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Study Committee B2
PS 1 / CHALLENGES & NEW SOLUTIONS IN DESIGN AND CONSTRUCTION OF NEW OVERHEAD LINES

Engineering Solutions to Mitigate Construction Challenges of New Overhead Lines

Rahul Puri **Abhishek** **Subhash C Taneja*** **Abhay Choudhary**

Power Grid Corporation of India Ltd., New Delhi
INDIA
*sctaneja@powergrid.in

SUMMARY

Indian transmission network has grown by leaps & bounds over the past decade and a large transmission network comprising of more than 4.2 lakh, (0.42 Million) circuit kms of transmission lines is already in place. Such phenomenal growth would not have happened without resorting to new indigenous unique engineering solutions to address several constructional challenges. The transmission lines traverse through varied types of terrain, plain as well as mountainous, encountering several river crossings, railway crossings, power line crossings and congested areas with severe space constraints especially near the boundary of substation. At times, such types of site constraints appear as major constructional challenge, which, if not addressed properly, may severely impact the cost as well as completion schedule of the transmission line. Therefore, all such constraints must be handled diligently and thorough analysis of possible solutions should be done, prior to final implementation. Project can be completed within scheduled target time andreasonable cost despite of multiple hindrances by adopting alternate/innovative solution suitable to site condition, conducting micro-level planning for the deployment of resources, manpower and materials.

The paper describes some of the efforts to address the various constructional challenges and highlights necessary design considerations for implementing new engineering solutions through example cases {such as Intersection Tower (Special Multi-circuit Tower), Use of special Obtuse Angle Tower, use of Two-tier Gantry in EHV/UHV transmission system and Rock Anchor Foundation in mid-stream of a large river}. Such unique approaches in construction of new transmission lines have been immensely useful to mitigate the adverse environment impact, saving cost, meet completion schedule, reduce outage duration& optimizing the Right of way requirements.

KEYWORDS
Open Cast Foundation – River – Hard Rock Strata – Rock Anchor – +/-800 kV HVDC
Intersection Tower – Blocking Corridor – Forest – No deviation in Route Alignment;
Obtuse Angle Tower – Severe ROW – Aux. X-arm – Two Tier Gantry – ‘I’ Type Layout.

1. ROCK ANCHOR FOUNDATION IN MID-STREAM OF A LARGE RIVER

At a time when Southern part of India was facing huge power deficit, the prestigious ± 800 kV Raigarh - Pugalur HVDC Line was envisaged having capacity to transmit 6000 MW power over a distance of 1765km. It is the fifth longest Transmission Line in the world.

By Dec'2019, all the Terminal and transmission line works were nearing completion and were expected to meet the completion schedule of March'2020 except for Tungabhadra River crossing. It was feared that an investment of $2 bn. would be stuck-up and there would be huge loss of tariff per day. The locations were falling under Srisailam Dam Reservoir area and the water level was over 10 m above the River bed level. Generally, water start receding after February and working window is only upto July before onset of next rainy season.

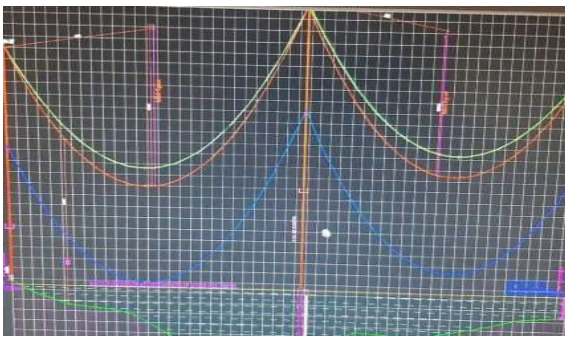


Figure 1: Crossing profile (Mid-stream location no.195)

Figure 2: Crossing view of river from google earth

- **INITIAL SOLUTIONS FOR TUNGABHADRA RIVER CROSSING**

  In order to ensure timely completion of the Line, the following was planned:

  - Provisional use of ERS (Emergency Restoration System) to provide connectivity over the River (ready by March 2020)
  - Simultaneous completion of regular pile foundation (ready by June 2020)

- **CHALLENGES IN EXECUTION AGAINST INITIAL SOLUTIONS**
  - Two ERS structures (91 m and 85 m tall) were erected by March 2020 to establish connectivity between two ends of the line at Tungabhadra River crossing. The line was test charged in April 2020. ERS Towers were deployed in the catchment area and the anchors were lying in the slushy area. Considering the release of back water from Srisailam Dam and high wind speeds, it was clear that the stability of ERS towers shall become very critical and cannot survive the ensuing rainy season. Thus, shifting of the line from ERS to permanent Towers was paramount.
  - Simultaneously, boring through hard rock strata continued for construction of Pile foundation in Tungabhadra river. The boring progress was extremely slow (about 0.7 to 1.1 m per day even after deployment of two hydraulic rigs) and it became progressively obvious that the pace of boring was not conducive for completion of pile foundation before onset of next rainy season. Still all efforts were being made to hasten the boring and ramping up the boring capability by deploying additional hydraulic rigs and higher capacity machines.

- However, sudden outbreak of Covid-19 pandemic changed everything. Government. of India implemented nationwide complete Lockdown effective from 25th Mar'2020 halting all field activities at site. No work was possible for three weeks, the duration of complete lockdown. Afterwards, the Government announced some relaxations for the Infrastructure Projects and movement of men and material was made possible at the location after obtaining specific permission from the concerned authorities.

- **ALTERNATIVE SOLUTIONS**

As it became clear that conventional pile foundation after boring through hard rock strata shall not be possible, alternatives were explored.

Option-I: Instead of single pile foundation in the midstream, provision of two open cast rock anchor foundations near both banks of the river. As the depth of water near river banks was 2-3m only, open cast foundations were proposed near both the banks of the River. Immediately, pits were excavated with available machinery at site. However, to the disappointment of everyone, hard strata was not found to rest the foundations even at reasonable depths and idea had to be dropped midway.

Option-II: As time was running, rock anchor foundation for the midstream location was deliberated. Since the area was under 5-6m depth of water in March 2020, open cast foundation at the mid-stream was never thought as a viable option earlier. But the excellent hard rock strata just 2-3 m below the river bed was a good opportunity to place the foundation safely. Immediately, discussions through virtual medium were held with domain experts and academia. Since it was a novel idea, everyone was apprehensive but under the ongoing constraints this was the only possible solution which could have been executed at site and completed by June 2020. After larger discussions, everyone conceded that if the foundation can be rested on rock anchors firmly embedded on the hard rock strata, the foundation shall be safe.

- **DESIGN OF FOUNDATION**

The foundations were to be made at the same location using rock anchors specially designed, based on the available soil investigation report using reference of IS 1892 ,for the location, due to hard strata available below the ground.

➢ **Characteristic Data of The River**

- Tungabhadra is a perennial river and tributary of Krishna river.
- Velocity of water in the river considered as 2.68 m/s.
- Maximum Discharge of water considered as 14866 Cusecs.
- Highest Flood Level (HFL) taken as 269.75 m and River bed level (GL) as 259 m. Hence, there was 10.75 m level difference between HFL and River bed.
- River width at the crossing section is approx. 1058 m. However, adjacent towers lie at a distance of 552 m and 506 m away the location.

- **Design Methodology**

  The foundation has been designed for following resistance using reference of CENTRAL BOARD OF IRRIGATION & POWER (CBIP) manual and Indian Standard (IS) 4091: -

- *Bearing Resistance*: - It is resisted by 6.0 m X 6.0 m square footing, considering bearing capacityof soil about 66 ton /m^2 to resist the compression load.
- *Uplift Resistance*: - This resistance against uplift load is provided by the

  - RCC (Reinforced Cement Concrete) weight of Top slab, Bottom slab and chimney

  - Grouting of 32 mm dia. reinforced bars, 13 bars per leg as rock anchor for 3.5 m depthbelow bottom of the slab.
- *Overturning*: - Stability of the foundation against overturning under the combined action of uplifts and horizontal shears is resisted by counter moment obtained by anchors rods and self-weight offoundation.
- *Sliding*: -The resistance against horizontal shears, which may cause sliding of foundation have been achieved by self-weight of foundation.
- *Loads (in MT):* - The following loads have been considered using reference of Indian Standard (IS) 802-1995 (Sec 1/ Part 1)-

Compression	Uplift	Side Thrust (Trans)	Side Thrust (Long.)
317	249	23	12

- **Design Features of The Foundation**

- Foundation has been casted in rocky strata using 13 Rock anchors which have been grouted upto 3.5 m depth from bottom of bottom slab having grout hole diameter of 15 cm. For grouting,cement sand mortar of 1:1 has been used.
- The special stub of about 14.5 m length has been used. Stub was fabricated in three parts and bolted suitably at site.
- Two concrete slabs of M25 grade design mix have been used in the foundation. Bottom slab of6m x 6m has been casted 3.5 m below river bed so that the top of bottom slab is at the river bedlevel. And top slab of size 3.8 m x 3.8 m has been provided upto 2.5 m above the river bed.
- Approx. 8.5m high circular chimney of diameter 1.9 m has been designed due to level difference between HFL and river bed.
- Approximately 900 cum concrete and 40 tonne reinforcement have been used for construction of the foundation.
- D type tower with +18m extension having 66 m height has been used to cross the span.
- Total weight of the tower is 90 Ton.
- Earlier Pile foundation was proposed for the location and some holes were already drilled up to 3-5 depth for casting of pile, the same holes were suitably filled with M25 grade concrete and reinforcement bars to act as shear Key for the footing.
- Quick setting compound were added in the chimney concrete to attain requisite strength early and to facilitate the commencement of tower erection.

- To diffuse water pressure in the lateral direction (direction of the water flow in the river), the top slab was tapered down so that the impact of flowing water and any debris shall be minimum.
- Circular chimney was used so that lesser moment generates at toe of foundation due to water current as foundation is in the mid-stream of a river which shall be under 10.75 m deep water during floods.

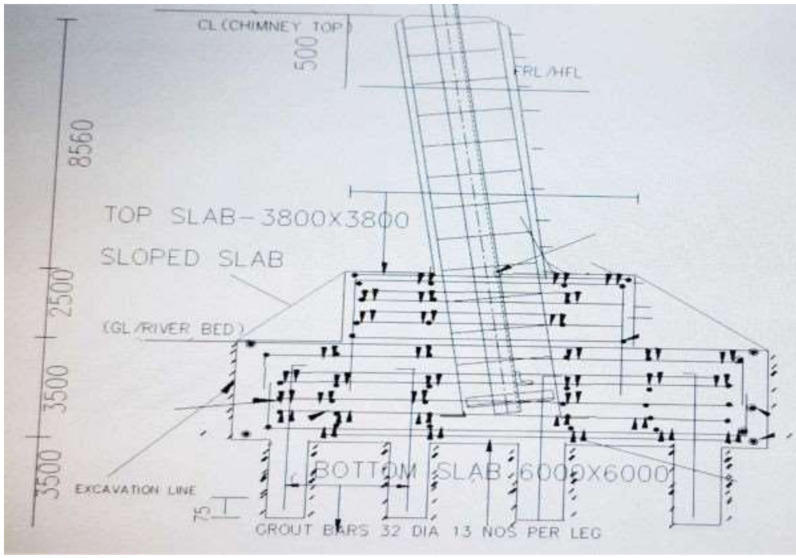


Figure 3: schematic diagram of foundation

- **Challenges Faced During Execution**

- As the foundation area was submerged under 3-4 m depth of water, primary task was to construct a temporary approach to the location. Sand/boulders from nearby area were dumped in the stagnant water to construct the approach road and a working platform of about 50m x 50m size which was about 500mm above the existing water level of the river. All this was done while the design was being developed.
- Once the design was ready, construction activities at the site were started. Despite the wide spread restrictions on movement of men and material, special permissions were obtained from the district authorities. Site activities commenced on 4th May 2020 and the foundation works in all respects were completed by 12.06.2020. Major constraints faced at site due to the COVID-19 pandemic are enlisted below: -
  a) Non-availability of drilling equipment/material for making holes and blasting.
  b) Non-availability of gelatine sticks for blasting in the local market. (had to be specially arranged from other places with special efforts)
  c) Non-availability of tractor mounted DTH (down-the-hole) machine for making 3.5 m deep 150 mm dia. holes for rock anchors.
  d) Severe restrictions on vehicle movement, sometimes detaining of vehicles up to 24 hours.
  e) Local people restrained to allow the migrant workers deployed for the construction due to COVID restrictions.

f) Special arrangements were made in the river to divert major share of flood waters to the other side of tower i.e. between 195-196, saving the approach road.

g) Prior to commencement of tower erection, the approach road which was the life line of the project was washed away by the flash floods. Hume pipes were laid under the approach road.

Figure 4: Photograph of approach road washed away due to flash flood

h) The total 90 MT tower DD (Double circuit tower designed up to 60-degree line deviation) +18 extension was erected, with the intermittent interruptions due to rainsas well as rise in water level in the river.

i) As the tower location was in the middle of river bed, fixing of Guy arrangements for tower erection had become a tough task. Many a times the erection workers had to swim to the points for fixing of guys with anchors.

- To overcome these challenges, pep-talk with the workforce were held daily. Briefing about Covid-19 pandemic and precautions to be adopted were discussed periodically. Workers were advised to remain in isolation from the general public. Daily monitoring of body temperature was maintained. Protein rich diet for the work force was ensured. These measures were proved successful when all the construction activities could be completed without any member of the workforce getting affected by the pandemic.

Figure 5, 6, 7 and 8: Actual site photographs

2. INTERSECTION TOWER (SPECIAL MULTI-CIRCUIT TOWER)

BACKGROUND

- There were two existing 400 kV D/C transmission lines namely Kota-Merta and RAPP (Rajasthan Atomic Power Plant)-Kota line terminating at 400/220 kV Kota sub-station in addition to few more lines.
- A new 400 kV D/C RAPP 7 & 8 – Kota line was to be terminated at the sub-station. Bays were allocated in between the above mentioned existing 400 kV lines.
- A 220 kV D/C KTPS-Kota line of other utility was over-crossing (on 400 KV D/C towers with 25 M Extension) both the 400 kV existing lines very close to the boundary wall of sub-station and a tower was placed in between the existing lines. This tower was blocking the take-off of the new line at Kota S/S.
- Entire area just behind the sub-station is a forest. Forest clearance for the new line was already obtained.

SOLUTION

- Option-I – Change the alignment of existing 220 kV line of other utility
- Option-II – Build this portion of the new line with 400 kV cable.
- Both the options would have involved more time due to resubmission/approval of forest proposal to forest authority and substantial increase in cost due to use of 400 KV cables or re-routing of 220 KV line.

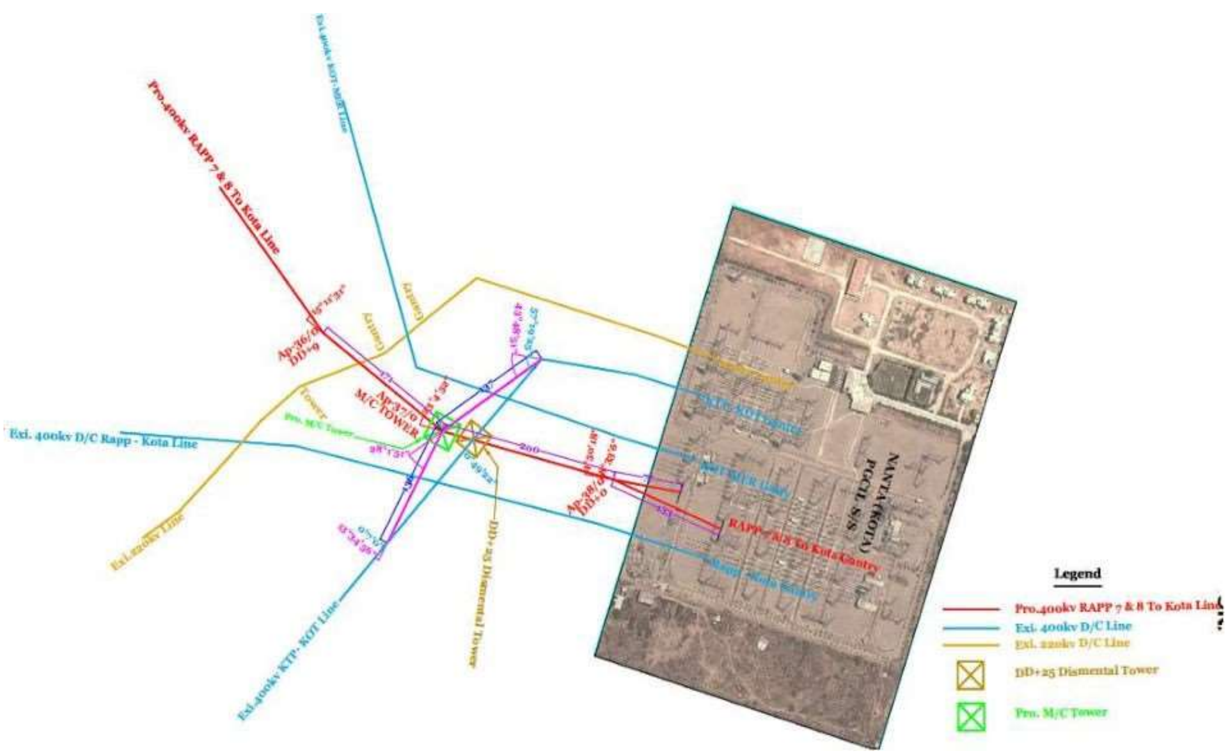


Figure 9: Sketch of new arrangement

- Option-III – A new engineering solution for addressing the challenge of space constraint was introduced to provide a multi-circuit tower with two circuits perpendicular to other 2 circuits in the alignment of our new line and close to the existing tower which was blocking corridor of the new line. Normally, all four circuits on a M/C tower are parallel to each other.
- Technical analysis for the same was done and tower drawings were modified. Main X-arms of bottom circuits were replaced with auxiliary X-arms. Presently, upper two circuits of M/C tower are being used for 220 kV line of other utility and bottom ones had been utilized for newly commissioned 400 kV D/C RAPP 7 & 8 - Kota line.

Figure 10: Actual site photograph

3. OBTUSE ANGLE TOWER

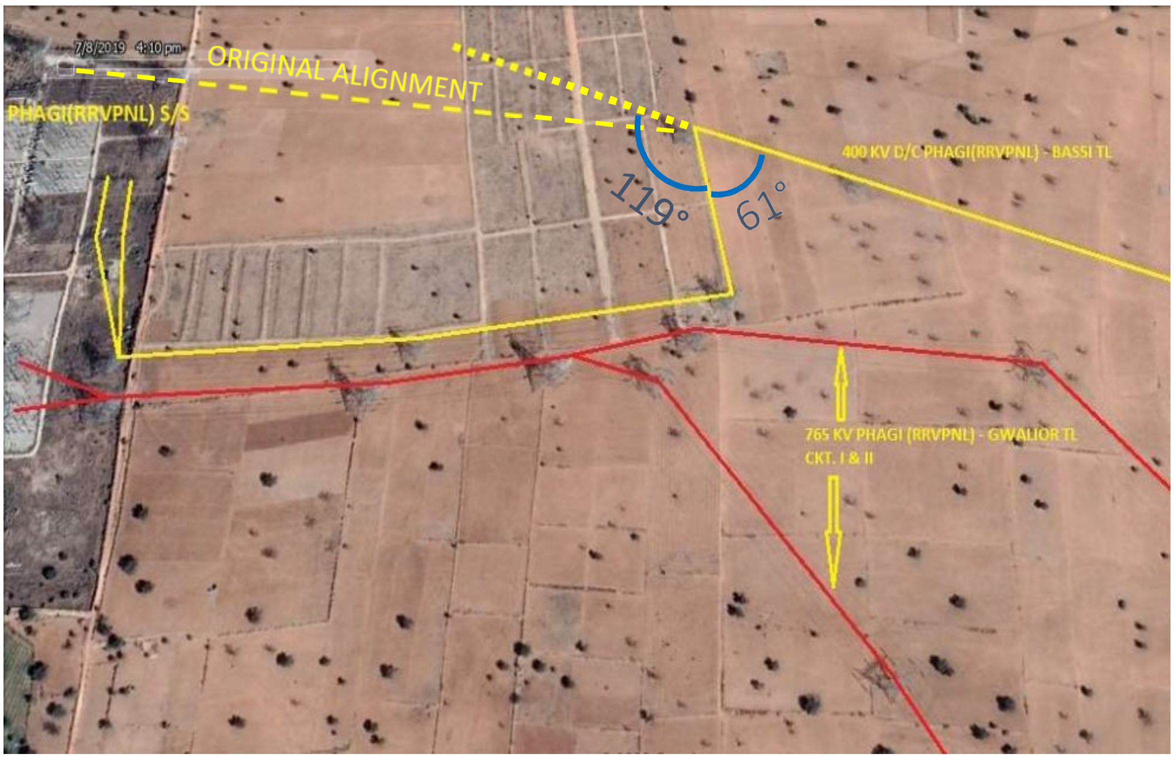
BACKGROUND

- Two 765 KV S/C Gwalior-Jaipur transmission lines, two 765 KV S/C Jaipur-Bhiwani lines and one 400 KV D/C Bassi-Phagi transmission line were to be terminated at Phagi (Jaipur).
- Met with Severe Right of way (ROW) problem just outside the Sub-station boundary due to development of a plotted colony blocking corridor of all of the above-mentioned lines.
- However, after lot of persuasion, the developer agreed to pass only the 400 kV line inside the colony along the periphery. All other 765 kV S/C lines were to be re-routed accordingly.

SOLUTION

- Option-I – Since construction of these lines was in advanced stage, re-routing from far away would have been a very difficult solution. Also, it would have caused severe ROW problem from other land owners.
- Option-II – Cabling in 400 kV line in this stretch would also have been a costly affair.

- Option-III – A new unique solution was finalised. Provided 119° angle of deviation with extended auxiliary cross arm on one of the towers in 400 KV D/C Bassi-Phagi line to re-route the line. The transmission line has almost taken 'V' turn on this tower.
- Also, a portion of the line was strung using Gantry, and BPI and again on tower for undercrossing 765 kV Phagi-Bhiwani line within boundary of Phagi S/S before final termination.
- Four 765 kV S/C transmission lines were converged on two lines using D/C towers avoiding passing through the plotted colony. Auxiliary X-arm was also provided on two 765 kV D/C towers for angle of deviation upto 90°.



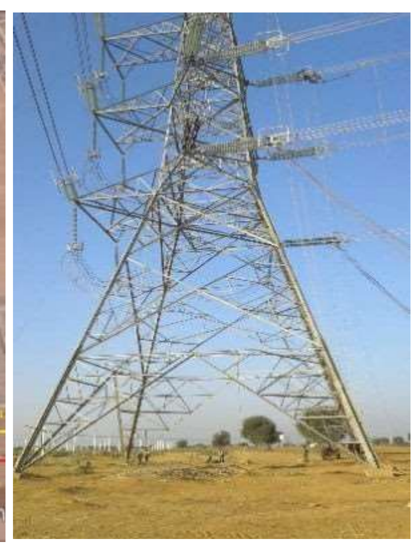


Figure 11 and 12: New arrangement on Google earth map

Figure 13: Actual site photograph

4. TWO-TIER GANTRY

BACKGROUND

- Two new transmission lines namely 400 kV D/C (Quad) Bareilly-Kashipur and 400 kV D/C (Quad) Kashipur-Roorkee line were to be terminated at 400/220 kV Kashipur Sub-station.
- One 400 kV D/C transmission line was to be terminated from front side and another from the back side in a sub-station having 'I' type layout.
- Due to approval delays, corridor of one transmission line from back side was blocked due to construction of a colony in the originally planned route.

SOLUTION

- Option-I – Laying of 400 kV cable in the affected stretch.
- Option-II – Terminate only one circuit of each line at Kashipur S/S and other circuit of both the lines may be directly connected to make it Bareilly-Roorkee line bypassing the Sub-station.
- Option-III – A new arrangement was finalized to provide Two-tier Gantry to make way for termination of all four circuits at the S/S from same side using a M/C Tower as dead-end tower. It also involved crossing of existing 400 kV D/C Kashipur-Moradabad transmission line.
- Total height of two-tier Gantry = 22+10+7.5 = 39.5 m and that of dead-end M/C Tower is 73 m.

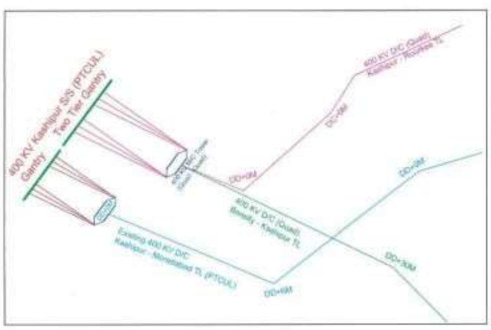


Figure 14: Sketch of new arrangement

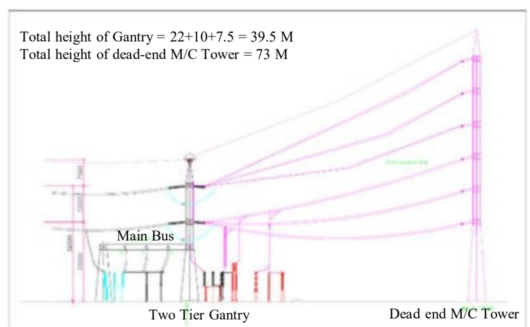


Figure 15: Section diagram

Figure 16 and 17: Actual site photographs

CONCLUSION.

Various constructional challenges of New OHL by adopting necessary design considerations for implementing new engineering solutions through example cases {such as Rock Anchor Foundation in mid-stream of a large river, Intersection Tower (Special Multi-circuit Tower), Use of special Obtuse Angle Tower, and use of Two-tier Gantry in EHV/UHV transmission system} can be mitigated. Such unique approach in construction of new transmission lines has been immensely useful to mitigate the adverse environment impact, saving cost, meet completion schedule, reduce outage duration & optimizing the Right of way requirements.

BIBLIOGRAPHY

- MANUAL ON TRANSMISSION LINES (Publication No. 323)-CENTRAL BOARD OF IRRIGATION & POWER (CBIP) .
- IS 802-1995 (Sec 1/ Part 1)- Use of structural steel in overhead transmission line towers materials, loads and design strengths.
- IS 1892-Code of practice for subsurface investigation for foundation.
- IS 4091-Code of practice for design and construction of foundations for transmission line towers and poles.