1. Background and Objectives

1.1 Metro Construction Project in Tier-2 Cities

In recent years, India has been under rapid urbanization, with 473 million people (in 2021), about 30% of the national population, living in cities, and there will be 40 cities with more than 2 million people by 2030[1]. In addition to the eight major Indian cities, called Tier-1 cities, such as Delhi, there is an urgent need to address urbanization in regional core cities, called Tier-2 cities, which have a population of 1-4 million people. However, the development of public transport systems such as metros has been delayed, which has caused more serious systemic and financial vulnerabilities to realize sustainable economic growth.

The Government of India has formulated the "Metro Policy 2017" to promote planned urban growth by providing an appropriate public transport system from the early stages of urban development. In this policy, emphasis is placed on developing the rail network with the expansion of budgets. In addition to Tier-1 cities, the development of metro projects in Tier-2 cities is also focused in the government budget for FY2021.

1.2 Significance of Metro Construction Project in Bihar State

This project is the first metro construction project in Patna (Tier-2 city with a population of 2.6 million), the capital of Bihar State (population of approximately 100 million) in eastern India bordering Nepal. The state's per capita GDP is $686 (2019), well below the Indian average of $1,930, so poverty reduction is a social challenge. On the other hand, the state has experienced remarkable economic growth, with an average GDP growth rate of 8.2% per year over the past five years (2015-2019, India's average is 6.7% per year). The state's capital, Patna, has also experienced rapid urbanization and faced the problem of insufficient urban public transport systems, which has led to increased use of personal transportation, congestion, and air pollution, as shown in Figure 1-1.

Source: JST

Figure 1-1: Current Status of Patna City

1.3 Goals to be Archived by Patna Metro Rail Project

In response to the above issues, the Bihar government has formulated the "Patna Master Plan 2031" (2016) and the Urban Transportation Plan (2018) for the sustainable development of Patna and has positioned metro construction as a key urban development project. Based on the above, JICA realizes that this project will contribute to achieving the following goals.

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1 United Nations (2018)

Table 1-1: Goals to be Achieved by Patna Metro Rail Project

Goals to be Achieved by Patna Metro Rail Project	
1)	Realization of infrastructure development policies and metro development policies in Tier-2 cities and urban development and transport plans formulated by the Bihar government
2)	Preventing urban problems such as uncontrolled development of cities and the formation of urban slums and reducing the time and cost of future infrastructure development
3)	Reduce environmental impact through the realization of public transportation-oriented cities in line with the Indian government's efforts[2]

1.4 Overview of this Survey

The outline of this survey and the alignment plan of the project are shown below.

Table 1-2: Outline of this Survey

Items	Contents
Project Name	Patna Metro Rail Project
Project Objectives	The objective of the project is to cope with the increase of traffic demand in Patna by constructing the new metro corridor 1 & 2, thereby contributing to the improvement of the urban environment and development of the economy as well as mitigation of climate change.
Project Outline	Construction of Metro Corridors 1 and 2 (total length approx. 32 km) in the center of Patna
Survey Area	Patna, Bihar, India
Survey Objectives	The objective of the survey is to conduct surveys, reviews and revisions on items, such as project objectives, outlines, cost estimation, implementation schedule, implementation scheme, organization plan, Operation and Maintenance plan, economic and financial analysis and Environmental and Social Impact Assessment, which are necessary for JICA to appraise the project as Japanese ODA Loan Project.
Implementation Agency	Patna Metro Rail Corporation Limited (hereafter called "PMRCL")
Other related Government Agencies and Institutions	The Government of Bihar, Ministry of Housing and Urban Affairs (hereafter called "MoHUA"), Delhi Metro Rail Corporation (hereafter called "DMRC")
Survey Period	April 2022 ~February 2023

Source: JST

[2] Reduction of greenhouse gas emissions per unit of GDP to be addressed in the "Nationally Determined Contributions (NDC)" under the Paris Agreement.

Source: Prepared by JST based on Google Earth

Figure 1-2: Alignment Map of Patna Metro Corridor 1 and 2

Detailed Project Report (DPR) was prepared by PMRCL in 2016 and approved by Bihar State Government in 2018. This JICA survey report was prepared based on DPR discussing with PMRCL and relevant authorities.

The overview of the technical features planned in DPR is below.

Table 1-3 Technical Features of Patna Metro

Item	Basic Specification	
Railway	Corridor 1: 17.78km Corridor 2: 14.20km Total: 31.98km	
Railway Structure	Elevated and Underground	
Number of stations	Corridor 1: 14 Elevated(8), Underground(6) Corridor 2: 12 Elevated(6), Underground(6)	
PHPDT	• Corridor 1 2024: 14516 2031: 23127 2041: 25323 2051: 32011	• Corridor 2 2024: 11252 2031: 17862 2041: 19507 2051: 22083
Daily Trips	• Corridor 1 2024: 557107 2031: 918479 2041: 1064379 2051: 1350815	• Corridor 2 2024: 327496 2031: 519803 2041: 537478 2051: 601942
Train Configuration	3 Car: DMC+TC+DMC 6 Car: DMC + TC + MC + MC + TC + DMC	
Minimum Headway in min	• Corridor 1 2024: 4.3 2031: 3.5 2041: 3.3	• Corridor 2024: 4.6 2031: 3.5 2041: 3.3

	2051: 3.0	2051: 3.0
Maximum Design Speed Maximum Scheduled Speed	95 km/h 85 km/h	
Track Gauge	1435 mm(Standard Gauge)	
Maximum Acceleration Rate	$1.2 m/s^2$	
Deceleration Rate	$1.1 m/s^2$(Maximum Service Brake) $1.3 m/s^2$(Emergency Brake)	
Axle Load	17T	
Traction System	AC25 kV 50Hz Overhead Collection System	
Train Control System	CBTC	
AFC Media	NCMC: National Common Mobility Card(Contactless Smart Card) QR ticket(Paper or Mobile)	
Gate Facility	Retractable flap gate	

Source: JST

1.5 Government Approval

1.5.1 Detailed Project Report (DPR)

The 30.91 km Patna Metro's Phase 1 project's Detailed Project Report (DPR) was prepared by PMRCL, supported by RITES, and approved by Bihar's state government on February 9, 2016. On September 25 2018, the Bihar government approved the constitution of Patna Metro Rail Corporation Ltd (PMRCL) as an implementing agency.

The project received the Central Government's approval on February 6, 2019, and PM Modi laid its foundation stone on February 17, 2019. In November 2019, the PMRCL unveiled a change in the project's Detailed Project Report (DPR) and alignment of both lines, 1) leading to the creation of a second interchange at Khemni Chak, 2) elimination of corridor 1's depot at Aitwarpur, and 3) the addition of 2 new stations at Ramkrishna Nagar and Jaganpura. In February 2020, DMRC reviewed the alignment as a General Consultant (GC) of the Patna Metro Rail Project and proposed the changes above in the alignment of Patna Metro. In the end, PMRCL prepared an updated DPR in 2021 with the engagement of RITES.

1.5.2 Approval of Patna Metro Rail Project by GoI

Regarding the approval of the Patna Metro Rail Project, it was given by the Government of India for the city of Patna to get rid of the traffic problem and improve the environment. PMRCL was formed from 19th February 2019 to implement the said project. The said Corporation has been established at Indira Bhawan at the 7th Floor. PMRCL is an unlisted public company incorporated on 18 February, 2019. It is classified as a state government company and is located in Patna, Bihar.

2. Overview of Patna City and Bihar State

This chapter describes the current conditions of Patna city and Bihar state.

2.1 Natural Features

2.1.1 Geography

Patna is situated on the southern bank of the Ganges River and straddles the rivers Sone, Gandak, and Punpun. The city is approximately 35 kilometers long and 16 to 18 kilometers wide and sprawls along the south bank of the Ganges River in Bihar, northeast India. The outline of Patna City is shown below.

- Total Area of Patna: 250 km^2 (97 sq mi)
- Municipal Area: 109.218 km^2 (42.169 sq mi)
- Suburban Area: 140.782 km^2 (54.356 sq mi)
- Average Elevation: 53 m (174 ft).

Source: JST based on Google Earth

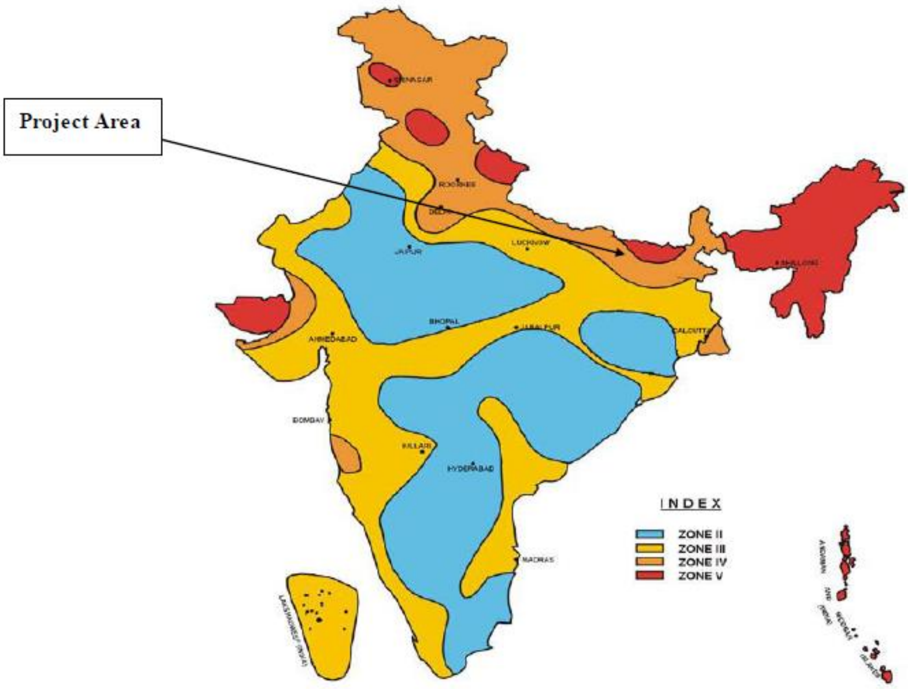
Figure 2-1: Geography of Patna

2.1.2 Geological Structure

Patna is situated approximately 110km from Bodh Gaya which is a holy place for Buddhist and playing role of gateway for tourist visiting Bodh Gaya. The city is located in the Indo-Gangetic plain, so naturally, fertile soil is one asset of the state. Thus Indo-Gangetic plain's soil is the backbone of agricultural and industrial development. The Indo-Gangetic plain in Patna consists of a thick alluvial mantle of drift origin overlying mostly the Siwalik and older tertiary rocks. The soil is mainly little young loam rejuvenated yearly by constant deposition of silt, clay, and sand brought by streams but mainly by floods. This soil is deficient in phosphoric acid, nitrogen, and humus, but potash and lime are usually present in sufficient quantity. The most common soil in Patna is the Gangetic alluvium of the Indo-Gangetic plain region. Patna is blessed with a vast stretch of very fertile flat land. It is drained by the Ganges River, including the northern tributaries of other rivers. The river Ganges flows through the middle of the city from west to east.

Patna, located near the Himalayan active seismic region, has been subjected to destructive earthquakes such as the 1803 and 1934 Bihar– Nepal earthquakes.

The country has been classified into different zones indicating the intensity of damage or frequency of earthquake occurrences. According to the Bureau of Indian Standards, the city falls under seismic zone-IV, on a scale of II to V (in the order of increasing proneness to earthquakes). The terrain of Patna city is mostly flat. The ground surface's average height is 48-63m above the mean sea level (MSL) range.



Source: Environmental Impact Assessment of Danapur – Mithapur – Khemni Chak and Patna Station – New ISBT Corridors of Patna Metro (Updated)

Figure 2-2: Seismic Hazard Map - Bihar

2.1.3 Climate

In Patna, the summer temperatures rise very high as the hot tropical sun beats down with all its intensity. The city, near four large rivers, experiences rather high humidity throughout the year. The summer begins in April and peaks in June/July, with temperatures soaring to 46° C until the moisture laiden monsoon wind brings some much-needed relief to the parched fields. The rains last through August & September and continue into early October. The northern Indian winters bring bitter cold nights and sunny days to Patna from November to February till the arrival of the spring that bringing the weather to a full cycle. The local almanac divides the year into six seasons of roughly two months. Apart from the usual four seasons: Summer, Monsoon, Winter, and Spring, you may add mild winter between Monsoon and Winter and Mild summer just before the onslaught of the extreme north Indian summer.

2.2 Social Environment

2.2.1 Population

According to the census conducted in 2011, the population in Patna was calculated approximately 1.68 million. Between the 2001 and 2011 census, Patna's population grew by 17.7% from 1.43 million. The population in 2021 is estimated at 1.95 million. Like many other cities in India, Patna is expected to continue its rapid growth in the coming years.

The population density in Patna Urban Area has increased from 13,220 persons per sq. km in 2001 to 17,500 persons per sq. km in 2011, and at present, it is about 18,500 persons per sq. km (CMP 2018). Rapid urbanization and an increase in rural-urban migration have resulted in a manifold increase in problems associated with urban infrastructure in developing economies.

2.2.2 Economy

Bihar, where Patna is located, has consistently achieved socio-economic development over the past decade despite limited financial resources. According to the new series of data on Gross State Domestic Product (GSDP), the growth rate of Bihar’s economy in 2018-19 was 10.53 percent (at constant prices) and 15.01 percent (at current prices), which is higher than the growth rate for the Indian economy.

As a center city of Bihar state, the economy of Patna has seen sustained economic growth. The economy has been spurred by growth in the fast-moving consumer goods industry, the service sector, and green revolution businesses which is on increasing production of food grains through the introduction of high-yielding varieties, use of pesticides and improved management techniques.

In 2009, the World bank stated Patna as the second-best city in India to start a business due to less procedures and cost required for start-up. As of 2011-12, the GDP per capita of Patna is 108,657 Rs., and its GDP growth rate is 7.29 percent. Patna is the 21st fastest-growing city in the world and the fifth fastest-growing city in India and registered an average annual rate of 3.72% during 2006-2011. The city's major business districts are Bander Bagicha, Exhibition Road, Gandhi Maidan, Frazer Road, Indra Puri,Maurya Lok, Boring Road, Kankarbagh and Raja Bazar.

Source: JST based on Google Earth

Figure 2-3: Major Business Districts in Patna

As an indicator of the state's growth, the gross state domestic product (GSDP) has increased as evidence of sustained growth for the last seven fiscals and has an impact on the gross district domestic product (GDDP) of the districts Patna, which tops the list. The economy here has seen sustained economic growth since 2011. The Fast-Moving Consumer Goods, the service sector, and green revolution businesses have boosted the city's economy.

2.2.3 Industry

GSDP of Bihar state during 2020-21 comprises 24% agriculture, 15% industry, and 61% services. On the other hand, the share of the labor force in 2005 is 56% in agriculture, 8% in industry and 36% in services.

Patna has been a major agricultural hub and center of trade in North East India. Bihar state has significant levels of production for the products of mango, guava, litchi, pineapple, eggplant, cauliflower, bhindi, and cabbage in India. Despite the states leading role in food production, investment in irrigation and other agriculture facilities has been inadequate in the past.

Besides agriculture, Patna is home to various small-scale and large-scale industries. The sugar industry is an important business in this area, and there are plenty of sugar mills in and around Patna. Sugar is an important business, and Patna is the brand center for sugar in eastern India. Leather, handicrafts, and agro-processing are the other major industries in Patna, and these industries provide a livelihood to the people of Patna. More than 3.6 million people are employed in the industries, and these industries provide a livelihood to the people of Patna.

Besides the above, a large number of manufacturing companies, Hero Cycle, Britannia Industries, PepsiCo, Sonalika Tractors, and ultra tech cement have come with their manufacturing plants in Patna metropolitan area. The world's second-largest leather cluster is in Fatuha at Patna. Patna is also emerging as an IT-based economy TATA Consultancy Service –Patna got operational in 2019 at its new office. Many businesses park has been introduced to the city.

As of 2019, 3.5 million tourists visited Patna. Of these, one million are foreign tourists, many of whom go to the Buddhist holy city of Bodh Gaya. In the earliest days tourism in Bihar was purely for educational purposes. As Patna is one of the most sacred cities of religions like Buddhism, Jainism, Sikhism and Islam, many people travel to Patna as part of religious tourism. Today, tourism in Patna is mainly either religious-based or moderated educational tourism. The Bihar government is also promoting adventure tourism.

According to JETRO, as of 2021, there are 70 Japanese company sites in Bihar. In Patna, there are 22 Japanese company sites of these. The industry sector of the 22 sites is dominated by the finance and insurance industry, which accounts for half of the total with 11 sites, followed by the manufacturing industry with 5 sites, the service industry with 2 sites, the information and communication industry and the wholesale industry with 1 site each.

2.2.4 Traffic

Recent rapid urban development in Patna has resulted in transport problems such as traffic congestion and an increase in traffic accidents in the city. Although the state governments and the local administrations have been making substantial efforts to improve urban transport, problems have been exacerbated to a large extent by the rapidly increasing number of private vehicles. The situation necessitates the assessment of the existing transportation infrastructure in the city.

Total vehicles in Patna city have increased tremendously. The share of two-wheelers registration comprises about 75%, while cars comprise about 13 %. The table below shows the city's growth and composition of vehicular traffic.

Table 2-1: Vehicle Registration in Patna

Vehicle Type	Year						
	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Trucks	2882	3251	3167	2868	383	3872	2866
Bus	302	352	244	308	601	595	435
Car	12493	13805	12537	11033	13643	18113	14863
Taxi	1181	1574	1488	1242	776	1358	1197
Jeep	2515	1706	1740	1800	1538	1967	3096
Three-Wheeler	3801	4432	6205	6087	4171	6429	3543
Two-Wheeler	50917	57836	58134	66889	74335	84008	84202
Tractor	1383	1410	1649	2033	2028	3355	1302
Trailer	839	846	693	516	806	2134	784
Other	30	21	5	2	18	14	3

Source: CMP2018

2.2.5 Politics

The politics of Bihar, an eastern state of India, is dominated by regional political parties. As of 2021, the main political parties are Rashtriya Janata Dal (RJD), Bharatiya Janata Party (BJP), Janata Dal (United) (JDU), and Indian National Congress (INC). As of 2022, Bihar is currently ruled by Mahagatbandhan (Grand alliance) coalition

Mahagathbandhan (MGB), also known as Grand Alliance, is a coalition of political parties in the Eastern state of Bihar in India, formed ahead of the 2015 Vidhan Sabha elections in Bihar. The alliance consists of Rashtriya Janata Dal (RJD), Janata Dal (United), Indian National Congress (INC), and Left parties including Communist Party of India (CPI), Communist Party of India (Marxist–Leninist) Liberation-CPIML(Liberation) and Communist Party of India (Marxist) (CPIM), with Nitish Kumar (Chief Minister) as the leader and Tejashwi Yadav (Deputy Chief Minister) as the chairperson. It is the ruling coalition government in Bihar.In August 2022, the Mahagathbandhan, Janata Dal (United) and Hindustan Awam Morcha joined together to form 2/3th Majority government in Bihar Legislative Assembly.

2.2.6 Culture

Hindi is the official language of the state of Bihar but many other languages are spoken too. Patna’s native Language is Magadhi or Magahi, named after Magadha, the ancient name of South Bihar is most widely spoken. English is widely spoken, and other spoken dialects and languages include Bhojpuri, Maithili, Bengali and Oriya.
According to the 2011 census of India, Patna's major religion is Hinduism with 86.39% followers. Islam is the second most popular religion in Patna with approximately 12.27% following it. Christianity, Jainism, Sikhism and Buddhism, with smaller followings, are also practiced in Patna.

2.2.7 Air pollution

Pollution is a major problem in Patna. According to the CAG report in 2015, Patna's Respirable Suspended Particulate Matter (RSPM) level (PM-10) is 355, 3.5 times higher than the prescribed limit of 100 micrograms per cubic metre, mainly due to vehicle and industrial emissions and construction activities in the city. In May 2014, a World Health Organisation study found Patna to be the second most polluted city in India after Delhi, with particulate matter (PM-2.5) in the state capital's air calculated at 149 micrograms, six times higher than the safe limit of 25 micrograms. Severe air pollution in the city has led to an increase in pollution-related respiratory diseases, including lung cancer, asthma, dysentery and diarrhoea. The smog that occurs in Patna during the winter season causes major disruptions to air and rail traffic every year.

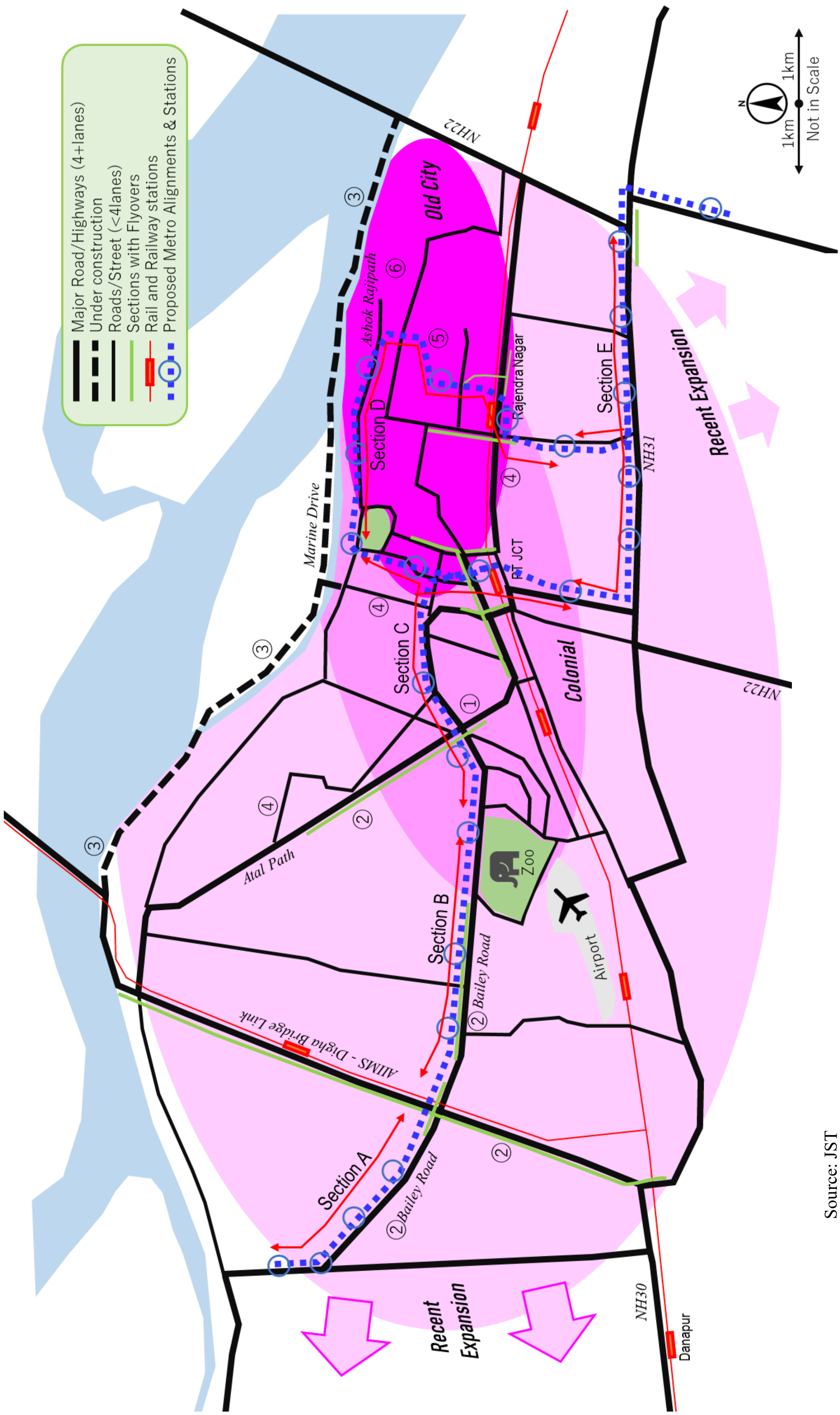
3. Review of Urban Development Policy

3.1 Urban Development Plan

Urban land use and development of urbanization are essential to understand Patna’s urban development plan. The following illustrates the historical views of urbanization, recent local mobility improvements and urbanization, and metro demand characteristics.

3.1.1 Patna Urban Development Characteristics and Traffic Growth

The figure below illustrates the historical urbanization and transport network system in Patna including road and highway, and railways, particularly for the influenced area of this metro development. This is an introduction based on observation of JST experts, and discussions with experienced local resources from academic and business sectors. This will give proper image of urbanization and traffic attribution in Patna to the readers and external stakeholders.



Source: JST

Figure 3-1: Illustration of Transport Network and Phased Urbanization in Patna

For simple explanation, it can be said that Patna city has three-phased urbanization history as shown in pink gradation on the map. The area with thick pink is traditional old city, which has high concentration of the 4-5 stories low quality housing and population with 200-300 persons per hectare, with relatively low-income level, under mixed land use of retails, residence, and education, historical and religious centres. The mobility in this area needs to rely on walk, motorcycles, autorickshaw, e-rickshaw, cycle rickshaw and small buses, as the roads are narrow, e.g., the main road Ashok Rajipath in this area has section less than 5.5m where cannot accept the bus operation, and not perfectly connected with other network.

The medium pink area is the urbanization during the British colonial period, which expanded in western direction of the Old city. The road network is well-organized with continuous grade separated junctions, due to the proper urban planning of British influence, similar to New Delhi. There are main railway station (Patna Junction), the Zoo and major cultural destinations, offices of the National Government and local administrative. There seems to be no dominant CBD, but area 1 is attractive for private businesses to establish branches. There are small agglomerations of offices, medium-high-class retails, The heights of building are 7-8 stories at maximum and most building are relatively aged more than 20 – 30 years.

The thinner pink zone is the area for recent urbanization and expansion. The major urbanization can be seen in the western direction. The recent road link improvement with flyovers, Bailey road, Atal Path, and AIIMS Digha Bridge Link, as identified with ② in the figure. The elevated sections of those links are developed in recent 10 years, dramatically improved the mobility and accessibility in this area. The western regions are major targets for private property and condominium development, with 10+ stories, 1000+ sqft. floors for new-families[3], and high-class education services[4] follows the development, as local property agents can obtain vacant lands relatively easier than other areas.

The other direction of urbanization is south and southeast, however, this area has mix-use of factories, industries, logistics services and residents, due to influence of the intercity highway networks consisted of NH22, NH31 and ISBT.

(1) The Game Changers in Patna

The on-going largest road network investment in Patna is the Marine Drive, 23-km length 4-lanes highway, running along the Ganges, elevated along the river or fully-access controlled on the bank of the river island, shown as ③ in the figure above. As shown below, this will form the full ring road function of Patna, and the CBD traffic can access intercity network escaping from the congested city centre by detouring to the Marine Drive.

[3] The average price range will be around 75-90 K USD per house (60-70 Lak in INR), 55-70 USD per sq.ft., which is relatively cheaper than edge of suburban of Mumbai, Maharashtra and Delhi, where it costs 75-90 USD per sq.ft. JST interviewed 4 local property agents in Patna in June 2022, and there were 8 on-sales condominium projects, and 6 are located in the hinterlands of Saguna More and Patripura section of the planned metro line, another is far west, and the last one is close to the Zero Mile junction.

[4] E.g., the metro station of RPS More means the Royal Public School, one of prestigious private high school in Patna.

Source: Map from CMP 2018, Photo by JST

Figure 3-2: Marine Drive and Patna Ring Road

This is constructed by Housing and Urban Development Corporation (HUDCO) and the Government of Bihar. It will be operated as toll road, and no information for toll. The project cost will be approx. 3,100 Crore INR in total, and 2,000 crore was funded by HUDCO and remaining was covered by the Government of Bihar.

Retail commercial development, i.e., modernized shopping malls, are still developing in Patna, however, one is active, two are expected to be opened in 2022, as shown in ④ in the map. The active one P&M mall, relatively smaller floor size compared with megamalls can be seen in Delhi and Mumbai, however, it attracts local families and provides urban entertaining opportunities. The other Ambuja city centre mall has larger floor, locates in CBD, classified as a medium-sized mall in Delhi or Mumbai, with selected tenants and office functions, which will be opened in 2022. The remaining one, Gravity mall are relatively small, located close to the Ranjendra Nagar Railway station.

The renovation of the Moin Ul Haq Stadium[5], locating along the Metro at ⑤ in the figure, is under procurement process, and will establish the international class cricket stadium with 30,000+ seat capacity with hotel and restaurant facilities.

(2) Metro Alignment and Urban Development

The blue line on the map depicts the alignment of the two routes. The followings can be considered as metro routing background and demand, based on the characteristics explained above.

Section A– rapid urbanization with mid-high range income groups, need qualified feeder services and pedestrian accessibility, particularly to the highly concentrated township developments near to the station. The area can expect further development by private investors for not only residentials but also schools, business centers, shopping malls.

Section B – relatively developed residential zones in the hinterland, and high dependence on 3W based accesses, which will bring large volume of passengers in the initial phase of operation of the Metro. The

5 https://timesofindia.indiatimes.com/city/patna/bihar-cm-reviews-plan-to-redevelop-patna-based-moin-ul-haq-stadium-into-a-word-class-sports-complex/articleshow/85693355.cms

recent flyover development brought smooth capacity along the Bailey Road, however, the road capacity of the surface level will be saturated and a proper road management will be needed. The station intervals are relatively longer than other sections, and may loss potential passengers.

Section C – covers CBDs and major transport hubs, and the metro can expect commuters, business users, tourists, and so forth. The connectivity to the Patna Junction Railway Station should be designed properly.

Section D – Ashok Rajipath and its hinterlands are highly dependent on walk and paratransit and have difficulties to expand its road-based services due to its poor road network. The "bring metro into old, high dense city" concept applied to this section is quite unique and worthy to sustain the old city, however, microscale accessibility improvement around the stations are essential. Note that the station access to the Moin Ul Haq Stadium should be secured for further large events and demand concentrations.

Section E – facing to the intercity highways, passenger characteristics are different from the other sections. The metro stations will be built on the northern side of the highway, it is difficult to attract the passengers from the southern side of the highway.

3.1.2 Current Transportation Development in Patna

(1) Existing Vehicle

Development of **vehicle registrations** for the year 2011-2017 is provided in DPR, and data for 2014 to 2017 are listed below. Based on the data available, JST estimated the annual registration data for the years before 2011 and after 2018 till 2021. The purpose is to estimate the total existing vehicle in Patna and the share by vehicle type. Vehicle-specific usage life is assumed, which is shown in the table below.

Table 3-1: Estimated Existing Vehicle in Patna

	Annual Vehicle Registration								Estimated total vehicles	Share
Vehicle type	2014	2015	2016	2017	*2018*	*2019*	*2020*	*2021*		
Trucks	2,868	383	3,872	2,866	*3,400*	*3,400*	*3,500*	*3,600*	*57,100*	*4.8%*
Bus	308	601	595	435	*600*	*700*	*700*	*700*	*6,500*	*0.5%*
Car	11,033	13,643	18,113	14,863	*16,700*	*17,300*	*17,900*	*18,500*	*154,300*	*13.0%*
Taxi	1,242	776	1,358	1,197	*1,200*	*1,200*	*1,200*	*1,200*	*8,100*	*0.7%*
Jeep	1,800	1,538	1,967	3,096	*3,100*	*3,100*	*3,200*	*3,300*	*24,500*	*2.1%*
Three-Wheeler	6,087	4,171	6,429	3,543	*4,900*	*5,000*	*5,000*	*5,000*	*50,800*	*4.3%*
Two-Wheeler	66,889	74,335	84,008	84,202	*93,000*	*99,000*	*105,000*	*111,000*	*833,400*	*70.4%*
Tractor	2,033	2,028	3,355	1,302	*3,400*	*1,800*	*3,700*	*2,100*	*28,300*	*2.4%*
Trailer	516	806	2,134	784	*1,500*	*1,600*	*1,600*	*1,700*	*19,900*	*1.7%*
Other	2	18	14	3	*0*	*0*	*0*	*0*	*200*	*0.0%*

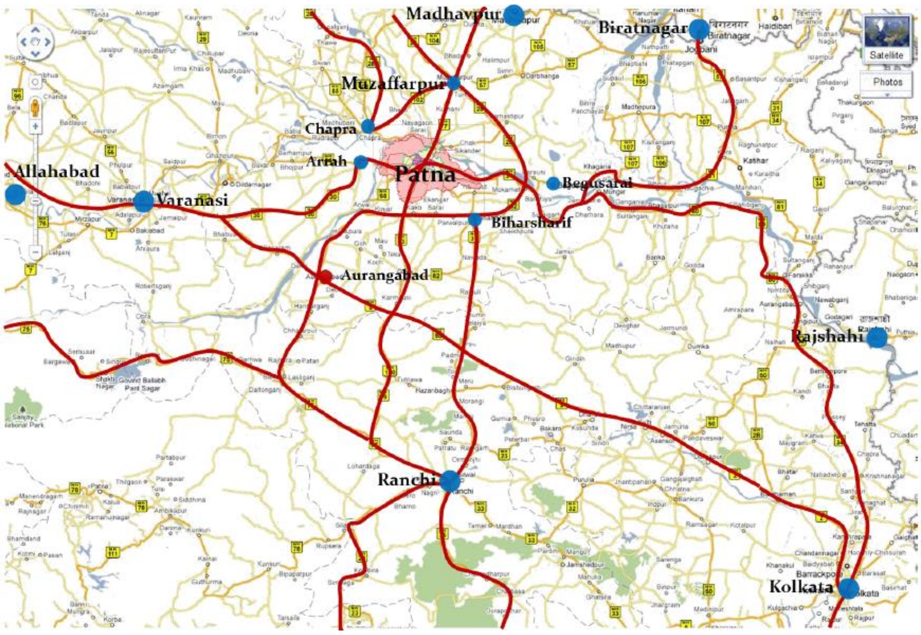
Note 1: Figure for year 2014-2017 are vehicle registration data from statistics, figure for year 2018-2021 (italicized) are estimated based on linear regression of the available data. Total vehicles and share are calculated based on the assumed vehicle life and covers both actual data and data estimated

Note 2: Vehicle life (year) assumed by the interviews with India experts: Trucks 20, Bus 15, Car 10, Taxi 7, Jeep 10, Three-Wheeler 10, Two-Wheeler 10, Tractor 15, Trailer 20, Other 15
Source: DPR (Revised by JST)

As per the estimation, total vehicles in Patna city have increased tremendously, and the amount has reached more than 1.1 million by 2021. The share of two-wheelers in Patna may reach about 70%, while cars is about 13%.

(2) Road

As shown in the map below, Patna is a major transport node in the National Highway Grid. The major roads include National Highways - 19, 30, 31 and 83. NH-19 that links Uttar Pradesh and NH-31 is important as it acts as a gateway to the states in northeast India. NH- 83 and 30 are entirely within the state and forms the regional connectivity of the area.



Source: Patna Master Plan 2031

Figure 3-3: Regional Connectivity of Patna

Within the study area, total toad length and distribution in terms of Right of Way are as follows.

Table 3-2: Road Length and ROW in Patna

Right of Way (m)	Length (km)	Percentage (%)
< 10	149.5	55.9
10 – 20	58.5	21.9
20 – 30	42.7	16.0
30 – 40	8.0	3.0
>40	8.9	3.3
TOTAL	267.5	100

Source: DPR

(3) Railway

The Howrah ‐ Delhi railway line traverses through the entire city length in the east-west direction. The railway line, aligned through the city on the southern bank of Ganga, has 5 major railway station serving Patna urban area viz Patna sahib, Gulzar Bagh, Patna junction and Phulwari Sharif and Danapur. The railway line towards south connects the PUA and PPA to Gaya. The railway infrastructure on the northern bank is growing fast as the head quarter of Eastern Central Railway is located at Hajipur. At present, Hajipur is connected by railways from Muzaffarpur, Samastipur and Darbhanga. In addition to this it has been now connected to Patna through Digha-Sonepur rail–road bridge.

The railway tracks serve both as a major movement corridor and as a barrier to north south connectivity of Patna city. To mitigate the linkage problem of northern part and southern part of the city across lines, road over bridges have been constructed on the north-south links. The BMU system of local trains connects the PUA brings the floating population from destination link areas in the west, Mokamah in the east as well as Jehanabad and Gaya in the south.

Major railway stations along main line are Patna Junction, Patna City and Rajendra Nagar Terminal. The new Patliputra Railway Station has started functioning along Patna-Hajipur rail link. In the proposed Master Plan existing rail network connecting Danapur railway station- Patliputra railway station- FCI godown – Patna railway station is proposed as 45m wide road.

(4) Bus

Bus transport in Patna is provided by Bihar State Road Transport Corporation (BSRTC). The Bihar State Road Transport Corporation (BSRTC) is a State Public Sector, currently 410 buses are plying in rural and urban areas under the Corporation. In addition, 231 buses are running under Public- Private Partnership (PPP) mode. In the light of increasing population of Patna, 107 buses have been provided for easy and speedy travel in Patna and nearby areas. Table below presents the summary of revenue collected and passengers carried by the BSRTC. The revenue collection by the Corporation has been growing steadily, and it was Rs. 151.2 crore in 2018-19, more than seven times the amount collected in 2014-15 (Rs. 21.6 crore). The revenue has increased by 42.3 percent annually during the last seven years. The number of passengers carried by the Corporation has also been growing annually at 13.4 percent. In 2018-19, it carried 320.0 lakh passengers, compared to 146.6 lakh passengers in 2012-13. This indicates the extended coverage of services.

Table 3-3: Revenue Collection and Number of Passengers Carried by BSRTC (2012-13 to 2018-19)

Particular	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	CAGR (2012-19)
Revenue Collection (Rs. crore)	26.0	21.1	21.6	24.9	61.4	124.8	151.2	**42.3**
No. of Passengers Carried (lakh)	146.6	152.3	110.6	126.6	184.5	212.0	320.0	**13.4**

Source: Bihar State Road Transport Corporation, GoB

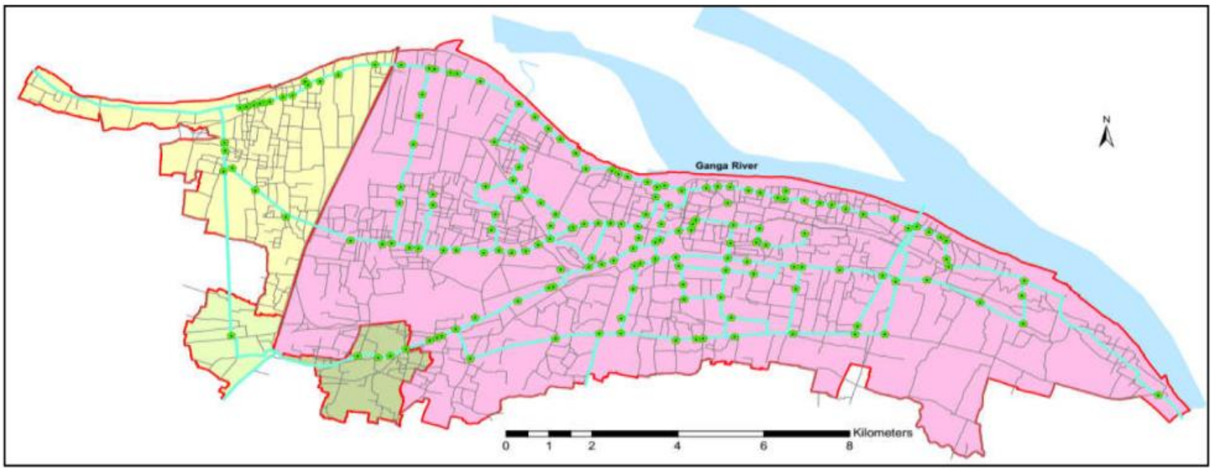
At present, City Bus Service is operational on more than 10 routes. The City Bus Service is operated by private bus operators in the PUA area. There is no uniform and a standard schedule of operation. The daily average number of trips per bus is 14. There are 350 mini-buses. The seating capacity of mini-bus is in the range of 15-20 and fare structure ranges from Rs.5 to Rs.15. In addition to these, public transport majorly includes shared autorickshaws.

Major bus routes are list below, which is followed by the Bus Route Map.

Table 3-4: Major Bus Route in Patna

Route No.	111/111A Kargil chowk	222 Kargil Chowk	444 Kargil Chowk	555 Kargil Chowk	888/888A Kargil Chowk
Bus stop	Patna Junction	Patna Junction	Patna Junction	Patna Junction	Patna Junction
	Income Tax Chauraha	R.Block	Rajendra Nagar Terminal	Rajendra Nagar Terminal	Income Tax Chauraha
	High Court	Satmurti	Dhankimore	Dhankimore	High Court
	Bihar Museum	Old Secretariat	Gayghat Bridge	Agamkunwa	Bihar Museum
	Hartali More Chowk	Chitkohra	Jaruwa	Tent city more	Hartali More Chowk
	Secretariat	Anisabad	Chaurasia Chowk	Mangal Talab	Secretariat
	Lalit Bhawan	Khojaemli	Paswan Chowk	**Patna Sahib Railway Station**	Lalit Bhawan
	Rajbanshi Nagar	Mahabir Cancer Sansthan	Ramashish Chowk		Rajbanshi Nagar
	Patna Zoo	Phulwari	Hajipur Junction		Patna Zoo
	I.G.I.M.S	Balmi	**Anwarpur Chowk**		I.G.I.M.S
	Gola Road	**AIIMS**			Gola Road
	R.P.S More				R.P.S More
	Saguna More				Saguna More
	Danapur Railway Station				Danapur Railway Station
					Shiwala More
					Hungama World Water Park
					Bihta
					IIT Bihta patna

Source: PMRCL



Note: CMP bus map shows road sections with bus service and locations of bus stops, but not the operational routes for each bus

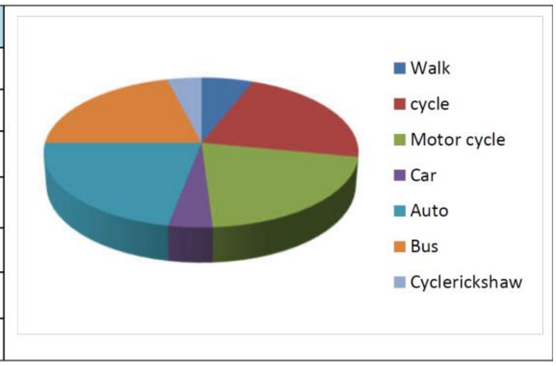
Source: CMP2018

Figure 3-4: Existing Bus Routes in Patna

(5) Current Modal Share

In terms of modal share, according to CMP2018, bicycle and autorickshaw are the major mode. However, the JST observed that the share of bicycles becomes relatively smaller, and more trips has been shifted to motorcycles. Auto (including e-rickshaws) may have larger percentage than indicated as 22.0% in CMP2018.

Mode of Journey	Percentage
Walk	6.00%
Bi-cycle	22.00%
Motor cycle	21.00%
Car	4.00%
Auto	22.00%
Bus	21.00%
Cycle-rickshaw	4.00%



Source: CMP 2018

Figure 3-5: Modal Share in Patna

3.1.3 Other Infrastructure Projects and Projects Supported by Other Donors

Apart from the above-mentioned Marine Drive Project and Patna Ring Road Project (Figure 3-2), there is also the Outer Ring Road Project that is currently under DPR preparation stage. The project is managed by National Highways Authority of India (NHAI)[6]. It is a 140 kilometer, 6-lane ring road expressway encircling Patna City. The Ring Road starts from Kanohli, connecting Naubatpur-Ramnagar-Kachchidaragarh-Bidupur-Chaksikander crossing the Sarai NH-77 and SH-74 towards the north of the city of Hajipur, then crossing the Gandak river, NH-19, Dighwara. The estimated cost to build this ring-road is Rs 15000 crores[7].

Patna Master Plan 2031 also proposed the Patna New Airport at Dumri, Punpun, 35km from Patna.

The table below summaries the infrastructure projects supported by other donors, including the Asian Development Bank and the World Bank. The New Ganga Bridge Project that connects with the Patna Ring Road. Other projects are with a wider scope, covering the whole Bihar State. The focus is not only on transportation infrastructure, but also on poverty reduction, water and energy supply in rural area.

Table 3-5: Infrastructure Projects Supported by Other Donors

No.	Project	Donor	Project Period	Outline of Project / Work
1	Bihar New Ganga Bridge Project	ADB	2016-2023	New Ganga Bridge is located about 10 km downstream and east of Patna. The main objective is to improve connectivity for Patna and the surrounding areas[8]
2	Bihar State Highways Project	ADB	2018-2023	The project will rehabilitate and upgrade about 230 kilometers of state highways in Bihar state[9]

6 https://nhai.gov.in/#/tender-detail/NDIwNTg
7 https://www.skyscrapercity.com/threads/patna-outer-ring-road-140-km-4-6-lane-u-c.2294075/
8 https://www.adb.org/projects/48373-007/main
9 https://www.adb.org/projects/51180-001/main

No.	Project	Donor	Project Period	Outline of Project / Work
3	Bihar Urban Development Investment Program	ADB	2013-2022	Water supply in Bihar regional cities, including Bhagalpur, Darbhanga, Gaya and Muzaffarpur[10]
4	Bihar Transformative Development Project	World Bank	2016-2023	The project is to diversify and enhance household-level incomes and improve access to and use of nutrition and sanitation services[11]
5	Solar Microgrids in Rural India	German Development Bank (KfW)	2022-2025	To support rural clean energy development, 1,300 grids in operation by 2025 across multiple markets

Source: Compiled by JST

3.2 Review of Public Transport Development Plan in Bihar

In response to the development challenges, the Bihar government has formulated the Patna Master Plan 2031 (PMP2031, 2016) and the Comprehensive Mobility Plan Patna (CMP2018) for the sustainable development of Patna and has positioned metro construction as a key urban development project.

The PMP2031 is aligned to the development mission and vision of the State. This encompasses the overall development in various sectors like economic growth path of Patna, keeping in view the projected population growth and associated developmental needs, the proposed land use change and development, proposed development in sanitation, water supply and transportation. The CMP2018 is developed aligned with the PMP2031 to comply with the transportation development needs of the area.

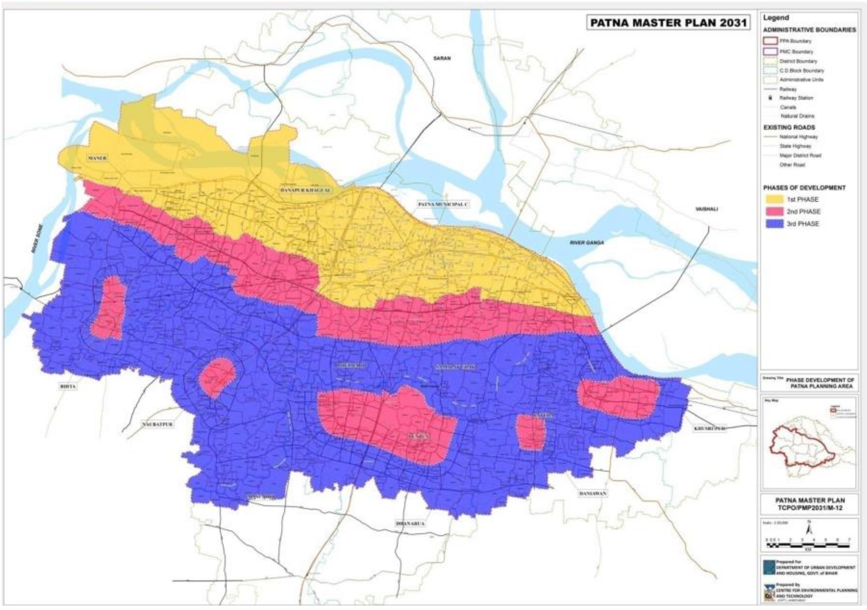
3.2.1 Patna Master Plan (PMP) 2031

Patna Master Plan 2031 was prepared by the Town and Country Planning Organization, Urban Development & Housing Department Patna, Bihar, in 2016. In this plan, there are three development phases; Phase I (2016-2021), Phase II (2021-2026), and Phase III (2026-2031). Patna Metro is positioned as a Phase I project, and the line stretches out in the yellow area in エラー! 参照元が見つかりません。

. It is also described that Patna Metro is in progress, and the proposed alignments in Patna Municipal Cooperation Area will later connect to the remaining part of the Patna Planning Area (PPA).

[10] https://www.adb.org/projects/41603-023/main
[11] https://projects.worldbank.org/en/projects-operations/project-detail/P159576

Map 36: Zones and Phased Development of PPA



Source: Patna Master Plan 2031

Figure 3-6: Metro Map on Patna Master Plan 2031

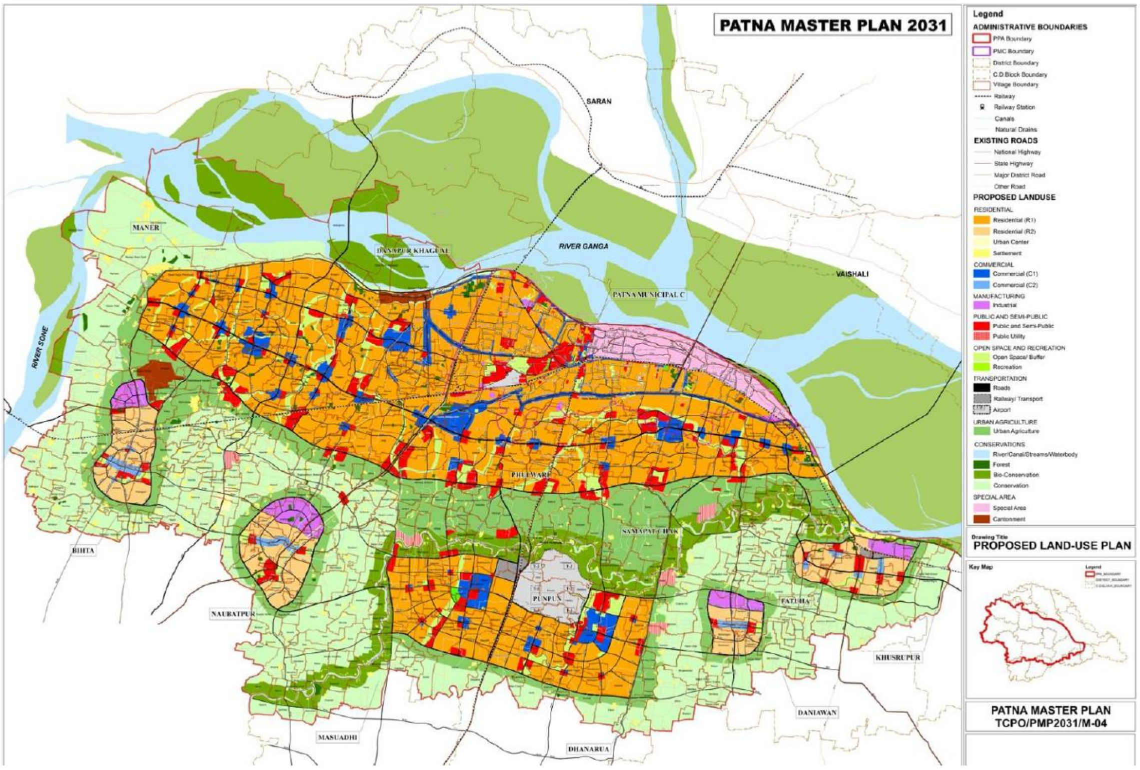
Patna Master Plan 2031 is evolved from the Master Plan 2001-21, Plan Update (1981-2001), and the first one in this series, the Master Plan (1961-81). The vision of the Master Plan 2031 is "*To develop Patna Planning Area as a modern economic region with locally competitive infrastructure and social amenities to address future requirements in harmony with its ecological resources*".

Following the Vision, development strategy that related to transportation infrastructure development is:

Transit Oriented Development (TOD) along the major corridors, which will emphasize movement through public transport. The Centers will be well-linked to the core city.

In the Master Plan, it highlighted the pedestrian-oriented design to encourage residents and workers to reduce use of personalized vehicles and use mass transit more often. Therefore, the development of metro system and the associated TOD is properly addressed in the long-term Master Plan.

The structure and shape of the transport network is dependent on land use. Public transport accessibility and connectivity should be framed around the structural form of urban growth envisaged. Master Plan 2031 suggested the land use plan as follows:



Source: Patna Master Plan 2031

Figure 3-7: Proposed Land Use Plan

3.2.2 Comprehensive Mobility Plan Patna (CMP2018)

Patna Comprehensive Mobility Plan 2018 (CMP2018) was developed in accordance with MoHUA criteria[12]. It highlighted the City's different short, medium, and long-term transportation infrastructures. Along significant travel corridors, the CMP2018 advocated mass transportation networks. In Patna, the Bihar government has planned to implement an efficient, safe, and high-capacity public transportation system. In 2018, National Institute of Technology (NIT) Patna conducted an alternatives analysis based on the CMP 2018 to determine the most viable mass transit system along two specified priority routes. Implementing a Metro Rail system on Patna's two busiest routes was advocated in the Alternatives Analysis Report. In the CMP2018, Patna Metro was regarded as the core business in the Sustainable Urban Transport (SUT) scenario, and demand forecasting was also conducted based on this scenario.

The CMP2018 seeks to "move people, not vehicles". By emphasizing the pre-eminence of public transport and non-motorized transport, and integrating the land use with transport networks, it seeks to achieve the objectives of sustainable development in Patna. The CMP2018vision for transport in Patna ensures that the city will have a planned, best performing transport system(s) that addresses the needs and concerns of the city. Accordingly, the transport vision for Patna can be defined as: "*To ensure that Patna will have a systematically planned urban transport system for the mobility of people and goods that is safe, efficient, economical and sustainable, which aims to support economic development while improving livability*".

The major goals for ensuring CMP2018 are based on social economic and environmental sustainability,

[12] According to Metro Rail Policy, 2017, "a Comprehensive Mobility Plan (CMP)", is a mandatory prerequisite for planning metro rail in any city. Cities having a population of two million and more may start planning for mass transit systems including metro rail based on the CMP".

including:

Goal 1: Develop public transit system in conformity with the land use that is accessible, efficient, and effective.

Goal 2: Ensure safety and mobility of pedestrians and cyclists by designing streets and areas that make a more desirable, livable city for residents and visitors and support the public transport system.

Goal 3: Develop traffic and transport solutions that are economically and financially viable and environmentally sustainable for efficient and effective movement of people and goods.

Goal 4: Develop a Parking System that reduces the demand for parking and need for private mode of transport and also facilitate organized parking for various types of vehicles.

3.2.3 Relevant Policy the Metro Project

(1) Metro Rail Policy, 2017[13]

Under the laws, the Union Cabinet approved the Metro Rail Policy in August 2017, and Appraisal Guideline was published.[14] Former and relevant acts and policies are described as follows.

1) Former Metro Acts and Policies
   - The Metro Railways (Construction of Works) Act, 1978
   - The Metro Railways (Operation and Maintenance) Act, 2002
   - The Metro Railways (Amendment) Act, 2009

2) Relevant Acts and Policies
   - Delhi Metro Railway (Salary, Allowances, Other Terms and Conditions of Service of the Claims Commissioner) Rules, 2007
   - Metro Railways General Rules, 2013
   - Metro Railways for Public Carriage of Passengers Rules, 2013
   - Metro Railways (Notice of Accidents and Inquires) Rules, 2014
   - Metro Railways (Carriage and Ticket) Rules, 2014

The following are some of the salient features of the metro policy. The Metro Rail Policy focuses on balancing the requests and necessity of the metro in each city. For this reason, each city must establish a UMTA (Unified Metropolitan Transport Authority), studied alternatives, and considers the feeder system.

Table 3-6: Contents of Metro Rail Policy, 2017

No.	Item
1	Recognition of the fast-growing need for improvements in the public transport system in a large number of cities
2	Evaluation of various options of Mass Rapid Transit Systems (MRTS), along with a comparative analysis of alternate modes of transport to be a vital part
3	Metro Rail system is often considered the most suitable urban transport system due to high capacity, 60,000 to 80,000 passengers per hour per direction (PPHPD), and speed, along with comfort, while the PPHPD of a BRTS typically has only a capacity of 10,000 to 15,000 PPHPD.
4	Comprehensive Mobility Plan (CMP) a pre-requisite for planning metro rail systems in any city

[13] http://mohua.gov.in/upload/whatsnew/59a3f7f130eecMetro_Rail_Policy_2017.pdf
[14] MoHUA Appraisal Guidelines for Metro Rail Project Proposals

No.	Item
5	Integration of suburban systems with the proposed metro rail
6	The Economic Internal Rate of Return (EIRR) of 14% and above is essential requirement for sanctioning of metro rail, since metro rail projects have significant economic and social benefits
7	Feeder systems up to a catchment area of 5 km of each metro station, and last-mile connectivity to be included in metro rail project proposals
8	Increased focus on maximizing non-fare box revenue and revenue through commercial development at stations and allocated land
9	Efforts to be made towards reducing costs of construction and operations, with the aim to standardize sub-systems and components
10	Exploration of various PPP models and encouragement for all forms of PPP, whether for full provisioning or for unbundled components
11	Appraisal by an independent agency as identified by the Ministry of Housing and Urban Affairs (MoHUA).

Source: Appraisal Guidelines for Metro Rail Project Proposals [15], Sept. 2017 MoHUA

[15] http://mohua.gov.in/upload/uploadfiles/files/Appraisal%20Guidelines%20for%20Metro%20Rail.pdf

3.3 Needs of Metro Development in Tier-2 Cities

3.3.1 Needs of Metro Development in Tier-2 Cities in India

In recent years, India has been under rapid urbanization. As per 2021, 473 million people (about 30% of the national population) are living in cities, and it is expected that there will be 40 cities with more than 2 million people by 2031. In addition to the eight major Indian cities, called Tier-1 cities, such as Delhi, there is an urgent need to address urbanization in regional core cities, called Tier-2 cities, which have a population of 1-4 million people.

Against this context, the Government of India has formulated the "Metro Policy 2017" to promote planned urban growth by providing an appropriate public transport system from the early stages of urban development. In this policy, emphasis is placed on developing the rail network with the expansion of budgets. In addition to Tier-1 cities, the development of metro projects in Tier-2 cities is also focused on the government budget for FY2021.

3.3.2 Needs of Metro Development in Patna

Patna, a Tier-2 city with a population of 2.6 million, is the capital of Bihar State (population of approximately 100 million) in eastern India bordering Nepal. In recent years, with the rapid urbanization in Patna, the registration of cars and two-wheelers increasing at high-pitched speed. However, the public transport infrastructure, which is now being gradually improved, cannot cope with the increases in the road transport demand, thereby causing a severe traffic congestion problem. It results in a loss in economy and damage to health due to pollution by cars, such as atmospheric contamination and noise. Under these circumstances, Patna is urgently required to improve public transport systems while eliminating traffic congestion and improving urban environments.

The development of metro system in Patna will realize the infrastructure development policies and metro development policies in Tier-2 cities and urban development and transport plans formulated by the Bihar government. It helps preventing urban problems such as uncontrolled development of cities and the formation of urban slums and reducing the time and cost of future infrastructure development, meanwhile, it can reduce environmental impact through the realization of public transportation-oriented cities in line with the Indian government's efforts.

3.3.3 Priority of Metro Development among Tier-2 Cities

The regional GDP per capita comparison study among Indian states shows the GDP per capita of the Bihar, the state that Patna belongs to, is smallest among the other states. The metro development priority depends on the city socio-economic status and loss of traffic congestion of the city, however, the giving priority to a city with the lowest regional GDP per capita needs justifications. The following two analysis may justify the priority of Metro Development in Patna among Tier-2 cities.

(1) Metro development status with Tier designation status

There are 8 designated cities as the Tier-1, and 101 cities as the Tier-2[16]. The following table shows the Top 30+ populated cities in India belongs to Tier-1 and Tier-2, their population in 2021, their recent annual population growth, and metro development status including number of metro operated lines, length of metro under operation, length of metro under construction, length of metro planned, and when its construction started and opened (for under construction section) as of June 2022, and its state and state capital status. Those cities can be classified as the following four groups.

- Green: Metro operation already opened, 13 cities. All Tier-1 cities included in this category, and five Tier-2 cities, Jaipur, Luknow, Kochi, Kampur and Nagpur are listed. Most are state capital status.
- Orange: Cities with metro under construction. Six cities including Patna belong to this category.
- Blue: Cities with metro plannings. Six cities belongs to this category.
- White: Cities with no metro planning[17] though those are ranked in top-30 populated city.

Generally, it can be said that metro installation are prioritized to the populated cities with state capital status, and it is natural that metro development in Patna can be prioritized though it locates in the state with lowest regional GDP.

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16 The classification of the Tier 1/2/3 is unofficial at present. The official classification uses X/Y/Z, however, the Tier 1/2/3 is used in this section for general understanding.
https://doe.gov.in/sites/default/files/21-07-2015.pdf

17 Six of 10 cities in this category belong to Kerala state.

Table 3-7: Top30+ Populated Cities with Metro Development Status

Populaiton Ranking		Population/Tier			Metro Development Data							
#	**City**	**Pop. In 2021**	**Growth**	**Tier**	**Operation Lines**	**Operation km**	**Under Constuction (km)**	**Planned (km)**	**Construction started**	**to be opened**	**State**	**Capital**
1	Delhi	31,181,377	2.94	1	10	348.12	40.85	82.29	-	-	NCR	Y
2	Mumbai	20,667,655	1.26	1	3	30.65	150.25	157.68	-	-	MH	Y
3	Kolkata	14,974,073	0.84	1	2	40.46	54.22	44.46	-	-	WB	Y
4	Bangalore	12,764,935	3.56	1	2	56.1	116.86	105.55	-	-	Karnataka	Y
5	Chennai	11,235,018	2.41	1	2	54.65	83.4	50.3	-	-	TN	Y
6	Hyderabad	10,268,653	2.64	1	3	67	–	58	-	-	Telangana	Y
7	Ahmadabad	8,253,226	2.40	1	1	6.5	53.27	7.41	-	-	Gujarat	Y
8	Surat	7,489,742	4.25	2	2		40.35		2021	2024	Gujarat	
9	Pune	6,807,984	2.69	1	2	12	44.23	30.67	-	-	MH	
10	Jaipur	4,007,505	2.51	2	1	11.97	–	26.36	-	-	Rajastan	Y
11	Lucknow	3,764,619	2.40	2	1	22.87	–	85	-	-	UP	Y
12	Kozhikode	3,742,198	5.25	2							Kerala	
13	Malappuram	3,608,928	6.42	2							Kerala	
14	Thrissur	3,212,604	4.71	2							Kerala	
15	Kochi	3,193,029	3.60	2	1	27.4	12.24	19.9	-	-	Kerala	Y
16	Kanpur	3,153,425	0.94	2	1	8.98	8.7	18.68	-	-	UP	
17	Indore	3,113,445	3.21	2	5		33.53	248	2018	2023	MP	
18	Nagpur	2,940,487	1.63	2	2	26.6	17.3	48.3	-	-	MH	
19	Coimbatore	2,860,445	2.65	2	5		147	147	2018	2027	TN	
20	Thiruvananthapuram	2,690,703	4.10	2							Kerala	
21	**Patna**	**2,481,530**	**1.85**	**2**	**2**		**30.91**		**2020**	**2024**	**Bihar**	**Y**
22	Bhopal	2,446,882	2.40	2	2		27.87	77	2018	2023	MP	Y
23	Agra	2,261,561	2.32	2	2		29.65		2020	2024	UP	
24	Vadodara	2,232,521	1.94	2							Gujarat	
25	Kannur	2,226,693	2.76	2							Kerala	
26	Visakhapatnam	2,225,906	2.34	2	3			76.9	TBD	TBD	AP	
27	Nashik	2,123,018	2.77	2							MH	
28	Vijayawada	2,104,113	3.15	2							AP	Y'
29	Kollam	1,940,571	4.81	2							Kerala	
30	Rajkot	1,933,522	2.95	2							Gujarat	
35	Varanasi	1,692,509	1.66	2	2			29.235	TBD	TBD	UP	
37	Srinagar	1,622,454	2.31	2	2			25	TBD	TBD	J/K	
45	Allahabad	1,415,463	1.56	2	2			40	TBD	TBD	UP	
46	Gwalior	1,409,820	2.28	2	3			58.1	TBD	TBD	MP	
49	Bareilly	1,285,964	2.44	2	6			117.3	TBD	TBD	UP	

Note: As of June 2022
Source: UN statistics, Wikipedia and JST (All sources are confirmed with origin)

(2) Regional and City-wise economic status

The Per Capita Income for Bihar[18] has increased from Rs. 21,750 in 2011-12 to Rs 30,617 in 2018-19, however, Bihar has the lowest per capita income among the states in India and it was at only 33.1 percent of the national average (Rs. 92,565) in 2018-19. There is a large disparity in Bihar's regional income level from the national average.

There are very limited reference about the city-wise Per Capita income, however, the same statistics shows city-wise per capita income, general expenditure and savings as follows.

[18] Bihar Economic Survey 2019-2020, P5

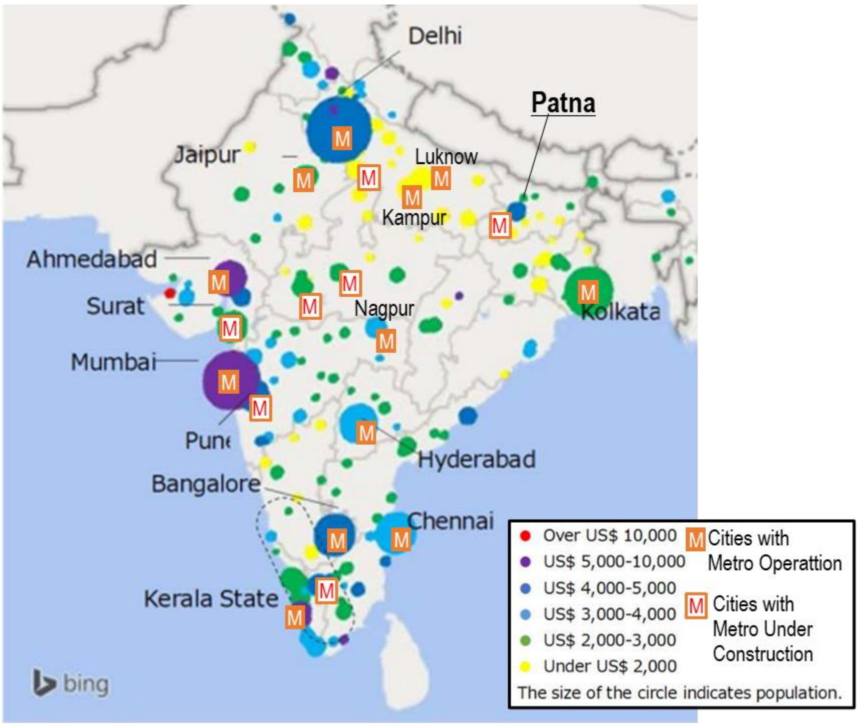
Table 3-8: Per Capita Income/Consumption/Saving for Patna and Bihar Average

Items	Bihar Average	Patna City	Difference
Gross District Domestic Products in 2011-2012 (Rs) in 2004 price	14,574	63,063	4.3
Consumption of Petrol per 1000 population (MT/1000 per) in 2018-19	5.9	13.8	2.3
Per capita Postal Saving in 2018-19 (Rs)	306.2	982.6	3.2

Source: Bihar Economic Survey 2019-2020, PP 19-21

As shown as above, Patna's per-capita income level was more than four times the state average in 2011, a bit old statistic though, it may suggests that the Patna's city-wise income level is more than average of the national income level. The other statistics shows that Patna has 2-3 times of purchasing and saving capacity compared to the state level. It should be noted that Patna is the district with highest values among all the districts in Bihar. It can be said that economic activities in Bihar are concentrated at Patna city, which may justify the metro development.

As a reference, the other statistic shows the city-wise income level in 2015 and metro development status. The size of the circle indicate population and color of the circle represents the level of income per capita. Patna's income level was categorized in the USD 4,000 – 5,000 in this study. Those Tier-1 cities like Mumbai and Ahmedabad have higher income level than Patna, however, Delhi, Bangarole, Kolkata, Hyderabad, Chennai and Pune are similar or lower income level than Patna. Although the Patna's income level reliability is low in this statistics, this map may suggest that the metro development has expanded to the cities with lower income levels (shown as dots in Yellow in the Uttar Pradesh)



Source: Y Suzuki (MGSSI) "INCOME LEVELS IN INDIA'S CITIES" and JST

Figure 3-8: Income Level of India Cities (2015) and Metro Development

4. Travel Characteristics and Demand Estimates

4.1 Overview of Existing Studies

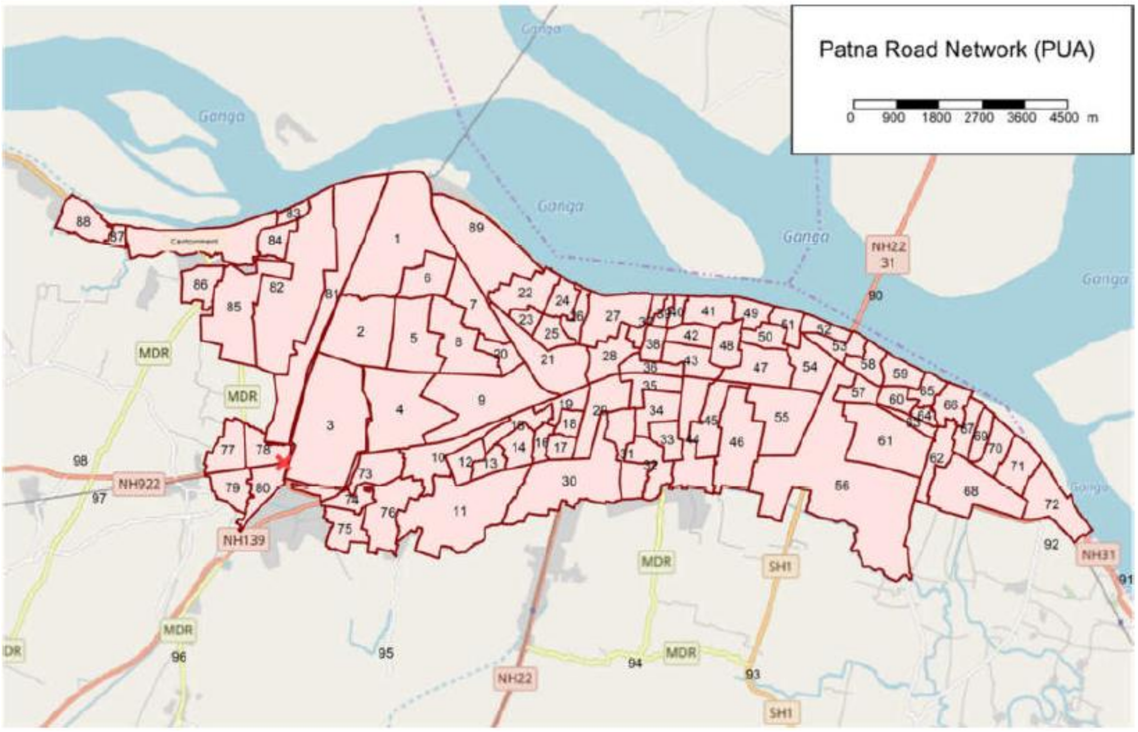
The Comprehensive Mobility Plan Patna in 2018 (CMP2018) initialized and developed by NIT Patna specified the whole framework of the demand forecast in Patna, which was utilized in the DPR. The following section shall explain the methodologies, frameworks and data set in CMP2018.

4.1.1 Methodology and Data Collection

(1) Methodology

The standard 4 stage transport model has been adopted for this study; this consists of the following stages:

- Stage 1 - Trip generation and attraction. The first step involves estimating the total number of trips produced and attracted to each Traffic Analysis Zones (TAZ, see Figure below, inner 89 zones and outer 11 zones), which were specified with the administrative zones in Patna. The number of persons expected to use the development would be estimated in this stage by using regression method to derive the relation between the trips produced and trip attracted. The average trip ratio per person was 2.29.



Source: Comprehensive Mobility Plan Patna 2018

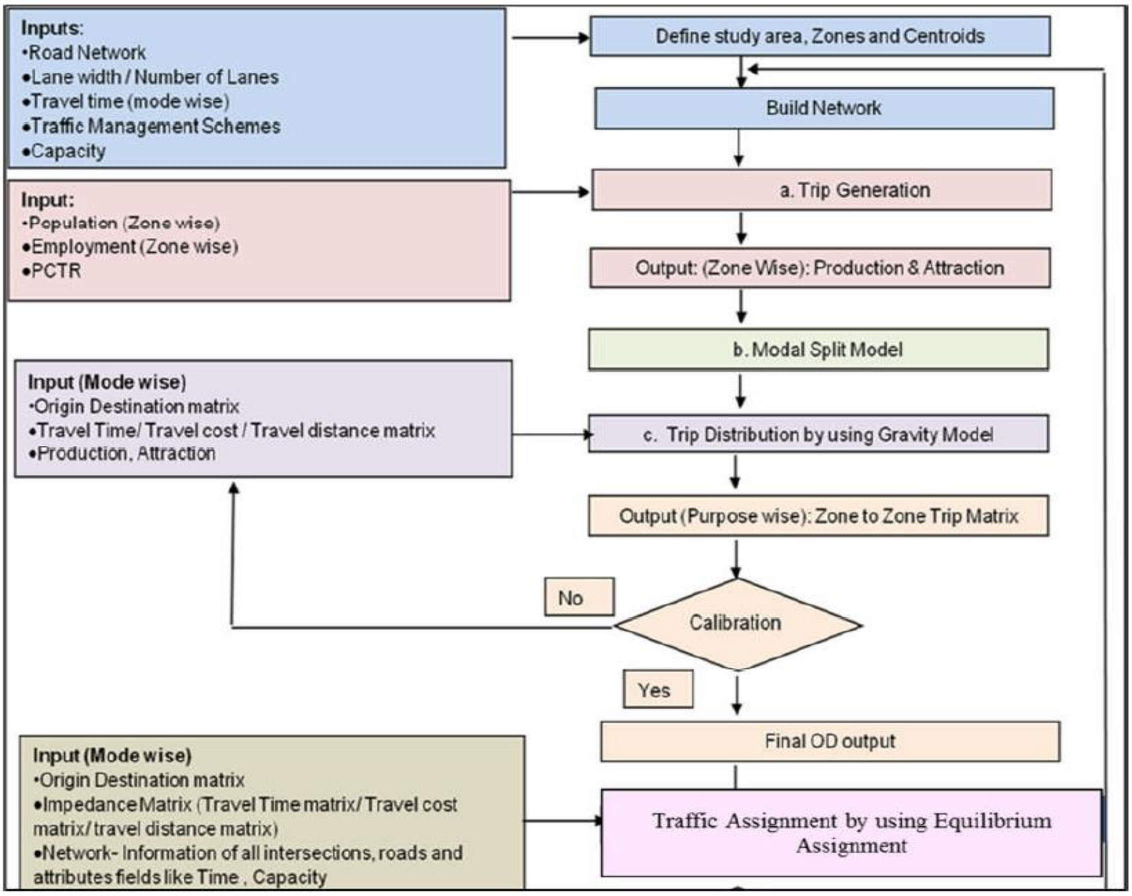
Figure 4-1: Traffic Analysis Zones

- Stage 2 - Trip distribution. In trip distribution process the productions and attractions calculated in the trip generation stage are distribution across the city based on the attraction between them. In trip distribution stage the demand matrices for each mode is generated by considering the base matrix which is derived from the survey data or the parameters determined in the existing model.

- Stage 3 - Modal split. Mode choice models should be developed for all modes of transport including public transport and para-transit modes. For our study, mode choice would be computed based on revealed and stated preference of individuals surveyed in the household survey. A Multi-nominal logit or Nested logit models or any other logit function were run to achieve the mode choice equations.
- Stage 4 - Trip Assignment. Trip assignment is the stage in the transport planning process wherein the trip interchanges are allocated to different parts of the network forming the transport system. In this stage the route to be travelled is determined and the inter-zonal flows are assigned to the selected routes. All assignment techniques are based on route selection. The choice of the route is made on the basis of number of criteria such as journey time, length, cost comfort, convenience, and safety.

For the above four stages of travel demand modelling, the PTV Visum software has been used for CMP2018. PTV Visum is a software system allows to model all private and public transport types in one single integrated model. The parameters involved in the model development are population, employment, school enrolments and transport systems of the city. A commuter decides on his/ her selection of travel mode considering a number of parameters including accessibility of travel mode from the house, total travel time, total cost of travel, convenience/comfort of travel and cost/convenience for reaching the destination at the other end of the main journey. The commuter evaluates the merits and demerits of all possible alternative modes and their combinations before deciding on the final selection of travel mode(s).

As per the India National Guideline, the general methodology for demand forecast is provided below, which shows the data set inputted to the model.



Source: Comprehensive Mobility Plan Patna 2018

Figure 4-2: Methodology for Traffic Demand Projection

(2) Household and Traffic Surveys for Data Collection

The household travel survey has been conducted to bring out socio-economic and travel characteristics of the study area like household size, income, and vehicle ownership, per capita trip rates for various purposes viz. Work, education and other trips, expenditure on transport, modal split and origin-destination matrices. To ensure that the sample was representative, the households interviewed during the survey were distributed throughout the study area in the same proportion as the distribution of population.

NIT Patna has also collected a total of 3,664 household interview samples[19] in 2018 for preparation of CMP2018 and development of Transport Demand Model using PTV VISUM. A random sampling technique was used to identify the sample. Further, care was taken that the representative households of all socio-economic strata i.e. High Income Groups (HIG), Middle Income Groups (MIG) and Lower Income Groups (LIG) were covered in the sample.

The data was collected through trained enumerators. The survey was initiated with a pilot survey in the field and amendments in the method of recording the observations were made wherever necessary before starting the actual survey.

[19] The number of the households in Patna was 334 thousand (Bihar Economic Survey-2020). The CMP2018 survey originally aimed 2% sampling, but it achieved 1% due to its budget and schedule limit. JST considers 2-3% is generally required for person trip surveys for modeling.

4.1.2 Results of CMP2018

Three Scenario on urban development are developed, namely the BAU (Business as Usual Scenario) and two options of the Sustainable Urban Transport (SUT) scenario. The BAU scenario is based on existing trends and no significant improvement to transit system of the city is proposed in this scenario. SUT scenarios lays emphasis equally on development of road as well as public transport infrastructure. Its option-1 covers mass rapid transit installation just reducing travel time only and option-2 considers improvement of safety and comfort of the mass rapid transit[20]. The base year is considered as 2018 (time of CMP2018 was conducted) and planning period has considered for next 20 years. As the Master Plan for Patna is prepared for 2031, the considered horizon years are 2031 and 2041.

The following assumptions have been made for forecasting transport demand for the years 2031 and 2041.

- Calibrated and validated travel demand model has been used.
- Land use parameters (population and employment) have been distributed in various traffic zones for 2031 and 2041.
- Inter-city passenger to/from the study area will grow at the growth rate of 4% in various adjoining towns.
- Inter and Intra-city goods traffic is expected to grow at 5% per annum up to 2041.

Table 4-1: Traffic Demand for Different Scenarios

Scenario	Vehicle Kilometres (km)	Vehicle Hours	Total Public Transport Trip (including IPT & Excluding Walk)	Modal Share of Total Public Transport (Including IPT Excluding Walk)	Average Trip Length for Public Transport and IPT Modes
Base Year 2018	5853687	239884	1100374	45%	4.77km
BAU Year 2031	9077803	343139	1451884	41.01%	4.51km
SUT Scenario (Option 1) Year 2031	5572609	202301	3270383	71.67%	5.22km
SUT Scenario (Option 2) Year 2031	5149166	207843	3417208	73.66%	5.29km
BAU Year 2041	12058035	516980	1381336	35.46%	4.85km
SUT Scenario (Option 1) Year 2041	6315024	233427	3708328	71.98%	5.25km
SUT Scenario (Option 2) Year 2041	5850142	239413	3874590	73.96%	5.30km

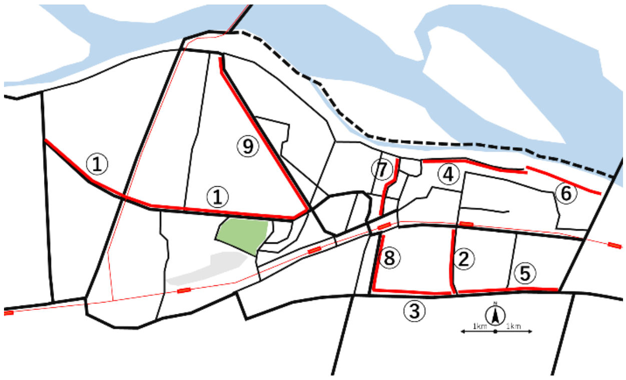
Source: Comprehensive Mobility Plan Patna 2018

Result of CMP2018 identified potential public transport corridors with high PHPDT density presented below. Bailey road has largest PHPDT in the list. Based on the result below, metro corridors were composed and proposed in the DPR. The CMP2018 did not discuss about demand along the final alignment of the Metro corridors, which was undertaken by the revised DPR in 2019.

[20] Actually, the CMP2018 considers Option-3, considering parking cost increase for private vehicles.

Table 4-2: Potential Section with High PHPDT by Road Sections

#	Road Sections	PHPDT	
		2031	2041
1	Bailey Road	23,315	28,638
2	Kankarbagh Road	18,216	20,128
3	Patna Bypass (NH30)	15,936	19,526
4	Ashok Rajipath West NIT	15,022	16,735
5	Patna Bypass (West Zeromile)	12,070	16,089
6	Ashok Rajipath East NIT	10,505	12,221
7	Frazer Road	16,308	19,399
8	Mithapur	16,438	20,141
9	Digha Ghat to Bailey Road	14,520	17,455



Source: CMP 2018, and JST

4.2 Reviews of Existing Studies

4.2.1 Review of DPR Demand Forecast

The scope of the DPR demand forecast is the Patna Urban Agglomeration (PUA) area. PUA as classified by Census 2011, comprises of Patna Municipal Corporation and outgrowth, Patliputra Housing colony, Phulwari Sharif, Danapur Cantonment, Khagaul and Saidpura. To understand the travel pattern of the city, a total of 99 zones called traffic analysis zones have been identified. Considering the ease of getting required zonal information, administrative wards were considered as zones within the Municipal Area. The areas that fall within Patna Urban area but outside the Municipal Boundary have been divided into zones based on homogenous land use and traffic generation points. A total of 89 internal zones inside PUA and 10 external zones have been considered for the study (same as CMP2018).

The Updated DPR of Patna Metro adopted the same model and framework of the CMP2018 study developed by the NIT Patna. The Updated DPR applied the SUT scenario Option-1 (most conservative scenario, just considering travel time reduction by Metro, not considering comfort and safety of Metro, or parking costs increase of private vehicle users) for its Metro installation scenario.

4.2.2 Demand Forecast for Patna Metro by DPR

The maximum PHPDT (peak hour peak direction trips) for proposed metro corridors for the years 2024, 2031, 2041 and 2051 are given below. This is followed by the station-wise PHPDT.

Table 4-3: Maximum PHPDT for Metro Corridors

S.No.	Corridor details	Maximum PHPDT			
		2024	2031	2041	2051
1	Danapur - Khemni Chak	14,516	23,127	25,323	32,011
2	Patna Station - New ISBT	11,252	17,862	19,507	22,083

Source: DPR

Maximum PHPDT is the key factor to specify the metro capacity. PHPDT can be derived from the estimation of the sectional passenger loadings by direction, and maximum sectional loading of both directions shall be taken as the maximum PHPDT. For example, the Corridor 1's maximum PHPDT is presented at the section Vikas Bhawan and Vidyut Bhawan of Khemni Chak bound direction. The sectional line loading is estimated by the traffic assignment model.

Table 4-4: PHPDT for Stations of Metro Corridor 1

Corridor-1: Danapur - Khemni Chak										
S.No.	FROM	TO	2024		2031		2041		2051	
			Danapur to Khemni Chak	Khemni Chak to Danapur	Danapur to Khemni Chak	Khemni Chak to Danapur	Danapur to Khemni Chak	Khemni Chak to Danapur	Danapur to Khemni Chak	Khemni Chak to Danapur
1	Danapur	Saguna More	2305	1837	3539	2886	4217	3425	5516	4371
2	Saguna More	RPS More	6564	4893	10076	7639	12042	8916	16061	11367
3	RPS More	Patliputra	8806	6640	13479	10356	16044	12090	21346	15475
4	Patliputra	Rukanpura	10273	7397	15708	11555	18679	13504	24869	17272
5	Rukanpura	Raja Bazar	12891	10008	20328	15306	22867	18024	29553	23810
6	Raja Bazar	Patna Zoo	14062	11334	22412	17171	24739	20622	31471	27569
7	Patna Zoo	Vikas Bhawan	14486	11739	23127	17768	25323	21478	32011	28791
8	Vikas Bhawan	Vidyut Bhawan	14516	11709	23079	17816	25007	21794	31274	29527
9	Vidyut Bhawan	Patna Station	13156	11781	20985	17846	22260	22251	27613	30377
10	Patna Station	Mithapur	11093	11073	16970	17883	19103	20723	24638	27848
11	Mithapur	Ramkrishna Nagar	9110	8239	14035	13227	15518	15786	19851	21878
12	Ramkrishna Nagar	Jaganpura	7474	6339	11587	9865	12851	12125	16185	17033
13	Jaganpura	Khemni Chak	7049	5755	10958	8940	12086	11048	15125	15662
MAX. PHPDT			14516		23127		25323		32011	

Source: DPR

Table 4-5: PHPDT for Stations of Metro Corridor 2

Corridor-2: Patna Station - New ISBT										
S.No.	FROM	TO	2024		2031		2041		2051	
			Patna Station to New ISBT	New ISBT to Patna Station	Patna Station to New ISBT	New ISBT to Patna Station	Patna Station to New ISBT	New ISBT to Patna Station	Patna Station to New ISBT	New ISBT to Patna Station
1	Patna Station	Akashvani	6351	4707	10226	7859	10682	8913	10919	10745
2	Akashvani	Gandhi Maidan	7811	6303	12455	10596	13083	12025	13523	14494
3	Gandhi Maidan	PMCH	9181	7527	14402	12412	15185	14036	15839	16709
4	PMCH	University	10126	8223	15738	13395	16705	15028	17694	17604
5	University	Moin UL Haq Stadium	11201	9862	17340	15513	18650	17011	20122	19478
6	Moin UL Haq Stadium	Rajendra Nagar	11121	10584	17161	16509	18393	18119	19855	20649
7	Rajendra Nagar	Malahi Pakri	10453	11252	15808	17862	17005	19507	18421	22083
8	Malahi Pakri	Khemni Chak	9690	10203	14551	16044	15536	17678	16742	19953
9	Khemni Chak	Bhoot Nath	9063	8764	13555	13504	14118	15081	14883	17114
10	Bhoot Nath	Zero Mile	8236	7684	12411	11504	12879	12773	13392	14395
11	Zero Mile	New ISBT	5907	5805	8476	8442	8934	9087	9200	9704
MAX. PHPDT			11,252		17,862		19,507		22,083	

Source: DPR

Daily trips for different modes are forecasted in the DPR as follows.

Table 4-6: Daily Trips

Mode	Trips Without Mass Transport System				Trips with Mass Transport System			
	2024	2031	2041	2051	2024	2031	2041	2051
Bus	185218	216178	240699	268000	93897	91671	116870	129423
Car	284950	361683	421223	479308	208662	211617	269795	298847
2 Wheelers	997327	1259655	1527511	1803847	600375	609660	736174	808904
Auto	854851	1039320	1203493	1391539	556431	564313	719453	809878
Taxi	32057	45730	60175	67000	10433	7024	8952	9884
Metro	-	-	-	-	884603	1438281	1601856	1952757
Total	**2354403**	**2922566**	**3453100**	**4009695**	**2354403**	**2922566**	**3453100**	**4009694**

Source:DPR

4.2.3 Revision of Demand Forecast by JST

(1) Review of DPR Model

DPR adopted the same model and framework that developed by the NIT Patna for CMP2018. Though the standard four-step demand modelling methodology is elaborated in CMP2018 and the DPR, it seems the steps are not followed based on the review of PTV Visum models received[21].

For mode choice (Step 3), the typical transport modelling allows the commuter decides on his/ her selection of travel mode considering the generalized cost, including cost of travel time, fare cost (in the case of public transport), vehicle cost and fuel cost (in the case of private transport), among others. Based on the generalized cost, mode choice analysis is carried out, which determines the modal share results. However, DPR model doesn't incorporate the generalized cost setting. For instance, fare setting for MRT services is not available in the model. The modal share is not the result of the modelling, rather than a pre-defined share.

Further examination of the DPR modelling shows that, for the trip purpose-based OD Matrix[22], a pre-defined share is applied for different OD Matrix for each mode[23]. For public transport mode, the share set for Home-Work Matrix is 0.70, for Home-Education Matrix is 0.71, and for Home-Others is 0.85. Please note the pre-defined share is a unified share for all zones. Since the mode choice analysis is not really carried out in the software, the projected model share is actually the direct result of the setting. As a result, an optimistic modal share of public transport is reported (which is about 70%, a demand-weighted average of the pre-defined share). The other modes showed the same result.

However, it is also not reasonable to deny the DPR model and its result completely. According to the interview with the modeller, the fixed rate of the mode choice share was computed based on the Stated Preference Survey. Certain logit function was adopted to achieve the mode choice equations. There is the challenge for JST to reproduce the mode choice analysis as the raw data for the Stated Preference Survey is not disclosed though JST has requested.

[21] During June to August 2022, JST tried to obtain the Visum model from DPR Consultant, and finally received that at the end of August. JST carried out the review and analysis in a short period.
[22] There are three types of trip purpose defined in the model: Home-Work, Home-Education, and Others
[23] Modes defined in the model includes Car, Cycle, Two-Wheeler, and Public Transport (MRT, Bus, and others)

(2) Revision of Demand Forecast by JST

Considering the availability of data and the limitation of time, JST improved the demand forecast model from the following aspects:

Revised the opening year of MRT from 2024 to 2026. At the time of DPR preparation, the completion of the construction work was estimated in 2024. The updated implementation schedule indicated 2026 to be the opening year. In the revision, OD Matrices are updated based on the population projection for 2026.

Revised the headway schedule of MRT. As mentioned earlier, the modal share for Public Transport Mode is pre-defined. Within Public Transport Mode, the distribution of traffic demand among MRT and other modes is based on the Headway-based assignment method[24]. DPR consultants assumed the average train speed as 50 km/h in the DPR model, which is too high for Metro operation. According to the latest operation plan, the speed is set at 35 km/h. Stop time at stations is set to be 40 seconds, which was ignored in the DPR model (set at 0 second).

The revision is based on the DPR model. Compared to CMP2018 models, DPR model updated the MRT alignment from the early design to the ongoing ones. In additions, DPR model considered the improvement of Patna road network, such as the Marine Drive Road that currently under construction. The updated demand forecast result by JST are listed in following tables.

The table below shows the forecasted daily ridership. Ridership of MRT for opening year 2026, future year 2031, 2041, 2051 is about 0.9, 1.2, 1.4, and 1.7 million respectively. Compared with the projection result of DPR (0.88 million in 2024, 1.4 in 2031, 1.6 in 2041, 1.9 in 2051), there is a slight increase for the opening year and about 10% decrease for the future years.

Table 4-7: Revised Daily Ridership for Metro Corridors

Total Daily Trips	2026	2031	2041	2051	Length (km)
Cor 1: Danapur - Khemni Chak	596,675	841,673	971,741	1,228,429	17.8
Cor 2: Patna Station - New ISBT	313,109	412,267	434,799	484,909	14.2
Total Daily Trips	909,784	1,253,940	1,406,540	1,713,338	32.0
Total Daily Trips / Operation KM	2026	2031	2041	2051	
Cor 1: Danapur - Khemni Chak	33,559	47,338	54,654	69,090	
Cor 2: Patna Station - New ISBT	22,050	29,033	30,620	34,149	
AAGR Cor1		7.1%	1.4%	2.4%	
AAGR Cor2		5.7%	0.5%	1.1%	

Source: JST

Compared with DPR projection, the revised total daily trips of Metro for 2026 increased from 884,603 to 909,784 (2.8%); for 2031 it decreased from 1,438,281 to 1,253,940 (-12.8%); for 2041 the decrease is about 12.2%; for 2051 the decrease is about 12.3%. Comparing the corridors, the total passenger volume of the Corridor 1 is larger than that of Corridor 2. The unit daily ridership per operation length shows similar characteristics for both corridors. Passenger volume per length of the Corridor 1 is 1.5 to 2.0 times larger than that of Corridor 2. It should be noted that the Annual Average Growth Rate (AAGR) during

[24] Three public transport assignment methods are available in PTV Visum: Headway-based, Timetable-based, and Transport System-based.

2026-2031 are relatively higher than other sections. Station-wise PHPDT for Corridor 1 and 2 are shown in tables below.

Table 4-8: Revised PHPDT for Stations of Metro Corridor 1

Year		2026		2031		2041		2051	
Station		To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur
Danapur	Saguna More	2,469	1,967	3,243	2,645	3,850	3,127	5,016	3,975
Saguna More	RPS More	7,030	5,241	9,233	7,000	10,994	8,140	14,606	10,337
RPS More	Patliputra	9,431	7,112	12,352	9,490	14,648	11,038	19,412	14,073
Patliputra	Rukanpura	11,003	7,922	14,394	10,589	17,053	12,329	22,616	15,707
Rukanpura	Raja Bazar	13,807	10,719	18,628	14,026	20,877	16,455	26,875	21,653
Raja Bazar	Patna Zoo	15,061	12,139	20,538	15,735	22,586	18,827	28,620	25,071
Patna Zoo	Vikas Bhawan	15,515	12,573	21,193	16,282	23,119	19,609	29,111	26,182
Vikas Bhawan	Vidyut Bhawan	15,547	12,541	21,149	16,326	22,831	19,897	28,441	26,852
Vidyut Bhawan	Patna Station	14,090	12,618	19,230	16,354	20,323	20,314	25,111	27,625
Patna Station	Mithapur	11,881	11,859	15,551	16,388	17,440	18,919	22,406	25,325
Mithapur	R. Nagar	9,757	8,824	12,861	12,121	14,167	14,412	18,052	19,896
R. Nagar	Jaganpura	8,005	6,789	10,618	9,040	11,733	11,070	14,719	15,490
Jaganpura	Khemni Chak	7,550	6,164	10,042	8,192	11,034	10,086	13,755	14,243
MAX. PHPDT		**15,547**		**21,193**		**23,119**		**29,111**	

Source: JST

The largest PHPDT volume on the Corridor 1 can be seen in the section of Patna Zoo – Vikas Bhawan, or Vikas Bhawan – Vidyut Bhawan for East-bound direction. It is true that those stations are close to CBD in Patna, and commuters from western region of Patna may concentrate in a morning peak hour.

Table 4-9: Revised PHPDT for Stations of Metro Corridor 2

Year		2026		2031		2041		2051	
Station		To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station
Patna Station	Akashvani	6,072	4,500	8,110	6,233	8,641	7,210	8,796	8,656
Akashvani	Gandhi Maidan	7,468	6,026	9,878	8,404	10,584	9,728	10,894	11,676
Gandhi Maidan	PMCH	8,778	7,196	11,423	9,844	12,284	11,355	12,759	13,460
PMCH	University	9,681	7,862	12,482	10,624	13,514	12,157	14,254	14,181
University	Moin Stadium	10,709	9,429	13,753	12,304	15,087	13,761	16,210	15,691
Moin Stadium	Rajendra Nagar	10,632	10,119	13,611	13,094	14,879	14,658	15,995	16,634
Rajendra Nagar	Malahi Pakri	9,994	10,758	12,538	14,167	13,756	15,780	14,839	17,790
Malahi Pakri	Khemni Chak	9,264	9,755	11,541	12,725	12,568	14,301	13,487	16,074
Khemni Chak	Bhoot Nath	8,665	8,379	10,751	10,710	11,421	12,200	11,989	13,787
Bhoot Nath	Zero Mile	7,874	7,346	9,843	9,124	10,419	10,333	10,788	11,596
Zero Mile	New ISBT	5,648	5,550	6,723	6,696	7,227	7,351	7,411	7,817

Year	2026		2031		2041		2051	
Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station
MAX. PHPDT	**10,758**		**14,167**		**15,780**		**17,790**	

Source: JST

For Corridor 2, maximum PHPDT can be identified in the section of Rajendra Nagar and Malahi Pakri in the South-bound direction. Those stations are located in a dense, mixed land use area, which can be considered second CBD in Patna.

The maximum PHPDT for proposed metro corridors for the years 2026, 2031, 2041 and 2051 are summarized below.

Table 4-10: Revised Maximum PHPDT for Metro Corridors

PHPDT	2026	2031	2041	2051
Cor 1: Danapur - Khemni Chak	15,547	21,193	23,119	29,111
Cor 2: Patna Station - New ISBT	10,758	14,167	15,780	17,790

Source: JST

Corridor 1 has relatively larger PHPDT volumes than Corridor 2 due to its operational length.

With the introduction of MRT, modal share for year 2031, 2041, and 2051 are estimated based on the traffic projection model. Excluding the walk and non-motorized modes, the modal share is listed below.

Table 4-11: Projected Modal Share (trip-based)

Mode	2031	2041	2051
Motor cycle	20%	19%	21%
Car	7%	7%	7%
Auto	26%	29%	26%
Bus	4%	5%	4%
Metro	43%	41%	43%

MRT takes about 41-43% of the modal share in the future, which is slightly lower than that estimated in DPR (46%-49%). For other modes, the share of Bus is about 5%, for Auto (rickshaw) is about 26%, for Motor cycle is 20%. Car (including Taxi) is still a small share, less than 10% in the future.

4.2.4 Estimation of Traffic Impact during Metro Construction Period

The required road closures during the construction period may result in traffic congestions and delays even though proper traffic management measures are taken. The JST estimated the negative traffic impact based on traffic model (Base model, without MRT), considering the expected station-specific road closure.

(1) Expected Road Closure and Phased Construction

The JST specified the required road lane closing during the construction period by station as shown in the table below. The numbers of lane and length of road closure were specified by station. This is estimated based on the field trip, the station drawings, and with the advice of construction specialist of the JST.

Table 4-12: Expected Road Closure during Construction Period

Corridor	Station name	Type	Influence level	Road lane (occupied/total)
Corridor 1				
1	Danapur	Elevated	medium	2/4
2	Saguna More	Elevated	low	2/6
3	RPS More	Elevated	medium	2/6
4	Patliputra	Elevated	low	0/6
5	Rukanpura	Underground	low	0/6
6	Raja Bazar	Underground	low	0/6
7	Patna Zoo	Underground	low	2/6
8	Vikas Bhawan	Underground	low	2/6
9	Vidyut Bhawan	Underground	low	2/6
10	Patna Station	Underground	medium	4/6
11	Mithapur	Elevated	low	0/6
12	Ramkrishna Nagar	Elevated	low	0/6
13	Jaganpura	Elevated	low	0/6
14	Khemni Chak	Elevated	**high**	4/6
Corridor 2				
1	Patna Station	Underground	medium	4/6
2	Akashvani	Underground	**high**	4/4
3	Gandhi Maidan	Underground	**high**	2/4
4	PMCH	Underground	medium	2/4
5	University	Underground	medium	2/4
6	Moin Ul Haq Stadium	Underground	low	0/0
7	Rajendra Nagar	Underground	**high**	4/4
8	Malahi Pakri	Elevated	**very high**	4/4
9	Khemni Chak	Elevated	**high**	4/6
10	Bhoot Nath	Elevated	low	0/6
11	Zero Mile	Elevated	low	0/6
12	New ISBT	Elevated	**high**	4/4

Source: JST

It should be noted that the lane closure at the Malahi Pakri is most critical, which is followed by Rajendra Nagar, as they are located at the road intersection or in front of station, while road section is narrow.

The estimation followed the latest Phased Construction Plan. The construction progresses are staggered into three stages and the affected stations and length of road closure are different for the stages.

Table 4-13: Phased Construction Plan

Phase	Planned Date	Corridor	Section
I	30th September 2025	Corridor-2	Malahi Pakri – New ISBT
II	9th January 2026	Corridor-2	Patna Jct. – Malahi Pakri
III	31st December 2026	Corridor-1	Danapur – Khemni Chak

Source: JST

(2) Introduction of the Modelling

CMP2018 Model is selected as the base model. 3 sub-models are created to simulate the 3 construction phases. Phase 1 sub-model only considers the road closure of Malahi Pakri to New ISBT section; Phase 2 sub-model considers the road closure of Patna Jct. to Malahi Pakri section, in addition to the sections considered in Phase 1, and so on.

The modelling considers the details of the road network. The length of the road closure follows the station drawings. Potential influence on adjacent road and intersections are considered. For example, for Malahi Pakri Station, one of the most affected stations, not only the North-South road section (about 150m) that overlaps with the MRT station area is closed, small sections of the East-West road that intersects with the affected road section are also adjusted, to better simulate the potential traffic stagnant at the local network.

Source: JST

Figure 4-3: Modelling of Road Closure for Malahi Pakri Station

In the modelling, capacity of relevant road sections is adjusted to reflect the impact of road lane closure. Comparing the sub-models with the base model, daily vehicle-km and vehicle-hours by vehicle types as well as for the whole network for the with and without road closure scenarios are estimated.

(3) Estimation Result and Comment

Daily vehicle-km and vehicle-hours for difference scenarios are listed in the table below.

Table 4-14: Estimation Result of Traffic Impact during Construction Period

	Vehicle-km	Vehicle-hour	Vehicle-km increased	Vehicle-hour increased	Percentage increased	
Base case	5863424	238768	na	na	na	na
Phase 1	5872147	241491	8722	2723	0.149%	1.141%
Phase 2	5873976	247017	10552	8250	0.180%	3.455%
Phase 3	5874288	247387	10863	8619	0.185%	3.610%

Source: JST

As indicated by the result, the impact of the Phase 1 is different from that of the other Phases. The road closure of Malahi Pakri in Phase 1 has a critical impact on the traffic. However, the detour to alternative routes with less congestion is possible, therefore the negative impact in terms of vehicle-km is larger for Phase 1 (0.149% increase) while the vehicle-hour increased (1.141%) are relatively small, compared to Phase 2. On the other hand, the trend of Phase 2 and 3 are similar, however, the negative impact of Phase 2 is severe to that of Phase 3 as the affected area of Phase 2 are located in the city center, where traffic amount is large. For Phase 3, the lane closures are relatively smaller due to the existing road width and condition are good, so the impact from road closure becomes smaller.

5. Civil Engineering and Alignment

This chapter mentions that the review result of the route and facility plan proposed in DPR to check those suitability, and gives some recommendations to improve the current plan. 5.1 Route Plan and Alignment

5.1.1 Route Plan

DPR describes two corridors of the route plan for Patna Metro. Corridor 1 runs between Danapur station and Khemni Chak station and Corridor 2 runs between Patna Junction Station and New ISBT station. This study aims to investigate these two corridors of Patna Metro Rail Network. The following chart is the summary of corridors as the subject for this study.

Table 5-1: Patna Metro Project Network Study Scope

Route.	Section	Length (km)
1) Corridor 1	Danapur - Khemni Chak	17.78
2) Corridor 2	Patna Junction - New ISBT	14.20
Total		31.98

Source: Detailed Project Report 2021, DMRC

(1) Corridor 1: Danapur – Khemni Chak

1) Description of the Route Alignment of the Corridor 1

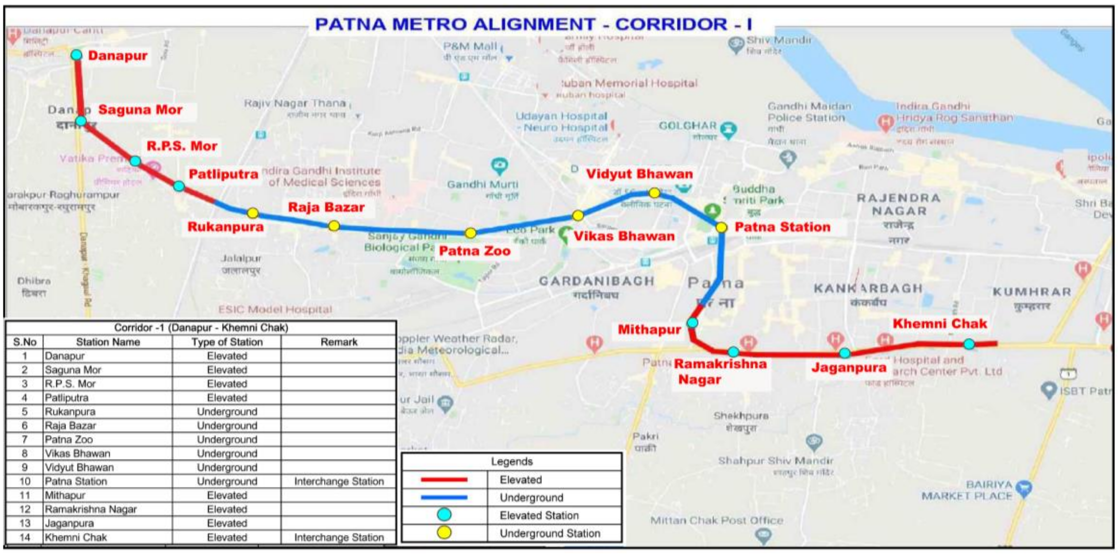
DPR describes the route of Corridor 1 that starts from Danapur station in western Patna and reaches to Khemni Chak stations in the southwestern part of the city. The route passes through Suguna - Danapur Main Rd, Bailey Rd, Fraser Rd, Patna Junction Station, Mithapur Bus Stand Rd, Patna - Sitamarhi Rd. According to DPR, the section between Danapur Station and Patiputra Station is supposed to be the elevated structure. The transitional section from elevated to underground starts at east of Patliputra station and the underground section continues to the eastward. Reverting back to the elevated structure starts between Patna Junction Station and Mithapur station and connect with Corridor 2 at Khemni Chak station.

2) Route Length by the structure type

The total length of this line from Danapur station to Khemni Chak station is 17.78 km. Referring to DPR, the breakdown categorized by the structure type is shown below.

Elevated	:	7.01 km
Elevated ramp	:	0.31 km
Ramp U-Type Retaining Wall	:	0.29 km
Underground	:	10.17 km
Total	:	17.78 km

Source: Detailed Project Report 2021, DMRC



Source: Detailed Project Report 2021, DMRC

Figure 5-1: Corridor 1: Danapur – Khemni Chak

(2) Corridor 2: Patna Junction – New ISBT

1) Description of the Route Alignment of the Corridor

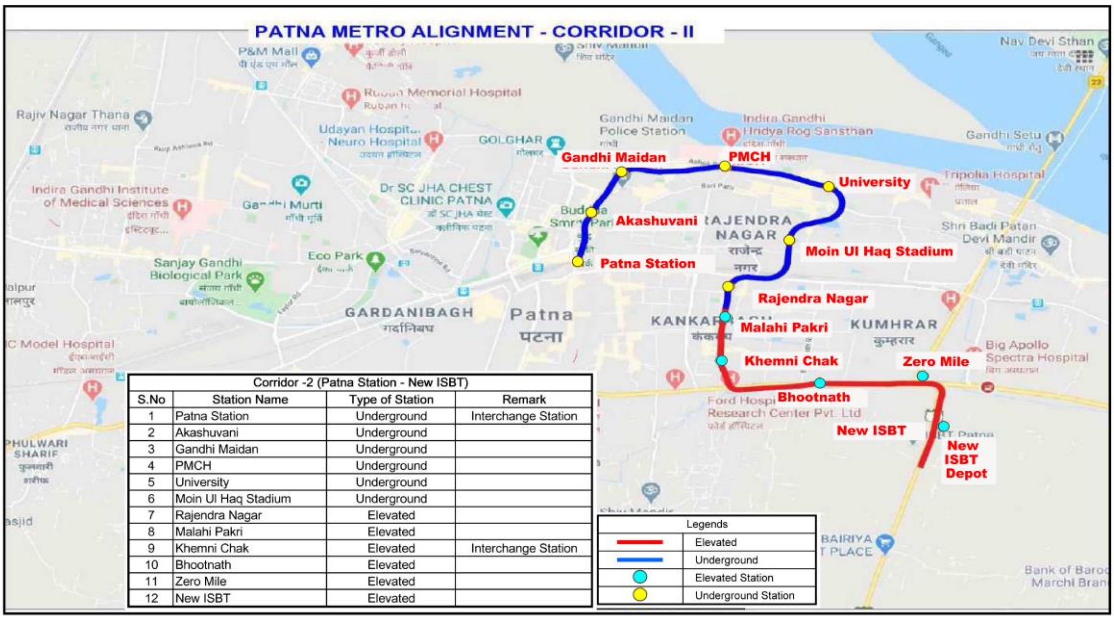
The route of Corridor 2 described in the DPR starts from Patna Junction Station, which is located north of another Patna Junction Station of Indian Railways, and reaches to NEW ISBT station in the southeast of Patna city via the northeast part of Patna city and Ragendra Nagar station. The route passes Fraser Rd, Gandhi Maidan Rd, Ashok Rajpath Rd, Moin Ul Hap, Rajendra Nagar Station, Kankarbagh Main Rd, Malahi Pakri Rd, 90 Feet Rd, Patna - Sitamarhi Rd and Bodhgaya Rd.
According to DPR, the section between Patna station and Rajendranagar station is an underground section, which transitions to an elevated section at the south of the Rajendra Nagar station, and thereafter an elevated section continues until the terminus, New ISBT station.
The depot is planned to be located adjacent to the New ISBT station and it is assumed to be jointly used for Corridor 1 and Corridor 2.

2) Route Length by the structure type

The total length of this line from Patna station to New ISBT station is 14.20 km. Referring to DPR, the breakdown categorized by the structure type is shown below.

Elevated	:	7.80 km
Elevated ramp	:	0.15 km
Ramp U-Type Retaining Wall	:	0.30 km
Underground	:	5.95 km
Total	:	14.20 km

Source: Detailed Project Report 2021, DMRC



Corridor -2 (Patna Station - New ISBT)

S.No	Station Name	Type of Station	Remark
1	Patna Station	Underground	Interchange Station
2	Akashuvani	Underground	
3	Gandhi Maidan	Underground	
4	PMCH	Underground	
5	University	Underground	
6	Moin Ul Haq Stadium	Underground	
7	Rajendra Nagar	Elevated	
8	Malahi Pakri	Elevated	
9	Khemni Chak	Elevated	Interchange Station
10	Bhootnath	Elevated	
11	Zero Mile	Elevated	
12	New ISBT	Elevated	

Source: Detailed Project Report 2021, DMRC

Figure 5-2: Corridor 2: Patna Station – New ISBT

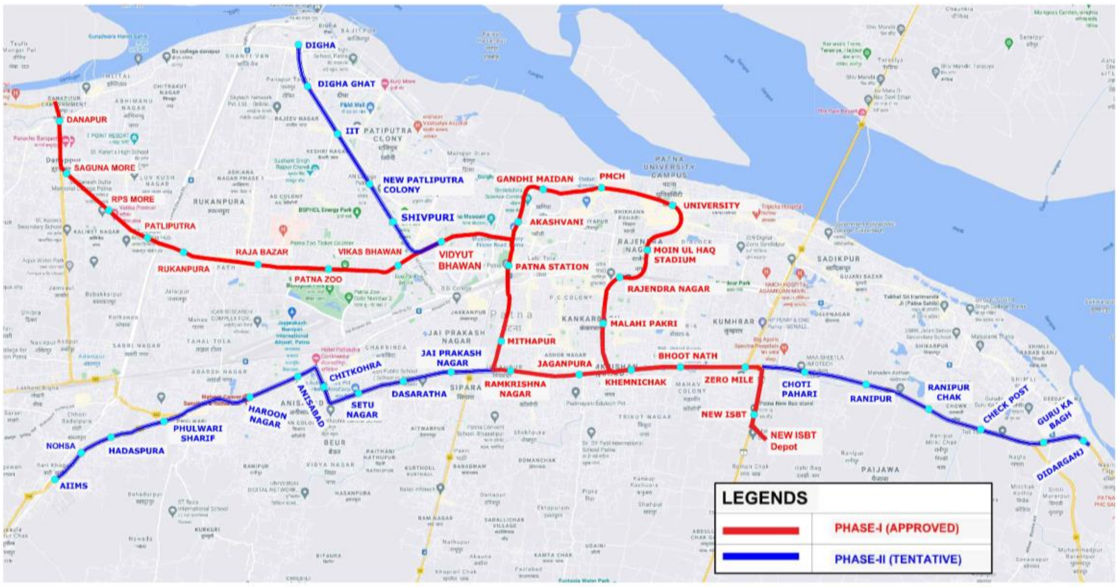
(3) Future Extension

According to PMRCL/DMRC, the following three routes are envisioned as future plan.t

- Vidyut Bhawan – Digha
- Ramkrishna Nagar – AIIMS
- Zero Mile - Didarganj

Although the future extension routes are supposed to branch off from Corridor 1 and Corridor 2, both Corridor 1 and Corridor 2 do not have a plan to arrange the through operation facility at stations to be connected with the future extension routes since they are still conceptual at this present.

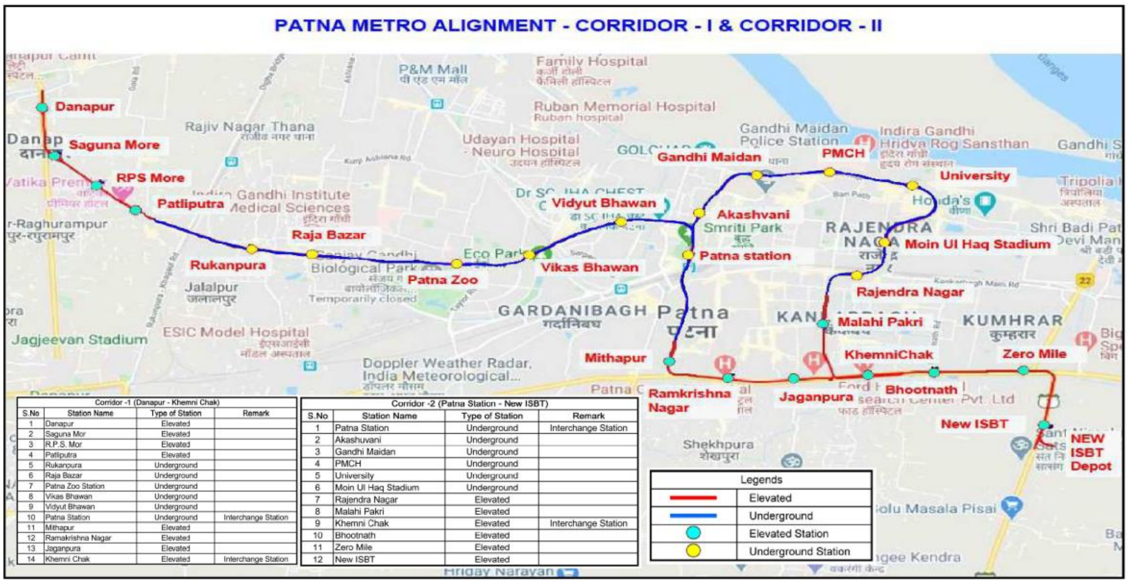
The locations of the future extension routes are shown in エラー! 参照元が見つかりません。.



Source: PMRCL/DMRC

Figure 5-3: Route Plan for Future Extension

5.1.2 Overview of Existing Studies



Corridor -1 (Danapur - Khemni Chak)			
S.No	Station Name	Type of Station	Remark
1	Danapur	Elevated	
2	Saguna Mor	Elevated	
3	R.P.S. Mor	Elevated	
4	Patliputra	Elevated	
5	Rukanpura	Underground	
6	Raja Bazar	Underground	
7	Patna Zoo Station	Underground	
8	Vikas Bhawan	Underground	
9	Vidyut Bhawan	Underground	
10	Patna Station	Underground	Interchange Station
11	Mithapur	Elevated	
12	Ramakrishna Nagar	Elevated	
13	Jaganpura	Elevated	
14	Khemni Chak	Elevated	Interchange Station

Corridor -2 (Patna Station - New ISBT)			
S.No	Station Name	Type of Station	Remark
1	Patna Station	Underground	Interchange Station
2	Akashuvani	Underground	
3	Gandhi Maidan	Underground	
4	PMCH	Underground	
5	University	Underground	
6	Moin Ul Haq Stadium	Underground	
7	Rajendra Nagar	Elevated	
8	Malahi Pakri	Elevated	
9	Khemni Chak	Elevated	Interchange Station
10	Bhootnath	Elevated	
11	Zero Mile	Elevated	
12	New ISBT	Elevated	

Source: Detailed Project Report 2021, DMRC

Figure 5-4: Corridor 1 and Corridor 2 Alignment

(1) Corridor 1

Corridor 1 starts at Danapur Station in the west of Patna City, across this city to east and west and reaches to Khemni Chak Station via Patna Junction Station which is a major station of the Indian Railways. The feature of this route by section is described below.

1) DANAPUR – PATLIPUTRA section

Danapur and Patliputra section is proposed as an elevated structure. Other than Danapur Station and Patliputra Station, there are Saguna Mor Station and R.P.S. Mor Station. All four stations in this section are the side platform type.

There is the wide road named Bailey Rd from Danapur Station to just before Patliputra Station. The viaduct is supposed to be located in the middle of this road. The ramp from the elevated to the underground starts from the east side of Patliputra Station, and therefore this station is located on the waterway at the north of the road.

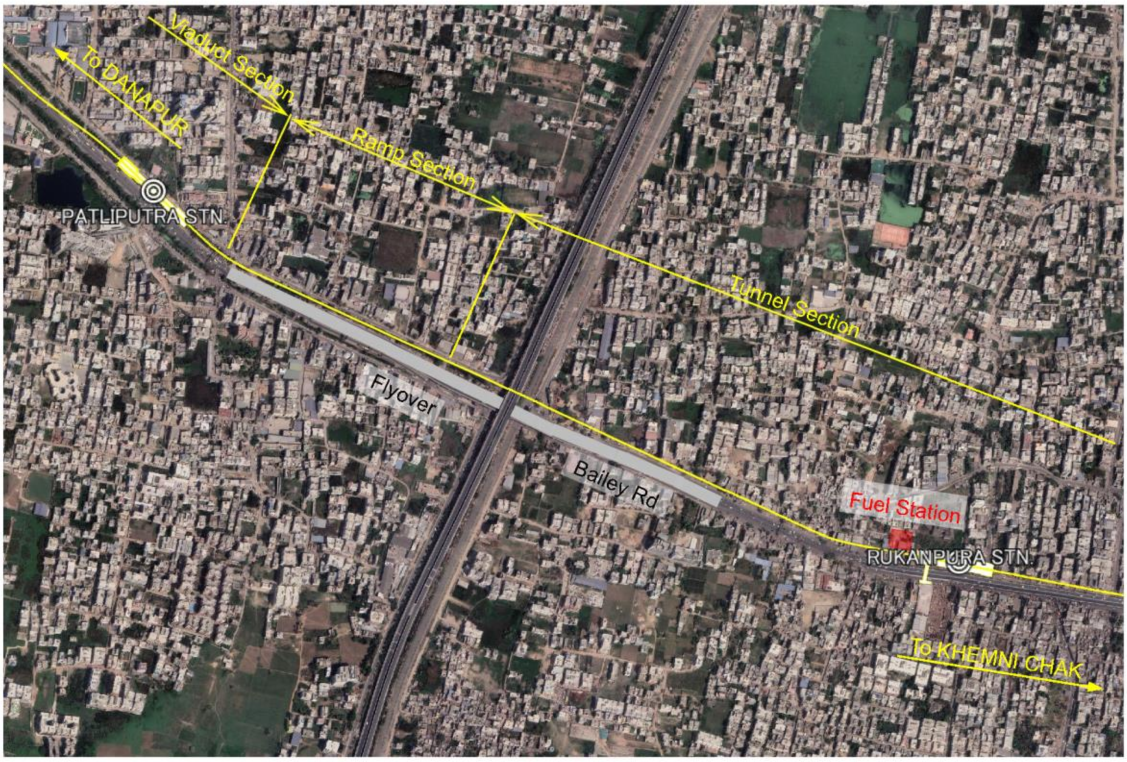
Source: Google earth, PMRCL, JICA Study Team

Figure 5-5: Location map between DANAPUR and PATLIPUTRA

2) PATLIPUTRA – RUKANPURA section

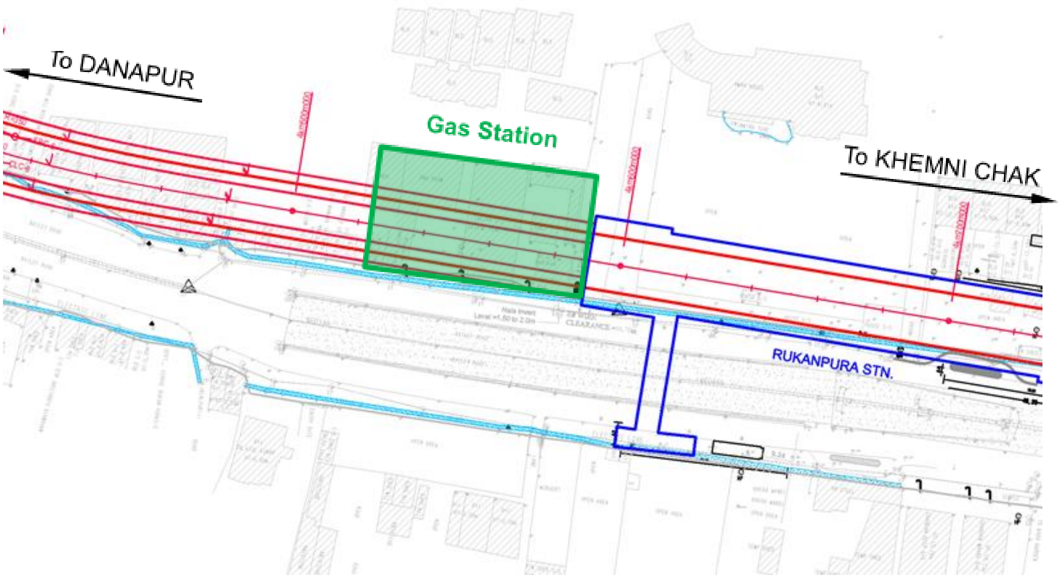
The ramp between the elevated section and the underground section starts from the east side of the elevated Patliputra Station. The gradient of the ramp is 3.76% and the elevated section is switched over to the underground section by utilizing the canal space on the north side of Bailey Rd. After this switch over, TBM tunnel section crosses the overpass. Since its pier foundations are supposed to be placed between tunnels, the proposed tunnel center spacing is 18.5 m, which is wider than usual, until it reaches just before the Rukanpura Station.

The switch-over ramp to the underground uses the existing waterway area, and therefore the relocation of the waterway is necessary. Nevertheless, this proposed location is appropriate for the ramp since it does not affect buildings. In fact, it would be unfeasibly to move the proposed ramp section to further east due to highly-dense buildings along Bailey Rd. As mentioned above, there is the existing overpass on Bailey Rd where the underground section passes. To avoid the foundation piles of this overpass, the route passes through the private land on the north side of the road. Also, TBM tunnel passes directly under a gas station just before the Rukanpura Station. Since the gas station has underground fuel tanks, it is necessary to consider the countermeasures not to affect the tanks such as the measuring work during construction.



Source: Google earth, PMRCL, JICA Study Team

Figure 5-6: Location map between PATLIPUTRA – RUKANPURA



Source: JICA Study Team

Figure 5-7: Location map of gas stations near RUKANPURA station

Source: JICA Study Team

Figure 5-8: Gas station situation near RUKANPURA Station

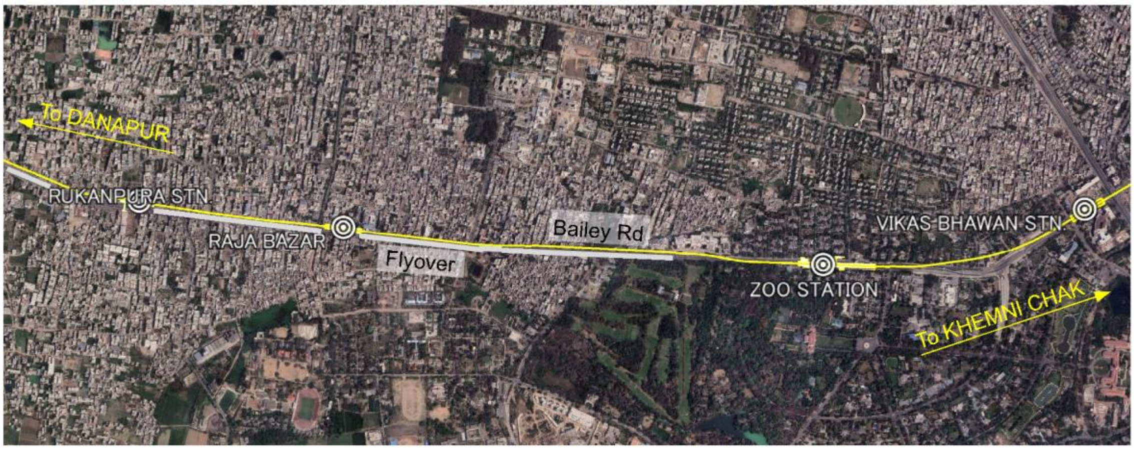
3) RUKANPURA and PATNA JUNCTION section

According to DPR, the underground section is proposed from Rukanpura Station to Patna Junction Station via four stations, namely Raja Bazar Station, Patna Zoo Station, Vikas Bhawan Station and Vidyut Bhawan Station. All these stations are the open-cut station and island-type platforms, and TBM tunnels are used between stations.
Rukanpura Station and Raja Bazar Station are located around Bailey Rd above which the overpass exists. To avoid the foundation piles of the overpass, DPR proposes three-layer underground stations under private land on the north side of the road.

Other stations, Patna Zoo Station, Viksa Bhawan Station and Vidyut Bhawan Stations, are expected to be right under Bailey Rd and the proposed station structure is two-layer underground station and island platforms. The length of Patna Zoo Station is longer than others for a crossover turnout between the eastbound and westbound lines. Although the inter-station from Patna Zoo Station and Vidyut Bhawan Station is basically a TBM tunnel section directly under Bailey Rd, only section from Patna Zoo Station to Vikas Bhawan Station avoids the north side of the Bailey Rd due to the cable-stayed bridge foundation of the interchange located on the road.

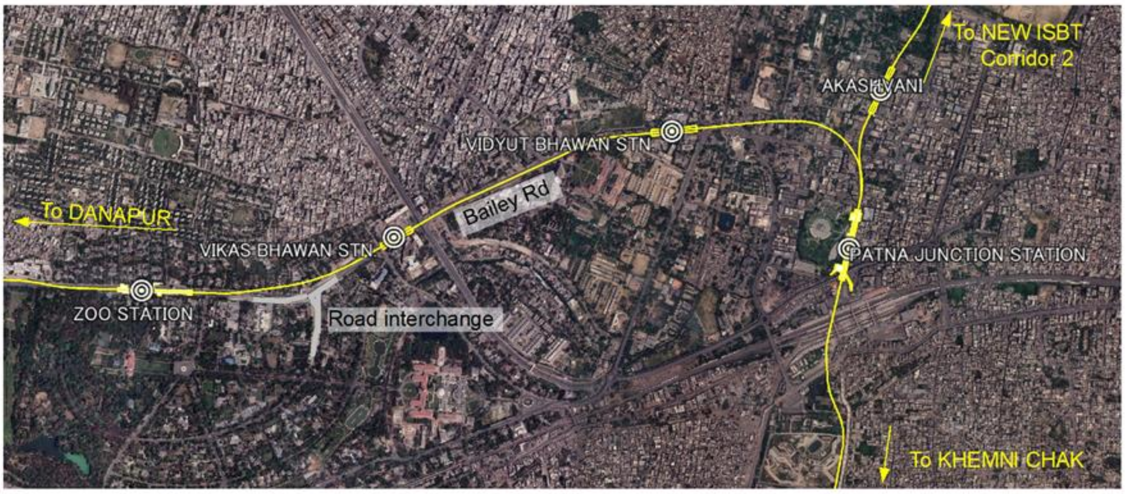
From Vidyut Bhawan Station to Patna Junction Station, the proposed route passes directly under the private property by a small radius curve to make a tight turn.

Patna Junction Station is the three-layer underground station commonly used with Corridor 2. According to DPR, Corridor 1 uses the third basement floor and uses the second basement floor. The island platform is proposed for both. Since Patna Junction Station is the origin station of Corridor 2, the length of this open-cut station is supposed to be longer for a crossover track to turn back.



Source: Google earth, PMRCL, JICA Study Team

Figure 5-9: Location map between RUKANPURA – ZOO STATION



Source: Google earth, PMRCL, JICA Study Team

Figure 5-10: Location map between ZOO STATION - PATNA JUNCTION

4) Between PATNA JUNCTION and MITHAPUR

This is a transitional section from underground to elevated. At the south side of Patna Junction Station, the route passes under another Patna Junction Station of Indian Railways. Transition to the elevated structure starts from the west side of Mithapur Bus Stand Rd. There is the overpass on this road, and therefore Corridor 1 basically needs to pass through the private land on the west side of the road. Nevertheless, this area mainly consist of vacant lots and marshes despite the vicinity of Patna Junction Station, and therefore a number of affected buildings is quite small.

The steepest gradient of the transitional section is 3.723% and Mithapur Station is located near the end point of the uphill.

Source: Google earth, PMRCL, JICA Study Team

Figure 5-11: Location map between PATNA JUNCTION – MITHAPUR

5) Mithapur - Khemni Chak section

This section is elevated section in which Ramakrishna Nagar Station and Jaganpura Station are located. While Khemni Chak Station, which is the junction station with Corridor 2, has three platforms and four tracks, other stations in this section are the side platform consist of two platforms and two tracks. Mithapur Station and Ramakrishna Nagar Station are located off the road. Conversely, Jaganpura Station and Khemni Chak Station are located on the road and a part of the section between these two stations needs to pass the private land to make a tight turn by a sharp curve. The radius of this sharp curve section is 135.00m.

Regarding the Khemni Chak Station, a crossover to connect with Corridor 2 and lead tracks for turn back are proposed to arrange at the east side of the station. Given that the trains of Corridor 1 are stabled at NEW ISBT depot of Corridor 2, trains use this crossover to move to the depot via Corridor 2.

Source: Google earth, PMRCL, JICA Study Team

Figure 5-12: Location map between MITHAPUR - KHEMNI CHAK

(2) Corridor 2

Corridor 2 starts from Patna Junction Station in the center of Patna City and reaches to NEW ISBT Station via the northeastern part of the city and Rajendra Nagar Station that is a major station of the Indian Railways.
The depot is located adjacent to NEW ISBT station and it accommodates all trains of Corridor 1 and Corridor 2.
Features of each section are described below.

1) PATNA JUNCTION - RAJENDRA NAGAR section

This section consists of an underground section and five stations, Akashuvani Station, Gandhi Maidan Station, PMCH Station, University Station and Moin ul Haq Station. The island-type platform is adopted to these five stations.
The route heads north from Patna Junction Station, runs around Patna City clockwise and reaches to Rajendra Nagar Station of the Indian Railways.
Patna Junction Station and Rajendra Nagar Station are the common station with Corridor 1. According to DPR, both stations are three-layer underground stations and the other stations are two-layer underground stations.
The inter-stations section is TBM tunnels and it passes under the private land outside the road except for the vicinity of Patna Junction Station and Rajendra Nagar Station

Source: Google earth, PMRCL, JICA Study Team

Figure 5-13: Location map between PATNA JUNCTION - RAJENDRA NAGAR

2) RAJENDRA NAGAR - MALAHI PAKRI section

This is the transitional section from the underground to the elevated section. The route has a tight turn by the sharp curve from the underground Rajendra Nagar Station to Malahi Pakri Rd where the ramp to the viaduct begins, and then it climb up the ramp with 3.962% gradient which is the steepest in Corridor 2.

The ramp from underground to elevated is arranged in the middle of Malahi Pakri Rd. and the Malahi Pakri Station is located adjacent to the top of the ramp.

This section uses 250m radius curve which is the smallest in the underground section.

Source: Google earth, PMRCL, JICA Study Team

Figure 5-14: Location map between RAJENDRA NAGAR - MALAHI PAKRI

3) MALAHI PAKRI - NEW ISBT section

The section between Malahi Pakri Station and New ISBT Station is elevated and it consists of three stations, Khemni Chak Station, Bhootnath Station and Zero Mile Station. Khemni Chak Station, which is the common station with Corridor 1, has three platforms and four tracks. The other stations are the side platform type composed of two platforms and two tracks.

From Khemni Chak Station to Zero Mile Station, the viaduct is arranged on the vacant land on the north of Patna – Sitamarhi Rd except for the vicinity of Khemni Chak Station. From Zero Mile Station to New ISBT Station, the viaduct is arranged in the middle of Bodhgaya Rd.

From Malahi Pakri Station to Khemni Chak Stationa and at the east side of Zero Mile Station, there are sharp curves passing through private lands to make a tight turn. The radius adopted to these two sharp curves is 123.20 m and 159.80 m respectively.

New ISBT Station has the lead track for turning back at south and the spur line from/to the depot is branched off from this track.

The location of the depot is the southeast of New ISBT Station and all trains of Corridor 1 and Corridor 2 are stabled and maintained.

Source: Google earth, PMRCL, JICA Study Team

Figure 5-15: Location map between MALAHI PAKRI – NEW ISBT

(3) Geometric Design Parameters

The geometrical parameters applicable to alignment design are listed below.

1) Horizontal Alignment

DPR recommends to use a horizontal curve in accordance with the existing road as much as possible. Given the maximum cant of 110mm and the cant deficiency of 85mm determined in DPR, the curve radius should be 500 m or more to achieve a speed of 90 km/h.
As a result of reviewing DPR, it is found that the current alignment plan has the curve of 123.2m radius in the elevated section in which the speed limit shall be applied. Likewise, though the recommended minimum curve radius for the underground section is 300 m due to the tunnel boring machine (TBM) construction, the curve of 250m radius is found in the current alignment plan.
The minimum allowable curve radius and the maximum cant proposed in DFR are shown in Table 5-2

Table 5-2: Horizontal Curves

Description	Underground Section	Elevated Section
Desirable Minimum radius	300 m	200 m
Absolute minimum radius	200 m	120 m
Minimum curve radius at stations	1000 m	1000 m
Maximum permissible cant	110 mm	110 mm
Maximum desirable cant	85 mm	85 mm

Source：Detailed Project Report 2021, DMRC

Cant Calculation Formula
Cm= (G･V･V) / 127･ R
Cm: Balanced Cant(mm) G: Gauge (mm), V : Speed(km/h) , R: Radius(m)

2) Transition Curves

The design principles for Transition Curves described in the DPR are as follows

- Length of Transitions of Horizontal curves (m)

  Minimum: 0.44 times of actual cant or cant deficiency (in mm), whichever is higher.

  Desirable: 0.72 times of actual cant or cant deficiency, (in mm), whichever is higher.

- The overlap between transition curves and vertical curves not allowed.
- Minimum straight between two Transition curves (in case of reverse curves):
  Either 25 m or Nil.
- Minimum straight between two Transition curves (in case of same flexure curves):
  Either 25 m or both curves should be converted into the compound curve by introducing a single transition between the two circulars.
- Minimum curve length between two transition curves: 25 m

3) Vertical Alignment and Track Center

a. Elevated Sections

According to DPR, while the viaduct supporting the track has a minimum separation of 5.5 m above the road, 5.65 m is proposed to account for future roadway raising. Although the rail level is to be finalized by the type of superstructure and detailed design, the minimum rail level of 8.5m from the ground surface is proposed for I-shaped girders and box girders.

That for elevated stations is determined by the same way while it requires to secure the vertical clearance of 3.5m for concourse.

Regarding the minimum track center spacing, 4.20m is proposed for the viaduct section though it depends on the adopted type of girders and superstructure. It is widened to 4.50 m in case of stations with scissor cross-over.

The following table shows both the minimum track center spacing and rail level from the ground surface for each section proposed in DFR.

Table 5-3: Minimum Track Spacing and Rail Level in the Elevated Section

Item	Minimum Track Spacing	Minimum Rail Level above Ground Level
Inter-station	4.20m	8.50m
Station w/o Scissor Cross-over	4.20m	12.00m
Station with Scissor Cross-over	4.50m	12.00m

Source: Detailed Project Report 2021, DMRC

b. Underground Sections

The rail level in the inter-station section of tunnel is determined by the minimum depth that ensures an earth cover equivalent to the TBM tunnel diameter against the building foundation. The rail level in the station section is recommended to be deep enough from the ground to build the concourse above the platform level.

The following table shows the track center spacing and track depth for each section proposed in DPR.

Table 5-4: Minimum Track Spacing and Rail Level in the Underground Section

Item	Minimum Track Spacing	General Rail Level (Depth) from Ground Level for 2 level stations
TBM Section	15.02m	15.00m
Cut & Cover Tunnel Section (except for the transition section)	4.20m	12.60m
Cut & Cover Station island platform	13.35m	14.00m
Cut & Cover Station Opposite platform	4.20m	14.00m

Source: Detailed Project Report 2021, DMRC

c. Gradients

According to DPR, stations are recommended to be located on level section, however, it allows 0.25% in case where a drainage gradient is required. Also, it recommends 2.0% or less gradient for the inter-station. However, steeper gradient is allowed up to 4.0% (curve compensation is considered) at maximum in unavoidable case, such as, where the grade of existing road is steeper than 2.0% or the grade at the rump between underground and elevated sections to shorten the slope section.

d. Vertical Curves

DPR proposes to insert the vertical curve, where the change in gradient exceeds 0.4%. , a vertical curve should be inserted. However, it instructs to use the circular curve or parabolic curve to connect all changes in grade. Overlap between vertical curves and the transition curves of the horizontal alignment is not allowed.

e. The radius of Vertical Curves

The parameter of vertical curve radius described in DPR is as follows.

Recommended vertical curve radius : 2500m
Minimum allowable vertical curve radius : 1500m
Minimum length of vertical curve : 20m

4) Design Speed

According to DPR, the maximum sectional speed is 90 km/h and it is subject to the speed limit determined by the horizontal curve radius, actual cant amount and cant deficiency.
Typical parameters of horizontal curve radius, actual cant, cant deficiency, design speed and transition curves length are summarized in Table 5.5: Cant and Transition Curve Length by Curve Radius.

Table 5-5: Cant and Transition Curve Length by Curve Radius

Radius (m)	Actual cant (mm)	Cant Deficiency (mm)	Design Speed (kmph)	Transition(m)	
				Minimum	Desirable
3000	20	12	90	10	15
2800	20	14	90	10	15
2400	25	15	90	15	18
2000	25	23	90	15	18
1600	30	29	90	15	22
1500	35	28	90	20	26
1200	40	39	90	20	29
1000	50	45	90	25	36
800	60	59	90	30	44

Radius (m)	Actual cant (mm)	Cant Deficiency (mm)	Design Speed (kmph)	Transition(m)	
				Minimum	Desirable
600	75	84	90	40	60
500	105	85	90	55	76
450	105	84	85	55	76
400	105	83	80	55	76
350	110	79	75	55	80
300	110	82	70	55	80
200	110	68	55	55	80
150	110	70	48	55	80
120	110	79	44	55	80

Source: Detailed Project Report 2021, DMRC

5.1.3 Reviews of Existing Studies and Proposals for Improvement

(1) Review of Horizontal Alignments

This study reviewed the curve parameters and curve sections of elevated and underground sections based on DPR and CAD drawings and checked the route plan and the alignment design. The alignment information used for the study is based on CAD data provided by PMRCL in early June 2022.

1) Minimum curve radius

Curves including the transition makes up 37% of the total length of Corridor 1 and Corridor 2. The minimum curve radius by sections is 1,200m in the ramp section between the underground and the elevated, 123.2m in the elevated section and 250m in the underground section. All curves are arranged with transition curves using clothoids, and therefore no simple curves and no compound curves are used while two reverse curves are used in Corridor 2 to connect the transition curves directly.

2) Curve length

As specified in the Indian regulation, the minimum length of a simple curve shall be 25m or more except for the transition curve. However, the review found the minimum curves length less than 25m in both corridors, specifically 20.11m in Corridor 1 and 19.26m in Corridor 2.
This study proposes the alignment modification that adjusts these non-compliant curves so as to satisfy the Indian regulation. The locations of the circular curve with improper length are shown in Table 5-6: List of locations where the circular curve length is insufficient

Table 5-6: List of locations where the circular curve length is insufficient

Route	Section	Original curve shape	Remark
Corridor 1	Raja Bazar Station - Patna Zoo Station	Curve radius : 2513.350m Transition curve length : 20.000m Circular curve length : **20.354m** < 25m	Intersection Point EBC-14 (ULC=14) East Bound Track (Up Track)
Corridor 1	Raja Bazar Station - Patna Zoo Station	Curve radius : 2500.000m Transition curve length : 20.000m Circular curve length : **20.111m** < 25m	Intersection Point WBC-14 (DLC=14) West Bound Track (Down Track)
Corridor 2	Akashuvani Station - Gandhi Maidan Station	Curve radius : 460.000m Transition curve length : 50.000m Circular curve length : **22.361m** < 25m	Intersection Point NBC-14 (DLC=14) North Bound Track (Down Track)
Corridor 2	- Rajendra Nagar Station	Curve radius : 622.515m	Intersection Point

Route	Section	Original curve shape	Remark
	- Malahi Pakri Station	Transition curve length : 35.000m Circular curve length : **19.265m** < 25m	SBC-16 (ULC=16) South Bound Track (Up Track)

Source：JICA STUDY TEAM

3) Proportion of curves

The table below shows the line length by radius based on the alignment calculations reconstructed from CAD drawings. Comparing to around 32km of the total length of two corridors, the length of curve sections is 11.8 km, which accounts for 37% of the total length.
The proportion of curve below is for the mainline section only, and therefore it does not include the spur line from/to the depot and tracks within the premise of the depot.

Table 5-7: Proportion of Curve

Radius		Corridor 1		Corridor 2		Sub total	
<=	<	DANAPUR - KHEMNI CHAK		PATNA JUNCTION – NEW ISBT			
	200	291m	(1.64%)	582m	(4.10%)	873m	(2.73%)
200	250	228m	(1.28%)	0m	(0.00%)	228m	(0.71%)
250	400	1,378m	(7.75%)	3,524m	(24.82%)	4,902m	(15.33%)
400	800	1,220m	(6.86%)	1,059m	(7.46%)	2,279m	(7.13%)
800	1200	1,090m	(6.13%)	672m	(4.73%)	1,762m	(5.51%)
1200	2000	448m	(2.52%)	444m	(3.13%)	892m	(2.79%)
2000	9999	816m	(4.59%)	89m	(0.63%)	905m	(2.83%)
Sub total		5,471m	(30.78%)	6,370m	(44.87%)	11,841m	(37.03%)
Dead end to Dead end		17,777m		14,198m		31,975m	

Source: JICA STUDY TEAM

4) Transition Curve

Since DPR does not describe the condition about the transition curve lengths such as the train speeds and cant of each curve, it is unable to confirm the adequacy of the transition curve lengths proposed in the current alignment plan.
To propose the alignment improvement plan, therefore, this study checked the train speed with considering the cant and the transition curve length and assessed those adequateness based on the original design.

The calculation results is summarized in" Table 5-8: Cant and Transition Curve Calculation Results"

Table 5-8: Cant and Transition Curve Calculation Results

Corridor 1 Up Track

IP No.	Radius	Speed	Balanced Cant.	Actual cant	Cant Deficiency	TRANSITIONS CURVE (TCL)														
	R	V	Cm	Ca	Cd	Desirable Length							Minimum Length							Adopted TCL (m)
	(m)	(km/h)	(mm)	(mm)	(mm)	0.72Ca (m)			0.72Cd (m)			Pickup	0.44Ca (m)			0.44Cd (m)			Pickup	
EBC-1	2505.03	90	37	20	17	14.4	<	15	12.24	<	15	**15**	8.8	<	10	7.48	<	10	**10**	**25**
EBC-2	200	55	171	105	66	75.6	<	80	47.52	<	50	**80**	46.2	<	50	29.04	<	30	**50**	**60**
EBC-3	550	90	166	100	66	72.0	<	75	47.52	<	50	**75**	44	<	45	29.04	<	30	**45**	**50**
EBC-4	605.03	90	151	90	61	64.8	<	65	43.92	<	45	**65**	39.6	<	40	26.84	<	30	**40**	**40**
EBC-5	350	55	98	55	43	39.6	<	40	30.96	<	35	**40**	24.2	<	25	18.92	<	20	**25**	**25**
EBC-6	1200	90	76	45	31	32.4	<	35	22.32	<	25	**35**	19.8	<	20	13.64	<	15	**20**	**25**
EBC-7	1300	90	70	40	30	28.8	<	30	21.6	<	25	**30**	17.6	<	20	13.2	<	15	**20**	**25**
EBC-8	350	75	182	110	72	79.2	<	80	51.84	<	55	**80**	48.40	<	50	31.68	<	35	**50**	**55**
EBC-9	3000	90	31	20	11	14.4	<	15	7.92	<	10	**15**	8.80	<	10	4.84	<	5	**10**	**15**
EBC-10	1500	90	61	35	26	25.2	<	30	18.7	<	20	**30**	15.4	<	20	11.4	<	15	**20**	**25**
EBC-11	1500	90	61	35	26	25.2	<	30	18.7	<	20	**30**	15.4	<	20	11.4	<	15	**20**	**25**
EBC-12	2213.35	90	41	25	16	18.0	<	20	11.5	<	15	**20**	11.0	<	15	7.0	<	10	**15**	**20**
EBC-13	1500	90	61	35	26	25.2	<	30	18.7	<	20	**30**	15.4	<	20	11.4	<	15	**20**	**20**
EBC-14	2513.35	90	36	20	16	14.4	<	15	11.5	<	15	**15**	8.8	<	10	7.0	<	10	**10**	**15**
EBC-15	1000	90	92	55	37	39.6	<	40	26.6	<	30	**40**	24.2	<	25	16.3	<	20	**25**	**25**
EBC-16	2013.35	90	45	25	20	18.0	<	20	14.4	<	15	**20**	11.0	<	15	8.8	<	10	**15**	**20**
EBC-17	613.35	90	149	90	59	64.8	<	65	42.5	<	45	**65**	39.6	<	40	26.0	<	30	**40**	**40**
EBC-18	600	90	153	90	63	64.8	<	65	45.4	<	50	**65**	39.6	<	40	27.7	<	30	**40**	**40**
EBC-19	700	90	131	80	51	57.6	<	60	36.7	<	40	**60**	35.2	<	40	22.4	<	25	**40**	**40**
EBC-20	1000	90	92	55	37	39.6	<	40	26.6	<	30	**40**	24.2	<	25	16.3	<	20	**25**	**35**
EBC-21	1016	90	90	55	35	39.6	<	40	25.2	<	30	**40**	24.2	<	25	15.4	<	20	**25**	**35**
EBC-22	465	85	176	105	71	75.6	<	80	51.1	<	55	**80**	46.2	<	50	31.2	<	35	**50**	**50**
EBC-23	1016	90	90	55	35	39.6	<	40	25.2	<	30	**40**	24.2	<	25	15.4	<	20	**25**	**35**
EBC-24	311	70	178	95	83	68.4	<	70	59.8	<	60	**70**	41.8	<	45	36.5	<	40	**45**	**45**
EBC-25	300	70	185	110	75	79.2	<	80	54.0	<	55	**80**	48.4	<	50	33.0	<	35	**50**	**55**
EBC-26	288	55	119	70	49	50.4	<	55	35.3	<	40	**55**	30.8	<	35	21.6	<	25	**35**	**45**
EBC-27	282	55	121	75	46	54.0	<	55	33.1	<	35	**55**	33.0	<	35	20.2	<	25	**35**	**50**
EBC-28	1212	90	76	45	31	32.4	<	35	22.3	<	25	**35**	19.8	<	20	13.6	<	15	**20**	**35**
EBC-29	2500	90	37	20	17	14.4	<	15	12.2	<	15	**15**	8.8	<	10	7.5	<	10	**10**	**15**
EBC-30	1200	90	76	45	31	32.4	<	35	22.3	<	25	**35**	19.8	<	20	13.6	<	15	**20**	**20**
EBC-31	135	44	162	85	77	61.2	<	65	55.4	<	60	**65**	37.4	<	40	33.9	<	35	**40**	**40**
EBC-32	455.03	80	159	90	69	64.8	<	65	49.7	<	50	**65**	39.6	<	40	30.4	<	35	**40**	**40**
EBC-33	700	90	131	65	66	46.8	<	50	47.5	<	50	**50**	28.6	<	30	29.0	<	30	**30**	**30**
EBC-34	500	85	163	90	73	64.8	<	65	52.6	<	55	**65**	39.6	<	40	32.1	<	35	**40**	**40**
EBC-35	805.03	90	114	70	44	50.4	<	55	31.7	<	35	**55**	30.8	<	35	19.4	<	20	**35**	**40**
EBC-36	800	90	114	70	44	50.4	<	55	31.7	<	35	**55**	30.8	<	35	19.4	<	20	**35**	**40**
EBC-37	9000	90	10	5	5	3.6	<	5	3.6	<	5	**5**	2.2	<	5	2.2	<	5	**5**	**15**
EBC-38	12000	90	8	5	3	3.6	<	5	2.2	<	5	**5**	2.2	<	5	1.3	<	5	**5**	**15**

Corridor 1 Down Track

IP No.	Radius	Speed	Balanced Cant.	Actual cant	Cant Deficiency	TRANSITIONS CURVE (TCL)						
	R	V	Cm	Ca	Cd	Desirable Length			Minimum Length			Adopted TCL
	(m)	(km/h)	(mm)	(mm)	(mm)	0.72Ca (m)	0.72Cd (m)	Pickup	0.44Ca (m)	0.44Cd (m)	Pickup	(m)
WBC-1	2500	90	37	20	17	14.4 < 15	12.24 < 15	**15**	8.8 < 10	7.48 < 10	**10**	**25.0**
WBC-2	205.03	55	167	100	67	72.0 < 75	48.24 < 50	**75**	44 < 45	29.48 < 30	**45**	**60.0**
WBC-3	555.03	90	165	100	65	72.0 < 75	46.8 < 50	**75**	44 < 45	28.6 < 30	**45**	**50.0**
WBC-4	600	90	153	90	63	64.8 < 65	45.36 < 50	**65**	39.6 < 40	27.72 < 30	**40**	**40.0**
WBC-5	355.03	55	96	55	41	39.6 < 40	29.52 < 30	**40**	24.2 < 25	18.04 < 20	**25**	**25.0**
WBC-6	2500	90	37	20	17	14.4 < 15	12.24 < 15	**15**	8.8 < 10	7.48 < 10	**10**	**25.0**
WBC-7	2500	90	37	20	17	14.4 < 15	12.2 < 15	**15**	9 < 10	7.5 < 10	**10**	**25.0**
WBC-8	366.5	75	173	105	68	75.6 < 80	49.0 < 50	**80**	46 < 50	29.9 < 30	**50**	**55.0**
WBC-9	3000	90	31	20	11	14.4 < 15	7.9 < 10	**15**	9 < 10	4.8 < 5	**10**	**20.0**
WBC-10	1500	90	61	35	26	25.2 < 30	18.7 < 20	**30**	15 < 20	11.4 < 15	**20**	**25.0**
WBC-11	1500	90	61	35	26	25.2 < 30	18.7 < 20	**30**	15 < 20	11.4 < 15	**20**	**25.0**
WBC-12	2200	90	42	25	17	18.0 < 20	12.2 < 15	**20**	11 < 15	7.5 < 10	**15**	**20.0**
WBC-13	1513.35	90	60	35	25	25.2 < 30	18.0 < 20	**30**	15 < 20	11.0 < 15	**20**	**20.0**
WBC-14	2500	90	37	20	17	14.4 < 15	12.2 < 15	**15**	9 < 10	7.5 < 10	**10**	**15.0**
WBC-15	1013.35	90	90	55	35	39.6 < 40	25.2 < 30	**40**	24 < 25	15.4 < 20	**25**	**25.0**
WBC-16	2000	90	46	30	16	21.6 < 25	11.5 < 15	**25**	13 < 15	7.0 < 10	**15**	**20.0**
WBC-17	600	90	153	90	63	64.8 < 65	45.4 < 50	**65**	40 < 40	27.7 < 30	**40**	**40.0**
WBC-18	613.35	90	149	90	59	64.8 < 65	42.5 < 45	**65**	40 < 40	26.0 < 30	**40**	**40.0**
WBC-19	713.3	90	128	75	53	54.0 < 55	38.2 < 40	**55**	33 < 35	23.3 < 25	**35**	**40.0**
WBC-20	1015	90	90	55	35	39.6 < 40	25.2 < 30	**40**	24 < 25	15.4 < 20	**25**	**30.0**
WBC-21	1000	90	92	55	37	39.6 < 40	26.6 < 30	**40**	24 < 25	16.3 < 20	**25**	**35.0**
WBC-22	450	85	181	110	71	79.2 < 80	51.1 < 55	**80**	48 < 50	31.2 < 35	**50**	**50.0**
WBC-23	1000	90	92	55	37	39.6 < 40	26.6 < 30	**40**	24 < 25	16.3 < 20	**25**	**35.0**
WBC-24	290	55	118	95	23	68.4 < 70	16.6 < 20	**70**	42 < 45	10.1 < 15	**45**	**45.0**
WBC-25	315	70	176	105	71	75.6 < 80	51.1 < 55	**80**	46 < 50	31.2 < 35	**50**	**55.0**
WBC-26	300	70	185	110	75	79.2 < 80	54.0 < 55	**80**	48 < 50	33.0 < 35	**50**	**50.0**
WBC-27	270	55	127	75	52	54.0 < 55	37.4 < 40	**55**	33 < 35	22.9 < 25	**35**	**50.0**
WBC-28	1200	90	76	45	31	32.4 < 35	22.3 < 25	**35**	20 < 20	13.6 < 15	**20**	**35.0**
WBC-29	1300	90	70	40	30	28.8 < 30	21.6 < 25	**30**	18 < 20	13.2 < 15	**20**	**20.0**
WBC-30	2500	90	37	20	17	14.4 < 15	12.2 < 15	**15**	9 < 10	7.5 < 10	**10**	**15.0**
WBC-31	140.03	44	156	85	71	61.2 < 65	51.1 < 55	**65**	37 < 40	31.2 < 35	**40**	**40.0**
WBC-32	450	80	161	90	71	64.8 < 65	51.1 < 55	**65**	40 < 40	31.2 < 35	**40**	**40.0**
WBC-33	705.03	90	130	65	65	46.8 < 50	46.8 < 50	**50**	29 < 30	28.6 < 30	**30**	**30.0**
WBC-34	505.03	85	162	90	72	64.8 < 65	51.8 < 55	**65**	40 < 40	31.7 < 35	**40**	**40.0**
WBC-35	800	90	114	70	44	50.4 < 55	31.7 < 35	**55**	31 < 35	19.4 < 20	**35**	**40.0**
WBC-36	805.03	90	114	70	44	50.4 < 55	31.7 < 35	**55**	31 < 35	19.4 < 20	**35**	**40.0**
WBC-37	9000	90	10	5	5	3.6 < 5	3.6 < 5	**5**	2 < 5	2.2 < 5	**5**	**15.0**
WBC-38	12000	90	8	5	3	3.6 < 5	2.2 < 5	**5**	2 < 5	1.3 < 5	**5**	**15.0**

Corridor 2 Up Track

IP No.	Radius	Speed	Balanced Cant.	Actual cant	Cant Deficiency	TRANSITIONS CURVE (TCL)														
	R	V	Cm	Ca	Cd	Desirable Length							Minimum Length							Adopted TCL
	(m)	(km/h)	(mm)	(mm)	(mm)	0.72Ca (m)			0.72Cd (m)			Pickup	0.44Ca (m)			0.44Cd (m)			Pickup	(m)
SBC-1	300	70	185	100	85	72	<	75	61.2	<	65	**75**	44.0	<	45	37.4	<	40	**45**	**45**
SBC-2	313.35	70	177	105	72	76	<	80	51.8	<	55	**80**	46.2	<	50	31.7	<	35	**50**	**55**
SBC-3	480	85	170	100	70	72	<	75	50.4	<	55	**75**	44.0	<	45	30.8	<	35	**45**	**45**
SBC-4	600	90	153	90	63	65	<	65	45.4	<	50	**65**	39.6	<	40	27.7	<	30	**40**	**45**
SBC-5	314	70	176	105	71	76	<	80	51.1	<	55	**80**	46.2	<	50	31.2	<	35	**50**	**50**
SBC-6	340	70	163	100	63	72	<	75	45.4	<	50	**75**	44.0	<	45	27.7	<	30	**45**	**45**
SBC-7	1500	90	61	35	26	25	<	30	18.7	<	20	**30**	15.4	<	20	11.4	<	15	**20**	**30**
SBC-8	314	70	176	105	71	76	<	80	51.1	<	55	**80**	46.2	<	50	31.2	<	35	**50**	**55**
SBC-9	814	90	112	65	47	47	<	50	33.8	<	35	**50**	28.6	<	30	20.7	<	25	**30**	**40**
SBC-10	1456.037	90	63	30	33	22	<	25	23.8	<	25	**25**	13.2	<	15	14.5	<	15	**15**	**15**
SBC-11	978	90	94	55	39	40	<	40	28.1	<	30	**40**	24.2	<	25	17.2	<	20	**25**	**25**
SBC-12	314	70	176	105	71	76	<	80	51.1	<	55	**80**	46.2	<	50	31.2	<	35	**50**	**55**
SBC-13	290	55	118	70	48	50	<	55	34.6	<	35	**55**	30.8	<	35	21.1	<	25	**35**	**50**
SBC-14	310	70	179	100	79	72	<	75	56.9	<	60	**75**	44.0	<	45	34.8	<	35	**45**	**45**
SBC-15	275	55	124	75	49	54	<	55	35.3	<	40	**55**	33.0	<	35	21.6	<	25	**35**	**45**
SBC-16	635	80	114	60	54	43	<	45	38.9	<	40	**45**	26.4	<	30	23.8	<	25	**30**	**30**
SBC-17	1000	75	64	30	34	22	<	25	24.5	<	25	**25**	13.2	<	15	15.0	<	15	**15**	**15**
SBC-18	928.03	90	99	60	39	43	<	45	28.1	<	30	**45**	26.4	<	30	17.2	<	20	**30**	**35**
SBC-19	749.785	90	122	75	47	54	<	55	33.8	<	35	**55**	33.0	<	35	20.7	<	25	**35**	**40**
SBC-20	360.185	75	176	105	71	76	<	80	51.1	<	55	**80**	46.2	<	50	31.2	<	35	**50**	**55**
SBC-21	704.815	90	130	80	50	58	<	60	36.0	<	40	**60**	35.2	<	40	22.0	<	25	**40**	**40**
SBC-22	132.5	44	165	100	65	72	<	75	46.8	<	50	**75**	44.0	<	45	28.6	<	30	**45**	**55**
SBC-23	499.785	85	163	100	63	72	<	75	45.4	<	50	**75**	44.0	<	45	27.7	<	30	**45**	**45**
SBC-24	462.515	85	177	95	82	68	<	70	59.0	<	60	**70**	41.8	<	45	36.1	<	40	**45**	**45**
SBC-25	700	90	131	80	51	58	<	60	36.7	<	40	**60**	35.2	<	40	22.4	<	25	**40**	**40**
SBC-26	825.03	90	111	65	46	47	<	50	33.1	<	35	**50**	28.6	<	30	20.2	<	25	**30**	**35**
SBC-27	164.837	48	158	95	63	68	<	70	45.4	<	50	**70**	41.8	<	45	27.7	<	30	**45**	**55**
SBC-28	609.785	75	104	55	49	40	<	40	35.3	<	40	**40**	24.2	<	25	21.6	<	25	**25**	**25**
SBC-29	1225.03	80	59	30	29	22	<	25	20.9	<	25	**25**	13.2	<	15	12.8	<	15	**15**	**15**

Corridor 2 Down Track

IP No.	Radius	Speed	Balanced Cant.	Actual cant	Cant Deficiency	TRANSITIONS CURVE (TCL)														
	R	V	Cm	Ca	Cd	Desirable Length							Minimum Length							Adopted TCL
	(m)	(km/h)	(mm)	(mm)	(mm)	0.72Ca (m)			0.72Cd (m)			Pickup	0.44Ca (m)			0.44Cd (m)			Pickup	(m)
NBC-1	295	55	116	70	46	50.4	<	55	33.1	<	35	**55**	30.8	<	35	20.2	<	25	**35**	**45**
NBC-2	300	70	185	110	75	79.2	<	80	54.0	<	55	**80**	48.4	<	50	33.0	<	35	**50**	**55**
NBC-3	480	85	170	100	70	72.0	<	75	50.4	<	55	**75**	44.0	<	45	30.8	<	35	**45**	**45**
NBC-4	614	90	149	90	59	64.8	<	65	42.5	<	45	**65**	39.6	<	40	26.0	<	30	**40**	**45**
NBC-5	300	70	185	110	75	79.2	<	80	54.0	<	55	**80**	48.4	<	50	33.0	<	35	**50**	**50**
NBC-6	320	70	173	90	83	64.8	<	65	59.8	<	60	**65**	39.6	<	40	36.5	<	40	**40**	**40**
NBC-7	1507	90	61	35	26	25.2	<	30	18.7	<	20	**30**	15.4	<	20	11.4	<	15	**20**	**30**
NBC-8	300	70	185	110	75	79.2	<	80	54.0	<	55	**80**	48.4	<	50	33.0	<	35	**50**	**55**
NBC-9	800	90	114	70	44	50.4	<	55	31.7	<	35	**55**	30.8	<	35	19.4	<	20	**35**	**40**
NBC-10	2000	90	46	30	16	21.6	<	25	11.5	<	15	**25**	13.2	<	15	7.0	<	10	**15**	**20**
NBC-11	1500	90	61	35	26	25.2	<	30	18.7	<	20	**30**	15.4	<	20	11.4	<	15	**20**	**25**
NBC-12	297	55	115	70	45	50.4	<	55	32.4	<	35	**55**	30.8	<	35	19.8	<	20	**35**	**50**
NBC-13	300	70	185	110	75	79.2	<	80	54.0	<	55	**80**	48.4	<	50	33.0	<	35	**50**	**50**
NBC-14	295	55	116	70	46	50.4	<	55	33.1	<	35	**55**	30.8	<	35	20.2	<	25	**35**	**45**
NBC-15	250	55	137	80	57	57.6	<	60	41.0	<	45	**60**	35.2	<	40	25.1	<	30	**40**	**50**
NBC-16	425	70	130	65	65	46.8	<	50	46.8	<	50	**50**	28.6	<	30	28.6	<	30	**30**	**30**
NBC-17	1005.03	75	63	30	33	21.6	<	25	23.8	<	25	**25**	13.2	<	15	14.5	<	15	**15**	**15**
NBC-18	923	90	99	60	39	43.2	<	45	28.1	<	30	**45**	26.4	<	30	17.2	<	20	**30**	**35**
NBC-19	745.815	90	123	75	48	54.0	<	55	34.6	<	35	**55**	33.0	<	35	21.1	<	25	**35**	**40**
NBC-20	365.215	75	174	105	69	75.6	<	80	49.7	<	50	**80**	46.2	<	50	30.4	<	35	**50**	**55**
NBC-21	699.785	90	131	80	51	57.6	<	60	36.7	<	40	**60**	35.2	<	40	22.4	<	25	**40**	**40**
NBC-22	123.2	44	178	105	73	75.6	<	80	52.6	<	55	**80**	46.2	<	50	32.1	<	35	**50**	**55**
NBC-23	504.815	90	181	100	81	72.0	<	75	58.3	<	60	**75**	44.0	<	45	35.6	<	40	**45**	**45**
NBC-24	457.85	85	178	95	83	68.4	<	70	59.8	<	60	**70**	41.8	<	45	36.5	<	40	**45**	**45**
NBC-25	700	90	131	80	51	57.6	<	60	36.7	<	40	**60**	35.2	<	40	22.4	<	25	**40**	**40**
NBC-26	820	90	112	65	47	46.8	<	50	33.8	<	35	**50**	28.6	<	30	20.7	<	25	**30**	**35**
NBC-27	159.807	48	163	100	63	72.0	<	75	45.4	<	50	**75**	44.0	<	45	27.7	<	30	**45**	**55**
NBC-28	614	75	104	55	49	39.6	<	40	35.3	<	40	**40**	24.2	<	25	21.6	<	25	**25**	**25**
NBC-29	1213	80	60	30	30	21.6	<	25	21.6	<	25	**25**	13.2	<	15	13.2	<	15	**15**	**15**

Source: JICA STUDY TEAM

5) Straight Line between Curves

It is recommended to arrange the straight line more than the train length (25m) or the transition curve between two successive curves to alleviate the motion of train occurred on the first curve before approaching to the next curve.
The current alignment has no sections where the straight line between curves is less than 25m. However, two reverse curves that directly connect two successive transition curve are identified in Corridor 2.
Verification of CAD data and detailed alignment calculations revealed that the distance between the curves is not exactly 0 m, that is, the transition curves are not directly connected. The alignment improvement plan propose to adjust to make these straight line be exactly 0 m.
Refer to "Table 5.9: The length of straight section between reverse curves" for the confirmation result.

Table 5-9: The length of straight section between reverse curves

Route	Section	IP Number	Straight section length between curves	Remark
Corridor 2	MALAHI PAKRI - KHEMNI CHAK	SBC-20 (ULC=20) SBC-21 (ULC=21)	0.002m	South Bound Track (Up Track)
Corridor 2	MALAHI PAKRI - KHEMNI CHAK	NBC-20 (DLC=20) NBC-21 (DLC=21)	0.003m	North Bound Track (Down Track)
Corridor 2	ZERO MILE - NEW ISBT	SBC-27 (ULC=27) SBC-28 (ULC=28)	0.546m	South Bound Track (Up Track)
Corridor 2	ZERO MILE - NEW ISBT	NBC-27 (DLC=27) NBC-28 (DLC=28)	0.551m	North Bound Track (Down Track)

Source: JICA STUDY TEAM

6) Curve Radius along with Platform

To ensure the safety of passenger boarding and alighting, it is desirable to make the gap between the train and the platform small. This study checked the curve radius of the centerline at the station based on DPR and CAD and found that 3 out of 26 stations in Corridor 1 and Corridor 2 are located on the curve. These locations are 2200m radius at Raja Bazar Station, 1213m radius at New ISBT Station and 1000m radius, the smallest radius, at Malahi Pakri Station.

Table 5-10：Curved section platform widening expansion

Radius of curve	Expansion	
	Inner track platform	Outer track platform
1000m	15mm	20mm

Source: SCHEDULE OF DIMENSIONS (PMRCL) March 2020

Nevertheless, since only slight increase in gap between the platform and the train is confirmed, there is no interference with passenger boarding and alighting.

(2) Review of Vertical Alignment

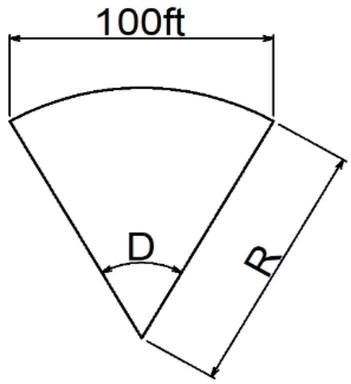
1) Steepest gradient

This study reconstitutes the gradient parameter of the mainline of Corridor 1 and Corridor 2 from CAD data provided. As a result, the gradients are identified in 47 sections in Corridor 1 and 35 sections in Corridor 2. Furthermore, 10 out of 47 sections in Corridor 1 and 6 out of 35 sections in Corridor 2 are 2.0% or more (-2.0% or less), and the steepest is 3.94% in Corridor 1 and 3.96% in Corridor 2. Both steepest gradients are arranged on ramps for the transition between underground and elevated. While the current plan consists of 2.0% gradient section where general conditions apply, there is no section exceeding 4% gradient which is applied for the inevitable case due to the topographical conditions.
However, it is necessary to correct the gradient where the slope and the curve are conflicted since the increase of running resistance is anticipated.

The formula used to compensate for gradient is as follows.

Gradient compensation
A gradient compensation of 0.04% per degree of curve shall be applied.
Source: SCHEDULE OF DIMENSIONS (PMRCL) March 2020

D =1746.38 / R
D : Degree of Curve (degree)
R : Curve Radius (m)
Note:
The above formulas are applicable formulas for ft - m conversion.



Source: JICA STUDY TEAM

Figure 5-16: Concept of Degree of Curve

Table 5-11: Result of Gradient Correction

Route	Section	Installed gradient	Minimum curve radius	Degree of Curve	Gradient compensation	Total Gradient
		A	R	D	0.04D	A + 0.04D
Corridor 1	PATLIPUTRA - RUKANPURA	3.938%	1200m	1.455316 degree	0.058%	3.996% < 4.00%
Corridor 1	PATNA JUNCTION - MITHAPUR	3.723%	1200m	1.455316 degree	0.058%	3.781% < 4.00%
Corridor 2	RAJENDRA NAGAR - MALAHI PAKRI	3.610%	250m	6.985560 degree	0.279%	3.889% < 4.00%
Corridor 2	RAJENDRA NAGAR - MALAHI PAKRI	3.962%	∞	0.00000 degree	0.000%	3.962% < 4.00%

Source: JICA STUDY TEAM

The steepest section of Corridor 1 (3.938%) is on the curve section, where a track center curve radius of 1200 m is adopted, and that of Corridor 2 (3.962%) is on a straight section. Even though the curve correction is taken into account, the gradients of both section is still allowable as being less than 4.0% which is inevitably applied for the topographic reason.

2) Gradient of station section

It is confirmed that all gradient at station sections of the two corridors is 0%. For underground station, the longitudinal drainage by the vertical gradient of the track cannot be expected without no slope, and therefore the cross section of drainage needs to be considered instead. Given with that each station has a drainage space directly under the platform, no problem is found regarding the drainage.

3) Radius of vertical curve

Vertical curves are arranges in eighty points in total of two corridors. The minimum vertical curve radius is 1500m and no vertical curve is less than it. Despite this, the recommended value is 2500m radius or more according to DPR.

4) Location of Minimum Vertical Curve

This study confirmed the location of vertical curve and found that the minimum vertical curve of 1500m radius is arranged at the adjacency of the transition curve on a flat section and at the circular curve

section where the curve length is restricted. In short, the minimum vertical curve is arranged at the location where the large vertical curve is difficult to use.
In addition, some underground sections use the minimum vertical section despite a larger radius curve is applicable. It is because this location is concave in the vertical alignment and the pit for the drainage in tunnel is installed. Arranging a larger radius vertical curve makes the gradient gentle and it may lessen the water catchment, and therefore this study concluded not to propose the change in the vertical curve radius.

5) Vertical curve length

The minimum length of a vertical curve is 20m as specified in DPR. In case where this parameter is not satisfied, the larger radius of the vertical curve would be needed to satisfy it. This study confirmed all vertical curves is more than 20m and satisfies the parameter of the minimum length of the vertical curve.

(3) Review of Conflicts

1) Vertical Curve and Transition Curve

A twisting of the track (twist irregularity) in inherent in a transition curve section. As regards a vertical curve section, a train is prone to the wheel climbing at a convex point. Similarly, the middle part of train is also prone to the same effect at a concave point due to the massive vertical force and the running resistance on the front of a train.
If such a transition curve and a vertical curve conflict with each other (both curves exist at the same location), they negatively affect the running stability and the ride comfort. Hence, such a conflict should be avoided as much as possible.
This study checked the beginning and end point of vertical curves and transition curves and confirmed there is no conflict points in Corridor 1. Conversely, there is one conflict points identified in Corridor 2 due to the difference in the position of the transition curves between the survey center line and the track center line. The alignment improvement plan proposes to reconfigure the vertical alignment to avoid it.

Table 5-12: Location of Conflicts

Route	Section	Conflict Situation	Remark
Corridor 2	GANDHI MAIDAN - PMCH	A vertical curve section conflicts with the transition curve of the southbound line.	Intersection Point SBC-6 South Bound Track (Up Track)

Source: JICA STUDY TEAM

2) Turnout and Transition Curve or Vertical Curve

Turnout is liable to cause the significant lateral force and vibration to the running train due to the small radius of the lead curve and the gap in gauge line. Therefore, the conflicts between a turnout and transition curve or vertical curve should be avoided.
This study checked the front and end point of turnout indicated in the horizontal alignment drawing and confirmed there is no conflict with the vertical curves and the transition curves in both Corridor 1 and Corridor 2.

(4) Proposal for alignment improvement

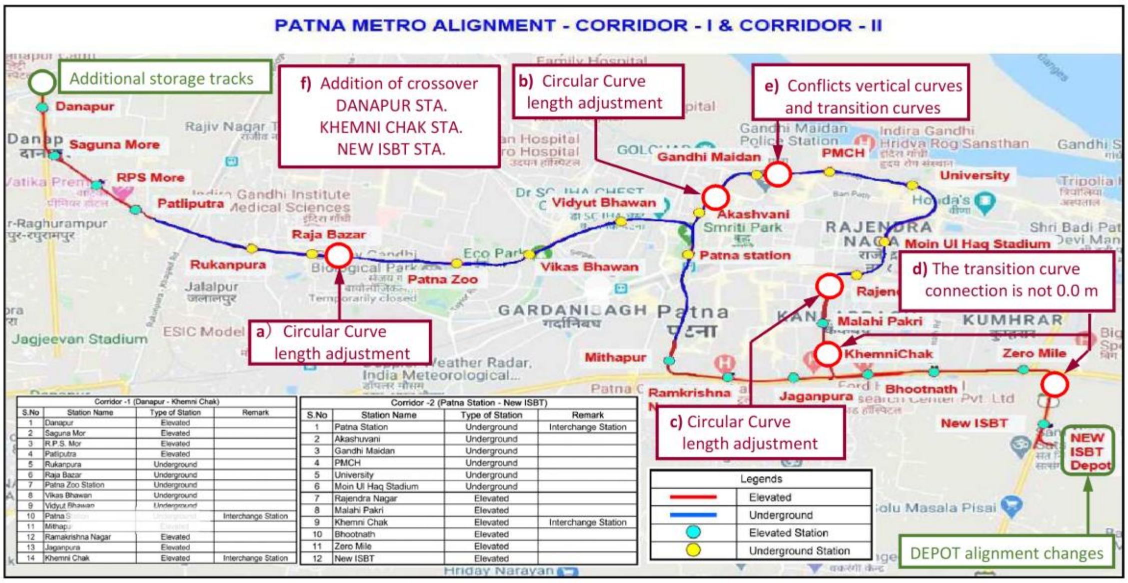
1) Proposal for the main line

The specification of the alignment from the alignment drawings provided and the geometric design parameters are reviewed. As a result, it is found that there were some locations not complied with the standard, and therefore this proposal is made to reconfigure the parameter.

Another proposal is to place an additional crossover at the terminus stations to ensure redundancy in the event of an anomaly.

The each location covered in this proposal are shown in "Figure 5-17: Location map of proposed improvements”.

Regarding the proposal for the depot and additional storage tracks, the detail is described separately in “Section 13”.



Corridor -1 (Danapur - Khemni Chak)			
S.No	Station Name	Type of Station	Remark
1	Danapur	Elevated	
2	Saguna Mor	Elevated	
3	R.P.S. Mor	Elevated	
4	Patliputra	Elevated	
5	Rukanpura	Underground	
6	Raja Bazar	Underground	
7	Patna Zoo Station	Underground	
8	Vikas Bhawan	Underground	
9	Vidyut Bhawan	Underground	
10	Patna Station	Underground	Interchange Station
11	Mithapur	Elevated	
12	Ramakrishna Nagar	Elevated	
13	Jaganpura	Elevated	
14	Khemni Chak	Elevated	Interchange Station

Corridor -2 (Patna Station - New ISBT)			
S.No	Station Name	Type of Station	Remark
1	Patna Station	Underground	Interchange Station
2	Akashuvani	Underground	
3	Gandhi Maidan	Underground	
4	PMCH	Underground	
5	University	Underground	
6	Moin Ul Haq Stadium	Underground	
7	Rajendra Nagar	Elevated	
8	Malahi Pakri	Elevated	
9	Khemni Chak	Elevated	Interchange Station
10	Bhootnath	Elevated	
11	Zero Mile	Elevated	
12	New ISBT	Elevated	

Source: Detailed Project Report 2021, DMRC, JICA STUDY TEAM

Figure 5-17: Location map of proposed improvements

a. Corridor 1 CLC-14 circular curve length adjustment

Circular curve length of CLC-14 is less than the minimum length of 25 m in the current alignment. This proposal is to adjust the transition curve length and ensure the necessary circular curve length.

Table 5-13: Corridor 1 CLC-14 Result of curve specification adjustment

Item		Unit	East Bound (Up Track)	West Bound (Down Track)	Remark
Original Radius	R	m	**2513.350**	**2500.000**	
Original Transition curve Length	TCL	m	20.000	20.000	
Original circular curve Length	CCL	m	**20.354**	**20.111**	< 25.0m
Proposed Radius	R	m	**2513.350**	**2500.000**	
Speed	V	km/h	90	90	
Balanced Cant	Cm	mm	36	37	
Actual cant	Ca	mm	20	20	
Cant Deficiency	Cd	mm	16	17	
Transition curve Desirable Length	0.72Ca	m	14.400	14.400	
	0.72Cd	m	11.520	12.240	
Transition curve Minimum Length	0.44Ca	m	8.800	8.800	
	0.44Cd	m	7.040	7.480	
Adopted transition curve length		m	**15.000**	**15.000**	
Proposed Circular Curve Length		m	**30.824**	**30.580**	> 25.0m

Source: JICA STUDY TEAM

In the meeting to discuss this proposal, it is confirmed that DMRC has already modified the alignment of the said circular curve and the deviations from the criteria has been resolved.
Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

b. Corridor 2 CLC-3 circular curve length adjustment

Circular curve length of CLC-3 is less than the minimum length of 25 m in the current alignment. This proposal is to adjust the transition curve length and ensure the necessary circular curve length.

Table 5-14: Corridor 2 CLC-3 Result of curve specification adjustment

Item		Unit	South Bound (UP Track)	North Bound (Down Track)	Remark
Original Radius	R	m	480.000	**460.000**	
Original Transition curve Length	TCL	m	50.000	**50.000**	
Original circular curve Length	CCL	m	**25.507**	**22.361**	North Bound < 25.0m
Proposed Radius	R	m	-	**480.000**	
Speed	V	km/h	-	85	
Balanced Cant	Cm	mm	-	170	
Actual cant	Ca	mm	-	100	
Cant Deficiency	Cd	mm	-	70	
Transition curve Desirable Length	0.72Ca	m	-	72.000	
	0.72Cd	m	-	50.400	
Transition curve Minimum Length	0.44Ca	m	-	44.000	
	0.44Cd	m	-	45.000	
Adopted transition curve length		m	-	**45.000**	
Proposed Circular Curve Length		m	-	**30.507**	> 25.0m

Source: JICA STUDY TEAM

In the meeting to discuss this proposal, it is confirmed that DMRC has already modified the alignment of the said circular curve and the deviations from the criteria has been resolved.
Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

c. Corridor 2 CLC-16 circular curve length adjustment

Circular curve length of CLC-26 is less than the minimum length of 25 m in the current alignment. This proposal is to adjust the transition curve length and ensure the necessary circular curve length.

Table 5-15: Corridor 2 CLC-16 Result of curve specification adjustment

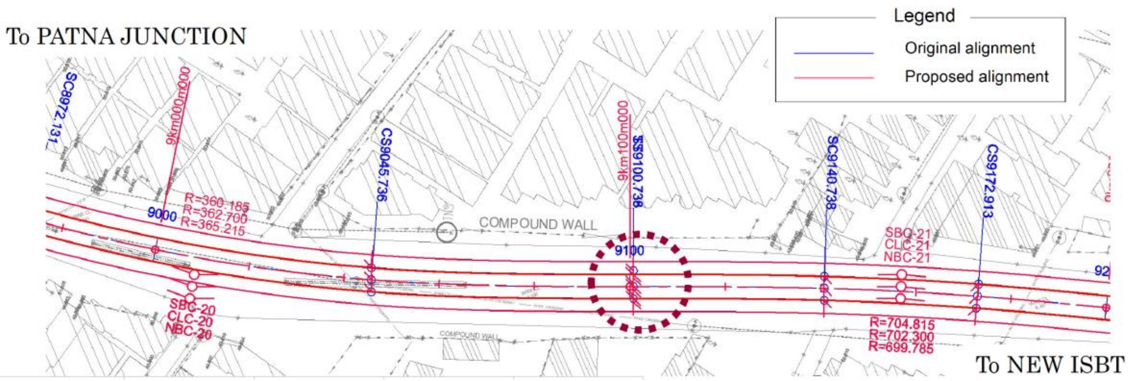
Item		Unit	South Bound (Up Track)	North Bound (Down Track)	Remark
Original Radius	R	m	**622.515**	425.000	
Original Transition curve Length	TCL	m	35.000	35.000	
Original circular curve Length	CCL	m	**19.265**	38.806	South Bound < 25.0m
Proposed Radius	R	m	**635.000**	-	
Speed	V	km/h	80	-	
Balanced Cant	Cm	mm	114	-	
Actual cant	Ca	mm	60	-	
Cant Deficiency	Cd	mm	54	-	
Transition curve	0.72Ca	m	43.200	-	
Desirable Length	0.72Cd	m	38.880	-	
Transition curve	0.44Ca	m	**26.400**	-	
Minimum Length	0.44Cd	m	23.760	-	
Adopted transition curve length		m	**30.000**	-	
Proposed Circular Curve Length		m	**25.354**	-	> 25.0m

Source: JICA STUDY TEAM

In the meeting to discuss this proposal, it is confirmed that DMRC has already modified the alignment of the said circular curve and the deviations from the criteria has been resolved.
Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

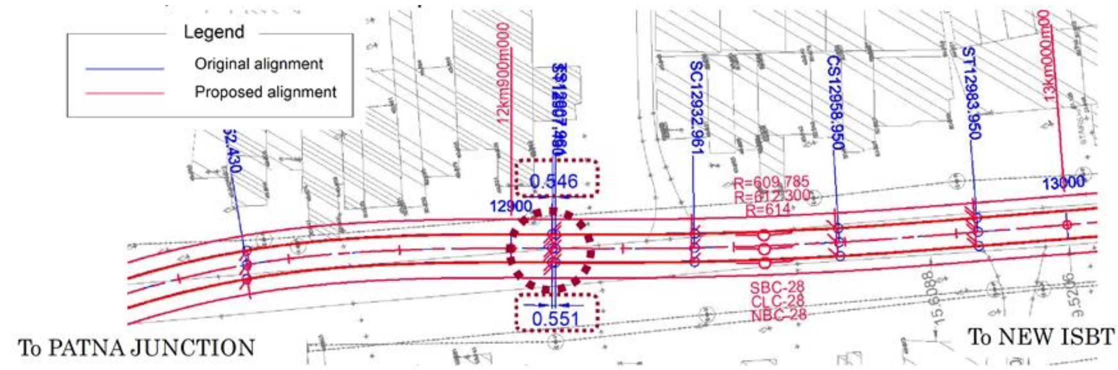
d. Correcting the batted part length of reversed curve to 0.0 m

In the current alignment, the straight section of batted of reverse curves is not 0.0m in both between CLC-20 and CLC-21 and between CLC-27 and CLC-28 on Corridor 2. The proposal is to correct this straight section to 0.0m by adjusting the IP coordinates.



Source: JICA STUDY TEAM

Figure 5-18: Reverse curve layout between CLC-20 and CLC-21



Source: JICA STUDY TEAM

Figure 5-19: Reverse curve layout between CLC-27 and CLC-28

Table 5-16: Reverse curve intersection coordinate adjustment result

Original Alignment

Item	Unit	South Bound (Up Track)		North Bound (Down Track)		South Bound (Up Track)		North Bound (Down Track)	
IP Name		SBC-20 (ULC=20)	SBC-21 (ULC=21)	NBC-20 (DLC=20)	NBC-21 (DLC=21)	SBC-27 (ULC=27)	SBC-28 (ULC=28)	NBC-27 (DLC=27)	NBC-28 (DLC=28)
Radius	m	360.185	701.815	365.215	699.785	164.837	609.785	159.807	614.000
Transition curve Length	m	55.000	40.000	55.000	40.000	55.000	25.000	55.000	25.000
Straight length	m	0.002		0.003		0.546		0.551	
EASTING		314,914.332842	314,968.525136	314,909.321257	314,963.748273	318,389.507745	318,318.901846	318,383.004017	318,313.982676
NORTHING		2,831,390.918299	2,831,252.824248	2,831,389.919738	2,831,251.227563	2,831,045.933013	2,830,776.145565	2,831,040.949148	2,830,777.216348

Proposed Alignment

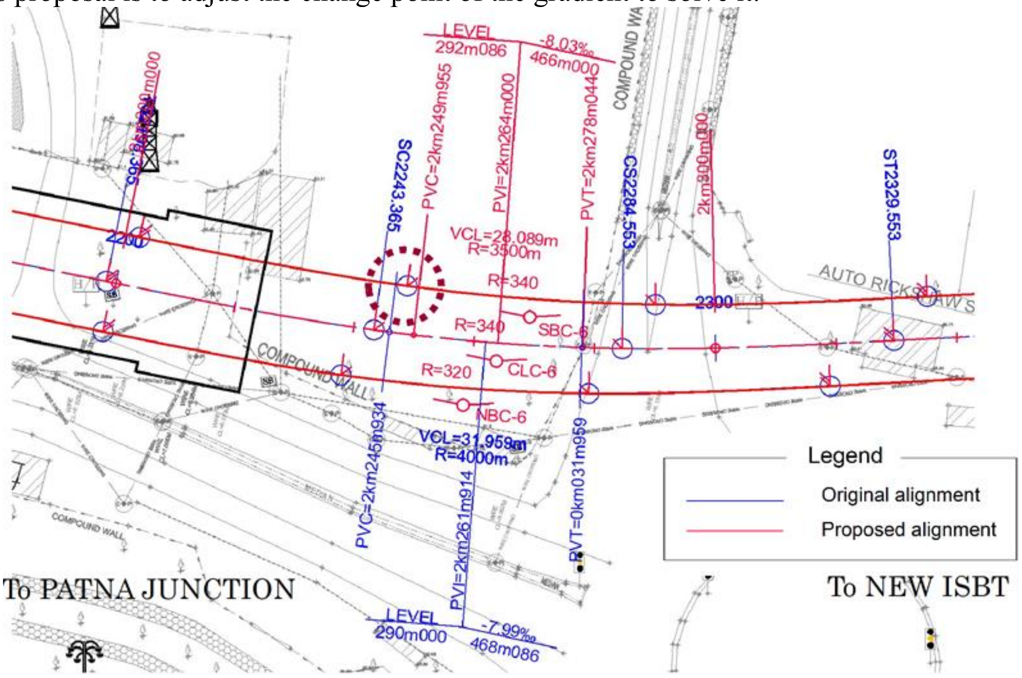
Item	Unit	South Bound (Up Track)		North Bound (Down Track)		South Bound (Up Track)		North Bound (Down Track)	
IP Name		SBC-20 (ULC=20)	SBC-21 (ULC=21)	NBC-20 (DLC=20)	NBC-21 (DLC=21)	SBC-27 (ULC=27)	SBC-28 (ULC=28)	NBC-27 (DLC=27)	NBC-28 (DLC=28)
Radius	m	360.185	701.815	365.215	699.785	164.837	609.785	159.807	614.000
Transition curve Length	m	55.000	40.000	55.000	40.000	55.000	25.000	55.000	25.000
Straight length	m	0.000		0.000		0.000		0.000	
EASTING		314,914.332859	314,968.525136	314,909.321280	314,963.748273	318,389.507745	318,318.983206	318,383.004017	318,314.064583
NORTHING		2,831,390.917445	2,831,252.824248	2,831,389.918568	2,831,251.227563	2,831,045.933013	2,830,776.611988	2,831,040.949148	2,830,777.685913

Source: JICA STUDY TEAM

In the meeting to discuss this proposal, it is confirmed that DMRC has already modified the alignment of the said circular curve and the deviations from the criteria has been resolved.
Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

e. Conflict between transition curves and vertical curves

The conflict between the transition curve and the vertical curve is identified in CLC-6 of Corridor 2. This proposal is to adjust the change point of the gradient to solve it.



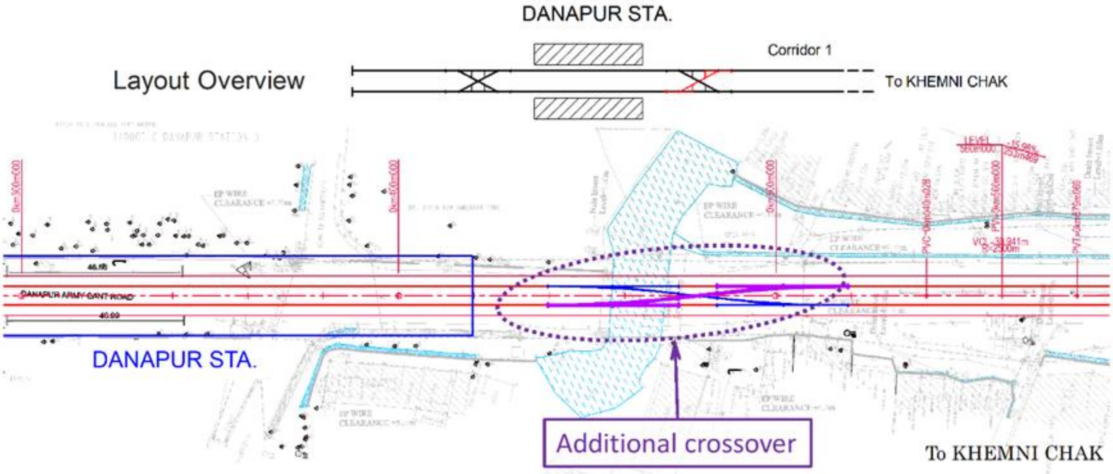
Source: JICA STUDY TEAM

Figure 5-20: Result of adjusting for conflicts between transition curves and vertical curves

In the meeting to discuss this proposal, it is confirmed that DMRC has already modified the alignment of the said circular curve and the deviations from the criteria has been resolved.
Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

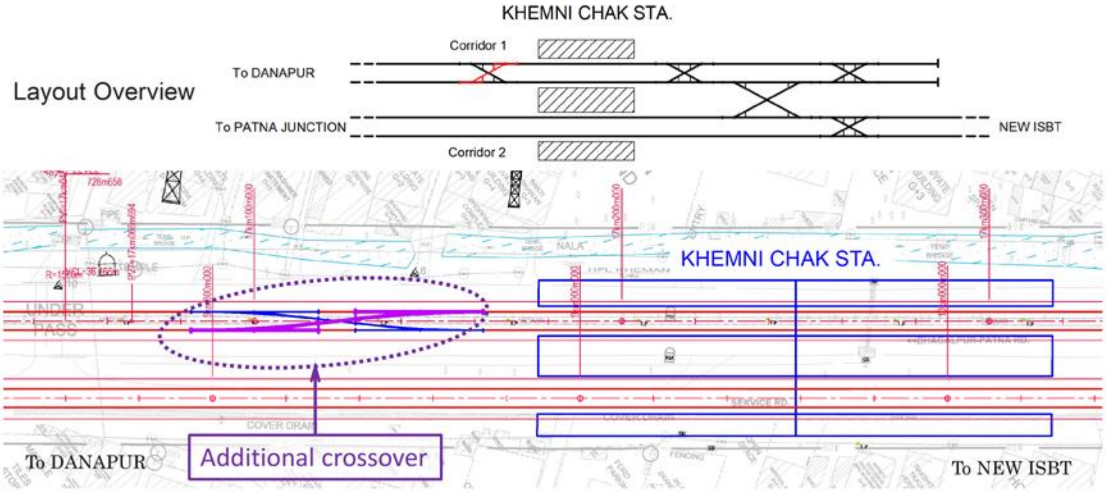
f. Additional crossover to the terminal stations

To ensure redundancy of train operations in the event of train breakdowns or other problems, it is proposed to add the crossover at the terminus stations, namely Danapur Station, Khemni Chak Station and New ISBT Station.



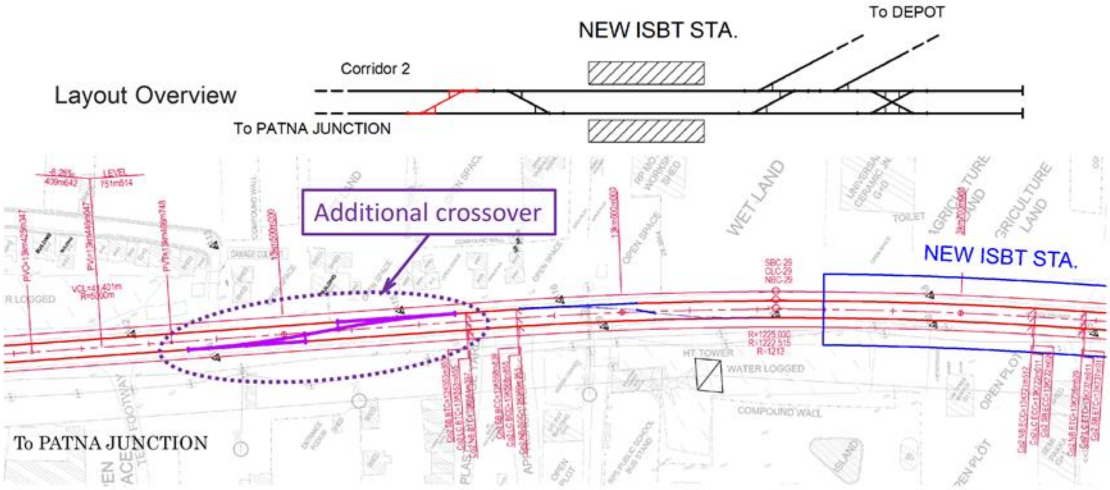
Source: JICA STUDY TEAM

Figure 5-21: DANAPUR Station Additional Crossover Layout



Source: JICA STUDY TEAM

Figure 5-22: KHEMNI CHAK Station Additional Crossover Layout



Source: JICA STUDY TEAM

Figure 5-23: NEW ISBT Station Additional Crossover Layout (Beginning Point Side)

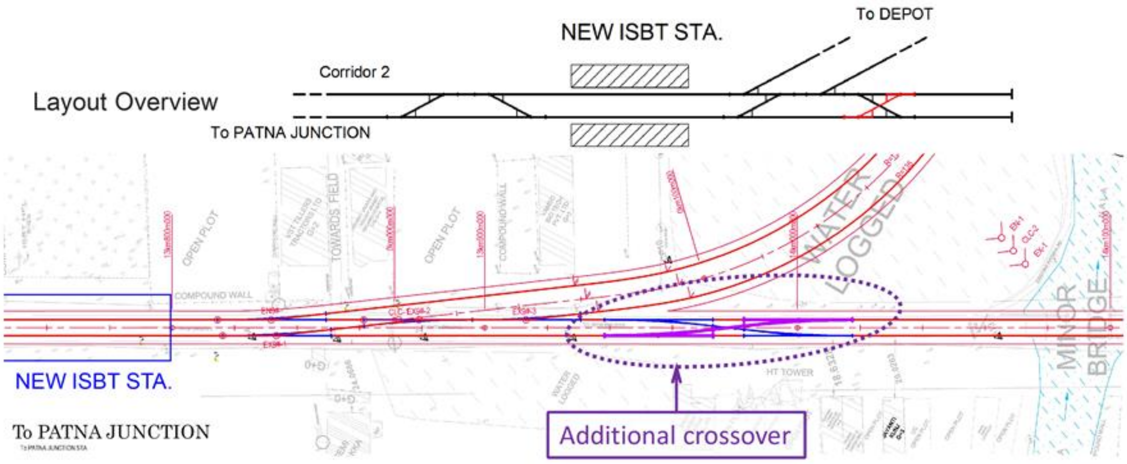


Figure 5-24: NEW ISBT Station Additional Crossover Layout (End Point Side)

In the meeting to discuss the said proposal, it is confirmed that the automatic train operation system is to be used for turning back at the terminal stations. This system has been used for other subway in India. Given with this, the time consumed for turning back is expected to be quite short, and therefore no operation issue is predicted even if either one of lead track becomes unusable. Due to this reason, the proposal for the additional crossover is not adopted.

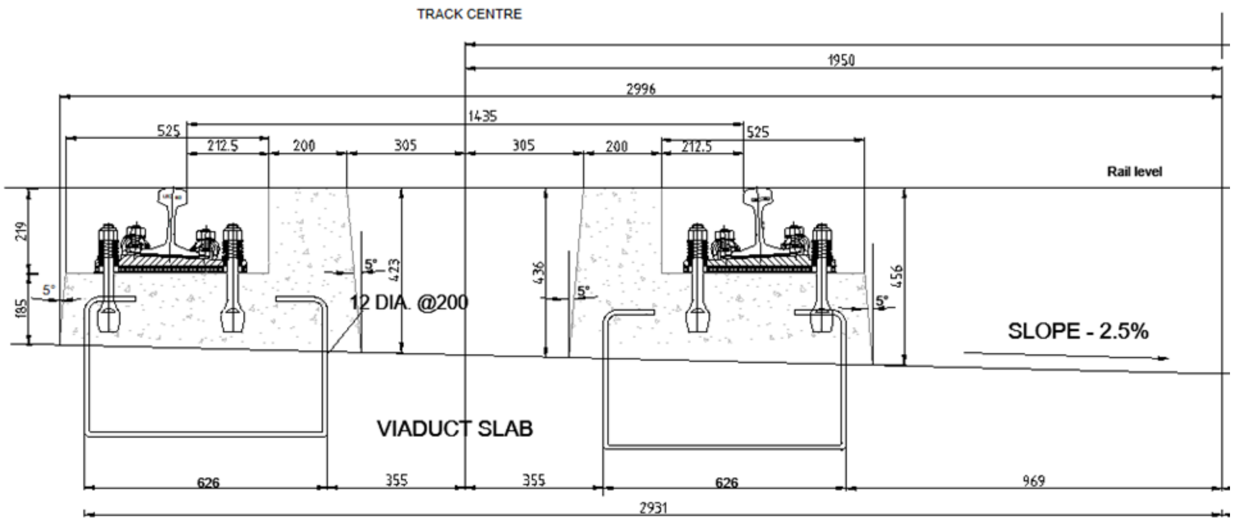
5.2 Track Structure

5.2.1 Overview of Existing Studies

The track structure are designed based on Procedure for Safety Certification and Technical Clearance of Metro Systems (hereinafter called PSTM) issued by Research Designs & Standards Organization (RDSO).

(1) Ballastless track

Plinth track is proposed to reduce maintenance costs for tunnel and elevated bridge sections. Plinth track uses reinforced concrete plinth instead of ballast, directly connecting fasteners on its plinth. The rectangle part sticking out on the plinth is to prevent trains from overturning. Plinth track has been used in almost all metros in India except for Delhi Airport Metro Express, whose design speed is higher than other Metros.



Source: PMRCL/DMRC

Figure 5-25: Cross Section of Plinth Track

(2) Ballasted track

The ballasted track is proposed in depot sections except for a washing line, inspection lines and lines in a workshop. In general,the ballasted track is used in depot area, because low-speed operation does not cause much track irregularity and it is easy to fix track settlement with low cost.

(3) Rail

UIC 60 kg grade 1080 head hardened rail (hereinafter called HH rail) for the main line and UIC 60kg grade 880 for the depot and continuous welded rail by flash butt welding or alumina-thermic welding based on PSTM are proposed.

(4) Turnout

All turnouts/crossovers on the main lines and other running lines shall be as follows:

Table 5-17: Turn-Outs

Description	Turn out Type
Main Line	1 in 9
Depot/ Yard Lines	1 in 7

Source: PMRCL/DMRC

5.2.2 Reviews of Existing Studies and Proposals for Improvement

(1) Plinth track

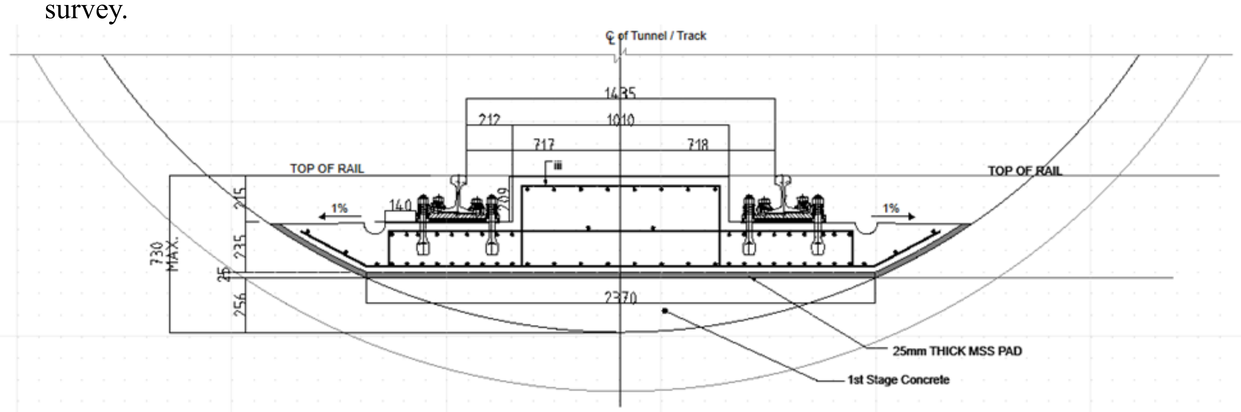
1) Precast and In situ Plinth

PSTM says that Plinth track has two types of structure: precast and in situ. In India, the former has mainly been used so far, and the latter has been used on a mass rapid transit, MRT Purple line in Thailand. The track structure that will be used for Patna metro has not been decided for the present. Precast Plinth is generally costly due to manufacturing concrete plinth in a plant, although its cost depends on a location of a plant and construction site. On the other hand, using the precast Plinth can enhance high quality and reduce the installation period. Thus it is recommended to decide on the track structure by comparing two types of Plinth tracks.

PMRCL states the intention to use in situ Plinth track in the talks during the JICA survey.

2) Mitigation major for noise and vibration

To evaluate noise and vibration from a Metro, It is common to major ground vibration in advance in a place of an existing metro where geography, civil and track structures are similar to a Metro concerned. If some major is required, Plinth track has an alternative structure, Mass Spring System (MSS), to mitigate noise and vibration. There is the elastic material capable of absorbing noise and vibration. PMRCL states that they would handle this matter according to circumstances in the talks during JICA survey.



Source: PMRCL/DMRC

Figure 5-26: Cross-section of Mass-Spring System for Plinth track

(2) Rail

1) Rail weight

The 60kg rail for the main line and depot lines is proposed. Considering an axle load of 17t, six train sets, and three minutes interval operations, a 60kg rail is adequate. But for depot lines, operation condition is not as severe as main lines, so it could use a UIC rail with a smaller cross-section than 60kg to reduce the construction costs.

PMRCL states the intention to use 60 kg, 880 grade Rail and CWR in Depot in the talks during the JICA survey.

2) Rail hardness

UIC 60 head hardened rail (hereinafter called HH rail) for the entire main line is proposed in order to reduce maintenance costs. PSTM says that HH rails shall be used on mainline on curves and approaches of stations, and application of HH rails for straight main line depends upon speed, axle load and other factors. As PSTM explains, if HH rail is used for entire main lines, including straight sections, proper rail grinding is recommended as preventive maintenance to remove the rolling contact fatigue layer, which might cause cracks on rails.

3) Rail welding testing

PSTM says that the ultrasonic test is used for a rail welding test. The ultrasonic test is suitable for Alumino-thermic welding. However, it is recommended to use magnetic particle testing for flash butt welding, which is suitable for detecting line-shaped faults developing close to the surface of rails.

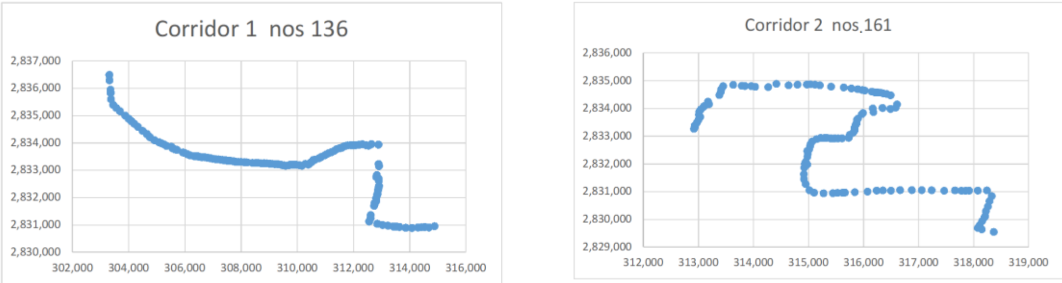
PMRCL states the intention to follow PSTM in the talks during the JICA survey.

5.3 Engineering Survey

5.3.1 Overview of Existing Survey

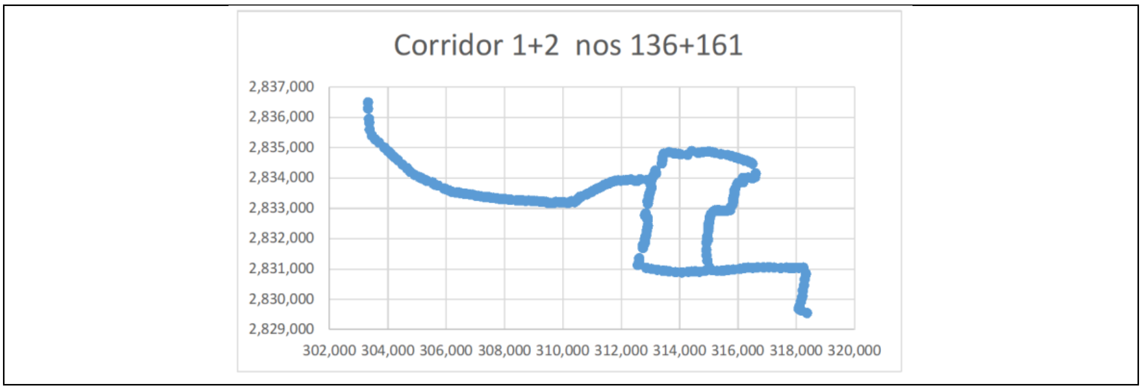
(1) Geotechnical Investigation

Boring survey the length of which are 40m have been carried out in 136 locations for the Corridor 1, 161 locations for the Corridor 2 and 3 locations for Depot area by PMRCL/DMRC. Also laboratory test was carried for setting the design parameter of soil. DPR mentioned geotechnical investigation method and the design parameter of soil,



Source: JST

Figure 5-27 : Boring Locations



Source: JST

Figure 5-28: Boring Locations of the Corridor 1 + 2

The geotechnical survey report described following the result of in-situ survey and laboratory tests.

1) Conducting standard Penetration Test (SPT) in the boreholes at regular intervals of 1.5m as per Indian Standard Specifications (IS-2131).
2) Collecting undisturbed soil samples from the bore holes at every change of strata, sealing, numbering and preserving them as per the IS code.
3) Collecting disturbed soil samples from the bore holes at 1.5m intervals starting from a depth of 0.5m below ground level and at every change of strata, numbering and preserving them as per the IS code.
4) Recording ground water table.
5) Collection of water samples from each borehole and conducting chemical tests on soil & water samples as per relevant BIS.

6) Carrying out the required Laboratory tests on the Soil specimens in order to establish their engineering characteristics.
7) Conducting in-situ permeability tests of soils.
8) Survey of boreholes for elevation and plotting of bore hole locations in alignment plan
9) Carrying out the following Laboratory tests on the selected Soil core samples in order to establish their engineering characteristics.
    - Sieve Analysis
    - Hydrometer analysis
    - Specific gravity
    - Moisture Content
    - Dry density
    - Atterbergs limits
    - Consolidation test
    - Tri-axial Shear Test (Consolidated Undrained & Consolidated Undrained)
    - Direct shear test
    - Chemical analysis of soil & water samples

In addition, the geotechnical survey report described recommendations for type of foundation, design parameter, analysis of borelogs & tests results along with soil bearing capacity values and calculations as per the requirements in the specification document.

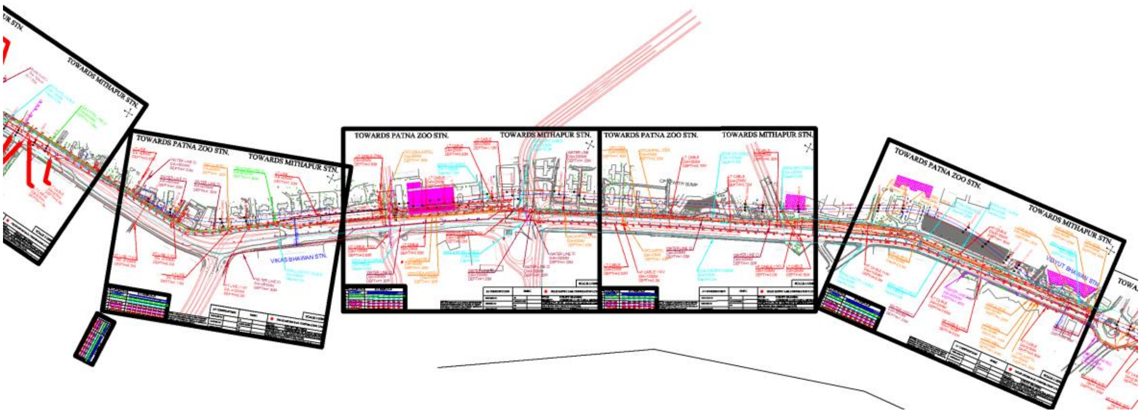
Limited number of borehole data at the Depot area are available due to the difficulty in getting permission for entry to the Depot area, however PMRCL/DMRC will carry out additional boring survey at the Depot area.

(2) Topographic Survey

The construction of viaduct section of the Corridor 1 and viaduct/underground section of the Corridor 2 were executed with latest topographic survey data and part of viaduct section are currently under construction.

(3) Underground Utility Survey

JST has received CAD data of underground utility such as electric, gas, water, sewer and communication.



Source: PMRCL/DMRC

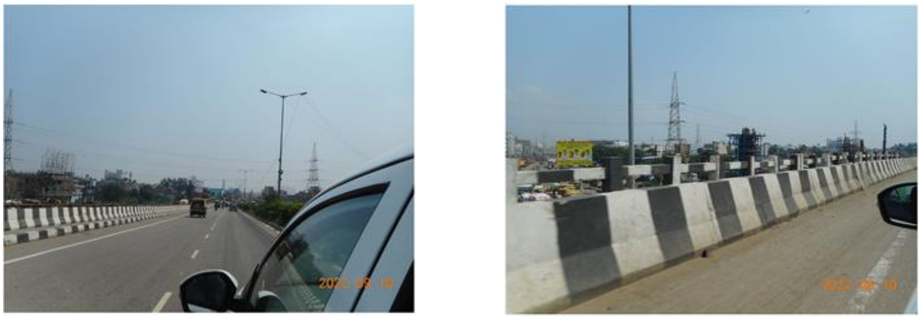
Figure 5-29: CAD Data of Underground Utility

(4) Overhead utility

The overhead utility such as high voltage power line is mentioned in DPR. JST confirmed the existence of many power distribution board during field survey.

Source: JST

Figure 5-30: High Voltage Power Line (Corridor2 ST12 NEW ISBT STATION)



Source: JST

Figure 5-31 : Crossing Location between Corridor 2 Elevated Alignment and High Voltage Power Line nearby Corridor2 ST11 Zero Mile

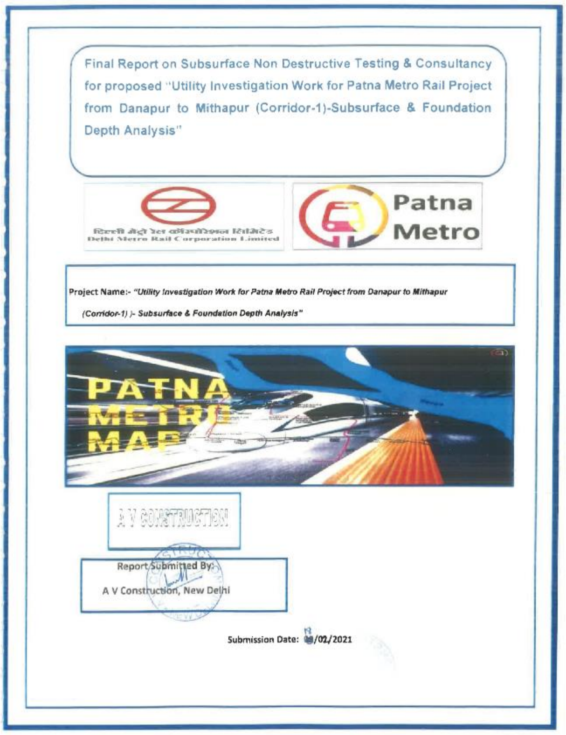
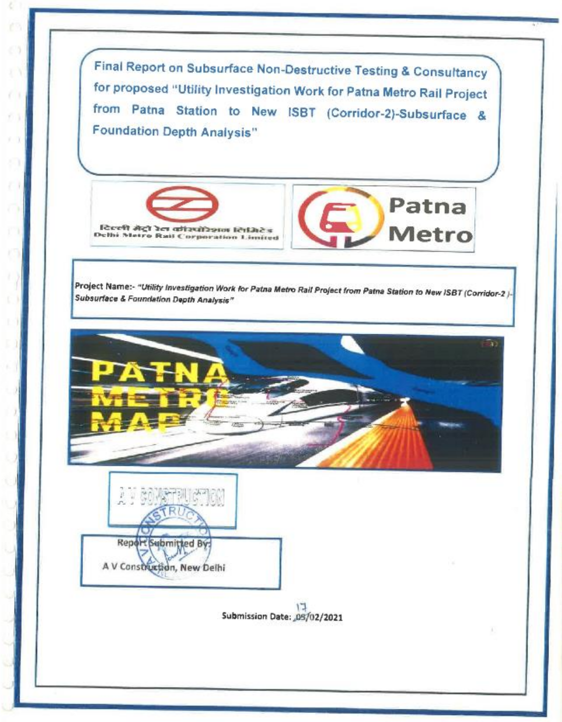

Source: JST

Figure 5-32: Power Distribution Board (Corridor2 ST04 PMCH STATION)

(5) Existing Building Survey

JST has received existing building survey report by PMRCL/DMRC.

PMRCL/DMRC assured to JST that TBM alignment avoid all pile foundation structures.

 Final Report on Subsurface Non Destructive Testing & Consultancy for proposed "Utility Investigation Work for Patna Metro Rail Project from Danapur to Mithapur (Corridor-1)-Subsurface & Foundation Depth Analysis" Patna Metro Project Name:- "Utility Investigation Work for Patna Metro Rail Project from Danapur to Mithapur (Corridor-1))- Subsurface & Foundation Depth Analysis" PATNA METRO MAP A V CONSTRUCTION Report Submitted By: A V Construction, New Delhi Submission Date: /02/2021 Corridor1	 Final Report on Subsurface Non-Destructive Testing & Consultancy for proposed "Utility Investigation Work for Patna Metro Rail Project from Patna Station to New ISBT (Corridor-2)-Subsurface & Foundation Depth Analysis" Patna Metro Project Name:- "Utility Investigation Work for Patna Metro Rail Project from Patna Station to New ISBT (Corridor-2)- Subsurface & Foundation Depth Analysis" PATNA METRO MAP A V CONSTRUCTION Report Submitted By: A V Construction, New Delhi Submission Date: 13/02/2021 Corridor2

Source :PMRCL/DMRC

Figure 5-33 : Existing Survey Report

5.3.2 Reviews of Existing Surveys and comments

(1) Geotechnical Investigation

- Additional geotechnical investigation will be carried out at the Depot area.
- Silt clay strata is distributed at the Depot area uniformly.
- Silt clay strata is distributed along the entire Patna Metro uniformly.
- The results of the standard penetration test (SPT) of the existing geological investigation are not in the range of soft ground.
- The information of the bearing strata for pier of the viaduct structure are confirmed on the geotechnical investigation report.
- The pile foundation of the pier shall be penetrated the silty sand soil strata below the silt clay strata.

Additional review comment and suggestion are as follows.

A. Review comment

1. Lab testing data and field data appear to be inconsistent with each other. OCR (Over consolidation Ratio) values less than 1 appear to be inconsistent with the field SPT N values (raw) at the depth of testing.

2. SPT N values broadly indicate stiff to very stiff to hard cohesive soils. OCR values indicate less than normally consolidated soils for the same UDS (Undisturbed Sample), which is not possible.

3. It is possible that the UDS samples extracted from strata indicating high SPT N values **may not be truly undisturbed at the time of sampling** resulting in the observed discrepancy between field and lab data.

4. In many boreholes OCR values at shallow depths indicate close to 1 or 1. Such values at shallow depths appear to be either in overburden, or, in soils which, at these depths, should be under consolidation (less than normally consolidated).

5. OCR values at greater depths indicate low figures in many boreholes, and high SPT N values. Such soils, with high SPT N values, are indicative of overconsolidated conditions, with anticipated OCR values greater than 1, **which is a discrepancy. This inconsistency cannot be explained looking at the existing geotechnical reports.**

6. There are very few locations wherein the UDS samples have been collected within the tunnel zone of influence. Even in such samples, OCR values are less than 1, whereas SPT values indicate otherwise. Hence, the discrepancy in such limited samples also persist, and need to be clarified by the geotechnical consultant.

B. Implications on Tunnel/Station structure

If the OCR values are less than 1, following phenomena of underground structure will occur.

1. **Diaphragm wall embedment** - Generally, D-wall embedment is approximately 5 m below the base slab in station structure. OCR values are not available, at the proposed depths of D wall embedment, to allow a clear understanding of the nature of the strata at this depth. If the OCR values of soil strata at base slab depth or Base slab depth minus 5 m, is less than 1, then it will be indicative of soft soils, and hence may affect the depth

of embedment of the Diaphragm wall.

2. **Launching Shaft/Station base slab** – As mentioned above, if similar strata with OCR less than 1 is encountered, at the depth of the base slab, it would be indicative of weak soils susceptible to settlement of the base slab for TBM launching. This could have implications for the TBM operations in launching/breakthrough zone.

3. **High water table** combined with soil strata in tunnel zone of influence (1XD, where D is the tunnel diameter) – If OCR values are less than 1, it could be indicative of weak soils with poor standup time in the crown area. This could be mitigated by using adequate face pressure/use of EPB TBM and primary grouting, depending on the soil conditions.

4. Given the general geological conditions of Patna area, the shifting course of the River Ganga, over the centuries, would indicate a strong possibility of the connection of the unconfined aquifer with the river. The soil strata in the influence zone of both the tunnel alignments are expected to be fluvial/alluvial deposits from the River Ganga, and hence, variation in the soil properties will be minor.

5. **Cross Passage** – Generally cross passages are constructed using NATM method. If cross passages encounter weak/soft strata, then ground treatment may be required to support the cross passage using appropriate tunneling techniques until the primary shotcrete is in place.

6. **Dewatering Method-** If OCR values are less than 1, the settlement/consolidation of ground is likely to occur.

C. Suggestions

1. **The discrepancy between OCR values and SPT N values need to be clarified.**

2. If required, additional tests may be considered by the Design Build Contractor to ensure appropriate stiffness of the soils in the crown, invert levels, and at the base slab levels and Base slab minus 5 m level to the satisfaction of the Engineer and the Employer.

3. In the absence of a satisfactory explanation to the discrepancy between the OCR values, and to eliminate time constraints, additional in-situ procedures such as Plate Dilatometer or Pressuremeter Testing may be considered to provide values of soil stiffness parameters at variable depths for select boreholes, especially in the underground sections parallel to and in proximity to the River Ganga. Such studies may eliminate the discrepancy observed between field SPT N values and OCR values by providing absolute figures for soil stiffness parameters. The implications of reliable soil stiffness parameters will be directly reflected in the tunnel segment/structure design, and support requirements needed during tunneling.

4. Both tests are considered equally useful in cohesive soils although the steel membrane in both Menard Pressuremeter test and Flat Plate Dilatometer test are sensitive to coarse

strata such as coarse sand and gravel due to damage to the flexible steel membrane while the equipment is pushed through such rough strata.

The below comment is reply comment from PMRCL/DMRC.

1. The consolidation tests were conducted on the UDS samples and OCR values were reported as per the data obtained from lab results.

2. In addition to the above field tests, detailed investigation during the construction stage have been conducted. From the investigation, the OCR values obtained are higher and much more optimized. Furthermore, Pressure meter tests have also been conducted to determine the properties of the strata and these data could be referred for the design.

As discussed with DMRC on 6th September 2022, DMRC will review report again and update accordingly following the comments and suggestions.

(2) Topographic Survey

Since the following situations have been confirmed, JST judged that the current topographic survey data was sufficient. Construction of viaduct section of the Corridor 1 and viaduct/underground section of the Corridor 2 are being executed with latest topographic survey data and part of viaduct section are currently under construction. Construction of guide walls and diaphragm wall are being installed at Corridor2 ST05 Moin Ul Haq.

Source: JST

Figure 5-34: Construction Condition of Guide Wall for Diaphragm Wall Construction at Corridor2 ST05 Moin Ul Haq

Source: JST

Figure 5-35: D-Wall Excavation Construction at Corridor2 ST05 Moin Ul Haq

The survey drawings contain information on ground facilities which could be used for design and construction. Additional topographic survey will be carried out by the contractors under the design build contract.

(3) Underground Utility Survey

JST has received CAD data of underground utility such as electric, gas, water, sewer and communication. JST confirmed that these data are enough for tendering process for construction package. The Contractor will carry out test digging and relocation of underground utility after obtaining approval by PMRCL/DMRC.

The utility type and relocation plan during construction stage is described in section "5.4.2 Reviews of Existing Studies and Proposals for Improvement (2) Construction 3) Underground Structure (Cut and Cover) ".

Source: JST

Figure 5-36: Test Digging of Underground Utility at Corridor 2 ST04 PMCH Station

(4) Overhead utility

The contract package PEUD-03R for Design, Supply, Erection, Testing & Commissioning for Modification and raising the height of the existing 132 kV Double Circuit Transmission line of BSPTCL of Corridor 2 has been contracted in July 2021.

(5) Existing Building Survey

JST confirmed with PMRCL/DMRC about foundation type (spread foundation or pile foundation) of existing building along underground TBM section.

Source: JST

Figure 5-37: Existing Building along Underground TBM Section nearby Cooridor1 ST06 Raja Bazar

PMRCL/DMRC explained/assured to JST that TBM alignment avoid all pile foundation of existing building structures.

(6) As Build Drawing of Existing Road Bridge

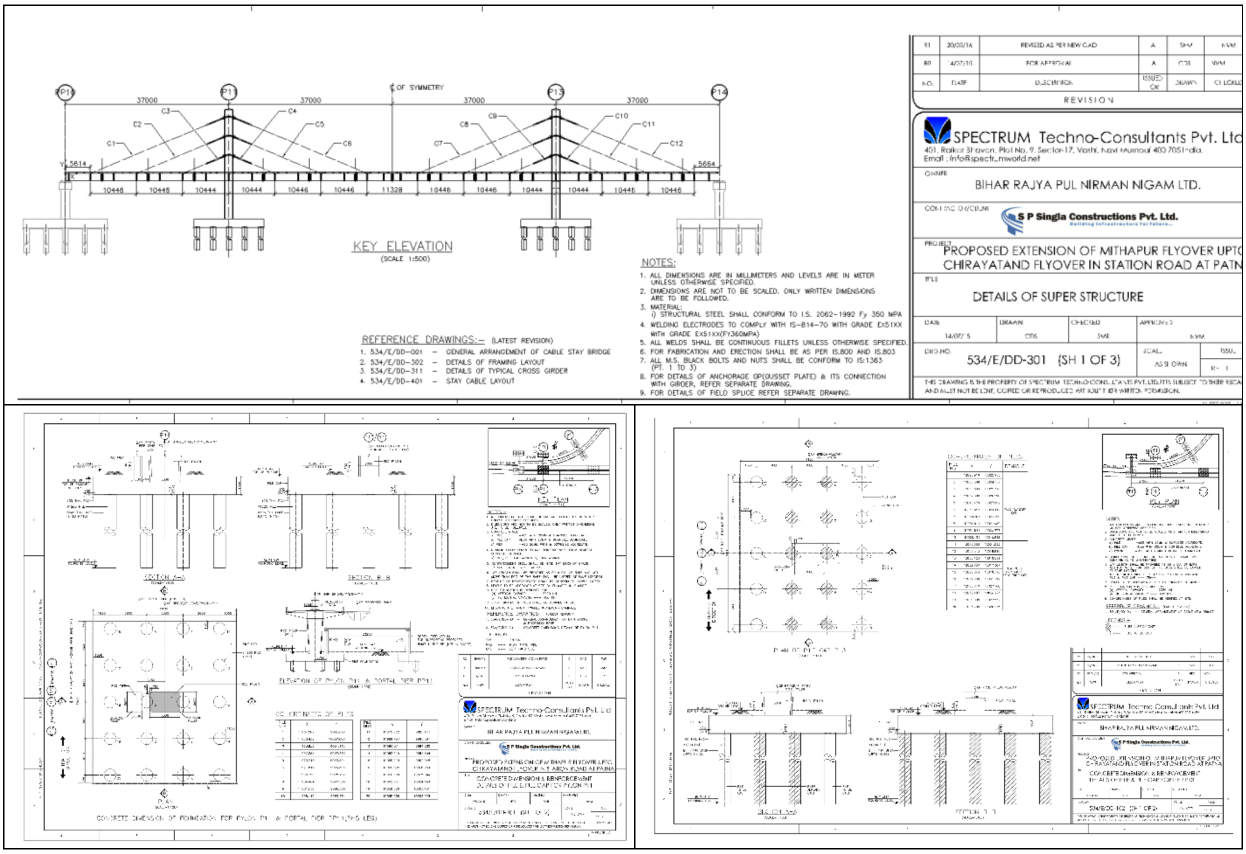
JST has received from PMRCL/DMRC below as build drawing of existing road bridges which are related to plan of underground structure.

1) Patna Bridge

Location between Corridor1 ST10 Patna Junction and pile foundation of the Patna Bridge and space between road and soffit side of bridge for construction was confirmed.

Source: JST

Figure 5-38: Patna Bridge

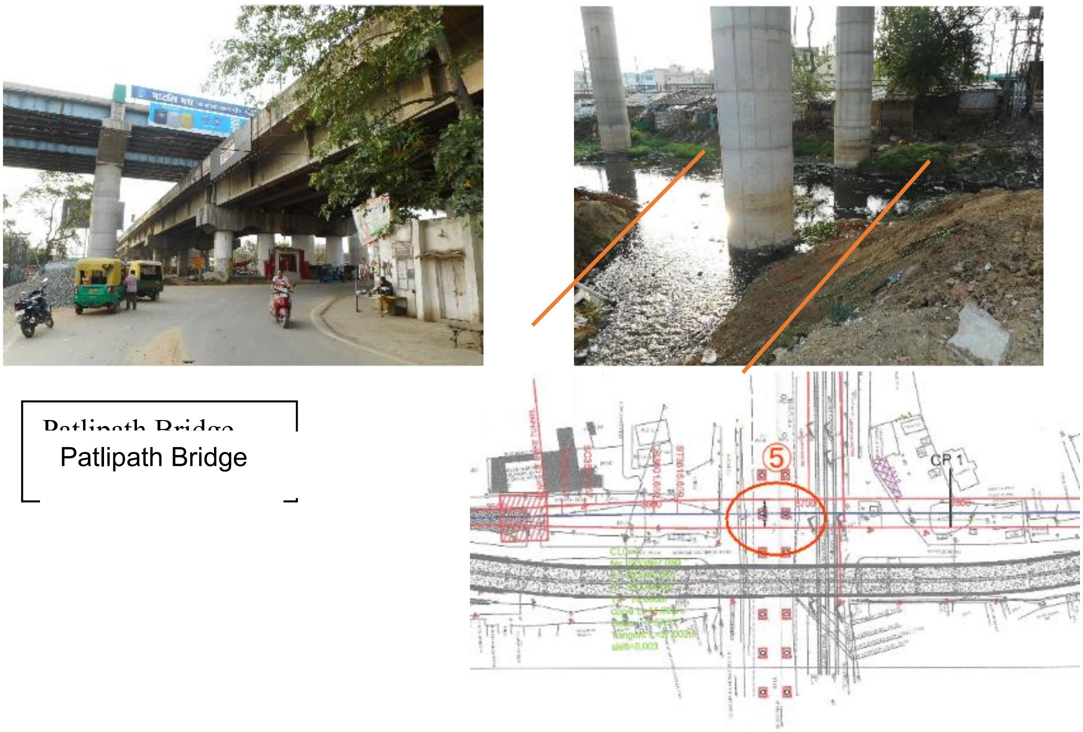


Source: PMRCL/DMRC

Figure 5-39 : As-build Drawing of Patna Bridge

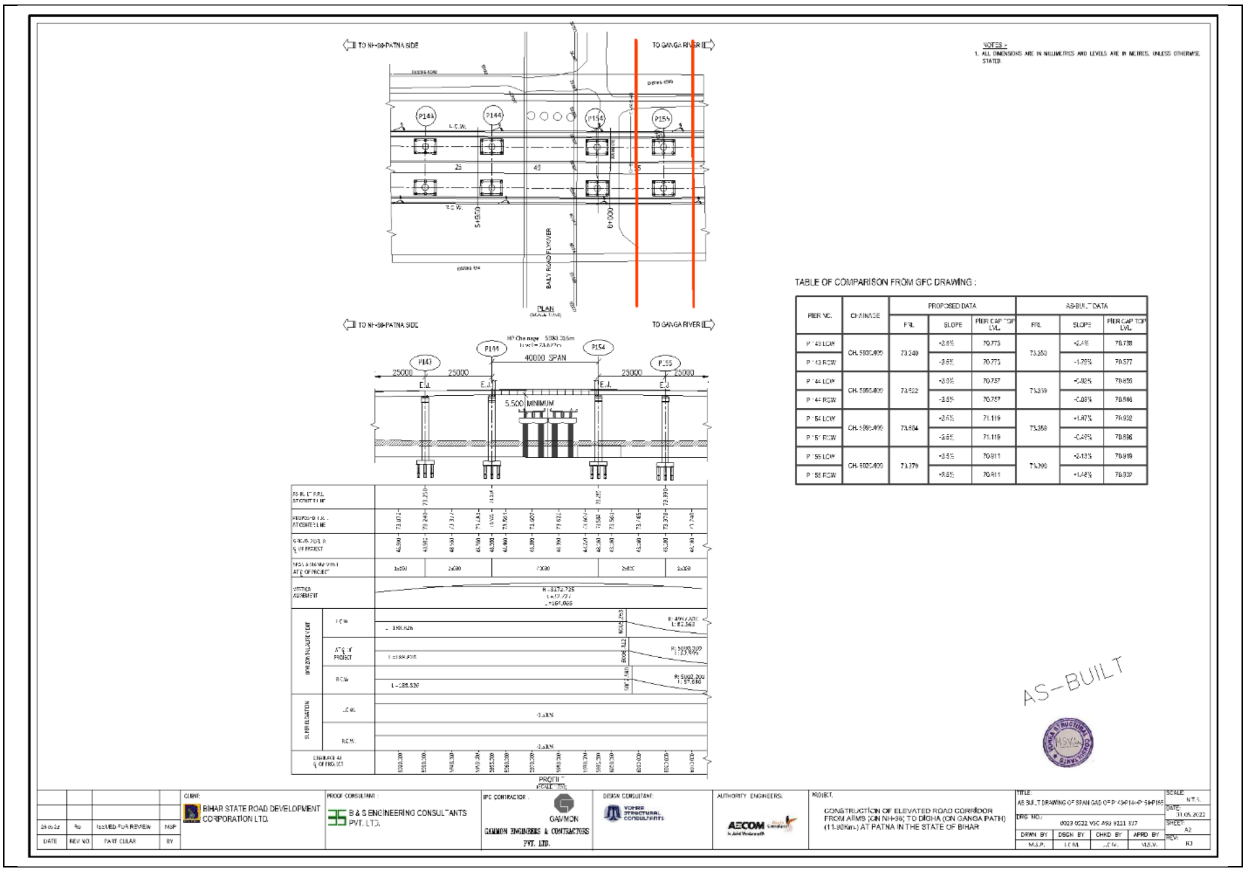
2) Patriputra Bridge (From Corridor1 ST04 Patliputra to ST05 Rukanpura Station)**:**

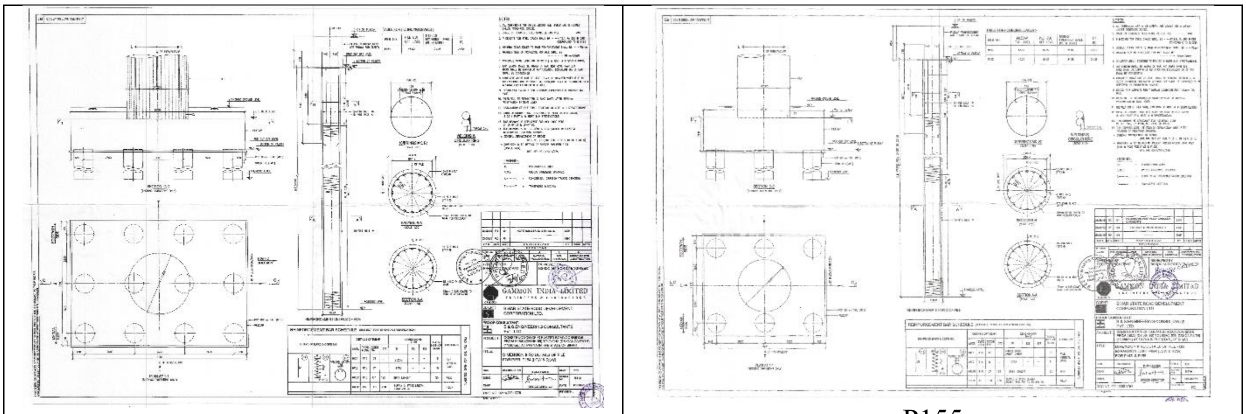
Distance between TBM machine and pile foundation of the Patriputra Bridge was confirmed.



Source: JST

Figure 5-40: Patriputra Bridge





P154 P155

Source: PMRCL/DMRC

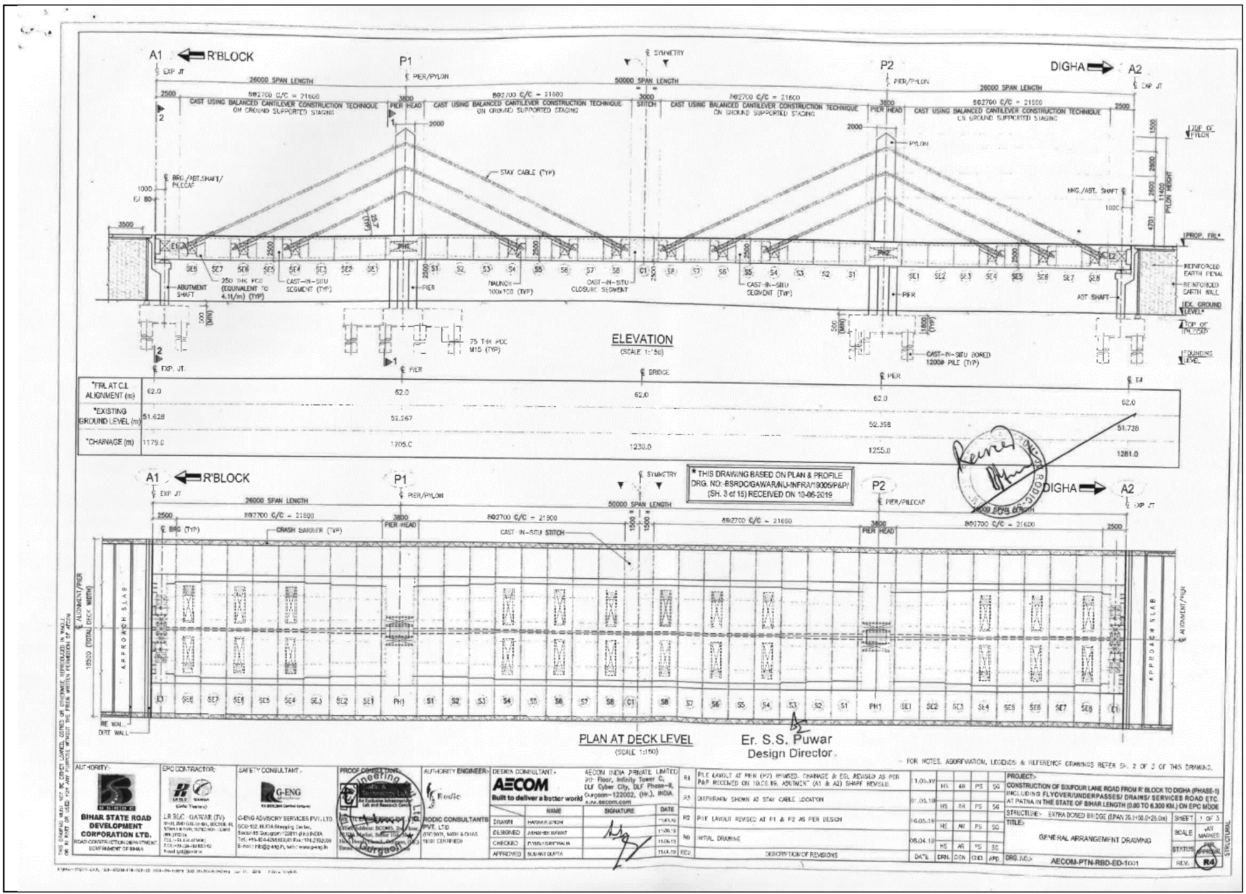
Figure 5-41 : As-build Drawing of Patriputra Bridge

3) Feet Road bridge

Distance between TBM machine and pier of the Feet road bridge was confirmed.

Source: JST

Figure 5-42: Feet Road Bridge

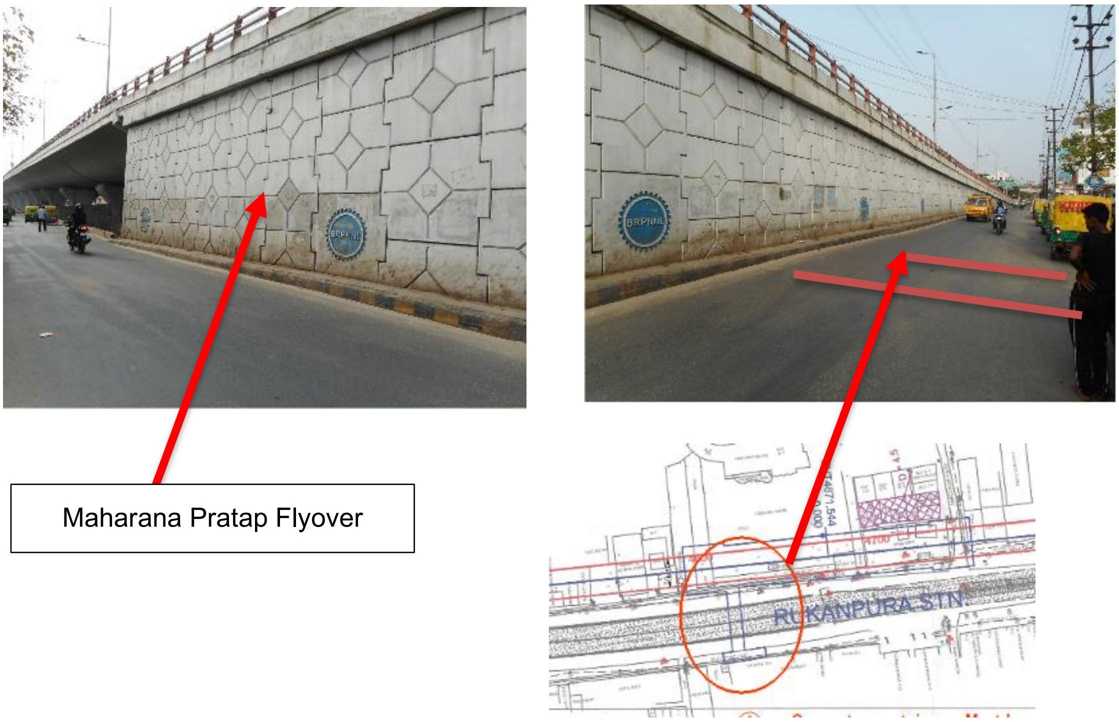


Source:PMRCL/DMRC

Figure 5-43 : As-build Drawing of Feet Road Bridge

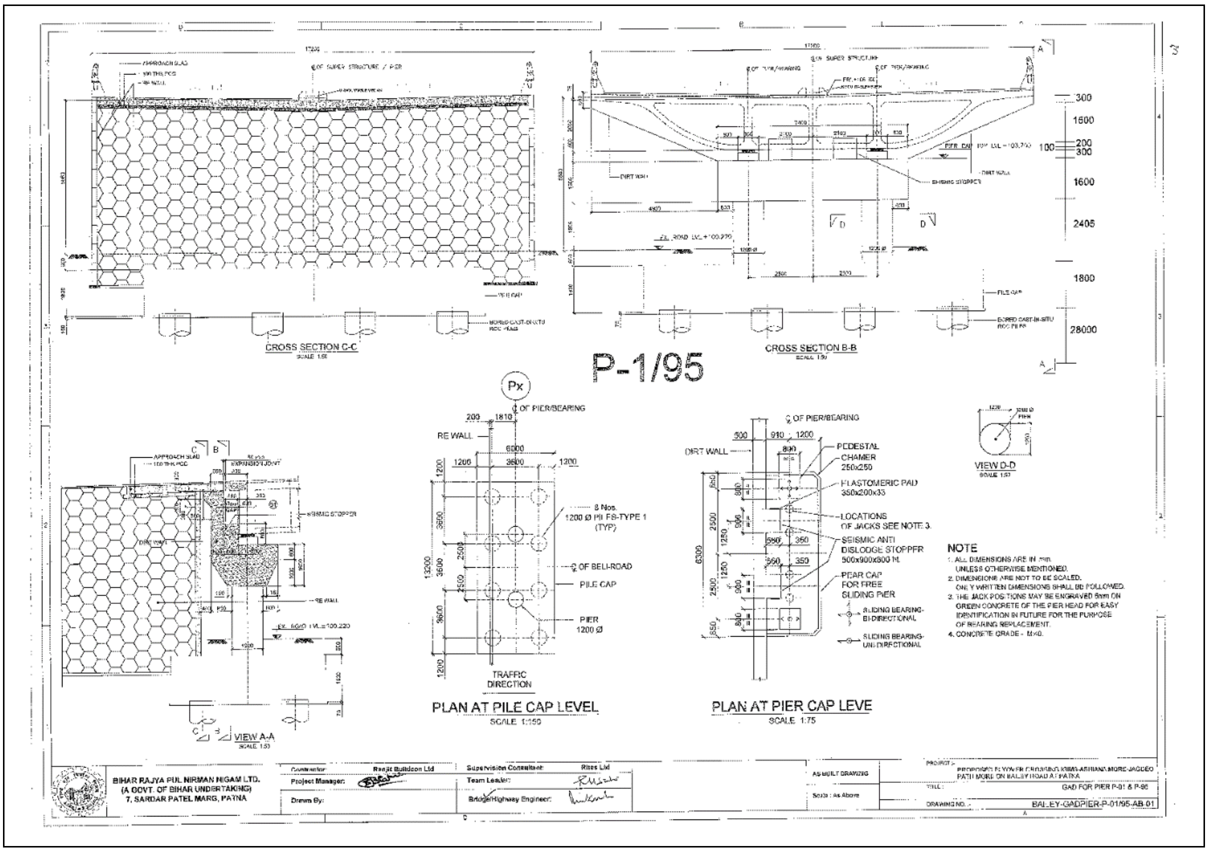
4) Reinforcement retaining wall embankment of Maharana Pratap Flyover

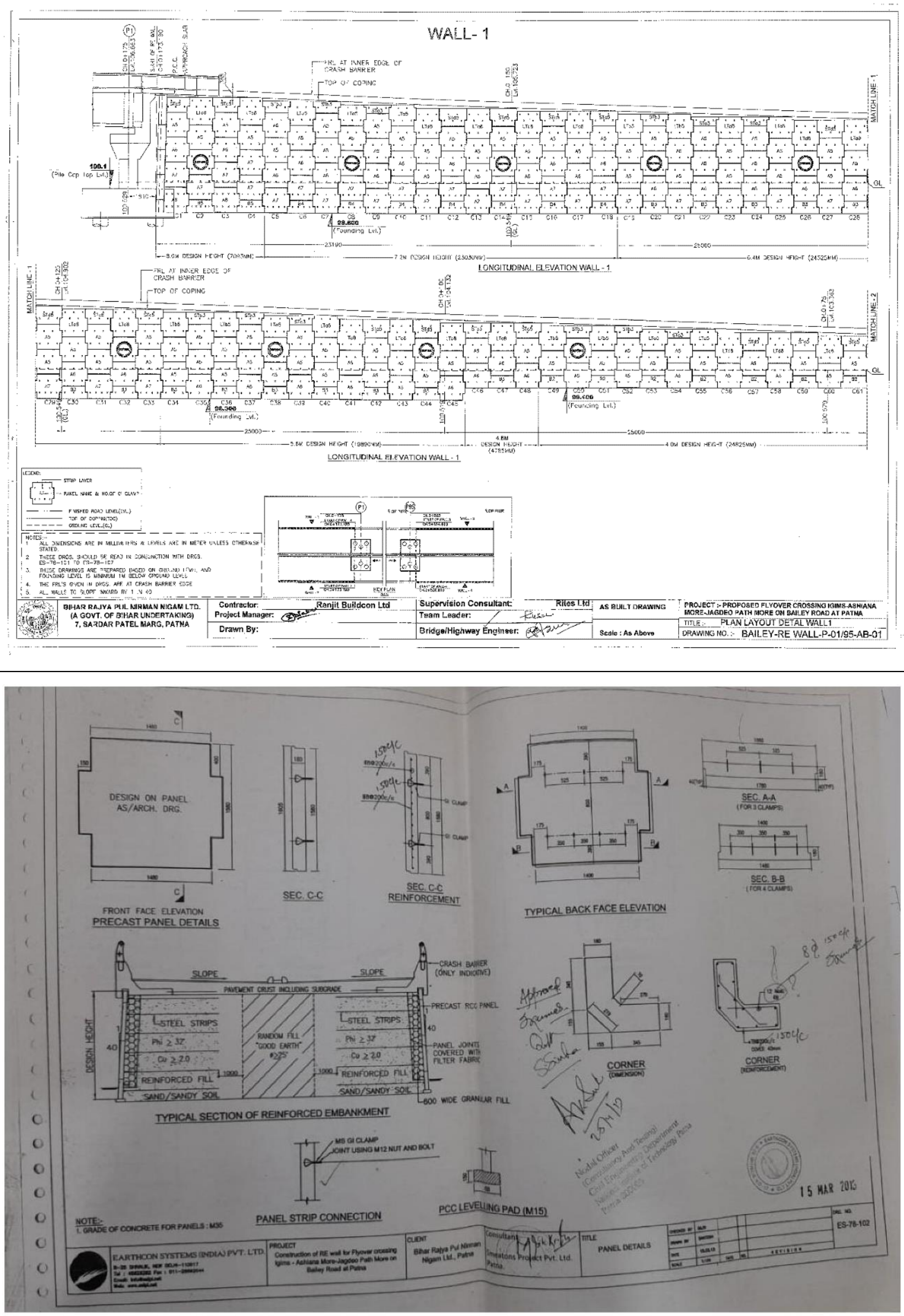
Underground entrance of Corridor1 ST05 Rukanpura is planed under the road embankment of Maharana Pratap Flyover. JST was confirmed with PMRCL/DMRC about entrance construction method.



Source: JST

Figure 5-44: Reinforcement retaining wall embankment of Maharana Pratap Flyover



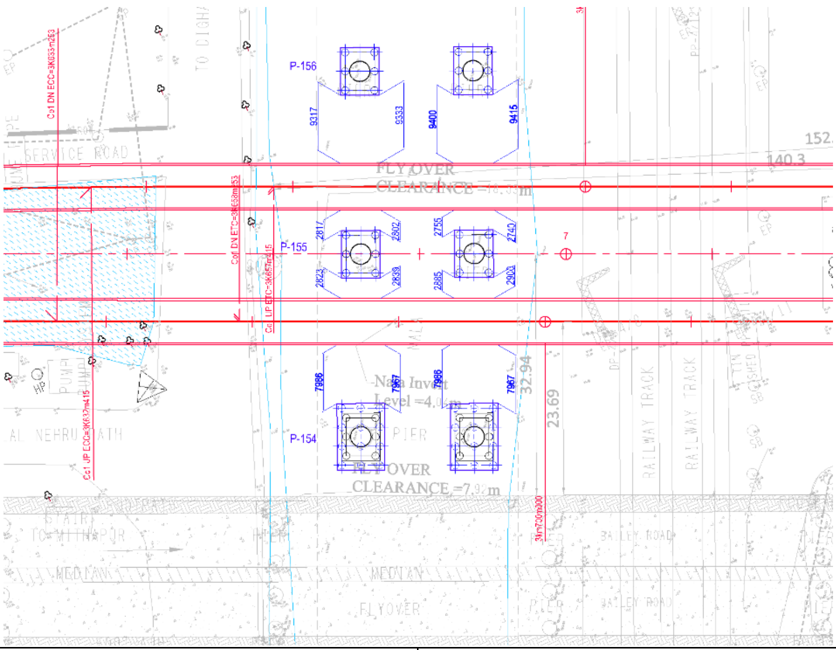


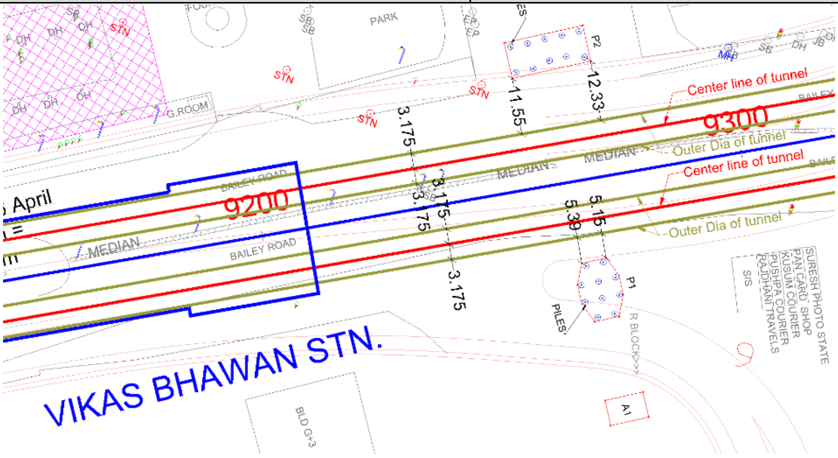
Source:PMRCL/DMRC

Figure 5-45: : As- built drawing of reinforcement retaining wall

The below table shows the contents of the review point and result.

Table 5-18: The Review Result of the Existing Road Bridges during Construction

Existing Road Bridge	Review Contents	Review Result
Patna Bridge	• Location between Corridor 1 ST10 Patna Junction and pile foundation of Patna Bridge • Degree of proximity both structures • Space between road and soffit side of bridge for construction	• Enough distance between Corridor1 ST10 Patna Junction and pile foundation of Patna Bridge • However, monitoring of bridge deformation has to be performed during station excavation stage.
Patriputra Bridge	• Space between TBM machine and pile foundation of the Patriputra Bridge • Degree of proximity both structures	• FEM analysis for proximity pile foundation at underground TBM has to be performed in Detailed Design stage • Monitoring of bridge deformation has to be performed during TBM driving
		
Feet Road	• Distance between TBM alignment and pile foundation of Feet road bridge, • Degree of proximity both structures	• FEM analysis for proximity pile foundation at underground TBM has to be performed in Detailed Design stage • Monitoring of bridge deformation has to be performed during TBM driving.

Existing Road Bridge	Review Contents	Review Result
		
Maharana Pratap Flyover (Reinforcement Embankment)	• Construction method of underground entrance of Corridor1 ST05 Rukanpura	• FEM analysis for entrance by non-digging construction under the road retaining wall has to be performed in Detailed Design stage • Monitoring of deformation of existing road surface and retaining wall has to be performed during construction stage.

Source: JST

5.4 Civil Engineering

5.4.1 Overview of Civil structure plan and design concept

(1) Civil Structure Type

The following figure shows schematic diagram of Patna Metro project, which contains tentative chainage of stations given by PMRCL/DMRC.

Source: JST

Figure 5-46: Schematic Diagram of Patna Metro (as of 15th September 2022)

The below tables show the lengths of structure type of Corridor 1 and 2.

Table 5-19: Structure Type of Corridor 1 (As of 15th September 2022)

Corridor1

Unit:m

No.	STATION		Chainage	Elevated			Underground		
				Viaduct	Station	Ramp	TBM	Station	Ramp
		Start Point	-0k012.998m						
		Start of Station	0k279.576m	292.574					
1	DANAPUR STN	Centre of Station	0k349.576m		140.000				
		End of Station	0k419.576m						
		Start of Station	1k113.270m	693.694					
2	SAGUNA MORE STN	Centre of Station	1k184.895m		143.120				
		End of Station	1k256.390m						
		Start of Station	1k966.560m	710.170					
3	R.P.S. MORE STN	Centre of Station	2k038.057m		143.000				
		End of Station	2k109.560m						
		Start of Station	2k714.460m	604.900					
4	PATLIPUTRA STN	Centre of Station	2k809.958m		191.000				
		End of Station	2k905.460m						
		End of Viaduct	3k026.960m	121.500					
		Null Point	3k181.960m			155.000			
	Ramp	End of U Type	3k326.900m						144.940
		Start of Shaft	3k502.850m						175.950
		End of Shaft	3k532.850m						30.000
		Start of Station	4k590.344m				1,057.494		
5	RUKANPURA STN	Centre of Station	4k671.544m					162.400	
		End of Station	4k752.744m						
		Start of Station	5k548.592m				795.848		
6	RAJA BAZAR STN	Centre of Station	5k629.792m					162.408	
		End of Station	5k711.000m						
		Start of Station	7k736.318m				2,025.318		
7	PATNA ZOO STATION	Centre of Station	7k846.516m					356.398	
		End of Station	8k092.716m						
		Start of Station	9k044.410m				951.694		
8	VIKAS BHAWAN STN	Centre of Station	9k126.905m					165.000	
		End of Station	9k209.410m						
		Start of Station	10k456.050m				1,246.640		
9	VIDYUT BHAWAN STN	Centre of Station	10k564.726m					217.400	
		End of Station	10k673.450m						
		Start of Station	11k757.420m				1,083.970		
10	PATNA JUNCTION STN	Centre of Station	11k988.747m					347.410	
		End of Station	12k104.830m						
		Start of Shaft	13k363.950m				1,259.120		
		End of Shaft	13k388.490m						24.540
	Ramp	Start of U Type	13k494.280m						105.790
		Null Point	13k640.060m						145.780
		Start of Viaduct	13k791.820m			151.760			
		Start of Station	13k960.261m	168.441					
11	MITHAPUR STN	Centre of Station	14k031.761m		143.000				
		End of Station	14k103.261m						
		Start of Station	15k266.900m	1,163.639					
12	RAMAKRISHNA NAGAR STN	Centre of Station	15k338.397m		143.000				
		End of Station	15k409.900m						
		Start of Station	16k220.350m	810.450					
13	JAGANPURA STN	Centre of Station	16k291.967m		143.120				
		End of Station	16k363.470m						
		Start of Station	17k177.330m	813.860					
14	KHEMNI CHAK	Centre of Station	17k247.382m		140.020				
		End of Station	17k317.350m						
		End Point	17k777.260m	459.910					
	Sub Total			5,839.138	1,186.260	306.760	8,420.084	1,411.016	627.000
				7,332.158			10,458.100		
	Total			17,790.258					

Source: JST

Table 5-20: Structure Type of Corridor 2 (As of 15th September 2022)

Corridor2

Unit:m

	STATION		Chainage	Elevated			Underground		
				Viaduct	Station	Ramp	TBM	Station	Ramp
		Start of Station	0k000.000m						
	PATNA JUNCTION STN	Centre of Station	0k115.000m					344.470	
		End of Station	0k344.470m						
		Start of Station	0k816.600m				472.130		
1	AKASHUVANI STN	Centre of Station	0k940.304m					237.400	
		End of Station	1k054.000m						
		Start of Station	2k019.130m				965.130		
2	GANDHI MAIDAN STN	Centre of Station	2k121.327m					206.030	
		End of Station	2k225.160m						
		Start of Station	3k231.000m				1,005.840		
3	PMCH STN	Centre of Station	3k344.763m					227.460	
		End of Station	3k458.460m						
		Start of Station	4k522.790m				1,064.330		
4	UNIVERSITY STN	Centre of Station	4k603.993m					162.400	
		End of Station	4k685.190m						
		Start of Station	6k176.930m				1,491.740		
5	MOIN UL HAQ STN	Centre of Station	6k279.127m					204.330	
		End of Station	6k381.260m						
		Start of Station	7k082.910m				701.650		
6	RAJENDRA NAGAR STN	Centre of Station	7k164.106m					162.400	
		End of Station	7k245.310m						
		Start of Shaft	7k804.200m				558.890		
		End of Shaft	7k834.200m						30.000
	Ramp	Start of U Type	7k949.870m						115.670
		Null Point	8k098.840m						148.970
		Start of Viaduct	8k249.870m			151.030			
		Start of Station	8k372.170m	122.300					
1	MALAHI PAKRI STN	Centre of Station	8k442.127m		140.050				
		End of Station	8k512.220m						
		Start of Station	9k888.600m	1,376.380					
2	KHEMNI CHAK STN	Centre of Station	9k958.265m		140.000				
		End of Station	10k028.600m						
		Start of Station	10k903.692m	875.092					
3	BHOOTNATH STN	Centre of Station	10k974.288m		140.018				
		End of Station	11k043.710m						
		Start of Station	12k222.131m	1,178.421					
4	ZERO MILE STN	Centre of Station	12k292.122m		140.000				
		End of Station	12k362.131m						
		Start of Station	13k659.550m	1,297.419					
5	NEW ISBT STN	Centre of Station	13k729.585m		140.030				
		End of Station	13k799.580m						
		End Point	14k197.595m	398.015					
	Sub Total			5,247.627	700.098	151.030	6,259.710	1,544.490	294.640
				6,098.755			8,098.840		
	Total			14,197.595					

STATION		Chainage	Elevated			Underground		
			Viaduct	Station	Ramp	TBM	Station	Ramp
Depot Line	Start of Depot Line	0k000.000m						
	End of Viaduct	0k231.130m	231.130					
	End t of Depot Line	0k390.354m			159.224			
Sub Total			231.130	0.000	159.224	0.000	0.000	0.000

Corridor2

Structure Type	Elevated			Underground		
	Viaduct	Station	Ramp	TBM	Station	Ramp
Sub Total	5,478.757	700.098	310.254	6,259.710	1,544.490	294.640
	6,489.109			8,098.840		
Total	14,587.949					

Source JST

(2) Design

Detailed design of civil structure will be carried out by the Contractor following FIDIC Yellow Design and Build which was applied to Delhi Metro Phase 1, 2, 3 and 4 project. Also specification for Patna Metro civil design refers to Delhi Metro Project Phase 4. The below figure shows the table of contents of specification for Patna Metro civil design.


OUTLINE DESIGN SPECIFICATIONS
FOR
PHASE - I OF PATNA MRTS PROJECT
(FEB 2020)

DELHI METRO RAIL CORPORATION LTD.
Metro Bhawan, Fire Brigade Lane,
Barakhamba Road, New Delhi-110001

Outline Design Specifications (Feb 2020)

Table of Contents

Source: PMRC/DMRC

Figure 5-47: Civil Design Specification for Patna Metro Project

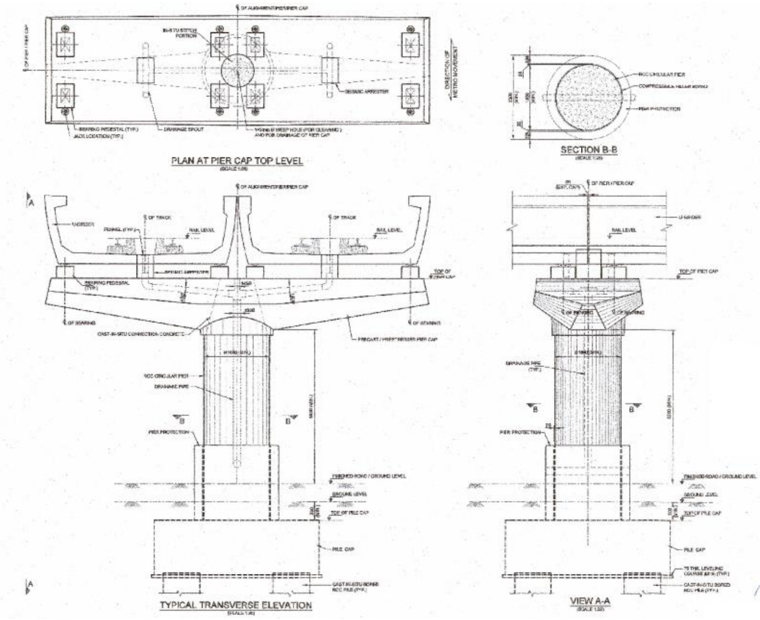
(3) Elevated Section

The viaduct alignment of the Corridor 1 is planned along the centre of existing roads, but part of section is planned at beside of existing road to fit for underground alignment. The viaduct alignment of the Corridor 2 is also planned along the centre of existing road, but section of National Highway 31 is planned at beside of existing road.

The soffit side of viaducts have a vertical clearance of a minimum of 5.5 m above road level. The viaduct structure types are U-shape and I-Shape pre-stressed concrete bridge for typical section and steel truss arch girder for long span bridge whose types were adopted the Delhi Metro Project.

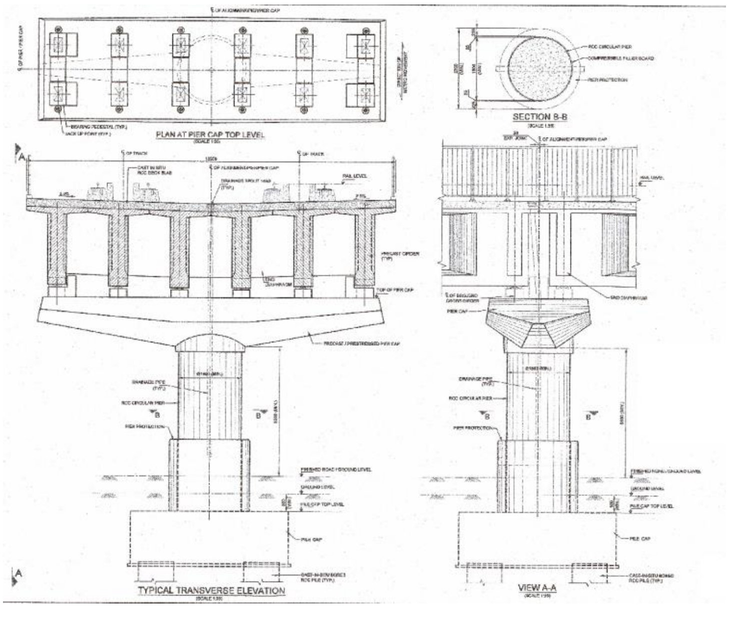
The station located above the central median is 2 (two) stories structure and the viaduct section of the Corridor 1 and the Corridor 2 were awarded and part of viaduct section are currently under execution. U-shape PC girder and pier column head are fabricating at the Corridor 2 casting yard.

The general drawings of viaduct for Corridor1 and 2 are shown below figures.



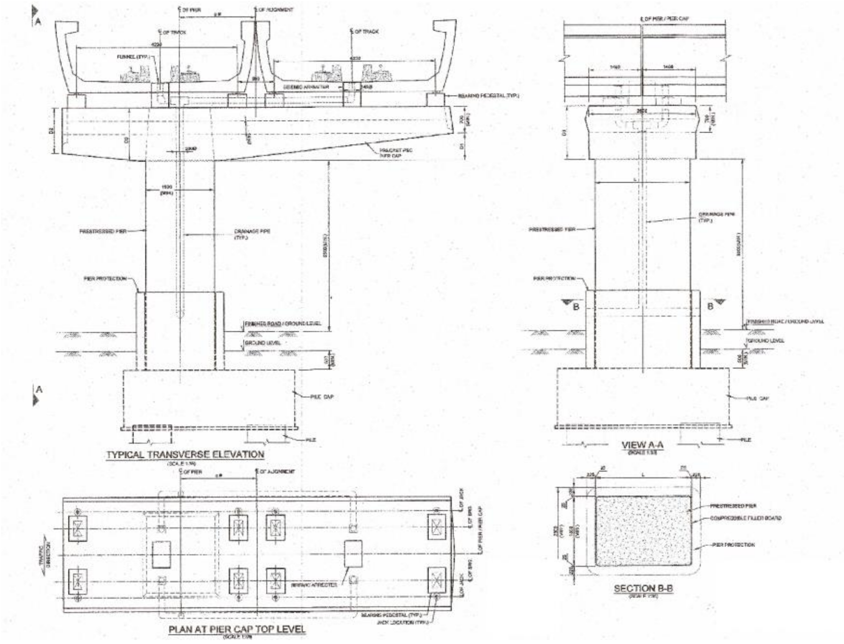
Source: PMRCL/DMRC

Figure 5-48: Typical Structure Type of Viaduct and Pier (1)



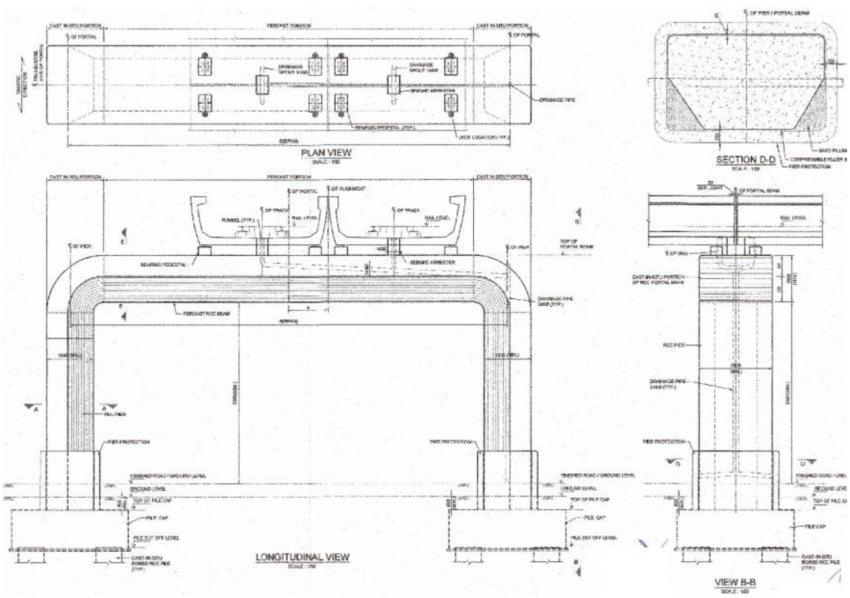
Source: PMRCL/DMRC

Figure 5-49: Typical Structure Type of Viaduct and Pier (2)



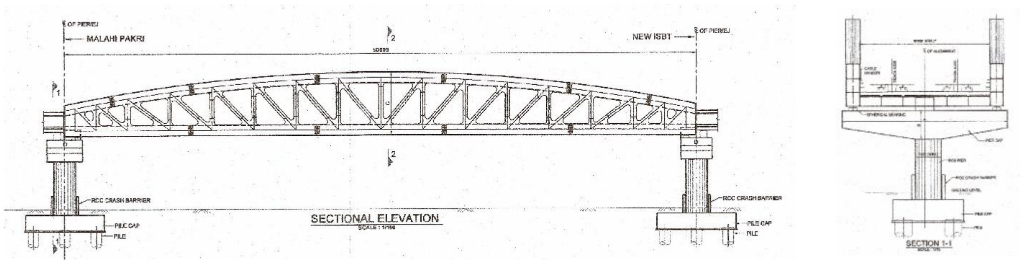
Source: PMRCL/DMRC

Figure 5-50: Structure Type of Viaduct and Pier (3)



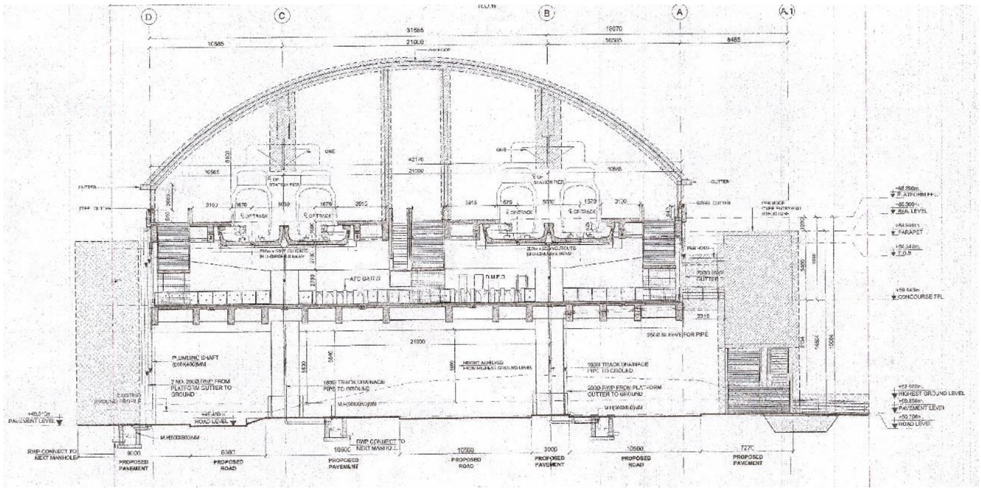
Source: PMRCL/DMRC

Figure 5-51: Structure Type of Viaduct and Pier (4)



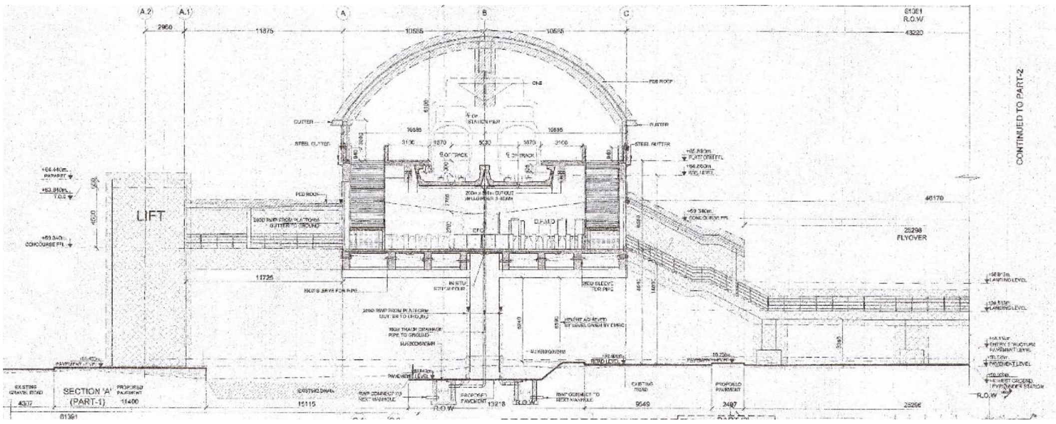
Source: PMRCL/DMRC

Figure 5-52: Structure Type of Viaduct (Truss Bridge) and Pier



Source: PMRCL/DMRC

Figure 5-53: Corrido2 ST09 Khemni Chak



Source: PMRCL/DMRC

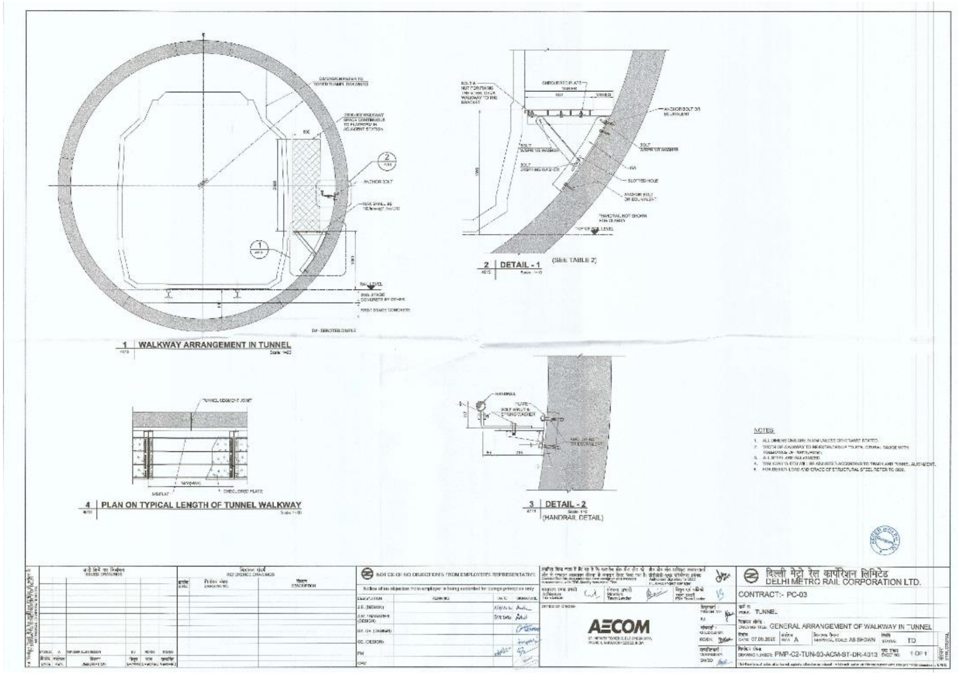
Figure 5-54: Corridor 2 ST11 Zero Mile

(4) Underground Section

Construction methods of underground section are:

<u>Between stations and shaft:</u>

- Single track TBM (Tunnel Boring Machine)
- TBM external diameter is Φ6.35m



Source: PMRCL/DMRC

Figure 5-55: General Arrangement Walkway in Tunnel

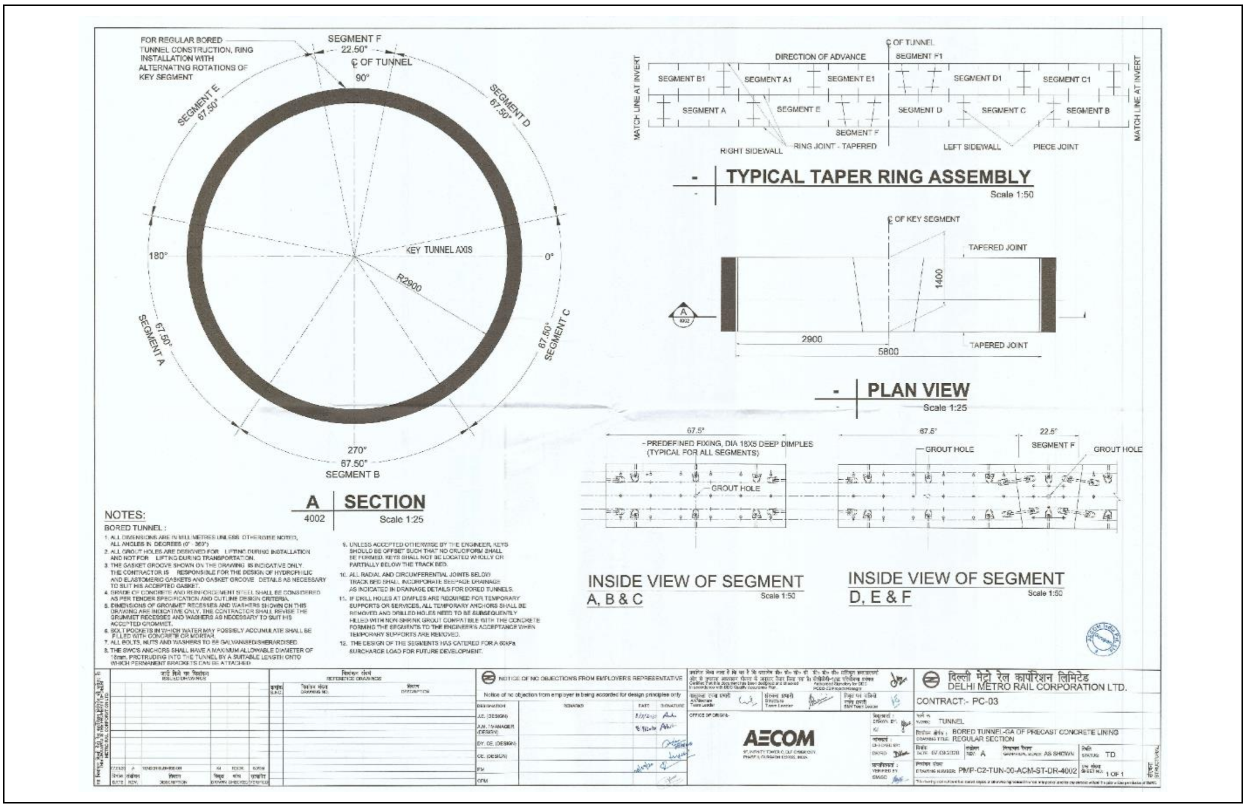


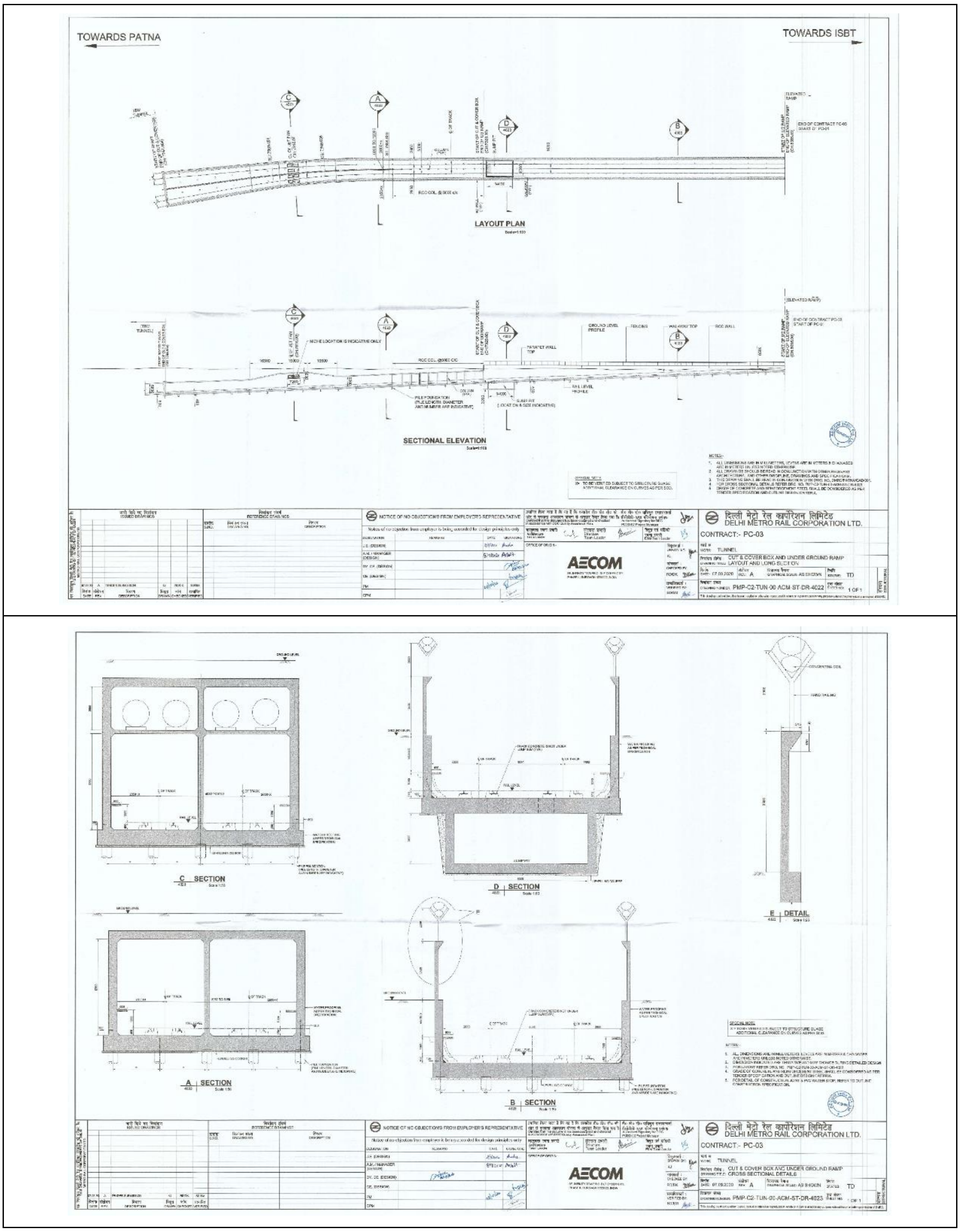
Figure 5-56 : Bored Tunnel General Arrangement of Precast Concrete Lining Regular Section

Station:

- Cut and cover method with diaphragm wall (D/Wall). D/Wall is permanent structure of side wall of station.

Ramp and shaft:

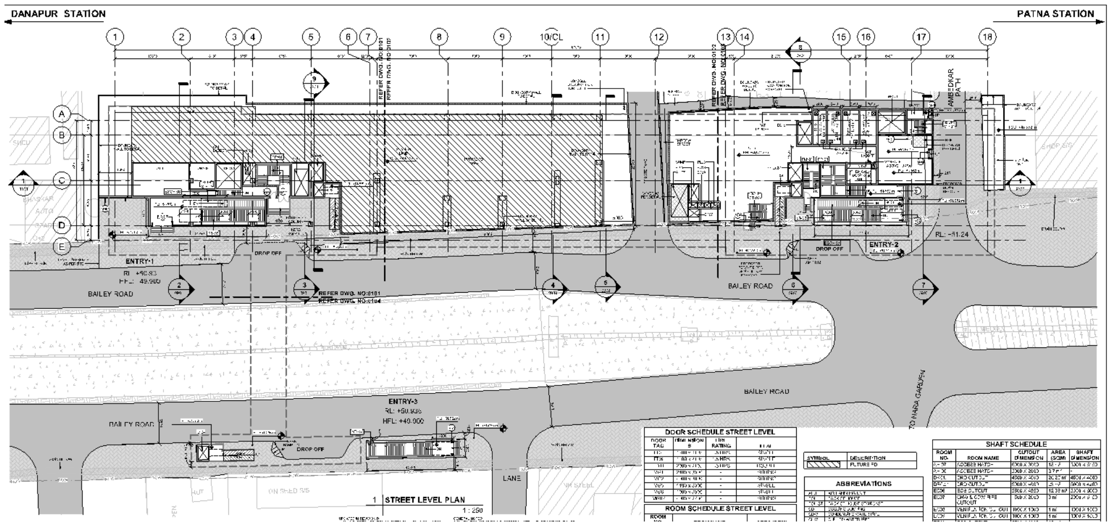
- Cut and cover method

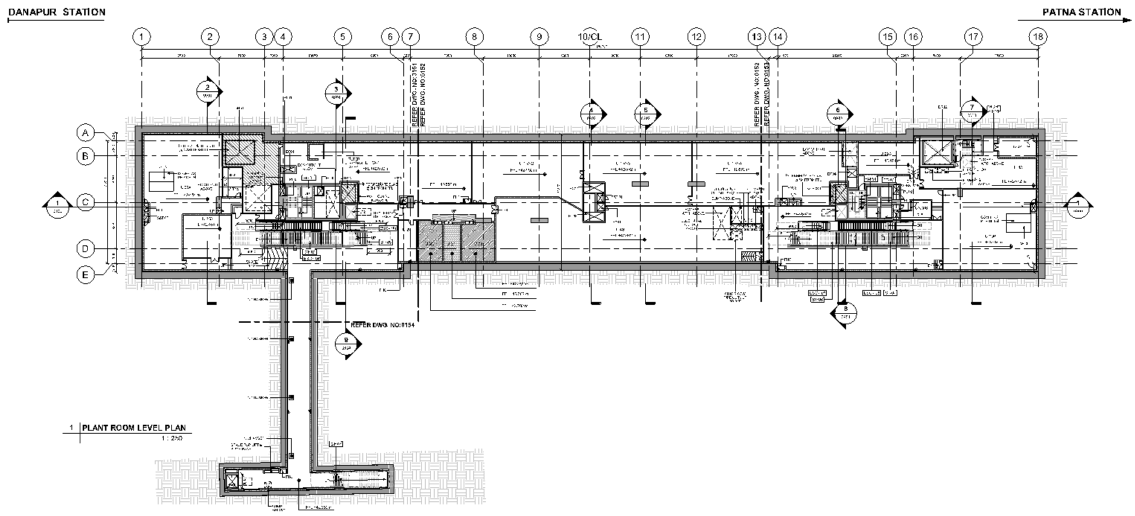


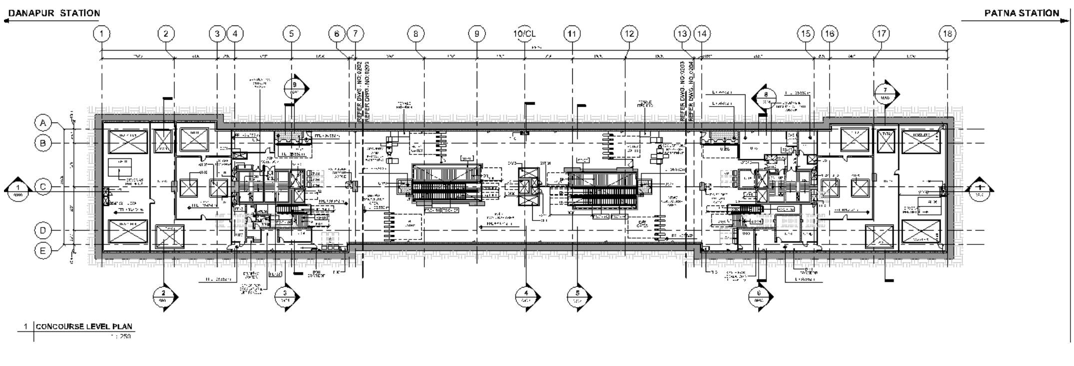
Source: PMRCL/DMRC

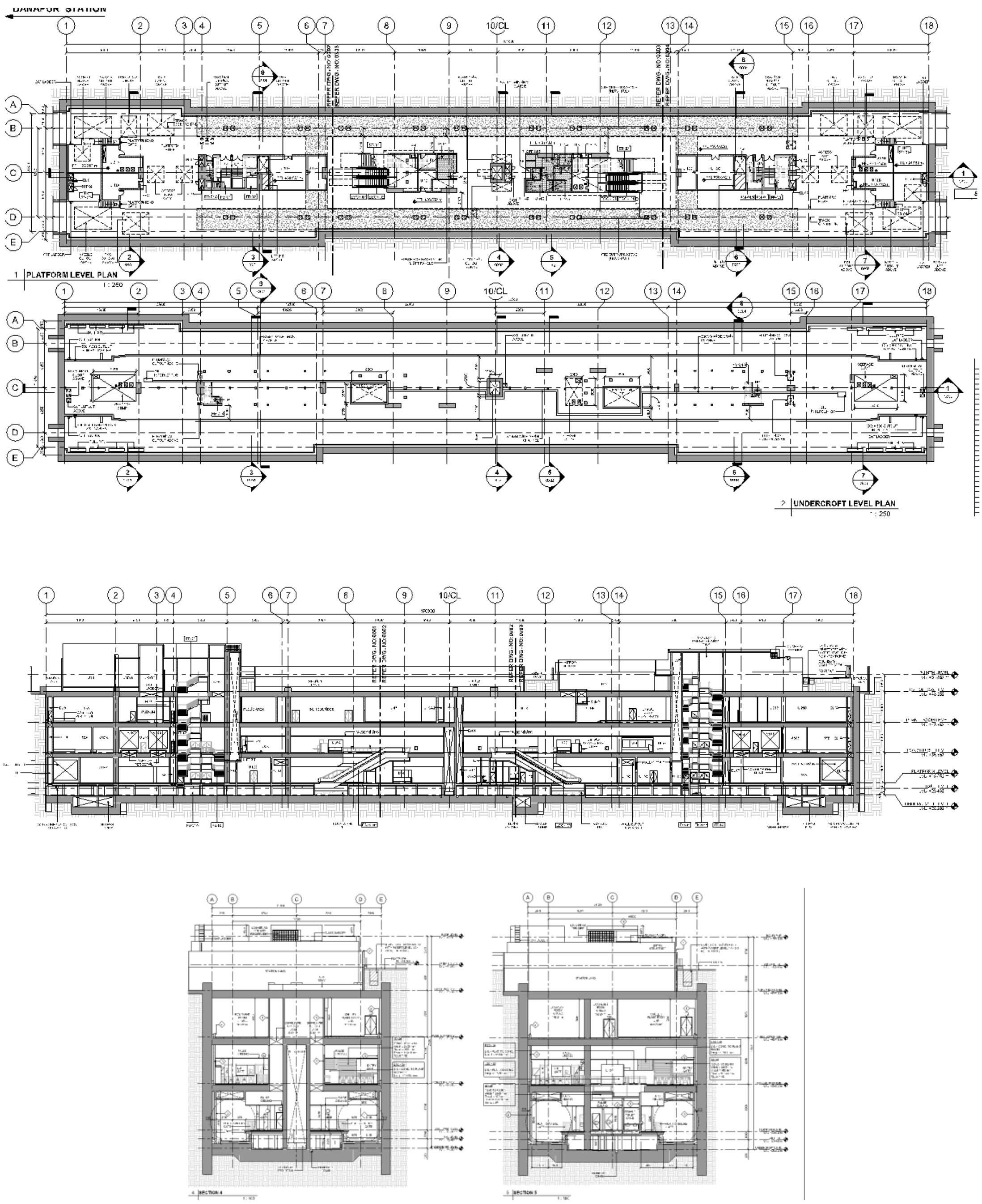
Figure 5-57 : Cut & Cover Box and Under Ground Ramp

JST received tender drawing of the Corridor 2, and basic design drawing of Corridor 1. The below figures show the general drawings of underground station of Corridor1.


DANAPUR STATION
PATNA STATION
ENTRY-1
ENTRY-2
ENTRY-3
BAILEY ROAD
DROP OFF
LANE
DOOR SCHEDULE STREET LEVEL
ROOM SCHEDULE STREET LEVEL
ABBREVIATIONS
SHAFT SCHEDULE
1 STREET LEVEL PLAN
1 : 250

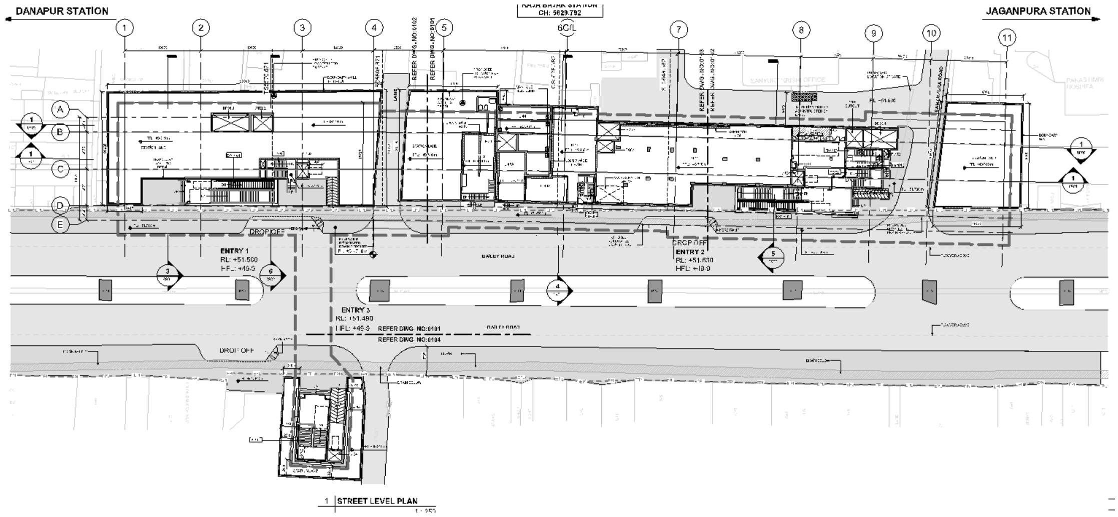

DANAPUR STATION
PATNA STATION
1 PLANT ROOM LEVEL PLAN
1 : 250

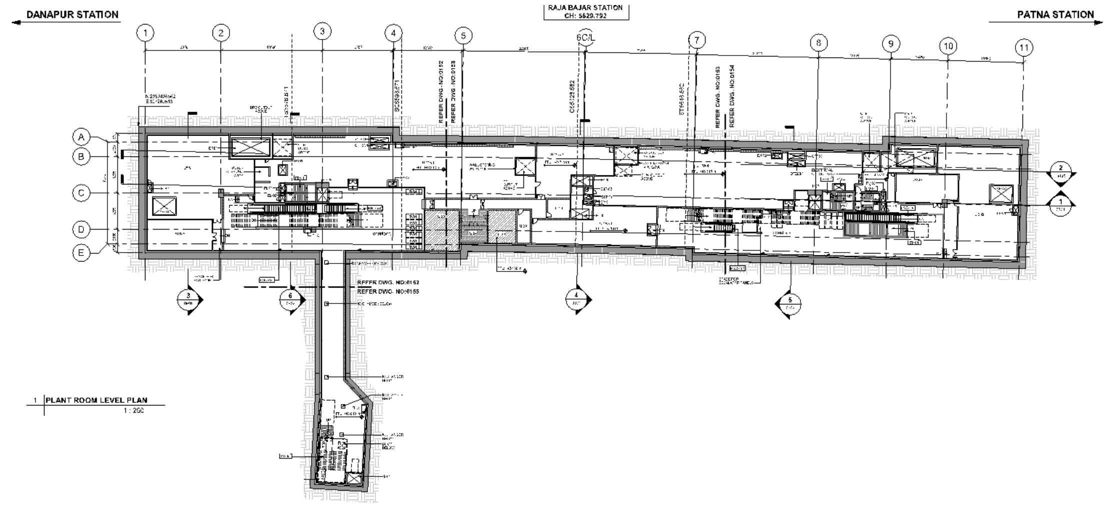

DANAPUR STATION
PATNA STATION
1 CONCOURSE LEVEL PLAN
1 : 250

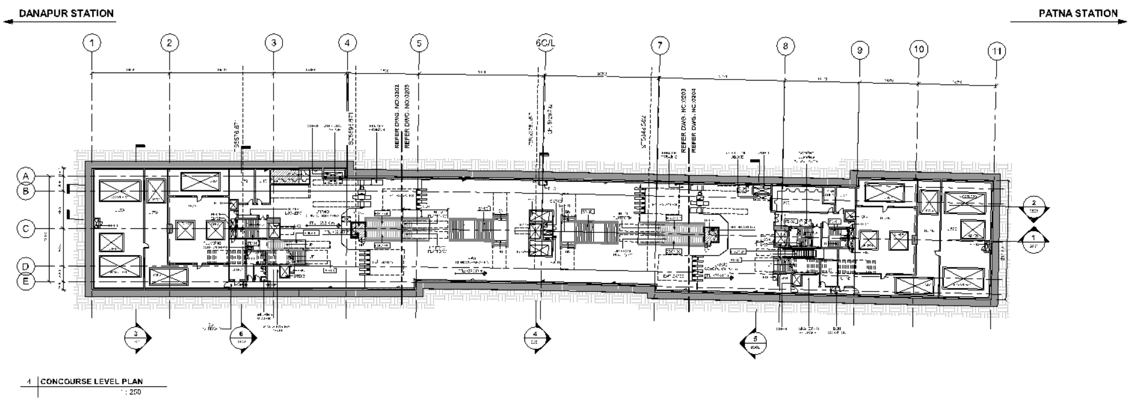


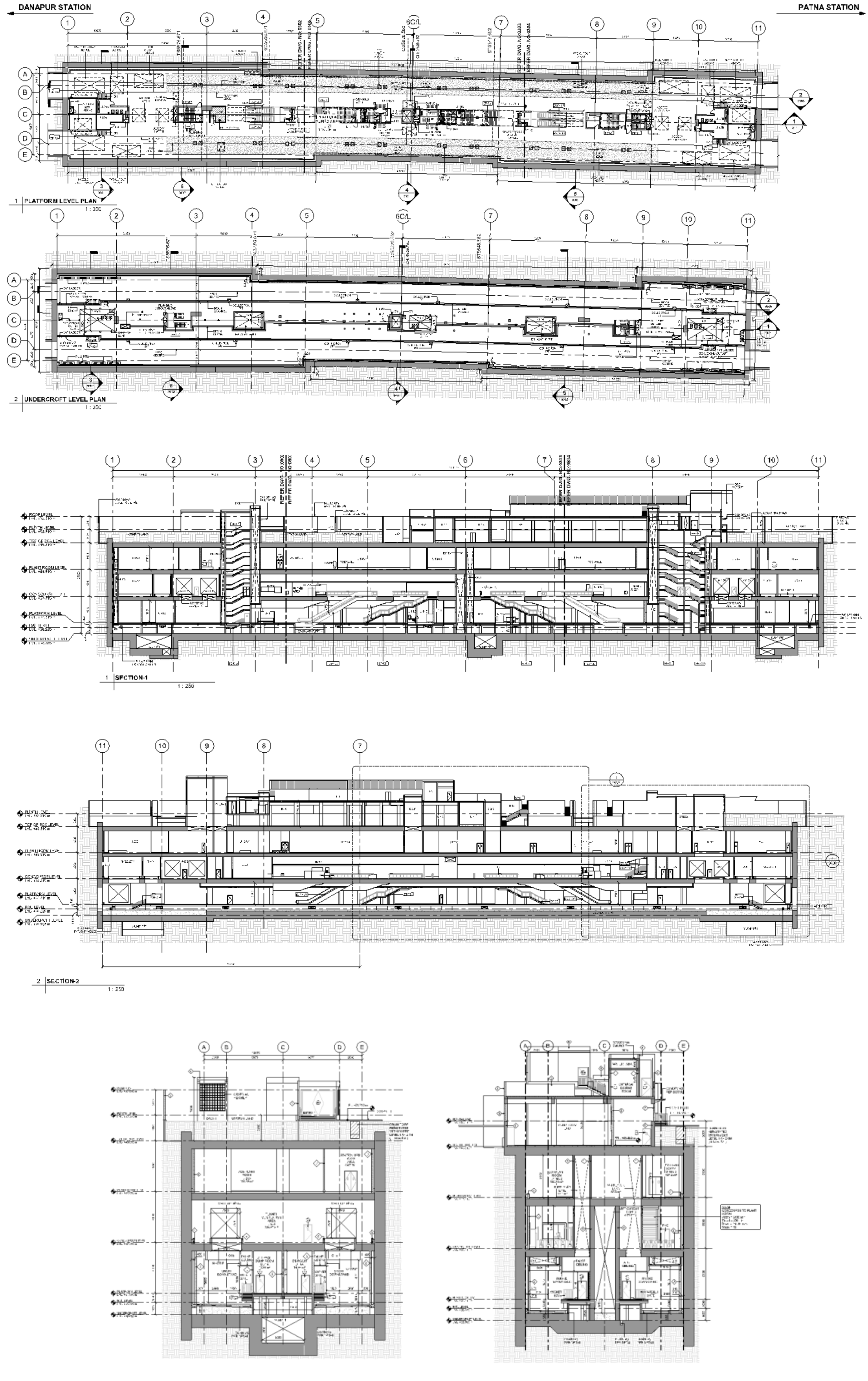
Source: PMRCL/DMRC

Figure 5-58: Corridor1 ST05 Rukanpura


DANAPUR STATION
RAJA BAJAR STATION
CH: 5629.792
JAGANPURA STATION
ENTRY 1
ENTRY 2
ENTRY 3
DROP OFF
1 STREET LEVEL PLAN

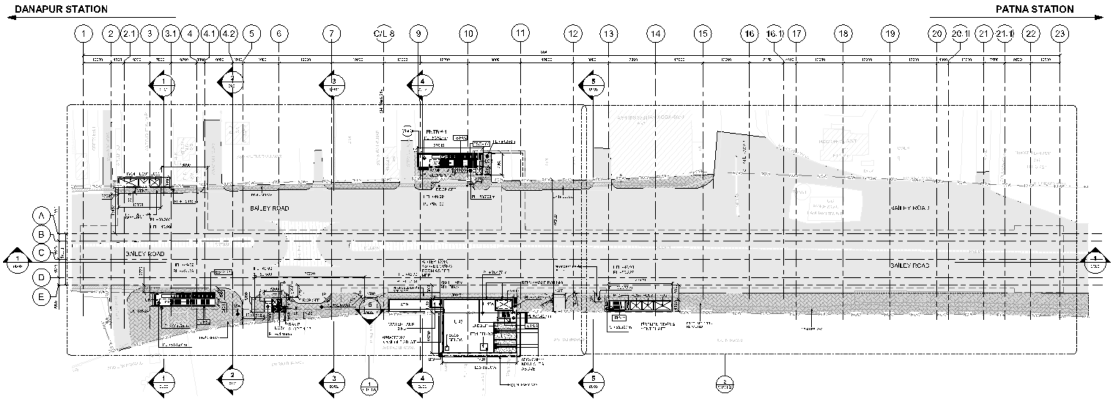

DANAPUR STATION
RAJA BAJAR STATION
CH: 5629.792
PATNA STATION
1 PLANT ROOM LEVEL PLAN
1 : 250

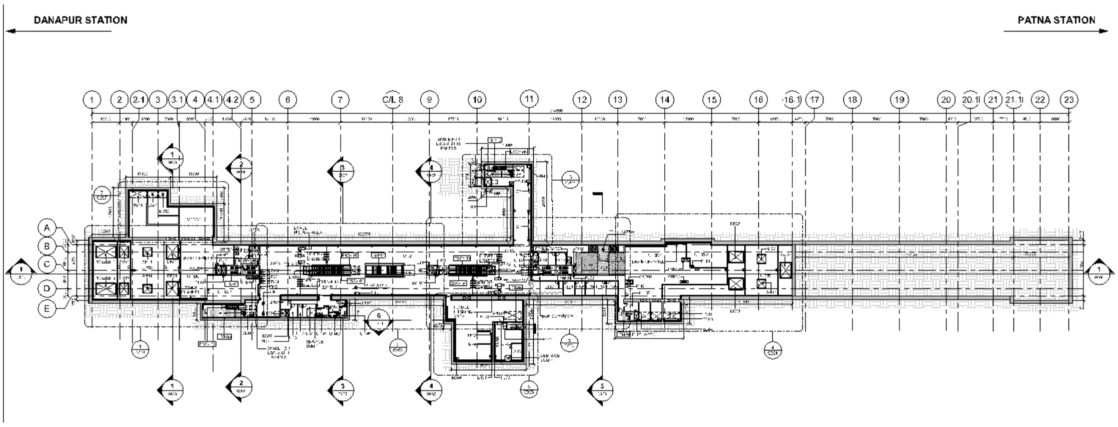

DANAPUR STATION
PATNA STATION
4 CONCOURSE LEVEL PLAN
1 : 250

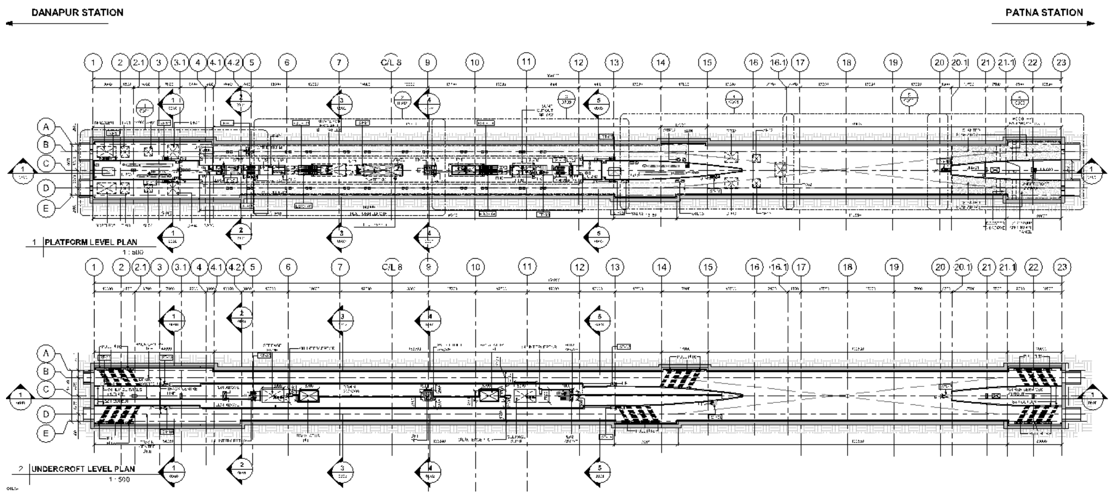


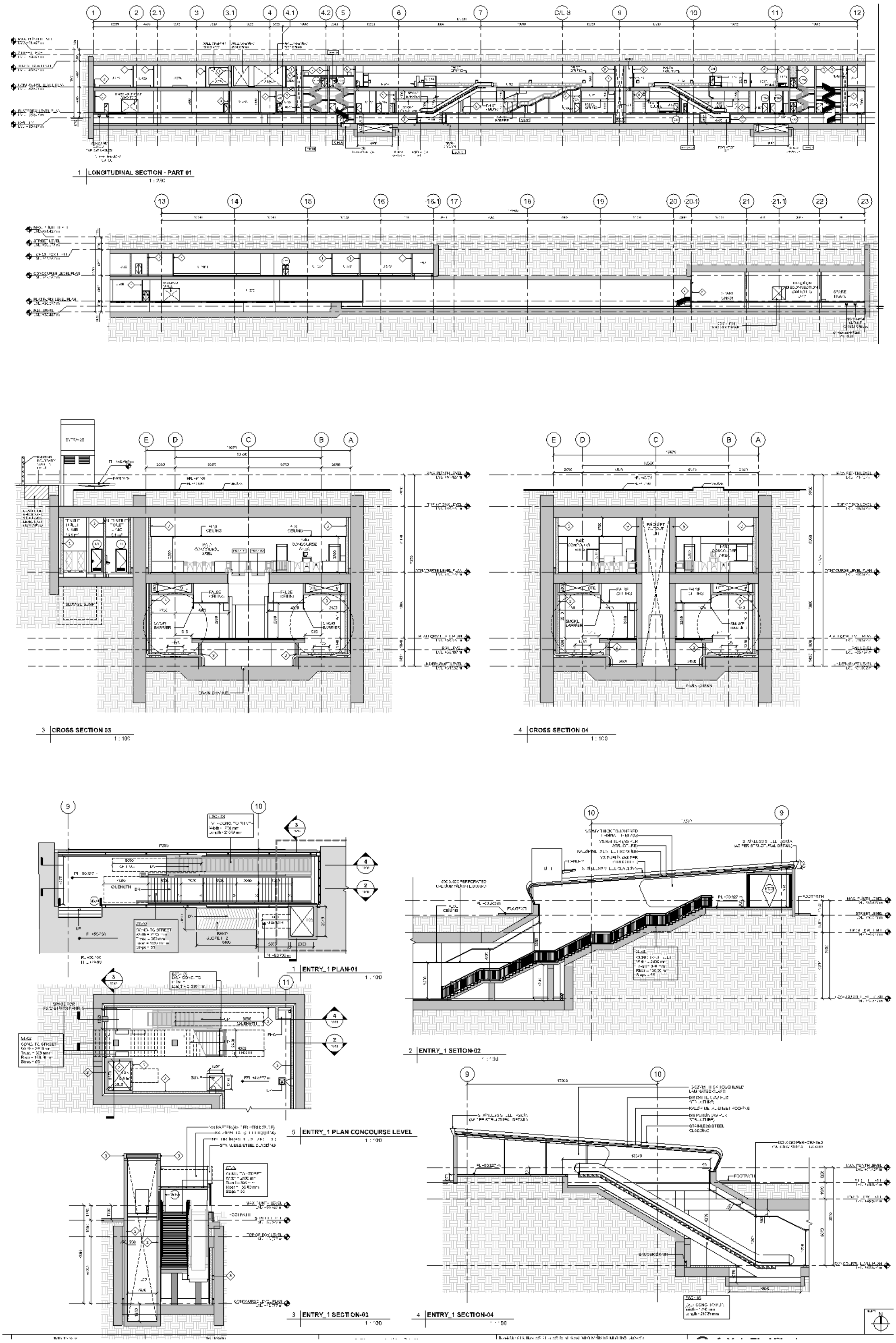
Source: PMRCL/DMRC

Figure 5-59: Corridor1 ST06 Raja Bazar


DANAPUR STATION
PATNA STATION
BAILEY ROAD

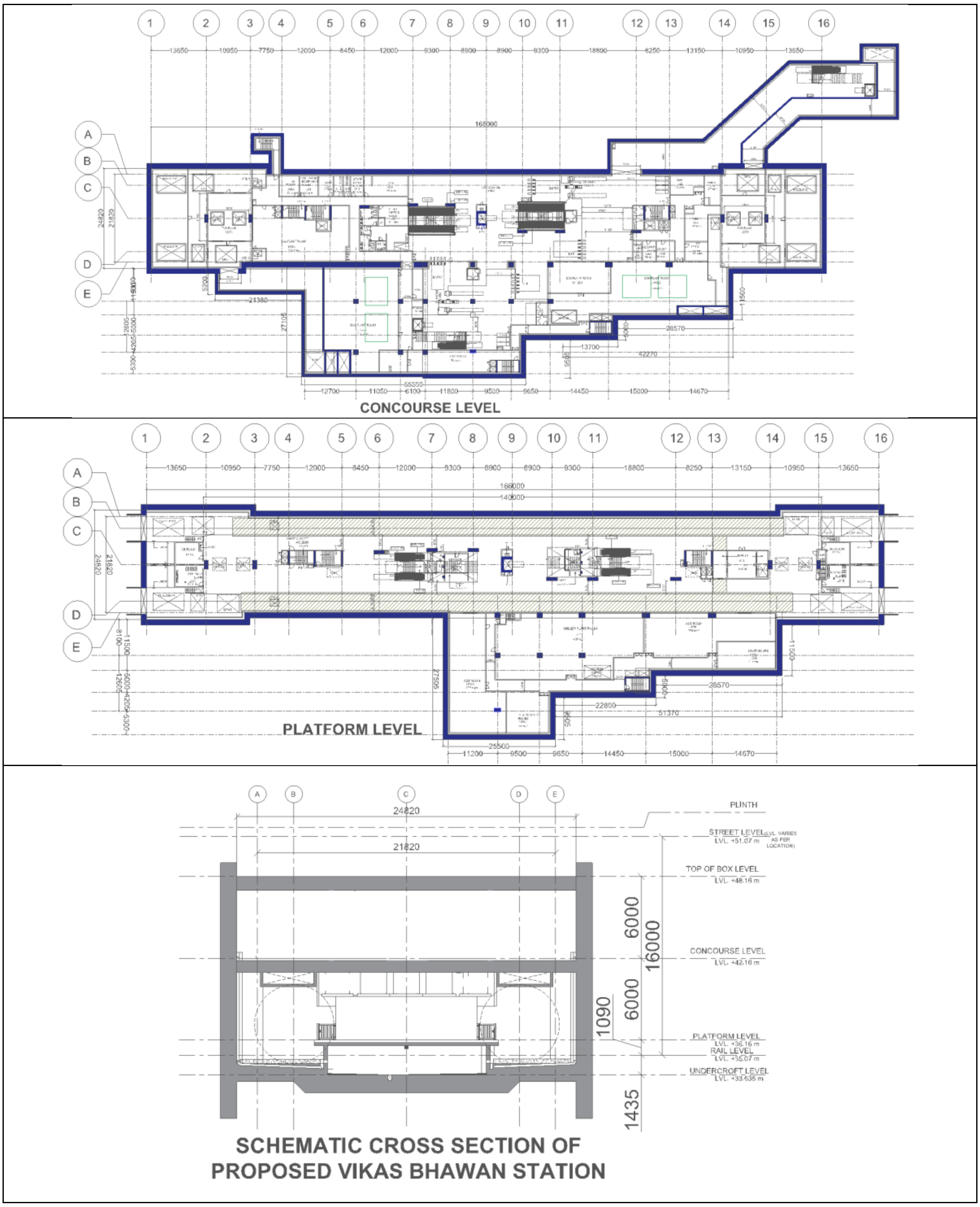

DANAPUR STATION
PATNA STATION


DANAPUR STATION
PATNA STATION
1 PLATFORM LEVEL PLAN
1 : 500
2 UNDERCROFT LEVEL PLAN
1 : 500



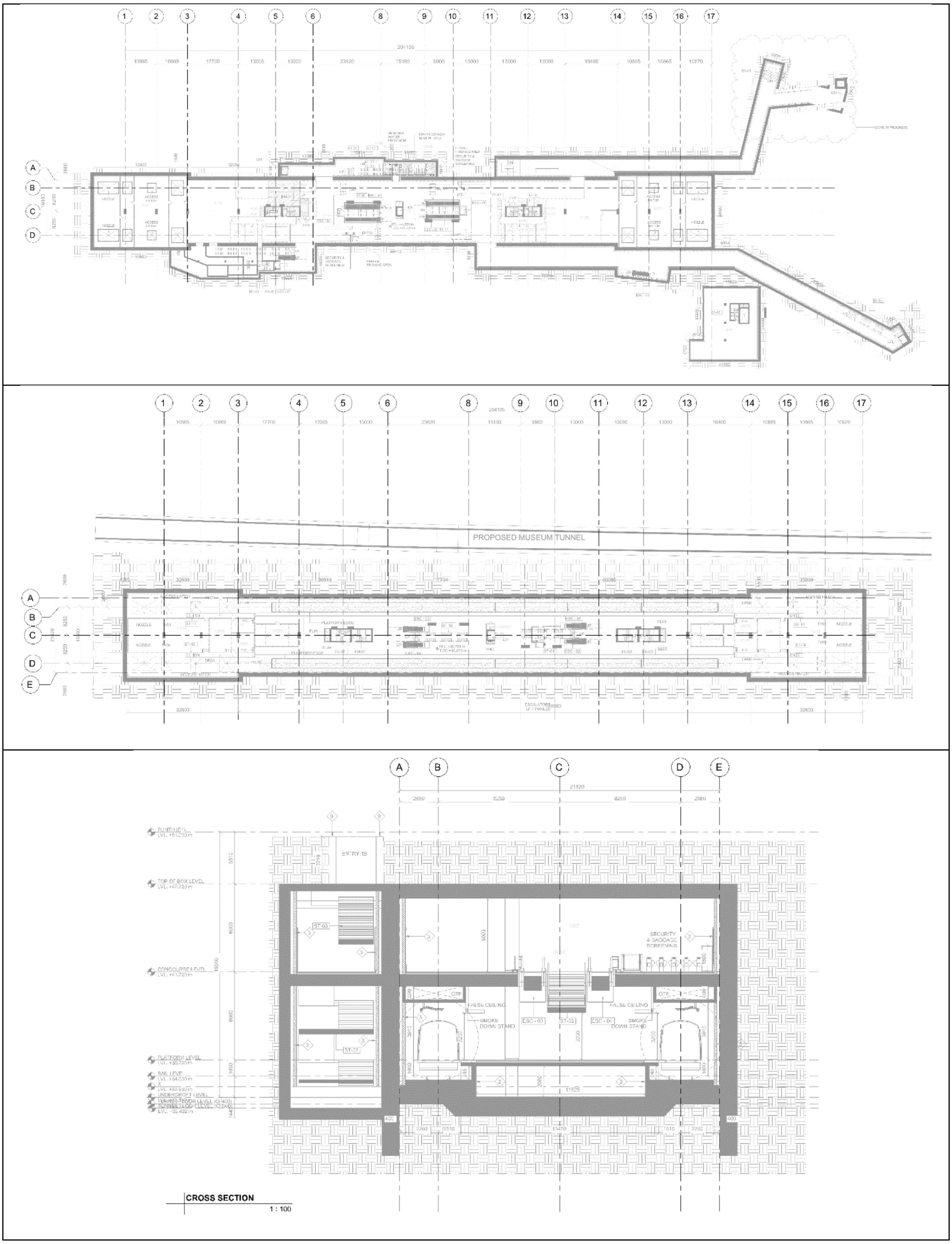
Source: PMRCL/DMRC

Figure 5-60: Corridor1 ST07 Patna Zoo



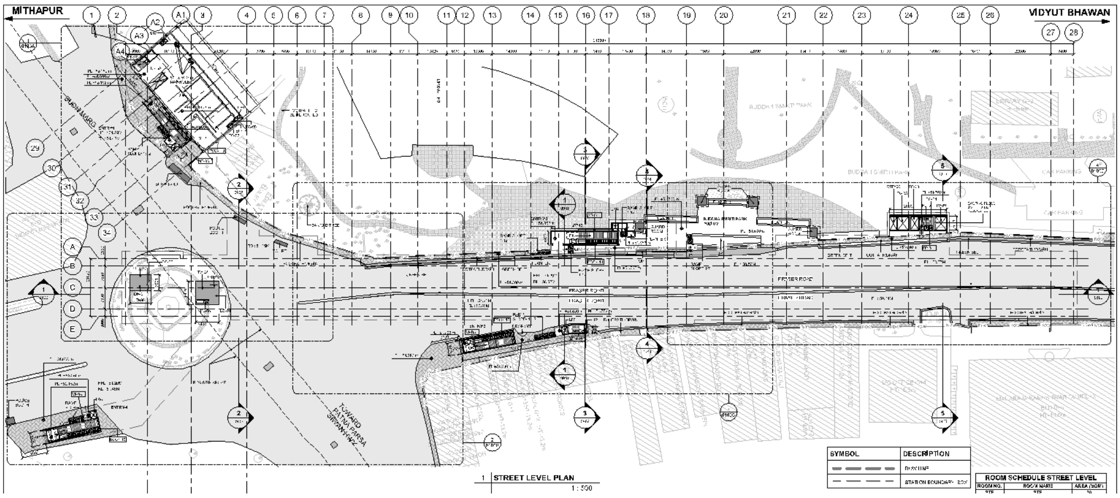
Source: PMRCL/DMRC

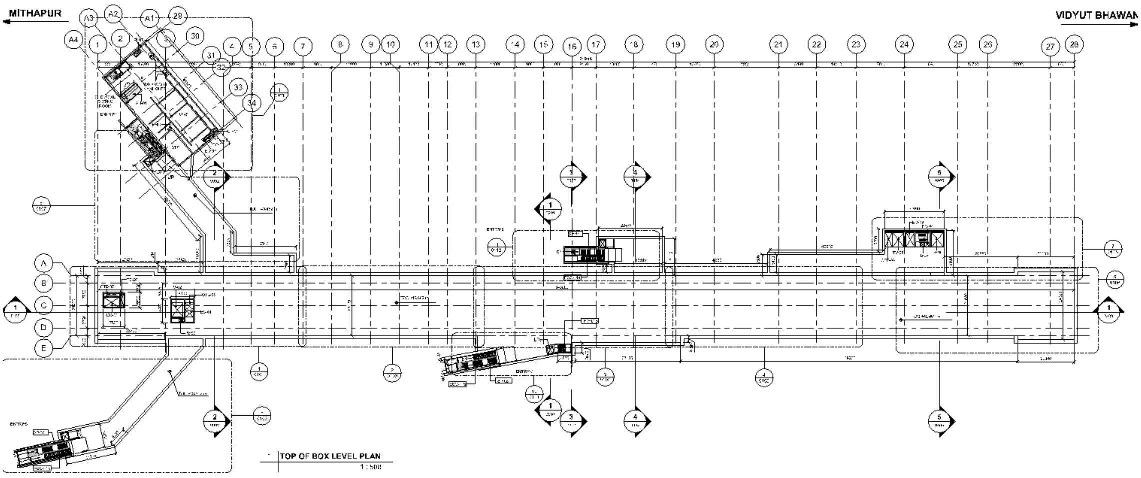
Figure 5-61 : Corridor1 ST08 Vikas Bhawan

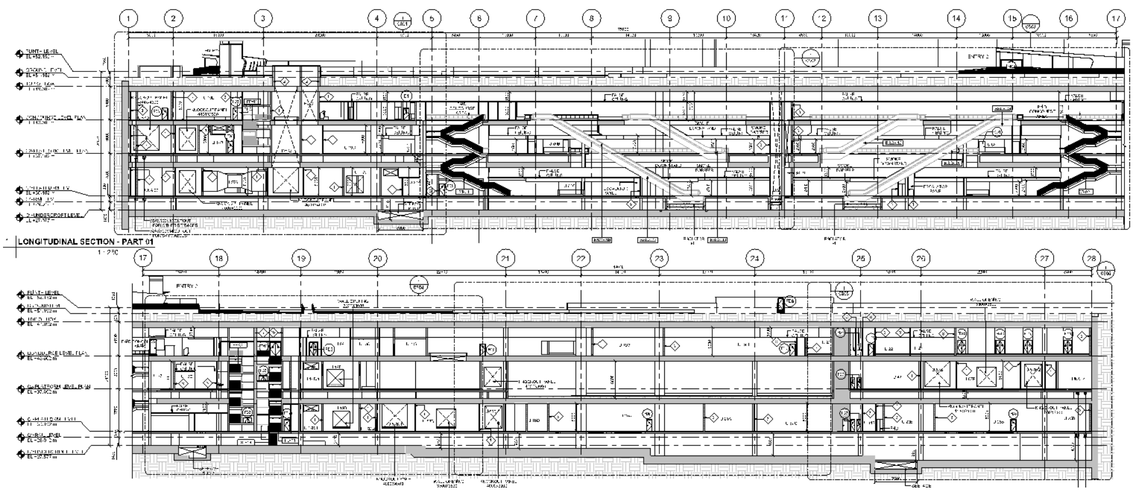


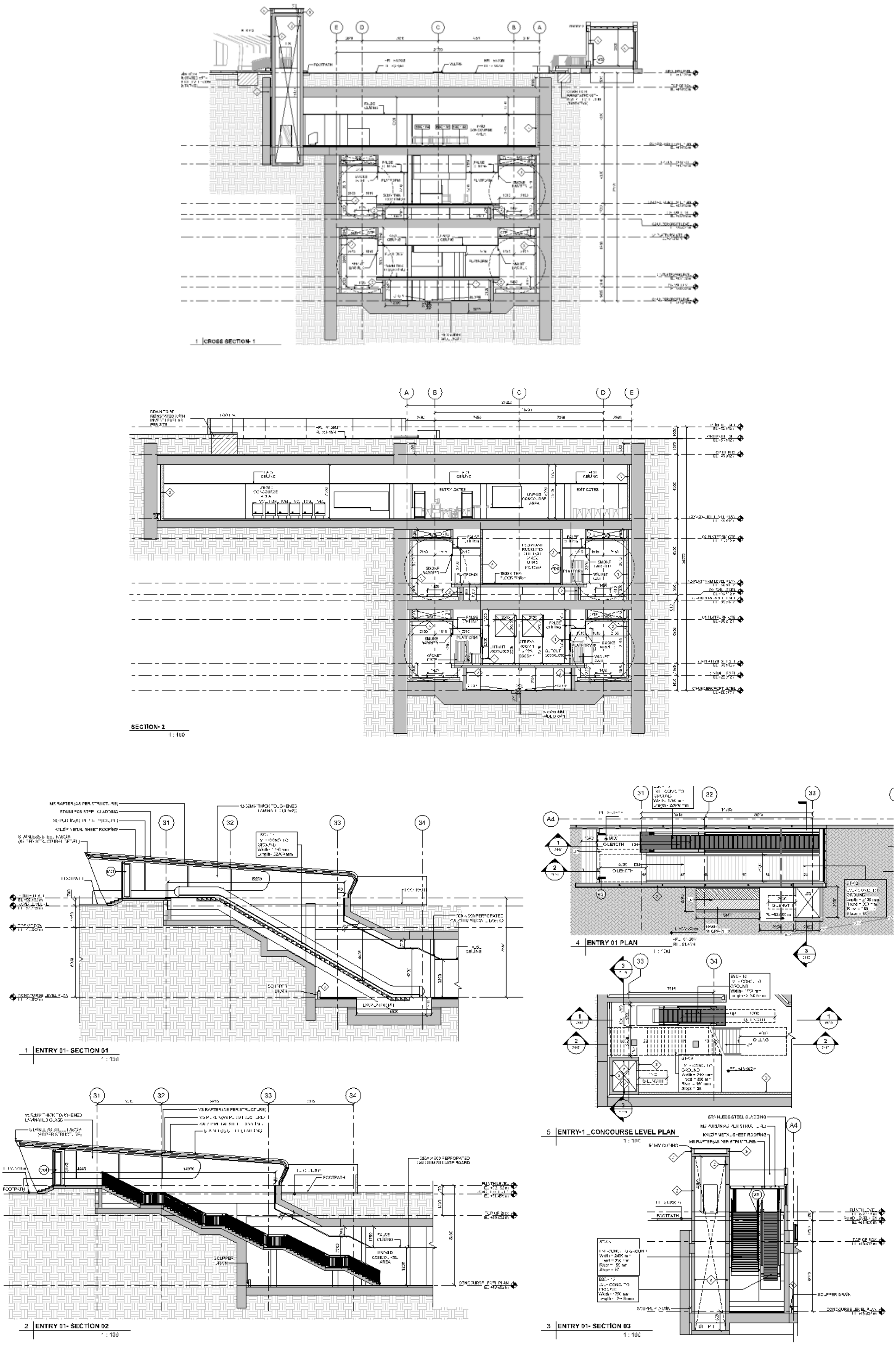
Source: PMRCL/DMRC

Figure 5-62 : Corridor1 ST09 Vidyut Bhawan


MITHAPUR
VIDYUT BHAWAN
SYMBOL
DESCRIPTION
ROOM SCHEDULE STREET LEVEL
1 STREET LEVEL PLAN
1 : 500


MITHAPUR
VIDYUT BHAWAN
ENTRY
TOP OF BOX LEVEL PLAN
1 : 500


LONGITUDINAL SECTION - PART 01



Source: PMRCL/DMRC

Figure 5-63: Corridor1 ST10 Patna Junction

5.4.2 Reviews of Existing Studies and Proposals for Improvement

India has experienced a number of metro construction projects. The DPR describes the civil works' overall plan based on their experiences. The following sections summarize major review points in each investigation, planning, basic design, and construction stage.

In addition, JST's proposals and recommendations for improvement of civil plan in further stages are described.

(1) Design

1) Elevated section

The packages of viaduct section of the Corridor 1 and the Corridor 2 have been contracted. Viaduct section between Corroidor2 ST09 Khemichak and Corridor2 ST11 Zero Mile via Corridor2 ST10 Bootnath are constructing now. Type of elevated structure and design specification are referred to Delhi Metro Project. It is adequate selection of civil structure.

Corridor2 ST09 Khemnichak

Corridor2 ST11 Zero Mile

Source: JST

Figure 5-64: Construction Condition of Elevated Section of Corridor2 (2022/5/15)

2) Underground section

<u>Underground Station</u>

The DPR described the use of diaphragm wall and secant piles and sheet pile which are often used in India for underground structure construction. These retaining walls have water stopping function, then adopting these retaining wall to Patna Metro project is adequate due to soil and water level condition which was surveyed by geotechnical investigation.

In addition, since detailed design of the underground station is carried out by the Contractor, it is not possible to confirm the reinforcement rebar arrangement in JICA survey, so it was not to confirm whether the reinforcement rebar arrangement can ensure the quality of concrete.

The review results of civil engineering part are shown below.

- **Corridor 1:** The received basic design drawing of underground station from PMRCL/DMRC applies the case of structure of Delhi Metro Project and the civil design specification is the same as the latest Delhi Metro Project. At this time, it is no objection for basic design drawing of civil.
  - **Corridor 2:** The received basic design drawing of underground station from PMRCL/DMRC applies the case of structure of Delhi Metro Project, and the civil design specification is the same as the latest Delhi Metro Project. At this time, it is no objection for basic design drawing of civil.

TBM Alignment

- JST was confirmed degree of proximity between existing Patriputra Bridge pile foundation and TBM, and vertical alignment of TBM under the each river point.
- **Corridor 1:** The proximate (4) four TBM are planned on the north side of Corridor1 ST10 Patna Junction which is the first case in India. In Japan, there are the proximate (4) four TBM construction such as Chofu Station on the Keio Main Line and Misasagi Station on the Kyoto Tozai Line.
- The two TBMs between Corridor 2 ST01Patna Junction and Corridor2 ST02 Akashuvani have already been contracted in the Corridor 2 package PC03. This construction sequence was confirmed and reported in this DFR section “ 5.4.2 Reviews of Existing Studies and Proposals for Improvement (2) Construction 8) Special construction methodology (ii) Integrated underground station and (iii) TBM tunnelling with minor clearance”

The below table shows a comparison table of 4 TBMs cases between Corridor1 ST10 Patna Junction Station and case of in Japan.

Table 5-21: Comparison Table of 4 TBMs Cases between Patna Junction Station and Case of in Japan

	Patna Junction Station	Keio Chofu Sta. (JPN)	Kyoto Subway (JPN)
TBM Segment external diameter	6.35m (TBM excavation diameter:6.70m)	6.70m	5.84 m
TBM vertical clearance between both segments	3.57m(0.56D)	Less than 1m	0.86 m
TBM procedure	Latest construction sequence; Upper TBM (Corrior2) is first Recommendation; Lower TBM (Corrior1) is first	Lower TBM was first	Lower TBM was first
Ground condition	Brownish Very Stiff to Hard Clayey stiff of medium plasticity	Sand and gravel	Shale
Ground water	GL (-1m) ~ (-4 m)	Submerged	GL -2 m
Soil improvement	—	Soil improvement for water stop	—

Source: JST

The below table shows a comparison table of vertical 2 TBMs cases in Japan.

Table 5-22: Comparison Table of Vertical 2 TBMs Case in Japan

	Shin Okachimati (JPN)	Ooimachi Station (JPN)
TBM Segment external diameter	Upper TBM: Ooedo Line 5.3m (single track) Lower TBM: Tsukuba Express Line 10.0m (double track)	Upper and Lower TBM: 10.1m (single track with platform)
TBM vertical clearance between both segments	7.3m(0.73D)	1.0m
TBM procedure	Upper TBM was first	Lower TBM was first
Ground condition	Sand and gravel	Upper TBM:Clay Lower TBM: Sand and gravel
Ground water	Submerged	Submerged
Soil improvement	Soil improvement for water stop	-

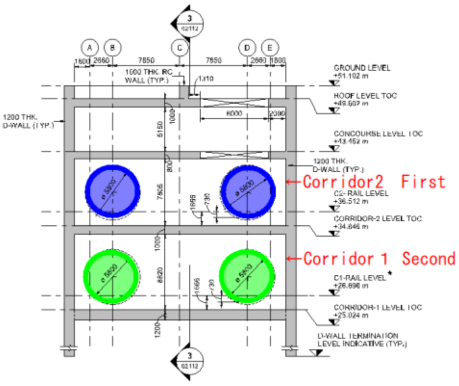
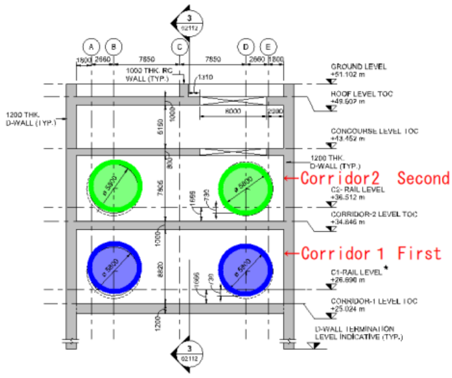
Source: JST

As mentioned above that TBM procedure of Contractor package of PC03 considers upper TBM first.

However, JST recommends lower TBM(Cooridor1) first for take into consideration of safety construction.

The below table shows the comparison table for risk assessment of alternative TBM construction sequence.

Table 5-23 : Comparison Table for TBM sequence at Patana Junction Station

	Case A Latest TBM construction sequence	Case B Alternative
TBM construction sequence	Upper TBM (Corrior2) is first 	Upper TBM (Corrior1) is first 
Influence of Upper/Lower TBM	・When lower TBM drives, upper TBM will receive settlement by lower TBM driving directly. ・Then segment lining of upper TBM will be deformed and beard additional stress.	・When upper TBM drives, lower TBM will receive rebound deformation by upper TBM driving directly. ・Then segment lining of lower TBM will be deformed and beard additional stress.
	Rebound value of lower TBM of Case B is less than settlement value of upper TBM of Case A	

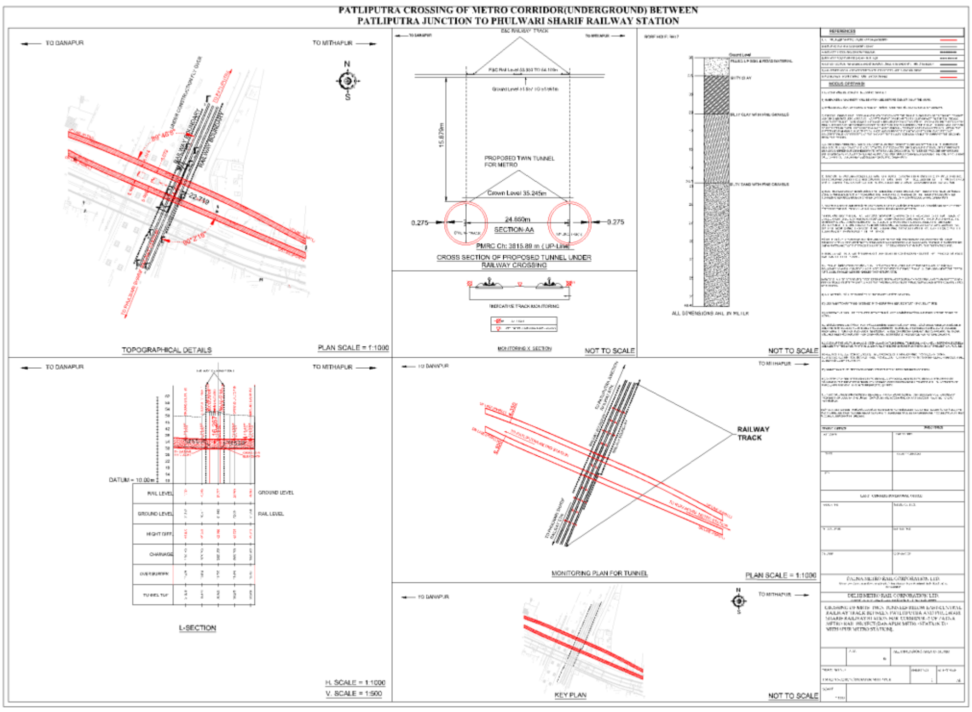
	Case A Latest TBM construction sequence	Case B Alternative
Countermeasure	・ Strengthen upper TBM segment lining.(e.g composite segment, steel segment)	・Strengthen lower TBM segment lining.(e.g composite segment, steel segment) ・Arrangement of propping into lower TBM segment
Interface	Please refer “ 5.4.2 Reviews of Existing Studies and Proposals for Improvement (2) Construction 8) Special construction methodology (iii) TBM tunnelling with minor clearance”	

Source: JST

TBM crossing point with Indian National Railway

TBM will pass under the existing Indian railway. The below figures show the monitoring plan prepared by PMRCL/DMRC.

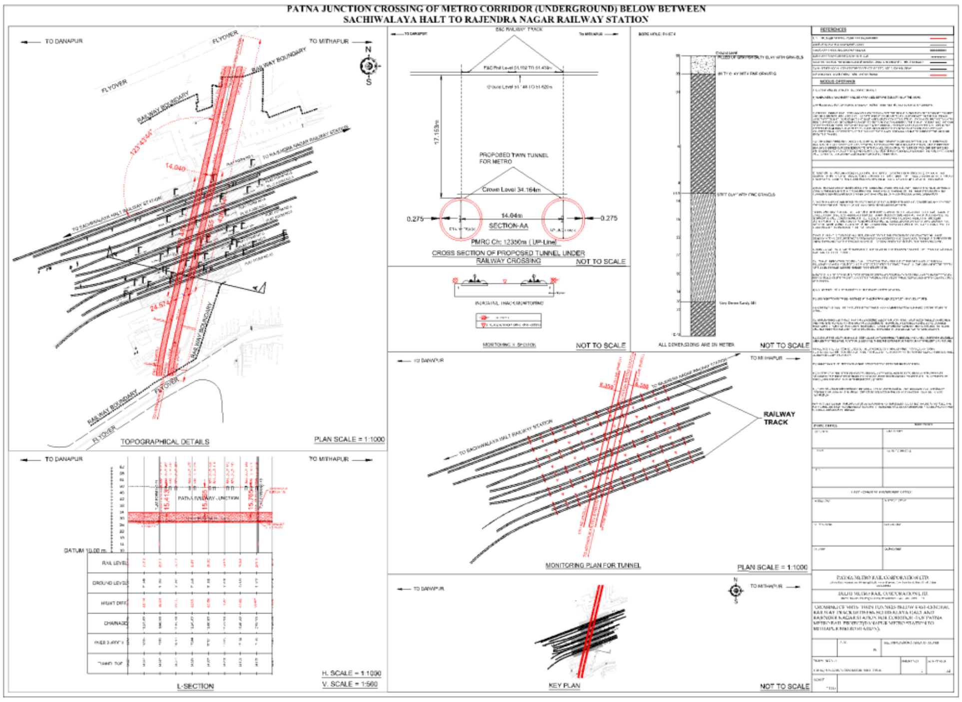
a) Partriputura Crossing of Metro Corridor 1 (Underground) Between Patriputra Junction to Phulwari Sharif Railway Station



Source: PMRCL/DMRC

Figure 5-65: Monitoring Plan at Partriputura Crossing

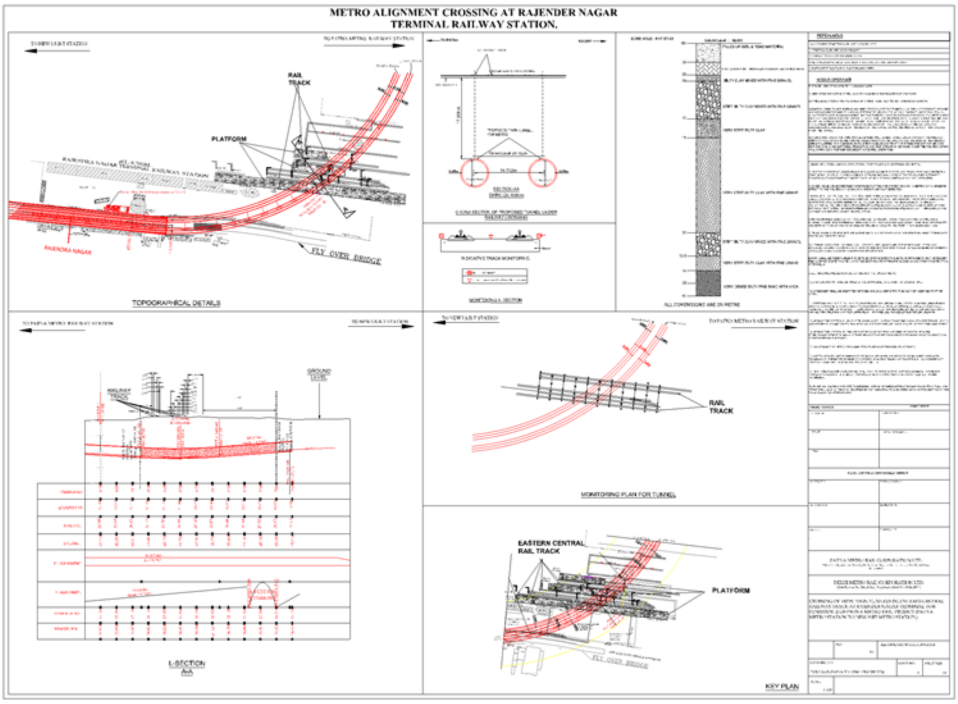
b) Patna Junction crossing of Metro Corridor1 (underground) below between Sachiwalay Halt to Rajendra Nagar Railway Station



Source: PMRCL/DMRC

Figure 5-66: Monitoring Plan at Patna Junction Crossing

c) Metro alignment crossing at Rajendra Nagar Terminal Railway Station in Corridor 2



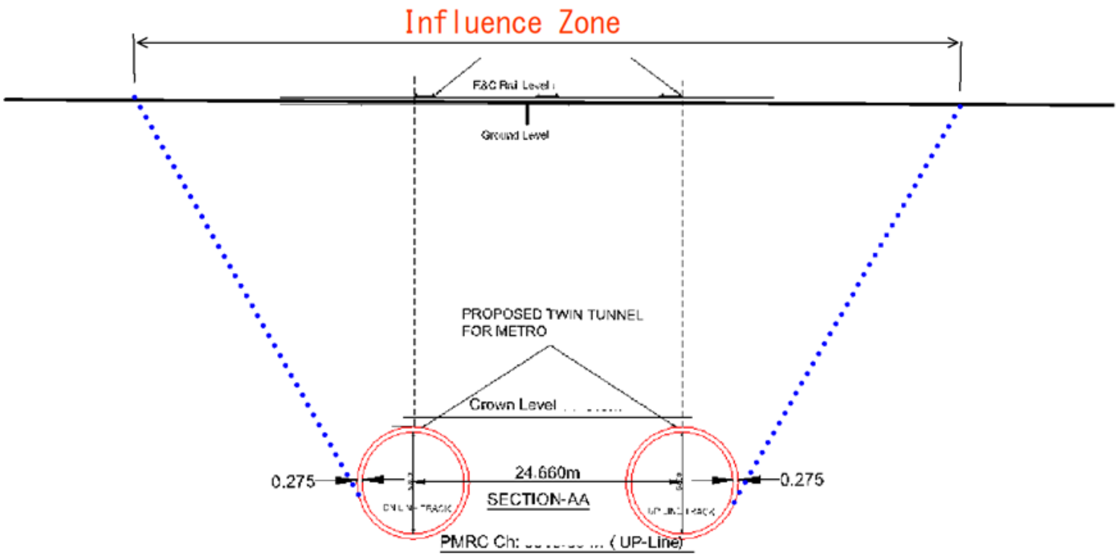
Source: PMRCL/DMRC

Figure 5-67 Monitoring Plan at Rajendra Nagar Crossing

Crossing angle between TBM and existing national railway are ;.

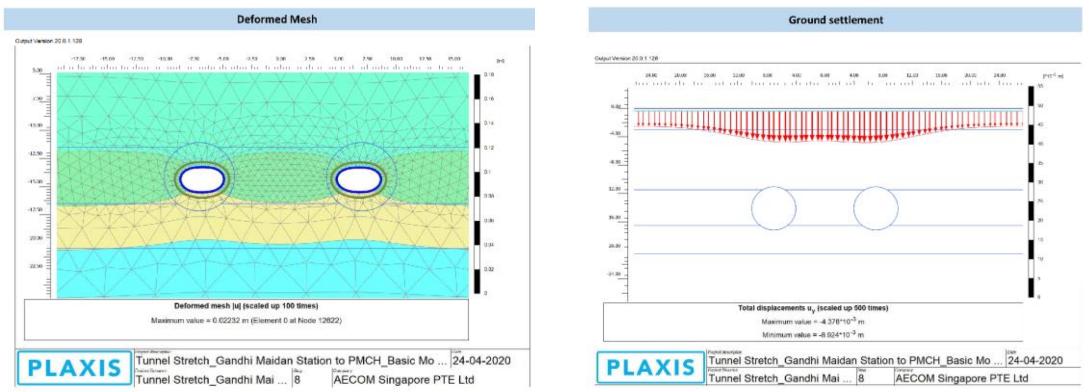
1) Partriputura: Right-angled plane crossing
2) Patna Junction; At an oblique angle crossing
3) Rajendra Nagar: Ditto

JST proposes modified monitoring area above 2) and 3) crossing point under take into consideration influence zone by TBM driving, modified monitoring zone has to be set from TBM alignment in parallel. And the monitoring zone shall be determined by the result of the Contractor's Finite Element Method (FEM) analysis.



Source: PMRCL/DMRC

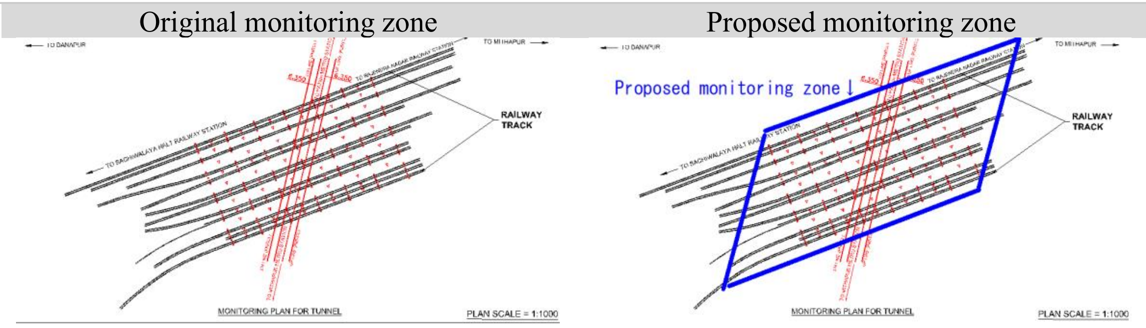
Figure 5-68: Influence Zone by TBM Driving



Source: PMRCL/DMRC

Figure 5-69: Example of FEM Analysis

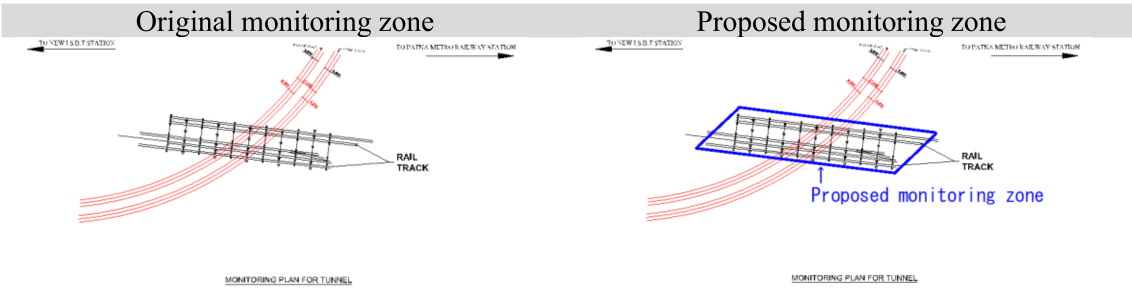
2) Patna Junction



Source: JST adds proposed monitoring zone

Figure 5-70: Proposed Monitoring Zone at Patna Junction

3) Rajendra Nagar

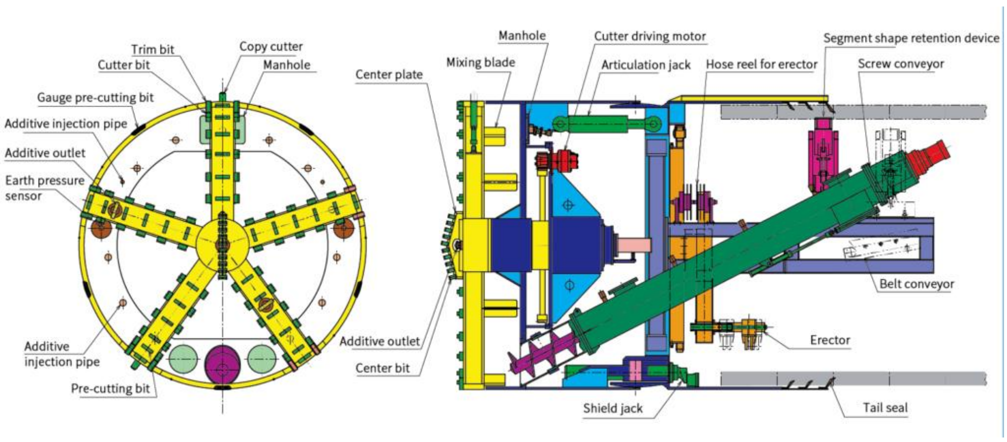


Source: JST adds proposed monitoring zone

Figure 5-71 Proposed Monitoring Zone at Rajendra Nagar Crossing

TBM Machine

DPR described Earth pressure type (EPB), Mud-pressure type and Slurry type TBM, TBM machine will be selected by the Contractor. Earth pressure type is one of the suitable TBM machine for Patna Metro due to soil condition.



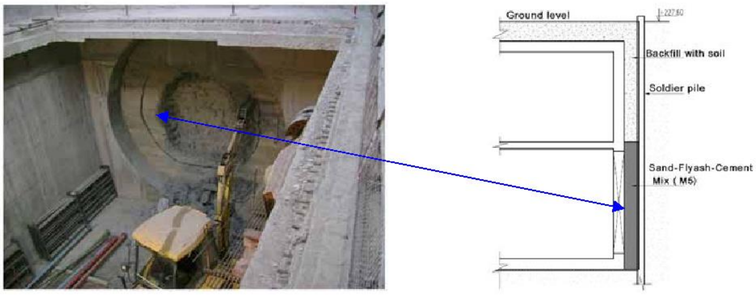
Source: UGITEC (https://ugitec.co.jp/en/)

Figure 5-72: General Assembly Drawing of EPB TBM

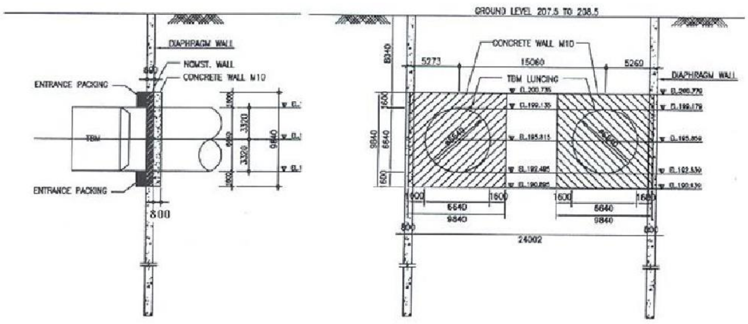
The construction method of TBM launching and retrieval

Regarding the construction method of TBM launching and retrieval, the construction method will be selected by the Contractor under Design Build contract. The tunnel eye protection method of Delhi Metro Phase2 is shown below figure for reference.

Case1 (Launching: Used Steel Pipe Pile)



Case2 (Launching: Used M5 concrete between temporary retaining wall and end wall of station)



Case3 (Launching: Used M10 concrete outside of diaphragm end wall of station)

Case4 (Retrieval: The diaphragm wall was demolished by breaker up to soil face reinforcement. Soil improvement of the diaphragm wall was not required.)

Source:

J. Tyag (Delhi Metro Railway Corporation, Delhi, INDIA), S. Lowry , K. Yamaoka , C. Izumi (Oriental Consultants Co., Ltd. Tokyo, JAPAN;A Study of Tunnel Eye Breaking Method for the Delhi Metro Phase-IIA Study of Tunnel Eye Breaking Method for the Delhi Metro Phase-II, WTC2010 VANCOUVER

Figure 5-73: The Construction Method of TBM Launching and Retrieval

Points of attention for TBM construction

The below table shows points of attention for TBM construction which were describes in "Standards Specifications for Tunneling - 2016 : Shield Tunnels, JAPAN Society of Civil Engineer"

Table 5-24 : Points of attention for TBM Construction

Item	Point of attention
Driving Management of and Earth pressure Balanced (EBP) Shield	(1) Face stability should be maintained while the cutting face is excavated by considering the ground conditions and the diameter of the tunnel. (2) The pressure in the chamber, plastic flow and excavated volume should be carefully controlled to maintain face stability, whole fluidity and water tightness of excavation soil should be maintained by adding additives suited to the geological condition. (3) A muck disposal facility should be selected om consideration of the soil characteristics. The capacity of the facility should be planned to meet the excavation schedule.
Primary Lining	As soon as excavation is completed, the primary ling should be installed correctly and securely in the prescribed way.
Backfill Grounding	Backfill grounding should be done with the most suitable grout material and by the most suitable grouting method. Backfill grouting should be done simultaneously with shield advancement or immediately after shield restarting so that the tail void is completely filled and any ground loosening or ground settlement is prevented.
Waterproofing and Corrosion Protection	(1) Waterproofing should be undertaken by a method that fits working condition in order to meet the purpose of the tunnel. (2) Corrosion protection should be undertaken to secure durability of the primary lining, especially when a secondary is not to be constructed, by taking into account the use and environmental conditions of the tunnel.
Auxiliary Measure	The ground is likely to become unstable because of water inflow or a lack of strength in sections where the shield starts or arrive at a shaft, where tunnels are connected, where a tunnel cross section on enlarged, when bits are replaced, when obstacles are removed, at shape curves, when the overburden is shallow, or when construction is in the close proximity of existing structure. In such places, appropriate auxiliary measures should be taken as required in combination with soil improvement measures to ensure ground improvement.
Ground Movements and Prevention Measures	Ground movements are affected by the planning and design of a tunnel, geological conditions, and construction conditions. Adverse influences on the surroundings should be minimized by applying proper construction method and executing prudent construction management.
Tunnel Construction with Shallow Overburden	When a shield tunnel is constructed with shallow overburden, the face pressure control and backfill grouting should be carefully managed so that influence on the ground surface and /or underground utilities should be minimized. Auxiliary measures should be taken as required to avoid tunnel uplift or segment deformation.
Rapid Operation	Rapid operation requires not only enhancing the capabilities of individual pieces of equipment and systems, but also selecting efficient combinations thereof. Quality should be

	fully ensured during construction and work should be carried out safely.
Neighbouring Construction	When shield tunnel is planned by neighbouring construction, preliminary consideration of the influence and necessary protection measures should be taken. Existing structure should be monitored during construction and the influence on existing structures carefully observed.
Construction of Multiple Parallel Shield Tunnels	When two or more parallel shield tunnels ate to be constructed, sufficient attention should be paid to the mutual influence of each tunnel. Ground and tunnel movement should be carefully observed. Auxiliary measures or reinforcement of tunnel should be taken when necessary.
Seabed or River Crossing	When a tunnel crosses under a seabed or river, secure construction operation in consideration of the ground and bay or river condition should be studied carefully.

Source: Standards Specifications for Tunneling - 2016 : Shield Tunnels, JAPAN Society of Civil Engineer

Cross Passage

The metro projects in India adopt NFPA130 and cross passage are planned in TBM section between station and station. The number of cross passage for the Corridor 1 and 2 are shown in the table below.

The construction method of the cross passage is NATM method with dewatering usually in Metro Project in India.

Table 5-25: The number of Cross Passage for Corridor 1

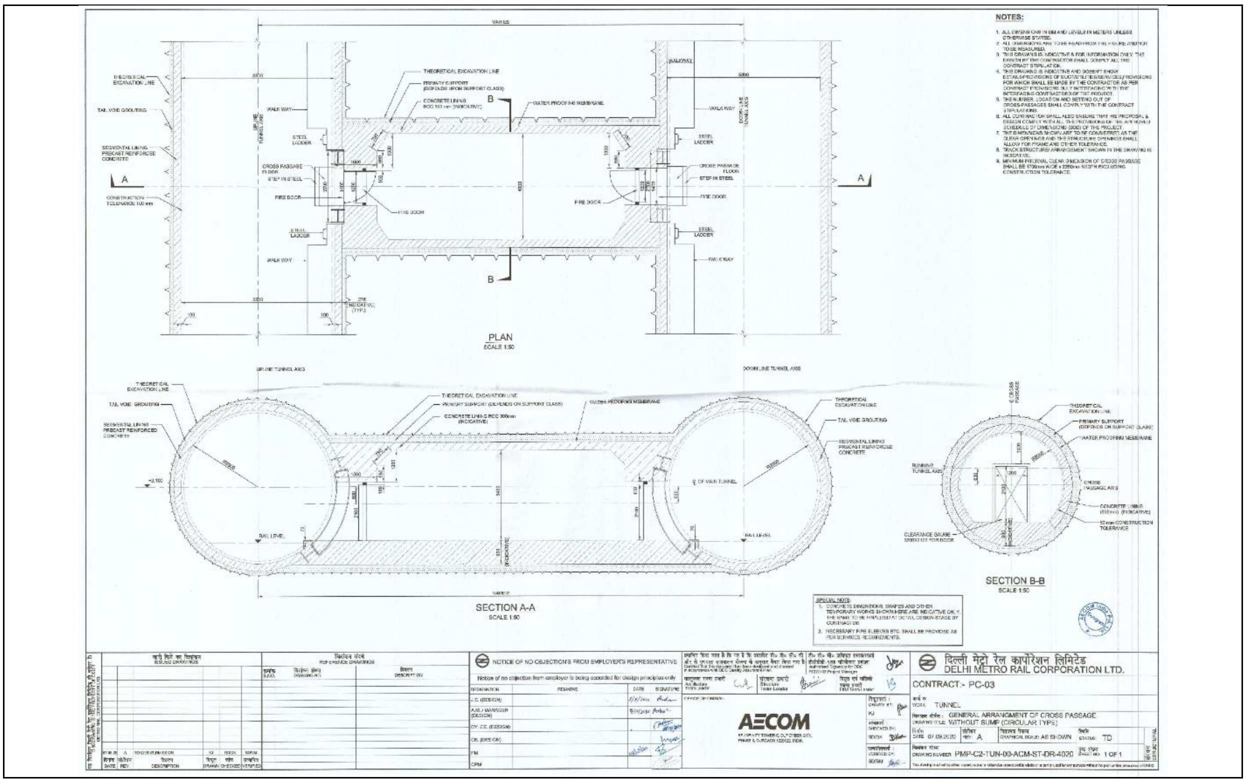
Location	Cross Passage	Cross Passage with Sump
From Ramp Shaft to ST 05 Rukanpura	1	1
From ST05 Rukanpura to ST06 Raja Bazar		1
From ST06 Raja Bazar to ST07 Patna Zoo	5	1
From ST07 Patna Zoo to ST08 Vikas Bahawan	2	
From ST08 Vikas Bahawan to ST09 Vidyut Bahawan	1	1
From ST09 Vidyut Bahawan to ST10 Patna Junction	1	1
From ST10 Patna Junction to Ramp Shaft	1	1
Total	11	6

Source: JST

Table 5-26: The Number of Cross Passage for Corridor 2

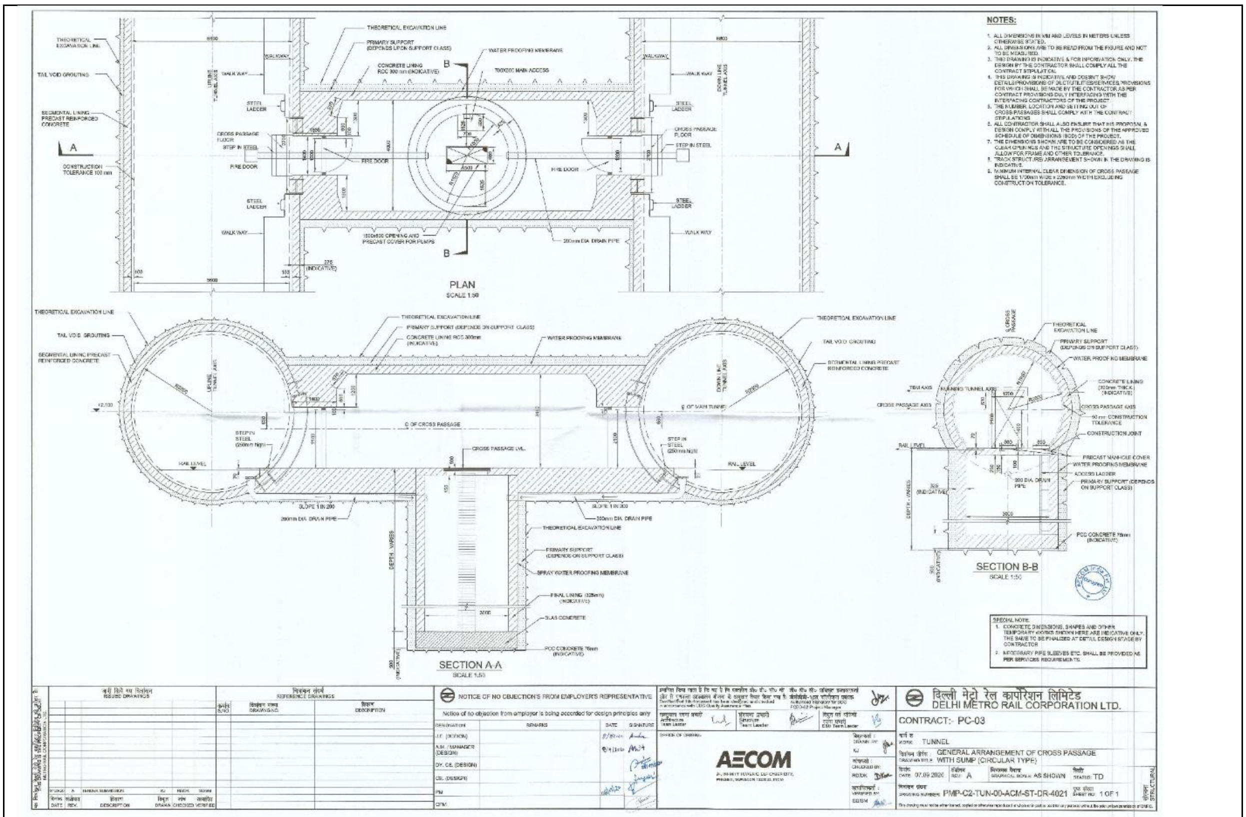
Location	Cross Passage	Cross Passage with Sump
From ST01 Patna Junction on to ST02 Akashuvani	1	
From ST02 Akashuvani to ST03 Gandhi Maidan		1
From ST03 Gandhi Maidan to ST04 PMCH		1
From ST04 PMCH to ST05 Univercity	1	1
From ST05 Univercity to ST06 Moin UL Haq	2	1
From ST06 Moin Ul Haq to ST07 Rajendra Nagar		1
From ST07 Rajendra Nagar to Ramp Shaft	1	
Total	5	5

Source: JST



Source: PMRCL/DMRC

Figure 5-74 : General Arrangement of Cross Passage without Sump



Source: PMRCL/DMRC

Figure 5-75 : General Arrangement of Cross Passage with Sump

3) Depot Civil

JST has received Tender Document PC04 for Depot.

JST has submitted some queries to PMRCL/DMRC as follows:

> 1) Please share Basic Design Drawing (plan, cross section and longitudinal profile) of drainage system and retaining wall and other civil structures at the Depot
>
> ⇒ JST has confirmed that DMRC is preparing above basic design by sub consultant using BIM systems.
>
> 2) Latest your formation level of the embankment at the Depot is almost the same as the level of the existing road. However, in the future, the level of the existing road will be high because of maintenance of pavement Please tell us how to decide the formation level of the embankment at the Depot.

And JST prepared below comment for Basic Design of Depot.

Review Comments on Geotechnical Investigation Report for PMRC Contract Package PC-02 Depot area

1. Observations

(1) Geotechnical Investigation Report

1) The depot area is mildly undulating topography with relatively high water table depths ranging between 2.90 m to 4.05 m below existing grades.
2) Uniform fill depths of unknown compaction and composition have been observed from the borelog and Geotechnical Lab data.
3) No lab testing on the conditions of existing fill soil have been observed

(2) Tender Document

1) Foundation recommendations have been reviewed for the Depot Area for both Open and Pile foundations. In areas of Boreholes BH-01 and BH-02,
2) The tender document for PC02 for Earthwork, Section S.02, provides adequate provisions for excavation and FILL
3) Borrow material for structural fill with c=0 and phi=30^0, density = 2.1 tonnes/m^3 has been considered, which appear to be adequate.

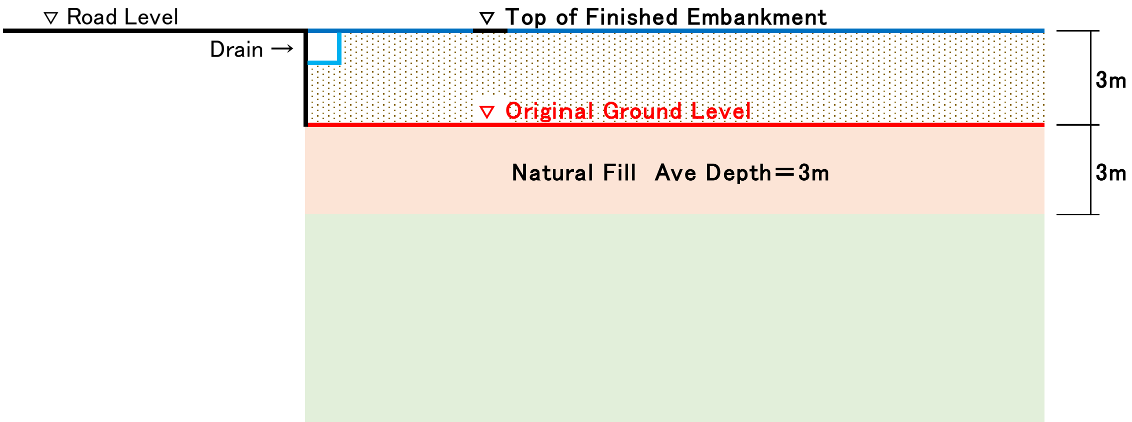
2. Comments

(1) Embankment

1) Top of embankment level has been considered at existing road grades. Accordingly, it is understood that the existing FILL MATERIAL will be removed completely, and hence, will not have any bearing on the open foundation.

2) Structural fill material has been proposed from 3.0 m above existing ground level but the finished level/ top of embankment or structural fill is to be clarified.

3) Final soil compaction of 95% MDD (Maximum Dry Density) has been proposed which is adequate, provided compaction up to this level is done in lifts. **This may be clarified.**



(2) <u>Settlement Analysis</u>

1) Settlement analysis of the natural ground within the zone/bulb of influence, arising out of the compaction process of the embankment, needs to be considered, as also OCR calculations from UDS.

2) It is observed that the total thickness of structural fill has been proposed at (3m: the existing FILL MATERIAL) plus (3.0m : Embankment Material) i.e., 6m.

3) Any settlement arising out of the compaction of 6.0 m structural fill on existing FILL MATERIAL grade and rail bed road, ballast, sleeper, rail and train load with impact or spread foundation load of building needs to be taken into consideration.

4) It is noted that settlement analysis have been considered only for borehole BH-03, without any clear indication of the zone of influence of settlement of natural ground at the time of compaction of high embankment. **The depth of the zone of influence, and its corresponding settlement analysis at various depths in natural soil, below formation level, may be clarified.**

(3) <u>Depth of Structural Fill and Depot Protection from Catastrophic /Force Majeure events</u>

1) It is understood that the structural fill depth is planned up to existing road level, although the proposed/future structures have variable clearances, from the existing road level, as indicated in the typical drawings.

2) To avoid any future damage to the Depot area arising out of

i) flooding/greater than designed rainfall,

ii) progressive enhancement of adjoining city in the future

・ there would be a ***possibility of drainage inflow from the road to inside the depot area, which will need to be addressed at this stage.***

- Accordingly, the ***structural fill height above the existing city road level may be reviewed*** to avoid any possible flooding inside the depot area, which could cause significant damage. It may be pointed out that a Nala (drain) and an adjoining pond, in close vicinity of the Depot area, has the potential to overflow into the depot area, in the event of more than designed rainfall design for the Depot.

(4) Open and Pile Foundation

1) Normal bored cast in-situ piles have been recommended, wherein the cutoff depth of pile has been indicated **at 3 m below existing grades.**
2) Depth of piles have been tentatively proposed from 28m to 32 m below existing grades. The safe load carrying capacity of a single pile, both in compression and uplift, as also deflection values at pile top (in mm), have been considered only between 28m and 32m below existing grades.
3) Pile diameter ranges have been assumed between 1000 mm and 1500 mm, for the structure foundations.
4) It is understood that the ***pile foundation recommendations***, summarized above, and, in section 2.8 of the Geotechnical Report, is ***based on the typical loadings assumed for the structures in the depot area. This may be clarified.***
5) ***Pile Foundations have been considered at the location of boreholes BH-01 and BH-02***, whereas ***open foundations (isolated, square footings) have been proposed at the location of Borehole-03.***
6) It is observed in the Depot Layout Plan, BH-01 is in the general vicinity of the residential areas, entry line, exit line, Auto coach washing plant, Control Room for Washing Plant, and underground tanks.
7) Similarly, BH-02 does not appear to be in the general vicinity of any structure location vis a vis the Depot layout Plan.
8) BH-03 is located in the general vicinity of most of the structures such as covered stabling yard, auxiliary substation (ASS), ETU office building and Compressor Room for Pneumatic Supply, amongst others.
9) Based on the above, there ***appears to be a discrepancy/lack of clarity regarding the basis for consideration of the proposal for the foundation type vis a vis foundation location. The same may be clarified in Detailed Design stage with additional geotechnical Survey.***

(5) Slope Stability Analysis of Embankment

Slope stabilization analysis/measures for the embankment should be considered to avoid any potential damage to the foundation pad arising due to slope failure of local/global nature due to any reason – natural/manmade.

(6) Borrow material for Embankment

1) The borrow material for Structural fill has been proposed with material of specification c=0 and phi=30 degrees, suitably compacted to 95% MDD, is an acceptable fill material.
2) If any other borrow material is to be considered as an alternative, for the high embankment, such as excavated material from tunnelling operations, which is all Clayey silt (CL-ML or CI material), suitability of this material has to be ascertained prior to using as structural fill material. The borrow material thus used, should be compactable to 95% MDD and should not cause differential settlement/adverse subsurface conditions that may damage to structure foundations.

(7) Flooding Condition

1) Highest Flood Level (HFL) conditions must be taken into account for Embankment design using a suitable recurrence flood interval e.g. "100 year flood", "500-year flood" or any other appropriate level, by the Contractor. As the depot would be housing the stabling lines, and all maintenance and operations facilities, it is suggested that the HE design should be considered on a conservative side, to avoid flooding conditions within the depot from adjoining areas at any cost.
    - Perimeter Drain, of suitable design, to handle the worst case runoff volume and running continuously along the Depot perimeter, is required.
    - The perimeter drain needs to be connected to the existing city drainage system (open/closed) with adequate assurances of continuous drainage at all times and under all conditions.
    - Hydrological analysis by the Contractor is necessary avoiding flooding problems arising due to the regional flow of surface runoff during adverse monsoon conditions that can cause the existing drainage facilities to be overwhelmed & ineffective.
2) The actual design and support/stabilization measures of the embankment will be responsibility of the Contractor.

4) Disaster risk assessment basic design

a) 【Recommendation】Countermeasure of rainwater flooding under climate change

Flooding: Countermeasure for flooding at the entrance of underground station is raised doorway usually. PMRCL/DMRC planned 60cm raised up form footpath elevation. JST recommended the prevention method of flooding in the case of future climate change as following report;

The following table shows outlines the flooding countermeasures used for entrances and exits of subways in Japan and Thailand. Using these countermeasures as references, it had planned to adopt stairs and frame barriers (as used in Bangkok and Singapore) as flooding countermeasures for Metro Manila Subway stations also.

Similar measures are planned for elevators, entrances, and exits, including elevating them to prevent flooding and installing a slope for those with disabilities.

Table 5-27 : Inundation Countermeasures for Subways in Japan and Thailand

	Tokyo Metro	Bangkok MRT
Countermeasure	At entrances and exits with a risk of inundation, stairs and frame barriers (35 cm × 2 tiers ＝ 70 cm) have been installed. At entrances and exits of stations at low elevations east of the Sumida River, water sealing doors have also been installed.	Stairs and frame barriers (1 m) have been installed at stations with a risk of inundation. The same countermeasures are utilized in Singapore.
Example	 	 

Source: Tokyo Metro https://www.tokyometro.jp/safety/prevention/wind_flood/index.html
JICA Study Team

Patna Metro has considered the raised floor level for each entrance of the underground station.

JST asked that how to decide on this raised height for each entrance of the underground station.

Entrances, elevators, and elevator sheds are required to have countermeasures against flooding while maintaining both convenience and accessibility during normal operation hours.

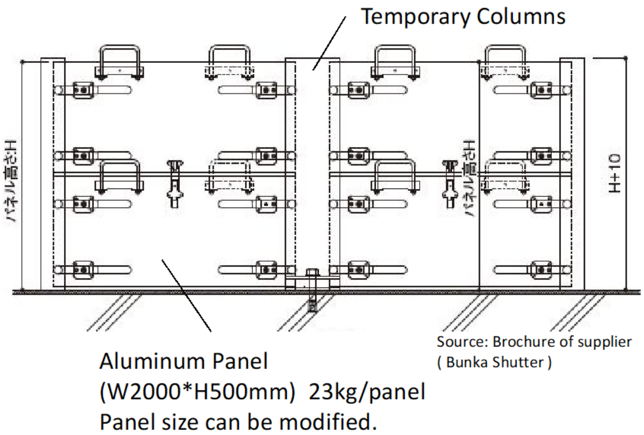
In principle, it is proposed to adopt a combination of raised entrance floor levels and flood barrier panels as are used in Japanese subways.

Floor Barrier Panels / Water-stop boards (an example of Japanese underground station)

Source: Tokyo Metro
https://www.tokyometro.jp/safety/prevention/wind_flood/index.html

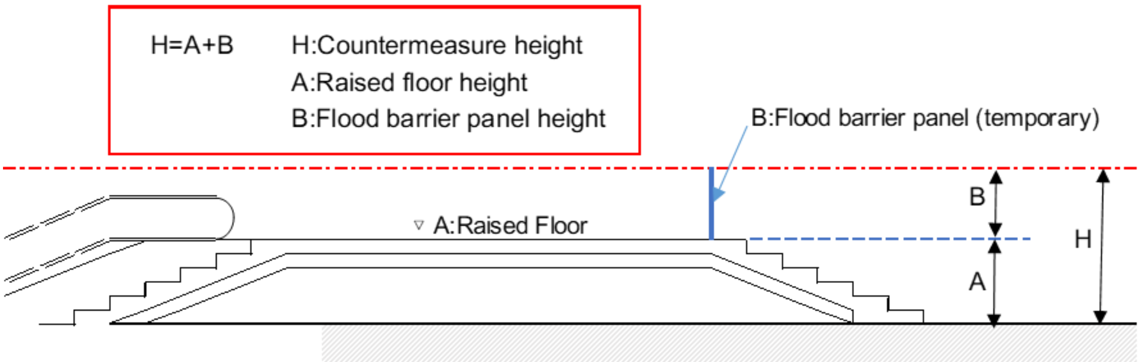
Figure 5-76 : Examples of Flood Countermeasures in Japan

Although there are different types of flood barrier panels, those made of aluminum are recommended because they have the following benefits: they can be produced and installed up to a maximum panel height of 1.5 m; there shall be no restriction on the installation width; stepwise installation with multiple layers of panels is possible; panels are lightweight, and all components can be handled and installed by station staff members without difficulty; and finally, they are less expensive than other types of flood barrier panels.



Source: JICA Study Team (Quoted from the catalog of a manufacturer)

Figure 5-77 : Examples of Flood Panel in Japan



Source: JICA Study Team

Figure 5-78 : Countermeasures for Flooding at Station Entrances

The below comment is reply comment from PMRCL/DMRC

For the purpose of design of entry/ exit structures, including lifts and escalators the following criteria has been followed: If the Highest Flood Level (HFL) is below road level, the plinth level of the entry/ exit structures will be taken as 600mm above road level. Where HFL is above road level, the plinth level of the entry/ exit structures will be taken as 450mm above HFL. All other structures i.e. ancillary building, vents are designed such that there are no openings below the HFL. This design criteria ensures there are no additional requirement of flood barriers.

b) **Earthquake**: Seismic design method is described in the Civil Engineering Design Specification. And there is no concern about liquefaction for underground section because soil condition is mainly silt and clay

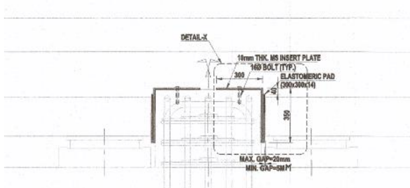
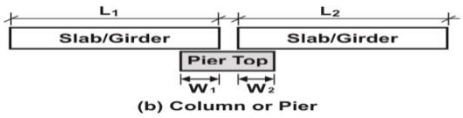
The below table shows reply comment from PMRCL/DMRC for the seismic design method for each civil structure.

Table 5-28 : Seismic Design Method by PMRCL/DMRC for Civil Structures

Structure type	Seismic design method
Pier	Seismic design has been considered for Pier design as per the "Indian Railway Standard Code for Earthquake Resistant Design of Railway Bridges (Seismic Code) 2020"
Embankment at New Depot	Seismic design is considered for embankment as per literature paper for "Earthquake Induced Soil Pressures on Structures" as mentioned in Outline Design Specifications
Retaining wall at Ramp section	Seismic design is considered for retaining wall as per literature paper for "Earthquake Induced Soil Pressures on Structures" as mentioned in Outline Design Specifications.
Underground structure such as , U-Type retaining wall at Ramp section, Shaft, Box Culvert and Cross passage,	Seismic design is considered for underground structure as per literature paper on "Seismic Design and Analysis of Underground Structures" by Hashash et el as mentioned in attacs.
TBM lining (RC-Segment),	Seismic design is considered as per literature paper "Seismic Design and Analysis of Underground Structures" by Hashash et el. which is worldwide accepted method for TBM lining.

The below table shows reply comment from PMRCL/DMRC for the seismic counter measure for each civil structure.

Table 5-29 : Seismic Counter Measure Method for Civil structures

<table>
<tr><th>Structure type</th><th>Purpose of seismic counter measure</th><th>Seismic countermeasure method by PMRCL/DMRC</th></tr>
<tr><td rowspan="2">Bearing</td><td rowspan="2">Superimposing rubber and steel plates in a sandwich-like shape, it has the effect of following the movement of the girder and reducing the seismic force.
However, if earthquake displacement of this system is large than allowable rail track displacement then it is necessary to stopper the system.</td><td>Seismic arrester has been provided with 10mm thick insert plate & 14mm thick elastomeric pad.</td></tr>
<tr><td>
</td></tr>
<tr><td>Girder Connection</td><td>A bridge collapse prevention device, connects the two consecutive girders with the cable chain and prevents the girder from falling.</td><td>Seismic arrester has been provided to prevent from collapse.</td></tr>
<tr><td colspan="2">Installation of displacement restricting structure</td><td>Seismic arrester has been provided as displacement restricting structure.</td></tr>
<tr><td rowspan="2">Bridge Seating width</td><td rowspan="2">When the support is compromised, the girder falls onto the beam and stops the formation of a difference in level on the bridge. Increase the area of the beam top surface to prevent the girders from dropping.</td><td>Seating width has been provided as per the “Indian Railway Standard Code Bridge Rules”: Reprint 2014</td></tr>
<tr><td>
</td></tr>
<tr><td>Displacement restriction device</td><td>When the bearing is compromised, the girder collapses onto the beam, impeding its ability to move and advance down the bridge.</td><td>Seismic arrester has been provided as displacement restricting structure.</td></tr>
</table>

5) Restrictions on Civil design

JST has confirmed with PMRCL/ DMRC about the clearance between the existing road and viaduct of Patna Metro. In the basic design drawing is designed for minimum 5.5m

(2) Construction

1) Substructure of Viaduct Section

The contractor should conduct test boring to check the depth of bearing strata before the main pilling works. The contractor executes pilling works with pilling machines, mobile cranes, and excavators within construction barricades. These machines are available without difficulty in India.

The contractor may carry the concrete from batcher plants located remotely. Concrete pouring into a bored hole should be through the proper size of tremie pipes. The contractor should plan well the concrete movement considering the time required against local traffic at each time.

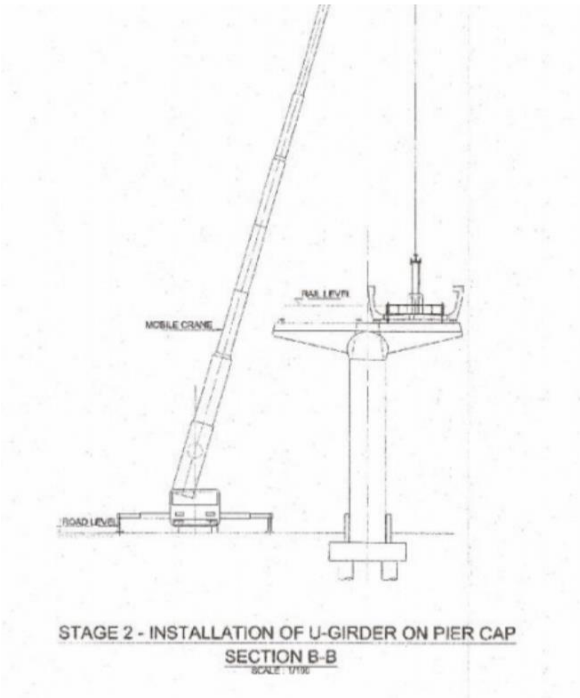
The contractor should remove the poor mixture section at the pile head before starting the footing structure. The contractor may use sheet piles to excavate for footing works due to the silty ground in Patna.

2) Superstructure of Viaduct Section

The contractor will make pieces of superstructures of the viaduct and station except for the pillar at the casting yard, minimizing the workload at the site. The shape of the superstructure is similar to many other metro projects in India. The contractor pre-casts the superstructure with steel molds. These pre-casting activities help streamline quality management.

The movement of pre-casted superstructures from the casting yard to the site may hamper the local traffic flow due to its speed and size. Therefore, the contractor has to plan the logistics activities at night or early morning, when the traffic volume is relatively low. In Patna, since the width of some roads is narrow, the contractor should study to decide the route from the casting yard designated by PMRCL in advance.

The contractor deploys mobile cranes to erect pieces of superstructures at the site. Actual erecting activities will happen at night as the mobile cranes should stand safety position by expanding outriggers while blocking some road lanes.



Source: PMRCL's Tender Document for PC-01

Figure 5-79: Erection of Superstructure Using a Mobile Crane

PMCRL renders casting yards to each civil contractor. The JST visited two casting yards for PC-01 and PC-04 Contractors. The area for both sites is sufficient for pre-casting works. Yet, the nature of land differs as below. PMCRL will take responsibility for getting consent to set up a concrete batching plant from the Bihar Pollution Control Board.

Table 5-30: Outline of Casting Yard

	PC-01	PC-04
Location	Eastern farmer's land along NH30 through public procurement	Government land inside the major bank of the Ganga River
Area	14 acres	12 acres

	PC-01	PC-04
Accessibility	Excellent. Next to NH30	Need to build a temporary road to a wide road on the bank
Fee	900,000 Rs. per month	free
Others	N/A	Needs for measures against flood

Source: JST

The PC-01 Contractor has established its casting yard, as shown in the photos below. The capacity of the concrete batching plant is 90 cubic meters per hour in total. The contractor operates it for 24 hours per day with two shifts. PMRCL will arrange a casting yard for PC-05 and 06 (underground civil portions under the JICA fund), where the contractors can establish TBM segment plants.

Source: JST

Figure 5-80: Casting Yard for PC-01 Contractor along NH30

3) Underground Structure (Cut and Cover)

The Cut and Cover works seem more straightforward than TBM, and non-experienced contractors among Joint Ventures might take responsibility for it. However, the contractor should ponder its detailed scheme based on the surrounding conditions, ground & water, proximity buildings, utilities, and local traffic because the underground earth (silty soil) will not stand like a rock, and it may get weak and distorted by heavy rain to potentially lead to some critical accidents at the site.

Additionally, the Cut and Cover sites on Corridor-1 do not have sufficient construction areas, unlike many cities in India. The contractor should prepare to manage a robust logistics plan to bring construction materials and discharge muck and debris not to hamper the construction progress. The contractor may want to utilize the temporary steel deck over the footprint of stations and entry/exit to balance construction efficiency with mitigation against the local traffic.

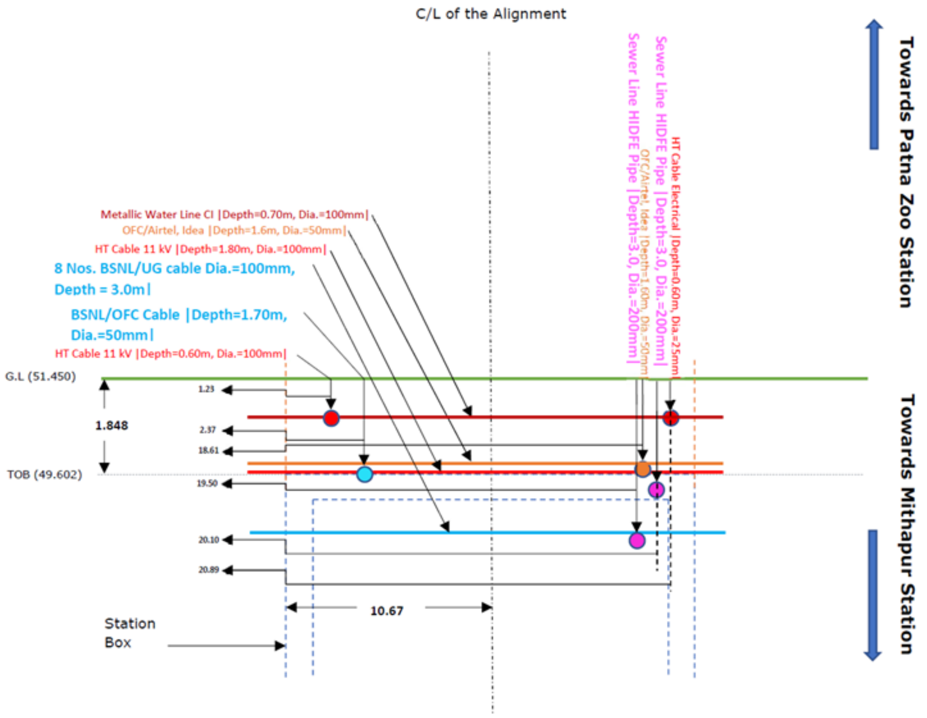
Regarding buried utilities, the contractor should divert some utility lines outside the station footprint or toward another road as the station box's top level is 1.5 meters at the minimum below the ground surface. In such a case, the contractor may need to manage areas beyond the station boxes and entries/exits. The sample of existing utilities located below 1.5 meters is as follows.

- Water pipe, 300 mm diameter, GL-1.8 m.

- BSNL/ OFC, 50 mm diameter, GL- 3.0m
- Airtel/ OFC, 50 mm diameter, GL- 2.0m
- HT (E) 11 kV, 100 mm diameter, GL- 1.8m
- Sewer RCC, 900 mm diameter, GL - 2.4m
- Gas, 200 mm diameter, GL -1.8m

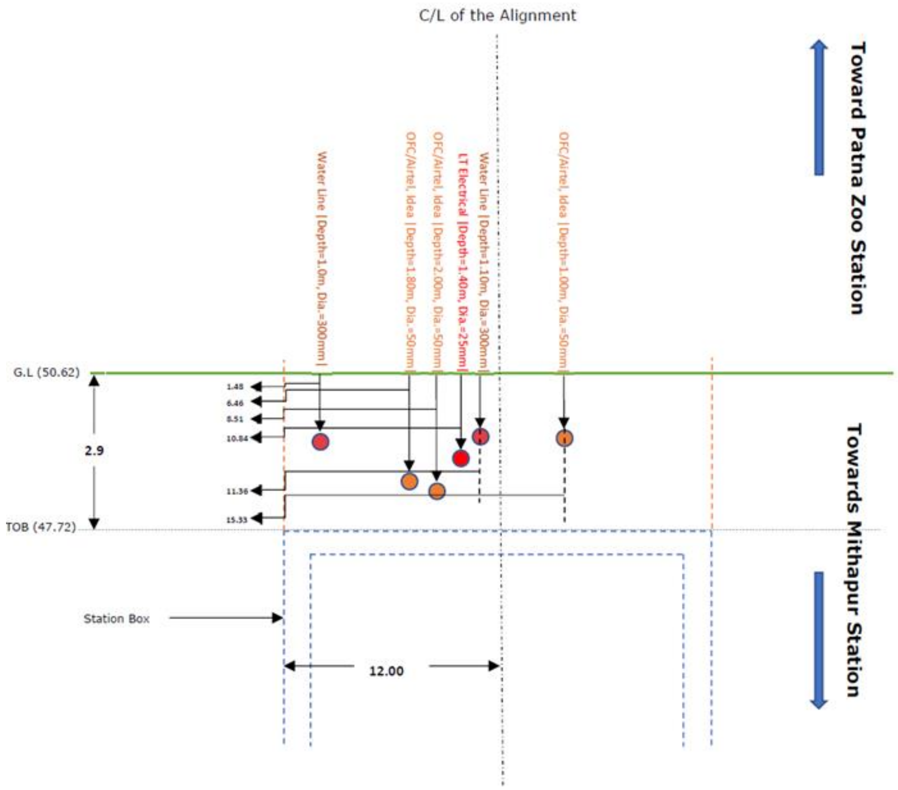
By the way, the utility identification drawings look over-sophisticated, connecting all lines throughout the alignment. The contractor should check the existence of uncharted utilities by test digging first.

The following section diagrams depict the relationship between utility lines and the station top slab in two typical stations. At Patna Junction, the contractor should divert several utility lines due to the shallow top slab. On the other hand, the contractor will not need to shift but suspend utilities at Vidyut Bhawan as the utility levels are shallower than the top slab.



Source:JST

Figure 5-81: U/G Utility Lines at Patna Junction Station



Source:JST

Figure 5-82: U/G Utility Lines at Vidyut Bhawan Station

4) Underground Structure (TBM)

The Corridor-1 has less access to open spaces to launch TBMs, while Corridor-2 has sufficient land. The contractors for Corridor-1 will need to manage on-demand construction transportation like in Tokyo and Singapore within the limited working area. PMRCL will allocate the casting yard and the muck disposal site dedicatedly to the individual contractors.

TBM's cutter bit and its alignment on the face should be customized to the silty ground even if the contractor utilizes second-hand machines. Otherwise, TBM might be stuck since it cannot scratch the earth as loosened silty soil fills gaps of cutter bits.

Based on the ground condition, TBM is expected to proceed at the average pace of 250 meters per month. With the figure, the number of TBM required for PC-05 and PC-06 to meet the construction period (42 months) will be three and two, respectively[25]. Two hundred fifty meters per month means that one TBM generates muck of over 300 cubic meters per day, which needs 100 dumping lorries to carry out from the launching shaft (where two TBMs usually work). Unless the Contractor maintains enough coordination with the local traffic authority, the traffic regulation (not but TBM system capacity) defines the TBM progress. That happened in Mumbai at the early stage until the contractor found the meeting points with the traffic police partly because the concerned persons could hardly envisage the effect of TBM works and balanced solutions since it was the first underground metro project in the city. To maintain the TBM

[25] Please see Attachment 15-Construction Speed and Required TBM Units for the detailed calculation.

progress requires a non-pure engineering aspect too.

The contractor should deploy sufficient capacity of ancillary facilities with a backup system. A generator is one of the most crucial facilities in terms of work progress and safety and should always be on standby. Besides, the contractor should store spare parts and lubricant at the site.

The contractor should pay close attention to breaking retaining walls, passing potentially affected existing structures/buildings, and cross-passage construction. Especially in cross-passage construction, the contractor, with its detailed designer, should analyze the deformation of the ground and segment rings to plan the supporting works like bracing inside of segment rings and earth treatment (grout injection) in advance.

For quality and maintenance management, the contractor should seal or paint the lot number on each segment lining to secure traceability.

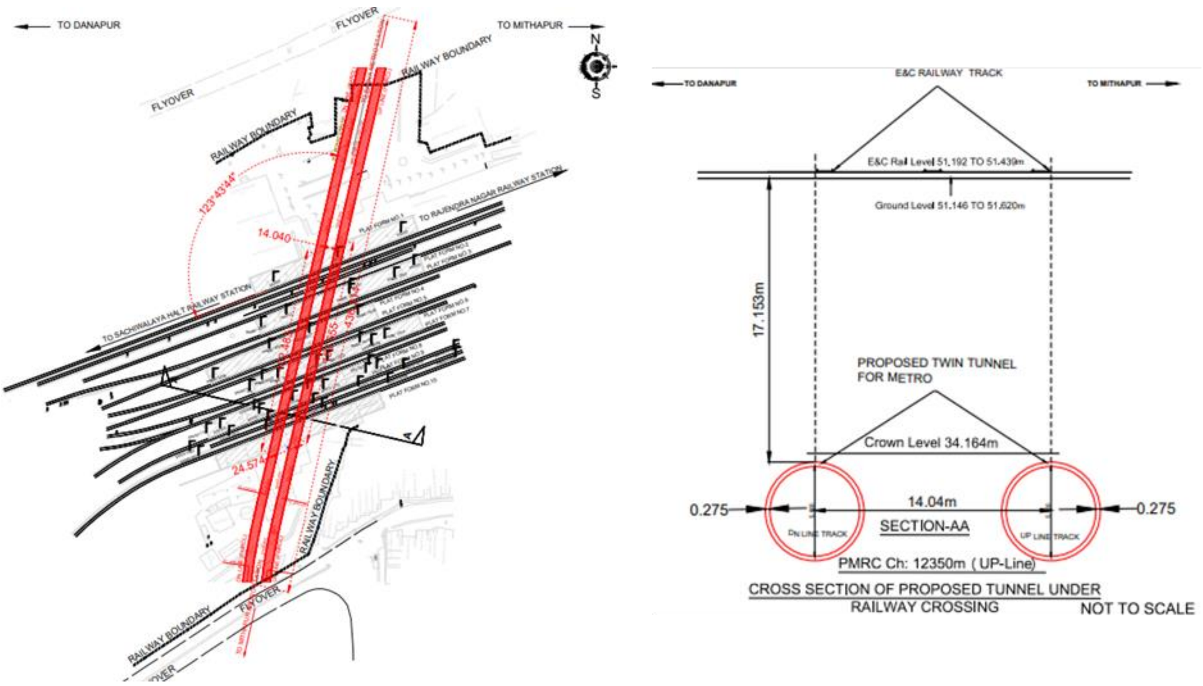
5) Protection of Proximity structures

There are three types of proximity structures to be checked in the Patna Metro project: (i) live railway lines, (ii) piles of existing superstructures along roads, and (iii) private/government land buildings.

(i) Live railway lines: the alignment of TBM passes the live railway lines between Patliputra and Rukanpura and near Patna Junction and Rajendra Nagar. The most extended section to underpass is at Patna Railway station, which will be nearly 150 meters long. PMRCL negotiated with East-Central Railway to get approval to pass TBMs. Due to the clearance between railway tracks and TBM (15-17 meters in the silty ground), a significant adverse impact may not cause. However, the Contractor should monitor rail level per the agreement with the Railway.

Source: JST

Figure 5-83: Railway Lines at Patna Railway Station



Source: PMRCL

Figure 5-84: Live Railway Lines Crossing at Patna Railway Station

(Plan (Left hand side) and Section (Right hand side)

(ii) Piles of existing superstructures along roads: Patna City has many elevated roads and junctions. Those structures should have material pile foundations in the silty ground. The contractor should take care of the existing structures in the affecting zone, irrespective of TBM works or Cut and Cover works. The contractor, with its detailed designer, should estimate physical conflict and negative causation during construction activities to take proper engineering measures if needed. Samples of possible actions are enforcing the retaining wall to mitigate relaxation of the ground backside of the wall and upgrading the segment lining to bear the load from the existing superstructures.

(iii) Private/government land buildings: Most buildings on the private and government land under which TBM will pass are low-rise buildings and envisaged to have masonry foundations. Such lightweight structures will not cause additional loads to underground structures. Nevertheless, a building itself may be vulnerable to even minor ground deformation. The contractor should conduct a building condition survey along the alignment at the beginning. Depending on the survey result, they might need to claim a change of alignment or demolition of affected buildings to PMRCL. By the way, the ongoing underground civil contract (PC-03) contractually instructs, under the Key Date Schedule, the Contractor to proceed with the building condition survey soon after the Letter of Acceptance (before signing the contract) to shorten the construction period. The same condition will come to JICA civil portion to achieve the challenging timeline, which should be explicitly described in the bidding documents.

6) Construction under Private Land

Based on the building condition survey, the contractor, with its detailed designer, should establish a protection plan against vulnerable buildings and monitoring methods.

The contractor should monitor the level (height) of the ground above the TBM alignment, including an affected zone. Adverse effects may happen when the contractor over or under-execute activities like poor TBM face pressure management, over-excavation, and failing to inject gaps between earth and linings. The contractor has to take more care of its sequential actions in the sensitive zone at a slower TBM speed.

7) Traffic diversion and traffic safety during construction

Overall, stations, excluding Khemni Chak, on NH30 and associated service roads, have sufficient spaces for elevated metro construction. The contractor may temporarily expand the barricade at night when erecting superstructures with mobile cranes. During barricade expansion, the contractor should deploy sufficient light for vehicle drivers to identify the road space.

Source: JST

Figure 5-85: Barricade Installation on NH30

Khemni Chak is an integrated station of the Corridor-1 & 2 and aligned at almost the entire width of NH30. The contractor will block lanes following pilling works of the station structures. Once the pier works finish, the contractor blocks the lane between the piers to build station slabs. Lastly, the contractor blocks side roads while making entries/exits. The location of barricades varies in line with the construction sequence. The contractor should harmonize its works across the station to avert “zig-zag” traffic flow.

The Corridor-1 elevated section and underground stations are located on/under wider roads than the Corridor-2. Except for Danapur and Patna Junction, the contractor will not need to consider regional detours to maintain local traffic and can keep using three to four lanes for construction activities. For underground stations, in addition to three to four lanes blocking, the contractor will install a temporary steel deck for local feeder traffic, under which the contractor builds underground structures.

Some underground stations of Corridor-2 like Akashuvani, PMCH, and University are located under or next to narrow roads. That may provide only one-way traffic with a regional detour. Besides, Rajendra Nagar is aligned under a busy four-lane road near an overpass road bridge. The contractor should negotiate with East-Central Railway to temporarily utilize the railway land for traffic diversion.

The contractor needs to install supplemental sign boards and blinking lights on the barricades at night. Furthermore, in case drivers’ vision might be hampered at the connection to feeder roads due to barricades, the contractor may need to half the height of the barricade at the corner.

PMRCL agreed to utilize JICA Standard Safety Specification (JSSS), whose Sub-provision 2.2.2 Working Area Perimeter refers to fencing to prevent access to the site by unauthorized persons, which is a common instruction from many employers. However, the JST observed that the number of security personnel was lacking, and the construction area was relatively open to the public. PMRCL may want to assign more security personnel to the Site to avoid any incidences involving a third party.

8) Special construction methodology

(i) Low headroom piling machine

The construction methodology deployed in the project is not unique except for piling work with low headroom in Patna Junction. The footprint of the station box reaches the elevated highway, and the contractor should use a low headroom pilling machine under the elevated road to install retaining walls. Through an interview with DMRC and PC-03 Contractor, the nationally leading construction company, the JST found that such a pilling machine is NOT commonly available in India.

PMRCL might consider shifting the station location to the north to avoid using such a unique machine. Nevertheless, maintaining the required track layout for two corridors after the shit is pretty challenging since Patna Junction is a longitudinally long station to include a switch-back section for the Corridor-2. PC-05 Contractor will need to import a low headroom piling machine.

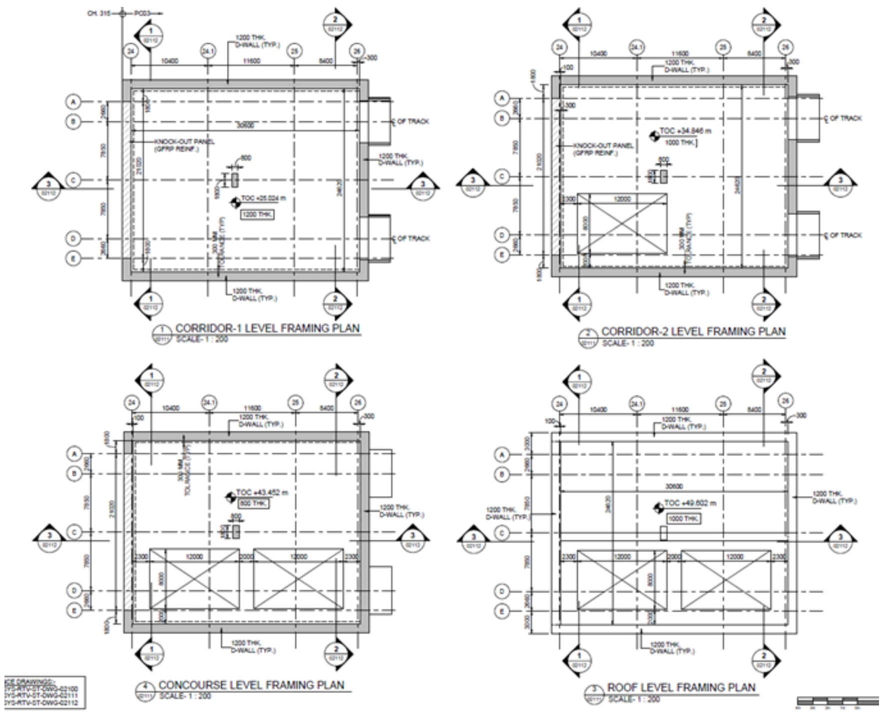
Source: JST

Figure 5-86: Elevated Road above Station Footprint at Patna Junction

(ii) Integrated underground station

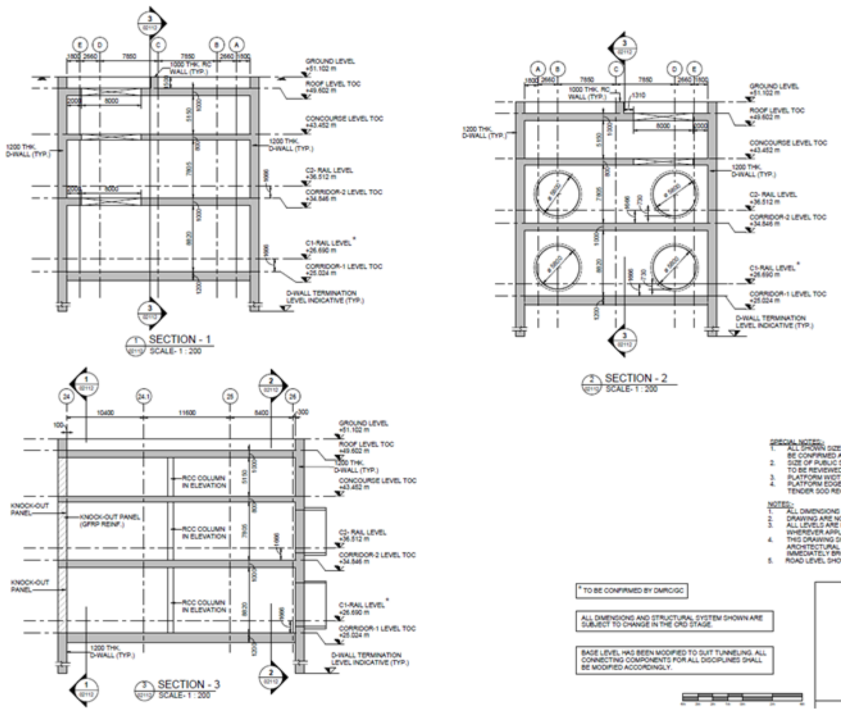
Patna Junction is an integrated underground station, where TBMs of Corridor-1 reach the bottom after TBMs of Corridor-2 are retrieved at the middle level. The Corridor-2 Contractor has already started its construction, and its TBMs will reach the station earlier than Corridor-1, while the Corridor-1 Contractor will build the station main box. PMRCL should settle many coordination issues like timeline, temporary facility, and workspaces before the physical interface.

PMRCL provided a solution to the interface, where the Corridor-2 Contractor builds the retrieval shaft next to the station box. The construction sequence is as follows. First, they retrieve their TBMs at the middle level. Next, they build the complete retrieval shaft until the bottom to render it for the Corridor-1 Contractor to recover their TBMs. Finally, the Corridor-1 Contractor breaks the temporary wall next to the station box. This scheme will work to solve the time difference between the two entities.



Source PMRCL

Figure 5-87: Plan Drawings of Retrieval Shaft next to Patna Junction



Source PC-03 Contractor

Figure 5-88: : Section Drawings of Retrieval Shaft next to Patna Junction

(iii) TBM tunnelling with minor clearance

The internal diameter of the TBM tunnel is at least 5.8 meters, and the external diameter can be 6.45 meters. Whereas TBMs run by two contractors get near one another by less than 3.5 meters at the point of the retrieval shaft of Patna Junction as mentioned in the previous sub-section. Insufficient clearance in silty earth will skew earth pressure loading on the TBM lining. Some portions of the lining should bear additional stress. Worse, the second TBM running gets soil loosened by the first TBM passing exposed to dropping, which can lead to extra load on the TBM lining and significant subsidence of the ground surface.

Two contractors from PC-03 and 05 should take responsibility for bringing engineering solutions to these risks. Appendix 20 of the Employer's Requirements of the PC-03 Contract describes the responsibility of respective contractors where each contractor, with its detailed designer, conducts design analysis for both sides of structures following the construction sequence. The PC-03 Contractor running the first TBM should share this information with the PC-05 Contractor. On the other hand, The PC-05 Contractor should verify the analysis by the PC-03 Contractor and monitor their TBM tunnels while proceeding with its TBMs. This collaborative approach will work practically, and the bidding documents of PC-05 should enclose the exact requirement.

6. Station Planning

6.1 Overview of Existing Studies

6.1.1 Outline of Station Planning

The outline of the station planning is shown in the table below.

Table 6-1: Corridor-1 Stations

Station No.	Station Name	Location	Elevated /Under Ground	Platform Type	Alignment
01	Danapur	Above of Saguna -Danapur Main Rd	Elevated	Side	Straight
02	Saguna Mor	Above of Beiley Rd	Elevated	Side	Straight
03	R.P.S. Mor	Above of Beiley Rd	Elevated	Side	Straight
04	PATLIPUTRA	Above of Beiley Rd	Elevated	Side	Straight
05	Rukanpura	Underground of Beiley Rd	Underground	Centre	Straight
06	Raja bazar	Underground of Beiley Rd	Underground	Centre	Straight
07	Patna Zoo	Underground of Beiley Rd	Underground	Centre	Straight
08	Vikas Bhawan	Underground of Beiley Rd	Underground	Centre	Straight
09	Vidyut Bhawan	Underground of Beiley Rd	Underground	Centre	Straight
10	Patna Junction	Underground of Fraser Rd, Near IR Patna St., Front of Buddha park	Underground	Side ＋Centre	Straight
11	Mithapur	Above of SHANTI MARKET BUS STAND Rd	Underground	Centre	Straight
12	Ramakrishna Nagar	North side of Bypass Rd	Elevated	Side	Straight
13	Jaganpura	North side of Bypass Rd	Elevated	Side	Straight
14	Khemni Chak	North side of Bypass Rd	Elevated	Side ＋Centre	Straight

Source: DPR 2021

Table 6-2: Corridor-2 Stations

Station No.	Station Name	Location	Elevated /Under Ground	Platform Type	Alignment
01	Patna Junction	Underground of Fraser Rd, Near IR Patna St., Front of Buddha park	Underground	Centre	Straight
02	Akashuvani	Underground of Fraser Rd	Underground	Centre	Straight
03	Gandhi maidan	Underground of Gandhi Maidan Rd, Front of Gandhi maidan park	Underground	Centre	Straight
04	PMCH	Underground of Ashok Rajpath Rd	Underground	Centre	Straight
05	University	Underground of Ashok Rajpath Rd	Underground	Centre	Straight
06	Moin Ul Haq	Underground of Moin-ul-Haq stadium site	Underground	Centre	Straight
07	Rajendra Nagar	Underground of Kankarbagh Rd, Near IR Rajendra Nagar St.	Underground	Centre	Straight
08	Malahi Pakri	Above of Malahi pakari	Elevated	Side	Straight
09	Khemni Chak	North side of Bypass Rd	Elevated	Side ＋Centre	Straight
10	Bhootnath	North side of Bypass Rd	Elevated	Side	Straight
11	Zero Mile	North side of Bypass Rd	Elevated	Side	Straight
12	New ISBT	Above Bairiya Rd, Near New Bus terminal	Elevated	Side	Straight

Source: DPR 2021

Elevated stations: Elevated stations are planned two types, Type 1 applies to all elevated stations except Khemni chak station, that has center type platform and two lanes. Type 2 applies has Khemni chak station that has four lanes and side and center type platform as transfer station.

Table 6-3: Outline of Elevated Station Type

	Station Type	Typical Station Name	Station building length	Station Building Width
Type 1	Elevated	Sagna More	141.7m	21.17m
Type 2	Elevated	Khemni chak	141.7m	42.17m

Source: DPR 2021

Underground stations: 7 types with different number of Underground floor and station dimensions according to site conditions.

Table 6-4: Outline of Underground Station Type

	Station Type	Typical Station Name	Underground Floors	Station building length	Station Building Width
Type 1	Underground	Rajabazar,	3	141.7m	21.07m
Type 2	Underground	Rukanpura, Patna University Vikash Bhawan	2	162.4m	24.22m
Type 3	Underground	PMCH	2	227.4m	21.07m
Type 4	Underground	Gandhi Maidan, Moin-U-Ihaq Stadium	2	204.4m	24.22m
Type 5	Underground	Akashvani	2	237.4m	21.07m
Type 6	Underground	Patna Junction	3	347.4m	23.42m
Type 7	Underground	Patna Zoo	2	356.4m	21.07m

Source: DPR 2021

6.1.2 Outline of Station Design Criteria

The next table summarizes the basic features of a typical station.

Table 6-5: Outline of Station Design Criteria

Length of Platform	Elevated Stations : 140.0m Underground Stations: 140.0m
Rolling Stock Composition	3/ 6 cars
Required Vertical Clearance	Minimum vertical clearance between the Concourse and the road: 5.5m
Platform Width	(Elevated Section: Side platform) Minimum 21.17m-wide proposed (Underground Section: Island platform) Minimum 21.07m-wide proposed The width of the platform is determined by the number of passengers demanded during peak hours.
Platform Screen Doors	PSD Installation is not mentioned.
Stairs, Escalators and Lifts for Normal and Emergency Operations	The specification shall comply with relevant sections of NBC 2016 Part 4 'Fire & Life Safety' & Annexure J (including amendment 1 issued in March 2021)

Source: DPR 2021

6.2 Reviews of Existing Studies and Proposals for Improvement

Station Tender or Basic drawings and design reports have already been prepared by PMRCL for all stations on corridor 1 and 2. A review was conducted the station planning described in the received DPR, drawing and design reports. In this chapter 6, comments and recommendations for the future developing of basic and detail design phase are mentioned for improvement.

24 stations of Corridor-1 and 2 were reviewed whether meeting with these criteria are as follows,

- Horizontal and vertical alignment, platform width and length following specifications
- The layout of stations in harmony with demand forecast and passenger flow
- Stairs, escalators and elevators enough capacity for peak-hour passengers
- Facility layouts following station operation
- Safe fire emergency evacuation
- Adequate station plaza
- The convenience of passengers at transfer stations

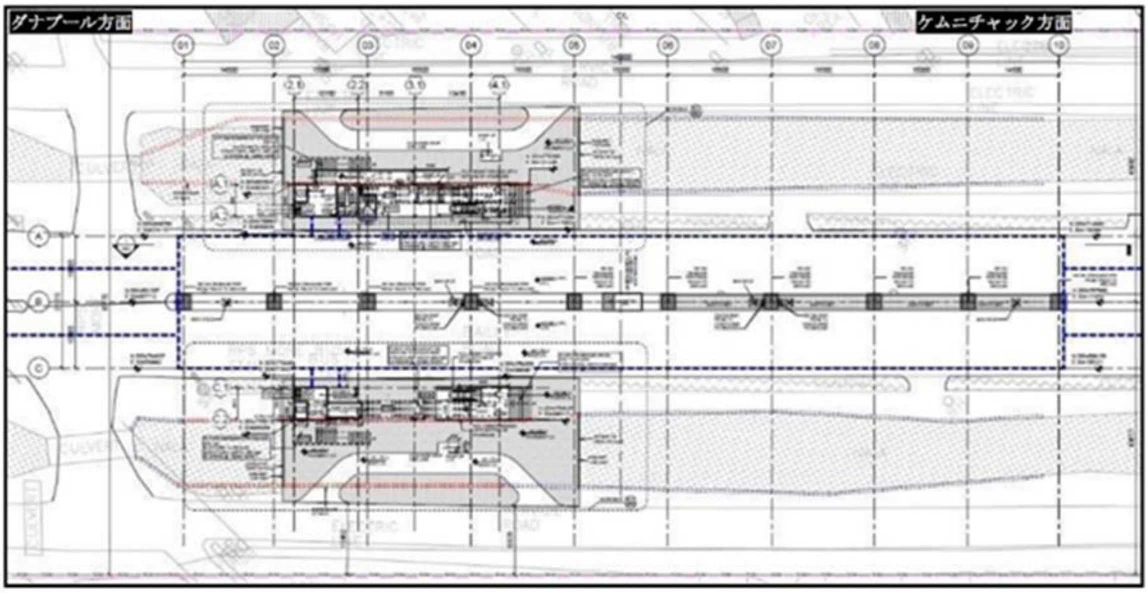
6.2.1 Location of Stations

Patna metro consists of 24 stations on two corridors with a total length of 31.448 km. The average distance between stations is approximately 1.367 km. Excluding Malahi Pakri and New ISBT underground station of corridor- 2, most stations are located on the straight part of the alignment which makes easier construction compared to the curved part of the alignment.

(1) Elevated Station

Basically, station location are planned on the median strip of the main road. Some elevated stations are planned to be located on the roadside or on the river parallel to the road depending on the surrounding conditions and the layout of the underground ramp connection.

In all cases, the footpaths on both sides of the road directly below or parallel to the station are connected to the station entrances and their associated footbridges. Therefore, that station users can access the station without having to cross the road. An example of an elevated station site layout is shown below.



Source：PCDD-01: Design Basis Report August 2022

Figure 6-1：PRS MOR Elevated station site plan

(2) Underground Station

Most stations except Malahi Pakri underground station of Corridor 2 are located avoiding intersections. Therefore, the station location is less convenient than stations located at intersections. However, it is to be easier than stations located at intersections in construction work and traffic control during construction.

6.2.2 Facility of Stations

The plans for the station facilities were confirmed in the design report, which includes basic design drawing and station facilities design criteria. They are based on the applicable sections of the NBC 2016 Rail Facility Standards, and the station facility design criteria are based on the Delhi Metro example.

The review results and recommendations/remarks for each facility are provided below.

(1) Station Structure

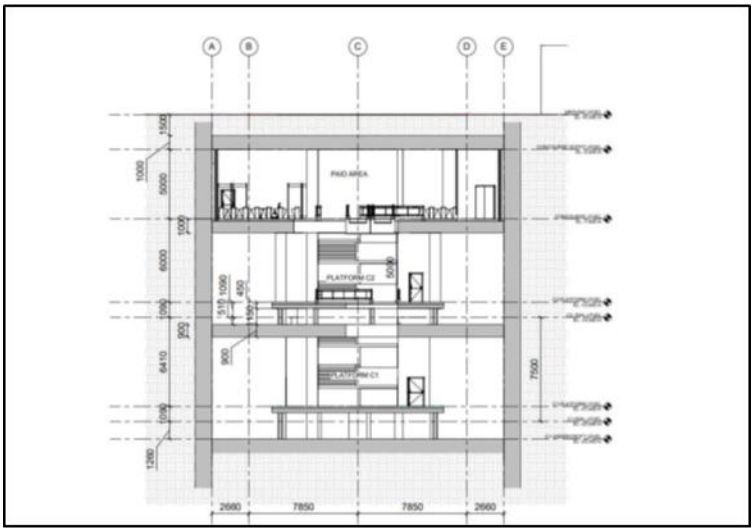
-Elevated stations

Station sizes and concourse formats are almost the same except for Khemni chak station. Therefore, passengers have few ways to recognize stations other than checking station name signs in the concourse from inside the train when outing the train, which may lead to the possibility of mistaking the station for the alighting station. It is recommended that the plan incorporate consideration to make it easier for passengers to recognize each station from inside the train by changing the color of the concourse interior at each station and by precisely arranging the station name signage.

-Underground station

The basic underground station is planned to have two layers with a concourse on the upper level and an island platform on the lower level with two tracks.

For some narrow underground sections and Patna Junction underground transfer station that included four tracks are divided three underground layers in order to reduce land acquisition and the extent of impact on the roadside.



Source：DPR2021

Figure 6-2 : Stack Platform type underground station section

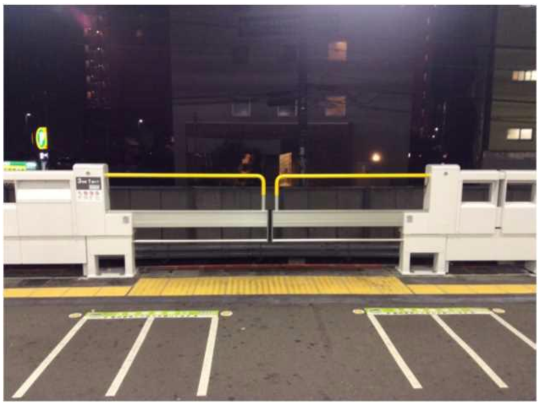
(2) Platforms

According to DPR and the design report, the width of the platform will not be standardized, but will be at least 3m, and the width will be altered for each station according to the expected number of passengers. For stations with few passengers, the width should be reduced to reduce costs.

(3) Platform Screen Door (PSD)

It is confirmed that there are not installed platform screen doors (PSD) to all stations in view of projected future passenger numbers and cost containment. That prevention of passengers falling from the platforms is to be monitored by CCTV or visually monitoring by station staff. For safety reasons, especially due to the risk of falls by visually impaired passengers, it is recommended that a post-installation type PSD be installed in the future if the PDS becomes necessary.

For future installation the PSD, Post-installation type PSD products should be considered and selected that are suitable for the station installation conditions. For example, platform end slab strength, Installation method, cargo door opening dimensions and construction period.



Smart home door® **Light weight type home door product**

Source: Guidance for considering the introduction of new platform doors - from various development cases

Figure 6-3: Products of Post-installation PSD

(4) Barrier-free design

Barrier-free measures in station facilities is designed in accordance with "Harmonised Guidelines and Space Standards for Barrier-Free Built Environment for persons with Disability and Elderly Persons in the year 2016" the barrier-free guidelines issued by the Ministry of Urban Development of India, and the Barrier-Free Standards for Station Facilities of the National Building Code of India (NBC2016).

The station facilities plan to be designed with consideration for persons with disabilities (physical, visual, hearing, internal diseases, etc.) in accordance with the guidelines and basic code that is confirmed in the Station Building design report.

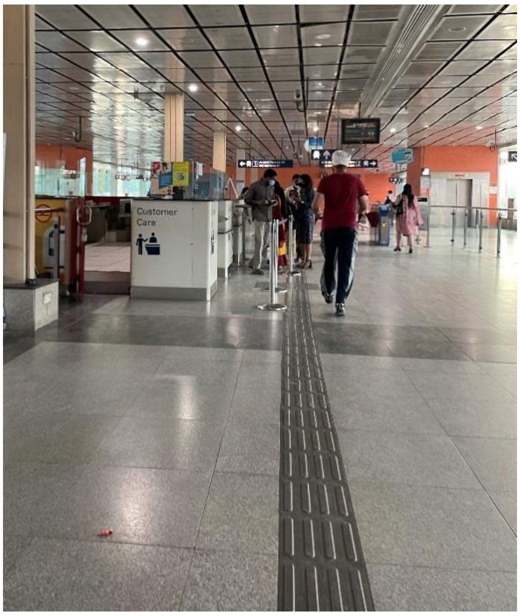
Table 6-6, the lists the design criteria for barrier-free design to be incorporated in the design of station facilities that is mentioned the Station Building design report.

Table 6-6: Patna Metro Station Facility Barrier-Free Design Criteria

Facility	Criteria
Station Entrances and Exits	• The station entrance/exit should not have a difference in level. If a level difference is unavoidable, install a ramp or a ramp plus staircase. • It is desirable that space be marked out near the station entrance/exit for vehicles carrying wheelchair users.
Reservation Or Information Counters	• Reservation or information counters should have unobstructed approaches for wheelchair users. • One counter height should be 750mm.
Concourse	• The concourse should not have a difference in level. If a level difference is unavoidable, install a ramp or a ramp plus staircase. • The floor surface of a concourse should be made of non-slip material. At places, where the difference in level such as stairs, it is desirable that the appearance of the surface material be changed using color contrast. • Install guiding blocks on the concourse for persons with impaired vision. • Wherever columns exist, an electrical/ fiber-optic/ equivalent provisions shall be made keeping in

Facility	Criteria
	mind the future of having revenue generating facilities as ATMS and also facilities for ease of passengers (coffee/ tea vending machines).
Staircase	For details, see the guidelines for staircases as per Part 4 'Fire & Life Safety' & Annexure J of NBC 2016 (including amendment 1 issued in March 2021).
Lifts (Elevators)	• Install a lift (elevator) to enable passengers with disabilities to move between floors. • For the lift (elevator), install one warning block for persons with impaired vision 300 mm away from the call button.
Toilets	Install a toilet and washstand suitable for use by wheelchair users and other passengers.
Ticket Gates	One of the ticket gates should have a continuous line of guiding tactile blocks for persons with impaired vision.
Platforms	• The platform should have one row of dotted guiding blocks for persons with impaired vision, 800 mm or more from the edge. • The paved surface of the platform must be made with a non-slip material • Stairs, kiosks and dustbins on the platform must not hinder the clear passage of persons with impaired vision and wheelchair users. • A bench should be installed on the platform, having guiding block around it.
Rolling Stock (Car) doors	• Car doors should be wide enough for wheelchair users (minimum 900mm) • The gap between car doors and the platform should be reduced to an absolute minimum.
Information	• The information board should be made easily readable by using sufficiently large text size, distinct contrast and illumination. • It is desirable that in addition to a printed version of train schedule, table of fares and other travel information also be in Braille.

Source: PCDD-01: Design Basis Report April 2022



Source: JST

Figure 6-4: Guide block installation example of Delhi Metro

(5) Gender and Infant considerations

It was confirmed from the tender drawings and questions and answers that the station facilities have the gender and infant considerations listed in Table 6-7. It is proposed that all stations should have a women's helpline desk staffed by women from the police or PMRCL security departments.

Table 6-7: Patna Metro Station Facility Gender and Infant design consideration plan

Facility	Gender and Infant considerations
Toilet separated male and female	The toilets are to be install for passengers and station staff in all station paid concourse area. Moreover, gender-segregated toilets for station staff in some station back-office areas.
Transgender toilet	The transgender toilet is to be installed alongside passenger toilet areas in the concourse are at some stations. Transgender people can use the toilets without having to worry about the stares of others which they felt when using the Male or Female toilets.
Diaper-changing tables	The diaper-changing table is to be install in multi-purpose toilets of a part of some stations. By installing the table in multipurpose toilets that can be used by both men and women.
Separate security gates	Two lines of security gates to be installed at all stations that are planned as separate rows for men and women. In addition, a women's body search area is planned with a curtain to prevent women from being seen by others.
Platform	The platform is designed to have a good view and to eliminate blind spots, thereby preventing and controlling crime and allowing female passengers to use the platform safely.

Source: JST

Multi and Transgender toilet

Diaper-changing tables

Source: JST

Figure 6-5: Examples accommodation of Gender and Infant considerations

(6) Station building exterior design

The exterior design plan for the elevated and underground station of Line 1 has already been prepared by PMRCL. The concept is to show Patna's glorious culture, history, and envisioned glorious future through design. The exterior of the elevated station is designed to express lightness by using a lot of latticework on the exterior walls and reducing the number of walls on the platform level as much as possible to increase transparency so that the plan is designed to be in harmony with the surrounding landscape. The latticework was designed by a Japanese design office and it is based on the lattice motif used at the Bihar Museum, one of the landmarks in Bihar.

Source: PCDD-01: Design Basis Report August 2022

Figure 6-6: Station exterior design perspective

6.2.3 Guideline for Evaluation of Emergency Evacuation

The station design adopts NBC 2016, Part 4 'Fire & Life Safety' & Annexure J (including amendment 1 issued in March 2021) and is being planned to meet the expected number of passengers during normal peak hours and to meet relevant requirements for emergency evacuation.

6.2.4 Interchange Stations

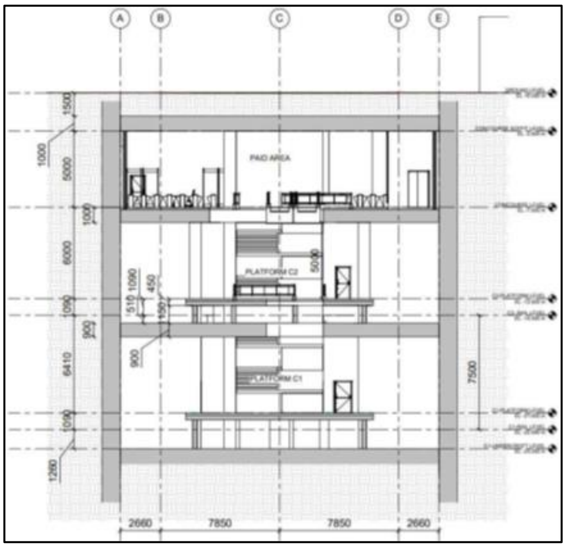
(1) Transfer Station between corridor 1 and 2

The two planned transfer stations for the corridors 1 and 2 are the Patna Junction underground station and the Khemni Chak elevated station. The Patna Junction underground station will be connected to each corridor by stack platform, while the Khemni Chak elevated station will be connected to each corridor by parallel platform that makes it easier for passengers to transfer between the two corridors. The Khemni Chak elevated station is twice width as the other elevated stations. It is possible that the evacuation route to be longer than at other stations. Therefore, evacuation safety should be validated.

Table 6-8: Outline of Interchange Station

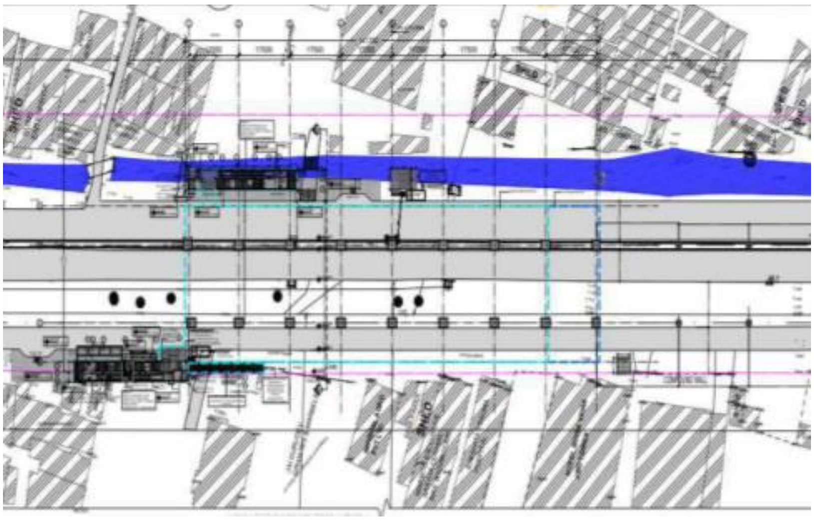
Station name	Interchange corridor	Type
Patna Junction	Corridor-1, Underground	Stack Platform
	Corridor-2, Underground	
Khemni Chak	Corridor-1, Elevated	Parallel Platform
	Corridoe-2, Elevated	

Source: DPR



Source: DPR

Figure 6-7: Section Drawing: Patna Junction Interchange Station



Source: DPR

Figure 6-8: Site Plan Drawing: Khemni Chek Interchange Station

(2) Transfer Station with Indian Railways Station

There are two existing transfer stations with Indian Railways (IR).
Patna Junction Underground Station (Corridor 1 and 2) and Rajendra Nagar Underground Station (Corridor 2).
Patna Junction underground station is located to the north side of the IR Patna station that is planned to be connected to the IR Patna station plaza by an underpass.
Similarly, Rajendra Nagar station is planned to be connected to the station plaza of IR Rajendra Nagar station through an underpass. These are allowing passengers to reach the station plaza without crossing the road on ground.
However, since both stations have only one underpass connect to the IR Station plaza, the underpass width should be adjusted to meet the expected future demand for transfers. In addition, the redevelopment of the plaza in front of the IR Patna station is planned for Patna Junction station in the future, the layout of entrances and exits should be carefully coordinated with the redevelopment plan so as not to impair the convenience of transfers.

6.2.5 Disaster control

(1) Flood control measure

In the Basic design, the subway entranced are planed that raised 450mm above the level of the sidewalk above ground to prevent water from flowing into the underground station in case of flooding. However, considering the expected increase in the number of cyclones and typhoons caused by global warming and the occurrence of torrential rains, it is recommended that watertight panels be installed at the station entrances to further prevent water inflow during flooding.

(2) Anti- earthquake measures

There was no major damage to buildings due to previous earthquakes in Patna that has been confirmed. The following measures plan to prepare for the expected earthquake level are confirmed.

Underground stations
The underground station is planned seismic design for considering the interaction between the ground and the station structure and the effects of earthquakes. The shaking of underground structures is significantly damped by forces acting in the same direction as the ground. Therefore, the interior finishing of the underground station building is regarded as a secondary member that is not subject to seismic forces and Secondary members will be designed as the seismic forces affect is nothing to them. Therefore, separate seismic measures are not envisaged for the secondary components.

Elevated stations
The Elevated station is planned to be seismic design same as underground stations, and no separate earthquake countermeasures are envisaged for secondary member in terms of interior and exterior. However, some buildings in Patna city were damaged by the earthquake in the past that were felt off or falling off interior and exterior finishing materials.

Therefore, as additional safety measures, the following reinforcements are recommended to prevent the interior and exterior finishing materials from falling out.

・Providing anti-sway bars on ceiling frames
・Using Light weight ceiling
・Considering the angle of displacement between layers of exterior finishing installation.

・Prevent block walls from collapsing, ensure that small columns and lintels are properly positioned and fixed to the structure with reinforcement bars.

・Using fall prevention implement for station equipment

7. Inter-Modal Integration

7.1 Overview of Existing Studies

Generally, the metro system is incomplete without the connectivity with existing public transport. Intermodal integration is crucial for success of multimodal transport system. Intermodal integration involves integrated public transit network planning, development of footpath and feeder networks, development of intermodal stations to minimize delay/transfers, among others.

CMP2018 provides the proposal on bus rationalization and feeder service planning to enhance the connectivity between metro and existing public transport. The existing route network requires substantial modification to increase the catchment, and to connect with metro corridors and scheduling plan. There is an urgent requirement of a well-planned Bus Network & Bus Transport Facilities to cater to the metro system. The public transport strategy for Patna is derived considering all the factors of existing situation and the best possible reorganization factoring all components of an efficient and sustainable system. Not all the routes can operate buses but identified routes may operate these mini buses after removing encroachment and widening of roads along with newer metro and ring road development.

Feeder services are required to utilize the high capacity of the metro system and support high frequency services in the main corridors. A feeder service can often provide a more frequent and useful local service and thus generate more local journeys if there is potential in the market. With high mode shift toward s E-rickshaw in Patna, these can form basis of a feeder network for mass transit systems.

CMP2018 also pointed out that the connectivity of public transport may further improve with the integrated fare system which comprises single ticketing facility for all public transport modes.

In Metro Policy 2017, the integration of various modes in urban area is addressed. Integration between various modes like roadway, railways, non-motorized transport, and other modes of transport enhances the mobility of the citizens and encourages public transport. Existing railway suburban services or circular rail systems, if any, should be integrated with the metro rail and other transport modes. It is imperative that the various service providers collaborate through signing of a Memorandum of Understanding (MoU), to provide seamless integration between the various modes.

The following photos illustrate the situation in front of Patna Junction Railway Station that observed by JST during the field survey in June 2022. The station plaza (shown as B and C) in front of the station is used for private car parking, where could be used for public transport connections. The roundabout beneath a flyover is used as un-organized bus stops and autorickshaw riding zones, which should be improved.

A. Layout of Patna Junction Railway Station with indications on parking area

B. Unorganized parking and traffic congestions in front of the station

C. Curent station front from another angle

D. Current station front from another angle

Source: JST

Figure 7-1: Patna Junction Railway Station Front

In comparison, the Bandra (W) Station in Mumbai is a good example on how regulation of Three-Wheelers and shift of feeder services can change the station front over the years.

7.2 Reviews of Existing Studies and Proposals for Improvement

Regarding integration of modes, DPR (Chapter 7) presents the following proposed measures to enhance connectivity between Metro and the existing public transport systems. The implementation of these policies should be secured by the Transport Department, Urban Development and Housing Department of the State Government of Bihar, PMRCL and relevant stakeholders.

Table 7-1: Measures to Strengthen Connectivity between Metro and Existing Transport System (proposed in DPR)

Focal Items	Policy/ Actual Idea
Ensure the intermodal integration with existing systems	Presented sidewalk and elevator improvements around six major stations (Danapur, Patna St, Mithapur, Rejendra Nagar, ISBT and Khmni Chak) with rail and bus terminal connections, ensuring the connection with entrances, measures to relocate squatters, and preparing space for buses and cabs to board and alight.
Feeder service concept	0.5 to 1 km on foot, but beyond that, policy to share by bus, bicycle, 3W, etc., with boarding and disembarking/connecting functions at each station.
Introduce feeder buses system	Establish feeder bus service with a route length of 3 to 5 km at 20 of 25 stations in total, operating every 6 to 20 minutes; estimated that 97 minibuses (35 seats) will be necessary for FY2041.
Introduce public share cycles	Estimated demand for a total of 1,700 units as of 2041

Focal Items	Policy/ Actual Idea
Introduce station surrounding facilities	Development of bus stops, car parking, bicycle parking, signages, etc.
Other measures for intermodal integration	Support for people with disability, barrier-free facilities, adjustment of operation schedule, consolidation/reduction of overlapping bus routes to avoid competition with Metro, fare coordination, provision of operation/transfer information and MaaS /ITS support, and organizational coordination to accelerate these efforts.

Source: DPR

The JST comments on those integration policies for the following:

- The public share bicycle services will be valuable for a feeder, however, various types of share mobility and providers have been proposed recently. It is better not to stick using bicycle for share services.
- The fare integration in the DPR proposes payment media integration among various transport services.
- Physical improvement at and around the stations should be incorporated into the metro station construction contract, therefore, the design should be done in the station design process for materialization. These designs will require the approval of the Urban Development and Housing Department of the Bihar Government.
- Transport Department of the Bihar Government should approve various transport service integration and rationalization. City Authority should be involved into the fare policy. Such policy approval requires unexpected time and difficulties with opposition groups and stakeholders.

JST proposes a roadmap of the intermodal integration policies in order to secure the implementation. The roadmap shows the policy and steps for implementation, entities in charge, expected months, and depicted time schedules as bar charts. The time schedule for implementation steps were adjusted to the opening of the metro for the Corridor 2 Phase1. The barchart suggests the following:

- JST expects the planning stage for the feeder bus services for the Corridor 2 Phase 1 should be started in the early months of 2023 to be ready for the metro opening.
- JST can suggest that policy development and arrangement of the smart ticketing must be started in 2022, otherwise the fare integration cannot be ready for the metro opening.
- This roadmap is assuming an ideal condition that PMRCL has proper personnel and technical capacity to handle those policies.
- The integration policy should be flexible to the market and passenger demand. JST proposed proper period of monitoring, revision and improvement procedure after the opening of the services.

Table 7-2: A Roadmap for Intermodal Integration Policies (proposed by JST)

					2022				2023				2024				2025				2026				2027				2028			
Cat.	Items	Activities	Entities in Charge	Period	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Expected event																																
		Opening of Corridor 2 Phase1 (provisional)	NA																													
		Opening of Corridor 2 Phase2 (provisional)	NA																													
		Opening of Corridor 1 (provisional)	NA																													
Physical Improvement at Major 6 stations																																
		Design & Coordination for Corridor 2-P1 (ISBT, Khem Chak)	PMRCL/UDHD	12			Design																									
		Implementation of Corridor 2-P1	PMRCL	12												Installation																
		Feeder bus coordination for corridor 2-P1	PMRCL/DoT	33					Policy approval						Procurement				Tes	Operation							Further monitoring					
		Design & Coordination for Corridor 2-P2 (Raj Nag, Patna St.)	PMRCL/UDHD	12					Design																							
		Implementation of Corridor 2-P2	PMRCL	12													Installation															
		Feeder bus coordination for corridor 2-P2	PMRCL/DoT	33						Policy approval																						
		Design & Coordination for Corridor 1 (Danapur, Mithapur)	PMRCL/UDHD	12											Design																	
		Implementation of Corridor 1	PMRCL	12																	Installation											
		Feeder bus coordination for corridor 1	PMRCL/DoT	33										Policy approval																		
Feeder Service Provision																																
	Bus services (case for Corridor 2-1)																															
		DoT approval for New route re-organization	PMRCL/DoT	18					Policy approval																							
		Employment and Procurement	PMRCL	12																												
		Test run/System/Installation	PMRCL/Operator	3																												
		Monitoring/Promotion	PMRCL/Operator	18																Promotion												
	Shared Mobility Services (case for Corridor 2-1)																															
		Planning/Design/Approval	PMRCL/DoT	6																												
		Procurement/Installation	PMRCL	6																												
		Monitoring/Operation/Promotion	PMRCL/Operator	18																Promotion												
Physical Infrastructure																																
		Planning/Design/Approval	PMRCL/UDHD	12					Design																							
		Execution	PMRCL	12												Execution																
		Follow-up, coordination	PMRCL/UDHD	12+																Follow-up												
General Coordination (case for Corridor 2-1)																																
	Operational Integration																															
		Route-coordination, Policy Development	PMRCL/DoT	12+											Policy																	
		Enforcement and Moniroting	PMRCL/DoT	12+															Enforcement				Further monitoring									
	Fare Integration																															
		Smartcard ticketing policy confirmation	DoT/PMRCL/Regional Authority	12				Policy																								
		Budget for bus/feeder services providers	DoT/PMRCL	12								Budgetization																				
		Procurement and Installation / Monitoring	PMRCL/Operator	12												Procurement																
		Monitoring, Assessment, and policy revision	DoT/PMRCL	12+															Enforcement				Further monitoring									
	Information integration																															
		Policy development and planning	DoT/PMRCL/City	6																												
		Budget for implementation	DoT/PMRCL	12								Budgetization																				
		Procurement and Installation	PMRCL/Operator	12												Procurement																
		Monitoring, Assessment, and policy revision	DoT/PMRCL	12+															Enforcement				Further monitoring									
	Institutional Integration																															
		Policy development and planning	DoT/PMRCL/Regional Authority	6																												
		Budget for implementation	DoT/PMRCL	12								Budgetization																				
		Implementation	DoT/Regional Authority	12												Procurement																
		Monitoring, Assessment, and policy revision	DoT/Regional Authority	12+															Enforcement				Further monitoring									

Source:JST

8. Train Operation Plan

8.1 Overview of Existing Studies

8.1.1 Operation Philosophy

The basic policy of train operation is as follows.

1) The train intervals match demand with a few exceptions.
2) The operation meets the demand for passengers economically both for peak and off-peak hours.
3) All the staff engage both for operation and maintenance.

8.1.2 Concept of Train Operation Plan

The concept of train operation plan is as follows.

1) The train operation is 19 hours/day from 5:00 to 24:00, and stopping time at station is 20 - 30 seconds.
2) The time from 24:00 to 5:00 is secured for maintenance for rolling stocks and facilities.
3) Margin time for the operation is 5 % of the total (including 8 % in coasting operation)
4) Scheduled speed is as follows.
   Corridor 1 (Danapur – Kemni Chak) : 35 km/h (Estimated value in DPR)
   Corridor 2 (Patna Station – New ISBT) : 35 km/h (Estimated value in DPR)
5) Time for turn-buck at end stations is as follows.
   Corridor 1 (Danapur – Kemni Chak) : 3 min. (Automatic turn-back without driver)
   Corridor 2 (Patna Station – New ISBT) : 3 min. (Automatic turn-back without driver)

8.1.3 Train Formation

The PMRCL assumes the following train formation.

1) Train formation
   - DMC : Driving Motor Car
   - MC : Motor Car
   - TC : Trailer Car
   - 3-car train set : DMC + TC + DMC
   - 6-car train set : DMC + TC + MC + MC + TC + DMC

2) Passenger capacity (@ 6 passengers per square meter of standee area)
   - DMC : 282 (42 seated + 240 standing)
   - MC/TC : 298 (50 seated + 248 standing)
   - 3-car train set : 862
   - 6-car train set : 1,756

   Car width 2.9m changed by PMRCL based on MOHUD guideline in July 2022
   - DMC : 252 (42 seated + 210 standing)
   - MC/TC : 268 (50 seated + 218 standing)
   - 3-car train set : 772

- 6-car train set : 1,576

3) Passenger capacity (@ 8 passengers per square meter of standee area)
   - DMC : 362 (42 seated + 320 standing)
   - MC/TC : 381 (50 seated + 331 standing)
   - 3-car train set : 1,105
   - 6-car train set : 2,248

   Car width 2.9m changed by PMRCL based on MOHUD guideline in July 2022
   - DMC : 322 (42 seated + 280 standing)
   - MC/TC : 341 (50 seated + 291 standing)
   - 3-car train set : 985
   - 6-car train set : 2,008

8.1.4 Future Prediction of Operation Plan

The PMRCL assumes the future operation plan as follows.

Table 8-1: Future Operation Plan (Corridor 1)

Section	Year	Operation interval (min)	No. of rakes		Total no. of cars	PHPDT
		Peak	3-car train	6-car train		
(Corridor 1) Danapur – Khemni Chak	2024	4.3	11 (2)	3 (0)	51	14,516
	2031	3.5	7 (2)	10 (2)	81	23,127
	2041	3.3	7 (1)	11 (2)	87	25,323
	2051	3.0	3 (4)	17 (0)	111	32,011

Source: DPR ( ) is number of reserved train

Table 8-2: Future Operation Plan (Corridor 2)

Section	Year	Operation interval (min)	No. of rakes		Total no. of cars	PHPDT
		Peak	3-car train	6-car train		
(Corridor 2) Patna Junction – New ISBT	2024	4.6	13 (2)	0	39	11,252
	2031	3.5	17 (3)	0	51	17,862
	2041	3.3	18 (3)	0	54	19,507
	2051	3.0	20 (3)	0	60	22,083

Source: DPR ( ) is number of reserved train

8.2 Reviews of Existing Studies and Proposals for Improvement

8.2.1 PHPDT by Demand projection

As results of Demand Projection, PHPDT is revised as follows. Except in 2026 Corridor 1, other PHPDT values are reduced from DPR.

Table 8-3: Revised PHPDT for Stations of Metro Corridor 1

Year		2026		2031		2041		2051	
Station		To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur
Danapur	Saguna More	2,469	1,967	3,243	2,645	3,850	3,127	5,016	3,975
Saguna More	RPS More	7,030	5,241	9,233	7,000	10,994	8,140	14,606	10,337
RPS More	Patliputra	9,431	7,112	12,352	9,490	14,648	11,038	19,412	14,073
Patliputra	Rukanpura	11,003	7,922	14,394	10,589	17,053	12,329	22,616	15,707
Rukanpura	Raja Bazar	13,807	10,719	18,628	14,026	20,877	16,455	26,875	21,653
Raja Bazar	Patna Zoo	15,061	12,139	20,538	15,735	22,586	18,827	28,620	25,071
Patna Zoo	Vikas Bhawan	15,515	12,573	21,193	16,282	23,119	19,609	29,111	26,182
Vikas Bhawan	Vidyut Bhawan	15,547	12,541	21,149	16,326	22,831	19,897	28,441	26,852
Vidyut Bhawan	Patna Station	14,090	12,618	19,230	16,354	20,323	20,314	25,111	27,625
Patna Station	Mithapur	11,881	11,859	15,551	16,388	17,440	18,919	22,406	25,325
Mithapur	R. Nagar	9,757	8,824	12,861	12,121	14,167	14,412	18,052	19,896
R. Nagar	Jaganpura	8,005	6,789	10,618	9,040	11,733	11,070	14,719	15,490
Jaganpura	Khemni Chak	7,550	6,164	10,042	8,192	11,034	10,086	13,755	14,243
MAX. PHPDT		**15,547**		**21,193**		**23,119**		**29,111**	

Source: JST

Table 8-4: Revised PHPDT for Stations of Metro Corridor 2

Year		2026		2031		2041		2051	
Station		To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station
Patna Station	Akashvani	6,072	4,500	8,110	6,233	8,641	7,210	8,796	8,656
Akashvani	Gandhi Maidan	7,468	6,026	9,878	8,404	10,584	9,728	10,894	11,676
Gandhi Maidan	PMCH	8,778	7,196	11,423	9,844	12,284	11,355	12,759	13,460
PMCH	University	9,681	7,862	12,482	10,624	13,514	12,157	14,254	14,181

Year		2026		2031		2041		2051	
Station		To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station	To Zero Mile	To Patna Station
University	Moin Stadium	10,709	9,429	13,753	12,304	15,087	13,761	16,210	15,691
Moin Stadium	Rajendra Nagar	10,632	10,119	13,611	13,094	14,879	14,658	15,995	16,634
Rajendra Nagar	Malahi Pakri	9,994	10,758	12,538	14,167	13,756	15,780	14,839	17,790
Malahi Pakri	Khemni Chak	9,264	9,755	11,541	12,725	12,568	14,301	13,487	16,074
Khemni Chak	Bhoot Nath	8,665	8,379	10,751	10,710	11,421	12,200	11,989	13,787
Bhoot Nath	Zero Mile	7,874	7,346	9,843	9,124	10,419	10,333	10,788	11,596
Zero Mile	New ISBT	5,648	5,550	6,723	6,696	7,227	7,351	7,411	7,817
MAX. PHPDT		**10,758**		**14,167**		**15,780**		**17,790**	

Source: JST

8.2.2 Influence of Car Width Reduction

Car width is changed from 3.2n (in DPR) to 2.9m (in MOHUA guideline) by PMRCL in July 2022. Capacity of rolling stock is reduced roughly 10% by the car width reduction. Confirmation about influence by the car width reduction is as follows including improvement for train operation.

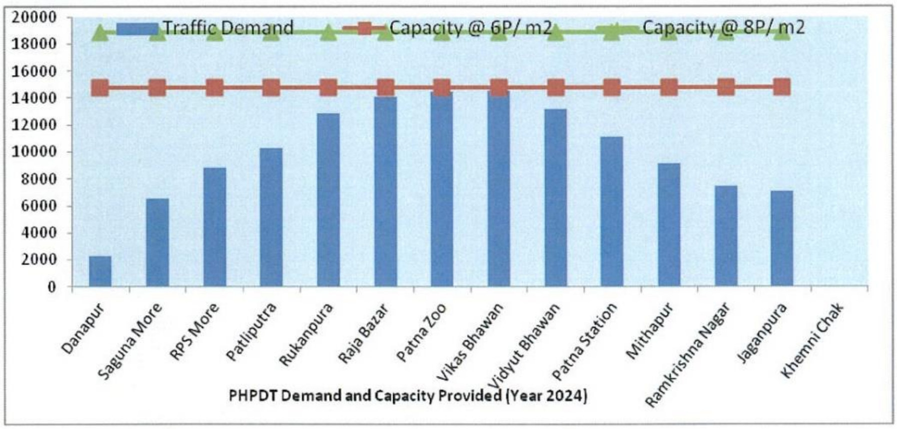
1) Change of Train Operation
   Corridor 1 3 cars : 12, 6 cars : 3 (in DPR) - - - > 3 cars : 10, 6 cars : 4
   Corridor 2 3 cars : 12 (in DPR) - - - > 3 cars : 11
   Headway 4.3, 4.6 min. (in DPR) - - - > 5.0 min.

2) Capacity of Corridor 1 at peak time (Ratio to dense crush load)
   Number of trains / hour 3 cars : 10 x (60/70) = 8.6, 6 cars : 4 x (60/70) = 3.4
   Ratio to dense crush load 15547 / (985 x 8.6 + 2008 x 3.4) = 1.02 = 102% based on Demand Projection
   (Ratio to dense crush load 14516 / (985 x 8.6 + 2008 x 3.4) = 0.95 = 95% based on DPR)

3) Capacity of Corridor 2 at peak time (Ratio to dense crush load)
   Number of trains / hour 3 cars : 11 x (60/55) = 12.0
   Ratio to dense crush load 10758 / (985 x 12.0) = 0.91 = 91% based on Demand Projection
   (Ratio to dense crush load 11252 / (985 x 12.0) = 0.95 = 95% based on DPR)

4) Reserved Train and Total number of cars
   Reserved train 3 cars : 3 trains, 6 cars : 1 train
   Total number of cars 3 x (10 + 11 + 3) + 6 x 5 = 102 cars (unchanged from DPR)

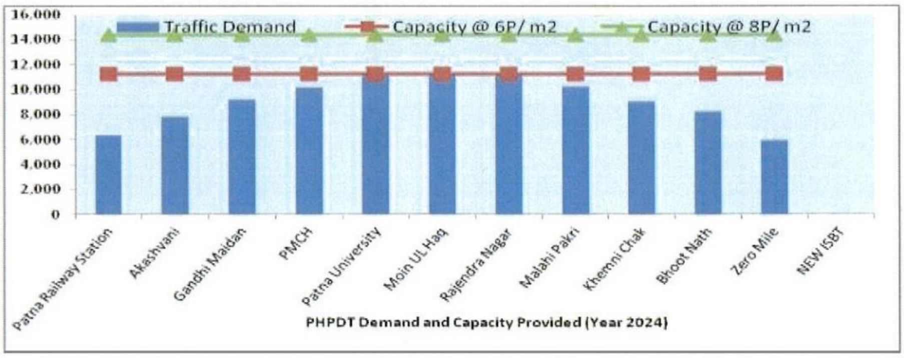
Ratio to dense crush load (@ 8 passenger/m²) at peak time on Corridor 1 is 102%, and Corridor 2 is 91%. Generally this confirmation should be based on crush load (@ 6 passenger/m²), however passenger demand of Patna Metro are shown in **Figure 8.1** (Corridor 1) and **Figure 8.2** (Corridor 2), the busiest sections are between limited number of stations. DPR in 2024 and Demand Projection in 2026 have the same tendency. Ratio to dense crush load 91 - 102% at peak time is acceptable.



Source: DPR

Figure 8-1: Corridor 1 Passenger Demand in 2024 (Lines of Capacity are based on DPR values)

It has the same tendency as Demand Projection in 2026.



Source: DPR

Figure 8-2: Corridor 2 Passenger Demand in 2024 (Lines of Capacity are based on DPR values)

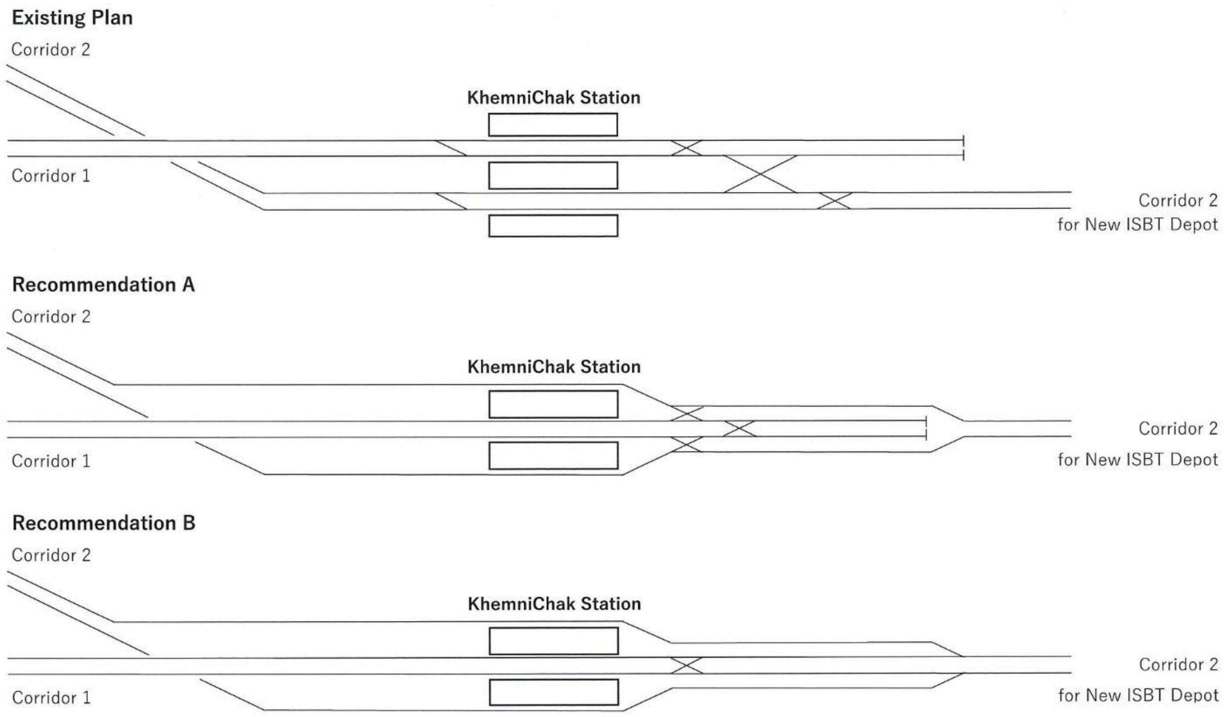
It has the same tendency as Demand Projection in 2026.

8.2.3 In/Out Depot Trains on Corridor 2

Patna Metro has only one depot at the end of Corridor 2 New ISBT. Corridor 1 in/out depot trains must run on Corridor 2 (ChemniChak – New ISBT) without passenger service, it is not only in early morning and midnight, but also before and after peak time. Junction station of both corridor Chemnichak should have good alignment to prevent interference of each trains.

Existing plan of alignment is shown in **Figure 8.3**, there are some routes across main line, waiting time on main line or at platform will occur. JST recommendations to prevent interference and reduce waiting time which are shown in this figure. Recommendation A (model: Shirokane Takanawa station of Tokyo

Metro) is possible to choose all route. Recommendation B (model: Mizonokuchi station of Tokyu Railway) is solution with minimum additional turnout.



Source: JST

Figure 8-3: Existing Plan and Recommendation for Alignment of ChemniChak

However, construction of ChemniChak station has already started, it is very difficult to change alignment including viaduct. Alternative recommendation is shown in **Figure 13.5** and **Figure 13.6**, it is additional storage track outside depot to reduce number of in/out depot trains.

8.2.4 Concerns for "3 and 6 Cars" Mixed Operation

Train operation of Corridor 1 is "3 and 6 cars" mixed operation, there are some concerns as follows.

1) Mixed operation is existing (e.g. 4 and 6 cars, 6 and 8 cars in DMRC), but 3 and 6 cars train length is doubled and half different. The short train will be crowded and boarding/alighting time will be longer (passenger waiting at the end of platform will rush for boarding), so there are possibility that on-time operation cannot be maintained.
2) As **Table 8-1** and **Table 8-2**at the beginning in 2024, there are no reserved train of 6 cars configuration. It means 6 cars train cannot be operated not only failed condition but also during monthly inspection of 6 cars train. It will cause confusion on a daily basis.
3) Initial cost of purchasing rolling stock will increase to prepare spare trains for 3 cars and 6 cars both.
4) Rescue operation must be considered for failed condition of one train on maximum gradient. The ramp from underground to elevated is 40/1000 gradient. 3 cars train cannot push 6 cars failed train on 40/1000 gradient.

As described below **8.2.5** and **8.2.6**, "3 and 6 cars" mixed train operation is possible. However, it is necessary to take measure to prevent problems. For example, passenger information at platform about number of vehicles of next train, balanced arrangement of "6 cars" train operation on Corridor 1, examination of tractive effort increasing at rescue operation, and so on.

8.2.5 Quantity of Rolling Stock

Train configuration for each corridor and each year is considered as follows without increasing total number of cars in DPR.

Table 8-5: Number of Trains and Vehicles

	2026		2031		2041		2051	
	3 cars	6 cars	3 cars	6 cars	3 cars	6 cars	3 cars	6 cars
Corridor 1	10	4	6	12	0	16	0	18
Corridor 2	11	0	15	0	17	0	19	0
Reserved	3	1	3	2	3	2	3	3
Total trains	24	5	24	14	20	18	22	21
Total vihecles	102		156		168		192	

Source: JST

- Total number of cars are same as DPR
- 4 sets of "3 cars" trains will be converted to 2 sets of "6 cars" trains in the future (around 2041). Rolling stock design should be included preparation for conversion of train configuration. In particular DMC front design (converted from evacuation door to gang way) and TCMS.

8.2.6 Rescue Operation on Maximum Gradient

Rescue scenario 6 cars dense crush load train failed on maximum gradient 4%.
3 cars tare weight train push the failed train, is it possible ?

1) Condition of calculation based on **Table 11.2**.
   Tare weight 3 cars : 124.3 t, 6 cars : 245.2 t
   Gross weight 3 cars : 174.5 t, 6 cars : 347.6 t
   at dense crush load = seated + standing 8 persons/sqm
   Inertia mass DMC, MC : tare weight + 10%, TC : tare weight + 5%
   Inertia mass + tare weight 3 cars : 134.7 t, 6 cars : 265.7 t
   Inertia mass + gross weight 3 cars : 184.9 t, 6 cars : 368.1 t
   Starting acceleration 1.2 m/s/s
   Starting resistance 0.04 kN/t
   Maximum gradient 4 %
2) Tractive effort of 3 cars at tare weight
   134.7 x 1.2 + 0.04 x 124.5 = 166.6 kN
3) Acceleration of rescue operation on 4% gradient
   {166.6 – (124.3 + 347.6) x 0.04 x 9.8} / (134.7 + 368.1) < 0 m/s/s - - - N/A
   It should be <u>more than 0.1 m/s/s</u>
4) Additional scenario 1 : <u>Passengers get off the failed train</u>
   {166.6 – (124.3 + 245.2) x 0.04 x 9.8} / (134.7 + 265.7) = 0.05 m/s/s - - - N/A
5) Additional scenario 2 : Passengers get off the failed train + tractive effort increase 15%
   {191.6 – (124.3 + 245.2) x 0.04 x 9.8} / (134.7 + 265.7) = 0.11 m/s/s - - - **OK**

Adhesion : 191.6 / (42 x 2 x 9.8) = 0.23 = 23% - - - **Acceptable**

Sand to prevent slip should be prepared at gradient wayside for rainy condition.

8.2.7 Hourly Train Operation Plan

Hourly Train Operation Plan for each corridor and each year is considered as follows.

Table 8-6: Hourly Train Operation Plan : Corridor 1 (Danapur – Khemni Chak)

Time of Day	2026			2031			2041		2051	
	Headway in min.	3 cars	6cars	Headway in min.	3 cars	6 cars	Headway in min.	6 cars	Headway in min.	6 cars
5 – 6	15	4		15		4	15	4	15	4
6 – 7	7.5	8		6		10	5.75	10.25	5	12
7 – 8	6	8.3	1.7	5	1.7	10.3	5	12	4.5	13.5
8 – 9	**5**	**8.6**	**3.4**	**4**	**5**	**10**	**4.5**	**13.5**	**4**	**15**
9 –10	**5**	**8.6**	**3.4**	**4**	**5**	**10**	**4.5**	**13.5**	**4**	**15**
10-11	6	8.3	1.7	5	1.7	10.3	5	12	4.5	13.5
11-12	7.5	8		6		10	5.75	10.25	5	12
12-13	7.5	8		6		10	5.75	10.25	5	12
13-14	7.5	8		6		10	5.75	10.25	5	12
14-15	7.5	8		6		10	5.75	10.25	5	12
15-16	7.5	8		6		10	5.75	10.25	5	12
16-17	6	8.3	1.7	5	1.7	10.3	5	12	4.5	13.5
17-18	**5**	**8.6**	**3.4**	**4**	**5**	**10**	**4.5**	**13.5**	**4**	**15**
18-19	**5**	**8.6**	**3.4**	**4**	**5**	**10**	**4.5**	**13.5**	**4**	**15**
19-20	6	8.3	1.7	5	1.7	10.3	5	12	4.5	13.5
20-21	7.5	8		6		10	5.75	10.25	5	12
21-22	7.5	8		6		10	5.75	10.25	5	12
22-23	10	6		7.5		8	7.5	8	7.5	8
23-24	15	4		15		4	15	4	15	4
Trains at peak		10	4		6	12		16		18
Total no. of trains /direction/day		145.6	20.4		26.8	177.2		200		226
		166			204					

Source: JST

Table 8-7: Hourly Train Operation Plan : Corridor 2 (Patna Junction – New ISBT)

Time of Day	2026			2031			2041		2051	
	Headway in min.	3 cars		Headway in min.	3 cars		Headway in min.	3 cars	Headway in min.	3 cars
5 – 6	15	4		15	4		15	4	15	4
6 – 7	7.5	8		6	10		6	10	5	12
7 – 8	6	10		5	12		4.5	13	3.75	16
8 – 9	**5**	**12**		**3.75**	**16**		**3.25**	**18.5**	**3**	**20**
9 –10	**5**	**12**		**3.75**	**16**		**3.25**	**18.5**	**3**	**20**
10 –11	6	10		5	12		4.5	13	3.75	16
11 –12	7.5	8		6	10		6	10	5	12
12 –13	7.5	8		6	10		6	10	5	12
13 –14	7.5	8		6	10		6	10	5	12
14 –15	7.5	8		6	10		6	10	5	12
15 –16	7.5	8		6	10		6	10	5	12
16 –17	6	10		5	12		4.5	13	3.75	16
17 –18	**5**	**12**		**3.75**	**16**		**3.25**	**18.5**	**3**	**20**
18 –19	**5**	**12**		**3.75**	**16**		**3.25**	**18.5**	**3**	**20**

Time of Day	2026			2031			2041		2051	
	Headway in min.	3 cars		Headway in min.	3 cars		Headway in min.	3 cars	Headway in min.	3 cars
19 –20	6	10		5	12		4.5	13	3.75	16
20 –21	7.5	8		6	10		6	10	5	12
21 –22	7.5	8		6	10		6	10	5	12
22 –23	10	6		7.5	8		7.5	8	7.5	8
23 –24	15	4		15	4		15	4	15	4
Trains at peak		11			15			17		19
Total no. of trains /direction/day		166			208			222		256

Source: JST

8.2.8 Operation Distance of Trains and Cars

Vehicle kilometer for each corridor and each year is calculated as follows.

Table 8-8: Vehicle Kilometer : Corridor 1 (Danapur – Khemni Chak)

	2026		2031		2041		2051	
	3 cars	6 cars	3 cars	6 cars		6 cars		6 cars
Length km	17.1	17.1	17.1	17.1		17.1		17.1
No. of working days per year	340	340	340	340		340		340
No. of trains per day each way	145.6	20.4	26.8	177.2		200		226
Daily train km	4980	698	917	6060		6840		7729
Annual train km (10^5 km)	16.93	2.37	3.12	20.60		23.26		26.28
Annual vehicle km (10^5 km)	50.80	14.24	9.35	123.62		139.54		157.67
	65.04		132.97		139.94		157.67	

Source: JST

Table 8-9: Vehicle Kilometer : Corridor 2 (Patna Junction – New ISBT)

	2026		2031		2041		2051	
	3 cars		3 cars		3 cars		3 cars	
Length km	13.6		13.6		13.6		13.6	
No. of working days per year	340		340		340		340	
No. of trains per day each way	166		208		222		256	
Daily train km	4515		5658		6038		6963	
Annual train km (10^5 km)	15.35		19.24		20.53		23.67	
Annual vehicle km (10^5 km)	46.05		57.71		61.59		71.02	
	46.05		57.71		61.59		71.02	

Source: JST

9. Signaling and Telecommunication

9.1 Overview of Existing Studies

9.1.1 Signaling Facilities

(1) Train Control System (CBTC)

PMRCL plans to introduce CBTC (Communication Based Train Control system), the train control system utilizing radio communication. CBTC conforms to IEEE 1474.1, IEEE 1474.2, IEEE 1474.3, IEC 62267, IEC 62278, IEC 62425, IEC 62290-1, IEC 62290-2, and IEC 62290-3, International standards. CBTC also conforms to the Indian regulation for licensing and radiation of frequency bands as per DoT, TRAI, and WPC guidelines. (However, CBTC will use the ISM band (2.4GHz) and won't require the license.)

The main technical specifications of CBTC for PMRCL are shown in the below table.

Table 9-1: The main technical specifications of CBTC

Main System/Device/ Equipment	The Main technical specifications
Automatic Train Supervision (ATS) subsystem	ATS subsystem enables monitoring and control of trains at OCC/BCC/DCC/SCRs. The main technical specifications of ATS subsystem are planned as follows: • Train describer, monitoring, and continuous regulation of train movement • Automatic and manual route setting • Automatic and manual train regulation • Short loop management • Timetable management • Display and plotting of train journey graph • Information transmission for display on PIDS and announcement on PA system • Monitoring and control for CBTC Equipment (ATS, ATP, ATO, and CBI device) • Operation assistance (alarm output and system-operating data storage, etc.) • The development process of ATS conforms to SIL 2 level of CENELEC standards EN 50126, EN 50128, and EN 50129.
Automatic Train Protection (ATP) subsystem	ATP subsystem is the primary subsystem in CBTC and enables its safety with the fail-safe principle. The main technical specifications of ATP subsystem are planned as follows: • Primary train detection method for CBTC-equipped train • Train location detection by onboard device, train location information transmission through radio communication (from onboard devices to ground facilities) • Signals and line information transmission through radio communication (from ground facilities to onboard devices) • The track-related speed profile (ATP speed profile) generation by continuous computation from the line data and the train data • Safety train separation (ATP gives the movement authority based on the moving block principle.) • Speed restriction section monitoring • Monitoring of maximum permitted speed on the line • Maximum permissible train speed monitoring • Constant speed monitoring • Monitoring of maximum speed set by the onboard unit • Monitoring of braking curve for defined target point (stopping point or speed restriction section, etc.)

	• Monitoring of stopping point to ensure that the train doesn't run into the hazard point located beyond • Monitoring for stopping the train in the target area of the station (ATP monitors the train to stop within the stopping window. The train is the application of FSB (Full Service Brake) or EB (Emergency Break) in case of breach of ATP speed profile.) • Cab signaling • The onboard device is redundant. Therefore, the changeover in the event of failure of one unit is automatic without the train operator's intervention. • ATP conforms to SIL 4 level of CENELEC standards EN 50126, EN 50128, and EN 50129.
Automatic Train Operation (ATO) subsystem	ATO subsystem enables automatic train operation between stations under ATP subsystem, which ensures safety. The main technical specifications of ATO subsystem are planned as follows: • Door automatic opening (after the train station stops at the station) • Automatic train operation (by closing doors and pressing the start button after the train is ready to start) • Train operation management according to headway or timetable • Station dwell time control • Automatic turn-back process control at the terminal station (automatic reversal control, etc.) • The development process of ATO conforms to SIL 2 level of CENELEC standards EN 50126, EN 50128, and EN 50129.

Source: DPR, JST

(2) Computer-Based Interlocking Device and Other Signaling Facilities

The main technical specifications of Computer-Based Interlocking Device and Other Signaling Facilities for PMRCL are shown in the below table.

Table 9-2: The main technical specifications of CBI and Other Signaling Facilities

Main System/Device/ Equipment	The Main technical specifications
Computer-Based Interlocking (CBI) Device	The main technical specifications of CBI Device are planned as follows: • Train describer, monitoring, and continuous regulation of train movement at SCRs • Automatic and manual route setting at SCRs • Automatic and manual train regulation at SCRs • Line Side Signal control at SCRs • Electric point machine control at SCRs • Hot standby system • Built-in Block function • CBI conforms to SIL 4 level of CENELEC standards EN 50126, EN 50128, and EN 50129. • CBI also conforms to RDSO/SPN/192/2005, the Indian standard.
Train Detection Device (Digital Axel Counter)	The main technical specifications of Digital Axel Counter are planned as follows: • Secondary train detection method for CBTC-equipped train (Backup device in case of ATP failure) • Train detection method for nonCBTC-equipped train • In equivalent area to CBTC controllable area • The device consists of the wheel sensor, the indoor unit, the junction box in the field, and cables between the wheel sensor and the indoor unit.
Line Side Signal	The main technical specifications of Line Side Signal are planned as follows: • Secondary train operation method for CBTC-equipped train (Backup device in case of ATP failure) • Train operation method for nonCBTC-equipped train • At stations with CBIs for point protection (for bidirectional operation) • Also, at intermediate locations between New ISBT Depot exit and New ISBT station entry (for induction of trains to optimize headway)

	• LED type signal for high reliability and less maintenance effort • Line Side Signal conforms to RDSO/SPN/153/2011, the Indian standard.
Electric Point Machine	The main technical specifications of Electric Point Machine are planned as follows: • Non-trainable, high thrust, additional external mechanical locking, and 3φ-380V-415V AC electric type for mainline • Non-trainable, clamp type locking, additional external mechanical locking, and 3φ-380V-415V AC or 110V DC electric type for New ISBT Depot • Electric Point Machine conforms to IRS S24, the Indian standard.
Close Circuit Television (CCTV) System • Onboard CCTV ~ OCC(BCC), etc.	The main technical specifications of CCTV System (Onboard CCTV～OCC, etc.) are planned as follows: • Information transmission between the train and OCC/BCC/DCC/SCRs through CCTV Network (including radio network) • 5.8GHz (ISM band) for CCTV radio network (different from 2.4GHz for CBTC radio network) • CCTV network separate from CBTC network (considering the critical/vital nature of CBTC network) • CCTV MMIs at OCC/BCC/DCC/SCRs • Playback of selected camera recordings • Playback of recorded/logged events • Display on the CCTV MMIs and Large Video Screens

Source: DPR, JST

(3) Others

- OCC (Operation Control Centre) is planned at New ISBT Depot, and BCC (Backup Control Center) is planned at Patna Junction Station.
- CBI for Corridor 1 is planned at Danapur, Patna Zoo, and Khemni Chak stations. The CBI at Khemni Chak Station is planned to be used commonly with Corridor 2.
- CBI for Corridor 2 is planned at Patna Junction, Malahi Pakri, and New ISBT stations.
- The independent CBI is planned at New ISBT Depot.
- Vehicles of Corridor 1 are planned to run on some sections of Corridor 2 (between Khemni Chak Station (The terminal station of Corridor 1) and New ISBT Depot) to accommodate them at New ISBT Depot.
- The Mainline is planned to be secured by ATP. In addition, some track sections in New ISBT Depot (IBL shed, Workshop shed, PWL, ICS, ETU and RGM, Loading/Unloading track, Track machine, mobile welding plant siding, etc.) are planned to be manually secured. Other track sections in New ISBT Depot are planned to be secured by ATP.
- Shunting routes and Electric Points in New ISBT Depot are planned to be set by the workstation in the New ISBT Depot control room.
- Corridor 1 and 2 are planned to introduce CBTCs manufactured by the same supplier because vehicles of Corridor 1 are planned to run on some sections of Corridor 2 and CBTCs manufactured by different suppliers are not compatible.
- The uninterrupted power supply (UPS) is planned to be commonly used for Train Control System (CBTC), Signaling Facilities, Telecommunication Facilities, and AFC system and supply power backup for about 2 hours.
- All equipment rooms are planned to be air-conditioned.

9.1.2 Telecommunication Facilities

(1) Telecommunication Facilities

The main technical specifications of main Telecommunication Facilities for PMRCL are shown in the below table.

Table 9-3: The Main Technical Specifications of Telecommunication Facilities

Main System/Device/ Equipment	The Main technical specifications
Transmission System	The main technical specifications of Transmission System are planned as follows: • FOTS (Fiber Optics Transmission System) and IP-MPLS (IP-Multi-Protocol Label Switching) proven in Indian railway • Outdoor single-mode optical fiber cable (144 cores or more: backbone optical fiber cable) • Steel armored, fire-retardant, fire-resistance, low-smoke, and zero-halogen optical fiber cable • Two backbone optical fiber cables in loop configuration (redundancy configuration) • Optical fiber cable conforms to the latest TEC and RDSO specifications, the Indian standard. • High-capacity and redundant core routers (GEIP (Gigabit Ethernet IP)- MPLS) at four important locations (Core network consists of these routers interconnected in the near-full mesh configuration over 100GE interfaces.) • Redundant routers (GEIP (Gigabit Ethernet IP)- MPLS) at OCC/BCC/New ISBT Depot/all stations/any other location (Distribution network consists of these routers.) • Redundant layer-3 aggregation and layer-2/layer-3 switches or routers at New ISBT Depot/all stations/any other location (Access network consists of these switches and routers for all IP end devices and interfaces with all subsystems.) • Transmission System conforms to ITU-T, IEEE, IETF, and RFC, International standards, or internationally accepted requirements.
Telephone Exchange (PBX)	The main technical specifications of PBX (SIP (Session Initiation Protocol) Server) are planned as follows: • About 3,000 users and 750 concurrent calls (expandable up to 10,000 users, 1,500 concurrent calls) (SIP-PBX at OCC/BCC) • 500 subscribers and 250 concurrent calls (SIP PBX at New ISBT Depot) • 120 subscribers and 60 concurrent calls (SIP PBX at underground stations) • 60 subscribers and 30 concurrent calls (SIP PBX at elevated stations)
Mobile Radio Communication System (TETRA)	The main technical specifications of TETRA are planned as follows: • Land mobile radio open standard for digital trunked radio technology (Digital type, duplex operation) • Minimum 8 channels • 380-400MHz • Fixed radio set at OCC/BCC/stations. Handheld set for maintainers and security personnel • Information transmission through radio communication between trains, OCC/BCC/stations, and handheld sets • Radio base station equipment with redundant configuration • TETRA conforms to the Indian regulation for licensing and radiation of frequency bands as per DoT, TRAI, and WPC guidelines.
Public Address (PA) System	The main technical specifications of PA System are planned as follows: • Automatic announcements of the destination of the subsequent trains linked to ATS • Automatic announcements for safety and security • Extensive system suitable for emergency evacuation • Fire-resistance, low-smoke, and zero-halogen cables • PA System conforms to IEC 60628 or any equivalent International/Indian standard and EN54xxx or any equivalent International/Indian standard

Main System/Device/ Equipment	The Main technical specifications
Centralized Clock System (GNSS synchronization)	The main technical specifications of Centralized Clock System are planned as follows: • Master clock synchronized with the GNSS signal • Slave clocks synchronized with the master clock time • Onboard devices and all subsystems (including Signalling Facilities) are synchronized with master clock time (through IP and radio networks)
Passenger Information Display System (PIDS)	The main technical specifications of PIDS are planned as follows: • True color LED type (at station platforms) • LED-backlit LCD type (at station concourses) • Flat-panel with LCD or LED as electronic Passenger Information Display Board • Display linked to ATS and by manual input from OCC/station • Visual display of train running status • Information display including destination, platform numbers, arrival/departure time, emergency messages, etc. in Hindi and English • IEC as applicable or any equivalent International/Indian standard
Close Circuit Television (CCTV) System	The main technical specifications of CCTV System are planned as follows: • CCTV cameras for all public and selected areas such as tunnel cross passages, ancillary buildings, OCC/BCC/SCRs • Full coverage and High-quality surveillance for crowded control and other emergencies • IP based system • Recording and storage facilities (to record and store events for seven days minimum) • IEC 60268 as applicable or any equivalent International (ONVIF, CE/FCC/UL, etc.)/Indian standard
Central Voice Recording System (CVRS) & Digital Voice Recording System (DVRS)	The main technical specifications of CVRS are planned as follows: • Radio communication recording • Live/Emergency broadcast (from OCC/BCC and all Direct Line Consoles) recording • Live announcement (from OCC/BCC to stations) recording • Emergency telephone communication (at OCC/BCC/underground sections) recording • Free space microphone (at OCC/BCC) recording The main technical specifications of DVRS are planned as follows: • Conversation recording (between all telephones, including Direct Line Consoles, Help Point Phones, and Emergency Telephone Lines)
Central Fault Reporting System (CFRS)	The main technical specifications of CFRS are planned as follows: • Integrated system for monitoring and controlling Telecommunication Facilities and for storing maintenance data of Telecommunication Facilities (for alarm management and failure analysis) • Information transmission between individual NMS (Network Management Systems) and CFRS (alarm notification, maintenance data, etc.) • Monitored systems ▪ PA System ▪ PIDS ▪ Centralized Clock System ▪ Telephone Exchange (PBX) ▪ Mobile Radio Communication System (TETRA) ▪ CCTV System ▪ Transmission System

Source: DPR, JST

(2) Others

- The uninterrupted power supply (UPS) is planned to be commonly used for Train Control System (CBTC), Signaling Facilities, Telecommunication Facilities, and AFC system and supply power backup for about 2 hours.

- All equipment rooms are planned to be air-conditioned.

9.2 Reviews of Existing Studies and Proposals for Improvement

9.2.1 Signaling Facilities

(1) Conformity Review with International Standards/Regional Standards and Appropriateness Review of Facility Plan

JST reviewed whether PMRCL's signaling facilities have adopted appropriate International/Regional Standards. The International/Regional Standards adopted for PMRCL's signaling facilities are shown in the following table

Table 9-4: International/Regional Standards adopted for PMRCL's signaling facilities

The main International/Regional Standards					Remark
		International Standards	Regional Standards: Overseas	Regional Standards: Domestic	
➢ Train Control System(CBTC) ・Automatic Train Supervision (ATS, SIL 2) ・Automatic Train Protection (ATP, SIL 4) ・Automatic Train Operation (ATO, SIL 2) ➢ Computer-Based Interlocking Device (CBI, SIL 4)	IEC 62278	✓			RAMS・SIL (Equivalent to EN 50126)
	IEC 62425	✓			RAMS・SIL (Equivalent to EN 50129)
	EN 50126		✓		RAMS・SIL
	EN 50128		✓		RAMS・SIL
	EN 50129		✓		RAMS・SIL
➢ Train Control System(CBTC) ・Automatic Train Supervision (ATS) ・Automatic Train Protection (ATP) ・Automatic Train Operation (ATO)	IEEE 1474.1	✓			CBTC
	IEEE 1474.2	✓			CBTC
	IEEE 1474.3	✓			CBTC
	IEC 62267	✓			ATO, etc.
	IEC 62290-1	✓			transport management and command/control systems
	IEC 62290-2	✓			
	IEC 62290-3	✓			
	Guidelines ・DoT ・TRAI ・WPC			✓	CBTC(Radio)[+] [+]CBTC doesn't require a license to

The main International/Regional Standards					Remark
		International Standards	Regional Standards		
			Overseas	Domestic	
					use the ISM band (2.4GHz).
➢ Computer-Based Interlocking Device (CBI)	RDSO/SPN/192/2005			✓	
➢ Line Side Signal (LED Type)	RDSO/SPN/153/2011			✓	
➢ Electric point machine	IRS: S24			✓	

Source: JST

1) Conformity with International Standards/Regional Standards

< Possibility of being restricted by International/Regional Standards>

JST has confirmed that PMRCL's signalling facilities would have few constraints imposed by International Standards or by Regional Standards established by Regional Authorities, the Indian Ministry of Railways, related Authorities, etc., for the following reasons.

- PMRCL's signaling facilities are equivalent to or similar to those proven in India.
- PMRCL's signaling facilities are planned considering International Standards or Regional Standards established by Regional Authorities, the Indian Ministry of Railways, related Authorities, etc.

JST has also confirmed that PMRCL has recognized that PMRCL's signaling facilities aren't restricted to International/Regional Standards.

<Conformity with Regional Standards for the safety certification (SIL) >
PMRCL plans to conform to CENELEC Standards for the safety certification (SIL) of its signalling facilities, such as CBTC. CENELEC Standards are European Regional Standards. JST guessed it would be difficult for some suppliers to bid on the project if PMRCL plans to conform only to CENELEC Standards. JST evaluates the construction cost issue is essential for PMRCL, and the construction cost could be lower if PMRCL could increase the number of bidders. Therefore, JST suggested that PMRCL would better change the plan to conform to International Standards such as ISO and IEC for its signaling facilities' safety certification (SIL).
JST inquired why PMRCL plans to conform only to the CENELEC Standard for its signaling facilities' safety certification (SIL) and received the following responses.

- PMRCL's specifications provide the safety certification (SIL-4/SIL-2) of CENELEC Standards or other recognized International Standards equivalent to CENELEC. However, if other recognized International Standards are followed in place of CENELEC, the following conditions are required to be met:

- A copy of the Standards followed shall be submitted in English language.
- A certificate from an independent recognized body shall be submitted stating that the proposed Standards are equivalent to CENELEC Standards.
- Credentials of the independent recognized body issuing such certificates shall be submitted for verification by the Engineer.
- The certificate of validator certifying that the system is equivalent to CENELEC SIL-4/SIL-2 compliant shall also be submitted.

That means PMRCL can also accept other recognized International Standards, such as ISO and IEC. Some Indian metro projects adopted the above process to conform to other recognized International Standards such as ISO and IEC.

JST has confirmed that PMRCL's signaling facilities have adopted appropriate International/Regional Standards.

JST recommends that PMRCL works on the project after confirming the conformity with International/Regional Standards if PMRCL changes The Signaling Facility Plan at the detailed design phase.

2) Appropriateness of Facility Plan

<CBTC>

PMRCL plans to run vehicles of Corridor 1 on some sections of Corridor 2 (between Khemni Chak Station (The terminal station of Corridor 1) and New ISBT Depot) to accommodate them at New ISBT Depot. JST confirmed it is challenging to introduce CBTCs manufactured by different suppliers for Corridor 1 and 2, considering that vehicles of Corridor 1 will be run on some sections of Corridor 2 and that CBTCs manufactured by different suppliers are not compatible.

JST inquired about The PMRCL's Signaling Facility Plan for CBTC and received the following response.

- PMRCL plans to introduce CBTCs manufactured by the same supplier for Corridor 1 and 2.

<The other facilities>

JST has confirmed The PMRCL's signaling facilities other than CBTC are also equivalent to or similar to those proven in India.

JST has confirmed The PMRCL's Signaling Facility Plan is appropriate.

(2) Appropriateness Review of Facility Plan suitable for the transportation capability based on traffic demand forecasts

<CBTC>

PMRCL plans to introduce CBTC, which can operate trains at minimum 2 minutes headway. In addition to CBTC as the train control system, PMRCL had also considered the feasibility of introducing DTG (Distance To Go), which is introduced on DMRC Phase 1 and 2 lines, etc. DTG is the train control system that works on the fixed block principle using AF track circuits (the train detection device). According to PMRCL, the minimum headway of DTG is 2 minutes 30 seconds. PMRCL targets introducing its transportation system to achieve future transportation capability of up to 67,000 PHPDT. In this case, PMRCL needs to operate trains at a minimum of 2 minutes headway.
JST has confirmed it is appropriate for PMRCL to introduce CBTC.

JST has confirmed The PMRCL's Signaling Facility Plan is suitable and appropriate for the transportation capability based on traffic demand forecasts.

(3) Procurement Feasibility Review from India and other countries (including Japan), Procurement Feasibility Review over the medium-to-long term

1) Procurement Feasibility from India and other countries

<Conformity with Regional Standards for the safety certification (SIL) >

PMRCL plans to conform to CENELEC Standards for the safety certification (SIL) of its signaling facilities, such as CBTC. CENELEC Standards are European Regional Standards. JST guessed it would be difficult for some suppliers to bid on the project if PMRCL plans to conform only to CENELEC Standards. JST evaluates the construction cost issue is essential for PMRCL, and the construction cost could be lower if PMRCL could expand its methods of Procurement. Therefore, JST suggested that PMRCL would better change the plan to conform to International Standards such as ISO and IEC for its signaling facilities' safety certification (SIL).
JST inquired why PMRCL plans to conform only to the CENELEC Standard for its signaling facilities' safety certification (SIL) and received the following response.

- PMRCL's specifications provide the safety certification (SIL-4/SIL-2) of CENELEC Standards or other recognized International Standards equivalent to CENELEC. However, if other recognized International Standards are followed in place of CENELEC, the required documents and certificates must be submitted and approved by PMRCL.
  That means PMRCL can also accept other recognized International Standards, such as ISO and IEC.

JST has confirmed that PMRCL has considered Procurement Feasibility from around the world for its signaling facilities.

2) Procurement Feasibility over the medium-to-long term

<Various Facilities>

PMRCL plans to conform to International Standards such as IEEE, IEC, etc., Standards equivalent to International Standards, and Regional Standards such as IRS and RDSO of domestic Standards. PMRCL also plans to introduce signaling facilities that are proven or available worldwide or in India.

JST has confirmed that PMRCL has considered Procurement Feasibility over the medium-to-long term for its signaling facilities.

(4) Appropriateness Review of Facility Flexibility and Stability

1) Facilities Flexibility

<CBTC>

Many global and Indian metro projects have introduced CBTC, which can achieve the moving block principle and potentially achieve DTO/UTO. The onboard device calculates the train position continuously, and CBTC recognizes its position through CBTC radio. Therefore, CBTC can stably detect the train position without track circuits. CBTC uses software to achieve the moving block principle. Therefore, JST expects CBTC is appropriate for future transportation improvements because CBTC would allow future transportation capability enhancement without software modification or with reasonable software modification.

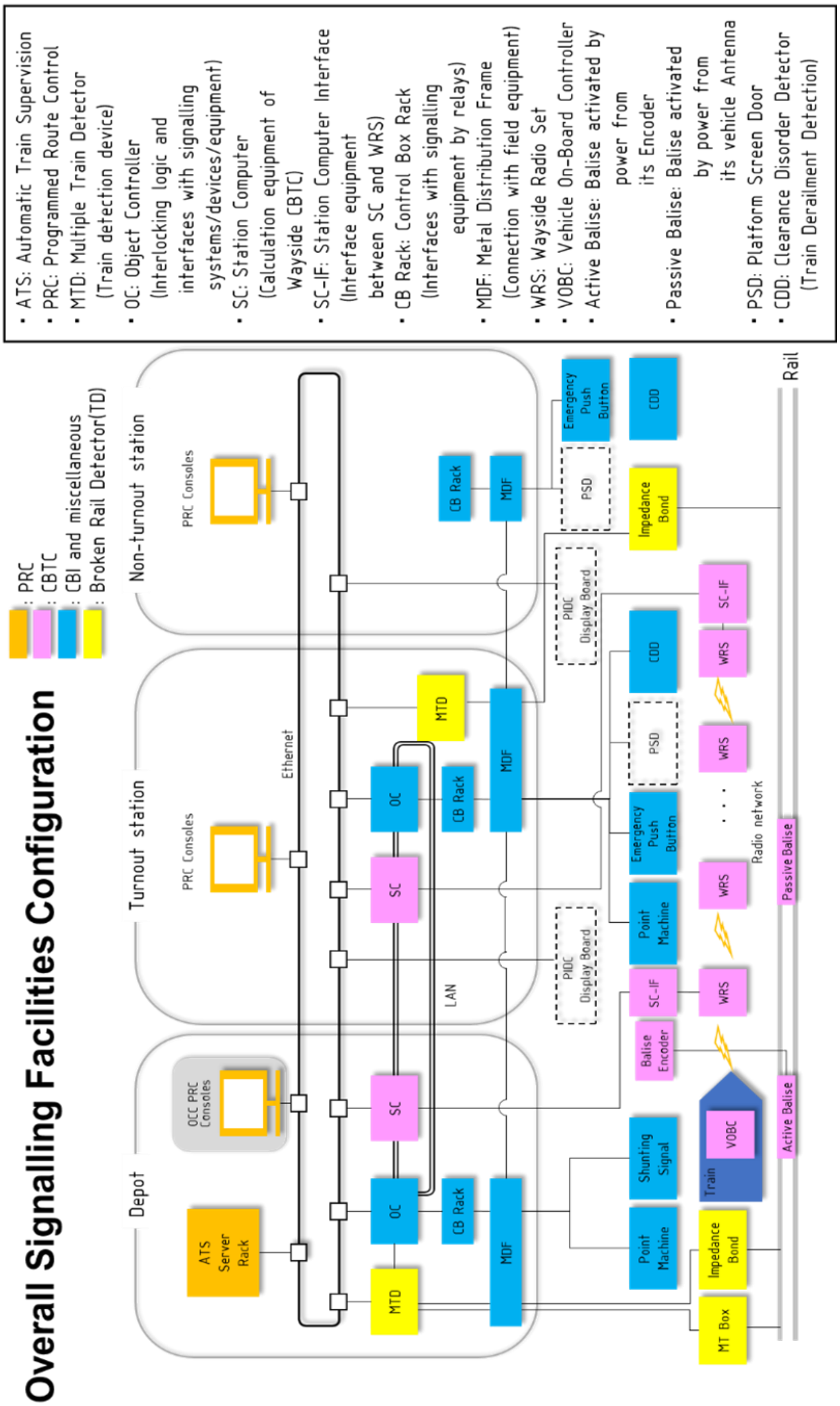
JST has confirmed that PMRCL has considered Facilities Flexibility for its signalling facilities.

2) Facilities Stability

<Various Facilities>

PMRCL plans various measures for data security and electrical interference protection, introduction of different networks for CCTV and CBTC to ensure data security for CBTC, and introduction of power and signaling cables separately to protect against electrical interference.

JST has confirmed that PMRCL has considered Facilities Stability for its signaling facilities.



Source:Nippon Signal Co., Ltd., JST (Add comment)

Figure 9-1: Example of Overall signaling Facilities Configuration

(5) Proposals for Improvement

PMRCL plans to introduce the latest systems/devices/equipment available and standardized worldwide. If PMRCL changes its plan to introduce an additional system/device/equipment or specification at the detailed design phase, an additional interface (including hardware or software) could be needed to connect with the existing system/device/equipment. In addition, the additional construction cost and procurement/construction period could be needed because systems/devices/equipment could be more complex.

JST recommends that PMRCL introduces the systems/devices/equipment or specification within the scope of the current plan.

- Regarding this JST proposal, JST has received the comment from PMRCL that the majority of the systems/devices/equipment or specification shall be within the scope of the current plan at the detailed design phase.

Corridors 1 and 2 around Khemni Chak Station are elevated sections proximate to each other.

PMRCL needs to provide documents to RDSO certifying interference robustness for CBTC Radio system in both out-of-band and in-band interferences.

JST recommends that PMRCL ensures the CBTC radio bands for Corridor 1 and 2 don't interfere at the detailed design stage.

- Regarding this JST proposal, JST has received the comment from PMRCL that at the detailed design stage, it shall be ensured that the CBTC radio bands for Corridor 1 and 2 don't interfere in proximity of Corridor 1 and 2 around Khemni Chak Station.

PMRCL plans to use UPSs commonly for its signaling facilities (including the train control system), telecommunication facilities, and AFC system facilities.

JST recommends PMRCL to use UPSs for facilities that could directly affect the train operation and UPSs for facilities that could not directly affect the train operation separately, with the perspective of stable train operation.

- Regarding this JST proposal, JST has received the following comments from PMRCL.
  - As per standard practice of DMRC from Phase 1/2/3 including Phase 4 projects, the UPS of S&T is designed and commissioned common for Signalling, Telecommunication, and AFC facilities keeping appropriate safety checks while designing to avoid failure of entire UPS due to fault in any other subsystems such as Telecommunication/AFC.
  - Hence, for Patna Metro Project also, a common UPS system with physically separate feeding MCCBs of appropriate ratings at the output ACDB panel of the UPS system has been planned for Signalling, AFC, Telecommunication, and other critical services which are essential for train operation.
  - Also, using common UPS for Signalling facilities along with Signalling, AFC, Telecommunication, and other critical services which are essential for train operation, cost of the contract in terms of Supply, installation, and commissioning, and then in terms of regular maintenance cost shall be reduced.

- ➢ JST agrees with the PMRCL's UPS installation method, as the planned method will likely lead to acceptable and stable train operations and cost savings.

9.2.2 Telecommunication Facilities

(1) Conformity Review with International Standards/Regional Standards and Appropriateness Review of Facility Plan

Table 9-5: International/Regional Standards adopted for Telecommunication facilities

The main International/Regional Standards					Remark
		International Standards+	Regional Standards		
			Overseas	Domestic	
➢ Transmission System	ITU-T Related Standards	✓			
	IEEE Related Standards	✓			
	IETF Related Standards	✓			
	RFC Related Standards	✓			
➢ Mobile Radio Communication System (TETRA)	Guidelines ・DoT ・TRAI ・WPC			✓	

+ "International Standards" in the table also include standards established by international parties and companies.
Source: JST

1) Conformity with International Standard/Regional Standards

< Possibility of being restricted by International/Regional Standards>

JST has confirmed that PMRCL's telecommunication facilities would have few constraints imposed by International Standards or by Regional Standards established by Regional Authorities, the Indian Ministry of Railways, related Authorities, etc., for the following reasons.

- PMRCL's telecommunication facilities are equivalent to or similar to those proven in India.
- PMRCL's telecommunication facilities are planned considering International Standards or Regional Standards established by Regional Authorities, the Indian Ministry of Railways, related Authorities, etc.

JST has also confirmed that PMRCL has recognized that PMRCL's telecommunication facilities aren't restricted to International/Regional Standards.

JST recommends that PMRCL work on the project after confirming the conformity with International/Regional Standards if PMRCL changes The Telecommunication Facility Plan at the detailed design phase.

<Conformity with Regional Standards>

PMRCL plans to conform to CENELEC Standards for some telecommunication facilities. CENELEC Standards are European Regional Standards. JST guessed it would be difficult for some suppliers to bid on the project if PMRCL plans to conform to CENELEC Standards.
JST evaluates the construction cost issue is essential for PMRCL, and the construction cost could be lower if PMRCL could increase the number of bidders.
JST inquired why PMRCL plans to conform to the CENELEC Standard for some telecommunication facilities and received the following response.

- PMRCL's specifications provide CENELEC Standards or other recognized International Standards equivalent to CENELEC. However, if other recognized International Standards are followed in place of CENELEC, the following conditions are required to be met:
  - A copy of the Standards followed shall be submitted in English language.
  - A certificate from an independent recognized body shall be submitted stating that the proposed Standards are equivalent to CENELEC Standards.
  - Credentials of the independent recognized body issuing such certificates shall be submitted for verification by the Engineer.

JST has confirmed that PMRCL's telecommunication facilities have adopted appropriate International/Regional Standards.

JST recommends that PMRCL works on the project after confirming the conformity with International/Regional Standards if PMRCL changes The Telecommunication Facility Plan at the detailed design phase.

2) Appropriateness of Facility Plan

<Various Facilities>

JST has confirmed that The PMRCL's telecommunication facilities are equivalent to or similar to those proven in India and the PMRCL's Telecommunication Facility Plan is appropriate.

(2) Appropriateness Review of Facility Plan suitable for the transportation capability based on traffic demand forecasts

<Various Facilities>

PMRCL plans to configure the backbone fiber optic cables for the Transmission System in consideration of its extension to the next-generation transportation network. PMRCL also plans to introduce Telephone Exchanges (SIP PBX) for OCC/BCC for 10,000 users and other facilities to accommodate future user growth.

JST has confirmed The PMRCL's Telecommunication Facility Plan is suitable and appropriate for the transportation capability based on traffic demand forecasts.

(3) Procurement Feasibility Review from India and other countries (including Japan), Procurement Feasibility Review over the medium-to-long term

1) Procurement Feasibility from India and other countries

<Conformity with Regional Standards>

PMRCL plans to conform to CENELEC Standards for some telecommunication facilities. CENELEC Standards are European Regional Standards. JST guessed it would be difficult for some suppliers to bid on the project if PMRCL plans to conform to CENELEC Standards. JST evaluates the construction cost issue is essential for PMRCL, and the construction cost could be lower if PMRCL could expand its methods of Procurement.

JST inquired why PMRCL plans to conform to the CENELEC Standard for some telecommunication facilities and received the following response.

- PMRCL's specifications provide CENELEC Standards or other recognized International Standards equivalent to CENELEC. However, if other recognized International Standards are followed in place of CENELEC, the required documents and certificates must be submitted and approved by PMRCL.

That means PMRCL can also accept other recognized International Standards, such as ISO and IEC.

JST has confirmed that PMRCL has considered Procurement Feasibility from around the world for its telecommunication facilities.

2) Procurement Feasibility over the medium-to-long term

<Various Facilities>

PMRCL plans to conform to International Standards such as IEEE, IEC, etc., Standards equivalent to International Standards, and Regional Standards such as DoT of domestic Standards. PMRCL also plans to introduce telecommunication facilities that are proven or available worldwide or in India.

JST has confirmed that PMRCL has considered Procurement Feasibility over the medium-to-long term for its telecommunication facilities.

(4) Appropriateness Review of Facility Flexibility and Stability

<Various Facilities>

PMRCL plans to introduce telecommunication facilities that are proven in India. PMRCL also plans to introduce durable fiber optic cables and redundant configuration for the backbone network of telecommunication facilities. In addition, Devices connected to the backbone network are required to be highly reliable and fault-tolerant. Therefore, these policies are expected to ensure stable data communications.

JST has confirmed that PMRCL has considered the Flexibility and Stability of its telecommunication facilities.

(5) Proposals for Improvement

PMRCL plans to introduce the latest systems/devices/equipment available and standardized worldwide. If PMRCL changes its plan to introduce an additional system/device/equipment or specification at the detailed design phase, an additional interface (including hardware or software) could be needed to connect with the existing system/device/equipment. In addition, the additional construction cost and procurement/construction period could be needed because systems/devices/equipment could be more complex. JST recommends that PMRCL introduces the systems/devices/equipment or specification within the scope of the current plan. Regarding this JST proposal, JST has received the comment from PMRCL that the majority of the systems/devices/equipment or specification shall be within the scope of the current plan at the detailed design phase.

PMRCL plans to use UPSs commonly for its signaling facilities (including the train control system), telecommunication facilities, and AFC system facilities. JST recommends PMRCL to use UPSs for facilities that could directly affect the train operation and UPSs for facilities that could not directly affect the train operation separately, with the perspective of stable train operation. Regarding this JST proposal, JST has received the following comments from PMRCL.

- As per standard practice of DMRC from Phase 1/2/3 including Phase 4 projects, the UPS of S&T is designed and commissioned common for Signalling, Telecommunication, and AFC facilities keeping appropriate safety checks while designing to avoid failure of entire UPS due to fault in any other subsystems such as Telecommunication/AFC.
- Hence, for Patna Metro Project also, a common UPS system with physically separate feeding MCCBs of appropriate ratings at the output ACDB panel of the UPS system has been planned for Signalling, AFC, Telecommunication, and other critical services which are essential for train operation.
- Also, using common UPS for Signalling facilities along with Signalling, AFC, Telecommunication, and other critical services which are essential for train operation, cost of the contract in terms of Supply, installation, and commissioning, and then in terms of regular maintenance cost shall be reduced.

JST agrees with the PMRCL's UPS installation method, as the planned method will likely lead to acceptable and stable train operations and cost savings

10. Fare Collection System

10.1 Overview of Existing Studies

10.1.1 AFC System Facilities

The main technical specifications of AFC System Facilities for PMRCL are shown in the below table.

Table 10-1: The Main Technical Specifications of AFC System Facilities

Main System/Device/Equipment	The Main technical specifications
Central Computer	The main technical specifications of AFC System Facilities are planned as follows: • Fare media ▪ NCMC (National Common Mobility Card) - Contactless smart card Interface Specification of NCMC Ecosystem Version 1.2 (Part IV to Part VII), CDAC, the Indian standard - qSparc (quick Specification for Payment Application of RuPay Chip, NPCI, the Indian standard) - NCMC recharge using cash, debit/credit card, and Netbanking/web portal ▪ Quick Response (QR) ticket - Paper or mobile (QR Ticketing System for Transit Operators -Specifications (v1.1)-, CDAC, the Indian standard) ▪ NFC IP-1 (ISO/IEC 18092) • AFC System Facilities ▪ All devices at the station (AFG, TOM/EOF, TVM/POM, etc.) are connected to the Station Computer with the local station network. ▪ All station computers are connected to the Central Computer with backbone optical fiber cables. ▪ Up to 256 Station Computers can be connected to the Central Computer. ▪ Retractable flap gate - Entry gate - Exit gate - Swing barrier (for disabled people) ▪ 25 passengers per minute per gate as AFG capacity
Station Computer	
Automatic Fare Gate (AFG)	
Ticket Office Machine (TOM) Excess Fare Office (EFO)	
Ticket Vending Machine (TVM) Passenger Operated Machine (POM)	
Ticket Reader (TR)	
Portable Ticket Decorder	

Source: DPR, JST

10.1.2 Others

The uninterrupted power supply (UPS) is planned to be commonly used for Train Control System (CBTC), Signalling Facilities, Telecommunication Facilities, and AFC system and supply power backup for about 2 hours.

10.2 Reviews of Existing Studies and Proposals for Improvement

10.2.1 Conformity Review with International Standards/Regional Standards and Appropriateness Review of Facility Plan

Table 10-2: International/Regional Standards adopted for PMRCL's AFC system facilities

The main International/Regional Standards					Remark
		International Standards+	Regional Standards		
			Overseas	Domestic	
Automatic Fare Collection (AFC) System	Interface Specification of NCMC Ecosystem Version 1.2 (Part IV to Part VII) 1	(✓)		✓	・The Rupay Chip is mounted on the fare media based on Type-A (ISO/IEC 14443) and EMV (Europay, Master, VISA: The credit-card companies standard)
	qSparc (quick Specification for Payment Application of Rupay Chip)			✓	
	ISO/IEC 18092 (IP-1)	✓			・NFC (Near Field Communication)

+ "International Standards" in the table also include standards established by international parties and companies.
Source: JST

(1) Conformity with International Standards/Regional Standards

<Possibility of being restricted by International/Regional Standards>

JST has confirmed that PMRCL's AFC system facilities would have few constraints imposed by International Standards or by Regional Standards established by Regional Authorities, the Indian Ministry of Railways, related Authorities, etc., for the following reasons.

- PMRCL's AFC system facilities are equivalent to or similar to those proven in India.
- PMRCL's AFC system facilities are planned considering International Standards or Regional Standards established by Regional Authorities, the Indian Ministry of Railways, related Authorities, etc.

JST has also confirmed that PMRCL has recognized that PMRCL's AFC system facilities aren't restricted to International/Regional Standards.

JST has confirmed that PMRCL's AFC system facilities have adopted appropriate International/Regional Standards.

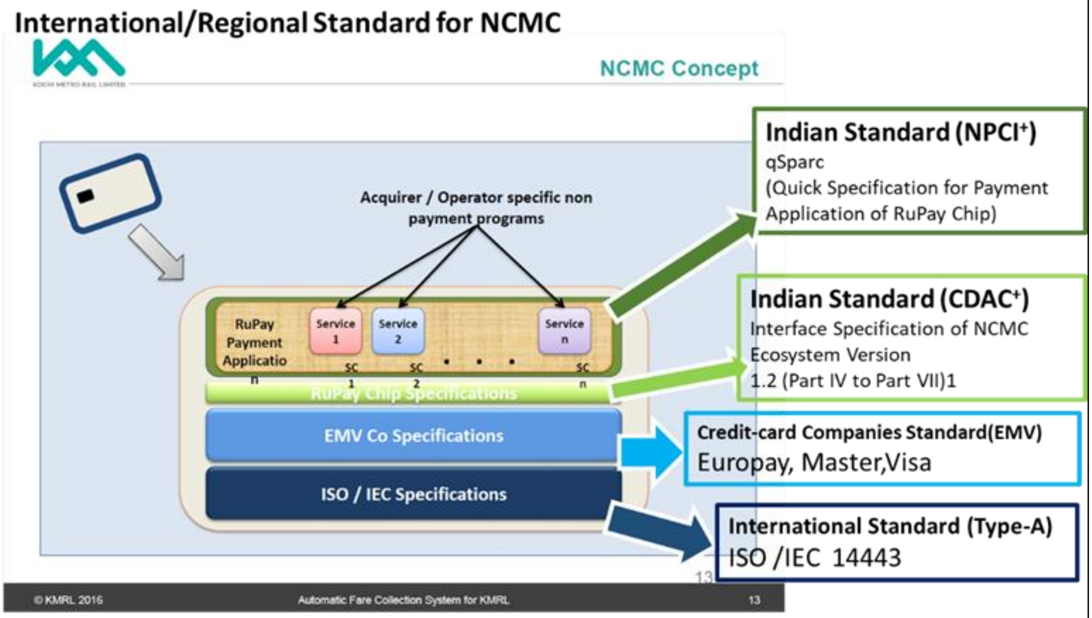
JST recommends that PMRCL work on the project after confirming the conformity with International/Regional Standards if PMRCL changes The AFC System Facility Plan at the detailed design phase.

(2) Appropriateness of Facility Plan

<NCMC>

JST has confirmed PMRCL plans to introduce the open-loop AFC System using NCMC (National Common Mobility Card), Indian public transportation standard fare media, to achieve full interoperability, "One Nation One Card."

JST has also confirmed that the Rupay Chip (Interface Specification of NCMC Ecosystem) is mounted on the fare media based on Type-A (ISO/IEC 14443) and EMV (Europay, Master, VISA: The credit-card companies standard) and that NCMC is activated by the dedicated app (qSparc: Indian standard).



Source:UNBUNDLING FOR PPP Automatic Fare Collection System for KMRL, PRAVEEN GOYAL (Kochi metro Director (Systems), JST (Add comment)

+CDAC: Centre for Development of Advanced Computing
+NPCI: Nation Payment Corporation of India

Figure 10-1: International/Regional Standard for NCMC

The comparison of the AFC system using only NCMC, which PMRCL plans to introduce, and the AFC system using NCMC and FeliCa is shown in the following figure.

Fare Media Brands and Features

	(Nationwide/Local Card) NCMC 	(Nationwide Card) NCMC + Combined Usage (Local Card) FeliCa 	【Reference】 FeliCa 
International /Regional Standard	○NCMC (Open-loop) ・Interface Specification of NCMC Ecosystem Version 1.2 (Part IV to Part VII), CDAC, the Indian standard based on Type-A (ISO/IEC 14443) and EMV (Europay, Master, VISA: The credit-card companies standard) ・qSparc, quick Specification for Payment Application of RuPay Chip, NPCI, the Indian standard ・ISO/IEC 18092 (NFC IP-1) ○FeliCa (Closed-loop) ・ISO/IEC 18092 (NFC IP-1)		
Automatic Fare Gate Capacity	About 30 people per minute per gate	About 30 to 60 people per minute per gate+ +It depends on the Fare Media Brand.	About 60 people per minute gate
Construction Cost	1	1.05～1.1++ ++The construction cost could be reduced because the number of Automatic Fare Gates can be reduced due to Automatic Fare Gate Capacity increase compared to NCMC installations.	1
Usage Example in India	(SBI Bank) Nagpur Metro Noida Metro (Axis Bank) Kochi Metro	・Ahmedabad Metro (Phase-1) Line 1, Line2 (FeliCa: Not in operation) ・Chennai Metro (Phase-1 including extension) Line1, Line2	—

Figure 10-2: Fare Media Brands and Features

JST has confirmed that PMRCL plans the Automatic Fare Gate (AFG) capacity as 25 people per minute per gate, and JST has guessed the AFC system using only NCMC would be more reasonable for PMRCL.

JST has also confirmed that The PMRCL's AFC system facilities are equivalent to or similar to those proven worldwide or in India.

In addition, JST has guessed that Indian-related metro corporations will modify their AFC systems to adapt to NCMC (Type-A and EMV, qSparc) because they have been strongly requested by the Indian-related authority (MoHUA) to achieve full interoperability by NCMC.

F.No. K-14011/18/2011(Pt.III)
Computer No. 9049079
Government of India
Ministry of Housing and Urban Affairs
Urban Transport Division

Nirman Bhawan, New Delhi
Dated: 09.05.2022

To

As per list annexed

Sub: Implementation of NCMC on interoperable basis-reg.

Sir/Madam,

Hon'ble Prime Minister launched NCMC on 04.03.2019 with the vision of 'One Nation One Card. Regarding this, MoHUA has already released ecosystem standards for adoption by metro corporations.

2. MoHUA, vide its previous communications has requested all Metro Corporations currently operating NCMC under exclusive arrangement to upgrade to full interoperability.

3. Further, report of the Committee on Business model of NCMC and implementation of NCMC on interoperable basis in various PTOs was circulated to all concerned Metro Corporations vide MoHUA's letter dated 03.08.2021 (copy enclosed). All Metro Corporations with exclusive arrangements were requested to derive appropriate business model for transition from exclusive arrangements to full Interoperability, vide this letter. Full interoperability implies that all Debit Cards, Credit Cards and Prepaid cards with NCMC feature issued by any Bank should be accepted at all AFC terminals.

4. Despite above, no progress in this regard has been communicated to MoHUA till date. Hence, in view of aforementioned facts and the need for early implementation of NCMC on interoperable basis, all the concerned Metro Corporations are directed as below:

- to switch from exclusive arrangements to fully interoperable non-exclusive arrangements by October, 2022.
- to ensure issuance of Prepaid cards with minimum KYC at metro premises.
- to ensure that all cards (debit/prepaid/credit) with NCMC feature are accepted in the network.

5. This letter issues with the approval of competent authority.
Encls: As above.

(P.C. Purkait)
Under Secretary to the Govt. of India
011-23062214
Email: pc.purkait@nic.in

Copy to:
1. The OSD(UT), MoHUA.

Under Secretary to the Govt. of India

Annexure-I

1. The Managing Director, Kochi Metro
2. The Managing Director, Noida Metro
3. The Managing Director, Maha Metro: Nagpur& Pune
4. The Managing Director, Delhi Metro
5. The Managing Director, Hyderabad Metro
6. The Chief Executive Officer, MMOPL

Source: PMRCL

Figure 10-3: The letter issued by MoHUA Urban Transport Division to strongly request to adapt to NCMC (Dated:09.05.2022)

JST has confirmed that there would be no technical concerns and requirements PMRCL couldn't solve without introducing FeliCa. Therefore, JST has confirmed that The PMRCL's AFC System Facility Plan is appropriate.

10.2.2 Appropriateness Review of Facility Plan suitable for the transportation capability based on traffic demand forecasts

<NCMC>

- PMRCL plans the capacity of the Automatic Fare Gate (AFG) as 25 people per minute per gate.

  PMRCL planned the capacity of the AFG as 35 people per minute per gate in DPR.

- JST inquired about why PMRCL changed the number of people from 35 to 25 and received the following response.
- 25 People per gate per minute is operation throughput based on experience in DMRC.

<Conclusion>

- JST has reviewed PMRCL's policies and confirmed The PMRLS's Facility Plan is suitable and appropriate for the transportation capability based on traffic demand forecasts.

10.2.3 Procurement Feasibility Review from India and other countries (including Japan), Procurement Feasibility Review over the medium-to-long term

<Various Facilities>

PMRCL plans to conform to International Standards such as IEC, etc., or Regional Standards such as domestic Standards of CDAC and NPCI.

PMRCL also plans to introduce AFC system facilities that are proven or available worldwide or in India.

JST has confirmed that PMRCL has considered Procurement Feasibility from around the world and over the medium-to-long term for its AFC system facilities.

10.2.4 Appropriateness Review of Facility Flexibility and Stability

<Various Facilities>

PMRCL plans to introduce AFC system facilities that are proven worldwide or in India.

JST has confirmed that PMRCL has considered the Flexibility and Stability of its AFC system facilities.

10.2.5 Proposals for Improvement

PMRCL plans to use UPSs commonly for its signaling facilities (including the train control system), telecommunication facilities, and AFC system facilities.

JST recommends PMRCL to use UPSs for facilities that could directly affect the train operation and UPSs for facilities that could not directly affect the train operation separately, with the perspective of stable train operation. Regarding this JST proposal, JST has received the following comments from PMRCL.

- As per standard practice of DMRC from Phase 1/2/3 including Phase 4 projects, the UPS of S&T is designed and commissioned common for Signaling, Telecommunication, and AFC facilities keeping appropriate safety checks while designing to avoid failure of entire UPS due to fault in any other subsystems such as Telecommunication/AFC.
- Hence, for Patna Metro Project also, a common UPS system with physically separate feeding MCCBs of appropriate ratings at the output ACDB panel of the UPS system has been planned for Signaling, AFC, Telecommunication, and other critical services which are essential for train operation.
- Also, using common UPS for Signaling facilities along with Signaling, AFC, Telecommunication, and other critical services which are essential for train operation, cost of the contract in terms of Supply, installation, and commissioning, and then in terms of regular maintenance cost shall be reduced.

JST agrees with the PMRCL's UPS installation method, as the planned method will likely lead to acceptable and stable train operations and cost savings.

11. Rolling Stock

11.1 Overview of Existing Studies

11.1.1 Route and Rolling Stock Plan

The target corridors are the two corridors (total 32.1km), as shown in the next table. These lines' characteristics are track gauge of 1,435mm, traction system of AC25kV 50Hz overhead collection system, and maximum gradient 4% for mainline.

Rolling stock dimensions are the length of 22m class, the width of 3.2m in DPR (PMRCL changed to 2.9m based on MOHUD guideline in July 2022), 3 cars or 6 cars of train configuration. Requested number of cars are 102 cars at the opening (2024), as shown in the next table.

Signal system in CBTC and PSD is installed at part of the stations.

Table 11-1: Rolling Stock Required

Corridor	km	Train	Car	Remarks
Corridor 1 Danapur – Khemni Chak	17.9	3 cars 14 6 cars 3	60	Underground :10.5km Elevated : 7.4km
Corridor 2 Patna Station – New ISBT	14.1	3 cars 14	42	Underground : 8.0km Elevated : 6.1km
Total	32.7	53	102	

Source: DPR

11.1.2 Technical Details

The next table shows the technical details of rolling stock.

Table 11-2: Technical Details of Rolling Stock

Item	Dimension	
Track Gauge	1,435mm	
Traction System	AC25kV 50Hz Overhead Collection System	
Train Configuration	6 cars train: DMC + TC + MC + MC + TC + DMC, 3 cars train: DMC + TC + DMC (notation in Japan: Mc – T – M – M – T – Mc, Mc – T – Mc)	
Car Body Material	Stainless Steel or Aluminium	
Car Dimension	Width of Body	2.9m (3.2m in DPR)
	Length of Body	DMC approx. 21.0m TC, MC approx. 20.5m
	Maximum Length over Coupler 22m	
	Height of Body Height of Floor	3.9m 1100mm (crush load)
Passenger Loading	Design of Traffic 6 passenger/m^2 Design of Propulsion System 8 passenger/m^2 Design of Mechanical Strength 10 passenger/m^2	
Passenger Capacity (@ 6 passenger/m^2)	DMC TC, MC 6 cars train	252 (seating: 42, standing: 210) 268 (seating: 50, standing: 218) 1,576 (seating: 284, standing: 1292) 282 (seating: 42, standing: 240) in DPR 298 (seating: 50, standing: 248) 1,756 (seating: 284, standing: 1472)
Weight	Tare Weight (max.)	DMC: 42.0 t, TC: 40.3 t, MC: 40.3 t (DMC: 42.5 t, TC: 40.8 t, MC: 40.8 t in DPR)
	Passenger Weight	DMC: 16.4 t, TC: 17.4 t, MC: 17.4 t (DMC: 18.3 t, TC: 19.4 t, MC: 19.4 t in DPR) @6 passenger/m^2 (0.065 t/passenger)
	Gross Weight (max.)	DMC: 58.4 t, TC: 57.7 t, MC: 57.7 t (DMC: 60.8 t, TC: 60.2 t, MC: 60.2 t in DPR) @6 passenger/m^2
Axle Load (max.)	16 t (17 t in DPR)	(@ 8 passenger/m^2)
Maximum Train Length	approx. 129.0 m	(6 cars train)
Maximum Speed	Design Speed Operation Speed	95 km/h 85 km/h
Wheel Profile	UIC 510-2	
Noise Limit	Qualitative Requirement	
Acceleration Rate	(Maximum)	1.2 m/s^2
Deceleration Rate	Max. Service Brake Emergency Brake	1.1m/s^2 1.3 m/s^2
Bogie and Suspension	Bolster Less Type	Air Suspension
Brake System	Electro-Pneumatic (EP) Service Friction Brake Failsafe Pneumatic Emergency Friction Brake Spring Actuated Air-release Parking Brake Electric Regenerative Service Brake Blending Function between EP and Regenerative brake Anti-Skid Function Disk Brake or Tread Brake	
Coupler	Between Units	Automatic Coupler with Pneumatic and Electrical Coupling

Item	Dimension	
	Front Cab end of DMC	Automatic Coupler with Pneumatic and Electrical Coupling
	Between Cars	Semi-Permanent Coupler
Emergency Door	Front Evacuation Door	
Passenger Doors	Bi-parting Sliding Door (Four Doors per Side) Electrical Control System	
Passenger Seats	Longitudinal Seats (Stainless Steel)	
Cooling of Equipment	Transformer CI and APS Traction Motor	Forced Cooling Self or Forced Cooling Self-Cooling
Control System	TCMS	
Propulsion System	VVVF inverter control (Switching device: IGBT) Traction motor: Induction motor (16 motors in 4M2T 6cars train)	
HVAC	Cooling, Heating, and Humidifier 25℃ with 60% RH in Saloon	
PA*/PIS*/PSSS*	Requested	
Battery	Nickel Cadmium Type	
Headlight Type	LED	
Coasting in Operation	8% (Run time in All-out mode +8%)	
Maximum Gradient	3% (partly 4%)	

Note: * PA: Passenger Address System, * PIS: Passenger Information Display System,
* PASS: Passenger Surveillance System (CCTV)
Source: PMRCL

11.1.3 Salient Features

(1) Train set

DMC : Driving Motor Car
MC : Motor Car
TC : Trailer Car

Standard car width of Indian metro is 3.2m or 2.9m, this project is 3.2m as for heavy traffic in DPR, but PMRCL changed to 2.9m based on MOHUD guideline in July 2022.

Car length is a 22m class, which is also as per Indian Metro standard. A cross-section is specified by kinematic envelope, including oscillating the car body, and no static rolling stock gauge is specified as in Japan. (Refer to JIS E4041, 8.2.2.1A)

(2) Passenger Capacity

The following passenger capacity is defined for each purpose.

AW0	No passenger (Tare weight)	
AW1	Seated capacity	(Capacity in Japan)
	(3.3 passenger/m² + Seated)	100%
AW2	4 passenger/m² + Seated	115%
AW3	6 passenger/m² + Seated	160% for design of traffic
AW4	8 passenger/m² + Seated	210% for design of propulsion system

10 Passenger/m² + Seated 260% for design of mechanical strength

(3) Weight

Maximum tare weight is 42 ton (42.5 ton in DPR), and maximum axle load is 16 ton at 8 passenger/m² (17 ton in DPR). It is a higher value than the example in Japan (less than 14 ton), but it is a traditional value in Indian Metro (AC25kV 50Hz) considering the European standard's crashworthiness

(4) Braking System

The service brake is blending of Electric-Pneumatic brake and Regenerative brake. It can realize to save energy consumption by air-supplement control. Holding brake in the dwelling is requested. Spring applied parking brake is requested too.

(5) Propulsion System

VVVF inverter control system with IGBT as a switching device and the induction motor is a proven design for metro EMU worldwide.

(6) Fire

Fire protection is specified by European Standard EN45545 or equivalent.

(7) Crash Worthiness

Crashworthiness is specified by European Standard EN15227 or equivalent. The compressive strength of the car body is 800kN (in Japan 490kN).

11.1.4 Others

(1) Cost

Estimated price excluding tax for one car is INR 8.0 Cr (JPY approx.1.28 Cr) based on MOHU guideline.

(2) Schedule

There are no clear explanations, but as per terms of the contract, the delivery is approximately 2 years.

11.2 Reviews of Existing Studies and Proposals for Improvement

11.2.1 Corridor and Rolling Stock Plan

For Corridor1 (17.9km) and Corridor 2 (14.2km), initial plans are 28 sets of "3 cars" trains and 3 sets of "6 cars" trains. There are no spare trains of "6-cars", and it is impossible to operate "3+3 cars" train, because of front evacuation in emergency situation. As stated in **Table8.3**, 24 sets of "3 cars" trains and 5 sets of "6 cars" train are recommended

11.2.2 Technical Features

It has a gauge of 1,435mm, body width of 2900mm (3200mm in DPR), and electrified system of

AC25kV50Hz.

It follows the Delhi Metro Line 7 and 8 (so called RS10 in the procurement category) except body width.

Acceleration of 1.2m/s/s seems to be excessive, and further consideration will be done in design stage.

11.2.3 Main Characteristic

3 cars are one unit, which is equipped with pantograph and main transformer on the intermediate T car and supplies power to converter-inverter (VVVF inverter) of the M car on both side. It is standard composition for MT ratio 67% Metro in India.

11.2.4 Cooling for CI and APS

Cooling system for CI (Converter/Inverter for propulsion system) and APS (Auxiliary Power Supply) should be self-cooling. Because forced air cooling causes noise and vibration, and maintenance for cooling system including dust filter is dirty and troublesome. It will be considered in design stage.

11.2.5 Preparation for Conversion of Train Configuration

As stated in 3.6 Train Operation Plan, 4 sets of “3 cars” trains will be converted to 2 sets of “6 cars” trains in the future (around 2041). Rolling stock design should be included preparation for conversion of train configuration. In particular DMC front design (converted from evacuation door to gang way) and TCMS. It will be prepared in design stage.

12. Power Supply and Traction

12.1 Overview of Existing Studies

12.1.1 Power Supply Facilities

(1) Power Receiving Facilities

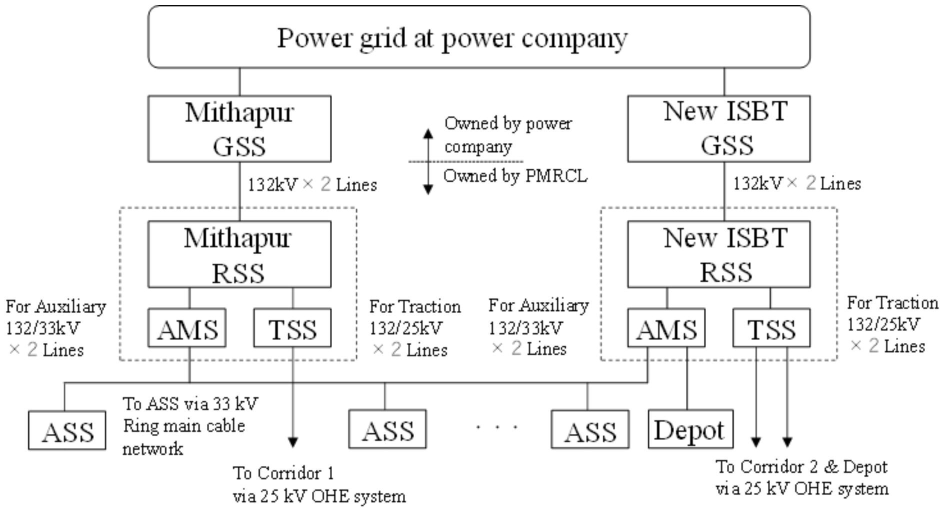
In power receiving equipment, power is received from grid substation (GSS) of BSPTCL's power grid to receiving substation (RSS) owned by PMRCL. The voltage is lowered for each railway equipment such as feeding line to supply traction loads for railways and auxiliary power supply for lights and power at stations and depots. Keeping in view of the reliability requirements and considering the complete length of corridors, two RSS are proposed to avail power supply from GSS at 132 kV voltage through cable feeders. The power supply of Mithapur RSS for corridor 1 is from Mithapur GSS and the power of New ISBT RSS for corridor 2 is from upcoming New ISBT GSS after its connectivity with LILO arrangement of Gaurichak-Fatuha transmission line. Each RSS planned for the power requirements with the respective feeding zones and the length of cables of from GSS is shown in the table below.

Table 12-1: Sources of Power Supply

Grid sub-station	RSS of PMRCL	Feeding Zone	Distance from GSS to RSS
Mithapur GSS (132 kV)	Mithapur RSS (132/33/25 kV)	Corridor 1	Contiguous site*
New ISBT GSS (132 kV)	New ISBT RSS (132/33/25 kV)	Corridor 2	0.3 km

*Originally it was 0.5km, but the location was changed.
Source: DPR and JST

The power supply from GSS at 132 kV will be stepped down to 25 kV single phase supply for traction and 33 kV 3-phase supply for auxiliary at each RSS cum TSS and AMS. The traction power will be fed to 25 kV OHE system through cable feeders and the auxiliary power will be distributed along the alignment through 33 kV Ring main cable network for feeding ASS. The structure diagram of the power receiving equipment is shown in the following figure.



Source: JST

Figure 12-1: The Structure Diagram of Power Receiving Equipment

Each RSS requires backup facilities and parallel supply of loads from two RSSs. In normal conditions, Mithapur RSS will feed corridor 1 and New ISBT RSS will feed Corridor 2. In case either of the two RSS fails, then the other RSS will feed both the corridors. Under normal conditions, the power supply from each RSS is shared, and all power shall be available from the other RSS in emergency conditions such as one RSS failure. Therefore it is necessary for Each RSS to be of sufficient capacity. However, in case of total grid failure, all trains may come to a halt but emergency lighting, fire and other essential services can be catered to by stand-by UPS/ DG sets.

Based on emergency demand expected at each RSS, 2 traction transformers of 132/25 kV, 30 MVA capacity each at Mithapur RSS and New ISBT RSS are required. Similarly, two Auxiliary transformers of 132/33 kV, 30 MVA capacity each are proposed to be provided at both RSSs. The main equipment of possible installation in RSS is shown in the table below.

Table 12-2: Main Equipment of Possible Installation in RSS

Field	Equipment of possible installation		Remark
Power Supply, Traction	Mithapur RSS, New ISBT RSS (cum TSS/AMS)	Transformer (132/25 kV, Single-phase, 30 MVA, ONAN)	For use In Traction
		Transformer (132/33 kV, 3-phase, 30 MVA, ONAN)	For use In Auxiliary
		Switchgear (rated current 2000A)	For use In Traction
		Switchgear (rated current 1250A)	For use In Auxiliary

Source: DPR and JST

Electricity is required for operation of Metro system for running of trains, station services (e.g. lighting, lifts, escalators, signaling & telecom, firefighting, etc.) and workshops, depots & other maintenance infrastructure within premises of metro system. The power requirements of a metro system are determined by peak-hour demands of power for traction and auxiliary applications. According to DPR, the power requirement for corridors is calculated by considering following points.

- Train operation with combination of 3 & 6 car rakes for Danapur to Khemni Chak corridor.
- Train operation with 3 car rakes for Patna Junction to New ISBT corridor.
- Peak period headway of 3.0 minutes for both corridors.
- Specific energy consumption of rolling stock – 75 kWh / 1000 GTKM
- Regeneration at 30%
- At grade/ Elev. station load – initially 200 kW, ultimate design 300 kW
- Underground station load – initially 1500 kW, ultimate design 2000 kW
- Depot auxiliary load – initially 1500 kW, ultimate design 2000 kW
- Power factor of load – 0.9
- Transmission losses at 5%

Keeping in view of the above norms, the power demand estimation of DPR for the proposed metro corridors is given in the table below. According to this table, traction and auxiliary peak demands in normal operation are less than a capacity of transformer of 30 MVA during the period respectively. And traction and auxiliary peak demands in an emergency situation of one side RSS failure are also less than double capacity of transformer of 30 MVA during the period respectively.

Table 12-3: Power Demand Estimation

Name of RSS	Peak Demand – Normal (MVA)				Peak Demand – Emergency (MVA)			
	2024	2031	2041	2051	2024	2031	2041	2051
Mithapur RSS (Corridor 1)								
Traction	6.75	10.12	10.91	14.01	12.03	16.77	18.05	22.08
Auxiliary	12.37	13.30	14.58	16.80	27.53	29.55	32.38	37.22
Total	19.12	23.42	25.49	30.81	39.56	46.32	50.43	59.30
New ISBT RSS (Corridor 2)								
Traction	5.27	6.65	7.14	8.07	12.03	16.77	18.05	22.08
Auxiliary	15.17	16.25	17.79	20.42	27.53	29.55	32.38	37.22
Total	20.44	22.90	24.94	28.48	39.56	46.32	50.43	59.30

Source: DPR

As can be seen by the table below, the estimated power requirement and capacity here are similar to those for Chennai metro Phase-II with 25 kV AC feeding system. In terms of ASS, the transformer capacity in Patna metro is lower due to energy saving about LED for lighting and VRV system for Air-conditioning. Therefore JST thinks that the capacity of transformer is appropriate. By the way, since Tunnel Ventilation System (TVS) in Patna metro underground station are not included in essential services, hence DG size for underground station is 380 kVA.

Table 12-4: Comparison of Power Requirement and Main Equipment Capacity

	Patna Metro	Chennai Metro *1
Power Requirement	Power Consumption of Rolling Stock: 75 kWh/1,000 GTKM Regeneration: 30%	Power Consumption of Rolling Stock: 70 kWh / 1,000 GTKM Regeneration: 30%

	Patna Metro	Chennai Metro *1
	Power Consumption of Elevated Station: Initially 200 kW, 2051yr 300 kW Power Consumption of Underground Station: Initially 1,500 kW, 2051yr 2,000 kW Power Consumption of Depot: Initially 1,500 kW, 2051yr 2,000 kW	Power Consumption of Elevated Station: Initially 200 kW, 2055yr 300 kW Power Consumption of Underground Station: Initially 1,000 kW, 2055yr 1,500 kW Power Consumption of Depot: Initially 1,500 kW, 2055yr 2,000 kW
RSS/TSS/AMS	2 nos.: Mithapur RSS, New ISBT RSS TSS : 132/25 kV 30 MVA AMS : 132/33 kV 30 MVA	12 nos.: Madhavaram RSS, Vasanthi RSS, YMCA RSS, Tharamani RSS, Siruseri RSS, Nadhamuni RSS, Mugalivakkam RSS, St. Thomas RSS, Medavakkam RSS, Perubakkam RSS, CMBT RSS, Kodambakkam RSS TSS : 110/25 kV 21.6 MVA or 30/42 MVA AMS : 110/33 kV 31.6 MVA/40 MVA
ASS	Elevated : 315 kVA or 500 kVA Underground : 2,500 kVA Depot : 2 × 2,500 kVA	Elevated : 500 kVA Underground : 3,200 kVA Depot : 2 × 2,500 kVA
DG	Elevated : 180 kVA Underground : 380 kVA Depot : 2 × 320 kVA	Elevated : 250 kVA Underground : 2 × 910 kVA Depot : 2 × 320 kVA

*1 Comprehensive Detailed Project Report for Chennai Metro Phase-II, Dec., 2018

Source: DPR and JST

It is possible for the rated current of the switchgear to evaluate the value from comparing the estimated loads with the rated breaking capacity.

Rated Breaking Capacity (Traction): $P_{\mathrm{TSS}} = 25\ \mathrm{k[V]} \times 2{,}000\ \mathrm{[A]} = 50\ \mathrm{M[VA]}$

Rated Breaking Capacity (Auxiliary): $P_{\mathrm{AMS}} = \sqrt{3} \times 33\ \mathrm{k[V]} \times 1{,}250\ \mathrm{[A]} = 71\ \mathrm{M[VA]}$

The rated breaking capacity of the above is more than traction and auxiliary loads. Therefore JST thinks that the selection of the rated current is appropriate.

(2) Feeder equipment

There are three standard and proven systems of electric traction for use in metro line:

- 750 V DC : Third Rail System
- 1,500 V DC : Third Rail/ Overhead Catenary System
- 25 kV AC : Simple feeding system/ BT feeding System

Each feature of traction system is shown in the table below. The selection of proper traction system has a significant impact on capital cost, operational cost, traffic growth, operational flexibility and expandability of the system in future. It is also linked to the ultimate capacity being planned. Appropriate selection of traction system at design stage is essential to achieve optimum performance of metro system.

Table 12-5: Feature of Traction System

Item	DC feeding system		AC feeding system
Supply voltage to the Rolling Stock	750 V (Third Rail System)	1,500 V (Third Rail/ Overhead Catenary System)	25 kV (Simple feeding system/ BT feeding System)

Item	DC feeding system		AC feeding system
Transportation Capability	60,000 PHPDT	60,000 ~ 80,000 PHPDT	60,000 ~ 100,000 PHPDT
Substation Distance	1-2 km	3-10 km	50 km (Simple feeding system) 30 km (BT feeding System)
Operation example in India	Kolkata Bangalore Kochi	Guangzhou Shenzhen	Delhi Jaipur Chennai Hyderabad Indian Railways
Aesthetic (Elevated)	Good	Good (Third Rail) Bad (Overhead Catenary System)	Bad
Initial Cost	High	High	Low
Voltage Drop	Big	Middle	Small
Energy Efficiency	Low	Middle	High
Risk of Electrical Shock	Big	Big (Third Rail) Small (Overhead Catenary System)	Small
Possible Problem	Electrical Corrosion	Electrical Corrosion Lightning Hazard	Inductive Interference Lightning Hazard

Source: DPR and JST

25 kV AC is most economical followed by 1500 V DC and 750 V DC traction systems both from initial cost point of view as well as energy efficiency. But from the aesthetic point of view, 750 V DC Third rail system is better. 25 kV AC system has an ability to carry a high traffic at a reduced cost with higher efficiency of operation. Considering the techno economic advantages offered by 25 kV AC system, it is proposed to adopt 25 kV AC system for Patna metro. Then the feature of traction system is shown in the table below. From the table, using overhead contact lines at the elevated section and overhead rigid conductor at the underground section gives various advantages. The traction system in DPR is similarly proposed like this.

Table 12-6: Characteristics of Electric Contact Line System

	Overhead Contact Lines	Overhead rigid Conductor
Current Collection Performance	Stable current collection at high speeds	The pantograph is less compliant than overhead lane Necessary parts to be supported in the upper part such as tunnel
Operating Speed	Up to about 300 km/h	Up to about 90 km/h
Maintenance and Management	Maintenance for contact line equipment involves work at heights. Easy track maintenance	Easy to maintain contact line equipment and track
Electric Shock Accident	Too few	Too few
Investment Costs	Low for initial capital investment	Slightly higher for initial capital investment
Impact of Natural Disasters	The high impact from strong wind and earthquake	Depend on the location
Route Conditions	Since electrical separation is required above the Rolling Stock; a certain support height is required.	Since small required electrical separation above the Rolling Stock allows slightly smaller tunnel diameters Continuous support to the structural shed, such as a tunnel, is required.

	Overhead Contact Lines	Overhead rigid Conductor
Section to be adopted	To be adopted in various sections	Mainly tunnel section

Source: JST

As for the feeding system, the simple feeding system will be adopted among the AC feeding system. The proposed simple feeding system here consists of contact wire, rail and return conductor. The feature of simple feeding system is very economical due to be the circuit construction simply. On the other hand, because return current flows into both rail and return conductor, leakage current causes the inductive interference of the communication line and rail potential is higher than other feeding systems.

The proposed 25 kV Rigid OHE system in underground section is similar to the one installed in underground sections of Delhi Metro. 25 kV Rigid OHE system comprises a hollow Aluminum Conductor Rail of adequate cross section with 150 mm^2 copper contact wire held with elastic pinch. The Al conductor rail is supported by an insulator and cantilever arrangement attached to drop-down supports fixed to tunnel roof. The supports are located at every 10 meters and there is no tension in the conductors and hence, no tensioning equipment is required in tunnel. The design of 25 kV rigid OHE system shall be in accordance to electrical clearances and contact wire height as per IEC 60913 and EN50122, which is summarized below.

- Contact wire height 4324mm (with pantograph locked down height of 4,048mm)
- Structure to Live parts clearances 270/170/150mm (Static/Dynamic/Absolute min dynamic)
- Vehicle to Live parts clearances 290/190/150mm (Static/Dynamic/Absolute min dynamic)

The main equipment of possible installation in the traction equipment is shown in the table below.

Table 12-7: Main Equipment of Possible Installation in Traction Equipment

Field	Equipment of Possible Installation		Remark
Power Supply, Traction	Contact Line System	Flexible OHE (Contact wire 150 mm^2 Cu-Ag)	Elevated
		(Catenary wire 125 mm^2 Cd-Cu)	
		(RC 233 mm^2 ACC)	
		(ATD Spring type)	
		Rigid OHE (Contact wire 150 mm^2 Cu)	Underground
		(Conductor Aluminum)	
	Feeding Post	3 nos (Mithapur, New ISBT, Depot)	
	Sectioning Post	1 no (Mithapur Station)	Corridor 1
	Sub Sectioning and Paralleling Post, Sub Sectioning Post	6 nos (CH: 0.086 km, 0.513 km, 2.94 km, 7.90 km, 13.950 km, 16.93 km)	Corridor 1
		7 nos (CH: 0.375 km, 6.30 km, 8.69 km, 9.69 km, 10.106	Corridor 2

		km, 13.50 km, 14.064 km)	

Source: DPR and JST

(3) Auxiliary power supply equipment

The auxiliary power will be required for the following.

- Lights & fans for station
- Service Buildings
- Foot over Bridges/ Subways
- Maintenance Depots
- Air-conditioning
- Lifts
- Escalators
- Water Supply Pumping Stations － for washing, toilets as well as fire protection measures.
- Equipment － Signalling, Telecom, Automatic Fare Collection, etc.

ASSs are envisaged to be provided at each station for stepping down 33 kV supply to 415 V for auxiliary applications. The ASS will be located at mezzanine or platform level inside a room. The demand of power at each elevated station is expected to be about 200 kW in the initial years and is likely to reach 300 kW in 2051. Similarly, for the underground stations, the auxiliary load requirements have been assessed at 1500 kW for underground station which is likely to increase to 2000 kW in 2051.

Two transformers of 315 kVA or 500 kVA of dry type cast resin transformer at each elevated ASS for the elevated stations is proposed to be installed. One transformer of 2,500 kVA at each underground ASS for the underground stations is proposed to be installed. Apart from stations, separate ASS is required at depot with two transformers of 2,500 kVA to cater to depot cum workshop load. The main equipment of possible installation in the auxiliary equipment is shown in the table below.

Table 12-8: Main Equipment of Possible Installation in Auxiliary Equipment

Field	Equipment of Possible Installation			Remark
Power Supply, Traction	33kV Ring Main Network	Cable	(3R × 1C × 400 mm^2, 33 kV XLPE insulated FRLS)	Elevated
Power Supply, Traction	33kV Ring Main Network	Cable	(3R × 1C × 400 mm^2, 33 kV XLPE insulated FRLSOH)	Underground
Power Supply, Traction	ASS	Transformer	(33 kV/415 V, 3-phase, 315 kVA or 500 kVA, dry type cast resin transformer)	Elevated (12 nos)
Power Supply, Traction	ASS	Switchgear	(HT, LT)	Elevated (12 nos)
Power Supply, Traction	ASS	DG	(180 kVA)	Elevated (12 nos)
Power Supply, Traction	ASS	Transformer	(33 kV/415 V, 3-phase, 2,500 kVA)	Underground (12 nos × 2*) *2nos for 1 Station
Power Supply, Traction	ASS	Switchgear	(HT, LT)	Underground (12 nos × 2*) *2nos for 1 Station
Power Supply, Traction	ASS	DG	(380 kVA)	Underground (12 nos × 2*) *2nos for 1 Station
Power Supply, Traction	ASS	Transformer	(33 kV/415 V, 3-phase, 2,500 kVA)	Depot (1 no)
Power Supply, Traction	ASS	Switchgear	(HT, LT)	Depot (1 no)

		DG (320 kVA)	
	LT load system (LT Power Distribution, Illumination System, Lifts and Escalators, Fire Detection and Alarm System, Fire Suppression, etc.)		

Source: DPR and JST

Specifications of auxiliary loads are assumed as follows.

Table 12-9: Specifications of Auxiliary Loads

Items	Specifications
LT Power Distribution	Main technical specifications are planned as follows ・ 33kV power supply is stepped down to 415V, 3-phase for distribution to consumption points ・ Composed of Lifts, Escalators, Light & power sockets, Fire system, VAC system and Signal & Telecom system, etc. Normative Reference ・ Low voltage power distribution cables shall comply with IEC 60502 or another applicable international standard ・ Fire resistant cables shall be used for safety purpose and comply with performance requirements of IEC 60331 and BS 6387.
Illumination System	Main technical specifications are planned as follows ・ For Illumination generally, all lighting fixtures shall be applied with 240V, single phase 50Hz power supply ・ Use of LED light fixtures is recommended at elevated and underground stations of corridor and office buildings of depot due to Energy savings, lower life cycle cost, longer life span, rugged nature etc. Normative Reference ・ Type and quality of fittings and their luminous intensity shall relate to space being illuminated and will take into account effect of architectural space concept and color scheme as per IS 3646
Lift and Escalator	Main technical specifications are planned as follows ・ Lifts are machine-room less type lifts with gearless drive and 3-phase VVVF drive ・ Escalators are heavy-duty public services escalators with 3-phase VVVF drive ・ Further, the escalators will be provided with infrared sensors to automatically reduce the speed (to idling speed) when not being used
Fire Detection and Alarm System	Normative Reference ・ Fire Detection and Alarm System shall be in conformance to applicable NFPA standard or Other International Standards and also comply with codes of practice, standards, regulations and requirements of PMRCL
Fire Suppression	Main technical specifications are planned as follows **a) Portable Fire Extinguishers** ・ Portable fire extinguishers shall be installed at all the stations ・ Extinguishers shall be conspicuously located in positions where they will be readily accessible and immediately available in the event of fire ・ Extinguishers shall be located near to room exits, corridors, stairways, lobbies and landings ・ Extinguishers shall be installed at a height of 1 meter above floor level and shall be placed in a manner such that extinguisher operating instructions face outward Normative Reference ・ Complied with relevant IS Codes and codes of practice, standards, regulations and requirements of PMRCL ・ Location and design of extinguisher cabinets provided shall comply fully to local fire authority requirements. **b) Wet Mains System** ・ Wet mains system is charged by the Fire pumps set ・ Fire pump set shall have dual power supply and system shall be designed to achieve a pressure of 3.5 Bar at remote fire hydrant point Normative Reference ・ Fire Fighting wet mains system shall be based on NFPA-13, NFPA-14 and NBC ・ System will draw water from fire water storage tank provided near station building based on NBC requirements **c) Fire Hose Cabinets** Normative Reference ・ Fire Hose Cabinets shall be provided as per NBC and fire authority regulations in internal and external public areas of the station.

Items	Specifications
	d) Fire Hose Reels ・ Hose-reel shall be provided in such a way that it covers entire Concourse/ Platform areas with suitable number of fire hose cabinets ・ Hose reels system will be based on direct feed from the Fire Water Wet mains ・ Hose-reels shall be of the swing-recessed type ・ Each hose-reel shall be an integral unit consisting of a stop valve, reel, hose, and shut-off assembly ・ Hose reel shall be designed so as to facilitate swift withdrawal of hose in any direction with reel axis horizontal <u>Normative Reference</u> ・ Hose reels shall meet the requirements of IS 12585. **e) Gas Flooding System** ・ Gas Flooding System is proposed to be provided for protection of equipment in RSS, AMS, TSS, ASS and S&T equipment in Depot Control Centre or Operational Control Centre <u>Normative Reference</u> ・ Design of system shall be in conformance to NFPA standards
Standby Diesel Generator (DG) Sets	Main technical specifications are planned as follows ・ It is proposed to provide standby DG set of 180kVA at all elevated stations and 380kVA at underground stations to cater to the following essential services - Lift Operation - Essential Lighting - Signaling & Telecommunications - Firefighting System - Fare Collection System ・ Silent type of DG sets, which have low noise levels and do not require separate room for installation ・ UPS with adequate power backup may be installed for the very essential lighting load.

Source: DPR

12.1.2 Mechanical Facilities

(1) Ventilation and Air Conditioning Facilities

<u>System configuration of Ventilation and Air-Conditioning</u>

According to the DPR, ventilation and air-conditioning equipment are used everywhere, i.e. elevated, at grade, underground section, and Depot. Ventilation and Air Conditioning systems (VAC systems) are planned for Station Air-conditioning Systems, Ventilation System for station plant rooms, Station Smoke Management Systems, Tunnel Ventilation Systems (TVS), and monitoring and control systems. The tunnel is equipped with a Track Exhaust System (TES).

Underground stations of the corridor are especially built in a confined space. A large number of passengers occupy concourse halls and the platforms, specifically at the peak hours. The platform and concourse areas have a limited access from outside and do not have natural ventilation. It is therefore, essential to provide forced ventilation in the stations and inside the tunnel for the purpose of the following.

・ Supplying fresh air for the physiological needs of passengers and the authority's staff

・ Removing body heat, obnoxious odours and harmful gases like carbon dioxide exhaled during breathing

・ Preventing concentration of moisture generated by body sweat and seepage of water in the sub-way

- Removing large quantity of heat dissipated by the train equipment like traction motors, braking units, compressors mounted below the underframe, lights and fans inside the coaches, A/c units, etc.
- Removing vapours and fumes from the battery and heat emitted by light fittings, water coolers, Escalators, Fare Gates, etc. working in the stations
- Removing heat from air conditioning plant and sub-station and other equipment, if provided inside the underground station.

Furthermore, a large quantity of heat generated in underground station cannot be extracted by simple ventilation, especially when the outdoor air temperature and humidity is high. It is, therefore, essential to provide mechanical cooling in order to remove the heat to the maximum possible extent.

The design conditions of the VAC system are in the table below. Outside ambient conditions are as per ISHRAE-2017.

Table 12-10: VAC System Design Requirements

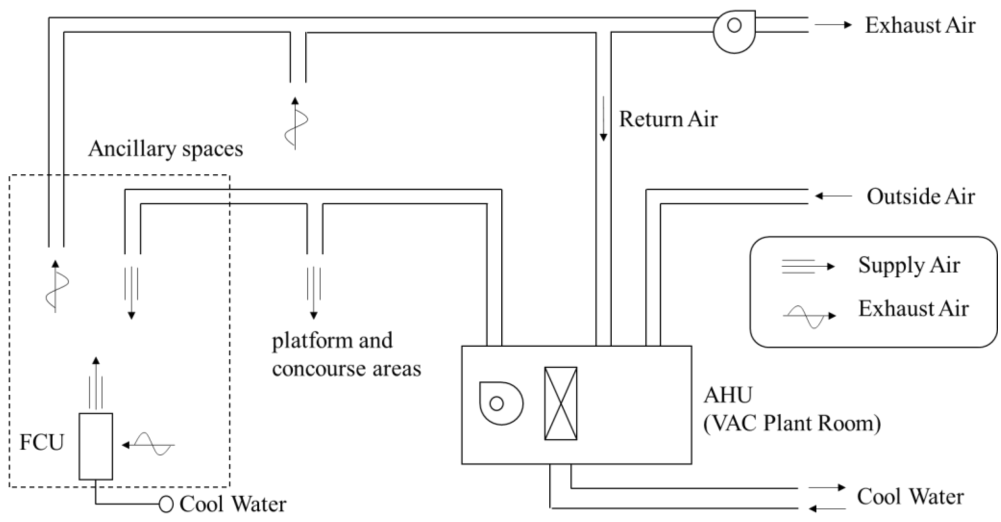
Item	Plan
Ambient air conditions	Summer : 39.5 °C (DB) 23.4 °C (WB) Rainy season : 33.0 °C (DB) 28.6 °C (WB) ※DB (Dry-bulb temperature) : Dry bulb temperature WB (Wet-bulb temperature) : Wet-bulb temperature
Indoor conditions	Platform Concourse: 27°C at 55% RH ※ RH (Relative Humidity): Relative Humidity
Tunnel conditions	Usual maximum : DB 40°C Maximum during congestion : DB 45°C
Minimum fresh air	10% or 18 cmh/person (station public) ※ Cmh (cubic meter per hour): Blower capacity, cubic-rice/hour (m^3/h)

Source: DPR

<u>Station Ventilation and Air Conditioning of ancillary spaces</u>

Platform, Concourse and Ancillary areas will be air-conditioned using supply air handling unit (AHU) located in air-handling plant rooms throughout the station as shown in Figure 12-2. Each platform will be served by at least two separate air handling units with the distribution systems combined along each platform to ensure coverage of all areas in the event of single equipment failure. These air conditioning systems mix return air with a desired quantity of outside air.

Ancillary spaces such as staff room, equipment plant room, will be mechanically ventilated or air conditioned in accordance with the desired air change rates and temperatures or humidity. All ancillary areas that require 24-hour air conditioning will be provided with fan-coil units (FCU). During the revenue hours when the main chilled water system is running the FCU will be used for air-conditioning. In non-revenue hours, small capacity air cooled scroll chillers will be operated.



Source: JST

Figure 12-2: Station Ventilation and Air Conditioning System Scheme

Specifications of AHU and FCU are assumed as follows.

Table 12-11: Specifications of AHU and FCU

Items	Specifications
AHU	Main technical specifications are planned as follows • Outside air requirement is based on occupancy, 7.5 cfm/person and 0.06 cfm/sqft as per ASHRAE standard or 10% of circulated air volume, whichever is the greater • Return air to platform areas is extracted and either returned to the AHU's or exhausted as required • Using of enthalpy sensors to determine benefits of using return air or outside air • Mixture of outside and return air is cooled by a cooling coil • Water-cooled chiller units with screw compressors are recommended to be provided and estimated capacity for a typical station would be around 750- 900 TR • In view of the temperate outdoor conditions, alternatively, it is possible to utilize air cooled chiller units • Considering outside temperature during winter season in Patna, train heat is utilized for station heating hence only cooling unit installed
FCU	Main technical specifications are planned as follows • FCU is exclusively for chilling • Fresh air can be planned either with separate fresh air unit or with AHU for technical room • Where fresh air is required it will be supplied to indoor unit via a fresh air supply system, complete with filter, common to a group of ancillary areas • Return air grilles will be fitted with washable air filters for re-circulation of air • Temperature of technical rooms are to be considered as 24°C±1°C with 50% RH and for non technical rooms design temperature may be considered as 25°C±1°C with 50% RH • Temperature control will include an alarm setting, which is activated on attaining high temperature

Source: DPR and JST

<u>Tunnel Ventilation System (TVS)</u>

The TVS is provided in a Subway system essentially to carry out the following functions

a) Train Pressure relief during normal operation
b) Ventilation during maintenance periods, if required
c) Removal of smoke during emergency conditions
d) Maintenance of smoke free evacuation route and provision of adequate fresh air during fire related emergencies.

There are various operating modes (scenarios) for the Tunnel Ventilation system. These are as follows.

Table 12-12: Operating Modes for Tunnel Ventilation

Conditions	Contents
Normal Conditions	Normal condition is when the trains are operating to timetable. During summer and the monsoon seasons, the vent shafts to the surface will enable the tunnel heat to be removed due to train movements. For less severe environmental conditions, the vent shafts will be open to atmosphere. For cold conditions, the closed system or open system mode may be used without any station air conditioning. System heating is achieved by the train heat released into the premises.
Congested Conditions	Congested conditions occur when delays cause the idling of a train in a tunnel section. Without forced ventilation, excessive tunnel temperatures may result reduced performance of coach air conditioners that may lead to passenger discomfort. During congested operations, TVS is operated to maintain a specific temperature in the vicinity of the car air conditioner condenser coils. The open system congested ventilation shall be via a 'push-pull' effect where tunnel vent fans behind the train are operated in supply and tunnel vent fans ahead of the trains are operated in exhaust mode.
Emergency Conditions	Emergency conditions are when smoke is generated in the tunnel or station trackway. In emergency conditions, TVS would be set to operate to control the movement of smoke and provide a smoke-free path for evacuation of the passengers and for the firefighting purposes.

Source: DPR

Specifications of TVS Fans are assumed as follows.

Table 12-13: Specifications of TVS Fans

Item	Specifications
TVS Fans	Main technical specifications are planned as follows ・ Tunnel ventilation fans will be installed in each of fan rooms near vent shafts ・ There shall be two fans in a fan room at each end of the station ・ Fan capacity depends on inter-station distances and may vary from 60 cum/s to 100 cum/s ・ Trackway exhaust system will have two fans of each 30 cum/s ・ Connections to tunnels and shafts will be through damper units that may be either electrically or pneumatic actuated

Source: DPR

Codes and Standards

The concept VAC design is guided by the following codes and standards.

SEDH – Subway Environment Design Handbook

ASHRAE – Handbook, current series

NFPA – 130, latest edition

(2) Other Mechanical Equipment

Control and Monitoring Facilities

For the underground stations, the control and monitoring of station services and systems such as station air-conditioning, ventilation to plant rooms, lighting, pumping systems, lifts & escalators, etc. shall be performed at Station Control Room (SCR). However, the operation and control of Tunnel Ventilation as well as Smoke Management system will normally be done through Operation Control Centre (OCC).

12.2 Reviews of Existing Studies and Proposals for Improvement

12.2.1 Power Supply Facilities

(1) Power Receiving Facilities

Power for the extended and newly constructed line sections are supplied by extension from the existing equipment or new one from the electric power company.

- JST queried PMRCL about the status of power purchase agreement including Renewable Purchase Obligation (RPO). In response to JST's inquiry, PMRCL made a reply, "The Power purchase & contract demand agreement will be done with SBPDCL (State DISCOM) prior to final installation, testing & Commissioning of the RSS." (Power requirement for both RSS with source connectivity has already been communicated to STU i.e., BSPTCL and the licencee company SBPDCL.) In fact, it isn't at present, however they said any arrangement will be entered. The required power purchase will be done in mid of year 2024 if as planned.

  The RPO targets for FY 2021-22 as stipulated by BERC are as given below:

  RPO (%) 17.00%

  Solar (%) 8.00%

  Non-solar(%) 9.00%

  Bihar has two big DISCOMs, NSPDCL and SBPDCL. According to BERC(2022), "*Tariff Order of DISCOMs (NBPDCL & SBPDCL) for FY 2022-23*" (p218), NBPDCL achieved 62.19% Solar and 114.67% Non-solar compliance and SBPDCL has achieved 59.34% Solar and 109.43% Non-solar compliance against the target for FY 2021-22. Bihar has not progressed in the use of solar power as a whole. Therefore the Commission directed to put forth more efforts to procure the balance solar energy required to meet the RPO requirements of FY 2021-22 and shortfall in FY 2019-20. The DISCOMs have submitted that they have already taken steps to enhance their Renewable Energy mix and SBPDCL could not only achieve the RPO targets, but also considerable surplus of Solar energy and Non-solar energy for FY 2022-23 to FY 2024-25.

- Power transmission lines are installed between RSS and GSS to receive power from BSPTCL. According to PMRCL, EHV cable would be installed and maintained by PMRCL.

- It is necessary for the stable operation and passenger security to deliver the stable electric supply. Therefore to ensure redundancy is important for the system design. Mithapur RSS and New ISBT RSS are fed from GSS at 132kV voltage through 2 cable lines respectively. Furthermore Each RSS has backup facilities and loads can receive parallel supply from two RSSs. In normal conditions, Mithapur RSS will feed corridor 1 and New ISBT RSS will feed Corridor 2. In case either of the two RSS fails, then the other RSS will feed both the corridors. Under normal conditions, the power supply from each RSS is shared, and all power shall be available from the other RSS in emergency conditions such as one RSS failure. For the above reason, JST evaluates that the measures of stable electric supply are sufficient.

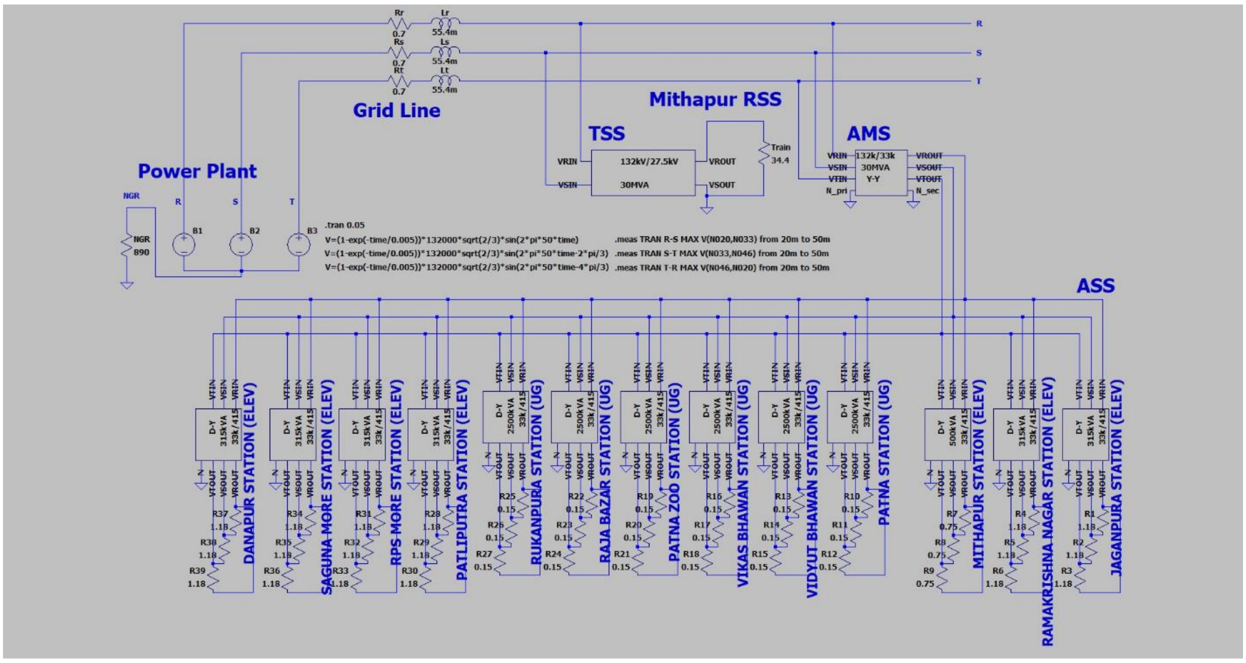
- According to PMRCL, Gas-Insulated Switchgear (GIS) is used in RSS/TSS and at ASS of underground stations. GIS confines high-voltage components in a single gas tank. Even its cost is relatively high, it reduces the site space, ensures the safety of electric power workers and workers of manufacturers, and prevents power reception failure due to wildlife intervention.
- JST queried whether it is possible for the protective relay in TSS to protect all corridor areas while extended feeding in power failure. PMRCL made a reply, “Protective relays in TSS are capable to protect all areas of TSS.”
- According to PMRCL, they are supposed to use Single-phase transformers in TSS. They have already ordered and the products are in testing stage. When Single-phase transformer instead of Scott-connected transformer is used, there is some possibility of causing any problem of unbalanced three-phase loads. Therefore JST suggested installing Scott-connected transformer. In response to JST's suggestion, PMRCL made a reply, “The voltage unbalancing will be taken care at Grid level as it is done in Delhi. Conditions in Patna are similar to Delhi. Moreover, Patna being a rapidly developing city is potentially cable of managing unbalancing at Grid Level only. Work has been already awarded for PE-01 (RSS contract) so any change at this stage is not possible.”

The phase voltage unbalance rate is defined according to IEC61000-4-30, the threshold doesn’t exist publicly. But when this unbalance becomes excessive, it can create problems for the lift and escalator, etc. in the station. Just for reference, the Approved Model Specifications of Japan recommend that electric supply systems using AC feeding system should be designed and operated to limit the maximum voltage unbalance to 3 percent.

If any problem caused by voltage unbalance occurs after the operation, it is necessary to take any countermeasure. Scott-connected transformer for traction is one of the solutions.

<u>Numerical Simulation of Voltage Unbalance</u>

JST investigated the effect of voltage unbalance on the low-voltage side of station’s ASS when single phase transformer is used for traction. Each component was modeled according to DPR and simulated using LTSpice XVII (hereinafter referred to as SPICE). The systematic diagram modeled on Mithapur RSS is shown below.



Source: JST

Figure 12-3: Systematic Diagram modeled on Mithapur RSS

The back impedance Z_L (Power Plant to Grid Line) is calculated using NEMA (National Electrical Manufacturers Association) Standard AB1, short-circuit capacity of power supply 1,000 MVA and X/R = 25. The short-circuit capacity at 132 kV is 1,000 MVA, and the reference capacity of the system is 10 MVA, in which case $\%Z_L$, Z_L and the back inductance L are following.

$$\%Z_L = 10\ \text{MVA} \div 1{,}000\ \text{MVA} = 1\%$$

$$Z_L = R_L + jX_L = (132\ \text{kV})2 \div 10\ \text{MVA} \times 1\% = 17.42\ \Omega$$

$$Z_L = 0.696 + j17.41\ (\because\ X/R = 25)$$

$$L = 17.41\ \Omega \div 2\pi f = 17.41 \div (2\pi f \times 50) = 0.0554\ \text{H}$$

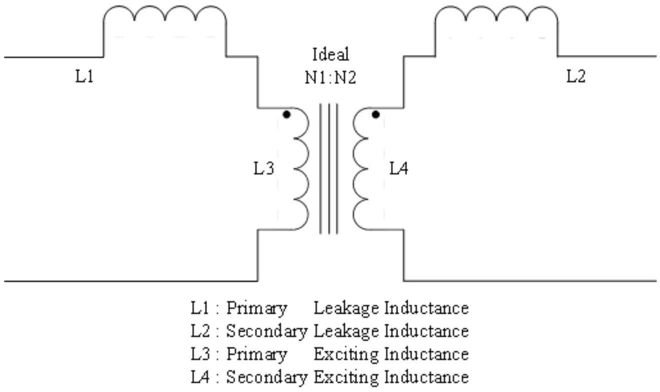
Concerning Transformers, since an exciting current is sufficiently small compared to the load current, the exciting current loss is not simulated here. The distribution of leakage inductance on the primary and secondary sides is mostly the primary side, and the secondary side is set to 1 nH for convenience purpose. Although the inductive coupling factor k is generally said to be 0.99 or more, it is set to 1, the same as an ideal transformer, in order to facilitate the convergence of calculations. Rated capacity, Connection, Primary Voltage, Secondary Voltage and % impedance of transformers used in the simulation are in the table below.

Table 12-14: Specifications of Transformer used in Simulation

	Rated Capacity (VA)	Connection	Primary Voltage (V)	Secondary Voltage (V)	%Z (Equipment base)	Remark
TSS	30 M	Single Phase	132k	27.5 k	13.8 %	Traction
AMS	30 M	Y – Y	132k	33k	12.5 %	Auxiliary
ASS	315 k	D – Y	33k	415	7 %	ELEV
	500 k	D – Y	33k	415	7 %	ELEV

	Rated Capacity (VA)	Connection	Primary Voltage (V)	Secondary Voltage (V)	%Z (Equipment base)	Remark
	2500 k	D – Y	33k	415	7 %	UG

As an example, we show how to derive the inductance of the transformer in AMS given the rated capacity, transformation ratio, and % impedance. The model of AMS's Transformer is shown below.



Source: JST

Figure 12-4: Model of AMS's Transformer

At first, to find the total impedance Z=R+jX. Since R is sufficiently small compared to X, only X is considered. The reactance component X=ωL for one phase is following.

$$X=(132\ \text{kV})^2 \div 30\ \text{MVA} \times 12.5\% = 72.6\ \Omega$$

The total leakage inductance on the primary and secondary sides is following.

$$L_{total}=72.6\ \Omega \div 2\pi f = 72.6 \div (2\pi \times 50) = 0.231\ \text{H}$$

Since L_2 on the secondary side is 1 nH, the primary side L_1 is 0.231 H. For the inductive coupling factor k=1, L_4 on the secondary side is arbitrarily set to 100 (a.u.). Considering the voltage ratio 132 kV/33 kV, the primary side L_3 is following

$$L_3=L_4 \times (132\text{kV} \div 33\text{kV})^2 = 1600\ \text{(a.u.)}$$

The inductance values to be input in SPICE are in the table below.

Table 12-15: Inductance Values of AMS's Transformer

k=1	Primary	Secondary
Leakage Inductance	L1: 231 (mH)	L2: 1 (nH)
Exciting Inductance	L3: 1600 (H)	L4: 100 (H)

*Calculated the other transformers in the same way according to the connection.

The back impedance, traction load and auxiliary load are used as parameters for the simulation conditions. The loads are simulated by inserting a resistance between the lines in the secondary side of TSS and ASS. The traction load is set to 0 MVA for no single transformer's load, 14 MVA for normal maximum load and 22 MVA for emergency maximum load under the condition of traction system failure in New ISBT TSS. The Auxiliary load is set to 13.9 MVA with a demand factor of 0.8 for the total equipment capacity of ASS. In this condition, effective line voltages of the secondary side at Patna

Station (UG) were obtained. According to IEC61000-4-30, Line voltage unbalance rate was calculated by the following formula.

$$V_{ub} = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}} \times 100$$

$$\beta = \frac{|V_{ab}|^4+|V_{bc}|^4+|V_{ca}|^4}{(|V_{ab}|^2+|V_{bc}|^2+|V_{ca}|^2)^2}$$

Simulation results are in the table below.

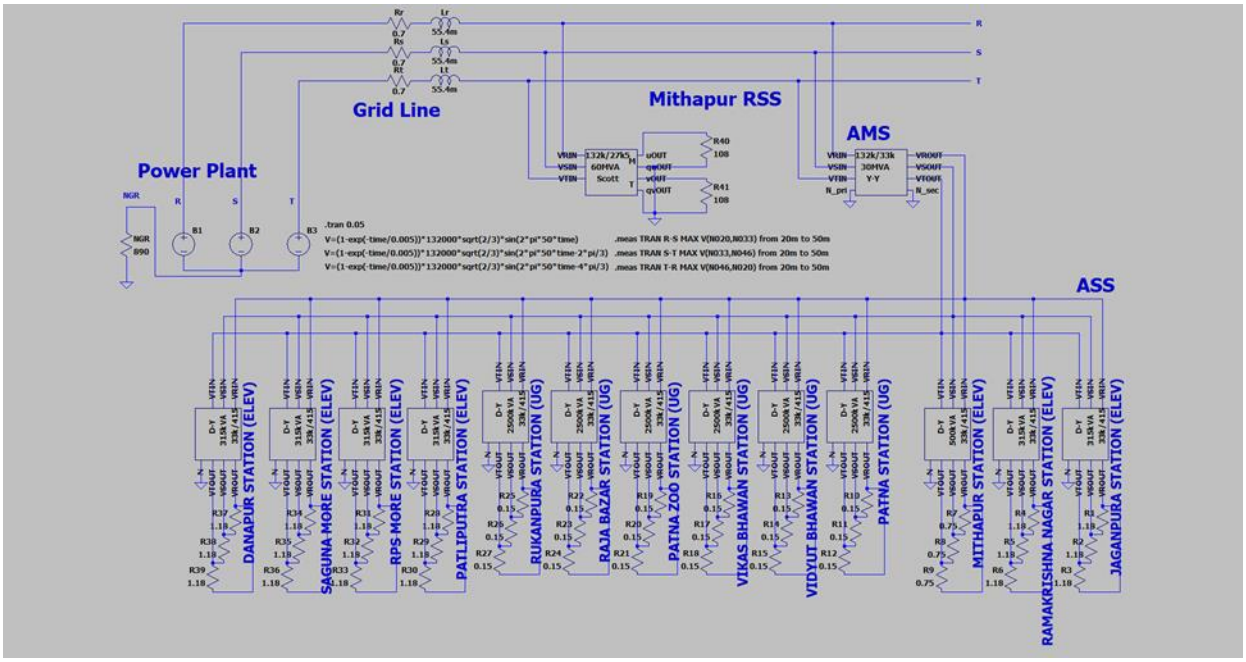
Table 12-16: Simulation Results

No.	Short-Circuit Capacity (MVA)	Traction Load (MVA)	Auxiliary Load (MVA)	Line Voltage *V*ab (V)	Line Voltage *V*bc (V)	Line Voltage *V*ca (V)	voltage unbalance rate *V*ub (%)
1	1,000	0	13.9	399.0	399.1	398.8	0.05%
2	700			398.0	398.1	397.8	0.05%
3	400			395.4	395.4	395.1	0.05%
4	1,000	14		391.8	397.8	401.0	1.35%
5	700			388.2	396.8	401.2	1.93%
6	400			378.7	394.1	401.1	3.38%
7	1,000	22		388.0	397.8	402.3	2.12%
8	700			382.7	396.8	402.9	3.03%
9	400			368.8	394.1	403.2	5.26%

According to the simulation performed under the conditions assumed as Mithapur RSS, if the traction load was 0 MVA, the voltage unbalance rate on the secondary side wouldn’t exceed 3 % even under the short-circuit capacity 400 MVA. Furthermore, It was found that the voltage unbalance rate would exceed 3 % when the short-circuit capacity of the power supply is below 400 MV under normal traction maximum load (14 MVA) or below 700 MVA under emergency traction maximum load (22 MVA). That is, as the short-circuit capacity decreases or the traction load increases, the phase balance is lost and the voltage unbalance rate increases. Although we did not perform the simulation for New ISBT RSS this time, we can expect similar results to the Mithapur RSS because of the similar facility configuration and demand forecast.

In a large city like Delhi, voltage unbalance may not be a problem as the short-circuit capacity of the power supply can be imagined sufficiently to be large. However, in Patna, there is a concern that the short-circuit capacity of the power supply can decrease due to the long distance from the power plant, in other words, the length of the transmission line. Therefore, regarding this point, it is important to confirm with State Transmission Utility (STU) how much the actual short-circuit capacity and the actual back impedance at the power receiving point of RSS will be. After that, it is necessary to consider the voltage unbalance. As a result of consideration, Scott-connected transformer for traction is one of the solutions if any measure is required.

A Scott-connected transformer is consisted of a kind of circuit used to produce two-phase electric power from 3-phase source. And it can balance load between the phases of the source. The system diagram with the Scott-connected transformer modeled is shown below. The capacity of Scott-connected transformer is set to 60 MVA (30 MVA × 2 circuit). And two circuit loads of the secondary side is under a balanced condition.



Source: JST

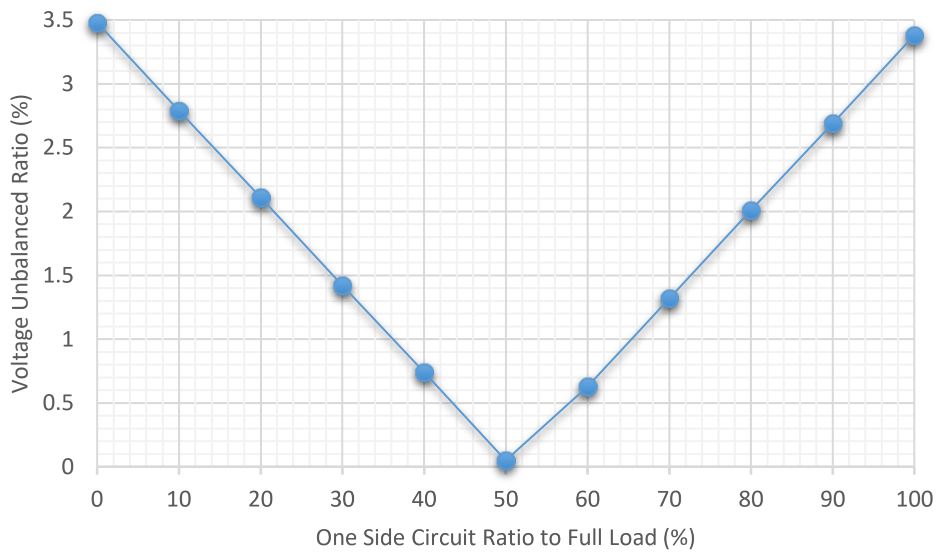
Figure 12-4: Systematic Diagram with Scott-Connected Transformer Modeled

Using this circuit model, simulations were performed with the single phase transformer under the same condition that the voltage unbalance rate exceeded 3%. Simulation results are in the table below.

Table 12-17: Simulation Results with Scott-Connected Transformer

No.	Short-Circuit Capacity (MVA)	Traction Load (MVA)	Auxiliary Load (MVA)	voltage unbalance rate *V*ub (%)	Remark
1	700	22	13.9	3.03%	Single Transformer (Ref)
2		11+11		0.05%	Scott-Connected
3	400	14		3.38%	Single Transformer (Ref)
4		7+7		0.05%	Scott-Connected

In this results, we can figure out that Scott-connected transformer would suppress the voltage unbalance if two circuit loads of the secondary side is under the balanced condition. In other words, the voltage unbalance can be suppressed if power distribution to feeders of two ways can be evenly distributed. However, if two circuit loads are unbalanced, the voltage unbalance rate increases with the load ratio. The relation between the voltage unbalance and the load ratio at No.4 is shown below.



Source: JST

Figure 12-5: Relation between Voltage Unbalance and Load Ratio

As you can see from this graph, the more balance the load ratio, the better the voltage unbalance get depressed. Conversely, when one circuit has almost the load, the voltage unbalance rate approaches value of the single-phase transformer. That is, provided that a certain degree of load ratio is maintained, the Scott-connected transformer can effectively reduce the voltage unbalance rate.

(2) Traction Power Facilities

- According to DPR, the high density traffic is supposed be like a peak period headway of 3.0 minutes for both corridors in the future. Considering the line length, estimated PHPDT and economic advantages offered by 25kV AC system, it is proposed to adopt 25kV AC system for Patna metro.
- When adopting AC feeding system we should concern about emerging of the Electro Magnetic Interference (EMI). Because Booster Transformer is proposed for EMI mitigation JST queried whether Booster Transformer would be installed or not. In response to JST's inquiry, PMRCL made a reply, "The department of telecommunication has given clearance to charge the system without using Booster Transformer." Therefore it is possible to use the simple feeding system in all areas.
- According to PMRCL, return conductor will be connected to main earth terminal at every 1 km in elevated station and 500 meter in underground section, similar to the practice being followed in DMRC. JST think that the earthed system is appropriate.
- JST queried about setting up sub sectioning posts in order to recover normal operation at in case of the feeder accident. In response to JST's inquiry, PMRCL made a reply, "There are 4 sub sectioning and paralleling post each in corridor 1 & corridor 2 to recover the normal operation, moreover, 2 sub sectioning post in corridor 1 & 3 in corridor 2 are provided for further smoothing of operation in case of faults." And the power supply in Depot is also redundancy. For the above reason, JST evaluates that the measures of stable electric supply are sufficient.

- JST queried whether any countermeasure such as mounting a backup battery to the train are considered when the train might stop at the way point between stations in case of all grid power outage. In response to JST's inquiry, PMRCL made a reply, “In their cases evacuation will be done as per established procedure.”
- JST queried about the distance (10 m) of each supporting point in the underground area. In response to JST's inquiry, PMRCL made a reply, “Maximum design speed of ROCS in the function of sag (corrugation) in Contact wire/ROCS, and as the contact is design and built, supporting distance will be decided as per the design of ROCS.” According to PMRCL, distance between two supports for most of the designs for a speed potential of 90 kmph is about 11 to 12 m under the rule in India. The distance of 10 m is same distance in Delhi metro, and they said that there is no problem with the equipment. Just for reference, the Approved Model Specifications of Japan recommend that the distance of each supporting point of ROCS should be designed to limit the maximum of 7 m considering with the sag of contact wire.

12.2.2 Mechanical Facilities

- The Indian Standards & Codes, which pertain to office-buildings, commercial centers and other public utility buildings, have no guidelines on temperature standards to be maintained for the underground mass rapid transit systems as yet. But the performance requirements for ventilation facilities meet the standards established in India and are considered reasonable.

13. Depot

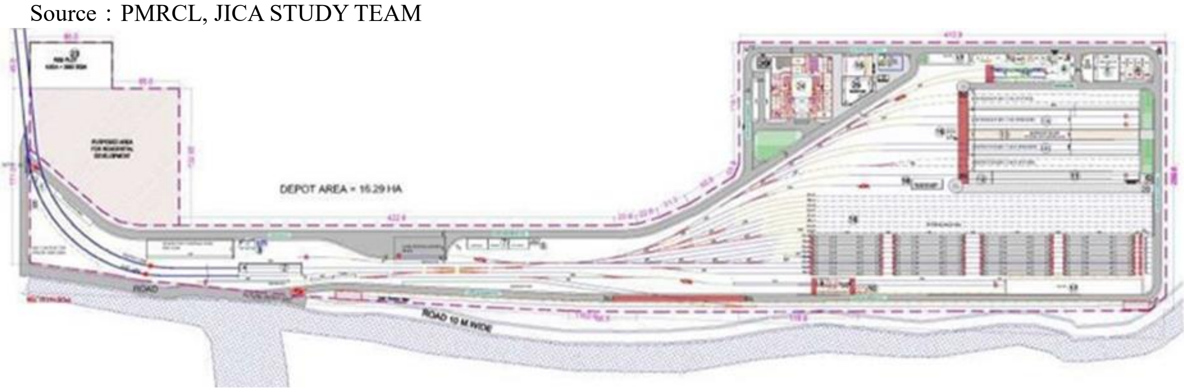
13.1 Track Layout

According to DPR, the rail depot is supposed to locate at the southeast of the Nwe ISBT station adjacently and the double track of access line between the main line and the depot is proposed. The depot is supposed to stable and maintain all trains of Corridor 1 and Corridor 2.
This section describes the issues on the current alignment of the depot as a result of reviewing.
The basic specifications of the depot are as follows.

Table 13-1: NEW ISBT Depot Basic Specifications

Item	Spec
Area	19.6ha
Stabling capacity	64 trainsets (3 cars per trainset)
Number of storage tracks	16 track (4 trainsets stabling per track)
Effective length of storage track	331m
Number of inspection track	5 track (Two of the tracks are planned for the future.)
Number of main workshop track	4 track (Two of the tracks are planned for the future.)
Wheel lathe track	1 track
Indoor cleaning track	1 track
Test track	1 track
Automatic train washing plant	1 set
Loading / Unloading track	1 track
Administration Office	1 building
Crew Office	1 building

Source：PMRCL, JICA STUDY TEAM



Source：Detailed Project Report 2021, DMRC

Figure 13-1: Current Layout Plan of New ISBT Depot

13.2 Issues identified by alignment review

(1) Number of trains stabling on storage tracks

The current depot layout has 16 storage tracks and one storage track can accommodate 4 trainsets of 3-cars train. Given this layout, it is readily anticipated that the trains parking at far end of storage track have the difficulty to depart since only one side has the depot access track. In general, one storage track accommodates it up to two trainsets. Therefore, it is recommended to make a train diagram for the depot operation and check whether it would be possible to achieve the train operation without any problem even if one storage track accommodates four trainsets.

Additionally, according the latest depot layout plan, only half of storage tracks will be operational at the time of the inauguration and another half of tracks will be available at the time of the future expansion. For the purpose of smooth train operation, it is recommended to build all 16 storage tracks at the time of the inauguration to reduce the number of stabling train per track.

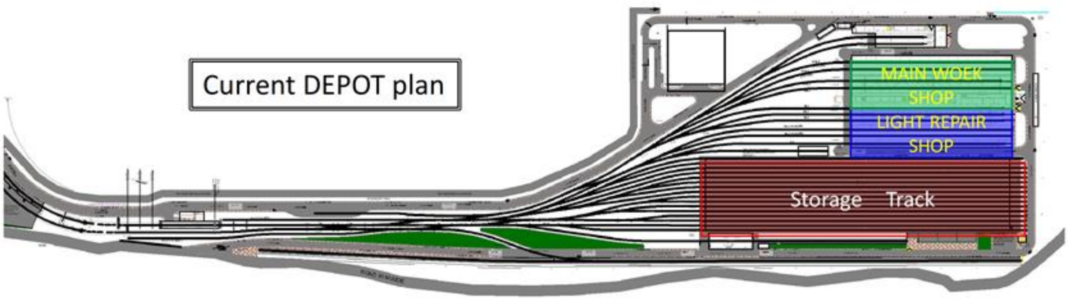
(2) Location of the main workshop and the test track

Since the main workshop and the test track are not adjacent to each other, trains need to cross the spur line from/to the depot to move to the test track after overhaul. Moreover, these trains are forced to switchback several times in a way to the test track due to the turnout layout.
Even the overhauled trains have the risk of getting stuck due to unexpected troubles. Therefore, the desirable alignment is to allow a train move smoothly from the main workshop and the test track. Given with the shape of the depot site, however, if the test track is located on the same side of the main workshop, it will be difficult to place some buildings on the current layout. In addition, the test run line is supposed to be fenced off from the surrounding area for safety reasons and there should be no railroad crossing. To achieve this, the test track would have to be located on the perimeter of the depot, otherwise the depot yard would be divided. Considering the current layout plan that has less impact on the surrounding area, the re-layout of test track is found difficult.

(3) Proposal for improvement of depot

1) Proposal for the depot alignment

As a result of study on the feasibility of re-layout of the overall facility layout, it is found that re-layout requires the significant change in the shape of depot site or the additional land. Therefore, it is concluded to follow the current plan of the basic facility layout in this study.



Source：Detailed Project Report 2021, DMRC

Figure 13-2: Location map of main facilities at New ISBT depot

a. Route improvement between the main work shop and the test track

As mentioned, the current alignment plan cannot place the test track beside the main work shop, and therefore a train needs to turn back three times on the way. See "Figure 13-3: Current route plan between depot and test track" for the travel route between the Main Work shop and the test track in the current plan.

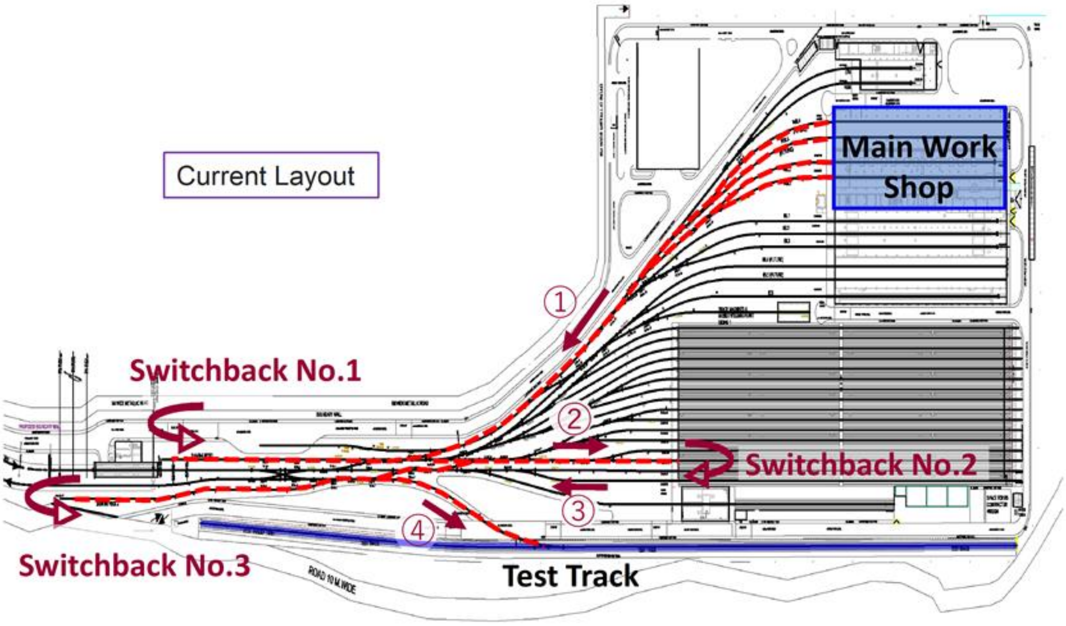
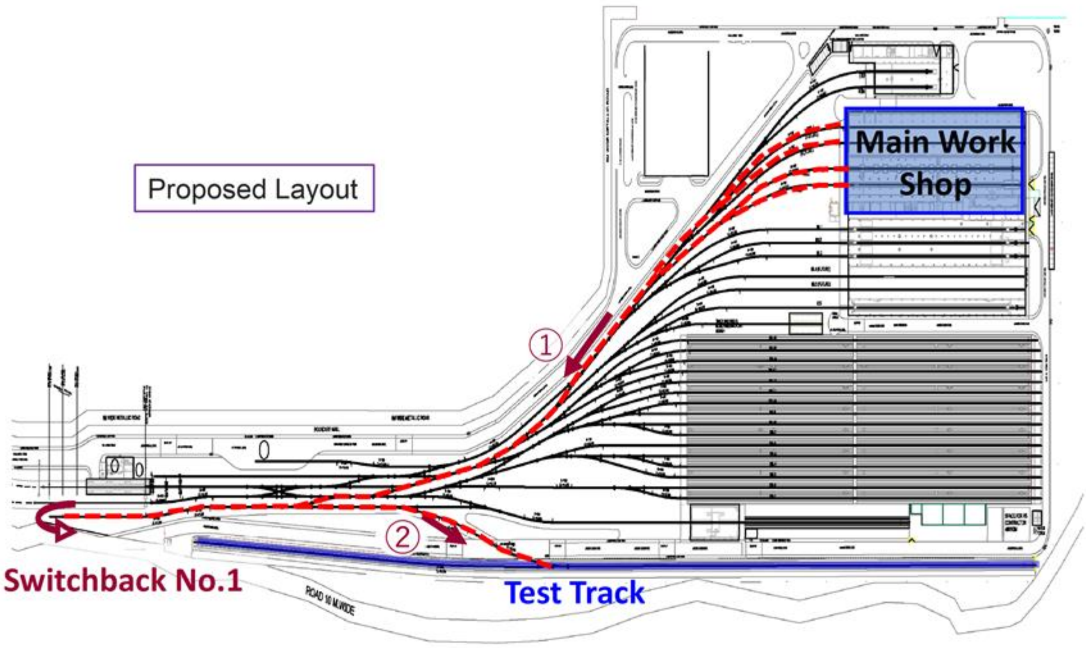


Figure 13-3: Current route plan between depot and test track

After assembling at the main workshop, trains move to the test track for the final operational testing. Troubles may be caused on the way before the operational testing is performed. Therefore, the route to the test track should be as short as possible to prevent such a risk from affecting the train dispatching from and returning to the depot. From this viewpoint, the frequent turn-back operation forced in the current plan has a high risk.

This study reviews the layout of turnouts and proposes the alignment modification that allow trains to move from the depot to the test track in the shortest route without turning back.

See "Figure 13-4: Proposal for improvement of train route between main workshop and test track" for the route of the test track train after the wiring change



Source：Detailed Project Report 2021, DMRC, JICA Study Team

Figure 13-4: Proposal for improvement of train route between main workshop and test track

In this proposed alignment, the route from the main workshop to the depot is simplified so that only one switchback is enough. Although additional four turnouts are required for this modification, there is no change in the function of the depot in general.
Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for depot plan after alignment change.

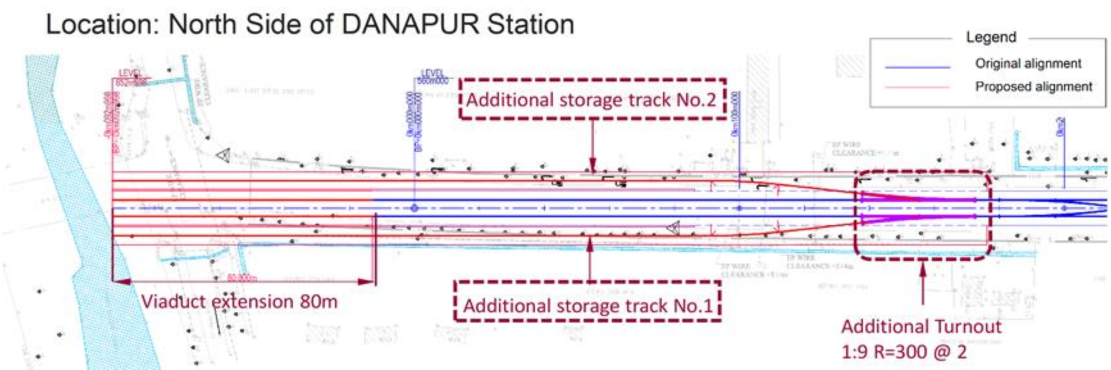
b. Results of depot improvement proposals

The proposed improvements have been adopted by PMRCL and, at the time of this report's writing, work has begun on the DEPOT alignment changes.

2) Proposal for storage track outside depot

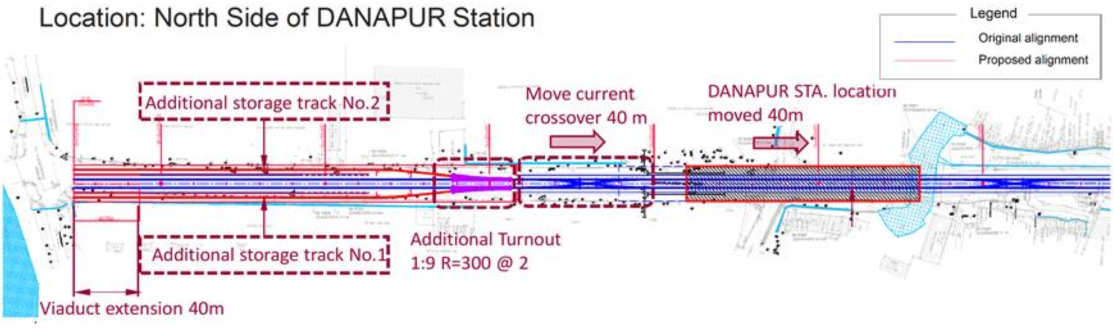
a. Addition of storage track to DANAPUR station

The current plan assumes that New ISBT depot accommodates all trains of Corridor 1 and Corridor 2. As seen in the layout of the Khemni Chak station where tracks of both corridors are linked, there is the branch of diamond crossing and out-of-service trains in Corridor 1 need to cross the main line to move to Corridor 2, and vice versa. This is not desirable since the diamond crossing causes blocking trains in Corridor 2 and affect the operation. It is difficult to completely avoid blocking by crossing, however the addition of storage track to Corridor 1 can lessen a number of trains crossing Corridor 2 by accommodating some trains.
The recommended location for this additional storage track is near the terminus. Considering the operation to send the out-of-service trains in early morning and midnight, the location is preferably far from the New ISBT depot. From these reasons, the proposed location of this additional storage track is near Danapur Station, the starting point of Corridor 1.
Figure 13-5: Additional storage track near DANAPUR station, Version 1 and Figure 13-6: Additional storage track near DANAPUR station, Version 2 show the proposed layout.



Source：JICA Study Team

Figure 13-5: Additional storage track near DANAPUR station, Version 1



Source：JICA Study Team

Figure 13-6: Additional storage track near DANAPUR station, Version 2

To avoid the additional land acquisition and the impact on the current plan, the proposed layout of the additional storage track is at the lead track at the north side of Danapur Station. In detail, one storage track is to be placed on both sides of the double track of lead track, that is, two storage tracks are proposed in total.

There are two proposed layout as shown in "Figure 13-5" and "Figure 13-6".

The difference is the end point of the viaduct on the north side. In case of Version 1, the viaduct is extended as reached to the river and may interfere with the road bridge. To avoid this, Version 2 shifts the Danapur Station 40 m south and change the position of the northern end of the viaduct accordingly.

b. Decision about Proposal for Additional Storage Track

PMRCL decided not to add the storage track since the variation in the alignment design at the current stage is difficult. Moreover, they did not consider both the change in the station location and the north extension of the viaduct preferred.

13.3 Depot Planning

The following lines, buildings, and facilities are planned in the depot.

Table 13-2: Lines, Buildings, and Facilities in Depot

Indoor Lines	Stabling Lines
	Inspection Lines
	Workshop Lines
	Pit Wheel Lathe
	Engineering Train Unit Workshop Cum Emergency Re-railing Shed
Outdoor Lines	Car Delivery Area
	Automatic Coach Washing Plant
	Test Track
	Heavy Cleaning Shed
Building	Train Operator Booking Office
	Administrative Building
	Watch Towers
Facilities	Power Supply
	Standby Power Supply
	Compressed Air Supply
	Water Supply, Sewerage and Drainage Works
Machineries	Plant and Machinery
Others	Parking Facilities

Source: DPR

13.4 Workshop Facilities

The following plant and machinery are planned in the depot and workshop.

Table 13-3: Plant and Machinery in Workshop

Category	Plant & Machinery	Quantity
Material Handling	Travelling over head EOT cranes for workshop 25/5T	1
	Travelling over head EOT cranes for inspection bay 1.5T	1
	Travelling over head EOT cranes for ETU shed 5T	1
	Jib crane for workshop 3T	1
	Synchronised pit jacks system for car lifting	2 set
	Car body stands for keeping 6 car shells	12
	Dummy bogies	6
	Mobile lifting jacks 15T	2
	Mobile lifting jacks 10T	2
	Battery powered locomotive	2
	OHE Inspection Car	2
	Road mobile crane 5T	1
	Fork lift truck 3T	2
	Fork lift truck 2T	2
	Pallet truck	4
	TATA truck	1
	Scissors type lifting trolley 2T	2
	Hydraulic trolleys 2T	2
Wheel Shop	500T wheel press	1
	Vertical boring m/c (Turret Lathe)	1
	Multipurpose wheel lathe	1
	Axle turning lathe	1
	Axle UST inspection machine	2
	Radial drill m/c	1
	Induction heater	2
	Bearing extractor	2
Bogie Shop	Bogie wash/cleaning plant	1
	Bogie static load testing m/c	1
	Shock absorber testing m/c	1
	Spring scragging & testing m/c	1
	Magnacheck crack detector	1
	Glowcheck crack detector	1
Rotating m/cs	Baking oven	1
	Dynamic balancing	1
	Traction motor test console	1
	Motor compressor test bench	1
	Tan delta testing instrument	1
Other m/cs	Under floor pit wheel lathe	1
	Chip crusher and conveyor for pit wheel lathe	1
	Automatic washing plant for metro cars	1
	High-pressure washing pump for front/rear end cleaning of cars	1
	Turntable for one car	1
	Turntable for bogies	4
	Driving cab simulator	1
	Water de-mineralization plant	2
	Painting booth for separate parts	1
	Floor cleaning machine	4

Category	Plant & Machinery	Quantity
	Welding equipment	5
	Compressor 500 cfm	1
	DG set 320 kVA	3
	Battery charger	2
Machine Shop	Guillotine sharing m/c	1
	Sheering, punching & cropping	1
	Universal tool cutter & grinder	1
	Vertical surface grinder	1
	Centre lathe 2m bed	1
	Centre lathe 1m bed	1
	Radial drill m/c	1
Test Benches /Instrument	Brake test bench	2
	SPM test bench	2
	Door test bench	2
	Inverter test bench	1
	Other test benches (MCB, PMPU, etc.)	1
	Oscilloscope	1
Furniture /Material Storage /Small Tools	Vertical storage system for DCOS store	1
	Computer MMIS with LAN connectivity	1
	Storage racks	LS
	Industrial furniture	LS
	Electric and pneumatic tools	LS
	Measuring and testing equipment	LS
	Tool kits	LS
	Mobile safety steps	10

Source: DPR