident that the 132 kV network forms the major part of the Bangladesh transmission system followed by 230 and 400 kV. Presently, though there is no 765 kV transmission system but it is under planning and development stage.

The salient features of the Bangladesh transmission system as per **PGCB Annual Report for 2021-22** are as under:



Source: PGCB Annual Report_2021-22

Table 2-1 – Salient features of Bangladesh Transmission System

2.2 TRANSMISSION LINE DETAILS

The excerpts of the transmission system as furnished by PGCB are as under:

2.2.1 Existing Lines

The details of existing lines of 132 kV, 230 kV and 400 kV are as under:

Table 2-2 – Details of Existing Lines

S. No	Voltage Level, kV	Route Length, km	Number of circuits
1.	132 kV	3,241	Double and Quad
2.	230 kV	1,754	Double and Quad
3.	400 kV	529	Double

2.2.2 Upcoming or Planned Lines

The upcoming line details are as under:

Table 2-3 – Details of Upcoming Lines

S. No.	Voltage Level, kV	Route Length, km	Number of circuits
1.	132 kV	1,069	Double and Quad
2.	230 kV	992	Double and Quad
3.	400 kV	1,282	Double

2.3 EXISTING TOWER PROFILE

The profile of existing towers for 132, 230 kV transmission lines that are not narrow based, are as under:

2.3.1 132 kV Tower

Table 2-4 – 132 kV Tower Specification

S. No.	No. of Circuit	Circuit Formation	Conductor Type	Conductor Configuration	Tower Type	Nomenclature (PGCB Standard)
1.	Double	Vertical	ACSR Grosbeak	Single	Suspension, Heavy Suspension,	1DL, 1D1, 1D25, 1DT6
2.	Double	Vertical	ACSR Linnet	Twin	Suspension, Heavy Suspension,	ST, ATb, ATc/TT

S. No.	No. of Circuit	Circuit Formation	Conductor Type	Conductor Configuration	Tower Type	Nomenclature (PGCB Standard)
3.	Four	Vertical	ACSR Grosbeak	Single	Suspension, Heavy Suspension,	1QL, 1Q15, 1Q30, 1QT6

2.3.2 230 kV Tower

Table 2-5 – 230 kV Tower Specification

S. No.	No. of Circuit	Circuit Formation	Conductor Type	Conductor Configuration	Tower Type	Nomenclature (PGCB Standard)
1.	Four	Vertical	Twin ACSR Mallard	Twin Bundle	Intermediate (Suspension)	2QL
					Intermediate (Heavy Suspension)	2Q1
					Angle (Tension)	2Q15
					Angle (Tension)	2Q30
					Angle/Terminal (Tension)	2QT6

The existing and planned 400 kV towers are already being erected with narrow base.

2.4 TOWER SPECIFICATIONS

The existing broad technical specifications of tower prevalent in Bangladesh transmission system are as under:

2.4.1 Design Parameters

PGCB has tower designs for different wind zone for the same voltage level. However, the design parameters considered for the study are as under:

Table 2-6 – Wind data considered for the study

Design Considerations	For on Ground Towers			For River Crossings Towers		
	132 kV	230 kV	400 kV	132 kV	230 kV	400 kV
3s gust wind speed (Failure Limit)	77.5 m/s	80 m/s	62.5 m/s		80 m/s	62.5 m/s
Wind load factor	1.15	1.15	1.15		1.15	1.15
Exposure category	C	C	C		C	C

Unless otherwise mentioned, tower structural loading shall be in accordance with ASCE 74-2009 and tower design shall be in accordance with ASCE 10-97/ASCE 10-15.

Table 2-7 – Tower Structural Loading

Loading Conditions	Wind Speed	Coincident Temperature	Design Aspect
Normal Condition (DL)	50% of FL	50˚C	Electrical Clearance of structure (PFC)
Normal Condition (DL)	15.6 m/s	50˚C	Electrical Clearance of structure (LIC)
Normal Condition (DL)	100% of FL	5˚C	Structure design
High Intensity Wind Condition	100% of FL	5˚C	
Security Condition	50% of FL	5˚C	
Safety condition	15.6 m/s	5˚C	

Note: DL - Damage Limit, FL - Failure Limit, PFC - Power Frequency Clearance, LIC - Lighting Impulse Clearance

2.4.2 Reliability Load Cases

These are applied to structure to design up to the failure limit (FL). The conductor shall be considered under “creep” condition. The various loads considered for normal and special normal conditions are as under:

2.4.2.1 Normal Conditions

The towers shall be designed for the following loads considered to be applicable simultaneously.

Vertical Loads – Due to dead weight of tower, insulators, conductor, earthwire, OPGW and other fittings

Transverse Loads – Due to wind at angles 0°, 22.5°, 45°, 67.5° and 90° on tower and its accessories

Longitudinal Loads - Conductor or earthwire/OPGW ultimate tensile strength is considered as unbalanced longitudinal load as under:

- Suspension towers - 3%
- Angle towers - 10%

For terminal towers, maximum working tension of conductor is considered as unbalanced longitudinal load.

2.4.2.2 Special Normal Condition

Eccentric Loads - loading caused by the conductors and earthwire or OPGW strung on one side of the tower

High Intensity Local Wind Loadings - by applying wind at 0°, 22.5°, 45°, 67.5° and 90° on tower body

2.4.2.3 Security Loading

The towers shall be designed for the following loads considered to be applicable simultaneously.

1. Vertical Loads – Due to dead weight of tower, insulators, conductor, earthwire, OPGW and other fittings
2. Transverse Loads – Due to wind (50% of failure Limit wind at angle 0°) on tower and its accessories
3. Longitudinal Loads

For intact point, unbalanced tension is similar to normal condition.

For broken point, unbalanced longitudinal tension shall be considered as per criteria given below:

Table 2-8 – Broken Point Longitudnal Loads

<table>
<tr><th>Tower Type</th><th>Conductor Tension</th><th colspan="2">Residual Static Load Factor</th><th>Load Factor</th><th>Broken Wire Assumption</th></tr>
<tr><td rowspan="4">Suspension/ Heavy suspension</td><td rowspan="5">Conductor tension at security condition</td><td>String Length</td><td>Factor</td><td rowspan="4">1.25</td><td rowspan="4">1 earthwire or 1 phase (all sub- phase) is broken</td></tr>
<tr><td>< 1m</td><td>1.0</td></tr>
<tr><td>1m< but < 2m</td><td>0.7</td></tr>
<tr><td>> 2m</td><td>0.6</td></tr>
<tr><td>Angle tower</td><td colspan="2">1.0</td><td>1.25</td><td>1 earthwire and 1 phase (all sub- phase) or 2 phase broken (all sub-phase) on the same side are broken</td></tr>
</table>

2.4.2.4 Safety Loading

1. Structure Erection - The specified construction and maintenance loading is applied to all phase conductor and earthwire/OPGW attachment points.

2. Ground Wire and Conductor Installation (Stringing) – Following criteria is considered:

- Only angle and sections towers shall be subjected to this load.
- For transverse and vertical loads, wind (15.6 m/s) on the wires and structure shall be considered. Use the lowest temperature (5° C) that can be expected to occur during stringing operations.

- The towers shall be designed for square rigging load assuming stringing tension working vertically and longitudinally simultaneously at the cross arm tip.
- For transverse wind loads, maximum design wind span with a load factor of 1.0 shall be considered.
- Longitudinal and vertical load factor shall be 2.0 for phase under stringing operation; this factor shall be 1.5 for strung phases.

3. Fall Protection Loads

Two person's fall arrest factored impact loading (21kN) at any cross arm tip point is considered.

4. Dropped conductor

In this case weight span is considered 1.5 times of maximum weight span with a load factor of 1.5 for all loads at that attachment point.

2.4.3.1 Observations on Tower Foundation

1. From the stability point of view of lattice tower consideration, choosing narrow base for a fixed height of tower inculcate more resistant force exerted by the four legs of the tower to counteract horizontal forces because of lever arm being shortened.

2. Because of less base plan dimensions of the tower possibility of soil improvement below the foundation would be a viable consideration and thus avoiding differential settlement and combined restrainment of the foundation for the tower will be achieved.

3. Though the cost of construction of superstructure and foundation of narrow base towers will be 10 to 15% higher but the socio-economic benefit achieved by reduction in footing area and right-of-way can easily offset the increased construction cost.
4. The top of foundation or pilecap should be kept at least 1000 mm below ground level so that the land at ground level of foundation area can be utilized for cultivation.

5. In order to balance out the additional loads owing to reduction in the base width of transmission tower, the size of pilecap must be kept same, whereas, the pile depth should be increased.

3.0 DESIGN OPTIMIZATION

3.1 INNOVATION TECHNIQUE IN TRANSMISSION LINE TOWER DESIGN

During the course of submission of the Interim report, various discussions were held with PGCB on the scope & reach of the innovation techniques for optimising the ROW for transmission line towers (TLT) being used by PGCB in Bangladesh. Based on the project understanding and its intent, consultant proposed various techniques for optimising the TLT to achieve the results for optimising the tower footprint / ROW / Base Width and prospective methods to be used for future design.

The following innovation options have been detailed out for the purpose of optimising the transmission line tower / ROW / tower weights depending upon the innovation criterion that fits well into the tower analysis without compromising on the PGCB's design basis / existing design criterion.

The innovation techniques detailed out below were applied to the reference towers owing to the reduction in tower base width and right-of-way is achieved successfully. These innovation options were applied to other transmission line towers suggested by Power Cell and the results obtained have been detailed out in this report.

3.2 INNOVATION IN TOWER DESIGNING

Innovations or design improvements, if applied with adequate design analysis can help improve the designs and at the same time reduce ROW requirements. The need of the hour is to adopt land optimization methodology that will allow obtaining more efficient solutions than conventional designs of high voltage transmission line towers. The optimization model has been developed based on few innovation processes by taking into account specific aspects related to transmission line structures in order to find a realistic approach of the problem.

Besides, these practical considerations facilitate the transference of optimized designs from numerical models to industrial applications. According to this idea, the proposed formulation tries to keep the main considerations related to the design process and includes all the design specifications established by PGCB, Bangladesh.

Proposed innovations & analysis must be done with a flexible approach for the optimization of self-supporting transmission line towers (TLTs). The analysis takes into account constructional and structural features to allow a direct application for prospective utility. Design methods need to be reformulated by including optimization techniques. Generally, though the traditional designs are usually effective, yet they are not the most efficient and environment friendly. Therefore, it becomes essential to have engineering design models that not only offers an optimised solution by way of quality and cost but also provide solutions to optimize the footprint area and right-of-way through innovative designs.

3.3 NEED FOR INNOVATIVE TRANSMISSION LINE TOWER DESIGN

Lattice towers are widely used for Transmission Line Towers / supports & similar purposes throughout the world, because they are the most economical and fulfil all requirements related to electricity transmission. The only problem in lattice tower is that they require a large area to stand as their base width is large. In last few decades many concepts have emerged in overhead power line designs mainly considering growing environmental constraints / Urban Land constraints despite increase in power demand. One of the concerns is the area of the land that is allocated for transmission line, which depends on voltage and design specification of the line. High price and limited availability of land, legal constraints on obtaining necessary permissions particularly in urban areas have created urge to think about reduction of land needed for the transmission line.

Nowadays, it has become necessary to design and construct a tower line with minimum base width, which can be erected by using minimum land. Several innovation techniques are being introduced with a new concept to minimize Right of Way (ROW) as well as land requirements by using composite angle and box sections and by replacing steel cross arm by insulated cross arm.

The study revealed that considerable reduction in height as well as ROW can be achieved by introducing new material instead of steel. The optimization was with reference to both tower weight and geometry. It can successfully be achieved by the control of a chosen set of key design parameters. It is likely that Design Parameters & the basis for design of transmission line needs a re-look and bring in more innovative / optimised solutions those could be easily analyzed by advanced design software available in today's world. This would need a shift from a conventional design basis to more innovative designs for fixing this challenge.

3.4 BASIS FOR INNOVATIVE TRANSMISSION LINE TOWER DESIGN

3.4.1 Structure Model

The main characteristics of the proposed optimization methodology for the design of high voltage towers and the practical considerations required to obtain adequate solutions have been duly discussed here.

In real applications, most of this kind of structures corresponds to three dimensional latticed structures assembled by joining a set of rolled steel sections. These steel bars usually correspond to symmetric L-shaped cross-sections according to a commercial catalogue. In addition, the steel sections are usually bolted in real designs due to practical considerations during the fabrication and erection.

Furthermore, high voltage transmission line towers usually have large dimensions and are built in practice by assembling a set of smaller blocks with predefined geometric and structural properties. Some of the most frequent blocks used in these towers are shown in figure below:

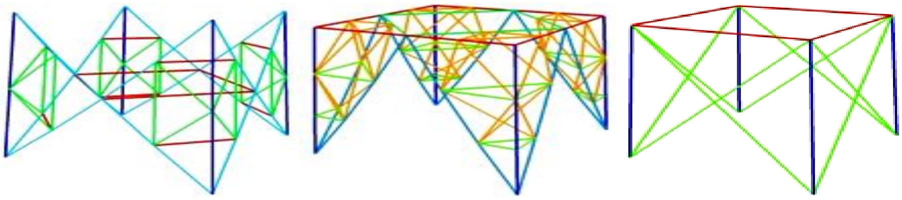


Table 3-1: Structure Model

3.4.2 Structural analysis

The structural analysis model proposed in this report corresponds to an articulated latticed structure made of predefined designed blocks and normalized steel rolled sections. Consequently, the numerical analysis model under the conventional hypotheses of small displacements, small displacements gradients and linear elasticity corresponds to a 3D analysis of articulated latticed structures using latest international softwares like PLSCadd / PLS Tower / I- Tower etc , Finite Element Analysis etc. Furthermore, the Bangladesh Standards and Norms corresponding to this kind of structures impose a set of load cases and design conditions. Self weight of the tower and the conductors

- Load on the full length of the conductors
- Wind load on the tower and on the conductors
- Tension imbalance of the conductors connected to the tower on both sides along the line.
- Cases of collapse of conductors.

While considering various options of applying innovative design alternatives on the transmission line towers, the application of such innovations will fulfil all the required design criteria as is being used by PGCB, Bangladesh. These options have been categorised into various categories based on the following design requirements. Each innovative idea has been listed and analysed its impact on reducing the tower footing area. Out of these, only the technical feasible option will be taken up for further analysis.

3.4.3 Economic Analysis

The economic analysis is the determination of the cost-effectiveness of the transmission line by comparing the benefits derived from the line and the costs incurred in constructing, operating, and maintaining the transmission line.

3.4.4 Life Cycle cost

The life cycle costs are the cumulative costs of a transmission line over time, measured using present value. The Present Value is the estimated current value of a future expenditure to be received or paid out, discounted to reflect the time value of money.

3.4.5 Optimised Design

An optimum design is the line option that has the minimum life cycle cost for given design criteria, boundary conditions, and constraints for an assumed time period (life cycle) and where dependability related costs and benefits are fully accounted for over the life cycle duration.

In order to meet the ever-increasing power demand, it becomes inevitable for generation and transmission utilities to expand their infrastructure. In this regard, the present study focuses on Innovation / optimization of power transmission towers / ROW requirements. Correlations have been developed for transmission line cost influencing parameters in terms of their design variables and are verified for accuracy by performing error analysis and observing key regression performance indicators. Based on the developed correlations, a mathematical model has been formulated to optimize the cost. The correlations developed and the cost optimization methodology employed for constructing overhead power transmission lines can be used by the line designers and developers for investment decision.

Table 3-2: Categories of Innovation / Optimisation with impacts on transmission line tower design

Category	Domain of modification	Preferred innovation options
Category A	• Structural / tower Configuration • Alterations in tower Geometry - Modifications • Tower Slopes alterations	• Modification in base width of tower, • Tower geometry • Modifications in peak • Modification in cross arms
Category B	• Structural material improvements, • Material of tower & bolts and tower types	• Use of higher steel grade • Higher grade of fasteners
Category C	• Structural Analysis methodology	• Modification in tower cross arm , • Uses of Minimum member size, • use of higher sections with different thickness, • modifications of redundant pattern, • use of redundant members
Category D	• Design criteria & design guideline adherence, • Tower design data / Loadings	• Optimisation & review of Tower Design Loadings, Wind pressure, FOS
Category E	• Modifications in Electrical	• Use of HTLS Conductor ,

Category	Domain of modification	Preferred innovation options
	requirements	• Optimise of Electrical clearances, • use of suspension towers up to 5 degree angle with sealing on swing , electrical clearances optimisation • Use of insulated cross arms

Table 3-3: Innovation Techniques which have Design Implications & Innovation linked to Design criteria

Category F (F.I)	• Latest in the Transmission line practices.	• Use of MCMV-NB Towers to increase line capability and reduce line corridors, hence cumulative ROW.
(F.II)	• Use of Suspension Tower with 6-degree angle of deviation • Re-configure the tower classification	• This will reduce the tower weight & base width of tower, otherwise designed as B Type with 15-degree deviation.
(F.III)	• Use of 8 leg tower with lattice construction and polymer insulators up to 220KV Voltage level	• Reduction in loads, reactions. • Though the tower weight will increase but the tower base will reduce appreciably, hence reduce the ROW.

3.4.6 Innovative Options

The innovative ideas considered for optimizing the tower design are based on following modification aspects.

- Structural Modification
- Tower Configuration
- Tower design data / Loadings
- Electrical Parameters
- Material of tower & bolts and tower types
- Modifications in existing design criteria.
- Re-configuration of tower classification.

Each innovative options listed and techniques offered have been analysed for its impact on reducing the tower footing area. Out of these, only the technical feasible option will be taken up for further analysis.

Some of the possible options are as under:

i. Modification in base width of tower

ii. Modification in peak
iii. Modification in tower cross arm
iv. Modification in tower cross arm
v. Use of high tensile low sag (HTLS) conductor
vi. Use of higher material grade
vii. Use of minimum member size
viii. Use of higher section with different thickness
ix. Modification in redundant pattern
x. Use of redundant members
xi. Modification in bolts diameter
xii. Modification in bolts material
xiii. Use of insulated cross arm
xiv. Use of different arrangements of insulated cross arm
xv. Modification in tower design loadings, wind pressure and factor of safety (FOS)
xvi. Use of multi-voltage multi-circuit (MVMCT) tower
xvii. Modify the angle of suspension tower to 6 degree and re-configure the classification of towers based on the angle of line deviation.
xviii. Use of 8-legged tower.

Details of each above option has been discussed as under:

3.4.6.1 Modification in base width of Tower

Category A	-	Structural / tower Configuration
Criteria / Method adopted	-	Bottom Body part of the tower will be considered as straight (avoid slope) to get the benefit in ROW. It shall be considered as part of tower design and tower will be analysed with this modification.
Analytical approach	-	An option for minimising the tower base width and excavation foot prints. Yes, can be considered for all tower design with stability analysis.
Outcome / Impacts	-	Reduction in tower footprint , ROW and excavation foot print.

3.4.6.2 Modification in Peak

Category A	-	Structural / tower Configuration
Criteria / Method adopted	-	Peak can be modified for single circuit towers to reduce peak height.
Analytical approach	-	Yes, can be considered for single circuit towers.
Outcome / Impacts	-	Reduction in Tower height and weight

3.4.6.3 Modification in Tower Cross Arm

Category A and E	-	Electrical / Structural / tower Configuration
Criteria / Method adopted	-	Cross arm end can be modified to reduce tower height
Analytical approach	-	Yes, can be considered for tension tower
Outcome / Impacts	-	Reduction in tower foot print

3.4.6.4 Modification in Tower Cross Arm

Category E	-	Reduction in electrical clearances
Criteria / Method adopted	-	Optimise phase-to-phase and phase-to-earth and metal clearances
Analytical approach	-	No
Outcome / Impacts	-	Reduction in Tower foot print , weight and ROW

3.4.6.5 Use of high tensile low sag (HTLS) conductor

Category E	-	Electrical Design loadings
Criteria / Method adopted	-	HTLS conductor can be used to reduce tower height
Analytical approach	-	Yes , can be considered for detailed analysis
Outcome / Impacts	-	Using this conductor, sag will be reduced and as a result the height of tower also gets reduced, owing to this significant reduction in tower weight and tower footprint can be achieved.

3.4.6.6 Use of Higher Material Grade

Category B	-	Steel Material
Criteria / Method adopted	-	Super high tensile steel can be used to reduce tower weight. Depending upon comparison in required quantity and cost, feasibility of innovative option solely depends on cost benefits
Analytical approach	-	Yes , can be considered for detailed analysis
Outcome / Impacts	-	Reduction in tower weight and tower foot print

3.4.6.7 Use of member with minimum size

Category C	-	Member section
Criteria / Method adopted	-	Minimum plate thickness - 6mm, Minimum Lattice thickness - 5mm Minimum redundant section 40x40x4 mm can be considered to reduce tower weight
Analytical approach	-	Yes, can be considered in all towers
Outcome / Impacts	-	Optimisation in tower size and weight

3.4.6.8 Use of higher section with different thickness

Category C	-	Irrational member section
Criteria / Method adopted	-	Higher section of various thickness as per latest trends can be considered to optimized tower weight
Analytical approach	-	Yes, can be considered in all towers
Outcome / Impacts	-	Optimisation in tower weight

3.4.6.9 Modification in redundant pattern

Category C	-	Arrangement of redundant pattern (Group A)
Criteria / Method adopted	-	Redundant can be arranged wherever required to reduce tower weight
Analytical approach	-	Yes, can be considered in all towers
Outcome / Impacts	-	Optimisation in tower weight

3.4.6.10 Use of redundant members

Category C	-	Design of redundant members
Criteria / Method adopted	-	Redundant members can designed for 1.5% force of supported member as per standard international practice to use lighter redundant
Analytical approach	-	Yes, can be considered in all towers
Outcome / Impacts	-	Lower sections of redundant can reduce tower weight

3.4.6.11 Modification in bolts diameter

Category B	-	Bolt diameter
Criteria / Method adopted	-	Two types of bolt diameter can be used like M16 and M24 to reduce quantity of bolts
Analytical approach	-	Yes, can be considered in all towers
Outcome / Impacts	-	Constructional benefit, reduction in size of joints, joint memebers and weight

3.4.6.12 Modification in bolts material

Category B	-	Bolt material grade
Criteria / Method adopted	-	Higher bolt grade (Grade 5.6/8.8) will be considered where its impact will maximise the benefit
Analytical approach	-	Yes, can be applied in all tower as per design requirement
Outcome / Impacts	-	Constructional benefit, reduction in size of joints, joint memebers and weight

3.4.6.13 Use of insulated cross arm

Category E	-	Insulated cross arm
Criteria / Method adopted	-	Use of compact towers with insulated cross arm to avoid weight of cross arms and inter layer space between cross arm is decreased to reduce tower height
Analytical approach	-	Yes, can be considered after comparing the cost of insulator and cost of cross arm weight
Outcome / Impacts	-	Optimisation on weight and foot print

3.4.6.14 Use of different arrangements of insulated cross arm

Category E	-	Insulator special arrangement
Criteria / Method adopted	-	Use of compact towers with "DIAMOND TYPE" insulated cross arm to reduce tower height drastically as used in UK
Analytical approach	-	Yes, can be considered after comparing the cost
Outcome / Impacts	-	Optimisation on weight and foot print

3.4.6.15 Modification in tower design loadings, wind pressure and factor of safety (FOS)

Category D	-	Design criteria and standardisation
Criteria / Method adopted	-	Analysis based on accepted loading criteria
Analytical approach	-	Yes, can be considered for all towers for analysis
Outcome / Impacts	-	Tower optimisation , design innovation, weight and foot print

3.4.6.16 Use of multi-voltage multi-circuit (MVMCT) tower

Category F	-	Design criteria, standardisation and tower configuration
Criteria / Method adopted	-	An innovative method to reduce the ROW width in the design of MVMCT. A study on MVMCT containing three different voltages such as 400/230/132 kV has been done and is demonstrated that the proposed design offers technically superior method and is also cost effective. ROW width is reduced when compared to conventional broad base towers which leads to a huge cost savings when a transmission line is considered. MVMCT also improves the transmission capacity.
Analytical approach	-	Yes, can be considered for all towers for analysis
Outcome / Impacts	-	It recduces the number of towers and accordingly reduces the number of land acquisitions, TL corridor & cumulative tower foot print.

3.4.6.17 Re-configure the tower classification

Category F.II	-	Design modification & revision in the design codes
Category / Method adopted	-	Increase angle of deviation of "A" Type tower to 6 degrees and classify the tower categories as explained in this report.
Analytical approach	-	Design load modifications, change in reactions will have to be analysed with new configuration
Out Come / Impacts	-	Reduction in tower weights, reduction in based width.

3.4.6.18 Use of 8-legged tower

Category F.III	-	Design modification & revision in the design codes
Category / Method adopted	-	Modify the tower geometry and analyse for stability / design loads as per the Bangladesh design code.
Analytical approach	-	Design load modifications, change in reactions will have to be analysed with new geometry.
Out Come / Impacts	-	Increase in tower weights, reduction in based width.

The modifications and its reasoning for carrying out the analysis for the reference tower is shown in table below:

Table 3-4: Analysis for the Reference Tower

Category	Domain of modification	Reason for adoption for analysis
Category A	• Structural / tower Configuration • Alterations in tower Geometery - Modifications • Tower Slopes alterations	• Shall be considered for analysis depending upon the requirement & the option which has a reasonable innovation impact.
Category B	• Structural material improvements, • Material of tower & bolts and tower types	• Shall be considered for analysis
Category C	• Structural Analysis methodology	• No Analysis proposed at this stage, shall be discussed with POWER Cell design team and the best option shall be chosen for analysis
Category D	• Design criteria & design guideline adherence, • Tower design data / Loadings	• Power Cell to consider this and give us their feedback, No analysis proposed at this stage.
Category E	• Modifications in Electrical requirements	• Options to be discussed with PowerCell before taken up for any analysis.
Category F	• Latest in the Transmission line practices	• No analysis proposed at this stage,

3.5 DESIGN OPTIMIZATION

3.5.1 Optimisation Concept

In general Optimization of Transmission Line Tower is aimed at achieving low cost, high performance, better and more reliable design strength. It is observed from the analytical work that the weight of tower with Optimized base width, Pattern Geometry, Base Configuration and Section Size Optimization shows an economical construction.

The electrical specifications decide the general shape of the tower with respect to its height at different levels (conductor and ground wire) and cross arm dimension. However there is a still scope for optimization of basic tower dimension such as base width and widths at cross arm level.

3.5.2 Design Criteria

3.5.2.1 Tower Selection

Selection of transmission tower is governed by the following factors:

1. Height of tower
2. Base width of tower
3. Cross arm length
4. Single circuit tower / double circuit tower
5. KV current capacity
6. Angle of deviation
7. Soil, Wind Speed & zone
8. Length of insulator assembly
9. Mid-span clearance required from consideration of the dynamic behaviors of conductor & lightning protection of the line
10. Minimum clearance of the lowest conductor of the ground level.
11. According to crossing of Power line, Railway line, National, District, Village Road & River

3.5.2.2 Tower Configuration

The main considerations in arriving at the tower configuration are: the specified electrical clearances; tower type; wind pressure; maximum and minimum temperature conditions; possible ice loads on the conductor and ground wire and terrain profile.

3.5.2.3 Height Determination

The basic design consideration which needs to be made for designing of a Transmission Tower is as follows:

1. The minimum ground clearance of the lowest conductor points above the ground level.
2. The length of the insulator string.
3. The minimum clearance to be maintained between conductors and between conductor and tower.
4. The location of a ground wire with respect to outermost conductors.
5. The mid span clearance required from considerations of the dynamic behavior of the conductor and lightning protection of the power line

Considering above the height of a transmission tower can be calculated as follows:

i.	Minimum permissible ground clearance	H1
ii.	Maximum sag of the overhead conductor	H2
iii.	Vertical spacing between the top and bottom conductors	H3
iv.	Vertical clearance between the ground wire and top conductor	H4
v.	Height of the tower	H1+H2+H3+H4

3.5.2.4 Sag Determination

The power conductor sags because of its self-weight and the maximum sag is observed under maximum temperature and no wind condition. Sag and tension are calculated for various wind and temperature combinations as per relevant standard. Maximum sag value is also used to determine the height of a transmission tower.

3.5.2.5 Electrical Clearances

The electrical clearances involve selection of minimum air gap clearances, to avoid interference between live and earthed parts of the transmission line. All the minimum electrical clearances are maintained according to relevant standards.

3.5.2.6 Wind Loading

The calculated loads as per the particular wind zone are applied to the tower structure.

3.5.2.7 Right of Way

The number of cross arms depends on the voltage level and number of circuits. ROW is the land strip required for erection, operation, maintenance and repair of the transmission line facilities. Its width relies on the line voltage rating, height of the structure, electromagnetic fields intensity and structure of the tower. ROW is fixed based on the tower geometry and electromagnetic fields.

3.5.3 Optimization

Optimization of the tower body includes optimization of tower structure layout (tower structure shape, section layout type) and component (section type, specification, material). The tower head and tower legs are optimized for components.

There are many restrictions on the size of the tower head, including clearance, height limit of each cross arm, cross arm spacing limit, etc. As such the optimization of the tower head structure is restricted for many reasons, i.e. for optimization the tower body can be a major target area. This mainly can be achieved by optimizing angel bar section or section arrangement types.

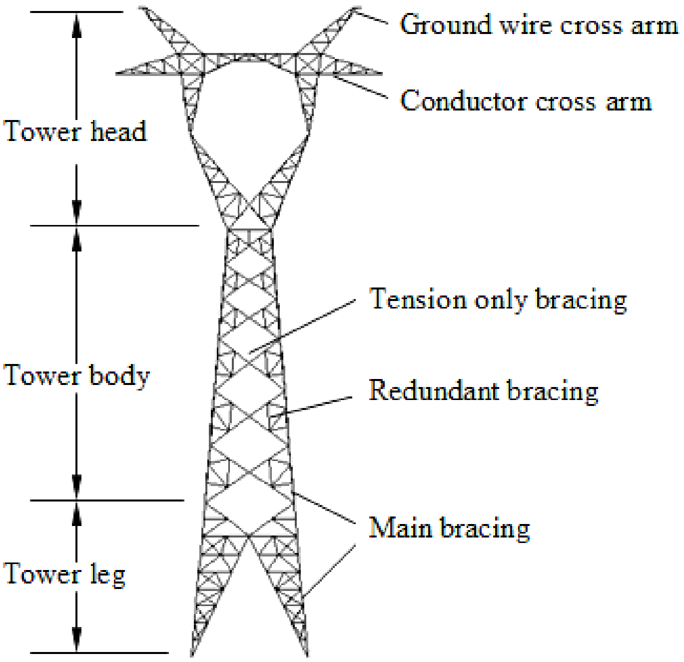


Table 3-5: Typical Tower Structure

The weight of foundation keeps reducing with increasing base width. But, for large base widths the cost of land acquisition is very high. Also, it is seen that the cost of tower increases with an increase in base width. This is because of heavy loads and poor distribution of loads via the bracings, leading to use of heavy sections. Base width depends upon the height, loads imposed upon the tower, wind loads and the height of application of external loads from ground level. Towers with larger base results in low footing cost and lighter main leg members at the expense of longer bracing members.

3.5.4 Optimisation Intent and its Outcome

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. In this report an attempt has been made to make the transmission line more cost effective with optimization through innovation to reduce the tower footprint and ROW needs. In addition to the configuration system the tower is analyzed for various trial innovation options and the section which gives optimum result is selected. The supports of EHV transmission lines are normally steel lattice towers. The cost of towers constitutes about half the price of the transmission line and hence optimum tower design will bring in substantial savings.

The efficient design of the transmission line towers is based on both electrical and structural considerations. The general shape and height of the tower is based on the electrical aspects and so the optimization can be performed to reduce the weight and to arrive at the best geometry shaping. Optimization is the process of finding the best solutions from which a design can derive maximum benefit from available resources. It not only enables the construction of efficient structures but also maintains safety and reliability.

Optimization of Transmission Line Tower is aimed at achieving low cost, high performance, better and more reliable design strength. It is observed from the analytical work that the weight of tower with Optimized base width, Pattern Geometry, Base Configuration and section size optimization shows an economical construction.

This report attempts to optimize the transmission line tower structure for a 132 kV multi-circuit tower with the conductor configuration provided by Power Cell along with other design parameters. Regarding base configuration, section size and pattern geometry as variable parameters. Due to multiple loading conditions, each member subjected to maximum stress under any of the loading conditions is assigned an angle size.

Switching surge overvoltage on transmission lines can also be effectively used, which also help optimize tower design and right-of-way width. Allowing reduction in the switching surge factors when combined with other design enhancements helps transmission line designers to optimize tower design to make it more compact and reduce tower foot print area. Significant cost savings are achieved in comparison to other options with the reduction of switching surge overvoltage.

3.5.5 Approach for Analysis

The Tower optimisation process involving application of innovative options as detailed above, would require analysis of the identified tower so as understand the results & impacts. While applying the optimisation Innovations, consultant’s approach has been as under:

1. **Calculation of Sag / tension:** Sag tension has been calculated as per input data sheets as provided by Power Cell and as recalculating these design parameters considering the conductor details. The power conductors’ sags because of its self-weight and the maximum sag is observed under maximum temperature and no wind condition. Sag and tension are

calculated for various wind and temperature combinations for further use in the tower analysis.

2. **Design Loads**: Loading calculation has been done as per latest ASCE 74 codes & associated norms.
3. **Electrical Clearances**: The electrical clearances involve selection of minimum air gap clearances, to avoid distracting sources between live and earthed parts of the transmission line structures. All the minimum electrical clearances are maintained according to Bangladesh specification.
4. **Tower Model / Structure Design Model:** All the Tower Models have been created in PLS software for the sake of analysis and these tower models have been generated on the basis of the existing towers line diagram. The basic Tower Model has been analysed to understand the existing tower behaviour, software response. Based on the merits, the Tower Model has further been modified as per the innovative techniques that were applied to the tower. Some dimensions in existing tower model have been modified without changing basic dimensions of tower model.
5. **Loads / Calculations:** The calculated loads as per the particular wind zone are applied to the tower structure. Loadings include self-weight, transverse loads, longitudinal loads, compression loads and tension loads. No deflection was observed in these towers after applying these loads that are calculated as per applicable standards. The loadings determination is done using various inputs like design wind pressure, angle of deviation, design wind span, pressure due to wind on conductor and ground wire, type of ground wire, insulator strings, etc. All the members of the tower are applied with the corresponding loading combinations as recommended.
6. Tower has been analysed with double strung condition.
7. Wind pressure on tower body has been applied directly in tower model.
8. Tower has been analysed in PLS tower model as per latest ASCE 74 criteria.

3.5.6 Type of Innovations applied

1. Tower geometry has been modified wherever applicable so that the tower base width can be optimised to benefit from ROW issues.
   a. The tower where the base width has been modified are 1QL, 1QT, 4DL,132KV ST,2QL & 2QT
   b. Towers where base width has not been modified are 2QL.
2. Tower Cross arm length has been modified as per swing angle & clearance to get benefit in weight.
3. Tower leg member used up to 5% safety and lattice member up to 10% safety to get benefit in weight.
4. Two types of bolt diameters have been suggested / used like M16 & M24 at the analysis stage. The grade suggested is 5.6 /5.0

5. Slenderness ratio of redundant used up to its maximum limit.
6. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used to get benefit in weight.
7. Minimum lattice / redundant section 40x40x4 are used to get benefit in weight.
8. Redundant pattern modified to get benefit in weight.
9. Redundant members have been designed for 1.5 % force of supported Member.

3.5.7 Results and Benefits of Innovation Analysis

1. Due to straightening the tower base width from normal tower level, ROW land issues can be minimized.
2. Suspension towers & Lower angle towers can be benefitted by above approach.
3. Higher angle towers & special angle towers may not be benefitted by straightening the base width.
4. Other above innovative ideas can be applied to all towers for optimization purpose.
5. Due to modification in tower structure above ground level, foundation volume may increase in some cases.

3.5.8 Tower Selection

As per discussions held with PGCB authority, most of the towers used for 400 kV and 230 kV are already designed with optimised base. However, the base optimization of 132 kV towers are yet to be done and also there is a proposal of using bundled conductor for 132 kV towers for enhancing the power carrying capacity. Since the Bangladesh grid comprises majorly population of 132 kV towers as such there is a substantial scope of land optimization considering the cost of land acquisition in Urban Bangladesh. PGCB is also planning to introduce 765kV system; however tower erection is yet to take place, though the designing of such towers is almost complete. There are various grid sub-stations where numbers of line are connected, which results in large land requirement for ROW. To tackle such problem, PGCB is using multi circuit towers, which results in optimisation of ROW and there is also a scope of optimisation of base for such towers. Such towers can be used for lines running parallel for optimisation of land requirement.

The transmission towers which are in the populated area are surrounded by inhabitants. In such cases converting the existing towers to multi circuit tower, for land optimisation, requires change in alignment, which is a tough task to execute. So, such towers can be omitted for modification.

Table 3-6: 230 kV Tower no. 78 at Tongi Substation

Table 3-7: 230 kV Tower no. 74 at Tongi Substation

PGCB during the course of this assignment have suggested following candidate towers whose details were shared with consultant. The towers are selected based on the following criteria:

1. Line / Tower Voltage Level
2. Number of Circuits
3. TL Conductor size / Profile
4. Type of Towers
5. Tower Location
6. Status of Optimisation
7. Tower population.

Towers selected for analysis as suggested by PGCB are as under:

Table 3-8: Towers considered for Analysis

S. No.	Tower Designation	Voltage Level
1	1 QL – MC SUSPENSION TOWER	132 KV
2	1 QT- MC ANGLE TOWER	132 KV
3	2 QL -MC SUSPENSION TOWER	230 KV
4	2 QT MC ANGLE TOWER	230 KV
6	4DL -DC SUSPENSION TOWER	400 KV
7	ST -TWIN GROSBEEK SUSPENSION TOWER	132 KV
Others Towers		
1	EHV Tower	765 KV
2	MV Tower	132/230/ 400
3	Double Circuit Tower	132

The details / parameters of the above towers were individually examined, studied and further analysed with innovation techniques for optimisation. The details are provided hereunder in this report.

3.6 STRUCTURAL ANALYSIS OF THE TOWER

Transmission line tower consists of linear structural members rigidly connected to one another through bolts. For the purpose of analysis, it is idealized as a space truss. A space truss is a 3-D assemblage of line members, each member being joined by hinges. Space truss idealization lead to the following assumptions:

1. The influence of gusseted connection in transmitting moment is neglected.
2. Leg members that are continuous are assumed to be hinged at the nodal points.
3. Loads are assumed to act only at the joints.

The use of design software's and IT tool has enabled the analysis of large structural systems to be carried out more easily and accurately. Among the various methods available for the truss analysis, the matrix formulation has the advantage over other methods, since the operation of matrix algebra can be provided in the form of a 'routine' in the computer program like PLS-Tower.

Every structure must fulfill the dual requirements of equilibrium and compatibility. The stiffness method maintains the compatibility of the structures and makes use of equilibrium conditions for the solution. For solving pin-jointed trusses, the stiffness method generally leads to fewer equations. Hence, the stiffness method is used for the analysis of transmission line towers.

Once the external loads acting on the tower are determined, one can proceed with an analysis of the forces in various members with a view to fix up their sizes. Axial force is the primary force for a truss element and therefore, the member is designed for either compression or tension. When there are multiple load conditions, certain members may be subjected to both compressive and tensile forces under different loading conditions. Hence, these members are designed for both compression and tension acting separately.

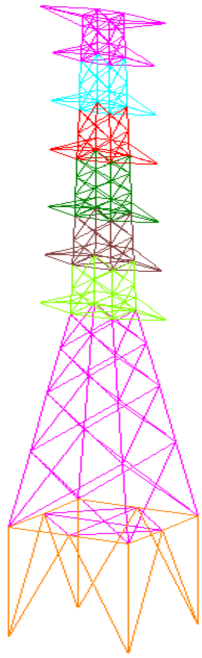


Table 3-9: Structural analysis of the tower

Models are also prepared with redundant which are in face sides of the models. Wind on tower has been calculated with these redundant sections area.

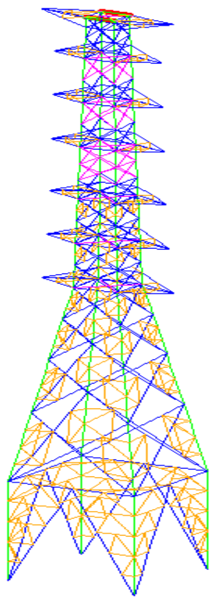


Table 3-10: Structural analysis of face sides of the models

One of the innovation options considered along with the above option is the practices followed with regard to the minimum angle sizes and minimum thickness of steel members adopted in the designs, based on experience and judgement, are briefly described below:

3.6.1 Minimum Angle Size

The present practice is not to allow angle leg width less than 45 mm through which a bolt of 16 mm diameter passes. This results in a number of main braces, cross-arm braces and almost all the redundant members of the tower being of this size, even though a smaller size may be adequate from stress requirements. Equal angle size 40 x 40 x 4mm can be used in place of equal angle 45 x 45 x5 mm for a number of braces and for almost all the redundant members.

3.6.2 Minimum Thickness and Slenderness ratio

Use of structural steel in overhead transmission line towers, the limiting values of the slenderness ratio for the design of transmission tower members can be used up to their maximum limit.

Limits of slenderness ratio have not been used in redundant design optimization. Redundant members are designed for 1.5% force of supported member to use lighter redundant.

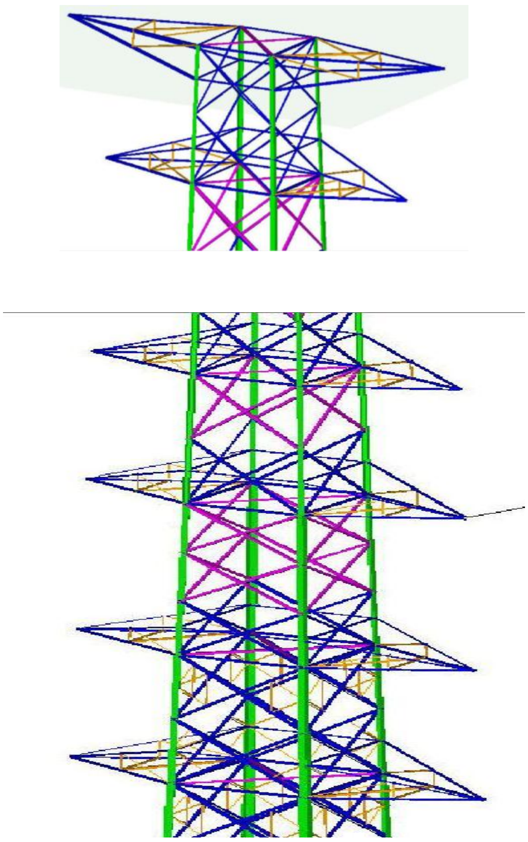


Table 3-11: Minimum Thickness and Slenderness ratio

4.0 ANALYSIS OF CANDIDATE TOWER

4.1 ANALYSIS OF TOWERS AND IMPACT ASSESSMENT

4.1.1 Methodology of Design Optimization of Towers

During project meeting with PGCB, they proposed 132kV multi circuit suspension tower -1QL for examination and review for optimization through innovation. The main intent is to use methods and options of innovation so as to optimize the reference tower through analysis to find the level of reduction in weight and tower footprint and ROW. Considering latest specification and latest design codes of Bangladesh for design of transmission line towers, this tower has been designed and analysed with results given below.

During the course of this assignment and study, Power cell referred towers of different voltages and design geometry / parameters for consultant's innovative analysis. Consultant during the study have applied the probable innovative techniques for the below set of towers as suggested by Power Cell.

Table 4-1: List of Transmission Tower considered for Innovative Analysis

S. No.	Tower Designation	Voltage Level
Referred Towers		
1.	1 QL – MC SUSPENSION TOWER	132 KV
2.	1 QT- MC ANGLE TOWER	132 KV
3.	2 QL -MC SUSPENSION TOWER	230 KV
4.	2 QT MC ANGLE TOWER	230 KV
5.	4DL -DC SUSPENSION TOWER	400 KV
6.	ST -TWIN GROSBEEK SUSPENSION TOWER	132 KV
Other Towers		
1	EHV Tower	765 KV
2	MV Tower	132/230/ 400
3	Double Circuit Tower	132

Following innovative and optimisation techniques have been analysed on the above towers based on the innovative categories that were found suitable to each tower.

The innovation techniques detailed out below were applied to the reference towers owing to that the reduction in tower base width and right-of-way have been achieved successfully. The innovation options have been applied to other transmission line towers suggested by Power Cell and the results obtained have been detailed in this report.

Proposed innovations and analysis has been done with a flexible approach for the optimization of self-supporting transmission line towers (TLTs). The analysis takes into account constructional and structural features to allow a direct application for prospective utility. Design methods need to be reformulated by including optimization techniques. Generally, though the traditional designs are usually effective, yet they are not the most efficient and environment friendly. Therefore, it becomes essential to have engineering design models that offer not only optimised solutions by way of quality and cost but also provide solutions to optimize the footprint area and right-of-way through innovative designs.

Table 4-2: Categories of Innovation / Optimisation with impacts of T.L. Tower Design

Category	Domain of modification	Preferred innovation options
Category A	• Structural / tower Configuration • Alterations in tower Geometry - Modifications • Tower Slopes alterations	• Modification in base width of tower, • Tower geometry • Modifications in peak • Modification in cross arms
Category B	• Structural material improvements, • Material of tower & bolts and tower types	• Use of higher steel grade • Higher grade of fasteners
Category C	• Structural Analysis methodology	• Modification in tower cross arm, • Uses of Minimum member size, • use of higher sections with different thickness, • modifications of redundant pattern, • use of redundant members
Category D	• Design criteria & design guideline adherence, • Tower design data / Loadings	• Optimisation & review of Tower Design • Loadings, Wind pressure, FOS
Category E	• Modifications in Electrical requirements	• Use of HTLS Conductor, • Optimise of Electrical clearances, use of suspension towers up to 5-degree angle with sealing on swing, electrical clearances optimisation • Use of insulated cross arms

Table 4-3: Innovation Techniques which have Design Implications and Innovation linked to Design criteria

Category F (F.I)	• Latest in the Transmission line practices.	• Use of MCMV- NB Towers to increase line capability and reduce line corridors, hence cumulative ROW.

(F.II)	• Use of Suspension Tower with 6 degree angle of deviation • Re-configure the tower classification	• This will reduce the tower weight & base width of tower, otherwise designed as B Type with 15 degree deviation.
(F.III)	• Use of 8 leg tower with lattice construction & polymer insulators up to 220KV Voltage level	• Reduction in loads, reactions. • Though the tower weight will increase but the tower base will reduce appreciably, hence reduce the ROW.

4.2 ANALYSIS OF TOWER TYPE 1QL AND 1QT6

Input data required for 1QL (Multi Circuit Suspension Tower) and 1QT6 (Multi Circuit Angle Tower) for the study were collected from PGCB, which is shown in table below:

Table 4-4: Input Data Required For 1QL Transmission Tower

SPECIFICATION FOR 1QL TOWER		
S. No.	**Description**	**Parameters**
1	**Voltage Class**	132kV
2	**Configuration**	Vertical
3	**Number of Circuits**	4
4	**Configuration of Earthwire**	Double peak
5	**Conductor**	Single ACSR Grosbeak
6	**EW parameters**	7x3.25steel EW
7	**OPGW parameters**	7x3.25steel EW equivalent OPGW
8	**Designation of Towers**	1QL
	A Suspension Tower (angular deviation)	**1QL:0°-1°**
9	**Extension required**	std.,1.5,3,4.5,6,9
10	**Spans**	
	Rulling/Average Span	330 m
	Wind Span-NC	330 m
	Wind Span-BWC	250 m
	Weight Span(max)-NC	525 m
	Weight Span(max)-BWC	395 m
	Weight Span(min)-NC	140 m
	Weight Span(min)-BWC	100 m
11	**Temperature Range**	
	Minimum Temperature	**5 °C**
	Everyday Temperature	**35 °C**
	Maximum Temp. (Conductor)	80 °C
	Maximum Temp.(OPGW)	50 °C

SPECIFICATION FOR 1QL TOWER		
S. No.	**Description**	**Parameters**
12	**Reference Wind velocity**	62.5 m /sec (3sGust)
13	**Minimum Ground Clearance**	7000mm
14	**Insulator Strings details**	
	Single/Double Suspension length	1843mm
	Single/Double Suspension weight	125kg
	Arcing Horn length	1612mm
15	**Minimum Electrical Clearances**	
	a Single/Double Suspension Insulator	
	0^0	1450 mm
	10^0	1450 mm
	45^0	900 mm
	Vertical Clearance	4000 mm
16	**Materials for towers**	
	A Mild Steel	275 MPa
	B High Tensile Steel	355 MPa
	C Bolts & nuts	ISO 898 GRADE 5.6/5
17	**Minimum Thickness of Members**	
	A Tower Legs, Peak & main Cross arms	6mm
	B All Other Members	5mm
	C All Redundant Members	4mm
	D Gusset plates	6mm
	E Min. Section without bolt hole	40mm
18	**Bolt Diameter**	
	Galvanized Hexagonal head of connection	16mm / 24mm
19	**Overload factor**	
	For Normal Condition	1.25
	For Broken Condition	1.25
20	**Base width of tower**	7.5m

4.4.1 Tower Type 1QL – 132 kV Multi Circuit Suspension Tower

Following are the steps and also the explanation for innovative options that have been applied on the new design of **Tower Type 1QL.**

4.2.1.1 Calculation of Wind Loads / Wind Pressure Calculation

Based on the applicable design codes, wind loadings on overhead conductor's influence line design in number of ways:

- The maximum span between structures may be determined by the need for horizontal clearance to edge of right-of-way during moderate winds.
- The maximum transverse loads for tangent and suspension structures are determined by infrequent high wind-speed loadings.

Wind pressure and load on conductor have been calculated below as per ASCE -74:

Table 4-5: Wind pressure load

PROJECT NAME : 132KV M/C TL BANGLADESH						
TOWER TYPE "1QL"						
WIND PRESSURE ON CONDUCTOR						
[AS PER ASCE MANUAL 74: 2009]						
$F = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$						
wherein						
Wind Load Factor (g_w) =	1.0	For Exposure Category "C" [Ref: Table 1-1]				
Newmerical Constant Figure (Q) =	0.613					
Basic Wind Speed (V_{50}) =	62.5	m/s (3sec Gust speed)				
Velocity Pressure Exposure Coefficient (K_z) =	$2.01*(z_h/z_g)^{2/\alpha}$	(for 33 < z_g < z_h)		(m)	(ft)	
=	1.326		Effective Height (z_h) =	38.137	125	Refer Table 2-1
			Gradient Height (z_g) =	-	900	
			Value of a =	9.5		
Topographic Factor (K_{zt}) =	1.00	(Due to absence of Topographical details)				
Gust Response Factor (G)						
Gust Response Factor for **Wires** (G_w) =	$(1+2.7*E*(B_w)^{0.5} /K_v^2$	k = 0.005	a_{FM} =		7.0	Refer Table 2-3
=	0.659			(m)	(ft)	
			Effective Height (z_h) =	38.137	125	
			Design Wind Span (S) =	330	1083	
			Turbulence Scale (L_s) =	-	220	
			Ratio of 3-sec gust to 10-min gust (K_v) =	1.43		
			$E = 4.9*k^{0.5}*(33/z_h)^{1/aFM}$ =		0.286	
			B_w = $1/[1+0.8*(S/L_s)]$ =		0.203	
Force Coefficient (C_f) =	1.00					
FOR CONDUCTOR $F_c = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$						
=	2093	N/m^2	*A			
=	213	Kg/m^2	*A			

Wind pressure and load on the tower structure have been calculated below as per ASCE -74:

Table 4-6: Wind pressure and load on the tower structure

PROJECT NAME : 132KV M/C TL BANGLADESH												
TOWER TYPE "1QL"												
WIND PRESSURE ON STRUCTURE												
[AS PER ASCE MANUAL 74: 2009]												
$F = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$												
wherein												
				Wind Load Factor (g_w) =	**1**	For Exposure Category "C" [Ref: Table 1-1]						
				Newmerical Constant Figure (Q) =	**0.613**							
				Basic Wind Speed (V_{50}) =	**62.5**	m/s						
				Velocity Pressure Exposure Coefficient (K_z) =	$2.01*(z_h/z_g)^{2/a}$		{for $33 < z_g < z_h$}			(m)	(ft)	
				=	**1.232**				Effective Height (z_h) =	**26.733**	88	
									Gradient Height (z_g) =	-	**900**	Refer Table 2-1
									Value of a =	**9.5**		
				Topographic Factor (K_{zt}) =	**1.00**	{Due to absence of Topographical details}						
				Gust Response Factor (G)								
				Gust Response Factor for Tower (G_t) =	$(1+2.7*E*(B_t)^{0.5}) / K_v^2$			k =	**0.005**	a_{FM} =	**7.0**	
				=	**0.848**					(m)	(ft)	Refer Table 2-3
									2/3rd of Total Height (z_h) =	**26.733**	88	
									Turbulence Scale (L_s) =	-	**220**	
									Ratio of 3-sec gust to 10-min gust (K_v) =	**1.43**		
										$E = 4.9*k^{0.5}*(33/z_h)^{1/aFM}$ =	**0.301**	
								B_t =	$1/[1+0.56*(z_h/L_s)]$ =		**0.817**	
				Force Coefficient (C_f) =				F =	0.025		C_f =	4.0
								F =	0.025 - 0.44		C_f =	$4.1-5.2*\Phi$
								F =	0.45 - 0.69		C_f =	1.8
								F =	0.70 - 1.00		C_f =	$1.3+7.0*\Phi$
FOR STRUCTURE $F_t = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$												
				=	**2502**	N/m^2	$*C_f*A$					
				=	**255**	Kg/m^2	$*C_f*A$					

4.2.1.2 Sag and Tension Calculation

Sag-tension calculations with ACSR conductors are more complex than such calculations with AAC, AAAC, or ACAR conductors. The complexity results from the different behaviour of steel and aluminium strands in response to tension and temperature. Steel wires do not exhibit creep elongation or plastic elongation in response to high tensions. Aluminium wires do creep and respond plastically to high stress levels because of different metallic property and elongation coefficients. They have the propensity to elongate twice as much as steel wires do in response to change in temperatures because of the thermal properties.

Table 4-7: Presents the various initial and final sag-tension values

PROJECT NAME : 132KV M/C TL BANGLADESH

TOWER TYPE "1QL"

SAG TENSION CALCULATION FOR PHASE CONDUCTOR

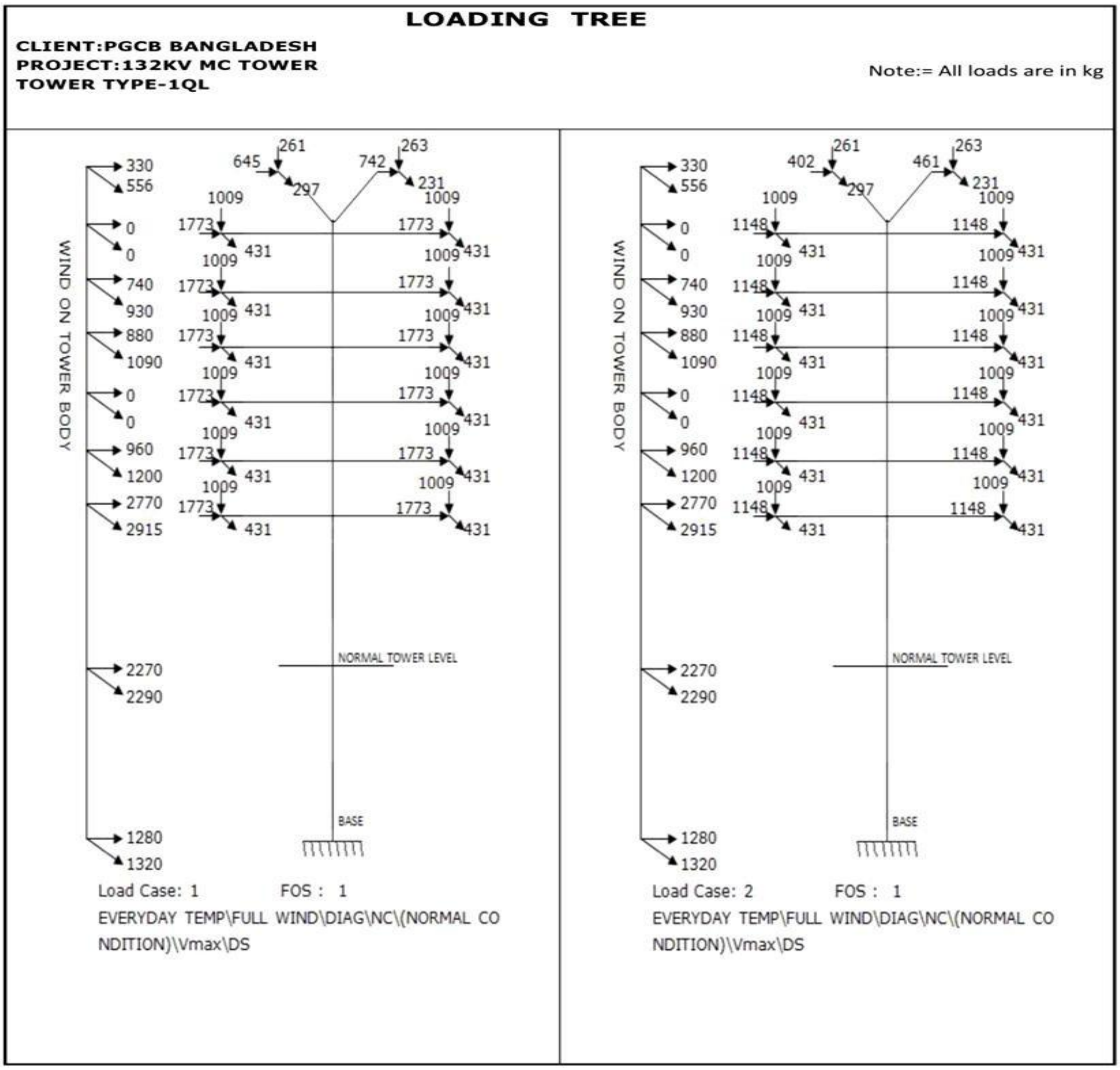
NAME OF THE CONDUCTOR	:	**GROSBEAK**	
AREA	:	374.33	mm^2
DIA	:	25.15	mm
WT OF CONDUCTOR	:	1.300	Kg/m
ULTIMATE TENSILE STRENGTH	:	11401	Kg
MODULUS OF ELASTICITY	:	7700	Kg/mm^2
MAX WORKING SPAN	:	330	m
MIN TEMPERATURE	:	5	^0C
EVERY DAY TEMPERATURE	:	35	^0C
MAX TEMPERATURE	:	80	^0C
COEFF OF LINEAR EXPANSION	:	1.92E-05	$/^0C$
INITIAL TEMP	:	35	^0C
INITIAL WIND PRESSURE	:	0	Kg/m^2
RADIAL ICE FORMATION	:	0	mm

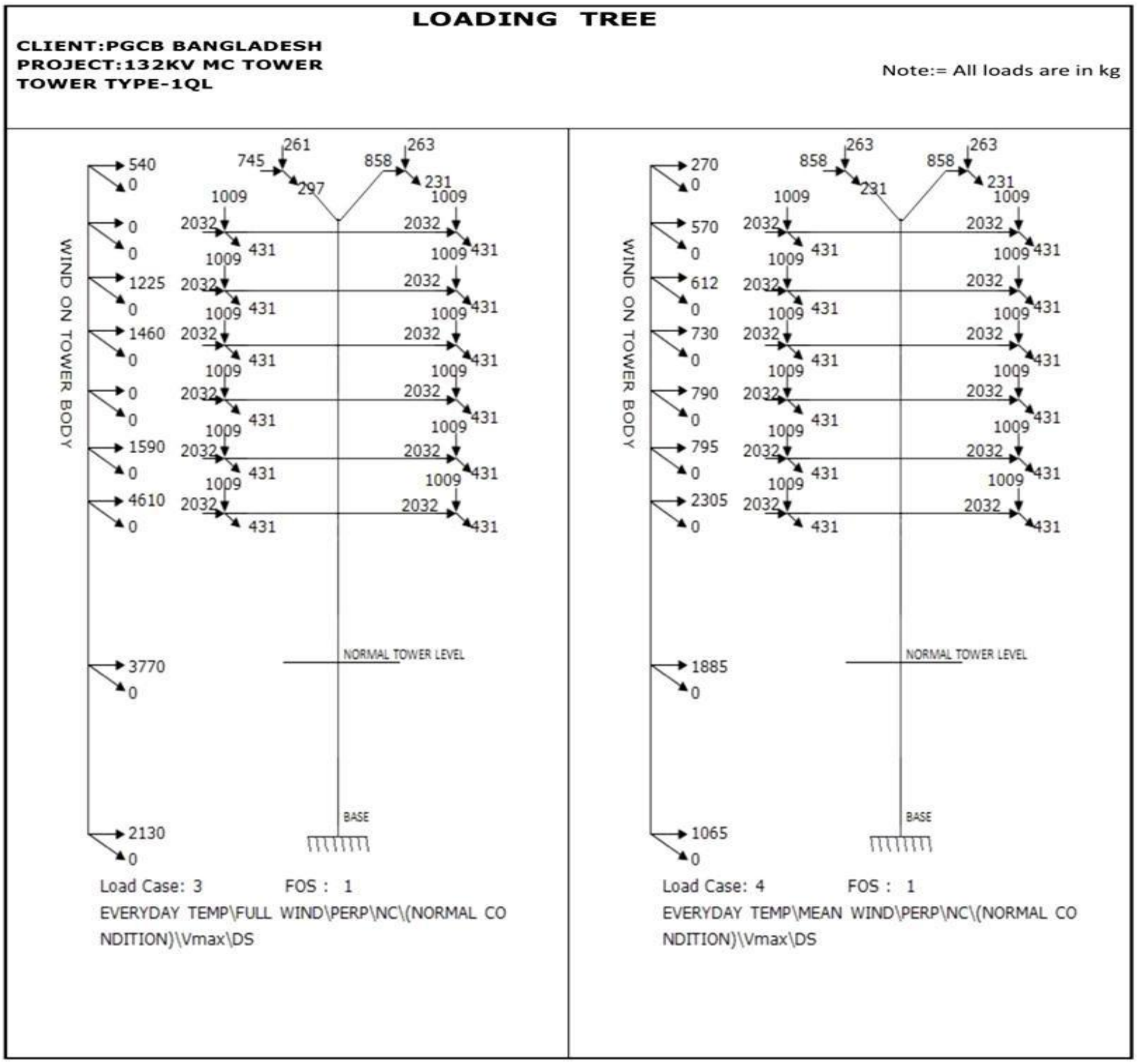
	WIND PRESS (Kg/m^2)	TEMP DEG (^0C)	ICE FORMATION (mm)	SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INITIAL	0	35	0	7.761	609.12	2280	20.0	330
	0	5	0	6.539	723.00	2706	23.7	330
50%	107	5	0	-	1275.48	4775	41.9	330
100%	213	5	0	-	1936.77	7250	63.6	330
	13	35	0	7.812	624.01	2336	20.5	330
100%	213	35	0	-	1803.31	6750	59.2	330
	0	80	0	9.470	499.18	1869	16.4	330
	Dynamic Wind Pressure (qho)		=	2093	N/m2 =	213	Kg/m2	

4.2.1.3 External Loads on Tower

External load means all the wire loads and wind loads on tower (Design Loads) that will be applied as per diagram below:

Table 4-8: External load on tower





4.2.1.4 Tower Configuration / Model

Depending upon the requirements of the transmission system, various line configurations have to be considered ranging from single circuit horizontal to double to multi circuit vertical structures and with single or V strings in all phases, as well as any combination of these. The configuration of a transmission line tower depends on following factors:

1. The length of the insulator assembly.
2. The minimum clearances to be maintained between conductors, and between conductor and tower.
3. The location of ground wire or wires with respect to the outermost conductor.
4. The mid-span clearance required from consideration of the dynamic behaviour of conductors and lightning protection of the line.
5. The minimum clearance of the lowest conductor above ground level. The tower configuration is determined essentially by three factors:

   (a) Tower height (b) Base width and (c) Top Hamper - width

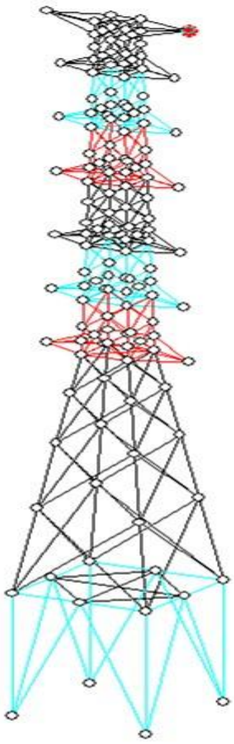


Figure 4-1: Tower Configuration Model

Spacing between the tower footings, i.e. the base width at the concrete level (or at the foot of the bottom panel) is the distance from the centre of gravity of one corner leg to the centre of gravity of the adjacent corner leg. This width depends upon the height, magnitude of the physical loads imposed upon the tower calculated from the size, type of conductors and wind loads and also upon the height of application of external loads from ground level. Towers with larger base, result in low footing costs and lighter main leg members at the expense of longer bracing members. There is a particular base width, which gives the best compromise for the total cost of the tower to be minimum. Through experience expanded over a number of years, certain empirical relations have also been developed for base widths. The ratio between total height of the tower upto the lower cross arm and base width is generally between 2.8 and 4.4.

In case of the reference tower, the base width of the structure at lower level has been proposed same as basic body level i.e. the lower part of the structure has been modelled with straight legs. As our main objective is to reduce footprint area, the tower lower part can be made straight to get this benefit. The tower has been analysed and optimized with the above configuration.

4.2.1.5 Structural Analysis of the Tower

Transmission line tower consists of linear structural members rigidly connected to one another through bolts. For the purpose of analysis, it is idealized as a space truss. A space truss is a 3-D assemblage of line members, each member being joined by hinges. Space truss idealization lead to the following assumptions:

1. The influence of gusseted connection in transmitting moment is neglected.
2. Leg members that are continuous are assumed to be hinged at the nodal points.
3. Loads are assumed to act only at the joints.

The use of design software and IT tool has enabled the analysis of large structural systems to be carried out more easily and accurately. Among the various methods available for the truss analysis, the matrix formulation has the advantage over other methods, since the operation of matrix algebra can be provided in the form of a 'routine' in the computer program like PLS-Tower. Every structure must fulfil the dual requirements of equilibrium and compatibility. The stiffness method maintains the compatibility of the structures and makes use of equilibrium conditions for the solution. For solving pin-jointed trusses, the stiffness method generally leads to fewer equations. Hence, the stiffness method is used for the analysis of transmission line towers.

Once the external loads acting on the tower are determined, one can proceed with an analysis of the forces in various members with a view to fix up their sizes. Axial force is the primary force for A truss element and therefore, the member are designed for either compression or tension. When there are multiple load conditions, certain members may be subjected to both compressive and tensile forces under different loading conditions. Hence, these members are designed for both compression and tension acting separately.

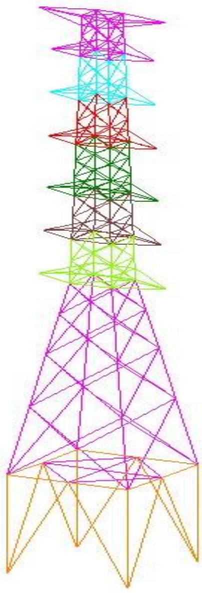


Figure 4-2: Structural analysis of the tower

Models are also prepared with redundant which are in face sides of the models. Wind on tower has been calculated with these redundant sections area.

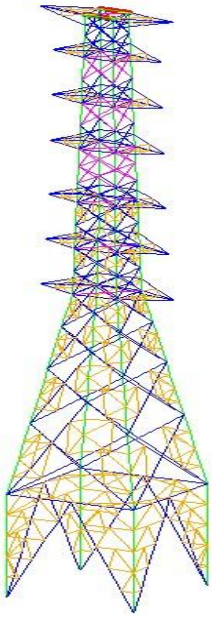


Figure 4-3: Structural analysis of face sides of the models

One of the innovation options considered along with the above option is the practices followed with regard to the minimum angle sizes and minimum thickness of steel members adopted in the designs, based on experience and judgement, are briefly described below:

4.2.1.6 Footprint Area of Tower Post Optimization

The tower footprint after modification and analysis of reference tower and the results are given below.

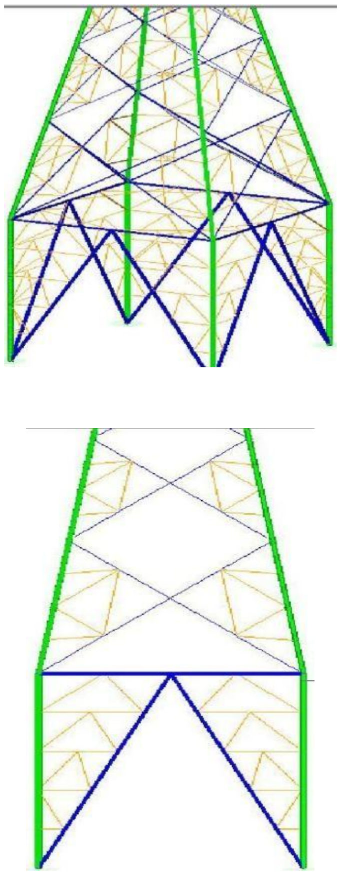


Figure 4-4: Tower footprint after modification and analysis

4.2.1.7 Innovation and Optimisation

The following innovation options were applied to the reference tower owing to that the reduction in tower base width and right-of-way has been achieved successfully.

Table 4-9: Innovation and Optimisation of Tower 1QL

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration ii. Alterations in tower Geometry - Modifications iii. Tower Slopes alterations	i. Modification in base width of tower, ii. Tower geometry, Leg member proposed straight. iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements, ii. Material of tower & bolts and tower	i. Use of different size Bolts, 16mm & 24mm i. Minimum plate thickness: 6mm, Minimum Lattice	As per the discussion held with PGCB on 25th July 2023. The orginal design

Category	Domain of modification	Preferred innovation options	Remarks
	types	thickness: 5mm are used. i. Minimum redundant sections used. /. Redundant members designed for 1.5 % force of supported members.	criteria of PGCB has been used
Category C	iv. Structural Analysis methodology	iv. Slenderness ratio of redundant used upto its maximum limit.	
Category D	vii. Design criteria & design guideline adherence, viii. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	iv. Modifications in Electrical requirements	NA	
Category F	iv. Latest in the Transmission line practices.	NA	

4.2.1.8 Tower Base Optimization

The base width of the original tower is 7.5 m and at +9 m level as per slope base width would be 10.056 m. It means land area required is 10.056 m x 10.056 m i.e. 101.12 m^2. Therefore, the area required when tower with +9 m extension is installed on ground is 101.12 m^2.

It was observed that after applying the innovative measures during analysis, the tower base width at +9 m level remains same as normal tower level i.e. 7.5 m, which means that the area required for tower with +9 m will be (7.5 x 7.5) 56.25 m^2.

Table 4-10: Reduction in Tower base in 1QL Tower

Description	Original Tower	Innovated tower	Reduction
Tower Basewidth/ ROW-area	101.12m^2	56.25m^2	44%

The total weight of the 1QL tower post optimization works out to **11.6 tons which is about 16% less** than the original weight.

4.2.1.8 Tower Foundation Analysis

<u>Foundation Analysis for 1QL – 132 kV double circuit Suspension Tower</u>

For optimization of transmission tower foot print, the 1QL type tower has been considered. The soil category considered is type-3 for loose sand or soft to medium clay soil which is same as the existing foundation of 1QL+ UPTO 9M EXT. Tower superstructure is designed and analyzed using PLS software.

Due to optimization of the footprint of the 1QL tower structure, the ultimate compression and uplift load reactions have been reduced. However, the ultimate shear forces have increased. The shear horizontal to leg longitudinal direction has increased enormously. The reactions for foundation design including comparison statement with existing tower foundation design are as below.

Table 4-11: Foundation Forces Analysis – 132 kV multi circuit Suspension Tower

TOWER FOUNDATION			
DESCRIPTION	**EXISTING**	**REVISED**	**REMARKS**
TYPE OF FOUNDATION	**1QL+ UPTO 9M EXT.**	**1QL+ 9M BE**	
Ultimate Factored Foundation Loads Calculation			
LOADS PER LEG ALONG LEG SLOPE (KG)	**REACTIONS FROM TOWER STRUCTURE**		**DIFFERENCE (KG)**
ULTIMATE COMPRESSION LOAD FOR FOUNDATION	**127705**	**106665**	**-21040**
ULTIMATE UPLIFT LOAD FOR FOUNDATION	**111399**	**116639**	**5240**
ULTIMATE SHEAR			
SHEAR HORIZONTAL TO LEG TRAN	**4118**	**4989**	**871**
SHEAR HORIZONTAL TO LEG LONG	**2449**	**11738**	**9289**

The foundation and pedestals/chimney have been designed with manual calculation using excel spread sheet. In this the number and diameter of piles have not been changed including pile cap. However, due to increase in the horizontal shear in longitudinal direction, the pile length has been increased to 20 m from 16 m. The foundation has been designed with three numbers of 500 mm diameter piles and 20 m length. There is no change in the pedestals/chimney size including reinforcement details.

It has been considered that the pile cap shall rest at 2 m below the natural ground level so that the land area at top of pile cap can be used.

The final outcome along with comparison of existing pile cap and proposed pile cap details are as under.

Table 4-12: Pile Cap Analysis – 132 kV multi circuit Suspension Tower

TOWER FOUNDATION - 1QL+ UPTO 9M BE			
DESCRIPTION	**EXISTING**	**REVISED**	**REMARKS**
TYPE OF FOUNDATION	**1QL+ UPTO 9M EXT.**	**1QL+ 9M BE**	
PILE DETAILS			
DIA OF PILES	500MM	500MM	
NUMBER OF PILES	3	3	
DEPTH OF PILES	16M	20M	Difference of 4M
REINFORCEMENT	9 NOS. 20 DIA.	9 NOS. 20 DIA.	

TOWER FOUNDATION - 1QL+ UPTO 9M BE			
DESCRIPTION	**EXISTING**	**REVISED**	**REMARKS**
TYPE OF FOUNDATION	**1QL+ UPTO 9M EXT.**	**1QL+ 9M BE**	
REINFORCEMENT LOWER SEGMENT (5m to Last Point)	6 NOS. 16 DIA	6 NOS. 16 DIA	
STIRRUPS	8 DIA 150MM C/C	8 DIA 150MM C/C	
PILE CAP DETAILS			
SIZE	2.3X2.1M (TRIANGLE SHAPE) - 3.375 SQM.	2.3X2.1M (TRIANGLE SHAPE) - 3.375 SQM.	
PILE CAP REINFORCEMENT			
BOTTOM LONGITUDINAL DIRECTION	16 DIA - 9 NOS.	16 DIA - 9 NOS.	
BOTTOM TRANSVERSE DIRECTION	16 DIA - 9 NOS.	16 DIA - 9 NOS.	
TOP LONGITUDINAL DIRECTION	16 DIA - 9 NOS.	16 DIA - 9 NOS.	
TOP TRANSVERSE DIRECTION	16 DIA - 9 NOS.	16 DIA - 9 NOS.	
CHIMNEY			
SIZE	450 X450MM	450 X450MM	
REINFORCEMENT	4 NOS. - 20MM DIA	4 NOS. - 20MM DIA	
STIRRUPS	10 DIA AT 150 C/C	10 DIA AT 150 C/C	

4.4.2 Innovative Analysis for Tower Type 1QT – 132 kV Multi Circuit Tension Tower

The applicable innovation techniques have been employed on 1QT towers out of the set of categories (A-F) defined above and depending upon the feasible innovation method, 1QT tower has been analysed for optimisation.

SPECIFICATION FOR 1QT TOWER		
S. No.	**Description**	**Parameters**
1	Voltage Class	132kV
2	Configuration	Vertical
3	Number of Circuits	4
4	Configuration of Earthwire	Double peak
5	Conductor Parameters	Single ACSR Grosbeak

SPECIFICATION FOR 1QT TOWER		
S. No.	**Description**	**Parameters**
6	EW parameters	7x3.25 steel EW
7	OPGW parameters Equivalent OPGW	7x3.25steel EW
8	Designation of Towers	
	A Angle Tower Type (angular deviation) 1QT6 (Angle):30°-60°	1QT6(Terminal):Max.angleofentry30°
9	Extension required if any	std.,1.5,3.0,4.5,6.0,9.0
10	Spans	
	A Rulling/Average Span	330 m
	Wind Span-NC 1QT6(Terminal):250m	1QT6(Angle):330m
	Wind Span-BWC 1QT6 (Terminal):190m	1QT6(Angle):250m
	Weight Span(max)-NC 1QT6(Terminal):395m	1QT6(Angle):525m
	Weight Span(max)-BWC 1QT6(Terminal):300m	1QT6(Angle):395m
	Weight Span(min)-NC	1QT6(Angle &Terminal):0m
	Weight Span(min)-BWC	1QT6(Angle &Terminal):0m
11	Temperature Range	
	Minimum Temperature	5 °C
	Everyday Temperature	35 °C
	Maximum Temp. (Conductor)	80 °C
	Maximum Temp.(OPGW)	50 °C
12	Reference Wind velocity	62.5 m/sec (3sGust)
13	Minimum Ground Clearance	7000mm
14	Insulator Strings details	
	a Tension Insulator String	
	Single Tension length	2486 mm
	Single Tension weight	200 kg
	Arcing Horn length	2336 mm
15	Minimum Electrical Clearances	
	Tension Insulators (Single/Double)	
	A Jumper	
	0^0	1450mm
	10^0	1450mm

SPECIFICATION FOR 1QT TOWER		
S. No.	Description	Parameters
	30^0	900mm
	B Pilot Insulators	
	15^0	1450mm
	Vertical Clearance	
	-Tension Tower(min)	4000mm
16	Materials for towers	
	A Mild Steel	275 MPa
	B High Tensile Steel	355 MPa
	C Bolts & nuts	ISO 898 GRADE 5.6/5
17	Minimum Thickness of Members	
	A Tower Legs, Peak & main Cross arms	6mm
	B All Other Members	5mm
	C All Redundant Members	4mm
	D Gusset plates	6mm
	E Min. Section without bolt hole	40mm
18	Bolt Diameter	
	Galvanized Hexagonal head of connection	16mm / 24mm
19	Overload factor	
	For Normal Condition	1.25
	For Broken Condition	1.25
20	Base width of tower	10 m

The innovation exercise primarily involves detailed tower analysis to be carried out on the tower model with application of the design loads. Based on the tower data, tower outline, tower configuration & design loads, the analysis process have been conducted on 1QT6 towers.

The design loads have been carried as under:

4.2.2.1 Calculation of Wind Loads / Wind Pressure / Loading pattern

Based on the applicable design codes, wind loadings on overhead conductors influence line design in number of ways:

i. The maximum span between structures may be determined by the need for horizontal clearance to edge of right-of-way during moderate winds.
ii. The maximum transverse loads for tangent and suspension structures are determined by infrequent high wind-speed loadings.
iii. Wind pressure and load on conductor have been calculated below as per ASCE -74:

PROJECT NAME : 132KV M/C TL BANGLADESH								
TOWER TYPE "1QT6"								
WIND PRESSURE ON CONDUCTOR								
[AS PER ASCE MANUAL 74: 2009]								
$F = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$								
wherein								
Wind Load Factor (g_w) =	**1.0**	For Exposure Category "**C**" [Ref: Table 1-1]						
Newmerical Constant Figure (Q) =	**0.613**							
Basic Wind Speed (V_{50}) =	**62.5**	m/s	(3sec Gust speed)					
Velocity Pressure Exposure Coefficient (K_z) =	$2.01*(z_h/z_g)^{2/a}$		{for $33 < z_g < z_h$}			(m)	(ft)	
=	**1.326**			Effective Height (z_h) =		**38.137**	125	Refer Table 2-1
				Gradient Height (z_g) =		-	**900**	
					Value of a =	**9.5**		
Topographic Factor (K_{zt}) =	**1.00**	{Due to absence of Topographical details}						
Gust Response Factor (G)								
Gust Response Factor for **Wires** (G_w) =	$(1+2.7*E*(B_w)^{0.5}/K_v^2$			k =	**0.005**	a_{FM} =	**7.0**	Refer Table 2-3
=	**0.659**					(m)	(ft)	
				Effective Height (z_h) =		**38.137**	125	
				Design Wind Span (S) =		**330**	1083	
				Turbulence Scale (L_s) =		-	**220**	
			Ratio of 3-sec gust to 10-min gust (K_v) =			**1.43**		
					$E = 4.9*k^{0.5}*(33/z_h)^{1/aFM}$ =		**0.286**	
				B_w =	$1/[1+0.8*(S/L_s)]$ =		**0.203**	
Force Coefficient (C_f) =	**1.00**							
FOR CONDUCTOR $F_c = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$								
=	**2093**	N/m^2	*A					
=	**213**	Kg/m^2	*A					

4.2.2.2 Calculation Sag on Conductor, Earth wire & OPGW (for tower 1QT6 as per the data sheet provided by Power Cell)

Sag-tension calculations for the conductors are required to assess the loading impacts on the tower. The complexity results from the different behaviour of steel and aluminium strands in response to tension and temperature. Steel wires do not exhibit creep elongation or plastic elongation in response to high tensions. Aluminium wires do creep and respond plastically to high stress levels because of different metallic property and elongation coefficients. These effects are considered for evaluation of tower design loads.

Wind loads /Loading pattern and sag/ tension details considered for analysis have been shown in Table 4-14 and Table 4-15 respectively

4.2.2.3 Methodology for Tower analysis - Tower 1QT

The standard tower analysis method has been followed after allowing the design parameters of Bangladesh design codes and using the options for optimisation.

The main intent is to use the methods & options of innovation to optimise the tower foot print / ROW.

Table 4-13: Wind Load, Loading parameters, Loading pattern Tower -1QT

PROJECT NAME : 132KV M/C TL BANGLADESH									
CLIENT : PGCB, BANGLADESH									
TOWER TYPE : "1QT6" - TENSION TOWER									
LOADING PARAMETERS									
For Earthwire		**GSW**	**OPGW**	**For Conductor (GROSBEAK)**			**For Insulator**		
Number Ne	=	1	1	Number Nc	=	1	Number Ni	=	2
Diameter De (m)	=	0.0098	0.0113	Diameter Dc (m)	=	0.02515	Diameter Di (m)	=	0.254
Weight We (kg/m)	=	0.398	0.401	Weight Wc (kg/m)	=	1.3	Weight Wi (kg)	=	200
Tension T_{e1} (kg)	=	2729	2927	Tension Tc (kg)	=	7250	Length Li (m)	=	2.486
Tension T_{e2} (kg)	=			Tension T_{c2} (kg)	=				
C_{xe}	=	1.0	1.0	C_{xc}	=	1.0	C_{xi}	=	1.0
Spans		**NC**	**BWC**	**Wind Pressure**			**Line Deviation (degree)**		
				Earth Wire Pe (kg/sqm)	=	213	Angle (min)	Ø1	30
Wind L_{wn} (m)	=	330	250	Conductor Pc (kg/sqm)	=	213	Angle (max)	Ø2	60
Max Wt Lwt (m)	=	525	395	Insulator Pi (kg/sqm)	=	213	**Factor Of Safety**		
Min Wt L_{wtmin} (m)	=	0	0	**Angle of wind incidence (degree)**			Maxm Wt Span =	F1	1.25
					ϴ =	0	Minm Wt Span =	F2	0.90
Longitudinal Tension Reduction Factor for Unbalanced in Tension in Normal Condition									
F_{te}	=	10	%	F_{tc}	=	10 %	EW / Condr Tension =	F3	1.25
UTS	=	7933	6157	UTS	=	11502			

LOAD CASE - FULL WIND LOADING AT 5⁰C PERPENDICULAR WIND (0⁰)					
ULTIMATE LOADING CALCULATIONS **INCLUDING FACTOR OF SAFETY**		**NORMAL CONDITION 0⁰ PERPENDICULAR WIND**			
FULL WIND LOADING AT -5⁰C PERPENDICULAR (0⁰) WIND		**Max. Weight**	**Min. Weight**	**Max. Weight**	**Min. Weight**
FOR EARTHWIRE		**GSW**		**OPGW**	
Transverse Loads					
Wind Load on Earthwire					
	Ne*De*Lwnnc*Pe *Cxe*Cos2ϴ=	685	685	794	794
Wind Load on Warning Sphere	6x0.2827xPex0.4x F1 =	0	0	0	0
Due to Deviation 2.0	*Ne*Te*Sin(Ø2/2) *F3=	3411	3411	3659	3659
	Total =	**4097**	**4097**	**4453**	**4453**

Vertical Loads						
Weight of Earth wire	1.0	*Ne*We*Lwtnc*F1=	261	-	263	-
		Ne*We*Lwtnc*F1 =	-	0	-	0
Weight of Warning Sphere	1.0	6x5.5xF1 =	0 -	- 0	0 -	- 0
		Total =	**261**	**0**	**263**	**0**
Longitudinal Loads		(UTS*Fte/100)*Ne *F3=	**992**	**992**	**770**	**770**
-						

FOR CONDUCTOR			**ACSR MALLARD**	
			Max. Weight	**Min. Weight**
- Transverse Loads				
Wind Load on Conductor		Nc*Dc*Lwnnc*Pc*Cxc*Cos2Θ=	1768	1768
Wind Load on Insulator	0.5	4*Ni*Li*Di*Pi*Cxi=	538	538
Due to Deviation	2.0	*Nc*Tc*Sin(Ø2/2)*F3=	9063	9063
Wind Load on Pilot Insulator	0.5	***2*2.023*0.280*297=**	**121**	**121**
		Total =	**11489**	**11489**
Vertical Loads				
Weight of Conductor		Nc*Wc*Lwtnc*F1=	853	-
		Nc*Wc*Lwtminnc*F1=	-	0
Weight of Insulators & Acc.	1.0	*Ni*Wi*F1=	500	360
Weight of Pilot Insulator		**2*250*F1=**	**625**	**450**
		Total =	**1978**	**810**
Longitudinal Loads		(UTS*Ftc/100)*Nc*F3=	**1438**	**1438**

For Earthwire		**GSW**	**OPGW**	**For Conductor (GROSBEAK)**			**For Insulator**		
Number Ne	=	**1**	**1**	Number Nc	=	**1**	Number Ni	=	**2**
Diameter De (m)	=	**0.00975**	**0.0113**	Diameter Dc (m)	=	**0.02515**	Diameter Di (m)	=	**0.254**
Weight We (kg/m)	=	**0.398**	**0.401**	Weight Wc (kg/m)	=	**1.3**	Weight Wi (kg)	=	**200**
Tension T_{e1} (kg)	=	**2729**	**2927**	Tension Tc (kg)	=	**7250**	Length Li (m)	=	**2.486**
Tension T_{e2} (kg)	=			Tension T_{c2} (kg)	=				
C_{xe}	=	**1**	**1**	C_{xc}	=	**1**	C_{xi}	=	**1**

Spans			NC	BWC	Wind Pressure			Line Deviation (degree)		
					Earth Wire Pe (kg/sqm)	=	213	Angle (min)	Ø1	30
Wind L_{wn} (m)	=		330	250	Conductor Pc (kg/sqm)	=	213	Angle (max)	Ø2	60
Max Wt Lwt (m)	=		525	395	Insulator Pi (kg/sqm)	=	213	**Factor Of Safety**		
Min Wt L_{wtmin} (m)	=		0	0	**Angle of wind incidence (degree)**			Maxm Wt Span =	F1	1.25
					Ө	=	22.5	Minm Wt Span =	F2	0.90

Longitudinal Tension Reduction Factor for Unbalanced in Tension in Normal Condition

Fte	=	10	%	Ftc	=	10	%	EW / Condr Tension =	F3 1.25
UTS	=	7933	6157	UTS	=	11502			

LOAD CASE - FULL WIND LOADING AT 5⁰C (22.5⁰) OBLIQUE WIND

ULTIMATE LOADING CALCULATIONS **INCLUDING FACTOR OF SAFETY**			**NORMAL CONDITION 22.5⁰ WIND**			
FULL WIND LOADING AT -5⁰C -			**Max. Weight**	**Min. Weight**	**Max. Weight**	**Min. Weight**
FOR EARTHWIRE			**GSW**		**OPGW**	
Transverse Loads						
Wind Load on Earthwire		Ne*De*Lwnnc*Pe *Cxe*Cos2Ө=	585	585	678	678
Wind Load on Warning Sphere		6x0.2827xPex0.4x F1 =	0	0	0	0
Due to Deviation	2.0	*Ne*Te*Sin(Ø2/2) *F3=	3411	3411	3659	3659
		Total =	**3996**	**3996**	**4337**	**4337**
Vertical Loads						
Weight of Earth wire	1.0	*Ne*We*Lwtnc*F 1=	261	-	263	-
		Ne*We*Lwtminnc *F1=	-	0	-	0
Weight of Warning Sphere	1.0	6x5.5xF1 =	0	-	0	-
			-	0	-	0
		Total =	**261**	**0**	**263**	**0**
Longitudinal Loads -		(UTS*Fte/100)*Ne *F3=	**992**	**992**	**770**	**770**

FOR CONDUCTOR		**ACSR MALLARD**	
-		**Max. Weight**	**Min. Weight**
Transverse Loads			
Wind Load on Conductor	Nc*Dc*Lwnn c*Pc*Cxc*Co s2Ө=	1509	1509

Wind Load on Insulator	**0.5**	4*Ni*Li*Di*Pi *Cxi=	538	538
Due to Deviation	**2.0**	*Nc*Tc*Sin(Ø 2/2)*F3=	9063	9063
Wind Load on Pilot Insulator	**0.5**	***2*2.023*0.280*297=**	**121**	**121**
		Total =	**11230**	**11230**
<u>Vertical Loads</u>				
Weight of Conductor		Nc*Wc*Lwtnc *F1=	853	-
		Nc*Wc*Lwtmi nnc*F1=	-	0
Weight of Insulators & Acc.	**1.0**	*Ni*Wi*F1=	500	360
Weight of Pilot Insulator		**2*250*F1=**	**625**	**450**
		Total =	**1978**	**810**
<u>Longitudinal Loads</u>		(UTS*Ftc/100) *Nc*F3=	**1438**	**1438**

For Earthwire		**GSW**	**OPGW**	**For Conductor (GROSBEAK)**			**For Insulator**		
Number Ne	=	**1**	**1**	Number Nc	=	**1**	Number Ni	=	**2**
Diameter De (m)	=	**0.00975**	**0.0113**	Diameter Dc (m)	=	**0.02515**	Diameter Di (m)	=	**0.254**
Weight We (kg/m)	=	**0.398**	**0.401**	Weight Wc (kg/m)	=	**1.3**	Weight Wi (kg)	=	**200**
Tension T_{e1} (kg)	=	**2729**	**2927**	Tension Tc (kg)	=	**7250**	Length Li (m)	=	**2.486**
Tension T_{e2} (kg)	=			Tension T_{c2} (kg)	=				
C_{xe}	=	**1**	**1**	C_{xc}	=	**1**	C_{xi}	=	**1**
Spans		**NC**	**BWC**	**Wind Pressure**			**Line Deviation (degree)**		
				Earth Wire Pe (kg/sqm)	=	**213**	Angle (min)	Ø1	**30**
Wind L_{wn} (m)	=	**330**	**250**	Conductor Pc (kg/sqm)	=	**213**	Angle (max)	Ø2	**60**
Max Wt Lwt (m)	=	**525**	**395**	Insulator Pi (kg/sqm)	=	**213**	**Factor Of Safety**		
Min Wt L_{wtmin} (m)	=	**0**	**0**	**Angle of wind incidence (degree)**			Maxm Wt Span =	F1	1.25
					ϴ =	**22.5**	Minm Wt Span =	F2	0.90
Longitudinal Tension Reduction Factor for Unbalanced in Tension in Normal Condition									

Table 4-14: Sag / Tension Calculation for Phase Conductor of Tower 1QT6

PROJECT NAME: 132KV M/C TL BANGLADESH						
TOWER TYPE "1QT6"						
SAG TENSION CALCULATION FOR PHASE CONDUCTOR						
NAME OF THE CONDUCTOR	:	**GROSBEAK**				-
AREA	:	374.33	mm^2			-
DIA	:	25.15	mm			
WT OF CONDUCTOR	:	1.300	Kg/m			
ULTIMATE TENSILE STRENGTH	:	11401	Kg			
MODULUS OF ELASTICITY	:	7700	Kg/mm^2			
MAX WORKING SPAN	:	330	m			
MIN TEMPERATURE	:	5	^0C			
EVERY DAY TEMPERATURE	:	35	^0C			
MAX TEMPERATURE	:	80	^0C			
COEFF OF LINEAR EXPANSION	:	1.92E-05	$/^0C$			
INITIAL TEMP	:	35	^0C			
INITIAL WIND PRESSURE	:	0	Kg/m^2			
RADIAL ICE FORMATION	:	0	mm			

	WIND PRESS (Kg/m^2)	TEMP DEG (^0C)	ICE FORMATION (mm)		SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INITIAL	0	35	0		7.761	609.12	2280	20.0	330
	0	5	0		6.539	723.00	2706	23.7	330
50%	107	5	0		-	1275.48	4775	41.9	330
100%	213	5	0		-	1936.77	7250	63.6	330
	13	35	0		7.812	624.01	2336	20.5	330
100%	213	35	0		-	1803.31	6750	59.2	330
	0	80	0		9.470	499.18	1869	16.4	330
	Dynamic Wind Pressure (qho)			=	2093	N/m2 =	213	Kg/m2	

Table 4-15: Sag / Tension Calculation for Earth Wire of Tower 1QT6

PROJECT NAME : 132KV M/C TL BANGLADESH						
TOWER TYPE "1QT6"						
SAG TENSION CALCULATION FOR EARTHWIRE						
NAME OF THE CONDUCTOR	:	GSW 7/3.25				-
AREA	:	58.07	mm^2			-
DIA	:	9.75	mm			
WT OF CONDUCTOR	:	0.398	Kg/m			
ULTIMATE TENSILE STRENGTH	:	7933	Kg			
MODULUS OF ELASTICITY	:	16514	Kg/mm^2			
MAX WORKING SPAN	:	330	m			
MIN TEMPERATURE	:	5	^0C			
EVERY DAY TEMPERATURE	:	35	^0C			
MAX TEMPERATURE	:	80	^0C			
COEFF OF LINEAR EXPANSION	:	1.30E-05	$/^0C$			
INITIAL TEMP	:	5	^0C			
INITIAL WIND PRESSURE	:	0	Kg/m^2			
RADIAL ICE FORMATION	:	0	mm			

	WIND PRESS (Kg/m^2)	TEMP DEG (^0C)	ICE FORMATION (mm)		SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INI	0	5	0		5.885	1585.41	921	11.6	330
50%	107	5	0		-	3084.11	1791	22.6	330
100%	213	5	0		-	4700.10	2729	34.4	330
	0	35	0		6.748	1382.53	803	10.1	330
	13	35	0		6.838	1431.88	831	10.5	330
100%	213	35	0		-	4489.53	2607	32.9	330
	0	80	0		8.004	1165.62	677	8.5	330
			Dynamic Wind Pressure (q_{ho})	=	2093	N/m^2 =	**213**	Kg/m^2	

Table 4-16: Sag / Tension Calculation for OPGW of Tower 1QT6

PROJECT NAME : 132KV M/C TL BANGLADESH						
TOWER TYPE "1QT6"						
SAG TENSION CALCULATION FOR OPGW						
NAME OF THE CONDUCTOR	:	OPGW				
AREA	:	48.6	mm^2			
DIA	:	11.3	mm			
WT OF CONDUCTOR	:	0.401	Kg/m			
ULTIMATE TENSILE STRENGTH	:	6157	Kg			
MODULUS OF ELASTICITY	:	17747	Kg/mm^2			
MAX WORKING SPAN	:	330	m			
MIN TEMPERATURE	:	5	^0C			
EVERY DAY TEMPERATURE	:	35	^0C			
MAX TEMPERATURE	:	80	^0C			
COEFF OF LINEAR EXPANSION	:	1.44E-05	$/^0C$			
INITIAL TEMP	:	5	^0C			
INITIAL WIND PRESSURE	:	0	Kg/m^2			
RADIAL ICE FORMATION	:	0	mm			

	WIND PRESS (Kg/m^2)	TEMP DEG (^0C)	ICE FORMATION (mm)	SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INI	0	5	0	5.885	1908.61	928	15.1	330
50%	107	5	0	-	3943.72	1917	31.1	330
100%	213	5	0	-	6022.39	2927	47.5	330
	0	35	0	6.806	1650.19	802	13.0	330
	13	35	0	-	1725.47	839	13.6	330
100%	213	35	0	-	5766.16	2802	45.5	330
	0	80	0	8.155	1377.24	669	10.9	330

4.2.2.4 Tower Configuration / Model-1QT6

Depending upon the requirements various line configurations have to be considered and analysed for multi circuit vertical structures and with single or V strings in all phases, as well as any combination of these. The configuration of a transmission line tower depends on following factors:

1. The length of the insulator assembly.
2. The minimum clearances to be maintained between conductors, and between conductor and tower.
3. The location of ground wire or wires with respect to the outermost conductor.
4. The mid-span clearance required from consideration of the dynamic behaviour of conductors and lightning protection of the line.
5. The minimum clearance of the lowest conductor above ground level. The tower configuration is determined essentially by three factors:

(a) Tower height (b) Base width and (c) Top Hamper - width

All the design criterion of PGCB has been used for the purpose of analysis.

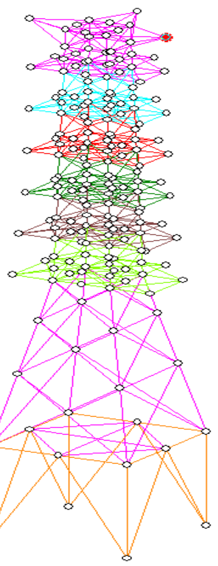


Table 4-17: Tower Model

Spacing between the tower footings, i.e. the base width at the concrete level (or at the foot of the bottom panel) is the distance from the centre of gravity of one corner leg to the centre of gravity of the adjacent corner leg. This width depends upon the height, magnitude of the physical loads imposed upon the tower calculated from the size, type of conductors and wind loads and also upon the height of application of external loads from ground level.

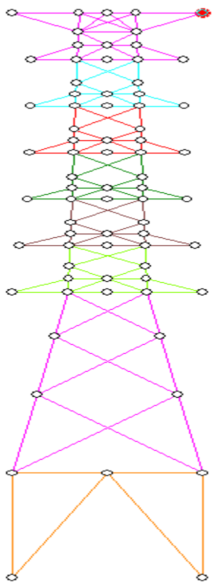
Towers with larger base, result in low footing costs and lighter main leg members at the expense of longer bracing members. There is a particular base width, which gives the best compromise for the total cost of the tower to be minimum. Through experience expanded over a number of years, certain empirical ratio between total height of the tower upto the lower cross arm and base width is generally between 2.8 and 4.4.

In case of the reference tower, the base width of the structure at lower level has been proposed same as basic body level i.e. the lower part of the structure has been modelled with straight legs. As our main objective is to reduce footprint area, the tower lower part can be made straight to get this benefit. The tower has been analysed and optimized with the above configuration.

4.2.2.5 Structural Analysis of the Tower

Since 1QT6 is a multi-circuit tower and its analysis is complex compared to 1QL because of connection points & application of tension. All tension points as per suggested tower have been considered with design loads as worked out. For the purpose of analysis, it is idealized as a space truss. A space truss is a 3-D assemblage of line members, each member being joined by hinges. Space truss idealization lead to the following assumptions:

1. The influence of gusseted connection in transmitting moment is neglected.
2. Leg members that are continuous are assumed to be hinged at the nodal points.
3. Loads are assumed to act only at the joints.



The use of design software and IT tool has enabled the analysis of large structural systems to be carried out more easily and accurately. Among the various methods available for the truss analysis, the matrix formulation has the advantage over other methods, since the operation of matrix algebra can be provided in the form of a 'routine' in the computer program like PLS-Tower. Every structure must fulfil the dual requirements of equilibrium and compatibility. The stiffness method maintains the compatibility of the structures and makes use of equilibrium conditions for the solution. For solving pin-jointed trusses, the stiffness method generally leads to fewer equations. Hence, the stiffness method is used for the analysis of transmission line towers.

Table 4-18: Tower Analysis

Once the external loads acting on the tower are determined, one can proceed with an analysis of the forces in various members with a view to fix up their sizes. Axial force is the primary force for a truss element and therefore, the member is designed for either compression or tension. When there are multiple load conditions, certain members may be subjected to both compressive and tensile forces under different loading conditions. Hence, these members are designed for both compression and tension acting separately.

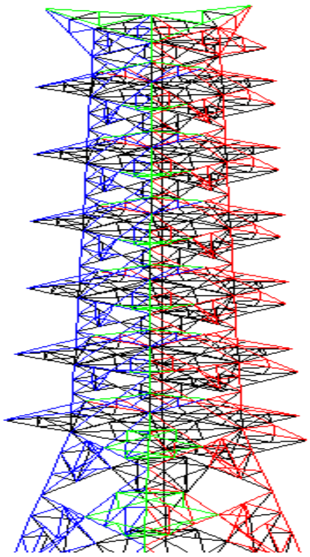
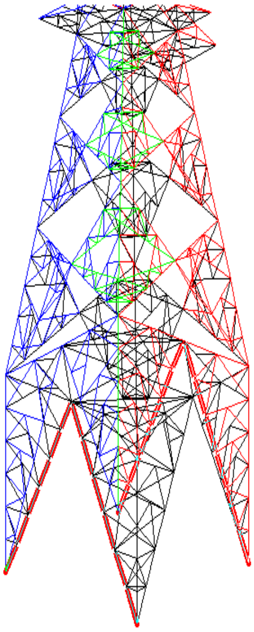
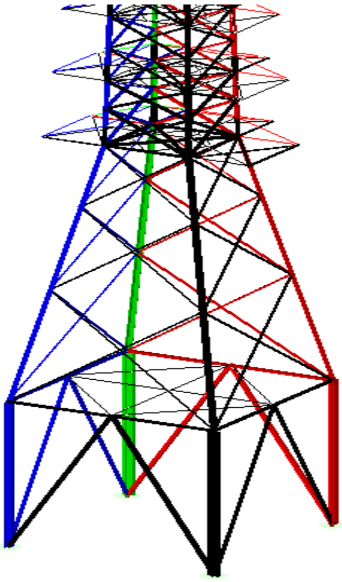


Table 4-19: Tower Structure Model PLS

Models are also prepared with redundant which are in face sides of the models. Wind on tower has been calculated with these redundant sections area.



One of the innovation options considered along with the above option is the practices followed with regard to the minimum angle sizes and minimum thickness of steel members adopted in the designs, based on experience and judgement, are briefly described below:



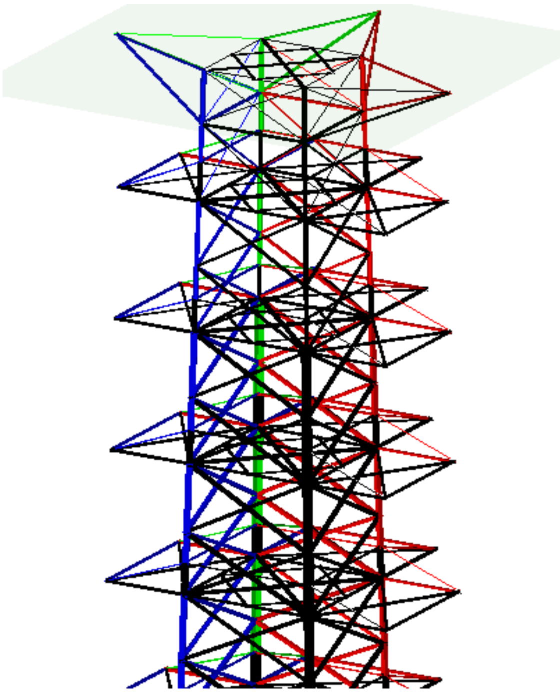


Table 4-20: Tower base / Modified Foot Print 1QT6 Tower

4.2.2.6 Tower Load Case - Tower 1QT6

The applicable load cases considered on the tower 1QT6 - M/C Tower for analysis are as under. Each load case & the critical load combination have been derived during analysis of this tower.

Table 4-21: List of Load cases -Tower 1QT6

PROJECT: 132 KV M/C BANGLADESH							
TOWER TYPE: "1QT"							
LIST OF LOAD CASES							
CASE NO	CONDTN	WIND	DIRECTION	NORMAL CONDTN/BROKEN CONDTN	COMBINATION	TEMPRATURE	STRUNG
1	EVERYDAY TEMP	FULL WIND	OBLIQUE	NORMAL CONDN.	(NORMAL CONDITION)	Vmax	DOUBLE STRUNG
2	MINIMUM TEMP	FULL WIND	OBLIQUE	NORMAL CONDN.	(NORMAL CONDITION)	Vmax	DOUBLE STRUNG
3	MINIMUM TEMP	FULL WIND	PERPENDICULAR	NORMAL CONDN.	(NORMAL CONDITION)	Vmax	DOUBLE STRUNG
4	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	NORMAL CONDN.	(NORMAL CONDITION)	Vmax	DOUBLE STRUNG
5	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	EW1+PC1+	Vmax	DOUBLE STRUNG
6	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	EW1+PC2+	Vmax	DOUBLE STRUNG
7	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	EW1+PC3+	Vmax	DOUBLE STRUNG
8	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	EW1+PC4+	Vmax	DOUBLE STRUNG
9	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	EW1+PC5+	Vmax	DOUBLE STRUNG
10	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	EW1+PC6+	Vmax	DOUBLE STRUNG
11	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	PC1+PC2+	Vmax	DOUBLE STRUNG
12	MINIMUM TEMP	PARTIAL WIND	PERPENDICULAR	BWC	PC1+PC3+	Vmax	DOUBLE STRUNG

(The complete Load sheet, wind calculation & Tower analysis shall be provided on request)

Loading Tree

Load Case			Joint Label	Vertical Load (N)	Transverse Load (N)	Longitudinal Load (N)	Transverse Wind (Pa)	Longitudinal Wind (Pa)
EVERYDAY TEMPFULL WINDDIAGNC	(NORMAL CONDITION)Vmax	DS	110P	2560	39187	9728	2349	403
			110X	2579	42531	7551	2349	403
			210P	19397	110128	14102	2349	403
			310P	19397	110128	14102	2349	403
			410P	19397	110128	14102	2349	403
			510P	19397	110128	14102	2349	403
			610P	19397	110128	14102	2349	403
			710P	19397	110128	14102	2349	403
			220P	19397	110128	14102	2349	403
			320P	19397	110128	14102	2349	403
			420P	19397	110128	14102	2349	403
			520P	19397	110128	14102	2349	403
			620P	19397	110128	14102	2349	403
			720P	19397	110128	14102	2349	403
			211P	19397	110128	14102	2349	403
			311P	19397	110128	14102	2349	403
			411P	19397	110128	14102	2349	403
			511P	19397	110128	14102	2349	403
			611P	19397	110128	14102	2349	403
			711P	19397	110128	14102	2349	403
MINIMUM TEMPFULL WINDDIAGNC	(NORMAL CONDITION)Vmax	DS	110P	2560	36814	9728	1501	1501
			110X	2579	39776	7551	1501	1501
			210P	19397	103999	14102	1501	1501
			310P	19397	103999	14102	1501	1501
			410P	19397	103999	14102	1501	1501
			510P	19397	103999	14102	1501	1501
			610P	19397	103999	14102	1501	1501
			710P	19397	103999	14102	1501	1501
			220P	19397	103999	14102	1501	1501
			320P	19397	103999	14102	1501	1501
			420P	19397	103999	14102	1501	1501
			520P	19397	103999	14102	1501	1501
			620P	19397	103999	14102	1501	1501
			720P	19397	103999	14102	1501	1501
			211P	19397	103999	14102	1501	1501
			311P	19397	103999	14102	1501	1501
			411P	19397	103999	14102	1501	1501
			511P	19397	103999	14102	1501	1501
			611P	19397	103999	14102	1501	1501
			711P	19397	103999	14102	1501	1501
MINIMUM TEMPFULL WINDPERPNC	(NORMAL CONDITION)Vmax	DS	110P	2560	40178	9728	2502	0
			110X	2579	43669	7551	2502	0
			210P	19397	112668	14102	2502	0
			310P	19397	112668	14102	2502	0
			410P	19397	112668	14102	2502	0
			510P	19397	112668	14102	2502	0
			610P	19397	112668	14102	2502	0
			710P	19397	112668	14102	2502	0
			220P	19397	112668	14102	2502	0

Table 4-22: Analysis Results and Outcomes - Tower 1QT6

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Modification in base width of tower,	
	ii. Alterations in tower Geometry - Modifications	ii. Tower geometry, Leg member proposed straight.	
	iii. Tower Slopes alterations	iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	As per the discussion held with PGCB on 25th July 2023. The orginal design criteria of PGCB has been used
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used.	
		iii. Minimum Lattice/ redundant sections used.	
		iv. Redundant members designed for 1.5 % force of supported members.	
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence,	No Change, as per Bangladesh design code	
	ii. Tower design data / Loadings		
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

Table 4-23: Comparison of Weights & Tower Foot Print after Analysis -Tower 1QT6

Description	Original Tower	Innovated tower	Reduction percentage
Tower Base width / ROW - area	179.5Sq.m	100Sq.m	44 %
Tower Weight	-	Approximate provided below	Approx. 8 T

4.2.2.7 Foundation Analysis for 1QT6 – 132 kV multi circuit Tension Tower

For optimization of transmission tower foot print, the 1QT6 type angle tower has been considered. The soil category considered is type -3 for loose sand or soft to medium clay soil which is considered same as the existing foundation of 1QT6+ 9M (Angle). Tower superstructure is analyzed and designed with PLS software.

Due to optimization of the footprint of the 1QT6 tower structure, the ultimate compression, ultimate uplift load, ultimate shear forces in Transverse and Longitudinal direction loads have significantly increased. The reactions for foundation design including comparison statement with existing tower foundation design are as shown in table below.

Table 4-24: Foundation Forces Analysis – 132 kV multi circuit Tension Tower

TOWER FOUNDATION - 1QT6+9m for 3 (9-600)			
DESCRIPTION	**EXISTING**	**REVISED**	**REMARKS**
TYPE OF FOUNDATION	1QT6+ UPTO 9M EXT.	1QT6+ 9M BE	
LOADS PER LEG ALONG LEG SLOPE (KG)	**REACTIONS FROM TOWER STRUCTURE**		Weight Difference (kg)
ULTIMATE COMPRESSION LOAD FOR FOUNDATION	411063	536160	125097
ULTIMATE UPLIFT LOAD FOR FOUNDATION	364820	570939	206119
ULTIMATE SHEAR			
SHEAR HORIZONTAL TO LEG TRAN	8929	50873	41944
SHEAR HORIZONTAL TO LEG LONG	7790	64892	57102

The foundation and pedestals/chimney have been designed with manual calculation using excel spread sheet. Due to increase in various foundation forces, the numbers of piles have been increased and pile cap size has also increased. The foundation is designed with nine (9) numbers of 600 mm diameter piles instead of four (4) numbers 600 mm diameter piles.

The pile cap size has been revised as 4.5 m x 4.5 m x 1.0 m instead of 2.7 m x 2.7 m x 0.9 m. Owing to this, reinforcements for pile caps have also increased. However, the pedestal/chimney sizes including reinforcement details have not changed.

It has been considered that the pile cap shall rest at 2 m below the natural ground level so that the land area at top of pile cap can be used.

The final outcome along with comparison of existing pile cap and proposed pile cap details are as under.

Table 4-25: Pile Cap Analysis – 132 kV multi circuit Tension Tower

TOWER FOUNDATION - 1QT6+9m for 3 (9-600)			
DESCRIPTION	**EXISTING**	**REVISED**	**REMARKS**
TYPE OF FOUNDATION	**1QT6+ UPTO 9M EXT.**	**1QT6+ 9M BE**	**DIFFERENCE**
PILE DETAILS			
DIA OF PILES	600MM	600MM	
NUMBER OF PILES	4 NOS.	9 NOS.	5 NOS.
DEPTH OF PILES	24M	24M	
REINFORCEMENT	16 NOS. 25 DIA.	16 NOS. 25 DIA.	
REINFORCEMENT LOWER SEGMENT (5m to Last Point)	8 NOS. 16 DIA	8 NOS. 16 DIA	
STIRRUPS	8 DIA 150MM C/C	8 DIA 150MM C/C	
PILE CAP DETAILS			
SIZE	2.7X2.7M (SQUARE SHAPE) - 7.29 SQM.	4.5X4.5M (SQUARE SHAPE) - 20.25 SQM.	12.96 SQM
DEPTH OF PILECAP	0.9M	1.0M	0.1M
PILE CAP REINFORCEMENT			
BOTTOM LONGITUDINAL DIRECTION	16 DIA - 19 NOS.	16 DIA - 36 NOS.	Increased
BOTTOM TRANSVERSE DIRECTION	16 DIA - 19 NOS.	16 DIA - 36 NOS.	Increased
TOP LONGITUDINAL DIRECTION	16 DIA - 17 NOS.	16 DIA - 31 NOS.	Increased
TOP TRANSVERSE DIRECTION	16 DIA - 17 NOS.	16 DIA - 31 NOS.	Increased
CHIMNEY			
SIZE	600 X600MM	600 X600MM	
REINFORCEMENT	12 NOS. - 16MM DIA	12 NOS. - 16MM DIA	
STIRRUPS	10 DIA AT 150 C/C	10 DIA AT 150 C/C	

4.3 INNOVATION AND OPTIMISATION OF TOWER TT-2QL & 2QT6

4.3.1 Input Data Required for Suspension tower 2QL and Angle tower 2QT6 Tower

For optimization of 2QL and 2QT6 towers the input data required for the study was collected from PGCB, which is shown in table below:

Table 4-26: Input Data Required For 2QL and 2QT6 Transmission Tower

S. No.	Description	Unit	Specification
1	**Voltage Class**		230kV
2	**Configuration**		Vertical
3	**Number of Circuits**		4
4	**Configuration of Earth wire**		Double peak
5	**Conductor Parameters**		Twin ACSR Mallard per phase
6	**EW parameters**		7x4.0 steel EW
7	**OPGW parameters**		7x4.0 steel EW equivalent OPGW
8	**Designation of Towers**		2QL, 2QT6
a	Suspension Tower (angular deviation)	degree	2QL: 0-1°
b	Angle Tower Type (angular deviation)	degree	2QT6 (Angle): 30°-60° 2QT6(Terminal): Max. angle of entry 30°
c	Angle Tower Type (angular deviation)	degree	
9	**Extension required if any**		2QL: std., 1.5, 3.0, 4.5, 6.0, 9.0, 12.0 2QT6: std., 1.5, 3.0, 4.5, 6.0, 9.0
10	**Spans**		
a	Rulling/Average Span	m	375
	Wind Span-NC	m	2QL& 2QT6(Angle): 375 2QT6(Terminal):315
	Wind Span-BWC	m	2QL& 2QT6(Angle): 275 2QT6(Terminal):0
	Weight Span (max)- NC	m	2QL& 2QT6(Angle): 510 2QT6(Terminal):430
	Weight Span (max)- BWC	m	2QL& 2QT6(Angle): 385 2QT6(Terminal):0
	Weight Span (min)- NC	m	2QL: 180; 2QT6(Angle & Terminal):0
	Weight Span (min)- BWC	m	2QL: 130; 2QT6(Angle & Terminal):0
11	**Temperature Range**		
a	Minimum Temperature	oC	5
b	Everyday Temperature	oC	35
c	Maximum Temp. (Conductor)	oC	80
d	Maximum Temp. (OPGW)	oC	50
12	**Reference Wind velocity**	m/sec	80 (3s Gust)
13	**Design Wind Pressure**		As Per Technical Spec.
a	On Conductor	kg/cm2	As per ASCE-74
b	On Earthwire	kg/cm2	As per ASCE-74

S. No.	Description	Unit	Specification
c	On Insulator	kg/cm2	As per ASCE-74
d	On Tower Body	kg/cm2	As per ASCE-74
14	**Minimum Ground Clearance**	mm	8000
15	**Altitude above mean Sea Level**	mm	
16	**Insulator Strings details**		As Per Technical Spec.
a	Suspension / Pilot Insulator Strings		
	Single / Double Suspension length	mm	Single/Double Suspension length 3000mm
	Single / Double Suspension weight	kg	Single/Double Suspension weight 250mm
	Arcing Horn length	mm	
b	Tension Insulator String		
	Single Tension length	mm	
	Single Tension weight	kg	
	Arcing Horn length	mm	
17	**Minimum Electrical Clearances**		As Per Technical Spec.
a	Single/Double Suspension Insulator		
	0^0	mm	
	45^0	mm	
	60^0	mm	
b	Tension Insulators (Single/Double)		
c	Jumper		
	0^0	mm	
	10^0	mm	
	25^0	mm	
d	Pilot Insulators		
	15^0	mm	
e	Conductor to Conductor		
	Vertical Clearance		
	- Suspension tower(min)	mm	
	- Tension Tower (min)	mm	
18	**OPGW Clearances**		As Per Technical Spec.
a	Mid span clearance between OPGW and Power Conductor		

S. No.	Description	Unit	Specification
	Suspension tower (min)	mm	
	Tension Tower (min)	mm	
b	Angle of Shielding (from vertical)		
d	Relation between Earthwire & OPGW Sag		
19	**Initial & Final Tension Limits for wires**		20% and 60% of UTS
20	**Broken Wire Condition**		As Per Technical Spec.
21	**Materials for towers**		As Per Technical Spec.
a	Mild Steel		
b	High Tensile Steel		
c	Bolts & nuts		
22	**Minimum Thickness of Members**		As Per Technical Spec.
a	Tower Legs, Peak & main Cross arms	mm	
b	All Other Members	mm	
c	Gusset plates	mm	
d	Min. Section without bolt hole	mm	
23	**Bolt Diameter**		As Per Technical Spec.
a	Galvanised Hexagonal head of connection bolt	mm	
24	**Overload factor**		As Per Technical Spec.
a	For Normal condition		
b	For Broken condition		

4.3.2 Analysis and Design of 230KV Transmission Tower - 2QL & 2QT6

The transmission line towers that need optimisation will have to be built with new / innovative design concepts using new materials and optimizing with restricted right of way. The innovative studies have been carried out the tower suggested by PGCB as per the innovative categories. While analysis of the tower the member stresses have been examined & it was noticed that failures observed during full scale load application as per the design loads & innovative options While analysing the 230KV towers, the details of Electric Tension, wind pressure, reliability level, reference wind application as per the Bangladesh design practice with prospective innovation techniques have not shown any fruitful result for optimisation of these 230KV towers. The 230KV tower appear to be optimised to an appreciable level, however, if there are few deviations taken on application of wind pressure , conductor tension limits, ruling span, an optimised solution may be worked out.

As the existing 230KV towers being used by PGCB do not offer an appreciable scope of innovative optimisation. As explained in the report, re-configuration of tower classification can be a worthy solution for ROW optimisation for use in urban Bangladesh.

4.3.3 Structural Analysis of the Tower 2QL & 2QT6

Modelling of the tower has been done in PLS and the required properties have been provided. Different loading conditions like Reliability condition, Security condition adopted for the conductor and ground wire, Safety condition for the angle tower as well as broken wire condition are considered for the analysis of the tower. Thus, according to that loading suitable member size adopted. Thus analysis has been carried out of the tower with application of Innovative categories, the tower resulted in failure at point "A.

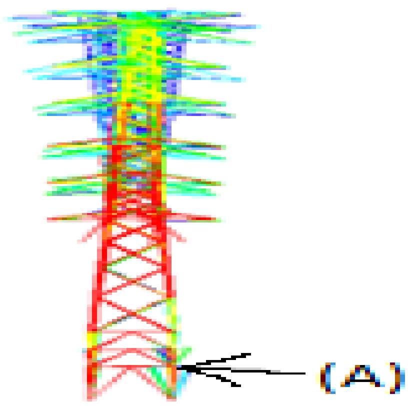


Table 4-27: Tower Failure at point 'A'

4.3.4 Analysis Results & Outcomes -Tower 2QL & 2QT6

Table 4-28: Innovation and Optimisation of Tower 2QL & 2QT6

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Base width of tower - already optimized in existing models, no further optimization possible.	In 2QL the base width at normal tower is 7000mm and the same at waist level is 3500mm, Hence the slope is now 8.78 deg. It is Almost a narrow base tower. Similarly, in 2QT6 the base width at normal tower is 10000mm and the same at waist level is 5000mm, Hence the slope is now 14.1 deg. It is also almost a narrow base tower. If we more optimized the tower base width, the tower cannot be stable due to huge failure in tower.(a sample pic is attached for reference as below)
	ii. Alterations in tower Geometry - Modifications	ii. Tower geometry, Leg member -already modified in existing models, not possible to further modification.	
	iii. Tower Slopes alterations	iii. Modification in cross arms, Cross arm length-already modified and optimized in existing tower models.	As we can see in line diagram of 2QL, the clearance for suspension insulator from tower body is most optimized in vertical direction and also in horizontal direction. Hence there is no more space for further optimized the cross arm.
Category	i. Structural	i. Use of different size	Leg member already contains M24 bolt and

Category	Domain of modification	Preferred innovation options	Remarks
B	material improvements,	Bolts, 16mm & 24mm	lattice contains M16 bolts existing towers.
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm	This will not affect any such drastic optimization.
		iii. Minimum Lattice/ redundant sections used	This already applied in existing models
		iv. Redundant members designed for 1.5 % force of supported members.	As we can see the failure condition in sample pic, hence redundant sections also become high even though we use 1.5% force of supported members.
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	This already applied in existing towers.
Category D	i. Design criteria & design guideline adherence, ii. Tower design data / Loadings	No Change, as per Bangladesh design code	Existing design already done as per Bangladesh specification/ code.
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

4.4 INNOVATION AND OPTIMISATION OF TOWER 400 KV DC SUSPENSION TOWER 4DL

4.4.1 Input Data Required for 4DL Towers

For optimization of 4DL towers the input data required for the study were collected from PGCB, which is shown in table below:

Table 4-29: Input Data Required For 4DL Transmission Tower

SPECIFICATION FOR 4DL TOWER		
S. No.	**Description**	**Parameters**
1	**Voltage Class**	400 kV
2	**Configuration**	Vertical
3	**Number of Circuits**	2
4	**Configuration of Earthwire**	Double peak
5	**Conductor**	Quad ACSR Finch per phase

SPECIFICATION FOR 4DL TOWER		
S. No.	**Description**	**Parameters**
6	**EW parameters**	ACSR Dorking EW
7	**OPGW parameters**	ACSR Dorking EW equivalent OPGW
8	**Designation of Towers**	4DL
	- Suspension Tower Type	4DL: 0^{o} - 1^{o}
9	**Extension Required**	Std: 1.5,3,4.5,6,9
10	**Spans**	
	- Ruling/Average Span	375 m
	- Wind Span - NC	410 m
	- Wind Span - BWC	240 m
	- Weight Span (max) - NC	650 m
	- Weight Span (max) - BWC	400 m
	- Weight Span (min) - NC	0 m
	- Weight Span (min) - BWC	0 m
11	**Temperature Range**	
	- Minimum Temperature	5 ^{o}C
	- Everyday Temperature	30 ^{o}C
	- Maximum Temperature (Conductor)	80 ^{o}C
	- Maximum Temperature (OPGW)	50 ^{o}C
12	**Reference Wind Velocity**	62.5 m/sec (3s Gust)
13	**Minimum Ground Clearance**	9000 m
14	**Insulator String Details**	
	- Single/Double Suspension Length	4700 mm
	- Single/Double Suspension Weight	450 kg
15	**Minimum Electrical Clearance**	

SPECIFICATION FOR 4DL TOWER		
S. No.	**Description**	**Parameters**
	- Single/Double Suspension Insulator	
	0^o	3100 mm
	10^o	3100 mm
	30^o	2800 mm
	50^o	1830 mm
	Vertical Clearance	8000 mm
16	**Materials for Towers**	
	- Mild Steel	275 Mpa
	- High Tensile Steel	355 Mpa
	- Bolts & Nuts	ISO 898 Grade 5.6/5
17	**Minimum Thickness of Members**	
	- Tower Legs, Peak & Main Cross arms	6 mm
	- All Other Members	5 mm
	- All Redundant Members	4 mm
	- Gusset Plates	6 mm
	- Min. Section without bolt hole	40 mm
18	**Bolt Diameter**	
	- Galvanized Hexagonal head of connection	16 mm / 24 mm
19	**Overload Factor**	
	- For Normal Condition	1.25
	- For Broken Condition	1.25
20	**Base Width of Tower**	7.96 m

4.4.2 Analysis and Design of 400 kV Transmission Tower - 4DL

The main objective of Optimization of 400 kV double circuit transmission line towers is that in which the base width of the transmission line tower is to be optimised. During discussions with PGCB it was understood that 400 kV TL towers being used in Bangladesh are narrow based and already optimised to the extent possible.

The aim of the assignment is to design the best optimized tower in which it results in the economy of the ROW / steel. By adopting suitable base width this can be achieved. The anticipated growth of electrical power and the transmission line infrastructure in the future is expected to grow, thus optimised towers will be very significant as far as ROW is concerned. The different wind loading conditions, sag and tension calculations and the loads acting on the tower have been computed by using Bangladesh design codes, thus 400 kV Double circuit has to be designed properly with tower angle to ensure safety for different practical load combinations.

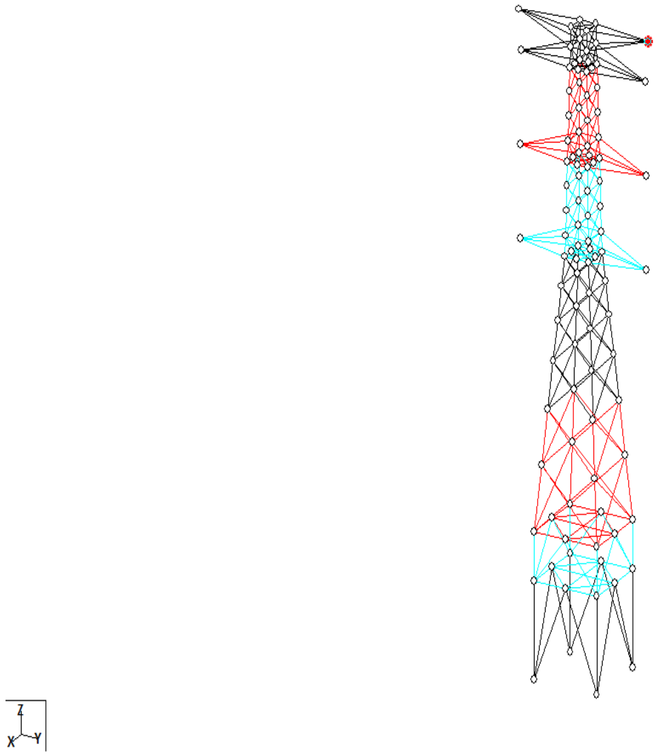
By altering few of the design components of the tower as per the category of Innovative the analysis response was not encouraging, the corresponding members, bracing sizes and material properties of the members have been changed for analyzing the economical section. It is implied that the existing 400 kV tower are best optimised, unless reverse design and corresponding analysis is done by fixing a pre-defined tower base width. Depending upon the modified tower base width, the member and bracing sizes will have to be suitably provided for different effective base width trials so as finalize the output of economical modified base width tower. Thus the best optimized tower can be obtained. This would need complete tower details & re-defining the tower design codes and economy of scale.

4.4.3 Analysis Results & Outcomes -Tower 4DL

Table 4-30: Innovation and Optimisation of Tower TT-4DL

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Base width of tower	Base Width of this tower has been modified.
	ii. Alterations in tower Geometry - Modifications	ii. Tower geometry, Leg member	Tower geometry & leg member modified.
	iii. Tower Slopes alterations	iii. Modification in cross arms, Cross arm length-.	As per the existing tower. The structural configuration cross arm of existing tower has been maintained.
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	M 24 & M 16 bolts used.
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm	

Category	Domain of modification	Preferred innovation options	Remarks
		iii. Minimum Lattice/ redundant sections used	Applied in the Innovation tower model.
		iv. Redundant members designed for 1.5 % force of supported members.	Applied in the Innovation tower model.
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	Applied in the Innovation tower model.
Category D	i. Design criteria & design guideline adherence, ii. Tower design data / Loadings	No Change, as per Bangladesh design code	Existing design already done as per Bangladesh specification/ code.
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	



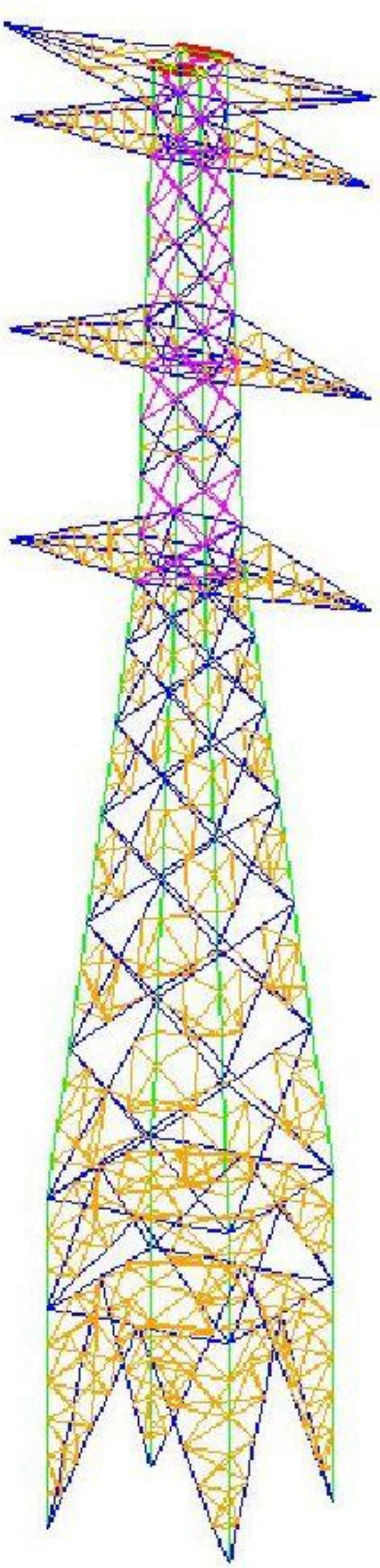
PROJECT : 400 KV D/C TRANSMISSION LINE			
TOWER TYPE "4DL"			
CLIENT : PGCB, BANGLADESH			
SAG TENSION CALCULATION FOR PHASE CONDUCTOR			
NAME OF THE CONDUCTOR	:	ACSR FINCH	
AREA	:	635.48	mm^2
DIA	:	32.85	mm
WT OF CONDUCTOR	:	2.130	Kg/m
ULTIMATE TENSILE STRENGTH	:	17785	Kg
MODULUS OF ELASTICITY	:	6392	Kg/mm^2
MAX WORKING SPAN	:	375	m
MIN TEMPERATURE	:	5	^oC
EVERY DAY TEMPERATURE	:	30	^oC
MAX TEMPERATURE	:	80	^oC
COEFF OF LINEAR EXPANSION	:	1.93E-05	$/^oC$
INITIAL TEMP	:	5	^oC
INITIAL WIND PRESSURE	:	213	Kg/m^2
RADIAL ICE FORMATION	:	0	mm

	WIND PRESS (Kg/m^2)	TEMP DEG (^oC)	ICE FORMATION (mm)	SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INITIAL	213	5	0	13.156	1539.27	9782	55.0	375
	0	5	0	9.786	602.06	3826	21.5	375
50%	107	5	0	-	999.89	6354	35.7	375
100%	213	5	0	-	1539.27	9782	55.0	375
	0	30	0	10.796	545.72	3468	19.5	375
	14	30	0	10.837	556.23	3535	19.9	375
100%	213	30	0	-	1461.16	9285	52.2	375
	0	80	0	12.679	464.68	2953	16.6	375

Wind pressure calculation for CONDUCTOR :

Dynamic Reference Wind Pressure (q_{ho})	=	2091	N/m^2 =	**213**	Kg/m^2
		(refer wind pressure calculation sheet)			

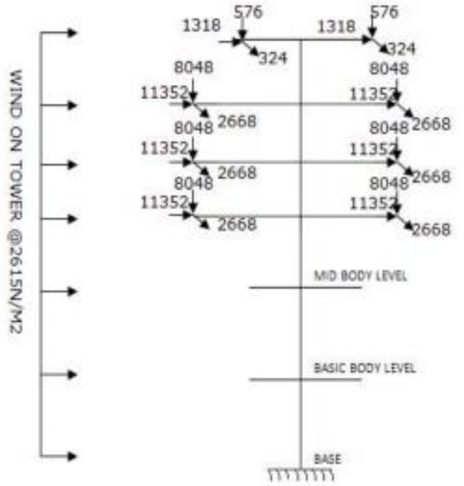
PROJECT NAME : 400KV D/C TRANSMISSION LINE,BANGLADESH				
TOWER TYPE "4DL"				
CLIENT : PGCB, BANGLADESH				
WIND PRESSURE ON CONDUCTOR				
[AS PER ASCE MANUAL 74: 2009]				
$F = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$				
wherein				
Wind Load Factor (g_w) =	**1.0**	For Exposure Category **"C"** [Ref: Table 1-1]		
Newmerical Constant Figure (Q) =	**0.613**			
Basic Wind Speed (V_{50}) =	**62.5**	m/s	(3sec Gust speed)	
Velocity Pressure Exposure Coefficient (K_z) =	$2.01*(z_h/z_g)^{2/a}$	(for $33 < z_g < z_h$)	(m)	(ft)
=	**1.359**	Effective Height (z_h) =	**42.67**	140
		Gradient Height (z_g) =	-	**900** Refer Table 2-1
		Value of a =	**9.5**	
Topographic Factor (K_{zt}) =	**1.00**	{Due to absence of Topographical details}		
Gust Response Factor (G)				
Gust Response Factor for **Wires** (G_w) =	$(1+2.7*E*(B_w)^{0.5}/K_v^2$	k = **0.005**	a_{FM} =	**7.0** Refer Table 2-3
=	**0.643**		(m)	(ft)
		Effective Height (z_h) =	**42.67**	140
		Design Wind Span (S) =	**410**	1345
		Turbulence Scale (L_s) =	-	**220**
		Ratio of 3-sec gust to 10-min gust (K_v) =	**1.43**	
		$E = 4.9*k^{0.5}*(33/z_h)^{1/aFM}$ =	**0.282**	
		$B_w = 1/[1+0.8*(S/L_s)]$ =	**0.17**	
Force Coefficient (C_f) =	**1.00**			
FOR CONDUCTOR $F_c = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$				
=	**2091**	N/m^2	*A	
=	**213**	Kg/m^2	*A	



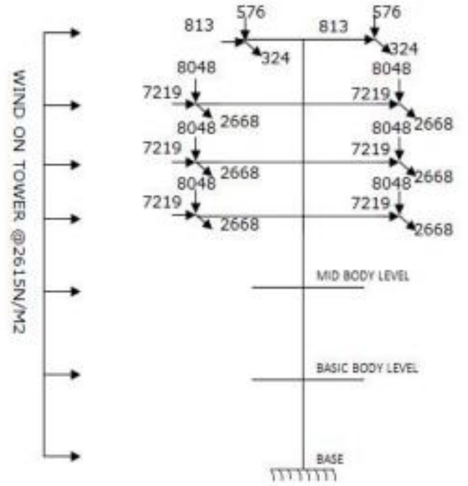
LOADING TREE

CLIENT:PGCB BANGLADESH
PROJECT:400KV DC TL
TOWER TYPE : 4DL

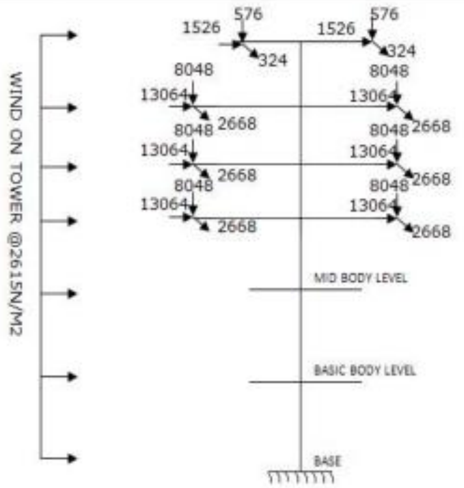
Note:= All loads are in kg



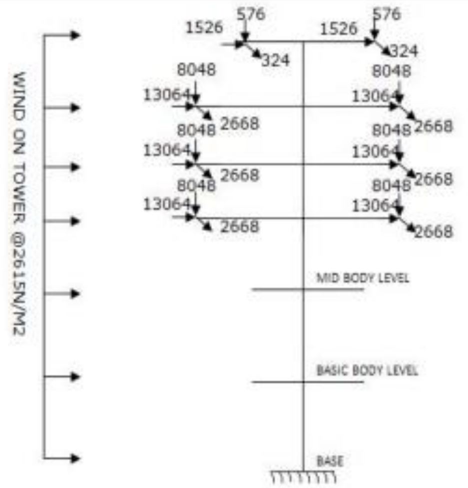
Load Case: 1 FOS : 1
EVERYDAY TEMP\FULL WIND\DIAG\NC\(NORMAL CONDITION)\Vmax\DS



Load Case: 2 FOS : 1
EVERYDAY TEMP\FULL WIND\DIAG\NC\(NORMAL CONDITION)\Vmax\DS



Load Case: 3 FOS : 1
EVERYDAY TEMP\FULL WIND\PERP\NC\(NORMAL CONDITION)\Vmax\DS



Load Case: 4 FOS : 1
EVERYDAY TEMP\MEAN WIND\PERP\NC\(NORMAL CONDITION)\Vmax\DS

4.4.4 Analysis of 4DL Tower

4.4.4.1 Innovation and Optimisation of 4DL Tower

The following innovation options were applied to the reference tower owing to that the significant reduction in tower base area and tower weight have been achieved successfully.

Table 4-31: Innovation and Optimisation of 4DL Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	x. Structural / tower Configuration xi. Alterations in tower Geometry - Modifications xii. Tower Slopes alterations	x. Modification in base width of tower, xi. Tower geometry, Leg member proposed straight. xii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	vii. Structural material improvements, viii. Material of tower & bolts and tower types	xiii. Use of different size Bolts, 16mm & 24mm xiv. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used. xv. Minimum Lattice/ redundant sections used. xvi. Redundant members designed for 1.5 % force of supported members.	As per the discussion held with PGCB on 25th July 2023. The orginal design criteria of PGCB has been used
Category C	v. Structural Analysis methodology	v. Slenderness ratio of redundant used upto its maximum limit.	
Category D	ix. Design criteria & design guideline adherence, x. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	v. Modifications in Electrical requirements	NA	
Category F	v. Latest in the Transmission line practices.	NA	

4.4.4.2 Tower Base Optimization

The base width of the original tower is 7.96 m and at +9 m level as per slope base width would be 10.664 m. It means land area required is 10.664 m x 10.664 m i.e. 113.72. Therefore, the area required when tower with +9 m extension is installed on ground is 113.72 m^2.

It was observed that after applying the innovative measures during analysis, the tower base width at +9 m level remains same as normal tower level i.e. 7.96 m, which means that the area required for tower with +9 m will be (7.96 x 7.96) 63.36 m^2.

Table 4-32: : Reduction in Tower base in 4DL Tower

Description	Original Tower	Innovated tower	Reduction
Tower Basewidth/ ROW-area	113.72m^2	63.36m^2	44.3%

The total weight of the 4DL tower post optimization works out to **30.2 tons which is about 17% more** than the original weight.

4.4.5 Civil Aspect of 4DL Tower

4.4.5.1 Foundation Design of 4DL Tower

Particulars	Parameters
TYPE OF FOUNDATION	**4DL**
SOIL CATEGORY	**3 (pile)**
Ultimate Factored Foundation Loads Calculation	
LOADS PER LEG ALONG LEG SLOPE	**REACTIONS FROM TOWER STRUCTURE (KG)**
ULTIMATE COMPRESSION LOAD FOR FOUNDATION	**427612**
ULTIMATE UPLIFT LOAD FOR FOUNDATION	**462369**
ULTIMATE SHEAR	
SHEAR HORIZONTAL TO LEG TRAN	**25827**
SHEAR HORIZONTAL TO LEG LONG	**30137**
PILE DETAILS	
DIA OF PILES	600MM
NUMBER OF PILES	9 NOS.
DEPTH OF PILES	18M
REINFORCEMENT	16 NOS. 25 DIA.
REINFORCEMENT LOWER SEGMENT (5m to Last Point)	8 NOS. 16 DIA
STIRRUPS	8 DIA 150MM C/C
PILE CAP DETAILS	
SIZE	4.5X4.5M (SQUARE SHAPE) - 20.25 SQM.
DEPTH OF PILECAP	0.9M
PILE CAP REINFORCEMENT	
BOTTOM LONGITUDINAL DIRECTION	16 DIA - 32 NOS.
BOTTOM TRANSVERSE DIRECTION	16 DIA - 32 NOS.
TOP LONGITUDINAL DIRECTION	16 DIA - 28 NOS.
TOP TRANSVERSE DIRECTION	16 DIA - 28 NOS.
CHIMNEY	
SIZE	600 X600MM
REINFORCEMENT	12 NOS. - 16MM DIA
STIRRUPS	10 DIA AT 150 C/C

4.5 INNOVATIVE ANALYSIS FOR SUSPENSION TOWER TYPE ST – 132 KV TWIN GROSBEAK TOWER

4.5.1 Input Data Required for Suspension ST Towers

For optimization of ST towers the input data required for the study were collected from PGCB, which is shown in table below:

Table 4-33: Input Data Required For ST Transmission Tower

SPECIFICATION FOR ST TOWER		
S. No.	**Description**	**Parameters**
1	**Voltage Class**	132 kV
2	**Configuration**	Vertical
3	**Number of Circuits**	2
4	**Configuration of Earthwire**	Single peak
5	**Conductor**	Twin ACSR Grosbeak
6	**EW parameters**	7x3.25 steel EW
7	**OPGW parameters**	7x3.25 steel EW equivalent OPGW
8	**Designation of Towers**	
	A Suspension Tower (angular deviation)	ST: 0^o - 1^o
9	**Extension Required**	Std: +6, +12
10	**Spans**	
	- Ruling/Average Span	330 m
	- Wind Span - NC	330 m
	- Wind Span - BWC	250 m
	- Weight Span (max) - NC	525 m
	- Weight Span (max) - BWC	395 m
	- Weight Span (min) - NC	140 m
	- Weight Span (min) - BWC	100 m
11	**Temperature Range**	
	- Minimum Temperature	5 ^oC
	- Everyday Temperature	35 ^oC
	- Maximum Temperature (Conductor)	80 ^oC
	- Maximum Temperature (OPGW)	50 ^oC

SPECIFICATION FOR ST TOWER		
S. No.	**Description**	**Parameters**
12	**Reference Wind Velocity**	62.5 m/sec (3s Gust)
13	**Minimum Ground Clearance**	7000 m
14	**Insulator String Details**	
	- Single/Double Suspension Length	1843 mm
	- Single/Double Suspension Weight	125 kg
	- Arcing Horn Length	1612 mm
15	**Minimum Electrical Clearance**	
	- Single/Double Suspension Insulator	
	0^{o}	1450 mm
	10^{o}	1450 mm
	45^{o}	900 mm
	Vertical Clearance	4000 mm
16	**Materials for Towers**	
	- Mild Steel	275 Mpa
	- High Tensile Steel	355 Mpa
	- Bolts & Nuts	ISO 898 Grade 5.6/5
17	**Minimum Thickness of Members**	
	- Tower Legs, Peak & Main Cross arms	6 mm
	- All Other Members	5 mm
	- All Redundant Members	4 mm
	- Gusset Plates	6 mm
	- Min. Section without bolt hole	40 mm
18	**Bolt Diameter**	
	- Galvanized Hexagonal head of connection	16 mm / 24 mm

SPECIFICATION FOR ST TOWER		
S. No.	**Description**	**Parameters**
19	**Overload Factor**	
	- For Normal Condition	1.25
	- For Broken Condition	1.25
20	**Base Width of Tower**	6.43 m

PROJECT NAME : 132KV D/C TWIN CONDUCTOR TL BANGLADESH

TOWER TYPE "ST"

CLIENT : PGCB, BANGLADESH

WIND PRESSURE ON CONDUCTOR

[AS PER ASCE MANUAL 74: 2009]

$F = \gamma_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$

wherein					
Wind Load Factor (γ_w) =	**1.0**	For Exposure Category **"C"** [Ref: Table 1-1]			
Newmerical Constant Figure (Q) =	**0.613**				
Basic Wind Speed (V_{50}) =	**62.5**	m/s	(3sec Gust speed)		
Velocity Pressure Exposure Coefficient (K_z) =	$2.01*(z_h/z_g)^{2/\alpha}$	{for $33 < z_g < z_h$}	(m)	(ft)	
=	**1.326**	Effective Height (z_h) =	**38.137**	125	Refer Table 2-1
		Gradient Height (z_g) =	-	**900**	
		Value of α =	**9.5**		
Topographic Factor (K_{zt}) =	**1.00**	{Due to absence of Topographical details}			
Gust Response Factor (G)					
Gust Response Factor for **Wires** (G_w) =	$(1+2.7*E*(B_w)^{0.5}/K_v^2$	κ = **0.005**	α_{FM} =	**7.0**	Refer Table 2-3
=	**0.659**		(m)	(ft)	
		Effective Height (z_h) =	**38.137**	125	
		Design Wind Span (S) =	**330**	1083	
		Turbulence Scale (L_s) =	-	**220**	
		Ratio of 3-sec gust to 10-min gust (K_v) =	**1.43**		
		$E = 4.9*\kappa^{0.5}*(33/z_h)^{1/\alpha FM}$ =	**0.286**		
		$B_w = 1/[1+0.8*(S/L_s)]$ =	**0.203**		
Force Coefficient (C_f) =	**1.00**				

FOR CONDUCTOR $F_c = \gamma_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$

=	**2093**	N/m^2	*A
=	**213**	Kg/m^2	*A

PROJECT NAME : 132KV D/C TWIN CONDUCTOR TL BANGLADESH

TOWER TYPE "ST"

CLIENT : PGCB, BANGLADESH

SAG TENSION CALCULATION FOR PHASE CONDUCTOR

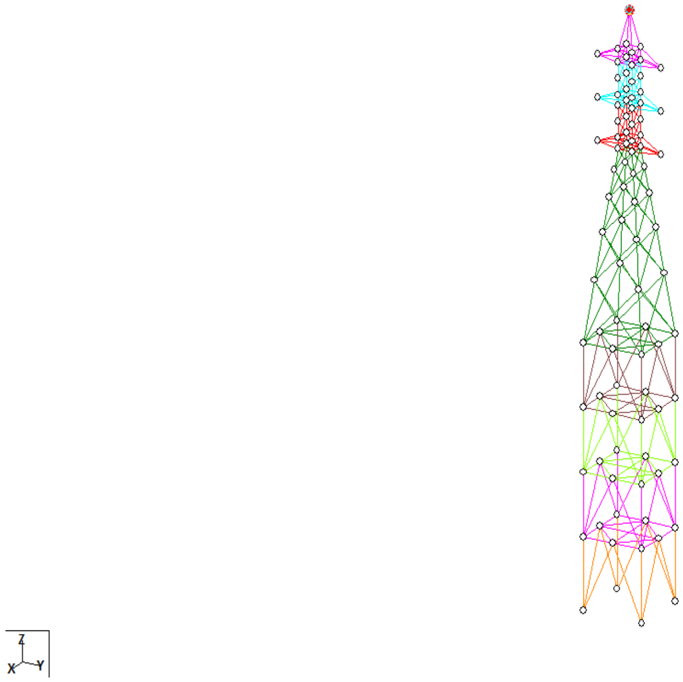
NAME OF THE CONDUCTOR	:	**GROSBEAK**	
AREA	:	**374.33**	**mm^2**
DIA	:	**25.15**	**mm**
WT OF CONDUCTOR	:	**1.300**	**Kg/m**
ULTIMATE TENSILE STRENGTH	:	**11401**	**Kg**
MODULUS OF ELASTICITY	:	**7700**	**Kg/mm^2**
MAX WORKING SPAN	:	**330**	**m**
MIN TEMPERATURE	:	**5**	**^0C**
EVERY DAY TEMPERATURE	:	**35**	**^0C**
MAX TEMPERATURE	:	**80**	**^0C**
COEFF OF LINEAR EXPANSION	:	**1.92E-05**	**$/^0C$**
INITIAL TEMP	:	**35**	**^0C**
INITIAL WIND PRESSURE	:	**0**	**Kg/m^2**
RADIAL ICE FORMATION	:	**0**	**mm**

	WIND PRESS (Kg/m^2)	TEMP DEG (^0C)	ICE FORMATION (mm)	SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INITIAL	0	35	0	7.761	609.12	2280	20.0	330
	0	5	0	6.539	723.00	2706	23.7	330
50%	107	5	0	-	1275.48	4775	41.9	330
100%	213	5	0	-	1936.77	7250	63.6	330
	13	35	0	7.812	624.01	2336	20.5	330
100%	213	35	0	-	1803.31	6750	59.2	330
	0	80	0	9.470	499.18	1869	16.4	330

WIND PRESSURE CALCULATION FOR CONDUCTOR :

Dynamic Reference Wind Pressure (q_{ho}) = 2093 N/m^2 = **213** Kg/m^2

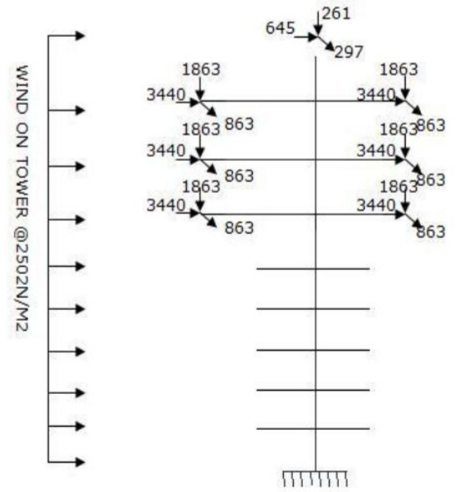
(refer wind pressure calculation sheet)


Z
X
Y

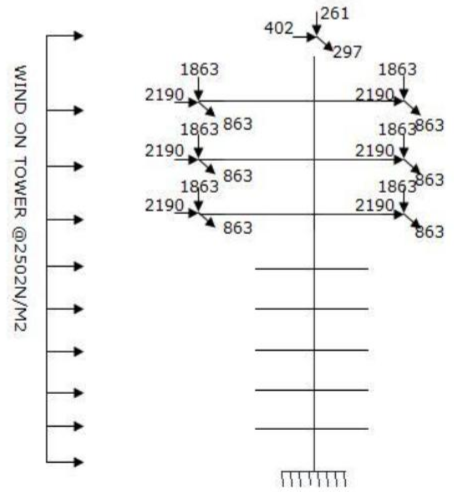
LOADING TREE

CLIENT:PGCB BANGLADESH
PROJECT:132KV TWIN GROSSBEAK TL
TOWER TYPE -ST

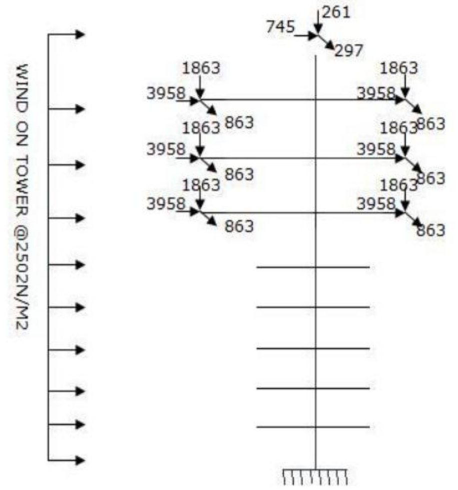
Note:= All loads are in kg



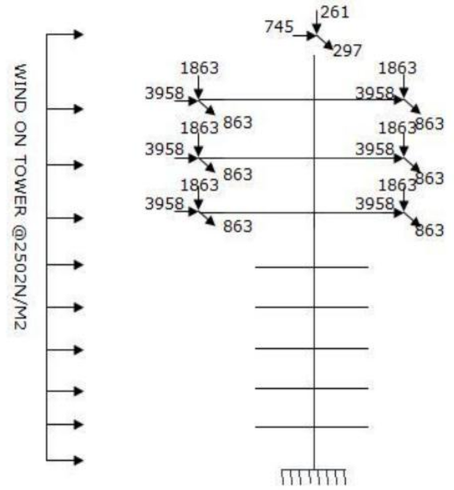
Load Case: 1 FOS : 1
EVERYDAY TEMP\FULL WIND\DIAG\NC\(NORMAL CONDITION)\Vmax\DS



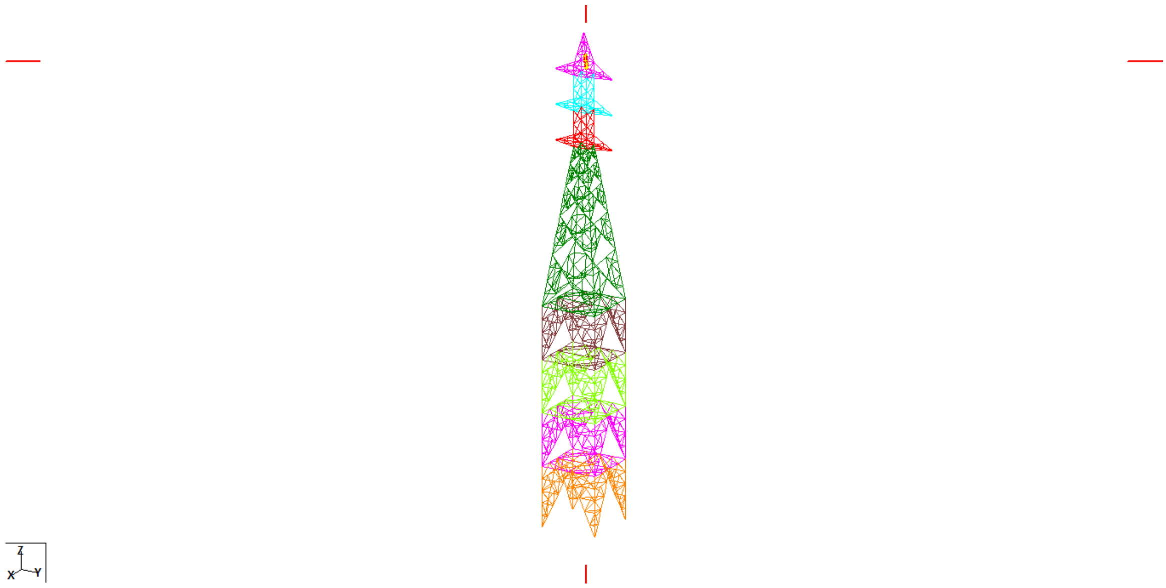
Load Case: 2 FOS : 1
EVERYDAY TEMP\FULL WIND\DIAG\NC\(NORMAL CONDITION)\Vmax\DS



Load Case: 3 FOS : 1
EVERYDAY TEMP\FULL WIND\PERP\NC\(NORMAL CONDITION)\Vmax\DS



Load Case: 4 FOS : 1
EVERYDAY TEMP\MEAN WIND\PERP\NC\(NORMAL CONDITION)\Vmax\DS



4.5.2 Analysis of 132 kV Twin Grosbeak 'ST' Tower

4.5.2.1 Innovation and Optimisation of ST Tower

The following innovation options were applied to the reference tower owing to that the significant reduction in tower base area and tower weight have been achieved successfully.

Table 4-34: Innovation and Optimisation of ST Tower

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration ii. Alterations in tower Geometry - Modifications iii. Tower Slopes alterations	i. Modification in base width of tower, ii. Tower geometry, Leg member proposed straight. iii. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements, ii. Material of tower & bolts and tower types	i. Use of different size Bolts, 16mm & 24mm ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used. iii. Minimum Lattice/ redundant sections used. iv. Redundant members designed for 1.5 % force of supported members.	As per the discussion held with PGCB on 25th July 2023. The original design criteria of PGCB has been used
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence, ii. Tower design data / Loadings	No Change, as per Bangladesh design code	
Category E	i. Modifications in Electrical requirements	NA	
Category F	ii. Latest in the Transmission line practices.	NA	

4.5.2.2 Tower Base Optimization

The base width of the basic tower is 6.43m and at 18.85m level as per slope base width would be 13.23 m. It means land area required is 13.23 m x 13.23 m i.e. 175.03m^2. Therefore, the area required when tower with +12 m body extension & 6.85m Leg extension is installed on ground is 175.03 m^2.

It was observed that after applying the innovative measures during analysis, the tower base width at 12 m body extension & 6.85m Leg extension m level remains same as basic tower level i.e. 6.43 m, which means that the area required for tower with 12 m body extension & 6.85m Leg extension m will be (6.43 x 6.43) 41.34 m^2.

Table 4-35: : Reduction in Tower base in ST Tower

Description	Original Tower	Innovated tower	Reduction
Tower Basewidth/ ROW-area	175.03m^2	41.34m^2	76%

4.5.3 Civil Aspect of 132 kV ST Tower

4.5.3.1 Foundation Design of ST Tower

Particulars	Parameters
TYPE OF FOUNDATION	**132kV Twin_ST**
SOIL CATEGORY	**3 (pile)**
Ultimate Factored Foundation Loads Calculation	-
LOADS PER LEG ALONG LEG SLOPE	**REACTIONS FROM TOWER STRUCTURE (KG)**
ULTIMATE COMPRESSION LOAD FOR FOUNDATION	**188473**
ULTIMATE UPLIFT LOAD FOR FOUNDATION	**201407**
ULTIMATE SHEAR	
SHEAR HORIZONTAL TO LEG TRAN	**16097**
SHEAR HORIZONTAL TO LEG LONG	**11328**
PILE DETAILS	
DIA OF PILES	600MM
NUMBER OF PILES	4 NOS.
DEPTH OF PILES	18M
REINFORCEMENT	16 NOS. 25 DIA.
REINFORCEMENT LOWER SEGMENT (5m to Last Point)	8 NOS. 16 DIA
STIRRUPS	8 DIA 150MM C/C
PILE CAP DETAILS	
SIZE	2.7X2.7M (SQUARE SHAPE) - 20.25 SQM.
DEPTH OF PILECAP	0.8M
PILE CAP REINFORCEMENT	
BOTTOM LONGITUDINAL DIRECTION	16 DIA - 17 NOS.
BOTTOM TRANSVERSE DIRECTION	16 DIA - 17 NOS.

Particulars	Parameters
TOP LONGITUDINAL DIRECTION	16 DIA - 15 NOS.
TOP TRANSVERSE DIRECTION	16 DIA - 15 NOS.
CHIMNEY	
SIZE	600 X600MM
REINFORCEMENT	12 NOS. - 16MM DIA
STIRRUPS	10 DIA AT 150 C/C

4.6 INNOVATIVE ANALYSIS FOR SUSPENSION TOWER TYPE 2QL – 230 KV MULTI-CIRCUIT TOWER WITHOUT CHANGING BASE WIDTH WITH 80M/SEC WIND

4.6.1 Input Data Required for Suspension 2QL Towers

For optimization of 2QL towers the input data required for the study were collected from PGCB, which is shown in table below:

Table 4-36: Input Data Required For 2QL Transmission Tower

S. No.	Description	Parameters
1	**Voltage Class**	230 kV
2	**Configuration**	Vertical
3	**Number of Circuits**	4
4	**Configuration of Earthwire**	Double peak
5	**Conductor**	Twin ACSR Mallard
6	**EW parameters**	7x4.0 steel EW
7	**OPGW parameters**	7x4.0 steel EW equivalent OPGW
8	**Designation of Towers**	2QL
	- Suspension Tower Type	2QL: 0^{o} - 1^{o}
9	**Extension Required**	Std: 1.5,3,4.5,6,9
10	**Spans**	
	- Ruling/Average Span	375 m
	- Wind Span - NC	375 m
	- Wind Span - BWC	275 m

S. No.	Description	Parameters
	- Weight Span (max) - NC	510 m
	- Weight Span (max) - BWC	385 m
	- Weight Span (min) - NC	180 m
	- Weight Span (min) - BWC	130 m
11	**Temperature Range**	
	- Minimum Temperature	5 ^{o}C
	- Everyday Temperature	35 ^{o}C
	- Maximum Temperature (Conductor)	80 ^{o}C
	- Maximum Temperature (OPGW)	50 ^{o}C
12	**Reference Wind Velocity**	80 m/sec (3s Gust)
13	**Minimum Ground Clearance**	8000 m
14	**Insulator String Details**	
	- Single/Double Suspension Length	3000 mm
	- Single/Double Suspension Weight	250 kg
15	**Minimum Electrical Clearance**	
	- Single/Double Suspension Insulator	
	0^{o}	2300 mm
	10^{o}	2300 mm
	45^{o}	1630 mm
	Vertical Clearance	6000 mm
16	**Materials for Towers**	
	- Mild Steel	275 Mpa
	- High Tensile Steel	355 Mpa
	- Bolts & Nuts	ISO 898 Grade 5.6/5
17	**Minimum Thickness of Members**	

S. No.	Description	Parameters
	- Tower Legs, Peak & Main Cross arms	6 mm
	- All Other Members	5 mm
	- All Redundant Members	4 mm
	- Gusset Plates	6 mm
	- Min. Section without bolt hole	40 mm
18	**Bolt Diameter**	
	- Galvanized Hexagonal head of connection	16 mm / 24 mm
19	**Overload Factor**	
	- For Normal Condition	1.25
	- For Broken Condition	1.25
20	**Base Width of Tower**	7.0 m

PROJECT : 230 KV M/C TRANSMISSION LINE

TOWER - 2QL

CLIENT : PGCB, BANGLADESH

WIND PRESSURE ON CONDUCTOR

[AS PER ASCE MANUAL 74: 2009]

$$F = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$$

wherein

Wind Load Factor (g_w) =	**1.0**	For Exposure Category **"C"** [Ref: Table 1-1]			
Newmerical Constant Figure (Q) =	**0.613**				
Basic Wind Speed (V_{50}) =	**80**	m/s	(3sec Gust speed)		
Velocity Pressure Exposure Coefficient (K_z) =	$2.01*(z_h/z_g)^{2/a}$	{for $33 < z_g < z_h$}	(m)	(ft)	
=	**1.395**	Effective Height (z_h) =	**48.4**	159	Refer Table 2-1
		Gradient Height (z_g) =	-	**900**	
		Value of a =	**9.5**		
Topographic Factor (K_{zt}) =	**1.00**	{Due to absence of Topographical details}			
Gust Response Factor (G)					
Gust Response Factor for **Wires** (G_w) =	$(1+2.7*E*(B_w)^{0.5}/K_v^2$	k = **0.005**	a_{FM} =	**7.0**	Refer Table 2-3
=	**0.645**		(m)	(ft)	
		Effective Height (z_h) =	**48.4**	159	
		Design Wind Span (S) =	**375**	1230	
		Turbulence Scale (L_s) =	-	**220**	
		Ratio of 3-sec gust to 10-min gust (K_v) =	**1.43**		
		$E = 4.9*k^{0.5}*(33/z_h)^{1/aFM}$ =	**0.277**		
		$B_w = 1/[1+0.8*(S/L_s)]$ =	**0.183**		
Force Coefficient (C_f) =	**1.00**				

FOR CONDUCTOR $F_c = g_w * Q * K_z * K_{zt} * V_{50}^2 * G * C_f * A$

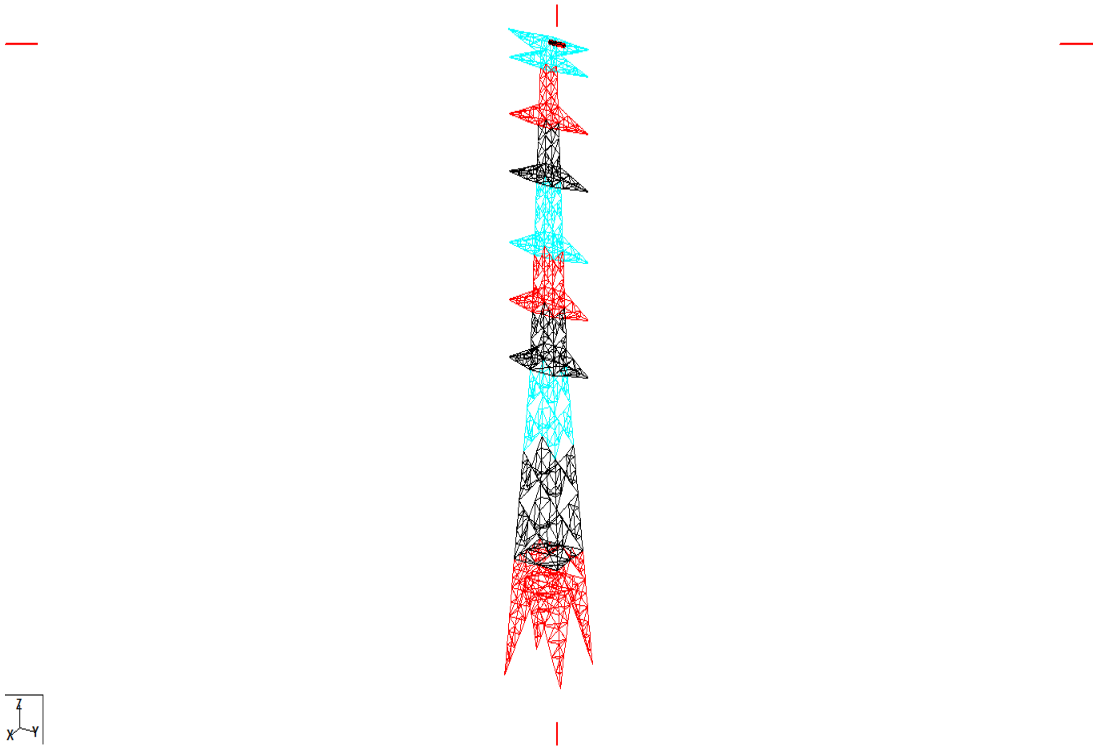
=	**3533**	N/m^2	*A
=	**360**	Kg/m^2	*A

PROJECT : 230 KV M/C TRANSMISSION LINE		
TOWER - 2QL		
CLIENT : PGCB, BANGLADESH		
SAG TENSION CALCULATION FOR PHASE CONDUCTOR		
NAME OF THE CONDUCTOR	:	ACSR MALLARD	
AREA	:	495.62	mm^2
DIA	:	28.95	mm
WT OF CONDUCTOR	:	1.9390	Kg/m
ULTIMATE TENSILE STRENGTH	:	17458	Kg
MODULUS OF ELASTICITY	:	8000	Kg/mm^2
MAX WORKING SPAN	:	375	m
MIN TEMPERATURE	:	5	^0C
EVERY DAY TEMPERATURE	:	35	^0C
MAX TEMPERATURE	:	80	^0C
COEFF OF LINEAR EXPANSION	:	1.79E-05	$/^0C$
INITIAL TEMP	:	5	^0C
INITIAL WIND PRESSURE	:	360	Kg/m^2
RADIAL ICE FORMATION	:	0	mm

	WIND PRESS (Kg/m^2)	TEMP DEG (^0C)	ICE FORMATION (mm)	SAG (m)	STRESS (Kg/cm^2)	TENSION (Kg)	F.O.S	SPAN (m)
INITIAL	360	5	0	17.802	2113.47	10475	60.0	375
	0	5	0	14.456	475.73	2358	13.5	375
50%	180	5	0	-	1227.29	6083	34.8	375
100%	360	5	0	-	2113.47	10475	60.0	375
	0	35	0	15.345	448.16	2221	12.7	375
	14	35	0	15.365	457.26	2266	13.0	375
100%	360	35	0	-	2039.41	10108	57.9	375
	0	80	0	16.604	414.17	2053	11.8	375

Wind pressure calculation for CONDUCTOR :

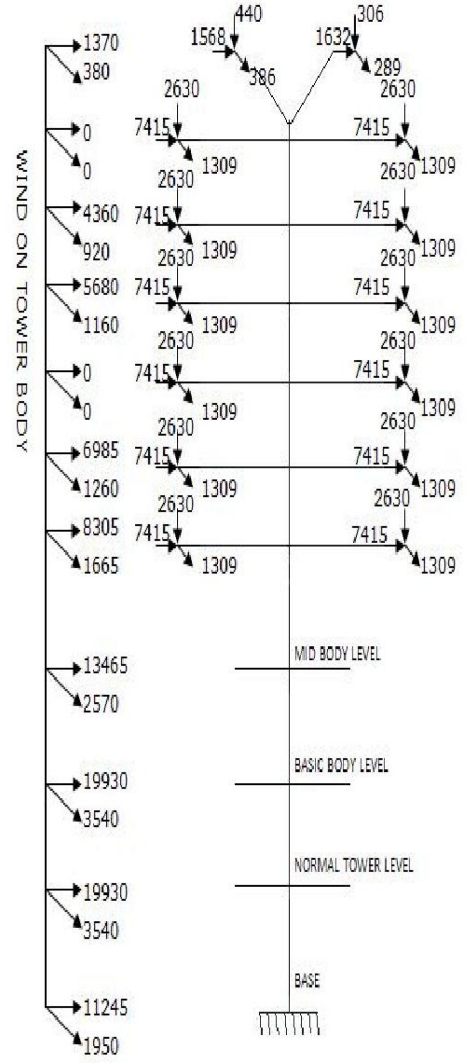
Dynamic Reference Wind Pressure (q_{ho})	=	3533	N/m^2 =	360	Kg/m^2
		(refer wind pressure calculation sheet)			


Z
X
Y

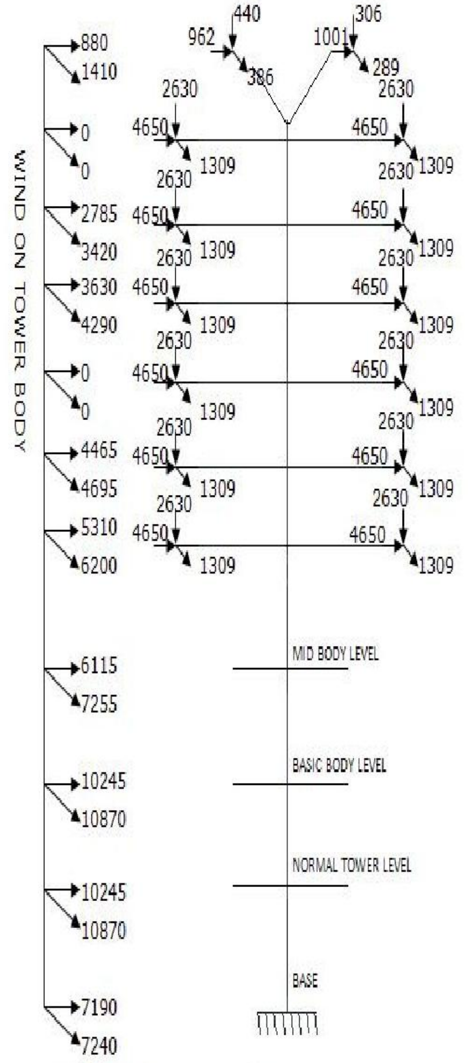
LOADING TREE

CLIENT:PGCB BANGLADESH
PROJECT:230KV MC TRANSMISSION LINE
TOWER TYPE : 2QL

Note:= All loads are in kg



Load Case: 1 FOS : 1
EVERYDAY TEMP\FULL WIND\DIAG\NC\(NORMAL CONDITION)\Vmax\DS



Load Case: 2 FOS : 1
EVERYDAY TEMP\FULL WIND\DIAG\NC\(NORMAL CONDITION)\Vmax\DS

Table 4-37: Optimization Options for 2QL Tower (80m/sec)

Category	Domain of modification	Preferred innovation options	Remarks
Category A	i. Structural / tower Configuration	i. Modification in base width of tower, ii. Tower geometry, Leg member proposed straight. iii. Modification in cross arms, Cross arm length modified as per swing angle.	The 2QL tower configuration has not been modified but the tower has been analysed with wind speed of 80m/sec
	ii.. Tower Slopes alterations	ii.. Modification in cross arms, Cross arm length modified as per swing angle.	
Category B	i. Structural material improvements,	i. Use of different size Bolts, 16mm & 24mm	As per the discussion held with PGCB on 25th July 2023. The orginal design criteria of PGCB has been used
	ii. Material of tower & bolts and tower types	ii. Minimum plate thickness: 6mm, Minimum Lattice thickness: 5mm are used.	
		iii. Minimum Lattice/ redundant sections used.	
		iv. Redundant members designed for 1.5 % force of supported members.	
Category C	i. Structural Analysis methodology	i. Slenderness ratio of redundant used upto its maximum limit.	
Category D	i. Design criteria & design guideline adherence,	No Change, as per Bangladesh design code	As per PGCB design criteria.
	ii. Tower design data / Loadings		
Category E	i. Modifications in Electrical requirements	NA	
Category F	i. Latest in the Transmission line practices.	NA	

The total weight of the 2QL tower (normal) post optimization works 42.4 MT

The optimisation techniques were also applied to 2QL tower with wind speed of 80m/sec and the outcome of the optimization was successful. On analysis of this tower it was noticed that the tower structure is stable with enhanced wind speed under the optimised condition. Hence the original 2QL tower appears to be stable & optimised at 80m/sec.

4.6.2 Civil Aspect of 2QL Tower

4.6.2.1 Foundation Design of 2QL Tower

Particulars	Parameters
TYPE OF FOUNDATION	**2QL**
SOIL CATEGORY	
Ultimate Factored Foundation Loads Calculation	
LOADS PER LEG ALONG LEG SLOPE	**REACTIONS FROM TOWER STRUCTURE (KG)**
ULTIMATE COMPRESSION LOAD FOR FOUNDATION	**518823**
ULTIMATE UPLIFT LOAD FOR FOUNDATION	**481940**
ULTIMATE SHEAR	

Particulars	Parameters
SHEAR HORIZONTAL TO LEG TRAN	**17049**
SHEAR HORIZONTAL TO LEG LONG	**9153**
PILE DETAILS	
DIA OF PILES	600MM
NUMBER OF PILES	9 NOS.
DEPTH OF PILES	16M
REINFORCEMENT	16 NOS. 25 DIA.
REINFORCEMENT LOWER SEGMENT (5m to Last Point)	8 NOS. 16 DIA
STIRRUPS	8 DIA 150MM C/C
PILE CAP DETAILS	
SIZE	4.5X4.5M (SQUARE SHAPE) - 20.25 SQM.
DEPTH OF PILECAP	0.9M
PILE CAP REINFORCEMENT	
BOTTOM LONGITUDINAL DIRECTION	16 DIA - 32 NOS.
BOTTOM TRANSVERSE DIRECTION	16 DIA - 32 NOS.
TOP LONGITUDINAL DIRECTION	16 DIA - 28 NOS.
TOP TRANSVERSE DIRECTION	16 DIA - 28 NOS.
CHIMNEY	
SIZE	600 X600MM
REINFORCEMENT	12 NOS. - 16MM DIA
STIRRUPS	10 DIA AT 150 C/C

4.7 765 KV DOUBLE CIRCUIT TRANSMISSION SYSTEM & TOWER -DA

Transmission line of 765 kV offers a number of technological and operational advantages for expansion of the nation’s energy grid system. It has got some of the major benefits as far as line loading capabilities are concerned. Major advantages are as under:

i. A single-circuit 765-kV line can carry as much power as three single-circuit 500-kV lines, three double-circuit 345-kV lines, or six single-circuit 345-kV lines, reducing the overall number of lines and rights of way required to deliver equivalent capacity.

ii. The high capacity of 765-kV technology can easily facilitate the efficient, economical integration of large-scale generation projects into the nation’s transmission grid.

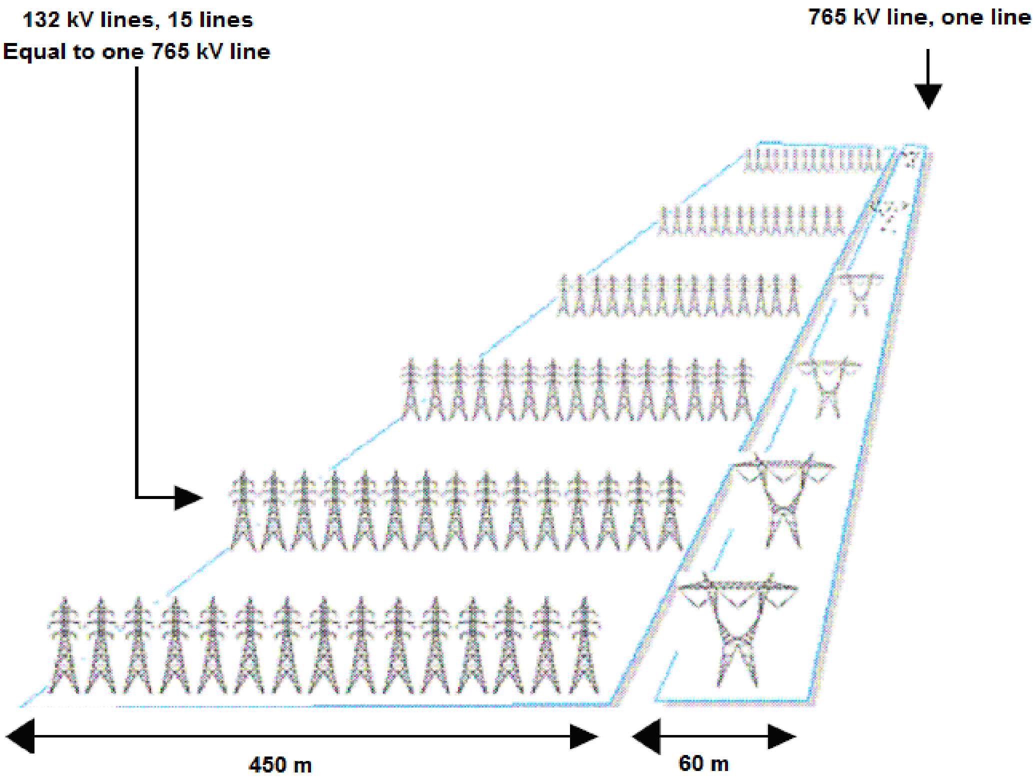


Figure 4-5: : Comparison of 132 kV and 765 kV line

iii. 765-kV projects use a typical right-of-way width of 80 meters. Standard industry right-of-way width for 500-kV is also 60 meters, and 36 M for 220-kV construction. For equivalent power carrying capability, lower voltages require more lines and as a result more right-of-way impact.

iv. Typical 765-kV lines have a tower height of approximately 45meters, This is 12-15 meters shorter than a typical 400-kV M/C tower.

4.7.1 Performance and Design Efficiency

i. Power losses in a transmission line decrease as voltage increases. Since 765-kV lines use the highest voltage available in the many countries including India, they experience the least amount of line loss.

ii. The greater transmission efficiency of 765-kV can be attributed mainly to its higher operating voltage (and thus lower current flow), and larger thermal capacity/low resistance compared to lower voltage lines. This allows 765-kV lines to carry power over significantly longer distances than lower voltages.

iii. With up to six conductors per phase, 765-kV lines are virtually free of thermal overload risk, even under severe operating conditions.

iv. By shifting bulk power transfers from the underlying lower-voltage transmission system to the higher-capacity 765-kV system, overall system losses are reduced significantly.

v. New 765-kV designs have line losses of less than one percent, compared to losses as high as 9 percent on some existing lines.
vi. The overlay of a 765-kV system allows for both scheduled and unscheduled outages of parallel lower voltage lines without risk of thermal overloads or increased congestion.
vii. Use of 765-kV technology allows transmission utilities to take advantage of economies of scale. A 765-kV transmission line provides the same capacity as three 400-kV lines or eight 220-kV lines.
viii. Utilizing 765-kV results in a substantial reduction in system losses. For instance, a loss reduction of 250 megawatts, equates to saving as much as 200,000 tons of coal, and 500,000 tons of CO2 emissions on an annual basis.
ix. The addition of 765-kV systems relieves the stress on underlying, lower voltage transmission systems, postponing the potential need for upgrades of these networks.
x. The advanced transmission system has major benefits for users because of enhanced reliability.

The application of 765 KV is very specific & the design objective is very clear. The 765 KV lines may face huge challenges during construction in particular within urban areas due to height of towers, erection challenges and availability of ROW. Generally the 765 KV transmission network is planned in such a way that it does not interfere with urban setup. These lines act as interconnecting / power evacuation lines from power generating plants to main power pooling stations.

A typical 765 KV Design data sheet & design parameters / analysis report based on Indian Standards / Indian design code is presented below.

Table 4-38: Data Sheet for 765 KV Tower

765KV D/C TRANSMISSION TOWER -DA							
1	Voltage Class	:	765KV				
2	Configuration	:	Conductors in Vertical Formation				
3	Number of Circuits	:	2				
4	Number of Sub-Conductors	:	6				
5	Configuration of Earth wire	:	At the top of the Structure : 2 nos of Earthwires 1 GSW + 1 OPGW (Equivalent TO GSW)				
6	Conductor	:	AL 59				
7	Earth wire	:	GSW 7/3.66 + OPGW				
8	Classification of Towers						
	Suspension Tower Type “DA”	:	0^0 - 2^0deviation				
9	Spans						
	Normal Ruling Span	:	400	m			
	Wind Span for all Towers	:	400	m			
	Weight Spans (m)	:	NC		BWC		
			MAX	MIN	MAX	MIN	
	“DA”	:	600	320	360	192	
10	Temperature Range						
	Minimum Temperature	:	0^0C				
	Maximum Temperature	:	53^0C [For Earthwire]				
		:	85^0C [For Conductor]				
11	Wind Pressure						
	Wind Zone / (Wind Speed)	:	3 /(44 m/s)				
	Reliability Level	:	2				
	Terrain Category	:	2		[As per Table 4, IS 802 (Part 1/Sec 1)]		
	Design Wind Pressure	:	757 N/m^2				
12	Insulator Strings						
	Suspension Insulator Strings:	:					
			Discs	Dia of Disc	Ins. Length	Dist of Coror	Weight
			(nos)	(mm)	(mm)	(mm)	(Kg)
	Suspension Insulator "I":		2x35	255	7600	6100	750
13	Minimum Electrical Clearances						
	(i) Double Suspension Insulator						
	"I" string	:	0^0 -	6100	mm		
			27^0 -	4400	mm		
			55^0 -	1300	mm		
(ii)	Vertical Phase to Phase spacing	:	15,000	mm			
(iii)	Horizontal Phase spacing	:	15,000	mm			
(iv)	Minimum Ground Clearance	:	15,000	mm			
14	Earth wire Clearances						
	(i) Mid span clearance between Earthwire and Conductor	;	9000 mm				

	(ii) Angle of Protection	:	10^0
	(iii) Earth wire Sag	:	Earth wire or OPGW sag at minimum Temp. no Wind shall be 90% of conductor sag at same condition.
15	Tension Limits for Conductor & Earth wire	:	(a) At every day Temp. no wind final unloaded tension should not exceed 22% of UTS of cond. & 20% of UTS of E/W. (b) At every day Temp. 100% design wind pressure or at minimum temp. 36% design wind pressure ultimate tension should not exceed 70% of UTS.
16	Loadings on Tower	:	As per IS 802 (Part1/Sec1) 1995 with ammendment that for BWC of Suspension tower 75% wind shall be considered instead of nil wind
17	Broken Wire Conditions	:	Suspension Tower: Any one phase conductor or Earthwire
18	Design Details	:	Towers to be designed as per provisions of as per IS 802 (Part1 / Sec2) 1992
19	Materials for towers		
	Mild Steel	:	IS 2062: 2000 - E250
	High Tensile Steel	:	IS 2062: 2000 - E350
	Bolts	:	IS 12427 Gr: 5.6
	Nuts	:	IS 1367 (Part 6) Property Class 5
20	Effective Slenderness Ratio (Kl/r)		
	a) Leg Members, Ground Wire Peak and Cross arm chord members		120
	b) Bracing and other members		200
	c) Redundant Members		250
	d) Tension - only members		400
21	Minimum Thickness of Members		
	a) Main Tower Legs		6 mm
	b) Other Members		4 mm
	c) Stubs and Gusset Plates		6 mm

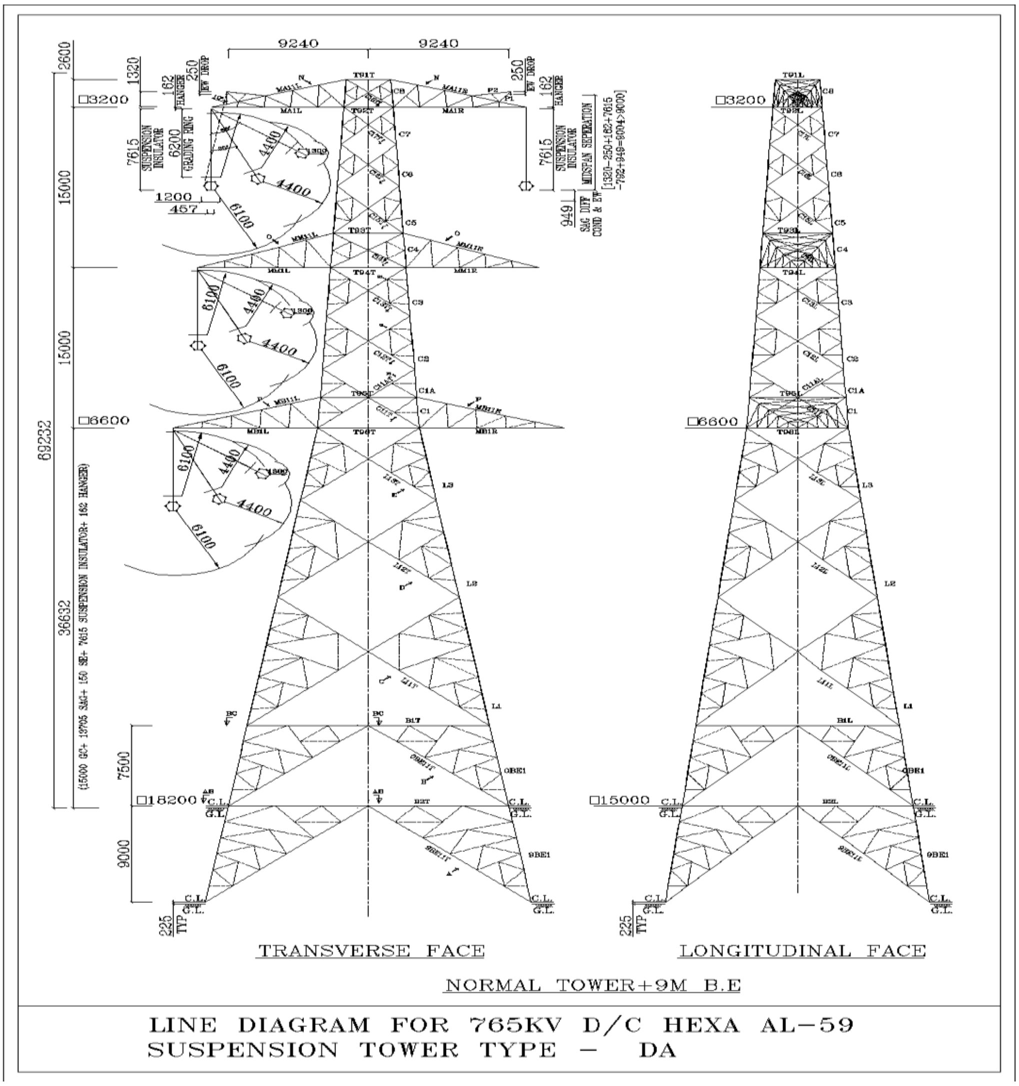


Figure 4-6: : Tower Out Line Drawing 765 KV (Typical) - Based on Indian Standards & design code.

5.0 LEGAL ASPECTS OF TRANSMISSION LINE

LEGAL ASPECTS OF TRANSMISSION LINE

5.1 APPLICABLE LAWS

As per our Understanding Power Grid Company of Bangladesh intends to erect Towers and transmit power lines for power supply. Hence, the below-mentioned legislations are relevant to their operation:

- The Electricity Act 2018
- The Electricity Rules 2020
- S.R.O No. 34/2022

5.2 DISCUSSIONS

5.2.1 Issues Relating to the Acquisition/Lease

Although there is a practice of misinterpreting the Section 14 of the Electricity Act 2018 ("Act") relating to the acquisition, the operation of tower erection and line transmission of Power Grid Company Limited ("Licensee/PGCB") will not fall under the extent of Section 14. This section is only applicable to the acquisition of land for the establishment of a power generation plant or substation. However, it is presumed that PGCB's operation of Tower erection does not require any acquisition or lease of the land but rather uses a portion of land by exercising the Right of Way over the land (which is discussed later) under Section 13 of the Act, with appropriate compensation as prescribed by Law.

5.2.2 Issues Relating to the Right of Way

During the development of the Transmission Line, PGCB will be able to exercise the Right of Way over the land. As per section 13 of the Electricity Act 2018, the licensee shall reserve the right of way over the land and the space above or underground thereof for the purpose of laying power supply lines or doing civil works under this Act. Provided that the licensee shall inform the land owner in writing before laying of power supply lines and doing civil works within a reasonable time. Hence the Licensee shall have the right to use the above and underground as well. However, this Right of way has some restrictions & requirements as well, such as:

5.2.2.1 Right of way accrues after obtaining permission

The Licensee is able to exercise the Right of Way only after getting permission to conduct civil works. If any licensee is permitted to lay power supply lines within the area of supply or, subject to the terms of his license, beyond the area of supply, the licensee may, as soon as may be, do necessary civil works, with intimation to the concerned person or the local authority, as the case may be, for supplying electricity to that area. Moreover, in case of doing civil works on, below, along or across the road or any part thereof, railway, canal or waterway or underground, the licensee shall have to give written notice to the person concerned or the local authority.

On receiving the above-mentioned notice the person or local authority, if aggrieved, may prefer an appeal to the Government, and the licensee may do civil works after the disposal of such appeal. However, in case of emergency requirements, the Licensee lay power supply lines without issuing notice. if any power supply line or civil works creates any obstacle to the proper execution of the legitimate authority of any person, the licensee may shift the site or power supply line or civil works [Section 6 of the Electricity Act 2018].

5.2.2.2 Restricted Areas

Educational Institutions, Religious places, huts, and densely populated areas shall primarily be avoided for the construction of towers except in the case of necessity [Rule 10 (4) of the Electricity Rules 2020]

5.2.2.3 Installation of Aerial Line

Subject to the prior approval of the government, the licensee may set up aerial lines alongside or across any road, railway, canal or waterway installing Aerial Line (Section 11 of the Act). The Licensee is required to file an Application to the Government stating the manner of installation of the Aerial Line [Rule 8(1)] and can proceed after obtaining permission from the Government.

5.2.2.4 Responsibility of Damage of Public Property

If any road, railway, underground drain, sewer or tunnel is damaged in a consequence of civil works, the part excavated shall have to be filled up by the soil, the part damaged shall have to be repaired and the garbage shall have to be removed immediately after such works so that the mass people do not have to face any accident, risk or disturbance [Rule 9]

Thus, subject to some restriction the Licensee can peacefully exercise its right of way during the usage of land for civil works. Although no such provision in law prevailed to restrain conducting Agricultural or any economic activities under the Tower area fully, some restrictions compel these economic or agricultural activities to remain limited. In this regard, the Licensee enjoys some power & benefits over the land which enables him to conduct civil work uninterruptedly, such as:

<u>Power of Removing Trees, Structure etc</u>

Structure below Aerial Line

If any trees, construction, or any structure is established near the Aerial Line which can interrupt Electricity Transmission or cause disturbance or create obstacles to the transmission or civil works, such structures, and trees shall be removed for the smooth operation of the civil work [Rule 8(6)]. However, the aggrieved party for such removal of the construction, structure, and trees can file an objection before the Deputy Commissioner or his authorized representative. If the Deputy Commissioner finds this civil works for the betterment of the Public Interest, he will still allow the License to remove such trees, construction and Structure, irrespective of the objection of the Aggrieved Party [Rule 8 (8)]. However, the Deputy Commissioner can order the Licensee to pay appropriate compensation to the Aggrieved Party.

Usage of the land below the Tower

The Landowner can utilize the land below the Tower after the completion of such civil work without causing any harm or interruption of the Electric Transmission and the tower. However if the Licensee assumed that the usage of the land may cause harm or threat to such transmission, he can restrain the Landowner to use the Land below the Tower [Rule 10(6)].

Right to remove Dangerous Trees

Right of Way is also discussed under Section 02D of the Safety Manual of the Power Grid Company of Bangladesh dated 01/07/06. In this section, Licensee is permitted to invoke the Right of Way in such a manner that may be necessary for the operation and maintenance of the lines (Transmission). As per Section 2E of the Manual, the definition of the Dangerous Tress has been given. In approximately level terrain trees which would reach within 5 ft (1.524m) of a point underneath the outside conductor are examples of dangerous trees. As directed by the Engineer portions of the right of way must be cut so that stamps will not prevent the passage of tractors and trucks along the right of way. A Prior Permission must first be secured.

From the above discussion, it is found that Agricultural works or economic activities are permitted with certain restrictions. However, nothing is clearly stipulated regarding the habitation under Tower. However, Rule 10(6) of the Rules provides that the Land Owner can use the land without affecting or damaging the electric transmission and tower. Whether this “Use” include habitats or not, is still a grey area, this issue is not clear yet. Since City life is densely populated and habitation is one of the major concerns in the city areas, therefore we assume specific guidelines regarding the habitation under Tower is needed to be framed.

5.2.3 Issues Relating to the Compensation

5.2.3.1 Compensation

Previously Section 12 of the Electricity Act 2018 was the only provision that provided Compensation only for the harm, damages or inconvenience caused in respect of doing Civil works, such compensation is to be paid to the affected person or the owner of the land for such usage. This Section was used to be a Generic Clause applicable to all types of Properties and the scale of Compensation was not fixed. Later on, Rule 10 of the Electricity Act 2020 was enacted where a detailed dictation is given on the amount of Compensation for every aspect. After that, the amount of Compensation is further clarified through the S.R.O No. 34/2022 published by the

Ministry of Power Energy and Mineral Resources which amended Rule 10(4) of the Electricity Rules 2020.

As per Rule 10(1) of the Rules, Licensee is under obligation to minimize the loss of any Movable and Immovable property as possible and is bound to compensate for such loss as occurred thereof. Hence, The Electricity Act and Rules divided the nature of the Compensation as follows:

- Compensation for Damages, Harm or Inconvenience to Movable Property [Section 12 of the Electricity Act 2018 read with Rule 10(1) & 10 (2)]
- Compensation for the usage of the Land (Section 12 of the Act read with Rule 10 (4) of the Electricity Rules, 2020)

Compensation for Damages, Harm or Inconvenience for Movable Property

Section 12 of the Electricity Act 2018, clearly stipulates that the Licensee is bound to pay Compensation for the tower erection to the Person affected or the owner of the land affected for damage, harm or inconvenience caused while doing civil works in such manner as maybe prescribed by rules. As per Rule 10 (2) of the Rules, if any damage to the Movable Property (e.g. Crops, grass, standing timber etc.) of anyone occurs, PGCB has to pay compensation to the affected person at the rate of the Market Price of the movable property. So, if Section 12 of the Act and Rule 10(2) are read together, it is found that the Licensee shall pay compensation at the rate of the Market value of such Movable Property to the Affected Person for the loss or damage or inconvenience of the Movable property (e.g. Crops, grass, fruits, standing timber etc) that occurred during the continuance of the Civil Work. ***Hence, any damage to Movable property caused during the continuance of civil works is liable to be compensated, not during the operation & maintenance.***

For measuring the amount of Compensation for this loss and damages under Section 12 of the Electricity Act 2018, Rule 10(3) of the Electricity Rules, 2020, will be applicable. In this regard, the Licensee shall collect reports from the following ministries and pay compensation as per their report:

- The Ministry of Housing & Public Works for the constructional loss,
- The Ministry of Agriculture for the damage to Crops
- The Ministry of Environment, Forest and Climate Change for the loss of Trees

Compensation for the Usage of Land

Section 12 stipulates the requirement of compensating the Land Owner for the Usage of Land as fixed by the Rule. Hence, Rule 10(4) of the Rules is a new provision that is introduced for ensuring Compensation for the Usage of Land. The Compensation under Rule 10 (4) is required to be paid against the use of the land to the Landowner. As per Rule 10(4) of the Electricity Rules, 2020 (as amended by S.R.O No. 34-Ain/2022 published by the Ministry of Power Energy and Mineral Resources), the Licensee has to pay compensation of @100% of the Market value of the property.

In this regard, the Sub-Registrar Office will help the Licensee know the land's Market value, and the Licensee is required to pay the full Compensation to the Deputy Commissioner. After receiving the amount of Compensation, the Deputy Commissioner will open an account and deposit the compensation money in the said Account. The Licensee can start his Operation as soon as the account is opened. The operation of the Licensee cannot be disturbed & interrupted even if any dispute or claim arises relating to the amount of the Compensation or the amount of it. Such dispute is required to be resolved through Section 53 of the Electricity Act without affecting the operation of the Licensee. As per Section 53 of the Electricity Act 2018, the dispute shall be resolved as per the Commission Act.

5.2.4 Issues Relating to the Optimisation of the Tower Footing

As per our understanding, the benefit of Compensation will be enjoyed because of the optimization of the tower. If the tower footing is redesigned considering a less area of land, it will affect the burden of Compensation under Rule 10(4) of the Rules. If the area of land for tower erection can be reduced, the amount of Compensation for the use of land under Rule 10 (4) of the Rules will be reduced. So, this will be a benefit of optimization of the Tower under the law.

6.0 BILL OF QUANTITY

BILL OF QUANTITY

6.1 FOR 1QL - 132 KV MULTI CIRCUIT SUSPENSIONTOWER

The bill of quantities for the existing and modified civil foundations of 1QL – 132 kV multi circuit transmission tower owing to tower footing area optimization are shown in tables below:

Table 6-1: BOQ for Optimised Tower 1QL-Suspension tower

Description		Stub	NT+9
Suspension Tower **1QL**			
(a) Fabricated Parts	MS	-	4,384
	HT	780	6,571
(b) Bolts & Nuts		30	620
Total Weight		**810**	**11,575**

Table 6-2: BOQ for Existing Foundation for 1QL Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	25
2	Backfilling with compaction	m3	11
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement - 500mm dia	m	192
4	Centering and shuttering, for Pile cap and pedestals	m2	26
5	Reinforcing Steel	kg	3,901
6	Lean / blinding concrete under Pile Cap	m3	2
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	12

Table 6-3: BOQ for Modified Foundation for 1QL Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	44
2	Backfilling with compaction	m3	29
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement	m3	240
4	Centering and shuttering, for Pile cap and pedestals	m2	32
5	Reinforcing Steel	kg	4,562
6	Lean / blinding concrete under Pile Cap	m3	2
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	13

The increase in BOQ of modified foundation from existing foundation corroborates the fact that the foundation for optimized tower will be heavy and strong to counter the increased weight of tower.

6.2 FOR 1QT6 – 132 KV MULTI CIRCUIT ANGLE TOWER

Similarly, the BOQ for existing and modified civil foundations of 1QT6 – 132 kV multi circuit transmission towers are shown in tables below:

Table 6-4: BOQ for Optimised Tower 1QT6-Angle tower

Description		Stub	NT+9
Tension Tower **1QT6** (30-60)deg& Terminal Tower(0-30deg)			
(a) Fabricated Parts	MS	-	8,879
	HT	3,715	35,516
(b) Bolts & Nuts		115	3,130
Total Weight		**3,830**	**47,525**

Table 6-5: BOQ for Existing Foundation for 1QT6 Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	49
2	Backfilling with compaction	m3	19
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement - 500mm dia	m	384
4	Centering and shuttering, for Pile cap and pedestals	m2	48
5	Reinforcing Steel	kg	13,637
6	Lean / blinding concrete under Pile Cap	m3	3
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	13,637

Table 6-6: BOQ for Modified Foundation for 1QT6 Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	186
2	Backfilling with compaction	m3	94
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement	m3	864

S. No.	Description	Unit	Quantity
4	Centering and shuttering, for Pile cap and pedestals	m2	86
5	Reinforcing Steel	kg	31,249
6	Lean / blinding concrete under Pile Cap	m3	9
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	31,249

6.3 FOR 132KV TWIN-ST-SUSPENSION TOWER

Table 6-7: BOQ for Optimised Tower 132KV TWIN-ST-Suspension tower

132 KV D/C TWIN GROSBEEK TRANSMISSION TOWER-ST TOWER WEIGHTS			
Description		**Stub**	**NT+BE**
Suspension Tower -ST			
b) Fabricated Parts	MS	-	5430
	HT	1030	11540
c) Bolts & Nuts		30	1030
Total Weigt		**1060**	**18000**

Table 6-8: BOQ for Modified Foundation for 132 kV ST Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	60
2	Backfilling with compaction	m3	33
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement	m3	288
4	Centering and shuttering, for Pile cap and pedestals	m2	48
5	Reinforcing Steel	kg	15,700
6	Lean / blinding concrete under Pile Cap	m3	3
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	24

6.4 FOR 2QL – 230 KV SUSPENSION TOWER

Table 6-9: BOQ for Optimised Tower 2QL-Suspension tower

230 KV M/C TRANSMISSION TOWER-2QL (80m/sec) WITHOUT OPTIMIZE THE BASE WIDTH TOWER WEIGHTS			
Description		**Stub**	**NT+9**
Suspension Tower -ST			

230 KV M/C TRANSMISSION TOWER-2QL (80m/sec) WITHOUT OPTIMIZE THE BASE WIDTH TOWER WEIGHTS			
Description		**Stub**	**NT+9**
a) Fabricated Parts	MS	-	8000
	HT	1600	32000
b) Bolts & Nuts		50	2400
Total Weigt		**1650**	**42400**

Table 6-10: BOQ for Modified Foundation for 2QL Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	173
2	Backfilling with compaction	m3	91
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement	m3	576
4	Centering and shuttering, for Pile cap and pedestals	m2	79
5	Reinforcing Steel	kg	28,113
6	Lean / blinding concrete under Pile Cap	m3	9
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	74

6.5 FOR 4DL – 400 KV SUSPENSION TOWER

Table 6-11: BOQ for Optimised Tower 4DL-Suspension tower

400 KV D/C TRANSMISSION TOWER-4DL TOWER WEIGHTS			
Description		**Stub**	**NT+9**
Suspension Tower -ST			
a) Fabricated Parts	MS	-	9975
	HT	2150	18525
b) Bolts & Nuts		60	1700
Total Weigt		**2210**	**30200**

Table 6-12: BOQ for Modified Foundation for 4DL Towers

S. No.	Description	Unit	Quantity
1	Earth work in excavation	m3	173
2	Backfilling with compaction	m3	91
3	Pilling Work including boring, pouring of concrete and binding placing reinforcement	m3	648

S. No.	Description	Unit	Quantity
4	Centering and shuttering, for Pile cap and pedestals	m2	79
5	Reinforcing Steel	kg	29,367
6	Lean / blinding concrete under Pile Cap	m3	9
7	Reinforced cement concrete works in Pile Cap and pedestals	m3	74

7.0 BARRIERS AND CONSTRAINTS

BARRIERS AND CONSTRAINTS

1. Implementation of Optimised Design in Existing Towers

Implementation of Optimised Design in existing tower is a tough decision to make. It requires a lot of effort and project planning to implement the modification in the existing tower infrastructure. It will ask for long line outages which is difficult to manage with the current system demand.

2. Impact due to Tower Cost

Some innovations may not be financially viable, viz. replacing lattice structure with pole structure, to optimise the foot print of the tower. As the cost of these towers are much higher than the lattice structure towers.

3. Adoptability in Bangladesh Scenario

Currently locations of some of the towers and ROW of some transmission line (mainly in urban area) are heavily inhabited, which will create major barrier in adopting any modifications. Also in such area modifying the route in line with the S/S orientation will be a tough task to adopt.

4. Relevance w.r.t. existing practice

Some existing practices viz.

- doing agriculture under the tower,
- doing some other small temporary economic activities under the tower

Such practices can be considered as multipurpose use of land and supporting the economy in both ways. So in such cases impact of tower footing optimisation reduces, though it considerably reduces the compensation fees.

5. Modification in Established Code

Though it is ideal to implement the optimised design within the existing code, however some modifications in standard can make optimisation more impactful. Some factors, such as factor of safety, deviation optimisation (for angle tower) etc. can be revisited to achieve more optimised design.

6. Suitability of Line Route

The adoptability of MC/MVMC towers (which will considerably reduce tower footprint and ROW) depends mainly on alignment of long parallel transmission line. Such scenario may be remote in existing Bangladesh transmission infrastructure, as existing system does not have many long distance bulk transmission lines.

8.0 TECHNO-ECONOMIC ANALYSIS

TECHNO-ECONOMIC ANALYSIS

8.1 BENEFIT-COST ANALYSIS OF GRID TRANSMISSION TOWER (GTT) DESIGN OPTIMISATION

In the Terms of Reference (ToR) it is stated that the objective of the study is to "*innovate best design for power grid transmission tower using optimum area of land.*"

In this section economic and financial aspects of the project are considered and a justification is provided for the adoption of the innovative design of GTTs.

For the benefit-cost analysis an incremental approach is adopted by comparing the innovative design with the existing design.

The benefit of the innovative design is in its reduced footprint or footing. This in turn, means that a smaller amount of compensation would have to be paid by the developer of the transmission line to the owner of the land.

On the other hand, the cost of the innovative design GTT is compared with the cost of the existing design GTT to determine the incremental cost of the former.

The benefit-cost analysis has been done for a planned multi circuit (1QL) 132 kV transmission line with a length of 1,070 km.

8.2 ANALYSIS FOR 1QL TOWER

The benefit of the innovative GTT design in relation to the existing design is captured in terms of the cost of compensation as presented in the table below.

Table 8-1: Compensation Saving Calculation for 1QL Towers

A	Assumptions		
1	Length of 132 kV Transmission line (km)		
	- Double circuit (1QL)		1,070
2	Average span of line (km)		0.33
3	Number of Towers		3,242
4	Number of 1QL Towers in a line	25%	811
5	Number of Suspension Towers in rural areas	90%	568
6	Number of Suspension Towers in urban areas	10%	243
7	Compensation rate in rural areas (BDT per decimal)		200,000
8	Compensation rate in rural areas (BDT per m^2)		4,942
9	Compensation rate in urban areas (BDT per decimal)		1,500,000

A	Assumptions		
10	Compensation rate in urban areas (BDT per m^2)		37,064
B	**Analysis**		
1	Reduction in footing area per tower (m^2)		44.87
2	Reduction in footing area of Suspension Towers in rural areas (m^2)		25,486.16
3	Reduction in footing area of Suspension Towers in urban areas (m^2)		19,903.41
C	**Compensation saving (BDT million)**		
1	Rural Areas		126.00
2	Urban Areas		404.00
	Total		**530.00**

As can be seen from the analysis of the benefits of the innovative GTT design, a total of BDT 503.00 million can be saved by way of one-time compensation to the landowners.

On the other hand, the innovative GTT design entails an increased use of steel sections, and this would increase the cost of the towers. The detailed computations of cost implications for a multi circuit (1QL) 132 kV transmission line with a length of 1,070 km are presented in the table below.

Table 8-2: Benefit-Cost Analysis of Innovative GTT Design for 132kV Transmission Line

1QL+9M (for each tower)	Existing	Innovative
Tower Weight (tonne)	13.880	11.600
Tower Cost* (million BDT)	1.25	1.04
Foundation Cost (million BDT)	1.56	1.87
Total Cost of Tower	2.81	2.92
Increase in tower cost (million BDT per GTT)		0.11
Total Route Length considered for Financial Analysis (based on the planned 132kV Line) (kilo-meters)		1,070
Total increase in GTT cost of Line (million BDT)		317.48
Saving in Compensation (million BDT)		530.00
Net Saving (million BDT)		441.84
Benefit-cost Ratio		3.36
** Reference Cost Data of steel (BDT/tonne)*		90,000

The analysis clearly brings out the net benefit of adopting the innovative GTT design for the multi circuit 132 kV transmission line. It is seen that for the proposed 1,070 km high voltage transmission line, a saving of BDT 441.84 million is possible. Moreover, the benefit-cost ratio is also very attractive at 3.36.

8.3 TOWERWISE BENEFITS

Considering the urban compensation as base the towerwise net benefits for various towers are as follows:

Tower Type	Increase in cost of each tower including foundation (in million BDT)	Net benefit (in million BDT)/ Tower	Remarks
1QL	0.11	1.55	
1QT6	7.22	(-) 5.56	Due to considerable increase in civil foundation
132kV twin conductor suspension tower	0.8	1.03	
4DL	1.61	3.35	

9.0 OTHER CONSIDERATIONS

OTHER CONSIDERATIONS

9.1 INNOVATION TECHNIQUES

9.1.1 Re-configuring the Tower Classification

According to different considerations, there are different types of transmission towers. The transmission line goes as per available corridors. Due to the unavailability of the shortest distance straight corridor transmission line has to deviate from its straightway when obstruction comes. In the total length of a long transmission line, there may be several deviation points.

1. Following angle of deviations are generally considered based on which tower characterization is done:

a) Angle of deviation 0^{o} to 2^{o}.

b) Angle of deviation 2^{o} to 15^{o}.

c) Angle of deviation 15^{o} to 30^{o}.

d) Angle of deviation 30^{o} to 60^{o}.

e) Angle of deviation 60^{o} to 90^{o}.

As per the force applied by the conductor on the cross arms, the transmission towers can be categorized in another way-

a) Tangent suspension tower
b) Angle tower or tension tower or sometimes it is called section tower.
c) Apart from the above-customized type of tower, the tower is designed to meet special usages listed below:

These are called special type tower
a) River crossing tower
b) Railway/ Highway crossing tower
c) Transposition tower

9.1.1.1 Re-define the angle of deviation of "A" Type Tower / Angle adjustments for Tension towers

One of the suggested methods to optimise the tower on the basis of its configuration and its design loads has been considered for examination. The modified tower configuration suggested for optimisation is as under:

a) A – type tower – angle of deviation 0^{o} to 6^{o}.

b) B – type tower – angle of deviation 6^{o} to 15^{o}.

c) C – type tower – angle of deviation 15^{O} to 30^{O}.

d) D1 – type tower – angle of deviation 30^{O} to 45^{O}.

e) D2 _ type tower – angle of deviation 45^{O} to 60^{O}.

f) E – type tower – angle of deviation 60^{O} to 90^{O} (To be designed as per the actual angle of deviation)

9.1.1.2 Results of Analysis & Benefits

By adopting the above tower classification, though, it might increase the design effort & cost but the relative benefits will offset those costs. The major benefits & analysis outcomes reveal the following:

a. With increased angle of deviation of A type tower, the tower design loads get optimised compared to B + 15 degrees, resulting in huge saving in tower weight & its base width.

b. Since the B Type tower is designed with design loads & angle deviations of 15 degrees, with a wide range of line deviation from 2 degrees to 15 degrees, the modified configuration will have a twin impact of weight reduction by segregating the line deviation up to 6 degrees & 6-15 degrees.

The swing angle of the line & clearances are maintained for 6 degrees suspension tower with the help of cross arm geometry & tower out line.

Typical outcome for such innovations will be around 70% saving of weight, which ultimately results in optimisation of tower footing.

9.1.1.3 Multi Voltage Multi Circuit Narrow Base Tower (MVMCT)

Considering the MVMCT towers (as per the applicability) results in substantial benefits in terms of ROW and power transmission capability. Various benefits of such towers are:

1. Old transmission lines can be dismantled or renovated by configuring new MVMCT lines using same old ROW with tolerable broadening so that transmission line of higher voltage rating of MVMCT line can transmit power between major substations while that of lower voltage line can transmit power between smaller substations.
2. The cost of towers ranges from one fourth to half of the transmission line cost and hence optimum design gives reasonable savings. Consequently, MVMCT line towers should be designed for structural and electrical requirements for a safe and economical design.
3. A few solutions for reduction of electric and magnetic field emissions caused by the overhead power lines are MVMCT.

4. When considering all the limitations the proposed MVMCT would solve all the issues of a transmission tower according to the present needs.
5. Due to technical and financial reasons, future electrical transmission towers need to adopt MVMCT concepts by maximizing power delivery with confined ROW.
6. The conductor configuration is considered to reduce the electro-magnetic fields and also to optimize the design.
7. When compared to conventional towers MVMCT gives huge savings in cost.

9.1.1.4 8-legged Lattice Tower

It has been observed in the analysis of a lattice transmission line tower, that, for the same conductor loads, the legs experience more forces when the base width of the tower decreases. A 4-legged tower can also be made compact up to a certain limit, but after reaching a minimum base width limit, the legs experience such heavy tension and compression force, the angle sections are not available to provide to take that heavy axial forces.

In such situation instead of going for monopole structure which reduces considerable foot print eight legged tower can be used, with much optimised weight. The outcome of analysis of a typical 220kV tower is furnished below:

Table 9-1: Benefit-Cost Analysis of Innovative GTT Design for 132kV Double Circuit Transmission Line

Description	4 Legged Tower	8 Legged Tower	Monopole
Weight of Structure	10.7 T	13.2 T	25.1 T
Base Width	12.2 m	4 m	2.2 m
Weight / Base Width Ratio	0.88	3.3 M	11.4

Ref.: A 220kV multi-circuit 0-2^{o} deviation line has been considered for the study. Source : CPRI, Vol.14(2)/154-161-December 2018

The base width of 8 legged tower is about 90% less than the 4 legged tower with an increase of weight only by 30 %.

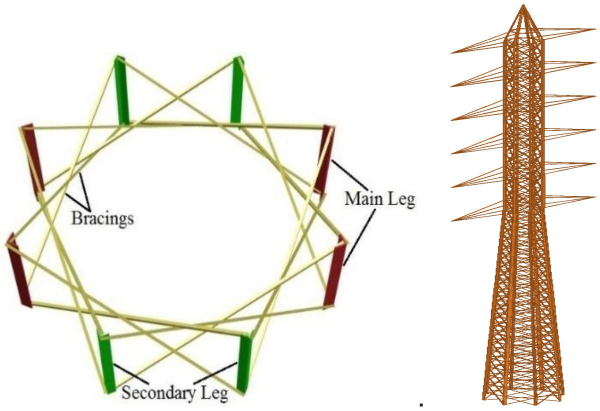


Table 9-2: 8-legged tower

9.2 MONO POLE

Currently where there is a problem of Right of Way tubular pole (Monopole) transmission towers are used. Such transmission poles can be installed in locations where limited space is available due to smaller footprint compared to lattice towers. Moreover such transmission poles are installed in places with existing corridors already used by other projects such as highways, roads, rail tracks, rivers and etc.

The main advantages of monopole transmission towers are:

- Less right-of-way
- Better Visual Appearance
- Less components, faster installation, and less Installation Cost
- Better reliability under extreme conditions
- Design Flexibility
- Easy for maintenance and repairs
- More safe
- Less prone to vandalism

With similar application the monopole towers weighs 7-8% less than the lattice type towers and also ROW required is around 20% that for lattice tower.

However Monopole towers have the following disadvantages:

- Monopoles are generally costlier than lattice angle towers due to higher cost of material
- Due to height limitation it is difficult to install monopole where span is required, viz. river crossing
- Erection/ Dismantling of Monopole tower is more cumbersome
- Applicable span length is less for monopole applications

Typical specification for monopole towers is as follows:

Tower Type	Polygonal/Round Self-supporting Monopole
Wind Speed	100~240 KMPH
Wind Pressure	As per the customer request
Steel Material	Q235, Q345, Q420
Height	10—50m

Appearance	Hot-dipped Galvanization or Painting
Connection	Overlap/Slip/Flange connection
Design Code	ANSI/TIA-222-G

9.3 EMERGENCY RESTORATION SYSTEM (ERS)

9.3.1 Reasons of Tower Failure

The transmission lines are mostly exposed in the air to the harsh environment of nature which produces various types of failures. The major reasons for the failure of transmission lines are:

1. The high wind velocity during storm, cyclone and local phenomenon of whirlwind and gale etc. which exceeds the wind speed for which the tower is designed.

2. Theft/sabotage of tower members, generally the theft of secondary members (connected with one or two bolts) of the towers, by the local people makes the tower structurally weak which ultimately leads to failure during high speed wind/ storms/whirlwind/ cyclone etc.

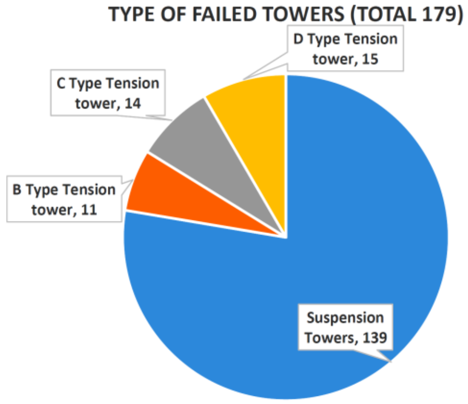
3. Lack of proper soil investigation and deficiency in design/construction of foundation of towers may also result in failure of towers.

4. Lack of proper foundation protection of towers in steep slope/hilly terrain. Many times landslide causes erosion of soil under the foundation which in turn causes the failure of foundation and subsequently failure of towers.

5. Owing to flash floods, soil erosion under the tower foundation (towers located near river bank) results in tower failure.

6. Shear failure of stubs of leg members of towers due to torsional forces on account of sinking of some of the legs.

As per the CEA India Report the failure rate of suspension towers are much more than the tension towers. Out of total 179 nos. of failed towers between April 2019 to December 2021, 139 Nos. (77.65%) are of suspension type towers and the remaining 40 Nos. (22.35%) are tension type towers. This is shown in pie chart below:



Source: CEA, India - Report of the Standing Committee of experts on failure of EHV transmission line towers (April 2019 - December 2021)

Table 9-3: Failure Rate of Type of Towers

9.3.2 Restoration of Transmission Line

Traditionally, restoration of transmission lines was accomplished using available spare towers. The typical self supporting lattice type towers were erected using derricks and in many cases complete new foundations had to be constructed. These operations were very time consuming and often resulted in prolonged outages. Many of the sites of these damaged transmission towers were difficult to access. The loss of these towers would sometimes result in backing down the generation and load shedding at industrial centers. With this methodology massive amount of inventory were to be managed to have spare lattice towers available for emergency restoration.

Lately, Emergency Restoration Systems (ERS) consist of lightweight modular aluminium structural components, insulators and hardware, anchoring systems, computer software for design and field training are being used. This system is used to build light weight guyed transmission towers, not the traditional self supporting type towers.

Restoration of damaged and collapsed transmission line tower can take a very long time which can vary from 3-4 weeks to 1-1.5 years depending on site conditions, availability of spare towers, requirement of pile foundation etc. By adopting the IEEE Standard 1070 Emergency Restoration System for restoration of collapsed towers. Manual erection of the ERS tower takes minimum of four to five days when restoring a collapsed tower. When hydraulic cranes or helicopters can be deployed, the restoration work can be done in 2-3 days time.

The adoption of ERS for restoration of transmission line is another innovative and unique but prevalent practice espoused by many developed countries for quick restoration of lines.

9.4 OPTIMIZATION OF TOWERS CLOSE TO GRID SUBSTATIONS

Functionally pooling stations & grid substations have multiple voltage level and multiple power inlets / out lets / many transformers which increases the number of substation bays and the area.

Since substations are demarcated with a defined boundary but the Transmission Lines emanating& getting terminated into these substations is high in number.

MVMC tower near to sub-station can be an ideal solution for ROW optimization near to sub-station, however tower just near to sub-station may not be a ideal candidate for optimization as these tower are special tower.

Towers near such grid substations are mostly of dead end types that have large angles to accommodate the different orientations of incoming and outgoing lines as well as the grid substation layout. The optimization of these towers may not result in any land saving owing to following reasons:

1. Less number of dead end towers near substation therefore the land saving will not be significant. Moreover, the land saved near the grid substation may not be useful for any other purposes.
2. Effective optimization will not be there as this may alter the orientation of incoming and outgoing lines.

10.0 COMMENTS AND REPLIES

COMMENTS AND REPLIES

S. No.	Interim Report Reference	Excerpt from report	Comments	Clarifications / Replies
PGCB				
1.	Page 8 of 62, Point 1.4 METHODOLOGY	"Only double circuit towers will be considered for the study".	Both double circuit and four circuit tower shall be considered for study.	Noted and incorporated at pg. no. 19 of this report
2.	Page 9 of 62, Point 1.4 METHODOLOGY	"4. The 132kV multi circuit towers (four circuits and six circuits) are being used by PGCB."	In addition to double circuits, 230kV and 132kV multi circuit towers (four circuit tower) are currently used by PGCB.	Noted and incorporated at pg. no. 20 of this report
3.	Page 9 of 62, Point 1.4 METHODOLOGY	"5. Line conductors in delta formation is being used for 400 kV transmission lines by PGCB."	Line conductors in delta formation is not being used for 400 kV transmission lines by PGCB.	Noted and removed
4.	Page 9 of 62, Point 1.4 METHODOLOGY		It should be mentioned that V type insulator string is used by PGCB in recent 400kV transmission lines.	Noted and incorporated at pg. no. 20 of this report
5.	Page 10 of 62, 1.4.2.7 Codes /Standard	"The applicable and relevant codes, standards, power grid manuals and best international practices will be followed for calculation of above mentioned aspects of the tower design."	PGCB specification shall be mentioned instead of power grid manuals.	Noted and incorporated at pg. no. 21 of this report
6.	Table 2-1 Details of Existing Lines	Number of Circuits 132kV - Double 230kV - Double	Number of Circuits 132kV - Double, Quad 230kV - Double, Quad	Noted and incorporated at pg. no. 25 of this report
7.	Table 2-2 Details of Upcoming Lines	Number of Circuits 132kV - Double 230kV - Double	Number of Circuits 132kV - Double, Quad 230kV - Double, Quad	Noted and incorporated at pg. no. 25 of this report
8.	2.3.2 230kV Tower	"Conductor Twin 37/4.176 AAAC"	Conductor shall be Twin ACSR Mallard.	Noted and incorporated at pg. no. 26 of this report
9.	2.4.1 Design Parameters	Design consideration table	PGCB have tower design for different wind zone for the same voltage level. It shall be included.	Noted and incorporated at pg. no. 26 of this report
10.	2.4.2.1	Longitudinal Loads	Longitudinal Loads information is missing.	Noted and incorporated at pg. no. 27 of this report
11.	3.1	As per discussions held with PGCB authority, most of the towers used for 400 kV and 230 kV are already designed with optimized base.	As per discussions held with PGCB authority, recent towers design used for 400 kV and 230 kV line are already designed with optimized base.	Clause has been modified at pg. No. 31 of this report
	3.2 Tower details Page 32 of 66		More types of tower need to be included in the study as agreed during discussion.	Clause has been modified at pg. No. 31 of this report
12.	4.0 Design Optimization		Soft copy (excel file and PLS tower file) are	Noted, will be shared

S. No.	Interim Report Reference	Excerpt from report	Comments	Clarifications / Replies
			needed for checking optimization proposal.	
13.	4.4.2 Tower Base Optimization Page 60 of 62	"The base width of the original tower is 7.5 m and at +9 m level as per slope base width would be 10.056 m. It means land area required is 10.056 m x 10.056 m i.e. 101.12. Therefore the area required when tower with +9 m extension is installed on ground is 101.12 m2. It was observed that after applying the innovative measures during analysis, the tower base width at +9 m level remains same as normal tower level i.e. 7.5 m, which means that the area required for tower with +9 m will be (7.5 x 7.5) 56.25 m."	Only +9m extension part has been optimized. Base width of 0+ meter extension is same as before. Therefore, base width optimization benefit is not available when 0+ meter extension tower is used.	During discussion we were informed that basic dimensions of towers 1QL & 1QT (provided by PGCB) cannot be changed, hence we've followed the configuration and try to optimize the existing provided tower line diagram.
BPDB				
1	3.1 Tower Selection : (page-32)	"As per discussions held with PGCB authority, most of the towers used for 400 kV and 230 kV are already designed with optimised base."	Therefore, only 132 kV towers have been considered for optimization. But, design optimization of 230 kV and 400 kV transmission towers needs to be included in the report;	The 230 KV & 400 KV towers have been optimised by applying innovative options to these towers, results are verified in the DFR. Refer clause nos. 4.3 and 4.4 of this report
2	3.1 Tower Selection" (page-32)	"PGCB is also planning to introduce 765kV system, however tower erection is yet to take place, though the designing of such towers is almost complete."	Hence, design optimization for 765 kV towers is also required which is not addressed in this study;	The optimized design is included in this report. Refer clause no. 4.5 of this report.
3	General Comment		Special types of tower design optimization at different voltage levels such as river-crossing (e.g. Padma river crossing) towers may be included in this study;	The river crossing towers are special tower, as tower footing optimization will not have much impact as such not considered for analysis
4	General Comment		Optimized design may be recommended for Feni - Chattogram Transmission Line which is passing through a narrow strip of land having serious ROW constraints;	The approach does not envisage line specific analysis
5	General Comment		Case study may be conducted using the	A general write up of such tower is included in the DFR

S. No.	Interim Report Reference	Excerpt from report	Comments	Clarifications / Replies
			MVMCT (multi-voltage multi-circuit) configuration like 132/230/400/765 KV for the proposed methodology to reduce the right of way;	
6	General Comment		Cost comparison analysis for individual tower to MVMCT configuration may be included in this report;	Since these are specific towers used for specific applications / corridors / configurations, hence the exact cost analysis may not be relevant, however, the range of benefits is provided in the DFR
7	General Comment		In tower design criteria, construction friendly designs i.e. erectable by helicopter or heavy cranes which change current erection methodologies to increase the productivity in construction may be incorporated.	As the objective of this assignment is limited to land optimization, as such these aspects are not included.