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BIM in Optimization of Power Duct for Efficient Cable Routing: An Industrial Approach

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Abstract

Objectives: This study was conducted to achieve optimized power duct sizes with ensuring sufficient bending for the electrical cables at the road junction locations. **Methods:** Used Revit tool, a Building Information Modelling (BIM) technology to integrate the design data of electrical cables and for modelling the power duct structure. Tools in the Revit software were used to automate the cable bending and clash detection simulations tasks. **Findings:** With the help of these tools, we modeled cable routing and optimized power duct structure sizes, saving 90% of man-hours and achieving 20% cost savings at the site compared to conventional methods. **Novelty:** It's a pioneering effort to integrate the design data of electrical cables and automate the cable routing by ensuring the sufficient bending radius by utilizing the tools in the Revit software. And optimization of the power duct size at the cable transition locations by performing multiple simulations of the model and clash detection.

Keywords: BIM; Revit; Virtual Design; Cable Routing; Electrical Design

1 Introduction

Smart cities are territories with a strong capacity for learning, innovation and creativity, supported by their population, knowledge institutions, and digital infrastructure and considered the future for advancing a nation's economy. The concept of smart city projects is to enhance quality of life, promote sustainability, drive economic growth, improve governance, and create more liveable, efficient, and connected communities for their residents. The smart city concept envisions cities as creative, sustainable areas that enhance quality of life, promote environmental friendliness, and bolster economic development prospects [1]. These projects are crucial for addressing the complex challenges of urbanization and development in India.

Dholera SIR (Special Investment Region) is a smart city project that was initiated by the Government of India. To oversee its development, Dholera Industrial City Development Limited (DICDL) was established as a project development corporation. The development plan and six town planning schemes have been prepared and approved by the Gujarat Infrastructure Development Authority (GIDB). DICDL plays an active role in the development of DSIR, with a specific focus on the TP2E area. The Dholera SIR project (Figure 1) extends approximately 57 sq. km and includes around 174.25km of roads with varying right-of-way widths from 12m to 55m. These road reserves also house essential services and utilities, such as storm water drainage, water supply, sewerage, power, telecommunications, and gas infrastructure.

The increase in urbanization, living standards, and technological advancements has led to a higher demand for energy. Smart Grid technology offers a solution by improving the generation, transmission, and distribution of electric power efficiently [2].

Power ducts were installed along the road network to accommodate electrical cables. However, challenges arose due to spatial constraints at road junctions. To overcome this, a BIM-based optimization approach was employed to evaluate and adjust power duct dimensions, allowing for optimal cable accommodation. As BIM offers an integrated platform for collaborating with multiple discipline models, simplifying planning for designers, and facilitating smooth construction by detecting and resolving clashes with other utilities during the design phase. [3]

BIM plays a pivotal role in designing complex projects due to its ability to address intricate designs. BIM can enhance the quality of building design information and establish effective mechanisms for sharing information among project team members. BIM has a broad range of potential application, from predicting subsidence risk to managing the maintenance [4]. The 3D visualization of the project aids in decision-making. Additionally, the BIM model continues to be valuable after construction, assisting in facility management and simplifying asset maintenance. BIM is instrumental in achieving optimal power duct design, streamlining decision-making processes, and ultimately resulting in significant time and cost savings. By leveraging BIM, the project team can identify potential issues early, thus circumventing the need for costly on-site rework. This proactive approach not only enhances efficiency but also contributes to substantial cost reductions, underscoring the value of BIM in the project's overall success.

The journal paper [3] discusses socket installation and external duct for buildings, focusing on comparing 2D CAD and BIM use cases. Another article [5] demonstrates an automatic generation method for MEP hangers that can serve as cable trays. Research paper [6] discusses various factors governing the energy consumption of a building and methods for energy efficient building design. This paper presents a methodology for automatically generating cable routing in underground power duct networks in infrastructure projects. While other journal articles focus on energy analysis, cable trays, and differences between 2D CAD and BIM, this paper specifically addresses automating cable routing at power duct junction locations using BIM tools.

Custom BIM models were created for seven key junctions, assessing cable bending limits and guiding dimension adjustments. This led to optimized power duct designs, ensuring smooth cable routing and successful integration at these junctions [7]. Looking ahead, the project endeavors to extend these optimized designs to all junctions across the project, resulting in an effective power duct design.

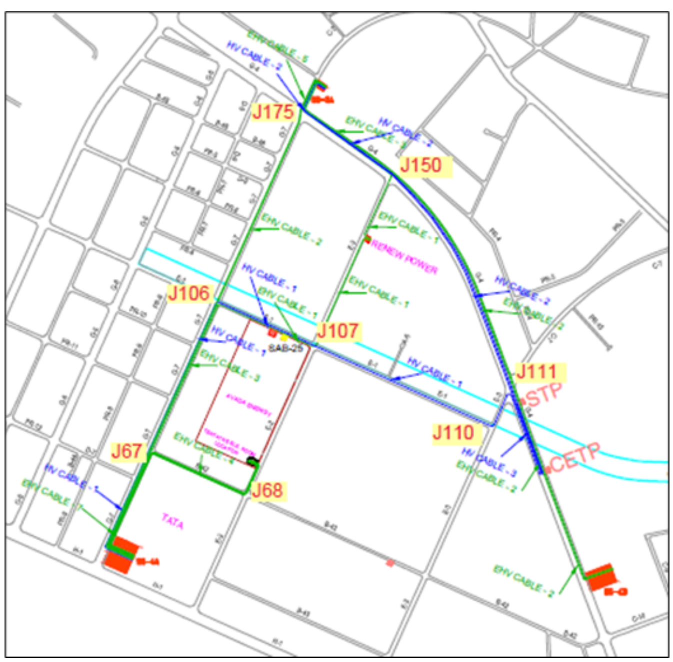


Fig 1. Layout of Dholera SIR project

1.1 Background

Power ducts play a pivotal role in this project, as they are designed with the different capacities of electrical cables from the substation locations to all the plots in the entire project. These power ducts come in different sizes and widths of 1.7m, 2.2m, and 2.7m. They were strategically constructed along the road network to accommodate electrical cables, aligning with the client's specifications. After construction, the power ducts were handed over to the client for the subsequent phase, which involved cable installation.

The responsibility for cable installation across the entire project was assigned to a third-party company. In this project, the electrical cables possess capacities of 33kV and 11kV, and they are of the 3-core Armored type. The armoring serves the crucial purpose of safeguarding the cable against mechanical damage. It is applied either directly over the core insulation or the inner sheath, depending on whether the cable is single-core or multi-core. However, significant challenges arose during this phase, particularly at all 84 road junctions, due to spatial limitations. The issue came to light during the cable installation process, specifically when attempting to route the cables from the power ducts to the cross duct (Figure 2) at these road junction locations. It became evident that the cables did not satisfy the necessary minimum bending radius required for entry into the cross duct, leading to complications and hindrances in the installation process.

This inadequate bending radius of the electrical cables could result in:

- **Cable damage:** When a cable is bent beyond its recommended minimum bending radius, it can cause the inner conductors or insulation to crack or break. This can result in electrical faults, short circuits, or open circuits.
- **Increased resistance:** Higher resistance can result in a voltage drop along the cable, which can affect the performance of connected devices and may even lead to overheating.
- **Reduced lifespan:** Cables that are bent too tightly can experience accelerated wear and tear, reducing their overall lifespan. Premature cable failure can be costly and lead to downtime in electrical systems.
- **Overheating:** Tight bends can restrict airflow around the cable, preventing proper heat dissipation. Over time, this can lead to overheating of the cable and adjacent components, posing a fire hazard and potentially damaging the cable's insulation.
- **Code violations:** In many electrical codes and standards, there are specific requirements for minimum bending radii to ensure safe and reliable installations. Failing to adhere to these regulations can result in non-compliance and potential legal or insurance issues.
- **Safety risks:** Improperly bent cables can create safety hazards, such as tripping hazards, if they are not routed properly or if they are damaged and exposed. Additionally, damaged cables can pose electric shock risks.

If a cable needs to be bent, it should be done carefully and without excessive force to maintain its integrity and performance. Unsupported cables were also at risk of premature failure at connector interfaces. Adhering to industry standards and electrical codes is crucial to ensuring safe and reliable electrical installations.

To prevent the above-mentioned damage to electrical cables, it is imperative to adhere to the prescribed bending radius specifications for each specific cable type and size. This study has been instrumental in comprehending customer requirements and assessing the design criteria based on IS codes and prevailing industry practices. The objective is to determine the minimum bending radius necessary to safely install electrical cables.

The efficient utilization of BIM in modelling existing conditions, coupled with the integration of cutting-edge tools for cable modelling, enables a thorough analysis of cable routing and facilitates the development of superior solutions. BIM serves as a pivotal tool in this regard, as it permits the evaluation of multiple solutions through adjustments to existing power duct structures.

A solution needs to be devised for the pre-existing power duct structures already in place on the site, along with their proximity to other utilities. Therefore, a thorough examination of on-site conditions and nearby structures is imperative to ensure feasibility. The solution must not have any adverse effects on the nearby structures.

When formulating the plan for routing the electrical cables, it is crucial to guarantee the maintenance of a proper bending radius. Additionally, safety concerns must be given paramount attention, particularly since these electrical cables are responsible for carrying a substantial power capacity.

2 Methodology

The BIM-based optimization approach was employed, focusing on comprehending the interactions between the design and implementation phases. BIM, in this context, is viewed as a process rather than a mere tool or piece of software. The methodology embraced to resolve this issue is illustrated in Figure 3.

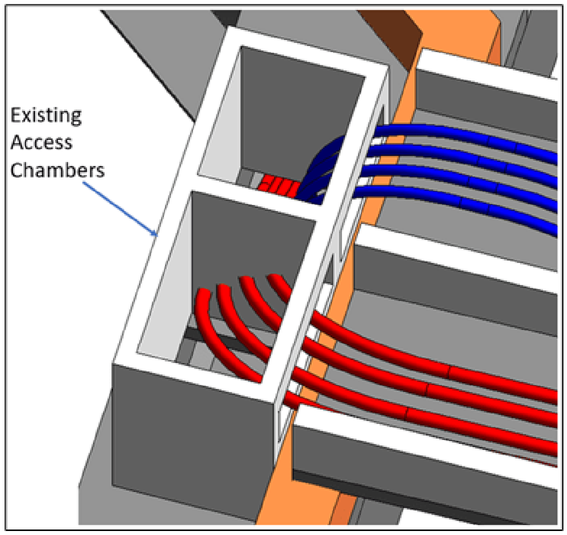


Fig 2. 3D Cable routing in Existing Power duct model

Ensuring an adequate bending radius for the electrical cables as they transition from the power duct to the cross duct is of paramount importance, alongside the need to reduce construction costs by optimizing the power duct. Recognizing the significance of this issue, both the customer and the project site team sought a solution. For the design team, finding a resolution using conventional methods through AutoCAD drawings and graphical representations proved to be a challenging endeavour, prompting the adoption of BIM as a more effective approach. Based on the origins of 3D modelling inputs, researchers have put forth a series of recommendations that should be considered when constructing a BIM model to facilitate production planning and control.

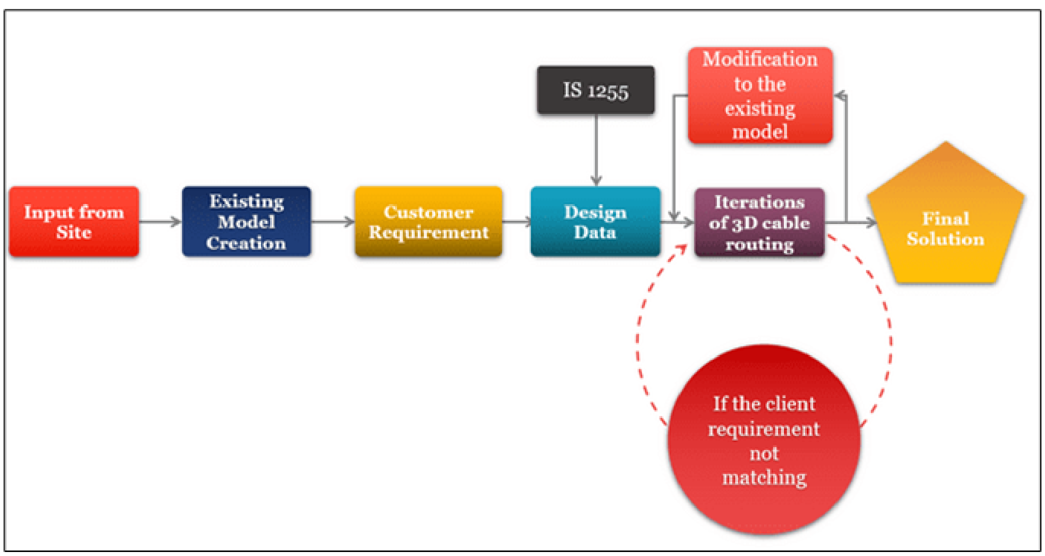


Fig 3. Processes Involved

- **Input from Site**: Collection of on-site data from the project site team regarding the construction particulars of cross ducts, power ducts, and their corresponding access chambers, as well as comprehensive details concerning nearby utilities.
- **Existing Model Creation**: An existing model has been developed using the data gathered from the site, which accurately reflects the prevailing site conditions.

- **Customer Requirement**: After multiple discussions with both the customer and the cable installation contractor, the requirements concerning the number of electrical cables passing through each power duct and the capacity of these cables have been obtained and documented.
- **Design Data**: The design data for the bending radius of the electrical cables has been gathered from the design team, following IS 1255 code standards.
- **Iterations of the 3D Cable Routing**: Generated electrical cable models with varying capacities for routing within the power ducts and cross ducts. Multiple iterations were performed to meet the customer's specifications. Adjustments were made to the existing power duct structures and their access chambers to determine the optimal cable routing, ensuring it complies with the customer's requirements while maintaining a sufficient bending radius.
- **Final Solution**: Using BIM models, we have developed several potential solutions that can be visually presented to all stakeholders involved. This approach enhances understanding and facilitates informed decision-making to reach a final consensus.

Following extensive discussions with both the project site and design teams and considering the provided customer requirement data, a total of eight road junctions were identified within the project. These junctions were selected based on considerations such as the size of the power ducts and the capacity of the electrical cables passing through them. This project has power ducts of three different sizes of 1.7m width (W) x 1.8m depth (D), 2.2m W x 1.8m D and 2.7m W x 1.8m D and cross ducts of size 1.5m W x 0.6m D. As-built data for the power ducts, cross ducts and other utilities was collected from the project site team for these eight road junctions.

To develop a solution for this issue, it became very difficult for the design team to use the conventional methods of AutoCAD drawings. The design team would not be able to develop a proper solution until and unless there was proper visual confirmation of the electrical cables passing through the cross ducts from the power duct with a sufficient bending radius.

To tackle this challenge, BIM has been embraced as the solution for ensuring the correct installation of electrical cables from the power duct to the cross duct. Additionally, BIM allows us to evaluate and adapt the dimensions of the power duct for optimal cable accommodation. BIM utilizes actual engineering data to create 3D models, enabling the identification and reduction of errors and conflicts even before construction begins on-site[8]. Its importance is underscored in various facets of the construction and design process, encompassing precise modelling, visual communication, and informed decision-making.

Here's how BIM Contributes to these areas:

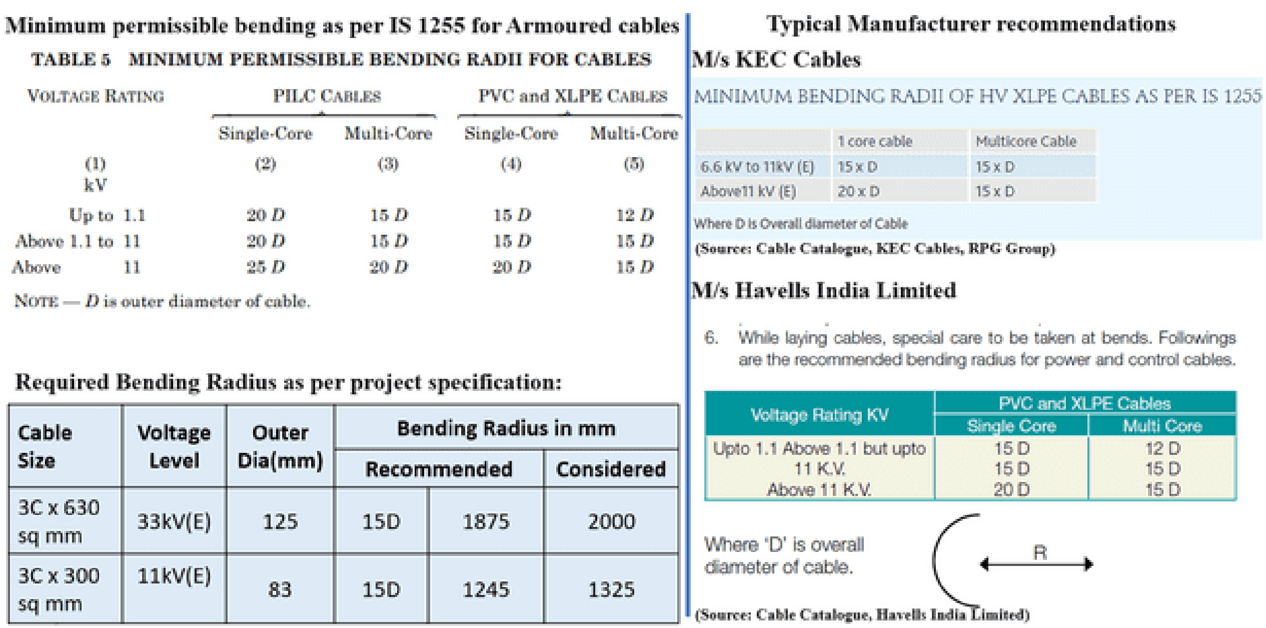
- **Accurate Modelling**: BIM enables the precise modelling of electrical cables, ensuring they are accurately sized and correctly positioned within the designated power ducts.
- **Clash Detection**: BIM software can automatically identify clashes or conflicts between different electrical cables and other structural components, such as power duct walls, access chambers, or any additional structures[9]. This early detection capability serves as a proactive measure to prevent costly errors and the need for rework during the construction phase.
- **Visual Communication**: 3D Visualization: BIM models offer comprehensive 3D representations of the project, enhancing stakeholders' comprehension of the design and construction processes. These visualizations encompass rendered images showcasing the arrangement of electrical cables within the power duct, as well as walkthroughs illustrating the path of electrical cables from the power duct to the cross duct. These visual aids significantly improve communication and understanding among project participants.
- **Simulation and Analysis**: BIM enables the execution of multiple simulations for electrical cable routing following customer requirements. These simulations provide valuable visual insights for evaluating the design's feasibility and performance.
- **Stakeholder Engagement**: BIM visualizations streamline engagement with customers, the project site team, the design team, and other stakeholders, enabling them to offer valuable feedback and approvals more effectively.
- **Decision Making**: Design Iteration: BIM facilitates the effortless exploration of various design alternatives. Design teams can swiftly generate and compare different design options, aiding in the identification of the most cost-effective and sustainable solutions.

In summary, BIM enhances collaboration and communication among project stakeholders, minimizes errors and rework, enhances project efficiency, and facilitates data-driven decision-making across the entire lifecycle of a structure. It has evolved into an indispensable tool within the construction and design industry, empowering teams to deliver projects with greater precision and efficiency, all while mitigating risks and reducing costs.

Revit software was chosen to create the BIM models and analyse the electrical cable routing. Revit offers an intelligent network for cable routing, utilizing both automatic and manual wiring systems. The software includes built-in technology for calculating the bending radius of cable sizes and routing connections [10]. These tools allowed for the precise loading of design data, including cable diameter and minimum bending radius, ensuring accurate cable modelling that adhered to the required bending radius. This helps in the elimination of manual errors. Power ducts, along with the access chambers and crossing ducts for all eight road junction locations were modelled in Revit software to reflect on-site conditions accurately. According to project specifications, the customer provided requirements for the electrical cable capacity and the number of cables passing at each junction (Table 1). We have chosen XLPE cable for the installation because of the characteristics and advantages these cables possesses like excellent electrical and physical properties, the capability of carrying large currents, ease of installation, free from height limitations and maintenance [11]. The design team determined the minimum bending radius for Armoured cables based on IS 1255 and consulted recommendations from leading cable manufacturers like KEC Cables and Havells India Limited. Following IS 1255 guidelines, a minimum bending radius of 15 times the cable diameter was considered [12]. It was concluded that for 33kV cables with a 125mm diameter, a minimum bending radius of 2000 mm is required, while for 11kV cables with 83mm diameter, a minimum bending radius of 1325mm is necessary (Figure 4).

Table 1. Customer's Requirements

S. No	Junction Name	Number of cables in Cross duct		Cross duct location	Width of Power duct (m)
		11 kV	33 kV		
1	J-67	1	3	Road B-42	1.7
2	J-68	-	4	Road B-42	1.7
3	J-106	-	2	Road E-1	2.2
4	J-107	1	1	Road E-2 Road E-1	2.2
5	J-110	1	-	Road E-2	2.2
6	J-111	-	2	Road C-7	1.7
7	J-150	-	1	Road G-4	2.7
8	J-175	-	2	Road G-4	2.7



Voltage Rating	PILC Cables Single-Core	PILC Cables Multi-Core	PVC and XLPE Cables Single-Core	PVC and XLPE Cables Multi-Core
(1) kV	(2)	(3)	(4)	(5)
Up to 1.1	20 D	15 D	15 D	12 D
Above 1.1 to 11	20 D	15 D	15 D	15 D
Above 11	25 D	20 D	20 D	15 D

Cable Size	Voltage Level	Outer Dia(mm)	Bending Radius in mm Recommended		Considered
3C x 630 sq mm	33kV(E)	125	15D	1875	2000
3C x 300 sq mm	11kV(E)	83	15D	1245	1325

	1 core cable	Multicore Cable
6.6 kV to 11kV (E)	15 x D	15 x D
Above11 kV (E)	20 x D	15 x D

Voltage Rating KV	PVC and XLPE Cables Single Core	PVC and XLPE Cables Multi Core
Upto 1.1	15 D	12 D
Above 1.1 but upto 11 K.V.	15 D	15 D
Above 11 K.V.	20 D	15 D

Fig 4. Design Data from IS 1255 for cable bending

To meet the design criteria and customer requirements, routing of electrical cable modelling commenced within both the power duct and the cross duct using conduit modelling techniques in Revit software. Before commencing the modelling work, two categories of conduits were created by modifying their parameters in the MEP Settings within Revit software. Created two standards for electrical cables of capacities 11kv and 33kV with the size of the conduit and the minimum bending radius to be maintained. Started modelling the routing of the conduit by selecting the appropriate start and end points. Revit will use the predefined or modified conduit type to create the conduit run, ensuring it meets the specified size and properties. Since the cables in the power duct and cross duct occupied different levels, the conduit tool facilitated connections between them while maintaining the prescribed minimum bending radius. Manual adjustments were made to the routing alignment to prevent clashes with surrounding elements. By using Revit's analysis tools, we have reviewed and analysed the conduit system for clashes, conflicts and other issues. We also ensured compliance with design and construction requirements.

3 Results and Discussion

Following a preliminary model analysis and simulations of cable routing, we identified two distinct solution categories based on power duct dimensions and cable routing.

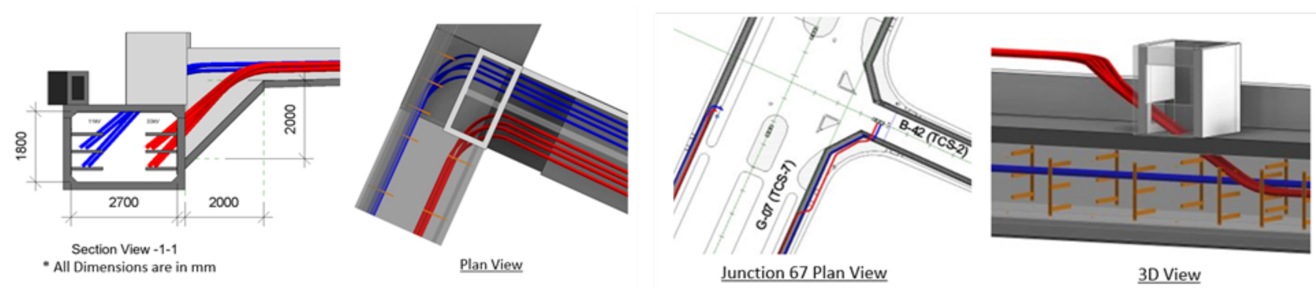
The solution falls into two categories:

1. Power Duct of widths 2.2m and 2.7m.
2. Power Duct of width 1.7m.

- **Power Ducts of widths 2.2m and 2.7m**

In alignment with the customer's precise requirements and the established design criteria, a comprehensive series of cable routing simulations was carried out, encompassing both 33kV and 11kV cables. Multiple solutions were explored to address the challenge. One approach involved considering the construction of a ramp-like structure at the cable entry point into the cross duct, as depicted in Figure 5**a**. However, it became evident that this option was not practically feasible for construction purposes. In the journal [4], the author discusses regarding the fulfilment of design requirement in executing the excavation work.

In a case study [3], Autodesk Revit software was used for a residential villa project to perform the external routing of a cable from the electrical room to inside the building. Based on this, an alternative proposal was considered. This proposal involved diverting the cable from the power duct before it reached the junction location through a cutout, as illustrated in Figure 5**b**. While this approach successfully met the cable's bending radius requirements, it raised safety concerns primarily due to the high-power capacity carried by these cables.



(a) (b)

Fig 5. (a) Cable entry through ramp (b) Cable taking out from power duct

In the journal paper [7], the author discusses the optimized electrical infrastructure design achieved through a comprehensive literature survey conducted in the most important academic sources. This survey helped in detecting a wide variety of definitions, strategies, models, and frameworks. After evaluating various options as previously mentioned, a definitive solution has been selected, giving utmost priority to safety, and minimizing the need for extensive construction modifications. The proposed final solution entails replacing the existing two access chambers, each measuring 1m x 1m (as shown in Figure 6**a**), with a single access chamber measuring 2.4m x 1.6m (as depicted in Figure 6 **b**). This modification guarantees a sufficient bending radius for the cables to smoothly enter the cross duct, eliminating any potential conflicts with the existing structures, as illustrated in Figure 7.

- **Power Duct of width 1.7m**

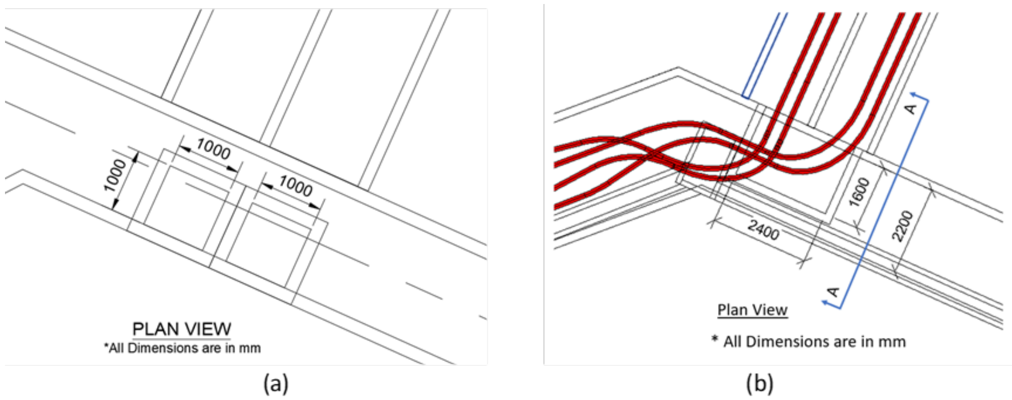


Fig 6. Plan View of (a) Existing Access Chambers (b) Proposed Access Chamber

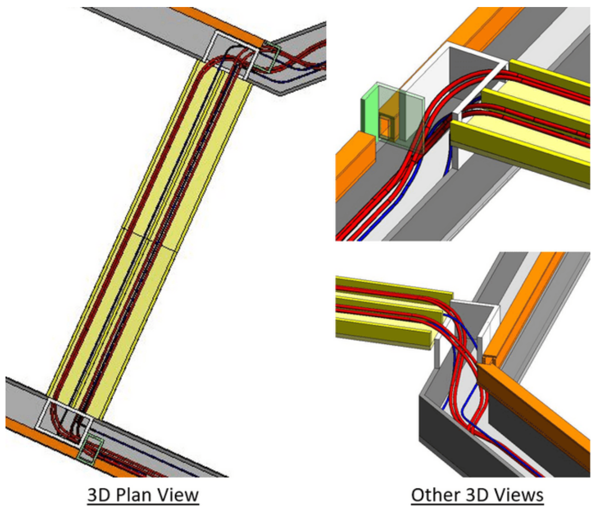


Fig 7. 3D View of Cable entry for Power Duct 2.2m and 2.7m

In the case of the 1.7m width power duct, it became evident that accommodating cable bending within the duct was unfeasible due to its limited size. Following extensive simulations of cable routing and discussions with the design and project site teams, the recommended solution involves the integration of additional access chambers, measuring 7.5m x 2.5m and 6.5m x 2.5m. These additional access chambers will ensure the requisite bending radius for cable entry, as detailed in Figure 8. The cables will pass through the power duct wall via a cutout and then enter the cross duct. These modifications to the power duct will allow the cables to maintain the necessary bending radius, as depicted in Figure 9.

The solutions developed in this study are applicable uniformly across all locations within the entire project. To ensure the preservation of an adequate bending radius for cable routing, a comprehensive 3D walkthrough of the cable routing process was conducted, spanning from the power duct to the crossing duct. This walkthrough has proven instrumental in decision-making by the customer and will assist the project execution team in the smooth installation of cables, eliminating potential complications. In contrast to traditional methods such as AutoCAD drawings, the adoption of BIM has resulted in remarkable efficiencies. In the journal [8], the author stated that with help of BIM, clashes were detected prior to real execution, thereby helping to save costs, time, and simplifying design and execution complexities. In our project by utilizing BIM, we have managed to reduce man-hours and time requirements by up to 90% while also achieving significant cost savings by eliminating rework at the construction site, amounting to a 20% reduction in expenses.

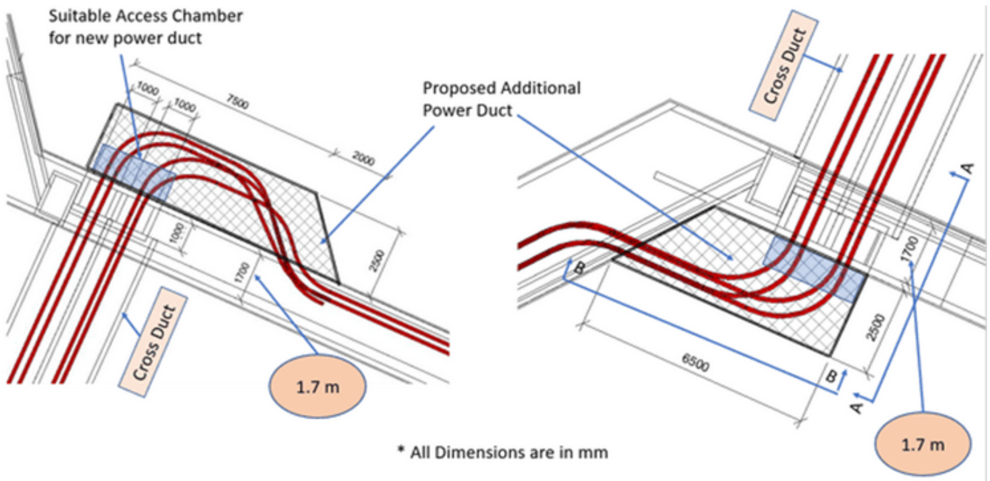


Fig 8. Proposed Additional Access Chambers for 1.7m width Power Duct

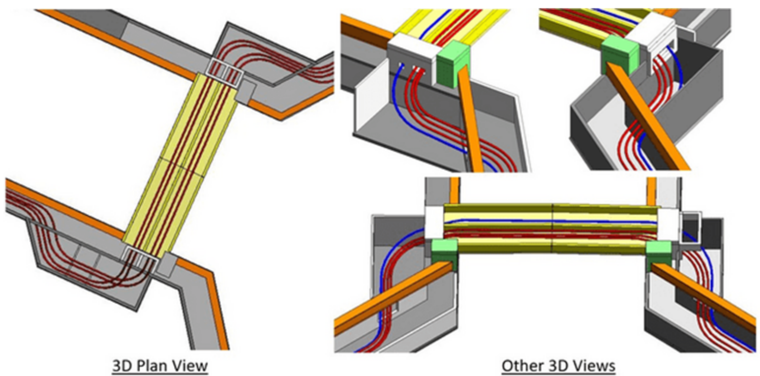


Fig 9. Cable entry for Power Duct 1.7m

4 Conclusion

This research demonstrates the significant impact of BIM on optimizing power duct integration for efficient cable routing in the Dholera SIR project. By utilizing BIM, this study has shown improvements in decision-making, time efficiency, and cost reduction by eliminating on-site rework. The analytical capabilities of BIM allowed us to identify and resolve cable bending space issues, leading to optimized power duct designs that address immediate challenges and set the stage for streamlined solutions across the project.

Furthermore, the experience with this project has provided valuable insights into the complexities of electrical cable routing within infrastructure projects. These insights will enhance the ability to plan and design future smart cities and infrastructure initiatives. By implementing BIM technology in the design stage of future projects, we can proactively address challenges before they arise during execution. This early integration of BIM enables more accurate planning, improved collaboration, and better visualization and simulation of projects, ultimately resulting in smoother execution, reduced rework, and improved overall project outcomes. In future research, we aim to focus on automating cable routing based on the design, which will significantly reduce time and help avoid issues during the site execution stage.

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