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Revolutionary Design and Optimization of Railway Electrification Overhead Equipment in High-Altitude Tunnels: A Case Study of the Magnificent T-80 Tunnel

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Abstract:
Railway electrification systems are critical for modernizing railway infrastructure, enhancing efficiency, and reducing environmental impact to obtain zero emissions targets. In high-altitude regions, such as mountainous terrains, unique challenges arise due to extreme weather conditions, terrain complexities, and operational requirements. This case study focuses on the innovative and optimized design of overhead equipment (OHE) for railway electrification in high-altitude tunnels, presenting a comprehensive analysis of the planning, design, and implementation process for 25kV AC Overhead equipment. The study begins with an overview of significant considerations in designing 25kV AC OHE systems for high-altitude tunnels, including altitude effects on electrical performance, weather effects, structural safety checks, fire scenarios, vibration effects, and tunnel bolt drilling for OHE equipment installation. It also covers aspects such as the selection of auto tensioning devices, electrical clearances, and earthing & bonding according to railway/EN/IEC standards. Also, the paper examines the monetary feasibility and environmental sustainability of the proposed OHE design, emphasizing the importance of life-cycle cost analysis and environmental impact valuation. It underscores the significance of adopting a holistic approach that balances technical requirements, operational efficiency, and environmental stewardship in railway electrification projects.

Keywords: 25 kV AC OHE/OCS, Tunnel, ROCS, FOCS, Anti-Creep, Cantilever, High-altitude, Bonding & Earthing, Fire scenarios, Vibration, ATD (Auto Tensioning Devices), Span Length, Sag, Versine, Tunnel Earth Wire (TEW), Modernizing Railway Infrastructure, Railway Electrification.

Introduction:
The T-80 tunnel is India's longest transportation railway tunnel, stretching a remarkable 11.2 kilometers in length. Situated within the Pir-Panjal Mountain range, it forms a crucial link as the broad-gauge mountain railway in India, connecting the northern states of Jammu and Kashmir. Remarkably, it operates at a depth of 440 meters below the existing Jawahar Tunnel, which provides the sole road link connecting the region to the rest of the country. However, despite its monumental significance, the T-80 tunnel presents unique challenges, particularly in providing an economical Over-Head Equipment

(OHE) system for railway electrification. In practice, the Rigid Overhead Equipment System (ROCS) has been installed in tunnel areas across Indian railways, including metros. However, as per research on innovative optimization in railway electrification, there emerges a compelling case for the adoption of a Flexible Overhead Catenary System (FOCS) specifically tailored for the T-80 tunnel. The design of the T-80 tunnel necessitates careful consideration of the mounting arrangement for OHE assemblies, encompassing bracket assembly, drop arm assembly, return current arrangement, earthing, tensioning device, and more, all within sub-zero conditions against the backdrop of the existing tunnel lining. In this regard, the anchoring arrangement for OHE assemblies must be meticulously devised to withstand static and dynamic loads, employing chemical anchor stainless steel fasteners with an embedded length not exceeding 210mm to accommodate the tunnel's 300mm thick concrete lining. Moreover, akin to existing tunnel electromechanical equipment rated at F250, designed to withstand temperatures of 250°C for 2 hours, the proposed OHE equipment within the T-80 tunnel must also adhere to the same fire rating standards to ensure safety and resilience. In essence, this research paper delves into the intricacies of optimizing the overhead equipment system for railway electrification within the challenging terrain of the T-80 tunnel. By proposing the adoption of a FOCS tailored to the tunnel's unique requirements, it seeks to pave the way for enhanced efficiency, reliability, and safety in India's railway infrastructure, furthering the nation's connectivity and progress.

Scope of the Research: -

This research aims to undertake a comprehensive examination of the detailed design work for the 12-kilometer-long overhead equipment (OHE) system, specifically tailored for the unique environmental conditions and operational requirements of tunnel T-80. The scope encompasses the preparation and submission of design and drawings essential for the effective operation of railway infrastructure within the tunnel. Tunnel T-80, situated amidst extreme weather conditions, necessitates meticulous design considerations to ensure optimal performance and safety of the overhead equipment with the compliance of the RAMS (Reliability, availability, maintenance, and safety). The following environmental parameters guide the design process conditions:

- Max. ambient air temperature - 25°C.
- Average day temperature - 22°C.
- Min. Ambient air temperature - 15°C.
- Altitude above MSL -1700 meter .
- Relative humidity - 100%
- Annual Rainfall (Max) - 705 mm.
- Average thunderstorm - 47 days/annum
- Terrain - Hilly
- Climate - Snowbound
- Derating Factor for high altitude - 0.7

In-depth investigations have been conducted to determine the design requirements for all equipment, fittings, lighting, telephones, jet fans, cables, CCTV, and fire-fighting arrangements within the tunnel, fig-1. Notably, these installations have been positioned on the left-hand side above the pathway inside the tunnel, relative to increasing chainage, while the OHE system has been situated on the right-hand side, maintaining a sufficient distance (>2m) from the centerline of the track. The research focuses on devising the layout plan for the entire section, ensuring adequate span length based on clearance and sag calculations by OHE system requirements. The layout plan serves as a blueprint for the installation and integration of overhead equipment within tunnel T-80, catering to the unique operational and environmental challenges presented by the high-altitude terrain and snowbound climate. Through detailed analysis and design considerations, this research endeavors to contribute valuable insights into the optimization and innovation of OHE systems for railway electrification in challenging terrains, ultimately enhancing the efficiency, reliability, and safety of railway operations in high-altitude regions.

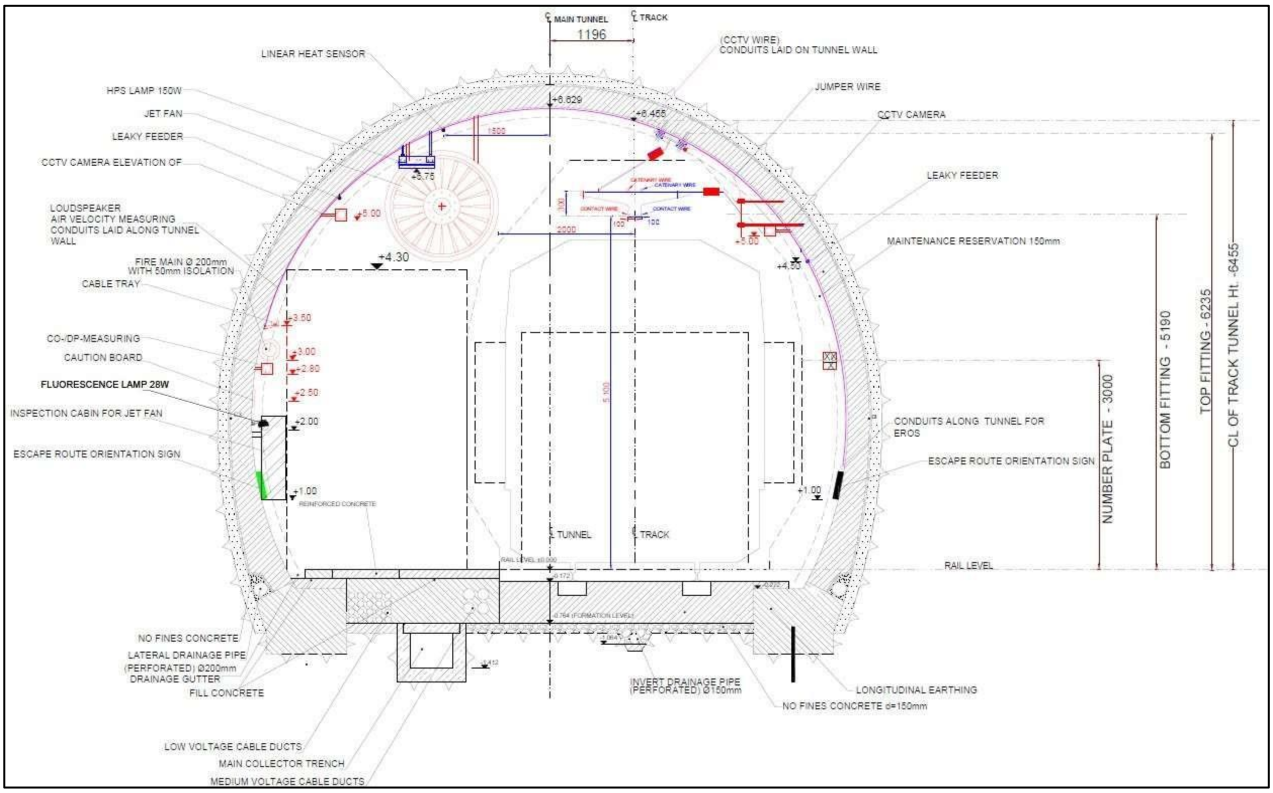

Fig-1: Tunnel full-loaded presentation

1. Span Length selection

The determination of span lengths is a critical aspect of overhead equipment (OHE) design, ensuring optimal performance and safety of railway electrification systems. Several factors influence the selection of span lengths, with particular attention to maintaining the pantograph strip within the current collection zones at permissible speeds and avoiding contact and catenary pushup infringement with required clearances under dynamic conditions. Additionally, the use of a bridge face cantilever for OHE installation inside the tunnel, where the track is eccentrically placed, necessitates careful consideration of span length limitations. The maximum allowable span length is constrained by the encumbrance limitation of the cantilever. As per the AC Traction Manual (ACTM), the maximum span length is determined based on ensuring the shortest dropper length meets the prescribed limit as per standard. Specifically, span lengths exceeding 31.50m result in the shortest dropper length falling below the allowable limit of 150mm, as outlined in ACTM para no- 5.5 vol-ii part –ii.

Several factors govern this limitation:

- Weight of overhead catenary system
- Tension in the conductors of the OHE, where the blow-off is inversely proportional to the tension in

the conductors.

- Lateral sway of the pantograph at top of the locomotive/EMU.
- Stagger effect at mid-span (applicable on tangent track only).
- Versine due to curvature of the track.
- Maximum stagger allowed for contact wire in the curve.
- Safe current collecting zone of the pantograph on either side of its central axis.
- Superelevation of rails of the track.
- By carefully considering these factors, the selection of appropriate span lengths ensures the efficient and safe operation of the OHE system, maintaining compliance with regulatory standards and
- operational requirements.

2. Anti – Creep Anchor

The positioning and installation of anti-creep anchors are critical aspects of railway electrification systems, particularly in tunnels where environmental conditions and structural constraints demand precise engineering solutions. In our research paper, titled "Optimizing Anti-Creep Anchors for Railway Electrification in Tunnels," we focus on the strategic placement and design considerations of anti-creep anchors to ensure the stability and performance of overhead equipment (OHE) wires in high-stress environments. One key finding of our study is the optimal location of the anti-creep anchor within the tension length. Based on our analysis, we recommend positioning the anti-creep anchor approximately in the center of a tension length, ensuring that it is situated within a span of less than 650 meters from one end. This placement maximizes the effectiveness of the anti-creep mechanism in preventing longitudinal movement or "creep" of the OHE wires, thereby enhancing the overall safety and reliability of the electrification system. Furthermore, our research highlights the importance of the fixing arrangement for the anti-creep anchor, particularly in tunnel environments where space constraints and structural considerations pose unique challenges. We propose a design solution that involves fixing the anti-creep anchor to the right-hand sidewall of the tunnel, providing a secure anchorage point while minimizing interference with other tunnel components. Through detailed simulations and field tests, we validate the efficacy of our proposed anti-creep anchor design and installation approach, demonstrating its ability to withstand dynamic forces and environmental stresses commonly encountered in tunnel railway operations. Our research contributes valuable insights to the field of railway electrification engineering, offering practical guidance for optimizing anti-creep anchors in tunnel environments to ensure safe and reliable rail transport infrastructure.

3. Cantilever

I delve into the engineering complexities and design considerations associated with cantilever assemblies used to support overhead equipment (OHE) conductors in railway tunnels. Focusing specifically on the T-80 Tunnel, which employs 25kV AC flexible polygonal regulated OHE, our study aims to provide insights into the design and optimization of cantilever structures to ensure safe and efficient rail electrification operations. One of the key challenges addressed in our research is the unique track geometry and limited clearances inside the T-80 Tunnel, which prohibits the use of traditional bracket assemblies for supporting OHE conductors. To overcome this challenge, we propose the use of bridge-face cantilever assemblies affixed to the tunnel wall surface. These cantilever structures feature a setting distance of 1700mm and are equipped with composite insulators to withstand the environmental stresses and dynamic loads encountered in tunnel railway operations. Additionally, our research emphasizes the importance of maintaining a nominal stagger within the tunnel, with a nominal value of +/- 150 mm on tangent tracks. This stagger adjustment ensures proper alignment and clearance of OHE conductors, minimizing the risk of interference or contact with adjacent components. Through rigorous analysis and calculations, we validate the structural integrity and performance of the proposed cantilever designs, considering factors such as, temperature variations, and dynamic forces exerted by passing trains. By offering practical recommendations and design guidelines, our research contributes to the advancement of railway electrification engineering, providing valuable insights for engineers, planners, and policymakers involved in similar infrastructure projects worldwide.

a) Fixing Arrangements of Cantilever/bracket –

We described the structural aspects and design philosophy for this project. It deals with considerations relating to the structural system used for the Top and Bottom Support of the Ordinary Bracket/bridge face for Tunnel (T-80) for Electrification.

The structural design is to be primarily based on the latest IS/EN codes of practice. Efforts have been made to incorporate all the structural aspects of the project in the paper but revision of the same due to any changes cannot be ruled out and may need necessary updates.

b) Support Structure: The structure is comprised of baseplates, Angles, and anchors assembly used for the support of overhead catenary tensioning equipment support assembly.

c) Material Specifications:

- Built-up Members E250BO (Fe410W) (Fy = 250 MPa) **as per IS: 2062.**
- Pipe & Square/Rectangular Hollow Sections (Fy = 250 MPa) **as per IS: 4923.**
- Anchor bolts Stainless steel (Cr-Ni-Mo-Ti alloy) according to EN-10088 or 316- S-11/ 316- S-31 have been used.
- Concrete grade M25 is adopted for the calculation in the existing tunnel.

d) Design research basis:

Dead Load

All Parts Self- weight (1.05)

Horizontal/Tensioning load

The backsets being Swiveling type, there is no transfer of horizontal tensioning loads (of 2000 kgf) happening at these locations.

Horizontal/Wind loads

Being inside the tunnel, the Wind blowing across does not hit the bracket. The Wind blowing along has only drag forces on tiny areas of the Catenary and Contact wire which eventually gets transferred to the Anchored locations e.g. ATD and the ACAs.

Horizontal/Wind loads

- Anchor Bolts → 4 nos. 20 Dia Embedded in concrete by 210mm (as per calculation).
- Base Plate 210 x 210 x 12 Thick. (For Top Fitting).
- Base Plate 210 x 210 x 15 Thick. (For Bottom Fitting).

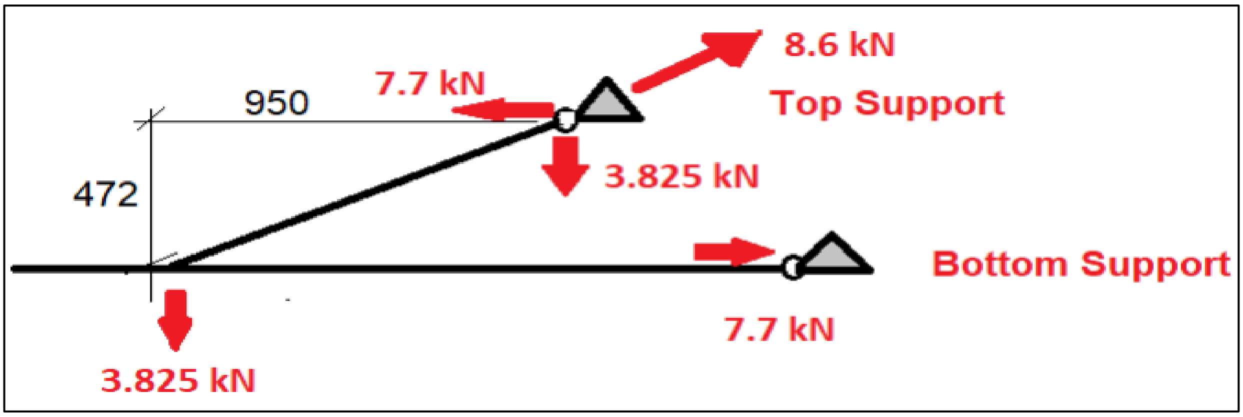

Fig-2: support reaction of bridge face cantilever

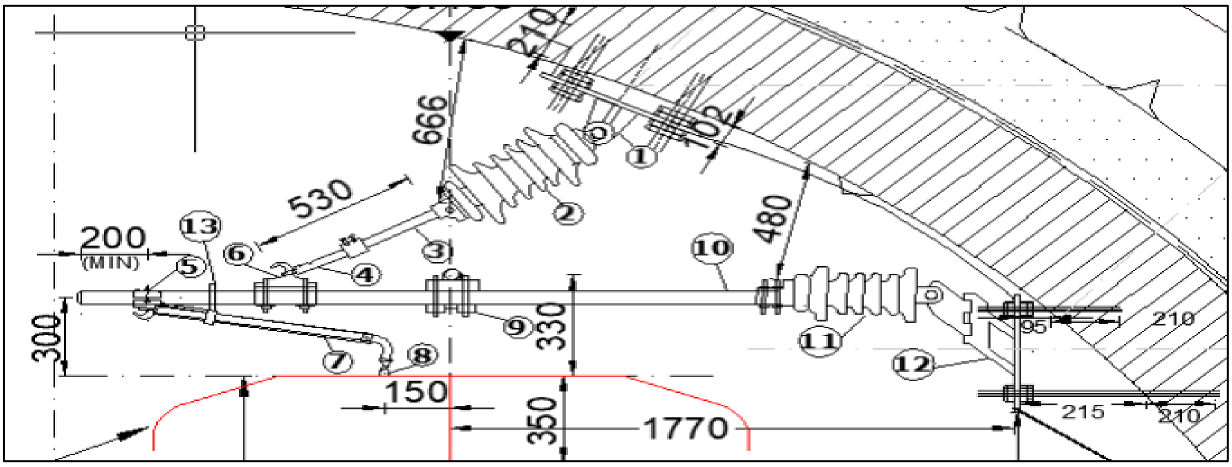

Fig-3: bridge face cantilever overview

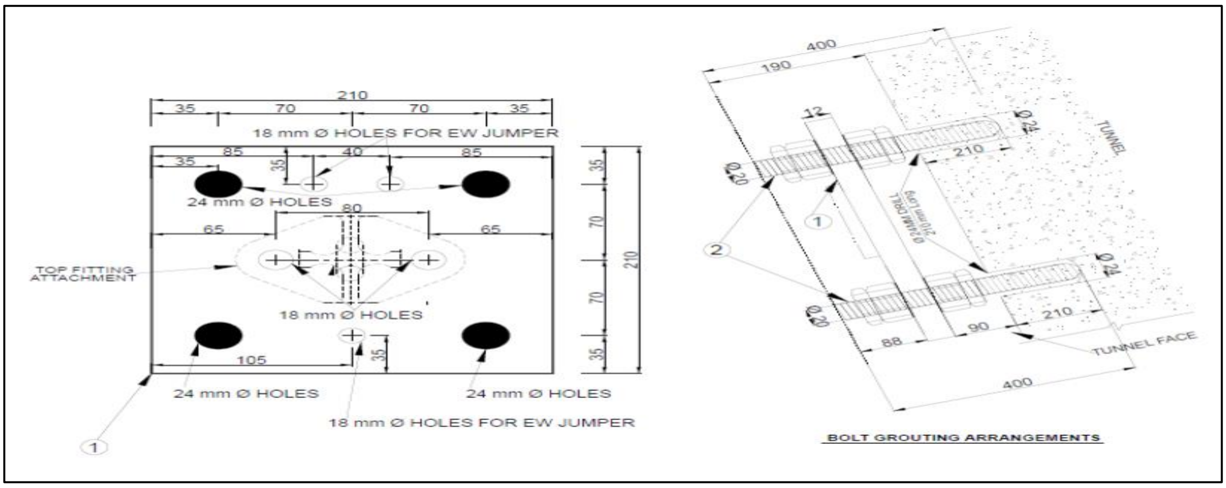

Fig-4: Top bracket base plate

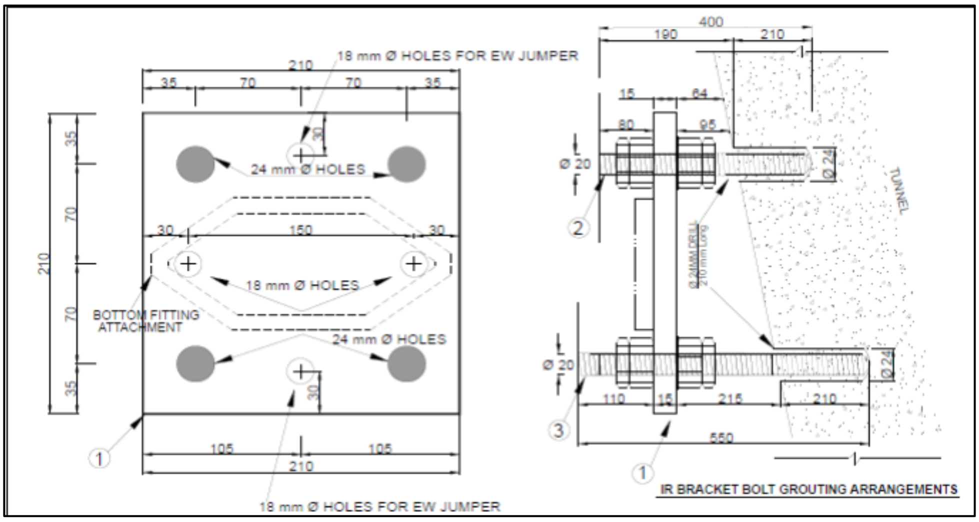

Fig-5: Bottom bracket base plate

4. Auto Tensioning Device:

Auto Tensioning Device is one of the critical components to maintaining constant tension of the overhead contact lines. Since the length of conductors varies according to temperature change, the Contact wire needs to be kept at constant tension as well as uniform height to safely supply the traction power to the pantograph. Therefore, to maintain the Contact wire at constant tension even in case the elasticity varies due to temperature change, the automatic tensioning device (Spring-Type Auto Tensioning Device) has been introduced. The ordinary 3-pulley type ATD shall not be used inside the Tunnel due to space and maintenance issues so in this paper I have suggested the STA (Spring type Auto tensioning device). And I have discussed the selection procedure of the STA in this paper.

Tension Length calculation - The formula for change in length of OHE conductor due to temperature variation is $\Delta L = L_{half} \times \alpha \times (T_{max} - T_{min})$.

Description	Value	Reference	Remarks
α	17×10^{-6} / °C	Thermal expansion coefficient for copper conductors	EN 50149 & EN 50119 shall be applicable
Lhalf	TBC	NA	Half Tension Length
Tmax	35°C + 15°C = 50°C	Maximum conductor temperature (ambient + heating due to loadcurrent)	As per Environmental condition
Tmin	-15°C	Minimum conductortemperature	

Table 1: Tension Length Calculation.

Considering a half tension length of 600m, the corresponding horizontal elongation of theconductor is:
$\Delta L = 600m \times (17 \times 10^{-6}) \times (50-(-15)) = 0.663m = 663mm$
Considering 5% extra tolerance, $\Delta L = 663 * 1.05 = 696 \approx 700mm$
Therefore, an automatic tension device offering a compensating length (Stroke) of > 700mm and can

withstand the conductor tension of 2000kgf±10% can be adopted for tensioning the contact and catenary wire but as per recommendations Spring Type ATD is required to be used inside T-80 Tunnel.
A typical comparative calculation for different Strokes of Spring Type ATD is given below:

ficient of thermal expansion; α	17 x 10^{-6} / °C	17 x 10^{-6} / °C
Tmax	50 °C	50 °C
Tmin	-15 °C	-15 °C
Stroke (m) as per Vendor	0.700	0.800
ximum half tension length, Lhalf (m)	600	700
Maximum Full Tension Length (m)	600 * 2 = 1200	700 * 2 = 1400

Table 2: Comparative Calculation for different strokes of Spring ATD

a) Fixing Arrangements or STA:

The structural system used for the support of overhead conductor tensioning equipment (i.e. ATD) support assembly for Tunnel (T-80) for Electrification. The structural design is to be primarily based on the latest IS/EN codes of practice. Efforts have been made to incorporate all the structural aspects of the project in the paper but revision of the same due to any changes cannot be ruled out and may need necessary updates.

b) Support Structure: The structure is comprised of baseplates, Angles, and anchors assembly used for the support of overhead cable tensioning equipment support assembly.

c) Material Specifications:

- Built-up Members E250BO (Fe410W) (Fy = 250 MPa) **as per IS: 2062.**
- Pipe & Square/Rectangular Hollow Sections (Fy = 250 MPa) **as per IS: 4923.**
- Anchor bolts Stainless steel (Cr-Ni-Mo-Ti alloy) according to EN-10088 10088-3:2005 Class- A4 (X5CrNiMo17-12-2) have been used.
- Concrete grade M25 is adopted for the calculation in the existing tunnel.

d) Design research basis:

- **Dead Load**

All Parts Self- weight (1.05)

- **Horizontal/Tensioning load**
- Horizontal tensioning loads of 2000 kgf (20 kN) have been applied to the support assembly at these locations.

e) Members Sizes taken:

At Anchor Location-A	At Stub Location-B	At SATD Hanger Location-C
Anchor Bolts → 4 nos. 24 Dia 400 Long, Angle Connected to Anchor Bolts → 75x75x10 Thk.	Anchor Bolts→4 nos. 24 Dia 400 Long, Base Plate- 550X550X30 Thk.	Anchor Bolts → 4 nos. 24 Dia 400 Long, Angle Connected to Anchor Bolts → 75x75x10 Thk.

Table 3: Member size for STA

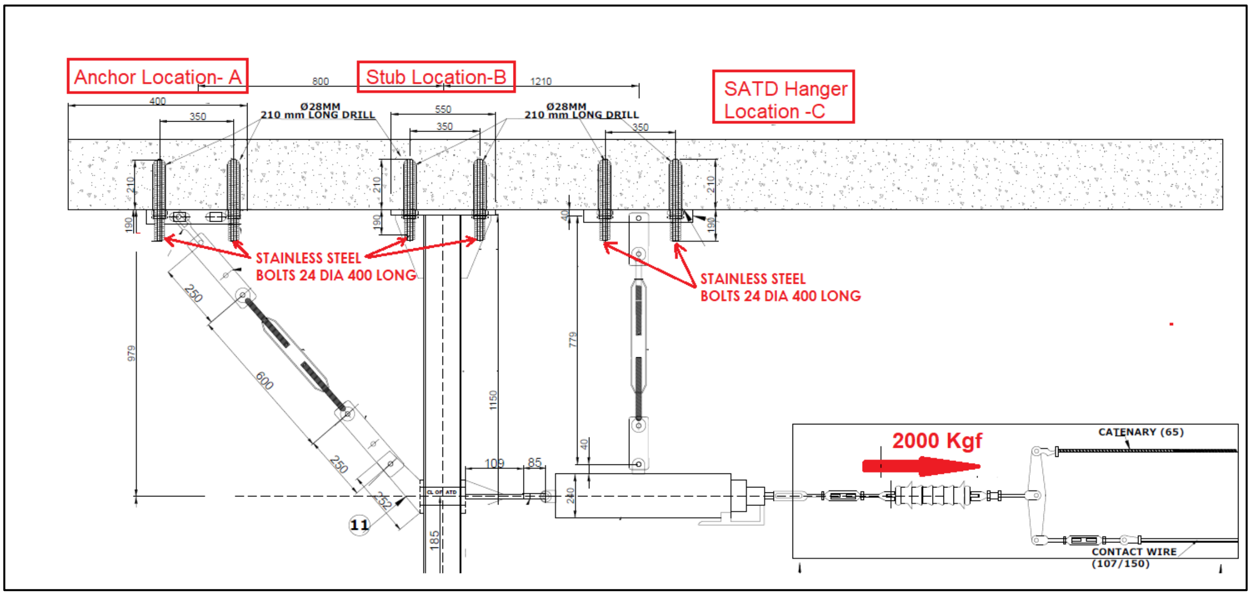

Fig-6: Tensioning Member Support Assembly

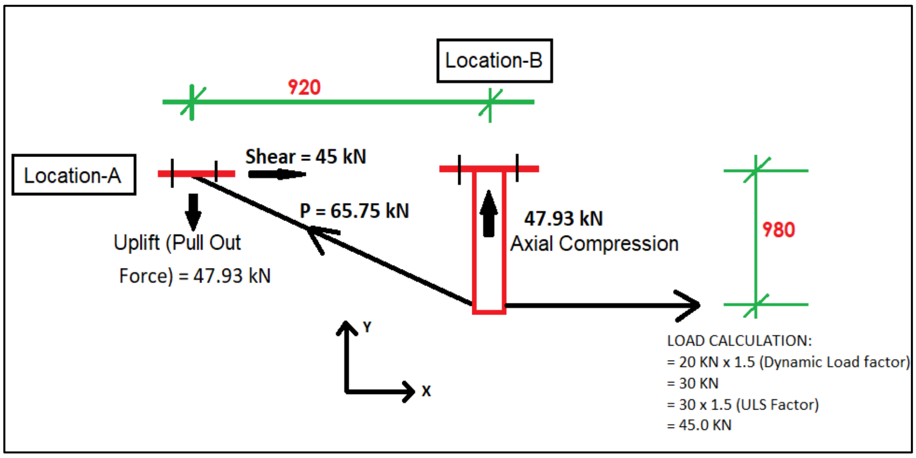

Fig-7: support reaction of STA

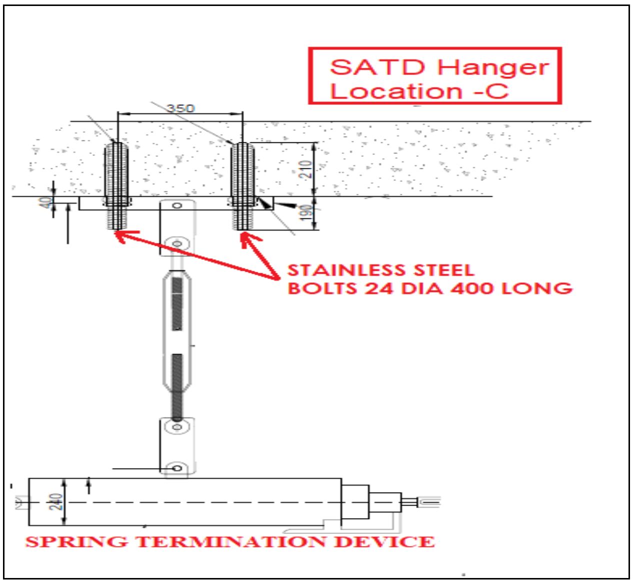

Fig-8: STA Hanger Location-C

Based on the calculation at this location, the hanger is not transferring any horizontal load being hinged by bolts at the top and bottom. In addition, the only vertical force being transferred at this location is the weight of the Spring Type Auto Tensioning Device weight (including SPS).

5. Fire Protection Concept:

Fire Rating required for all overhead equipment- 2hrs at 250°C. This would mean the componentshave to achieve 2 hours of fire resistance in a standard test by ASTM E119. 2-hour fire rating relates only to the ability of individual components and assemblies in a building to meet the required performance in the standard test for 2 hours. The temperature of 250°C does not cause any melting or plastic

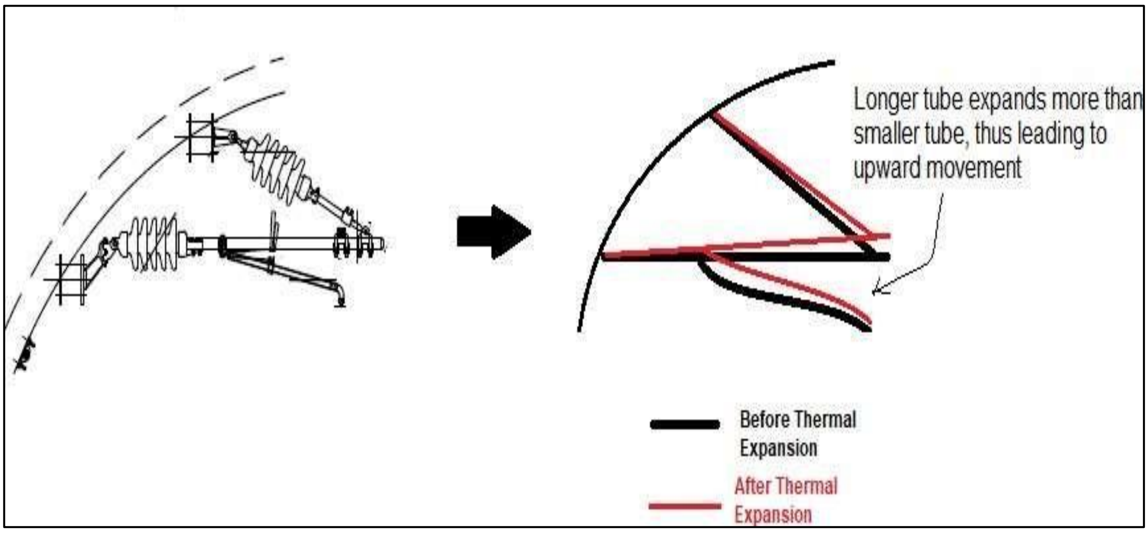

Fig-8: Fire Scenario Impact

deformation of the Bracket/ Stay Tube. The tubes can only elongate. But being swivel type, the bracket will have no problem. Similarly, the effect of Raised Temperature in the Catenary and Contact wire localized fire can be minimal, and that too due to the local elongation of the wire. 250°C is very far from the melting point of copper (i.e. 1075°C), and there is no melting or plastic deformation. In any case, the tunnel having a fire scenario of 2 hours without much oxygen or flammable material inside, doesn’t look likely.

6. Effect of Sub-Zero Temperature inside the tunnel:

For this project, I must investigate the effects of extreme cold conditions on the performance and durability of various components of overhead catenary systems (OCS/OHE) within tunnel environments. Focusing on the T-80 Tunnel project and similar high-altitude railway electrification projects, we analyze the design considerations and material properties necessary to withstand sub-zero temperatures effectively. The sub-zero temperatures encountered in high-altitude railway tunnels pose significant challenges to the structural integrity and functionality of OCS components. Our study assesses the impact of low temperatures on key materials used in OCS construction, including steel, copper, and porcelain insulators.

Effect on Steel: Through our analysis, we determined that steel components of the OCS, such as support structures and cantilevers, exhibit minimal susceptibility to sub-zero temperatures. Steel's inherent strength and resilience make it well-suited for enduring cold conditions without experiencing significant material degradation or performance issues.

Effect on Copper: Similarly, copper conductors utilized in the OCS demonstrate negligible effects from sub-zero temperatures. Copper's excellent conductivity and ductility enable it to maintain optimal electrical performance and mechanical integrity even in extremely cold environments, ensuring reliable power transmission within the tunnel.

Effect on Porcelain: Porcelain insulators, commonly employed in OCS/OHE installations for their high electrical insulation properties, also exhibit minimal susceptibility to sub-zero temperatures. Porcelain's low coefficient of thermal expansion and excellent thermal stability allow it to withstand freezing temperatures without compromising its insulating capabilities or structural integrity.

My findings indicate that the design of OCS/OHE components for high-altitude tunnel applications must prioritize materials and configurations capable of withstanding sub-zero temperatures effectively. By selecting robust materials and implementing appropriate design strategies, railway engineers can ensure the reliable and safe operation of overhead catenary systems in cold and challenging tunnel environments, facilitating efficient rail electrification and transportation in mountainous regions.

7. Resistance against Seismic Forces and Vibrations

I must investigate the capacity of overhead catenary systems (OCS/OHE) to withstand seismic forces and mechanical vibrations prevalent in tunnel environments, particularly in earthquake-prone regions. Focusing on the T-80 Tunnel project and similar high-altitude railway electrification projects, we analyze the design considerations and structural integrity required to mitigate the effects of seismic events and vibrations on OCS components.

Bracket: The bracket, being of swivel-type design, demonstrates minimal susceptibility to seismic forces and vibrations. Its ability to rotate and adapt to dynamic movements helps mitigate the impact of ground motion, ensuring the stability and functionality of the OCS.

Wires (Catenary and Contact): The catenary and contact wires may experience additional forces and displacement during seismic events, necessitating careful consideration in their design and installation. Evaluating their capacity to withstand increased acceleration and dynamic loading is essential for preventing wire sagging or breakage, which could compromise the safety and reliability of the OCS.

Incorporating relevant Indian Standard Codes, such as IS:1893:2016 - Criteria for Earthquake, into the design and assessment of OCS components is imperative for ensuring compliance with seismic safety regulations and mitigating the risks associated with earthquake-induced ground motion. By adhering to robust design standards and conducting thorough structural analyses, railway engineers can enhance the resilience and performance of OCS in high-altitude tunnel environments, safeguarding railway infrastructure and operations against seismic events and vibrations.

8. Earthing & Bonding Methodology Inside the Tunnel

CDEG software performed an earthing & bonding simulation study for the T-80 tunnel and proposed an appropriate scheme for the safe & reliable operation of the system The following cases were simulated -

- Normal Condition
- Short Circuit
- Rail Breakage

a) Tunnel Earth Wire Sizing

To carry partial traction, and return current, Tunnel earth wire (TEW) is proposed inside the tunnel. TEW also provides earthing for the exposed part of the OHE network (bridged cantilever). A tunnel earth wire of 95 sq. mm. copper is proposed and is running with a suitable mounting arrangement below the bridged cantilever running throughout the tunnel stretch The TEW is terminated to the Earth-mat outside the tunnel at both sides. The Thermal Sizing of earth wire is based on Annexure. A of BS EN 60865-1: Short-circuit currents — Calculation of effects- Part 1: Definitions and calculation methods of the current limits on conductors concerning thermal parameters.

b) Modelling of 1x25 kV Network

The 1×25 kV single-phase transformer at Traction sub station supplies power to the rolling stock. In this system, the current is mainly carried between the OHE and return through the rail. The below component is modeled as per arrangements and inputs.

• TSS transformer
• TSS Grid
• • Contact & Catenary wire
• Rolling Stock as lumped load

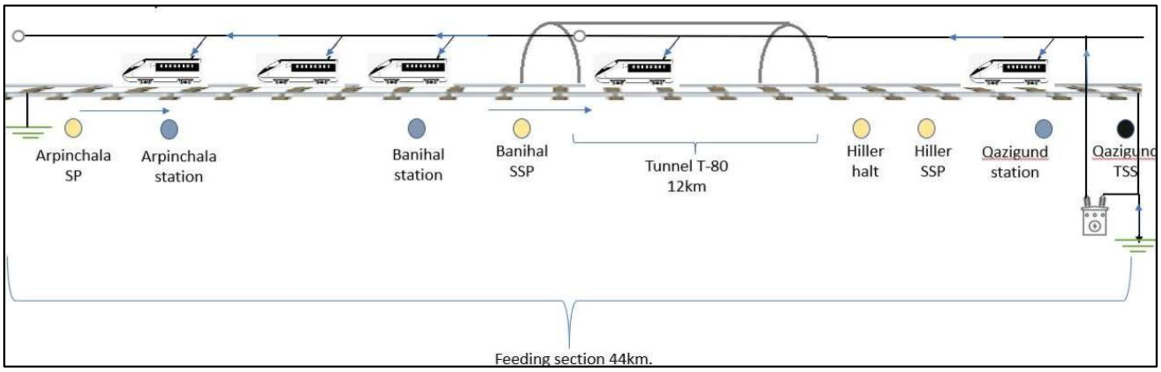

Fig 9: T-80 Tunnel Network Model overview

As per Table 6 of BS EN 60865-1

$$S_{thr} = \frac{1}{\sqrt{T_{kr}}} \sqrt{\frac{\kappa_{20}\, c\, \rho}{\alpha_{20}} \ln \frac{1+\alpha_{20}\left(\vartheta_e - 20\ {}^\circ\mathrm{C}\right)}{1+\alpha_{20}\left(\vartheta_b - 20\ {}^\circ\mathrm{C}\right)}}$$

For 1 Second Withstand time

Description	**Notation**	**Value**	**Unit**
Conductor Cross Section	A	9.5E-05	Sq. m
Fault Duration	T_{kr}	1	Second
Specific Thermal Capacity	c	390	J/ (kg K)
Specific Mass	θ_ρ	8900	kg/m3
Temperature Coefficient	α_{20}	0.0039	1/K
Temperature Limit	θe	170	˚C
Initial Temperature of Conductor	θ_b	40	˚C
Specific Conductivity at 20˚C	K_{20}	5.6E+06	1/Ωm
Maximum Current	S_{thr}	13167	Amps

Table 4: 1 Second Withstand time

For 0.3 Second Withstand time:

Description	**Notation**	**Value**	**Unit**
Conductor Cross Section	A	9.5E-05	q. m
Fault Duration	T_{kr}	0.3	econd
Specific Thermal Capacity	c	390	(kg K)
Specific Mass	$\theta\rho$	8900	g/m3
Temperature Coefficient	α_{20}	0.0039	K
Temperature Limit	θ_e	170	C
Initial Temperature of Conductor	θ_b	40	C
Specific Conductivity at 20˚C	K_{20}	5.6E+06	Ωm
Maximum Current	S_{thr}	43892	mps

Table 5: 0.3 Second Withstand time

As per EN 60865-1, the thermal rating calculation was performed for TEW (95 Sq.mm Cu conductor). The maximum current allowable for 0.3 Sec is 43.89 kA and for 1 Sec is 13.16 kA. However, from the simulation, it is inferred that the max. short circuit current is 5 kA. Hence, the sizing of TEW is sufficient.

Conclusion:

In conclusion, this research paper has provided compelling evidence in favor of adopting the Flexible Overhead Equipment/Overhead Contact System (OHE/OCS) system over the Rigid Overhead Contact System (ROCS) for railway electrification projects, particularly in high-altitude tunnel environments such as the T-80 Tunnel in Jammu and Kashmir. By extensively analyzing the cost-effectiveness, technical feasibility, and safety considerations of both systems, we have demonstrated that the OHE/OCS system offers significant advantages in terms of cost savings, installation flexibility, and performance resilience.

Our findings indicate that the OHE/OCS system can potentially save approximately 13-14 lakh per kilometer compared to the ROCS system, making it a more economical choice for railway electrification projects, especially in challenging terrains like mountainous regions. Additionally, we have outlined specific technical specifications and installation procedures for the OHE/OCS system, including the use of full-thread 8.8-grade HDG bolts grouted with non-shrinkable cementitious grout to ensure structural integrity and stability.

Furthermore, we have highlighted the importance of using advanced technologies and specialized equipment, such as Spring Type Auto Tensioning Devices (ATDs), to maintain optimal tension and performance of the overhead conductors inside the tunnel. By selecting the appropriate ATD model, such as the KRSB-20-S76 model from D2 Engineering, Korea, railway authorities can ensure the reliable and efficient operation of the OHE/OCS system in the T-80 Tunnel and similar infrastructure projects.

Overall, our research supports the in-principal approval of the OHE/OCS system by the Research Design and Standards Organization (RDSO) and recommends its implementation in the T-80 Tunnel project. By embracing innovative solutions and leveraging international best practices, railway authorities can enhance the efficiency, safety, and sustainability of railway electrification initiatives, ultimately contributing to the modernization and development of railway infrastructure in India.

Acknowledgement:
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