Patna Metro Rail Corporation Limited
Republic of India

Preparatory Survey on Patna Metro Rail Project

Final Report (Advanced Version)

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Japan International Cooperation Agency

Oriental Consultants Global Co., Ltd.
Nippon Koei Co., Ltd.
Padeco Co., Ltd.
Japan International Consultants for Transportation Co. Ltd

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Abbreviations and Acronyms

AAGR	Annual Average Growth Rate
AC	Alternating Current
ACDB	AC Distribution Board
ADB	Asian Development Bank
AF	Audio Frequency
AFC	Automatic Fare Collection
AFG	Automatic Fare Gate
AHU	Air Handling Unit
AI	Airtificail Intelligence
AMS	Auxiliary Main Substation
App	Application
ASI	Archaeological Survey of India
ASS	Auxiliary Substation
ATD	Auto-Tensioning Device
ATM	Automated Teller Machine
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train supervision
B/C	Benefit over Cost
BCC	Buckup Control Center
BERC	Bihar Electricity Regulatory Commission
BSPTCL	Bihar State Power Transmission Company Limited
BT	Existing Bus Terminal
CBD	Central Business District
CBI	Computer-based Interlocking
CBM	Condition-Bsed Maintenance
CBTC	Continuous Automatic Train Control System
CCHS	Central Clearing House System
CCTV	Close Circuit TeleVision
CDAC	Centre for Development of Advanced Computing
CE	Conformitè Europëenne
CENELEC	Comité Européen de Normalisation ELECtrotechnique
CFRS	Central Fault Reporting System
CIBE	Commercial, industrial and business enterprise
CMP2018	Comprehensive Mobility Plan Patna in 2018
CP	Counterpart
CVC	Central Vigilance Commission
CVRS	Central Voice Recording System
DC	Direct Current
DCC	Depot Control Center

DDC	Detail Design Consultant
DF/R	Draft Final Report
DG	Diesel Generator
DISCOM	Distribution Company
DMRC	Delhi Metro Rail Corporation
DoT	Department of Telecommunications
DPR	Updated Detailed Project Report for Metro Rail System in Patna
DTG	Distance To Go
DTO	Driverless Train Operation
DVRS	Digital Voice Recording System
DX	Digital Transformation
E&M	Electrical & Mechanical
EB	Emergency Break
EC	Environmental Clearance
EDC	External Development Charge
EFO	Excess Fare Office
EHV	Extra High Voltage
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EMI	Electro Magnetic Interference
EMP	Environmental Management Plan
EMV	Europay Master Visa
EN	European Norm
ESIA	Environment and Social Impact Assessment
EV	Electric Vehicle
F/R	Final Report
FAR	Floor-Area Ratio
FCC	Federal Communications Commission
FCU	Fan Coil Unit
FGD	Focus Group Discussion
FIRR	Financial Internal Rate of Return
FOTS	Fiber Optics Transmission System
FRBM	Fiscal Responsibility and Budget Management
FS	Feasibility Study
FSB	Full Service Brake
GDP	Gross Domestic Product
GE	Gigabit Ethernet
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gases
GNSS	Global Navigation Satellite System
GoB	Government of Bihar
GoI	Government of India

GPS	Global Positioning System
GSDP	Gross State Domestic Product
GSS	Grid Substation
HH	Household
HH rail	Head Hardened rail
HT	High voltage
IDA	International Development Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	the Internet Engineering Task Force
IP	Internet Protocol
IPP	Indigenous Peoples Plan
IPT	Intermediate Public Transport services
IRR	Internal Rate of Return
IRS	Indian Railway Standard
ISM	Industrial, Scientific and Medical
ISO	International Organization for Standardization
IT/R	Interim Report
ITU-T	International Telecommunication Union Telecommunication standardization Sector
JST	JICA Study Team
LAP	Land Acquisition Plan
LARRA 2013	Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act 2013 (Land Acquisition Act (2013))
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LILO	Line In Line Out
LT	Low voltage
LVC	Land Value Capture
MaaS	Mobility as a Service
MCCB	Molded Case Circuit Breaker
MMI	Man Machine Interface
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MPI	Multidimentional Poverty Index
MPLS	Multi-Protocol Label Switching
NBC	National Building Code
NCMC	National Common Mobility Card
NFC	Near Field Communication
NFPA	National Fire Protection Association
NMS	Network Management System
NPCI	National Payment Corporation of India
O&M	Operation and Maintenance

OCC	Operation Control Center
OHE	Overhead Equipment
ONVIF	Open Network Video Interface Forum
PA	Passenger Address system
PAH	Project Affected Households
PAP	Project Affected Person
PBX	Private Branch eXchange
PCs	Public Consultations
PIDS	Passenger Information Display System
PMP2031	Patna Master Plan 2031
PMRCL	Patna Metro Rail Corporation Limited
POM	Passenger Operated Machine
PPP	Public Private Partnership
PSD	Platform Screen Door
PSTM	Procedure for Safety Certification and Technical Clearance of Metro Systems
QOL	Quality of Life
QR	Quick Response
qSparc	Quick Specification for Payment Application of Rupay Chip
RAP	Resettlement Action Plan
RC	Return Conductor
RDSO	Research Designs & Standards Organisation
RFC	Request for Comments
ROCS	Rigid Overhead Conductor System
RPO	Renewable Purchase Obligation
RSS	Receiving Substation
SC	Scheduled Caste
SBPDCL	South Bihar Power Distribution Company Limited
SCR	Station Control Room
SD	Subordinate Debt
SGB Park	Sanjay Gandhi Botanical Park
SIA	Social Impact Assessment
SIL	Safety Integrity Level
SIP	Session Initiation Protocol
ST	Scheduled Tribe
STU	State Transmission Utility
SUICA	Super Urban Intelligent Card
TBM	Tunnel Boring Machine
TEC	Telecommunication Engineer Center
TES	Track Exhaust System
TETRA	TErrestrial Trunked RAdio
TOD	Transit Oriented Development
TOM	Ticket Office Machine

TR	Ticket Reader
TRAI	Telecom Regulatory Authority of India
TSS	Traction Substation
TTC	Travel Time Cost
TVM	Ticket Vending Machine
TVS	Tunnel Ventilation System
UL	Underwriters Laboratories (Limited Liability Company)
UPS	Uninterruptible Power Supply
UTO	Unattended Train Operation
VAC	Ventilation and Air Conditioning
VCF	Value Capture Finance
VOC	Vehicle Operating Cost
VRV	Variable Refrigerant Volume
VVVF	Variable Voltage Variable Frequency
WPC	Wireless Planning&Coordination Wing
XLPE	Cross-linked Polyethylene
JSSS	JICA Standard Safety Specification
ROD	Revenue Operation Date
SBD	Standard Bidding Documents
ICB	International Competitive Bidding
LCB	Local Competitive Bidding
JPG	JICA Procurement Guideline
QCBS	Quality- and Cost-Based Selection
PQ	Prequalification
MPW	Manual for Procurement of Works
SPD	Standard Prequalification Document
LOA	Letter of Acceptance
GC	General Consultant
E/N	Exchange of Notes
CMRS	Commissioner of Metro Railway Safety
CCSHE	Conditions of Contract on Safety & Health and Environment
PSHS	Particular Safety & Health Specification

1. Background and Objectives

1.1 Outline of Metro Construction Project in India

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]. Based on the economic scale, the Government of India divides its cities into three categories, namely Tier-1, Tier-2 and Tier-3. In addition to the eight major Indian cities, called Tier-1 cities[2], 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"[3] 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[4].

1.2 Outline of Patna City, Capital of 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] United Nations (2018)
[2] Ahmedabad, Bengaluru, Chennai, Delhi, Hyderabad, Kolkata, Mumbai, Pune
[3] https://mohua.gov.in/upload/whatsnew/59a3f7f130eecMetro_Rail_Policy_2017.pdf
[4] https://www.indiabudget.gov.in/budget2021-22/doc/bh1.pdf

1.3 Expected Outcomes to be Archived by the Patna Metro Rail Construction Project

In response to the above issues, the Bihar government has formulated the "Patna Master Plan 2031"[5] (2016) and the Comprehensive Mobility Plan, Patna (hereafter called "CMP2018" (2018)) for the sustainable development of Patna City. The Patna Metro Rail Construction Project, which is the first metro construction project in Patna City, is positioned as a key urban development project. Based on the above, JICA realizes that this project will contribute to achieving the following outcomes.

Table 1-1: Expected Outcomes to be Achieved by the Patna Metro Rail Construction Project

Expected Outcomes to be Achieved by the Patna Metro Rail Construction Project	
1)	Realization of urban development and public transport plans promoted by the Government of both India and Bihar.
2)	Deterrence of urban problems, such as uncontrolled development of cities and the formation of urban slums, and reduction of time and cost of future infrastructure development, by promoting planned urban development centered on metro.
3)	Reduce environmental impact through the realization of public transportation-oriented cities in line with the Indian government's efforts[6]

Source: JICA

1.4 Overview of this Survey

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

Table 1-2: Outline of this Survey

Items	Contents
Project Name	The Patna Metro Rail Construction Project
Project Objectives	The objective of the project is to cope with the increase in traffic demand in Patna City 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 City.
Survey Area	Patna City, 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

[5] http://udhd.bihar.gov.in/PMP2031/data/pmp-2031-report.pdf

[6] 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 (hereafter called "DPR") was prepared by PMRCL in 2016 and approved by Bihar State Government in 2018. This JICA survey report was prepared based on DPR discussion 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: 14,516 2031: 23,127 2041: 25,323 2051: 32,011	• Corridor 2 2024: 11,252 2031: 17,862 2041: 19,507 2051: 22,083
Daily Trips	• Corridor 1 2024: 557,107 2031: 918,479 2041: 1,064,379 2051: 1,350,815	• Corridor 2 2024: 327,496 2031: 519,803 2041: 537,478 2051: 601,942
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 2051: 3.0	• Corridor 2024: 4.6 2031: 3.5 2041: 3.3 2051: 3.0

Item	Basic Specification
Maximum Design Speed Maximum Scheduled Speed	90 km/h 80 km/h
Track Gauge	1435 mm(Standard Gauge)
Maximum Acceleration Rate	1.2m/s^2
Deceleration Rate	1.1m/s^2(Maximum Service Brake) 1.3m/s^2(Emergency Brake)
Axle Load	16T
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)

Patna Metro's DPR was prepared by PMRCL as an Employer, and RITES as a Consultant, to confirm the feasibility of the project. DPR was approved by Bihar's state government on February 9, 2016.

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 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.

A Memorandum of Understanding (MoU) was signed between PMRCL and DMRC in September 2019 and DMRC was appointed as an Implementation Support Consultant of the Patna Metro Rail Construction Project. In February 2020, DMRC reviewed the alignment 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 the Patna Metro Rail Construction Project by GoI

The Patna Metro Rail Construction Project was approved in 2019 by the Government of both India (GoI) and Bihar (GoB) for the city of Patna to mitigate the traffic problems and improve the environment conditions of the citizens. The total construction cost of the project approved by the GoI is Rs.13365.77crores.

1.5.3 Incorporation of PMRCL

PMRCL was incorporated on 19th February 2019 to implement the said project, functions as a Special Purpose Vehicle (SPV) which is jointly and equally owned by the GoI and GoB. GoI, GoB and PMRCL signed a MoU in November 2019. Its equity share capital at the beginning was Rs.0.05 Cr, and the total paid-up capital is Rs.525.00 Cr as of March 31, 2022.

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 City is situated on the southern bank of the Ganges River. 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. The Sone River flows to the west of the city, the Gandak River to the north and the Punpun River to the south. Patna City is also located approximately 110 km from the Buddhist holy city of Bodh Gaya and serves as a gateway for tourists visiting Bodh Gaya and other Buddhist sites.

- Total Area of Patna City: 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 City

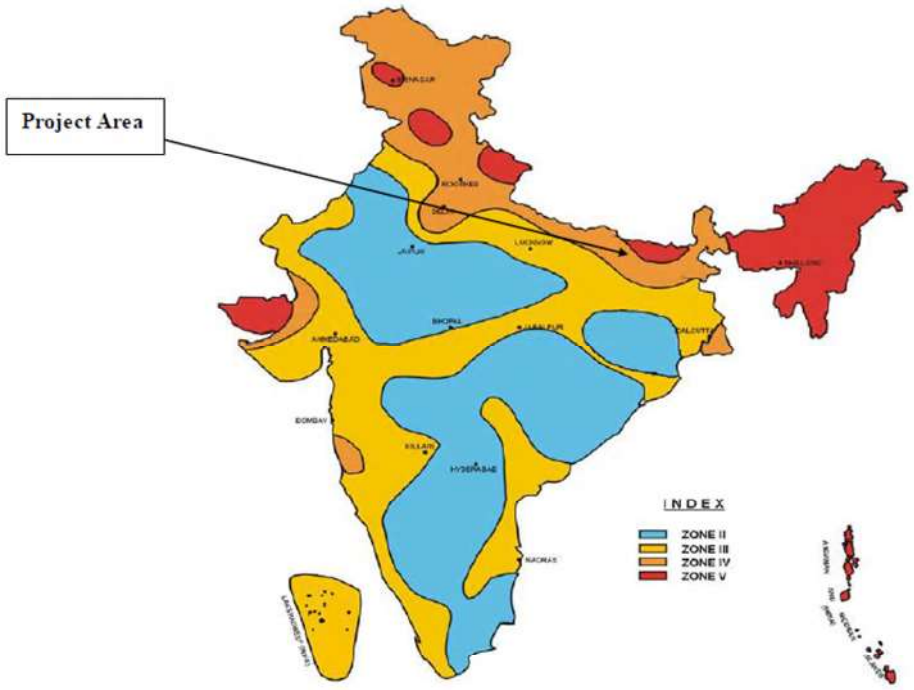
2.1.2 Geological Structure

Patna 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 City 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 City is the Gangetic alluvium of the Indo-Gangetic plain region. Patna City 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 City, 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

Patna City has a humid subtropical climate (Cwa) under the Köppen climate classification. In Patna City, 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 laden 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 City from November to February till the arrival of 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 City was calculated at approximately 1.68 million. Between the 2001 and 2011 census, Patna City's population grew by 17.7% from 1.43 million. The population in 2018 is estimated at 2.62 million. Like many other cities in India, Patna City 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) which is by far the highest, almost double that of other representative Tier-2 cities such as Lucknow, Kochu and Jaipur. In addition the population density of Bihar is the highest in India, so 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 City is located, has the lowest GDP per capita (2020-2021) in India at USD 588, well below the Indian average of USD 1966. The poverty rate (2022) was 33.74% in Bihar, compared to 21.92% for India as a whole.

Bihar has consistently achieved socio-economic development over the past decade. 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. (Bihar Economic Survey 2019-2020)

As a central city of Bihar state, the economy of Patna City 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 are 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 City as the second-best city in India[7] to start a business due to fewer procedures and cost required for start-up. As of 2011-12, the GDP per capita of Patna City is 108,657 Rs., and its GDP growth rate is 7.29 percent. In terms of CAGR between 2006 and 2020, Patna City is the 21st fastest-growing city in the world and the fifth fastest-growing city in India[8] 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.

[7] Doing Business In India 2009 (World Bank): 1st New Delhi, 2nd Patna, 3rd Jaipur, 4th Hyderabad, 5th Bhubaneshwar, 6th Noida, 7th Ludhiana, 8th Indore, 9th Gurgaon, 10th Chennai and Kolkata

[8] The world's fastest growing cities and urban areas from 2006 to 2020 (City Mayors): 1st Ghaziabad, 2nd Surat, 3rd Faridabad, 4th Nashik, 5th Patna, 6th Rajkot, 7th Jaipur, 8th Delhi, 9th Pune, 10th Indore



Source: JST based on Google Earth

Figure 2-3: Major Business Districts in Patna City

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 City, 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 City 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 City 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 City. Sugar is an important business, and Patna City is the brand center for sugar in eastern India. Leather, handicrafts, and agro-processing are the other major industries in Patna City, and these industries provide a livelihood to the people of Patna City. More than 3.6 million people are employed in the industries, and these industries provide a livelihood to the people of Patna City.

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 City. Patna City 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 City. 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 City is one of the most sacred cities of religions like Buddhism, Jainism, Sikhism and Islam, many people travel to Patna City as part of religious tourism. Today, tourism in Patna City 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 City, 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 Politics

The politics in Bihar state is dominated by regional parties. The ruling camp comprises the Rashtriya Janata Dal (RJD), Janata Dal (United) (JDU), Indian National Congress (INC), Communist Party of India (CPI) and other left parties, which hold two-thirds of the seats in the assembly. The ruling alliance forms a coalition of parties called the Mahagathbandhan (MGB), which is known as the Grand Alliance. In the opposition camp, the Bharatiya Janata Party (BJP), India's first national ruling party, which constituted the National Democratic Alliance (NDA) and was in power until August 2022, has 1/3 of the seats in the parliament.

On 9 August 2022, the State Chief Minister, Nitish Kumar, resigned as Chief Minister and the JDU led by him left the NDA and dissolved its coalition with the BJP. The JDU then joined the MGB and Nitish Kumar became the state chief minister again the following day on 10 August. The JDU is currently the first ruling party in Bihar state.

2.2.5 Culture

Hindi is the official language of the state of Bihar but many other languages are spoken too. Patna City's native Language is Magadhi or Magahi, named after Magadha, the ancient name of South Bihar and 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 City's major religion is Hinduism with 86.39% followers. Islam is the second most popular religion in Patna City with approximately 12.27% following it. Christianity(0.51%), Jainism(0.09%), Buddhism(0.02%) and Sikhism, with smaller followings, are also practiced in Patna City.

2.2.6 Air pollution

Air pollution is a major problem in Patna City. In 2018, the amount of particulate matter ($PM_{2.5}$) was observed at approximately 140μg/ m^3 which is ten times higher than the WHO standard (annual average 15μg/m^3). Therefore, Patna City is the 5th worst air pollution level.

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.

According to Comprehensive Clean Air Action Plan for the City of Patna (2019) reported by Bihar state, the transportation (19% of total emissions) is the third largest factor of $PM_{2.5}$ emissions after industry (29%) and household emissions (22%). It has been predicted that if $PM_{2.5}$ emissions continue to increase in the current level without public transport improvement, emissions from transportation will increase by approximately 88% in 2030.

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

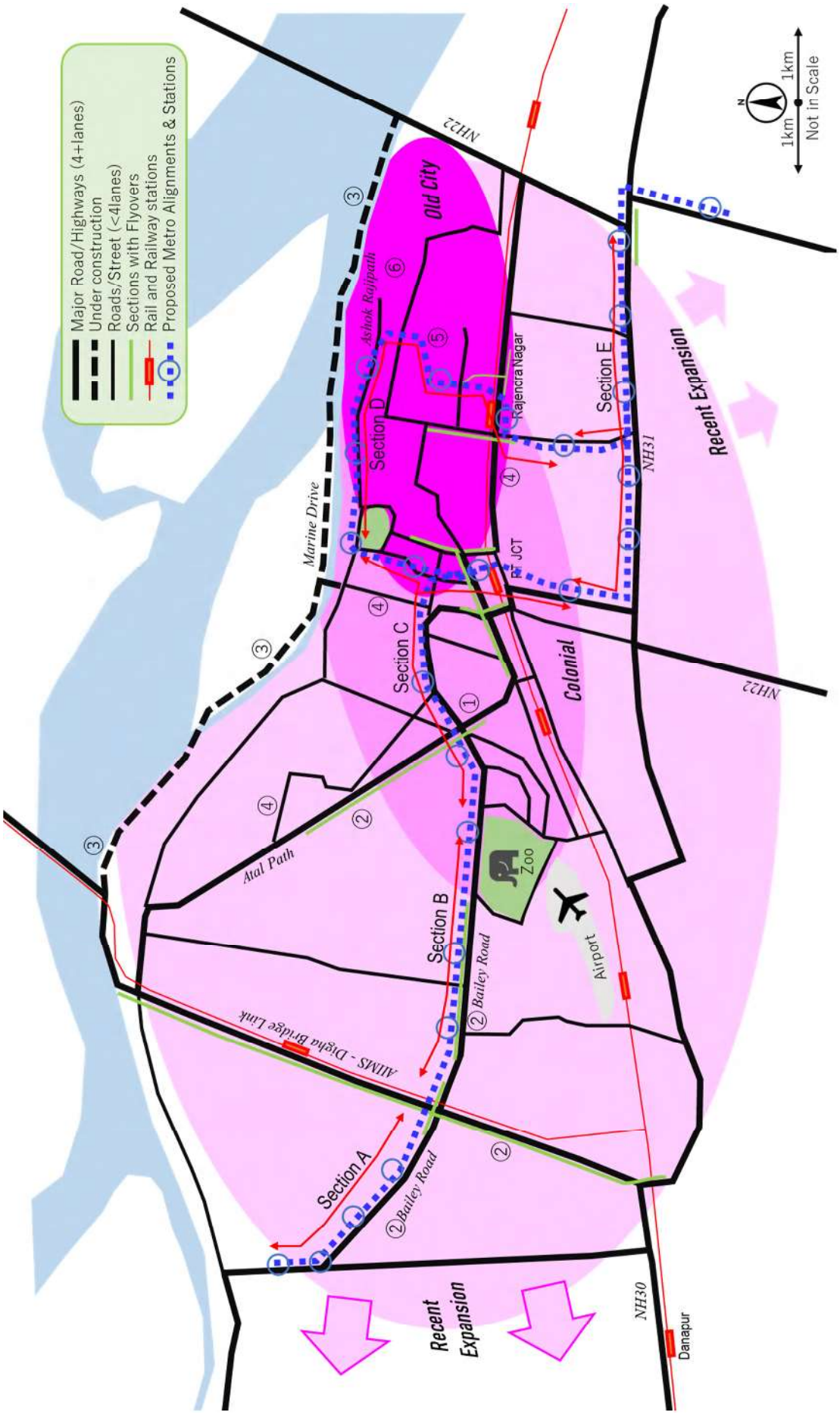


Figure 3-1: Illustration of Transport Network and Phased Urbanization in Patna City

Source: JST

For a 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 a traditional old city, which has a high concentration of the 4-5 stories low quality housing and population of 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 walking, motorcycles, autorickshaw, e-rickshaw, cycle rickshaw and small buses, as the roads are narrow, e.g., the main road Ashok Rajpath in this area has section less than 5.5m where cannot accept the bus operation, and not perfectly connected with another 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 administration. There seems to be no dominant CBD, but area 1 is attractive for private businesses to establish branches. There are small agglomerations of offices, and medium-high-class retails. The heights of the 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 improving 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[9], and high-class education services[10] follow 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 a mix-use of factories, industries, logistics services and residents, due to influence of the intercity highway network consisting of NH22, NH31 and ISBT.

(1) The Game Changers in Patna City

The on-going largest road network investment in Patna City 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 ③in the figure above. As shown below, this will form the full ring road function of Patna City and the CBD traffic can access intercity network escaping from the congested city center by detouring to the Marine Drive.

[9] 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.

[10] 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

Marine Drive 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. Impacts on the Patna Metro Rail Construction Project are expected to include a decrease in through traffic in the old city area and an increase in traffic congestion at connection points.

Retail commercial development, i.e., modernized shopping malls, are still developing in Patna City, however, one is active, and two are expected to be opened in 2022, as shown ④in 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 center mall has the 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 Rajendra Nagar Railway station.

The renovation of the Moin Ul Haq Stadium[11], located along the Metro ⑤in 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, and shopping malls.

Section B – relatively developed residential zones in the hinterland, and high dependence on 3W based

[11] 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

accesses, which will bring large volume of passengers in the initial phase of operation of the Metro. The 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 lose 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 Rajpath 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 City

(1) Existing Vehicle

Development of vehicle registrations for the years 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 City 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 City

	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 years 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 City may reach about 70%, while cars are about 13%. The state's per capita GDP (2020-2021) is 588 dollars, which is well below the Indian average of 1,966 dollars and also the lowest level in India. Therefore, it is assumed that the reason why the number of vehicle owned is still small is this per capita GDP level is below the per capita income level, 1,000-3,000 dollars, where motorization is generally said to progress rapidly.

(2) Road

As shown in the map below, Patna City is a major transport node in the National Highway Grid. The major roads include National Highways – 20, 22, 31 and 33. NH- 20 and 22 are North-South directional regional connectivity of Bihar. NH-31 that links Uttar Pradesh and NH-33 is important as it acts as a gateway to the states in northeast India[12].



Source: Patna Master Plan 2031

Figure 3-3: Regional Connectivity of Patna City

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

Table 3-2: Road Length and ROW in Patna City

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

[12] The numbering system of the Indian National Highway was revised in 2010, and odd numbers are given to east-west directional corridors, and even numbers are to north-south. The CMP2031 explained the number of the National Highways with the old numbering system.

Speed and delay surveys carried out on major roads in the city show that journey speed on major roads during peak hours are in the range of 20-30 km/h. The average journey speeds on each major road are shown in the table below.

Table 3-3: Average Speed at Peak Hour on major corridors in Patna City

Road Name	Observed Journey Speed in Peak Hour (Km/Hr)
Hajipur Road near Gandhi Thana	30
Fatuah Road	25
Didarganj under bridge	15
SH 1, Gaya Jahanabad Road	20
Jahanabad Road near Patna Central School	20
Gaya - Jahanabad Road	20
In front of AIIMS	25
Danapur Khagaul Road	25
Danapur Contempanent Road	20
Danapur Maner Road	15
Frazer Road	25
Ashok Rajpath	20
Khemnichak Road	20
Chirayatand over bridge	30
Gandhi Maidan (Near S K Memorial)	30

Source: CMP2018

It is noted that JICA implemented "Bihar National Highway Improvement Project" with Yen-loan funding since 2013. The project scope aims widening to 4 lanes for 127km section from the southern part of Patna City, via Gaya to Dobhi City. The metro project section slightly overlap with the road improvement, which may make synergy in traffic improvement in the southern part of Patna City.

(3) Railway (Indian Railway)

This section explains about the ordinary regional railway systems in and around the Patna City, which is undertaken by the Indian National Railway, which is a statutory body under the ownership of the Ministry of Railways, Government of India. There are 16 regional divisions of the Indian Railway, and the Patna and Surrounding region belongs to the Eastern Central 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 the south connects Patna 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 local trains brin 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 the 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.

Major railway lines, its operation frequency and train fare are presented below.

Table 3-4: Major Railway Lines in Patna City

Sl.	From	To	Distance (Km)	Train type	Frequency of train	Train Fare (INR)			
						1AC	2AC	3AC	SL
1	PATNA	NEW DELHI	1,004	Mail Express	02 weekly trains and 04 daily trains	2,960	1,755	1,240	475
				Superfast		3,225	1,910	1,350	510
				Express		4,080	3,305	2,420	-
				Premium Trains		4,115	3,345	2,415	-
2	PATNA	BANGALORE (KARNATAKA)	2,704	Mail Express	01 weekly train	-	-	-	-
				Superfast		-	3,465	2,380	920
				Express		-	-	-	-
				Premium Trains		-	-	-	-
3	PATNA	HOWRAH (WEST BENGAL)	532	Mail Express	02 Weekly trains and 03 daily trains	2,130	1,280	915	350
				Superfast		2,585	2,105	1,540	595
				Express		2,585	2,105	1,540	-
				Premium Trains		-	-	-	-
4	PATNA	MUMBAI (MAHARASTRA)	1,710	Mail Express	03 weekly trains and 02 daily trains	4,425	2,600	1,795	670
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	4,750	3,375	2,195
5	PATNA (DANAPUR)	PUNE (MAHARASTRA)	1,748	Mail Express	01 daily train	-	2,700	1,880	715
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-
6	PATNA (DANAPUR)	CHENNAI CENTRAL	2,337	Mail Express	03 weekly trains	-	3,200	2,205	850
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-
7	PATNA	AHMEDABAD (GUJARAT)	1,660	Mail Express	03 weekly trains	-	2,575	1,775	665
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-
8	PATNA	JAIPUR (RAJASTHAN)	1,167	Mail Express	04 Weekly trains	3,545	2,100	1,470	560
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-

Sl.	From	To	Distance (Km)	Train type	Frequency of train	Train Fare (INR)			
						1AC	2AC	3AC	SL
9	PATNA	PURI	931	Mail Express	03 Weekly trains	-	2,210	1,610	595
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-
10	PATNA	GOA	2,390	Mail Express	01 Weekly train	-	3,230	2,225	860
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-
11	PATNA	RANCHI	411	Mail Express	04 daily trains	1,485	890	700	235
				Superfast		-	-	-	-
				Express		-	-	-	-
				Premium Trains		-	-	-	-

Note: 1/2/3 AC, First/Second/Third Class Air Conditioned; SL, Sleeper Class

Source: Indian Railways

(4) Bus

Bus transport in Patna is provided by Bihar State Road Transport Corporation (BSRTC) in two modes, namely, direct management mode and private consignment mode by Public-Private Partnership (PPP). 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 the 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 3-5: 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, however, its operational details are unclear. The seating capacity of the 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.

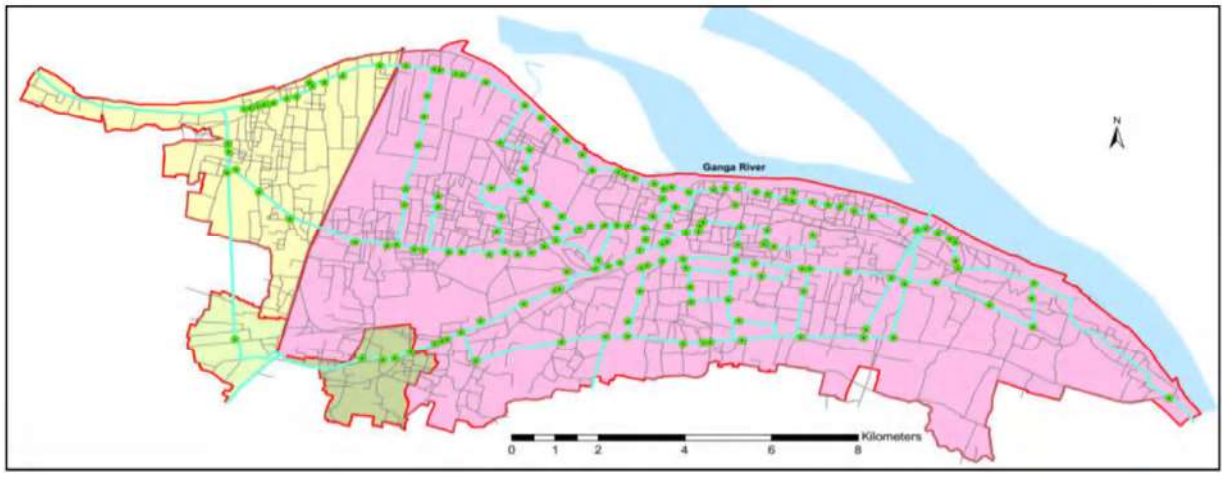
IC Card payment is available for buses operated by BSRTC. According to the interview with Department of Transportation, BSRTC plans to promote IC Card payment to private bus operators, however the acceptance is not high.

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

Table 3-6: Major Bus Route in Patna City

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

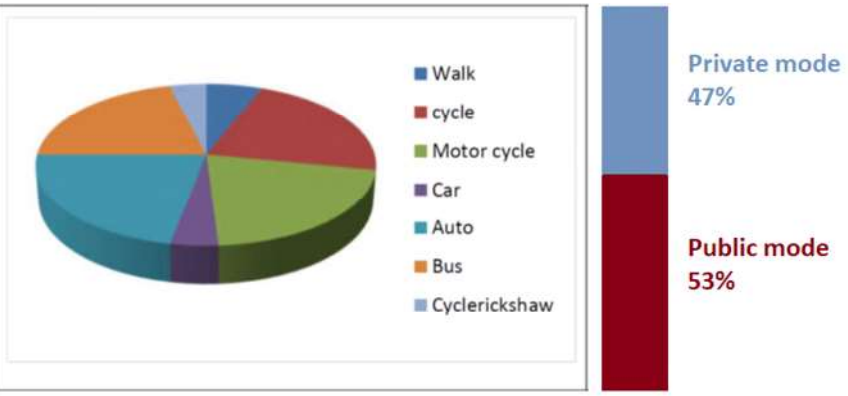
Source: CMP2018

Figure 3-4: Existing Bus Routes in Patna City

(5) Current Modal Share

In terms of modal share, according to CMP2018, bicycle and autorickshaw are the major modes. 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%



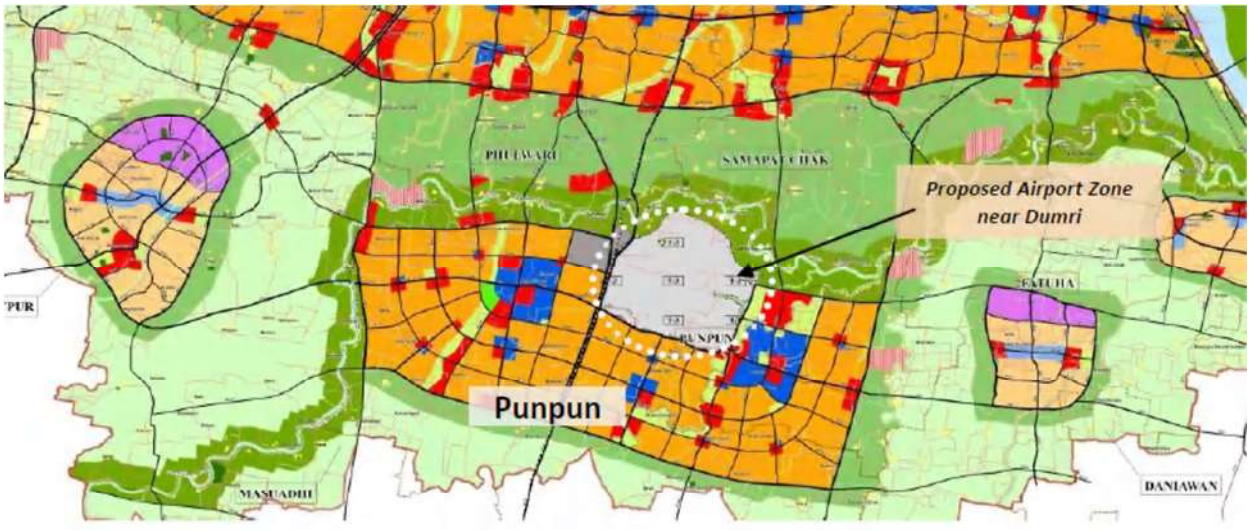
Source: CMP 2018, JST

Figure 3-5: Modal Share in Patna City

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)[13]. 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-22 and SH-74 towards the north of the city of Hajipur, then crossing the Gandak river, NH-31, Dighwara. The estimated cost to build this ring-road is Rs 15000 crores[14].

Patna Master Plan 2031 also proposed the Patna New Airport at Dumri, Punpun, 35km from Patna City.. The location map of the proposed airport is shown below.



Source: PMP2031

Figure 3-6: Location of Patna New Airport

[13] https://nhai.gov.in/#/tender-detail/NDIwNTg
[14] https://www.skyscrapercity.com/threads/patna-outer-ring-road-140-km-4-6-lane-u-c.2294075/

The table below summarizes 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 of the Bihar State. The focus is not only on transportation infrastructure, but also on poverty reduction, water and energy supply in rural area.

Table 3-7: Infrastructure Projects Supported by Other Donors

No.	Project	Donor / Implementing Agency	Project Period	Outline of Project / Work
1	Bihar New Ganga Bridge Project	ADB / BSRDCL	2016-2023	New Ganga Bridge is located about 10 km downstream and east of Patna City. The main objective is to improve connectivity for Patna City and the surrounding areas[15], Project Cost 715 M USD, ADB loan commitment 500 M USD, the construction was completed and the project will be closed by June 2023.
2	Bihar State Highways Project	ADB / BSRDCL	2018-2023	The project will rehabilitate and upgrade about 230 kilometers of state highways in Bihar state[16], route map is provided in Figure below. Project cost 304 M USD, ADB loan commitment 200 M USD.
3	Bihar Urban Development Investment Program	ADB / UDHD, Bihar	2013-2022	Water supply in Bihar regional cities, including Bhagalpur, Darbhanga, Gaya and Muzaffarpur [17]. Project cost 84 M USD, ADB loan commitment 57 M USD.
4	Bihar Transformative Development Project	World Bank, BRLPS	2016-2023	The project is to diversify and enhance household-level incomes and improve access to and use of nutrition and sanitation services[18]. Project cost 415 M USD, WB loan commitment 290 M USD.
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

Note: BSRDCL (Bihar State Road Development Company Limited), UDHD (Urban Development and Housing Department, State of Bihar), BRLPS (Bihar Rural Livelihoods Promotion Society, an autonomous body under the Department of Rural Development)

Source: Compiled by JST

[15] https://www.adb.org/projects/48373-007/main
[16] https://www.adb.org/projects/51180-001/main
[17] https://www.adb.org/projects/41603-023/main
[18] https://projects.worldbank.org/en/projects-operations/project-detail/P159576



Source: ADB

Figure 3-7: Bihar State Highway Project Supported by ADB

Other than Donor assistance, Bihar state government started 30 irrigation projects for rural development across the state with 1,469 Crore INR since 2020 under the management of the Bihar Water Department[19]. It is expected to improve food production as well as livelihoods enhancement, and completed in 2025.

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 City and has positioned metro construction as a key urban development project.

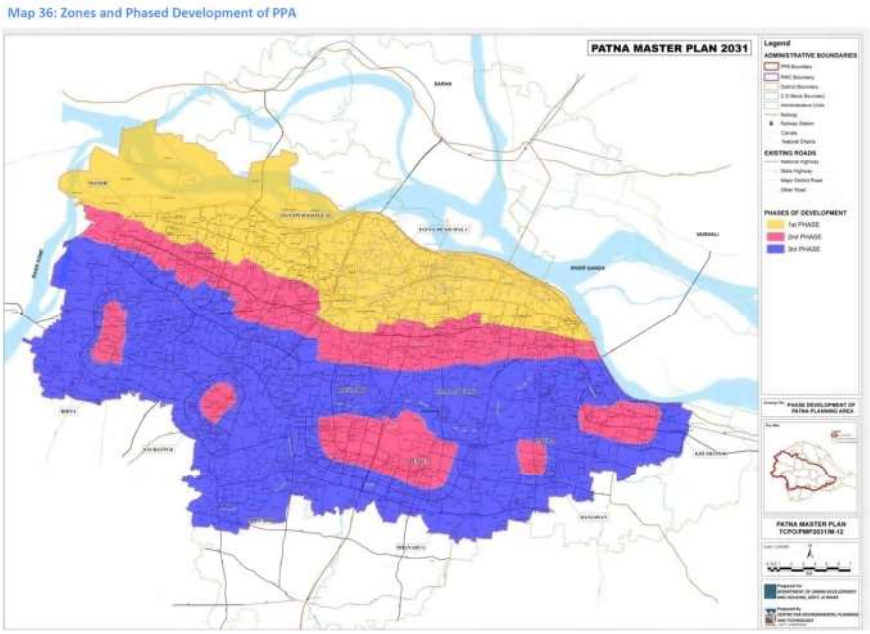
The PMP2031 is aligned to the development mission and vision of the State. This encompasses the overall development in various sectors like economic growth path of Patna City, keeping in view the projected population growth and associated developmental needs, the proposed land use change and development, 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 Figure 3-8.

[19] https:///timesofindia.indiatimes.com/city/patna/cm-launches-30-irrigation-projects-worth-rs1469-crore/articleshow/77771504.cms

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).



Source: Patna Master Plan 2031

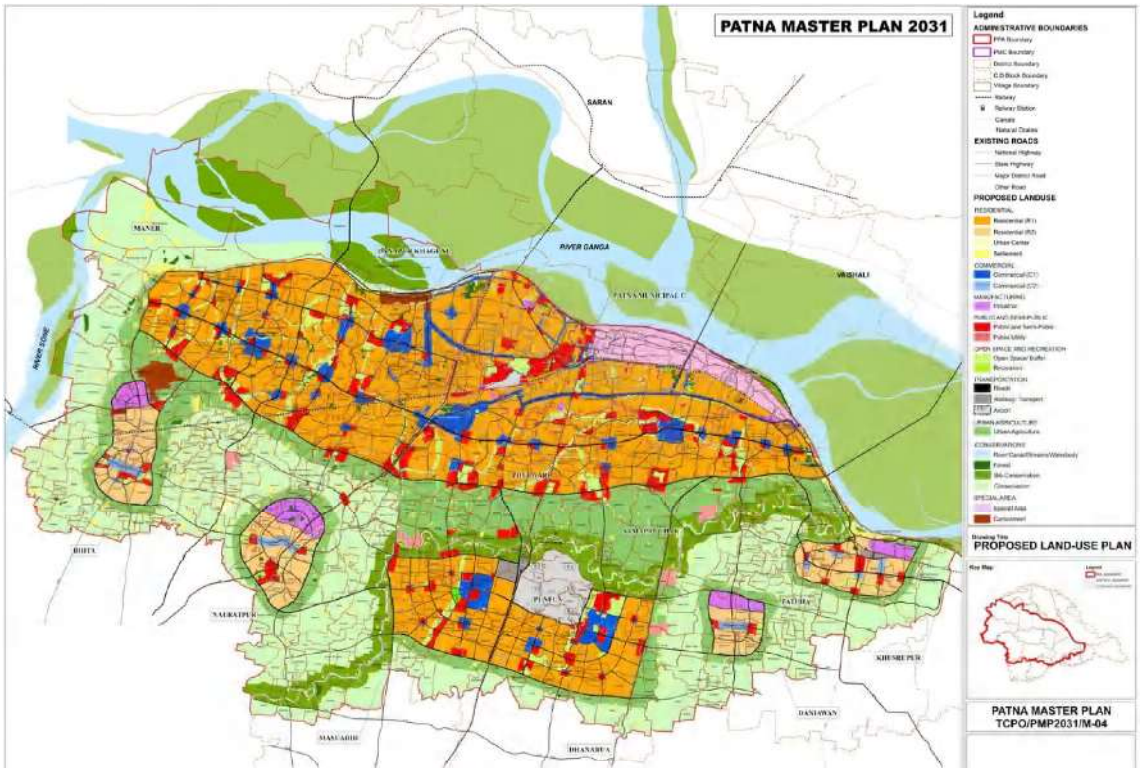
Figure 3-8: Metro Map on Patna Master Plan 2031

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, the 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 are 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 3-9: Proposed Land Use Plan

In general, orange to yellow for residential areas, blue for commercial areas, red for public and administrative facilities, purple for industrial areas, and green for green areas and non-urbanized areas, and the density of uses is indicated by the color shade. It is assuming a multi-center city structure, with residential areas covering the entire Patna City area, and blue (commercial) and red (public and administrative facilities) areas dispersed along the main roads. In addition, several satellite cities are proposed to be formed in the southern suburbs, with some of the satellite cities combining industrial sites and low-density housing. It is also proposed that a green belt be maintained between the satellite cities and the Patna City limits. It is noted that the pink area in the northeastern part of Patna City is the old city of Patna, which has been designated as a "Special Area" for preservation.

3.2.2 Comprehensive Mobility Plan Patna (CMP2018)

Comprehensive Mobility Plan Patna 2018 (CMP2018) was developed by MoHUA criteria[20]. 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 City, 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 City's two busiest routes was advocated in the Alternatives Analysis Report. In the CMP2018,

[20] 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".

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 land use with transport networks, it seeks to achieve the objectives of sustainable development in Patna City. The CMP2018 vision for transport in Patna City 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 City 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, including:

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

Goal 2: Ensure the 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 for the Metro Project

(1) Metro Rail Policy, 2017[21]

Under the laws, the Union Cabinet approved the Metro Rail Policy in August 2017, and Appraisal Guideline was published.[22] 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

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

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 3-8: 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) is a pre-requisite for planning metro rail systems in any city
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 are 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[23], Sept. 2017 MoHUA

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 of 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.

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

3.3.2 Needs of Metro Development in Patna City

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 City, the registration of cars and two-wheelers increasing at a 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 the economy and damage to health due to pollution by cars, such as atmospheric contamination and noise. Under these circumstances, Patna City is urgently required to improve public transport systems while eliminating traffic congestion and improving urban environments.

The development of the metro system in Patna City 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 women's empowerment. At the same time, it reduces the time and cost of future infrastructure development, meanwhile, it can contribute to regional economic development and 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 Bihar, the state that Patna City belongs to, is the 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, 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 City 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[24]. The following table shows the Top 30+ populated cities in India belonging to Tier-1 and Tier-2, their population in 2021, their recent annual population growth, and metro development status including number of metros 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 are included in this category, and five Tier-2 cities, Jaipur, Lucknow, Kochi, Kanpur 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 belong to this category.
- White: Cities with no metro planning[25] though those are ranked in top-30 populated cities.

[24] 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

[25] Six of 10 cities in this category belong to Kerala state.

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

Table 3-9: 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: For the metro development status, 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[26] 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.

[26] Bihar Economic Survey 2019-2020, P5

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

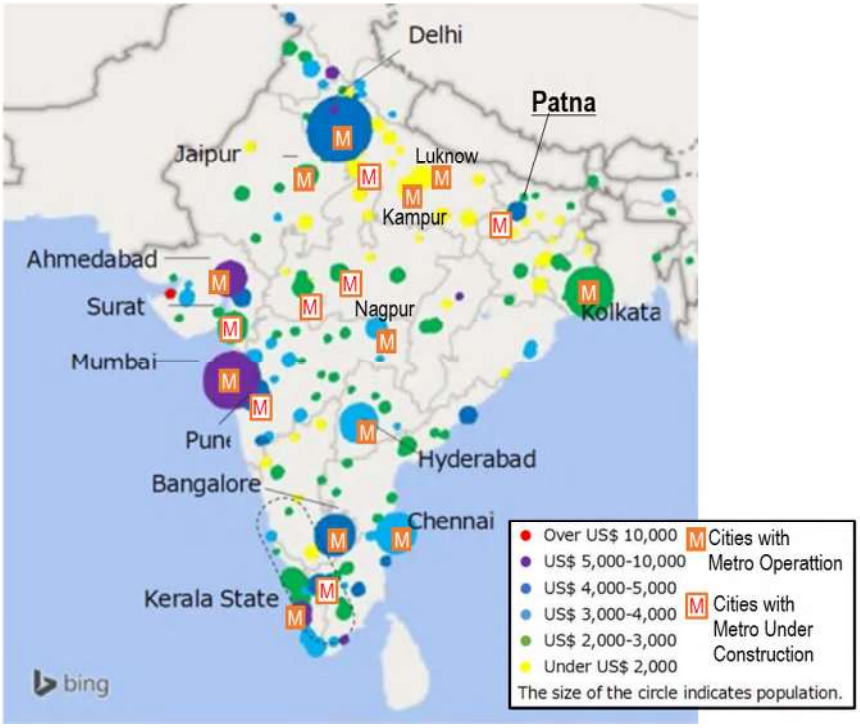
Table 3-10: Per Capita Income/Consumption/Saving for Patna City and Bihar Average

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 City's per-capita income level was more than four times the state average in 2011, a bit old statistic though, it may suggest that the Patna's city-wise income level is more than average of the national income level. The other statistics shows that Patna City has 2-3 times of purchasing and saving capacity compared to the state level. It should be noted that Patna City 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 City'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, Bangalore, Kolkata, Hyderabad, Chennai and Pune are similar or lower income level than Patna. Although the Patna City's income level reliability is low in this statistics, because the figures are higher than those of other documents and research reports, 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 3-10: Income Level of Indian Cities (2015) and Metro Development

4. Travel Characteristics and Demand Estimates

4.1 Overview of Existing Studies

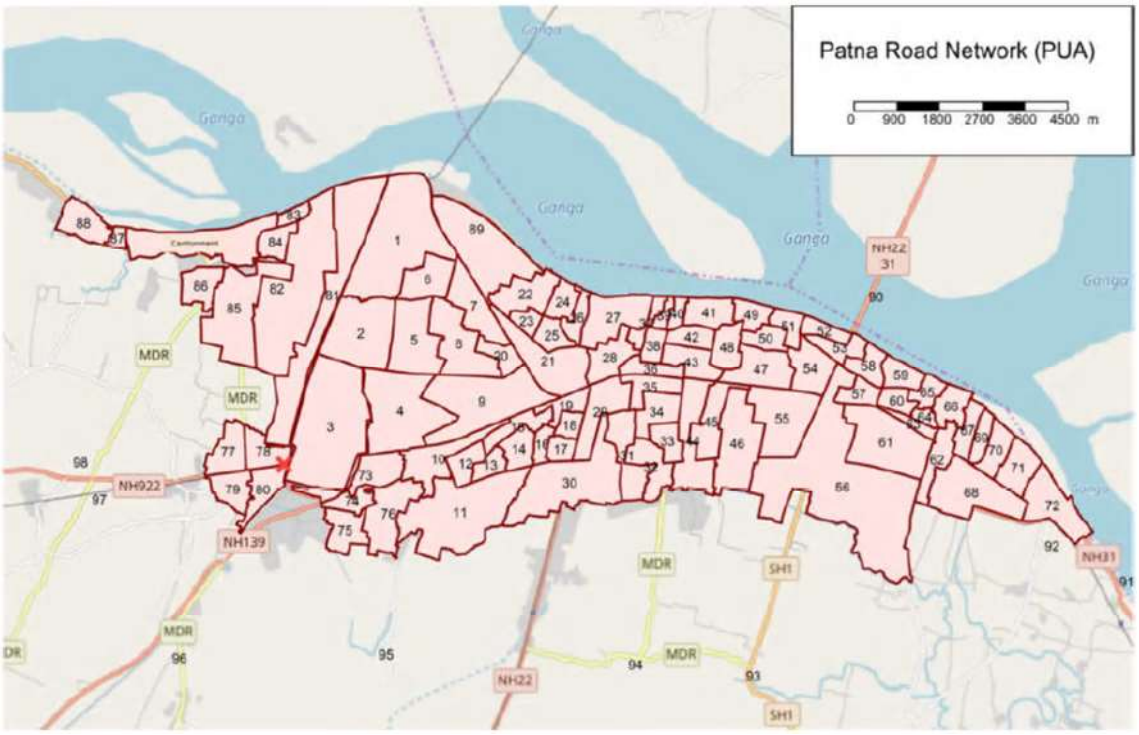
The Comprehensive Mobility Plan Patna in 2018 (CMP2018) initialized and developed by NIT Patna specified the whole framework of the demand forecast in Patna, which was utilized in the DPR. The following section shall explain the methodologies, frameworks and data set in CMP2018.

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 City. The number of persons expected to use the development would be estimated in this stage by using the regression method to derive the relation between the trips produced and the trip attracted. The average trip ratio per person was 2.29.



Source: Comprehensive Mobility Plan Patna 2018

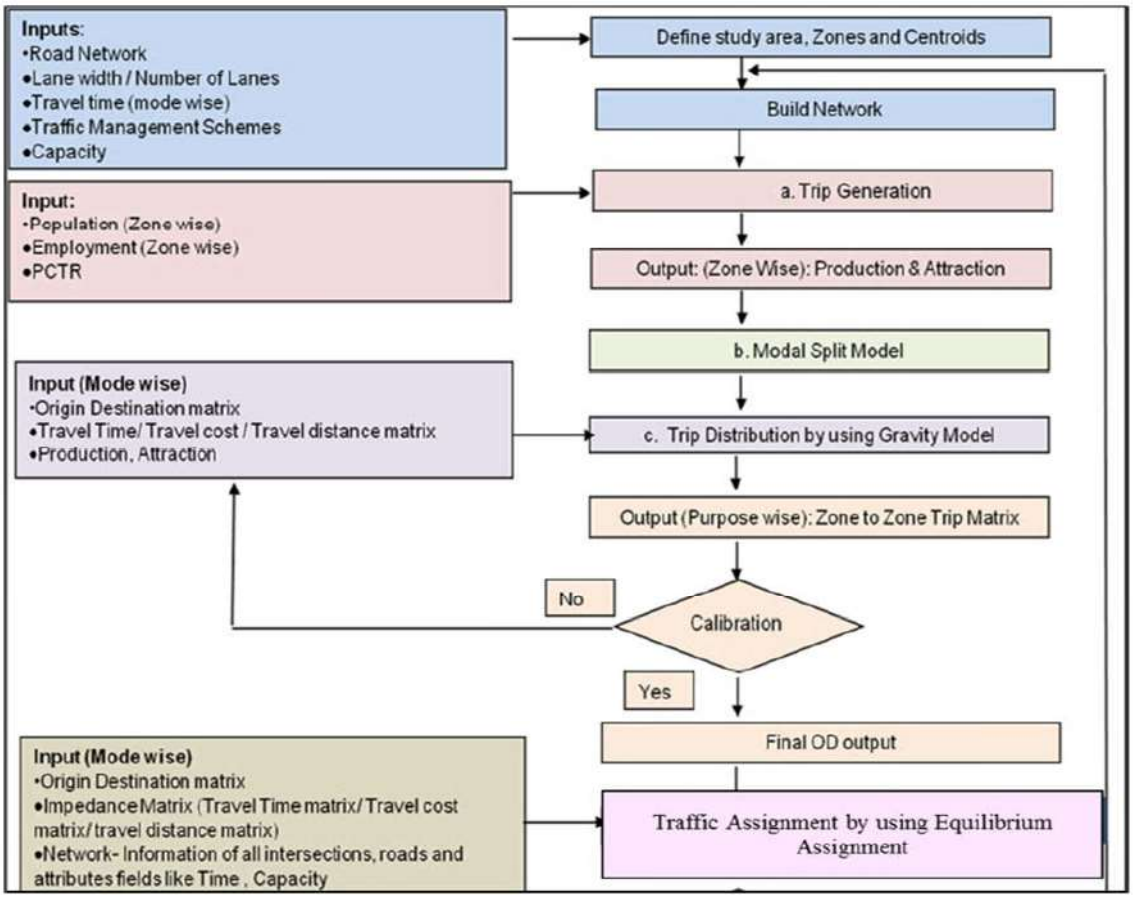
Figure 4-1: Traffic Analysis Zones

- Stage 2 - Trip distribution. In the trip distribution process, the productions and attractions calculated in the trip generation stage are distributed across the city based on the attraction between n them. In trip distribution stage the demand matrices for each mode are 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 preferences 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. The 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 based on 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 of several 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 input 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[27] in 2018 for the preparation of CMP2018 and development of the 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.

[27] 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 of 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[28]. The base year is considered as 2018 (time of CMP2018 was conducted) and planning period has been 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

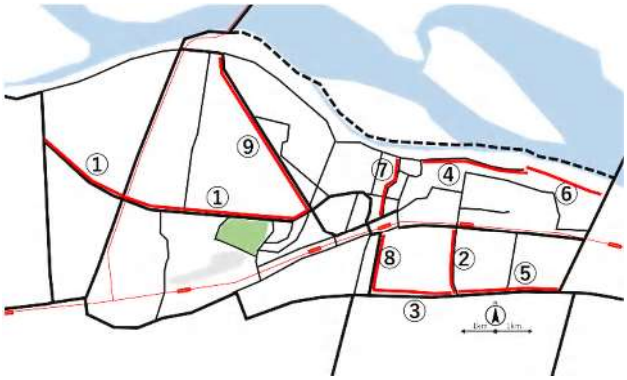
Source: Comprehensive Mobility Plan Patna 2018

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.

[28] 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 the maximum sectional loading of both directions shall be taken as the maximum PHPDT. For example, the Corridor 1's maximum PHPDT is

presented in 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[29].

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, the 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[30], a pre-defined share is applied for different OD Matrix for each mode[31]. For public transport mode, the share set for Home-Work OD Matrix is 0.70, for Home-Education OD Matrix is 0.71, and for Home-Others OD is 0.85. Please note the pre-defined share is a unified share for all zones. Since the mode choice analysis is not 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 modeler, 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 a 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 it.

[29] 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.
[30] There are three types of trip purpose defined in the model: Home-Work, Home-Education, and Others
[31] 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:

First, revised the opening year of MRT from 2024 to 2028. At the time of DPR preparation, the completion of the construction work was estimated in 2024. The updated implementation schedule indicated 2028 to be the opening year. In the revision, OD Matrices are updated based on the population projection for 2028.

Second, 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[32]. 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).

JST proposed 3 scenarios for the demand projection:

Scenario 1, keep the modal share setting in DPR models. As mentioned in previous section, modal share of public transport in this scenario is about 70%. According to CMP2018 and DPR Report, assumptions for scenario 1 include: the achievement of the planned land use in the Master Plan 2031, the development of TOD and a fully developed modal integration (improved comfort and safety, higher frequency of public transport, parking management, etc.). Currently, the assumed developments are not established in Patna City. Therefore, Scenario 1 can be regard as the optimistic scenario.

Scenario 2, modal share of public transport is set at 50%. Based on the review of existing literature, it is reported that the actual metro ridership is low at the opening year for India cities, and on average it is about 30% of the projected ridership for the opening year[33]. To be conservative, JST discounted the projected ridership by DPR. Considering the average public transport share in second-tier cities in India, such as Lucknow and Nagpur[34], a 50% of public transport modal share is proposed for conservative scenario.

Scenario 3, a hybrid scenario of Scenario 1 and 2. This scenario recognizes the optimistic tendency of demand projection at the initial stage and expects the planned development to be achieved as time goes by (see the Box on Japan's case below). A staged public transport modal share is expected: for the initial 3 years 2028-2031 after opening, the projection result of Scenario 2 is adopted; the share will reach the level of Scenario 1 by 2051; In between a staged (at 5-year interval) gradual increase of public transport modal share is assumed.

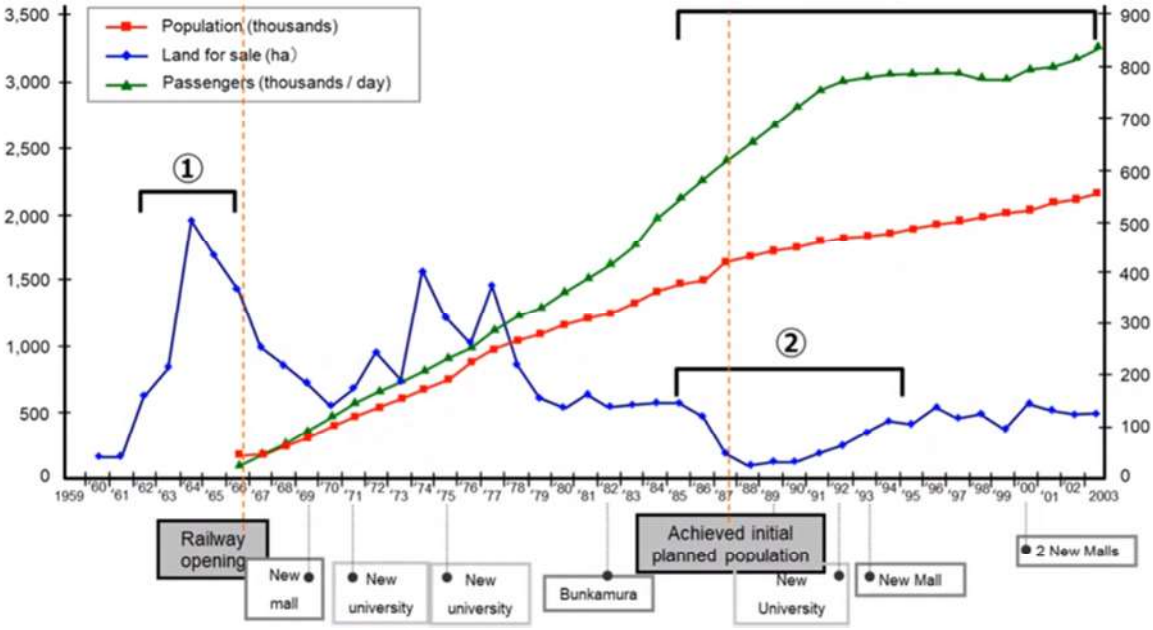
[32] Three public transport assignment methods are available in PTV Visum: Headway-based, Timetable-based, and Transport System-based.

[33] https://citizenmatters.in/india-metro-rail-systems-bengaluru-chennai-delhi-30244

[34] For second-tier cities with population of 2-4 million, the average modal share for walking is about 25%, for Bus and IPT is about 15%. Source: https://mohua.gov.in/upload/uploadfiles/files/traffic_transportation.pdf, https://wrirosscities.org/sites/default/files/India-Integrated-Transport-Indicators-EMBARQ.pdf

Box: The Increase of Metro Ridership – Case of Tokyu Den-en-toshi Line in Japan

Japan's Tokyu Den-en-toshi Line is a major commuter line operated by the private railway operator Tokyu Corporation and connecting south-western suburbs of Tokyo and neighbouring Kanagawa Prefecture. The commuter line started its operation in 1966, and the increase of ridership after its opening is presented below.



Source: The 50 Years History of Tokyu Corporation, Nikken Sekkei Institute

Figure 4-3: Increase of Ridership after Metro Opening

The green line is the actual ridership (thousands/day), the bule line is the land for sale (ha) along the commuter line, while the red line indicates the increase of population in the metro line served area. It took about 20 years from the opening to achieving the planned population. Below the horizontal axis, the development of TOD including shopping malls, the establishment of universities are marked. The decrease of land for sale also suggests the development of real estate.

In the case of Patna, similar ridership boosters can be identified. Patna is famous for education sector. With the development of metro corridors, foundation of new schools and relocation of the existing schools to the metro adjacent area are expected. In terms of real estate development, as introduced in Section 3.1, the western part of the city has seen the rapid construction of high-rise condominiums. Super shopping mall of Ambuja City Centre is about to open, and many are under planning. Overall, an increase of metro ridership can be expected, however, it may take years (20 years in the Japanese case) for the development.

The revision is based on the DPR model. Compared to CMP2018 models, the DPR model updated the MRT alignment from the early design to the ongoing ones. In addition, 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 the following tables.

The table below shows the forecasted daily ridership. For Scenario 1, ridership of MRT for opening year 2028, future year 2030, 2031, 2041, 2051 is about 1.05, 1.19, 1.25, 1.41, and 1.71 million respectively. For

Scenario 2, it is 0.71, 0.80, 0.84, 0.95, and 1,16 million. 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 about 10-20% decrease for Scenario 1, and 40-50% decrease for Scenario 2.

Table 4-7: Revised Daily Ridership for Metro Corridors – Scenario 1

Mode	without MRT					with MRT				
	2028	2030	2031	2041	2051	2028	2030	2031	2041	2051
Bus	210,759	211,755	216,178	240,699	268,000	135,895	125,949	121,808	160,023	164,244
Car	324,244	350,721	361,683	421,223	479,308	163,182	183,441	192,799	217,550	266,845
2-Wheelers	1,134,855	1,222,180	1,259,655	1,527,511	1,803,847	503,596	566,119	594,857	671,629	824,949
Autorickshaw	972,732	1,012,967	1,039,320	1,203,493	1,391,539	805,309	765,497	749,829	985,103	1,027,775
Taxi	36,478	43,777	45,730	60,175	67,000	15,099	11,125	9,333	12,257	12,543
Metro	-	-	-	-	-	1,055,986	1,189,268	1,253,940	1,406,540	1,713,338
Total	2,679,067	2,841,400	2,922,566	3,453,101	4,009,694	2,679,067	2,841,400	2,922,566	3,453,101	4,009,694

Source: JST

Table 4-8: Revised Daily Ridership for Metro Corridors – Scenario 2

Mode	without MRT					with MRT				
	2028	2030	2031	2041	2051	2028	2030	2031	2041	2051
Bus	244,679	191,594	189,690	230,980	239,742	101,314	87,874	82,253	115,045	109,381
Car	360,906	443,415	466,401	525,974	644,365	324,791	365,115	384,001	433,085	530,663
2-Wheelers	1,017,615	1,250,260	1,314,373	1,483,502	1,820,839	928,927	1,044,256	1,097,732	1,239,051	1,520,977
Autorickshaw	1,036,980	916,522	911,974	1,154,900	1,244,813	600,382	534,080	506,334	708,219	684,461
Taxi	38,887	39,609	40,127	57,745	59,935	11,257	7,762	6,302	8,812	8,353
Metro	-	-	-	-	-	712,396	802,312	845,944	948,890	1,155,858
Total	2,679,067	2,841,400	2,922,566	3,453,101	4,009,694	2,679,067	2,841,400	2,922,566	3,453,101	4,009,694

Source: JST

JST estimated the station-wise PHPDT for Corridor 1 and 2 for Scenario 1 and 2. Based on the staged demand projection, the PHPDT for Scenario 3 is calculated. To be specific, for 2028, 2030, and 2031, PHPDT is the same as that of Scenario 2; For 2051, the same as Scenario 1; For 2041, it is the average of the 2 scenarios. PHPDT for 2030 is provided, to track the performance after 2-year's opening. PHPDT of Scenario 3 is shown below.

Table 4-9: PHPDT for Stations of Metro Corridor 1 – Scenario 3

Year		2028		2030		2031		2041		2051	
Station		To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur	To Khemni Chak	To Danapur
Danapur	Saguna More	1,933	1,541	2,038	1,658	2,188	1,784	3,224	2,618	5,016	3,975
Saguna More	RPS More	5,505	4,104	5,801	4,391	6,229	4,723	9,205	6,816	14,606	10,337
RPS More	Patliputra	7,385	5,569	7,763	5,953	8,333	6,402	12,265	9,242	19,412	14,073
Patliputra	Rukanpura	8,616	6,204	9,048	6,642	9,711	7,144	14,279	10,323	22,616	15,707
Rukanpura	Raja Bazar	10,811	8,394	11,674	8,816	12,567	9,463	17,481	13,778	26,875	21,653
Raja Bazar	Patna Zoo	11,794	9,506	12,858	9,899	13,856	10,616	18,912	15,764	28,620	25,071
Patna Zoo	Vikas Bhawan	12,149	9,845	13,266	10,244	14,298	10,985	19,358	16,419	29,111	26,182
Vikas Bhawan	Vidyut Bhawan	12,174	9,820	13,243	10,267	14,268	11,014	19,117	16,660	28,441	26,852
Vidyut Bhawan	Patna Station	11,034	9,880	12,038	10,289	12,974	11,033	17,017	17,010	25,111	27,625
Patna Station	Mithapur	9,303	9,287	9,774	10,247	10,491	11,056	14,603	15,842	22,406	25,325
Mithapur	Ramkrishna Nagar	7,640	6,910	8,078	7,583	8,677	8,177	11,863	12,068	18,052	19,896
Ramkrishna Nagar	Jaganpura	6,268	5,316	6,665	5,672	7,163	6,099	9,824	9,269	14,719	15,490
Jaganpura	Khemni Chak	5,912	4,827	6,302	5,141	6,775	5,527	9,239	8,446	13,755	14,243
MAX. PHPDT			**12,174**		**13,266**		**14,298**		**19,358**		**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. Those stations are indeed close to CBD in Patna, and commuters from western region of Patna City may concentrate in a morning peak hour.

Table 4-10: PHPDT for Stations of Metro Corridor 2 – Scenario 3

Year		2028		2030		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	To Zero Mile	To Patna Station
Patna Station	Akashvani	4,754	3,524	5,415	4,147	5,471	4,205	7,235	6,037	8,796	8,656
Akashvani	Gandhi Maidan	5,847	4,718	6,601	5,588	6,664	5,669	8,862	8,145	10,894	11,676
Gandhi Maidan	PMCH	6,873	5,635	7,645	6,558	7,705	6,641	10,285	9,507	12,759	13,460
PMCH	University	7,580	6,156	8,361	7,085	8,420	7,167	11,315	10,179	14,254	14,181
University	Moin UL Haq Stadi	8,385	7,383	9,216	8,232	9,277	8,300	12,632	11,522	16,210	15,691
Moin UL Haq Stadiun	Rajendra Nagar	8,325	7,923	9,124	8,768	9,182	8,833	12,458	12,273	15,995	16,634
Rajendra Nagar	Malahi Pakri	7,825	8,423	8,421	9,471	8,458	9,557	11,518	13,213	14,839	17,790
Malahi Pakri	Khemni Chak	7,254	7,638	7,757	8,514	7,785	8,584	10,523	11,974	13,487	16,074
Khemni Chak	Bhoot Nath	6,784	6,561	7,229	7,181	7,252	7,225	9,563	10,215	11,989	13,787
Bhoot Nath	Zero Mile	6,165	5,752	6,614	6,134	6,640	6,155	8,723	8,652	10,788	11,596
Zero Mile	New ISBT	4,422	4,346	4,539	4,515	4,535	4,517	6,051	6,155	7,411	7,817
MAX. PHPDT			**8,423**		**9,471**		**9,557**		**13,213**		**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 2028, 2030, 2031, 2041 and 2051 are summarized below. Corridor 1 has relatively larger PHPDT volumes than Corridor 2 due to its operational length.

Table 4-11: Revised Maximum PHPDT for Metro Corridors

PHPDT	2028	2030	2031	2041	2051
Cor 1: Danapur - Khemni Chak	12,174	13,266	14,298	19,358	29,111
Cor 2: Patna Station - New ISBT	8,423	9,471	9,557	13,213	17,790

Source: JST

The trips made between two adjacent stations of proposed metro corridors have been worked out for the horizon years of 2028, 2030, 2031, 2041 and 2051. The section loads for the horizon years for Corridor 1 (Danapur to Khemni Chak) and Corridor 2 (Patna Station to New ISBT), in terms of Total and Direction wise Peak hour station loads (boarding & alighting) on are presented in below tables.

Table 4-12: Direction Wise Peak Hour Station Loads on Corridor 1

Year	2028					
Direction	Danapur to Khemni Chak		Khemni Chak to Danapur		Total (Both Side)	
Station Name	Board	Alight	Board	Alight	Board	Alight
Danapur	1,933	0	0	1,541	1,933	1,541
Saguna More	3,626	54	74	2,637	3,700	2,690
RPS More	2,068	189	230	1,695	2,298	1,884
Patliputra	1,623	392	541	1,176	2,164	1,568
Rukanpura	3,839	1,644	1,645	3,835	5,485	5,478
Raja Bazar	3,101	2,119	2,067	3,179	5,169	5,299
Patna Zoo	1,918	1,562	1,569	1,909	3,488	3,471
Vikas Bhawan	1,464	1,439	1,464	1,439	2,929	2,878
Vidyut Bhawan	2,160	3,299	2,639	2,700	4,799	6,000
Patna Station	2,097	3,828	3,146	2,552	5,243	6,380
Mithapur	1,099	2,762	3,297	921	4,395	3,682
Ramkrishna Nagar	517	1,889	2,066	472	2,582	2,361
Jaganpura	154	511	618	127	772	639
Khemni Chak	0	4,556	3,471	0	3,471	4,556
Total	**25,599**	**24,244**	**22,828**	**24,183**	**48,427**	**48,427**
Year	**2030**					
Direction	**Danapur to Khemni Chak**		**Khemni Chak to Danapur**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Danapur	2,038	0	0	1,658	2,038	1,658
Saguna More	3,821	57	78	2,811	3,899	2,868
RPS More	2,162	200	240	1,803	2,402	2,003
Patliputra	1,703	419	568	1,256	2,271	1,675
Rukanpura	4,359	1,732	1,868	4,042	6,227	5,775
Raja Bazar	3,430	2,246	2,287	3,370	5,717	5,616
Patna Zoo	2,090	1,681	1,710	2,055	3,799	3,736
Vikas Bhawan	1,552	1,574	1,552	1,574	3,104	3,149
Vidyut Bhawan	2,387	3,592	2,918	2,939	5,305	6,532
Patna Station	1,861	4,125	2,792	2,750	4,653	6,876
Mithapur	1,211	2,907	3,633	969	4,844	3,876
Ramkrishna Nagar	604	2,016	2,414	504	3,018	2,521
Jaganpura	166	530	664	133	829	662
Khemni Chak	0	4,888	3,728	0	3,728	4,888
Total	**27,384**	**25,970**	**24,451**	**25,865**	**51,834**	**51,834**

Year	2031					
Direction	**Danapur to Khemni Chak**		**Khemni Chak to Danapur**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Danapur	2,188	0	0	1,784	2,188	1,784
Saguna More	4,103	62	83	3,022	4,187	3,083
RPS More	2,320	215	258	1,938	2,577	2,153
Patliputra	1,828	450	610	1,350	2,437	1,801
Rukanpura	4,717	1,860	2,022	4,341	6,738	6,201
Raja Bazar	3,702	2,414	2,468	3,620	6,170	6,034
Patna Zoo	2,252	1,810	1,842	2,211	4,094	4,021
Vikas Bhawan	1,667	1,697	1,667	1,697	3,335	3,394
Vidyut Bhawan	2,576	3,871	3,149	3,167	5,726	7,038
Patna Station	1,958	4,440	2,937	2,960	4,895	7,400
Mithapur	1,306	3,121	3,919	1,040	5,226	4,161
Ramkrishna Nagar	655	2,168	2,620	542	3,275	2,710
Jaganpura	179	568	714	142	892	710
Khemni Chak	0	5,258	4,011	0	4,011	5,258
Total	**29,450**	**27,934**	**26,300**	**27,816**	**55,750**	**55,750**
Year	**2041**					
Direction	**Danapur to Khemni Chak**		**Khemni Chak to Danapur**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Danapur	3,224	0	0	2,618	3,224	2,618
Saguna More	6,070	88	124	4,321	6,194	4,409
RPS More	3,370	311	375	2,802	3,745	3,113
Patliputra	2,671	657	891	1,971	3,562	2,628
Rukanpura	6,201	2,999	2,918	6,373	9,119	9,372
Raja Bazar	4,959	3,529	3,306	5,292	8,265	8,821
Patna Zoo	2,971	2,524	2,430	3,085	5,401	5,609
Vikas Bhawan	2,165	2,406	2,165	2,406	4,330	4,813
Vidyut Bhawan	3,388	5,488	4,141	4,490	7,530	9,978
Patna Station	3,332	5,746	4,999	3,831	8,332	9,577
Mithapur	1,757	4,499	5,273	1,500	7,031	5,999
Ramkrishna Nagar	882	2,921	3,529	730	4,412	3,652
Jaganpura	258	843	1,034	211	1,292	1,053
Khemni Chak	0	7,129	6,336	0	6,336	7,129
Total	**41,251**	**39,140**	**37,520**	**39,630**	**78,771**	**78,771**

Year	2051					
Direction	**Danapur to Khemni Chak**		**Khemni Chak to Danapur**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Danapur	5,016	0	0	3,975	5,016	3,975
Saguna More	9,723	134	198	6,560	9,922	6,695
RPS More	5,287	480	587	4,323	5,875	4,803
Patliputra	4,217	1,013	1,406	3,040	5,623	4,053
Rukanpura	9,065	4,805	4,266	10,212	13,331	15,017
Raja Bazar	7,243	5,498	4,828	8,246	12,071	13,745
Patna Zoo	4,234	3,744	3,465	4,575	7,699	8,319
Vikas Bhawan	2,908	3,578	2,908	3,578	5,817	7,156
Vidyut Bhawan	4,830	8,159	5,903	6,676	10,733	14,835
Patna Station	4,924	7,630	7,386	5,086	12,310	12,716
Mithapur	2,580	6,934	7,741	2,312	10,322	9,245
Ramkrishna Nagar	1,397	4,731	5,588	1,182	6,986	5,913
Jaganpura	397	1,360	1,586	340	1,983	1,701
Khemni Chak	0	10,064	10,553	0	10,553	10,064
Total	**61,821**	**58,131**	**56,417**	**60,107**	**118,238**	**118,238**

Source: JST

Table 4-13: Direction Wise Peak Hour Station Loads on Corridor 2

Year	2028					
Direction	**Patna Station to New ISBT**		**New ISBT to Patna Station**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Patna Station	4,754	0	0	3,524	4,754	3,524
Akashvani	1,241	148	138	1,332	1,380	1,481
Gandhi Maidan	1,338	313	335	1,250	1,672	1,563
PMCH	1,140	433	489	1,010	1,629	1,443
University	2,065	1,259	1,112	2,339	3,176	3,598
Moin UL Haq Stadium	1,156	1,216	946	1,486	2,102	2,702
Rajendra Nagar	752	1,252	752	1,252	1,504	2,504
Malahi Pakri	1,400	1,970	2,099	1,314	3,499	3,284
Khemni Chak	671	1,141	1,566	489	2,237	1,630
Bhoot Nath	380	999	1,142	333	1,522	1,332
Zero Mile	312	2,056	1,770	363	2,082	2,419
New ISBT	0	618	541	0	541	618
Total	**15,210**	**11,405**	**10,888**	**14,692**	**26,098**	**26,098**

Year	2030					
Direction	**Patna Station to New ISBT**		**New ISBT to Patna Station**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Patna Station	5,415	0	0	4,148	5,415	4,148
Akashvani	1,363	177	151	1,592	1,515	1,769
Gandhi Maidan	1,372	328	343	1,313	1,715	1,641
PMCH	1,154	438	495	1,022	1,650	1,460
University	2,074	1,219	1,117	2,264	3,190	3,484
Moin UL Haq Stadium	1,047	1,139	857	1,392	1,904	2,531
Rajendra Nagar	595	1,298	595	1,298	1,190	2,596
Malahi Pakri	1,679	2,343	2,518	1,562	4,197	3,905
Khemni Chak	819	1,347	1,912	577	2,731	1,925
Bhoot Nath	469	1,084	1,407	361	1,877	1,446
Zero Mile	362	2,436	2,049	430	2,411	2,866
New ISBT	0	672	647	0	647	672
Total	**16,349**	**12,481**	**12,091**	**15,960**	**28,441**	**28,441**
Year	**2031**					
Direction	**Patna Station to New ISBT**		**New ISBT to Patna Station**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Patna Station	5,471	0	0	4,205	5,471	4,205
Akashvani	1,372	180	152	1,617	1,525	1,796
Gandhi Maidan	1,371	329	342	1,315	1,713	1,644
PMCH	1,151	437	493	1,019	1,645	1,456
University	2,066	1,210	1,113	2,246	3,179	3,456
Moin UL Haq Stadium	1,030	1,125	843	1,375	1,872	2,500
Rajendra Nagar	574	1,298	574	1,298	1,148	2,597
Malahi Pakri	1,705	2,378	2,558	1,585	4,263	3,963
Khemni Chak	834	1,367	1,945	585	2,778	1,952
Bhoot Nath	478	1,090	1,433	363	1,912	1,453
Zero Mile	366	2,471	2,074	436	2,440	2,907
New ISBT	0	675	657	0	657	675
Total	**16,418**	**12,558**	**12,185**	**16,046**	**28,604**	**28,604**

Year	2041					
Direction	**Patna Station to New ISBT**		**New ISBT to Patna Station**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Patna Station	7,235	0	0	6,037	7,235	6,037
Akashvani	1,884	257	209	2,317	2,094	2,575
Gandhi Maidan	1,882	459	471	1,833	2,352	2,291
PMCH	1,613	585	692	1,363	2,305	1,947
University	2,873	1,557	1,547	2,890	4,421	4,447
Moin UL Haq Stadium	1,332	1,506	1,090	1,840	2,422	3,346
Rajendra Nagar	780	1,719	780	1,719	1,559	3,439
Malahi Pakri	2,283	3,278	3,424	2,185	5,707	5,463
Khemni Chak	1,140	2,100	2,659	900	3,799	3,000
Bhoot Nath	691	1,531	2,073	510	2,764	2,041
Zero Mile	541	3,213	3,064	567	3,604	3,780
New ISBT	0	919	1,023	0	1,023	919
Total	**22,254**	**17,122**	**17,031**	**22,163**	**39,285**	**39,285**
Year	**2051**					
Direction	**Patna Station to New ISBT**		**New ISBT to Patna Station**		**Total (Both Side)**	
Station Name	**Board**	**Alight**	**Board**	**Alight**	**Board**	**Alight**
Patna Station	8,796	0	0	8,656	8,796	8,656
Akashvani	2,464	366	274	3,293	2,737	3,660
Gandhi Maidan	2,465	600	616	2,401	3,082	3,001
PMCH	2,209	715	947	1,668	3,156	2,382
University	3,900	1,944	2,100	3,610	6,000	5,553
Moin UL Haq Stadium	1,686	1,900	1,379	2,323	3,065	4,224
Rajendra Nagar	1,019	2,174	1,019	2,174	2,038	4,349
Malahi Pakri	3,142	4,494	4,713	2,997	7,855	7,491
Khemni Chak	1,538	3,035	3,588	1,301	5,126	4,337
Bhoot Nath	972	2,173	2,915	724	3,886	2,897
Zero Mile	797	4,174	4,515	736	5,311	4,910
New ISBT	0	1,200	1,607	0	1,607	1,200
Total	**28,987**	**22,777**	**23,672**	**29,883**	**52,659**	**52,659**

Source: JST

With the introduction of MRT, modal share for year 2028, 2030, 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 4-14: Projected Modal Share (trip-based)

Scenario 1	without MRT					with MRT				
Mode	**2028**	**2030**	**2031**	**2041**	**2051**	**2028**	**2030**	**2031**	**2041**	**2051**
Bus	7.9%	7.5%	7.4%	7.0%	6.7%	5.1%	4.4%	4.2%	4.6%	4.1%
Car	12.1%	12.3%	12.4%	12.2%	12.0%	6.1%	6.5%	6.6%	6.3%	6.7%
2-Wheelers	42.4%	43.0%	43.1%	44.2%	45.0%	18.8%	19.9%	20.4%	19.5%	20.6%
Autorickshaw	36.3%	35.7%	35.6%	34.9%	34.7%	30.1%	26.9%	25.7%	28.5%	25.6%
Taxi	1.4%	1.5%	1.6%	1.7%	1.7%	0.6%	0.4%	0.3%	0.4%	0.3%
Metro	-	-	-	-	-	39.4%	41.9%	42.9%	40.7%	42.7%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Scenario 2	**without MRT**					**with MRT**				
Mode	**2028**	**2030**	**2031**	**2041**	**2051**	**2028**	**2030**	**2031**	**2041**	**2051**
Bus	8.4%	6.7%	6.5%	6.7%	6.0%	3.8%	3.1%	2.8%	3.3%	2.7%
Car	13.5%	15.6%	16.0%	15.2%	16.1%	12.1%	12.8%	13.1%	12.5%	13.2%
2-Wheelers	38.0%	44.0%	45.0%	43.0%	45.4%	34.7%	36.8%	37.6%	35.9%	37.9%
Autorickshaw	38.7%	32.3%	31.2%	33.4%	31.0%	22.4%	18.8%	17.3%	20.5%	17.1%
Taxi	1.5%	1.4%	1.4%	1.7%	1.5%	0.4%	0.3%	0.2%	0.3%	0.2%
Metro	-	-	-	-	-	26.6%	28.2%	28.9%	27.5%	28.8%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: JST

MRT takes about 40% of the modal share for Scenario 1 and slightly less than 30% for Scenario 2. Both are lower than that estimated in DPR (46%-49%). For other modes, the share of Bus is about 5% for Scenario 1 and 3-4% for Scenario 2, for Auto (rickshaw) is about 30% for Scenario 1 and about 20% for Scenario 2. Car (including Taxi) is a small share, less than 15% for both scenarios 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 the station as shown in the table below. The numbers of lanes 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 4-15: 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 the road section is narrow.

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

Table 4-16: 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

The 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, but 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 4-4: Modelling of Road Closure for Malahi Pakri Station

In the modelling, the 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 different scenarios are listed in the table below.

Table 4-17: Estimation Result of Traffic Impact during the 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 increase (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 more 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 being good, so the impact of road closure becomes smaller.

5. Civil Engineering and Alignment

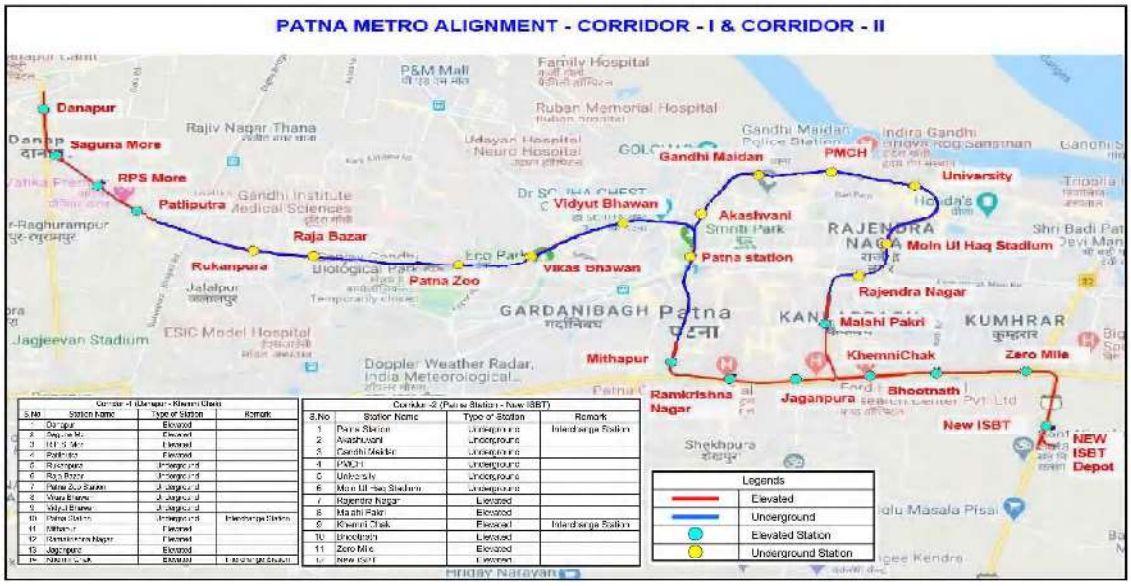
This chapter mentions that the review result of the route and facility plan proposed in DPR to check those suitability, and gives some recommendations to improve the current plan.

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 the Patna Metro Rail Network. The following chart is the summary of corridors as the subject for this study.



Source: DPR

Figure 5-1: Patna Metro planned route

Table 5-1: Patna Metro Rail Construction 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: DPR

(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, and Patna - Sitamarhi

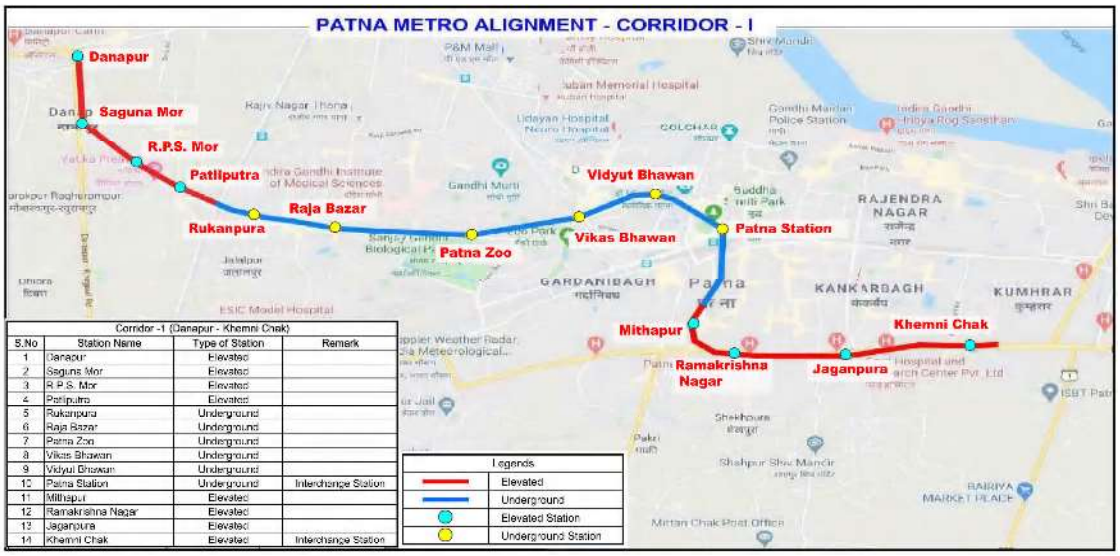
Rd. According to DPR, the section between Danapur Station and Patiputra Station is supposed to be the elevated structure. The transitional section from elevated to underground starts at east of Patliputra station and the underground section continues to the eastward. Reverting to the elevated structure starts between Patna Junction Station and Mithapur station and connects 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: DPR



Source: DPR

Figure 5-2: 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 Rajendra 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.

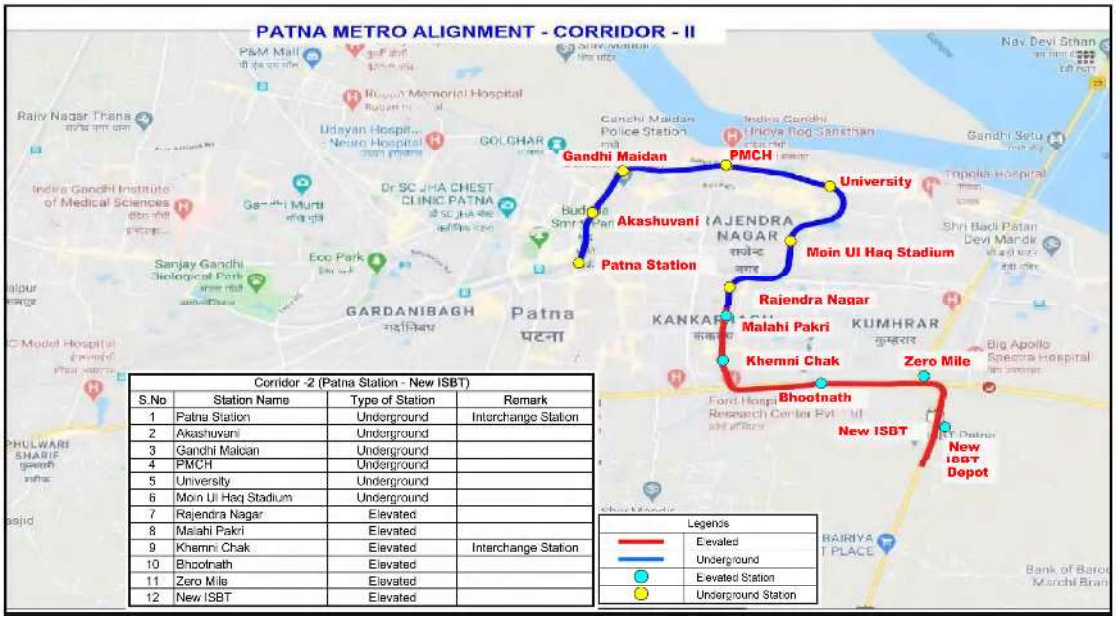
The depot is planned to be located adjacent to the New ISBT station and it is assumed to be jointly used for Corridor 1 and Corridor 2.

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: DPR



Source:DPR

Figure 5-3: 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

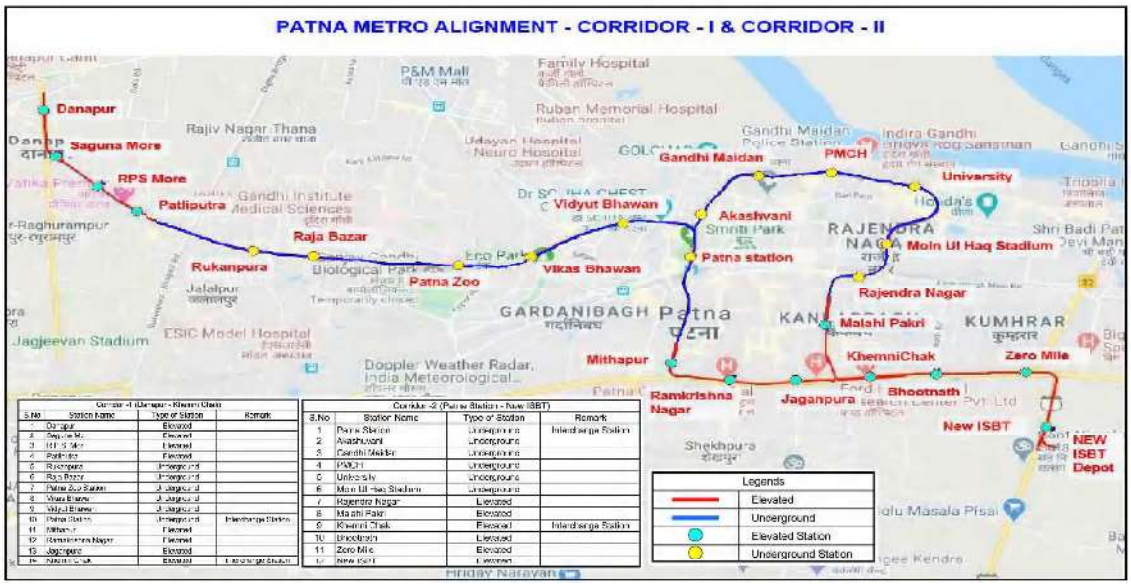
connected with the future extension routes since they are still conceptual at this present. The locations of the future extension routes are shown in Figure 5-4.



Source: PMRCL/DMRC

Figure 5-4: Route Plan for Future Extension

5.1.2 Overview of Existing Studies



Source: DPR

Figure 5-5: 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, JST

Figure 5-6: Location map between DANAPUR and PATLIPUTRA

2) Patliputra – Rukanpura section

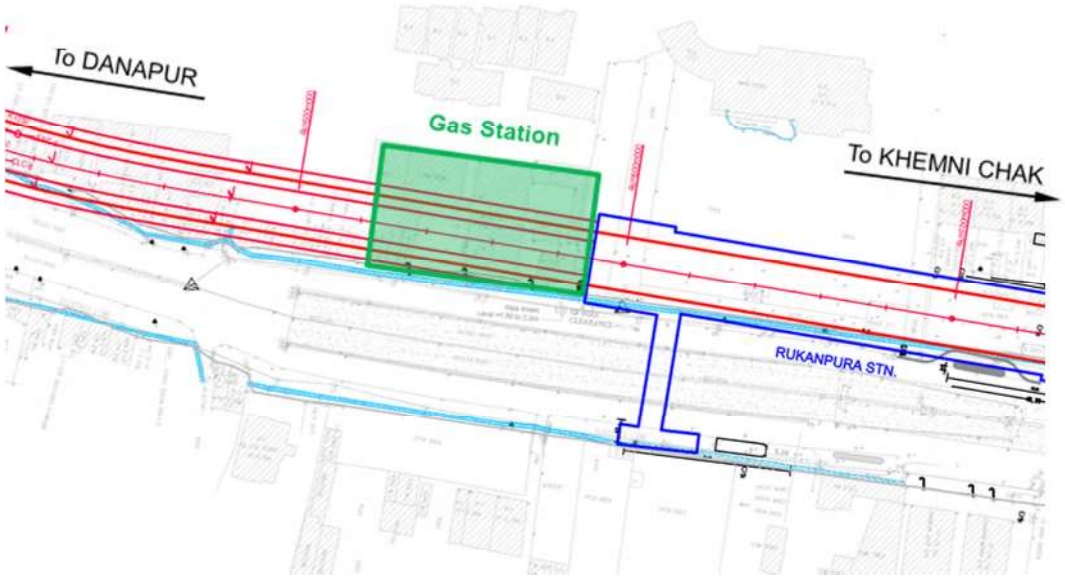
The ramp between the elevated section and the underground section starts from the east side of the elevated Patliputra Station. The gradient of the ramp is 3.76% and the elevated section is switched over to the underground section by utilizing the canal space on the north side of Bailey Rd. After this switch over, the 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 unfeasible 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, JST

Figure 5-7: Location map between PATLIPUTRA – RUKANPURA



Source: JST

Figure 5-8: Location map of gas stations near Rukanpura station



Source: JST

Figure 5-9: 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 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, Vikas 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 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, JST

Figure 5-10: Location map between Rukanpura –Patna Zoo Station



Source: Google earth, PMRCL, JST

Figure 5-11: Location map between Patna 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 an 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 several 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, JST

Figure 5-12: Location map between PATNA JUNCTION – MITHAPUR

5) Mithapur - Khemni Chak section

This section is an 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 consisting 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 the NEW ISBT depot of Corridor 2, trains use this crossover to move to the depot via Corridor 2.



Source: Google earth, PMRCL, JST

Figure 5-13: 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 Rajendra Nagar Station which 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, JST

Figure 5-14: 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, JST

Figure 5-15: 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 Station and at the east side of Zero Mile Ssharp curves are passing through private lands to make a tight turn. The radius adapted 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, JST

Figure 5-16: 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	1,000 m	1,000 m
Maximum permissible cant	110 mm	110 mm
Maximum desirable cant	85 mm	85 mm

Source: DPR

Cant Calculation Formula

$Cm = (G \cdot V \cdot V) / 127 \cdot R$

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 can't deficiency (in mm), whichever is higher.
  Desirable: 0.72 times of actual cant or can't 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 in the same way while it requires to secure the vertical clearance of 3.5m for the 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: DPR

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: DPR

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, the steeper gradient is allowed up to 4.0% (curve compensation is considered) at maximum in unavoidable case, such as, where the grade of the 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	:	2,500m
Minimum allowable vertical curve radius	:	1,500m
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.

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
3,000	20	12	90	10	15
2,800	20	14	90	10	15
2,400	25	15	90	15	18
2,000	25	23	90	15	18
1,600	30	29	90	15	22
1,500	35	28	90	20	26
1,200	40	39	90	20	29
1,000	50	45	90	25	36
800	60	59	90	30	44
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: DPR

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 clothoid, 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 curve length less than 25m in both corridors, specifically 20.11m in Corridor 1 and 19.26m in Corridor 2.

This study proposes an alignment modification that adjusts these non-compliant curves to satisfy the Indian regulation. The locations of the circular curve with improper length are shown in Table 5-6

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 : 2,513.350m 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 : 2,500.000m Transition curve length : 20.000m Circular curve length : **20.111m** < 25m	Intersection Point WBC-14 (DLC=14) West Bound Track (Down Track)
Corridor 2	AkashvaniAkashvani 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 - Malahi Pakri Station	Curve radius : 622.515m Transition curve length : 35.000m Circular curve length : **19.265m** < 25m	Intersection Point SBC-16 (ULC=16) South Bound Track (Up Track)

Source: JST

3) Proportion of curves

The table below shows the line length by radius based on the alignment calculations reconstructed from CAD drawings. Compared 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 the 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: JST

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 are summarized in Table 5-8

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**

Source: JST

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**	

Source: JST

Corridor 2 Up Track

IP No.	Radius	Speed	Balanced Cant.	Actual cant	Cant Deficiency	TRANSITIONS CURVE (TCL)							Adopted TCL (m)
	R	V	Cm	Ca	Cd	Desirable Length			Minimum Length				
	(m)	(km/h)	(mm)	(mm)	(mm)	0.72Ca (m)	0.72Cd (m)	Pickup	0.44Ca (m)	0.44Cd (m)	Pickup		
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**

Source: JST

Corridor 2 Down Track

IP No.	Radius	Speed	Balanced Cant.	Actual cant	Cant Deficiency	TRANSITIONS CURVE (TCL)							Adopted TCL (m)
	R	V	Cm	Ca	Cd	Desirable Length			Minimum Length				
	(m)	(km/h)	(mm)	(mm)	(mm)	0.72Ca (m)	0.72Cd (m)	Pickup	0.44Ca (m)	0.44Cd (m)	Pickup		
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: JST

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 proposes to adjust to make these straight line be exactly 0 m.

Refer to Table 5-9.

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: JST

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 2,200m radius at Raja Bazar Station, 1,213m radius at New ISBT Station and 1,000m 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
1,000m	15mm	20mm

Source: SCHEDULE OF DIMENSIONS (PMRCL) March 2020

Nevertheless, since only slight increase in the 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.

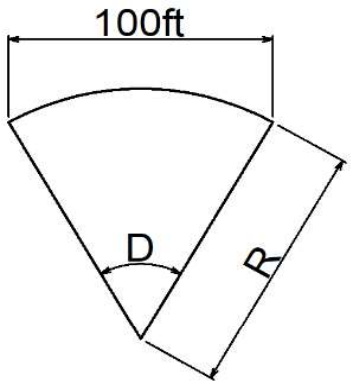
Source: SCHEDULE OF DIMENSIONS (PMRCL) March 2020

$D = 1746.38 / R$

D: Degree of Curve (degree)

R: Curve Radius (m)

Note: The above formulas are applicable formulas for ft - m conversion.



Source: JST

Figure 5-17: 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%	1,200m	1.455316 degree	0.058%	3.996% < 4.00%
Corridor 1	PATNA JUNCTION - MITHAPUR	3.723%	1,200m	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: JST

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 account considered, 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 arranged 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 being 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 satisfy 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 the 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 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 are one conflict point 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: JST

2) Turnout and Transition Curve or Vertical Curve

Turnout is liable to cause significant lateral force and vibration to the running train due to the small radius of the lead curve and the gap in the gauge line. Therefore, the conflicts between a turnout and transition curve or vertical curve should be avoided.

This study checked the front and end points 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

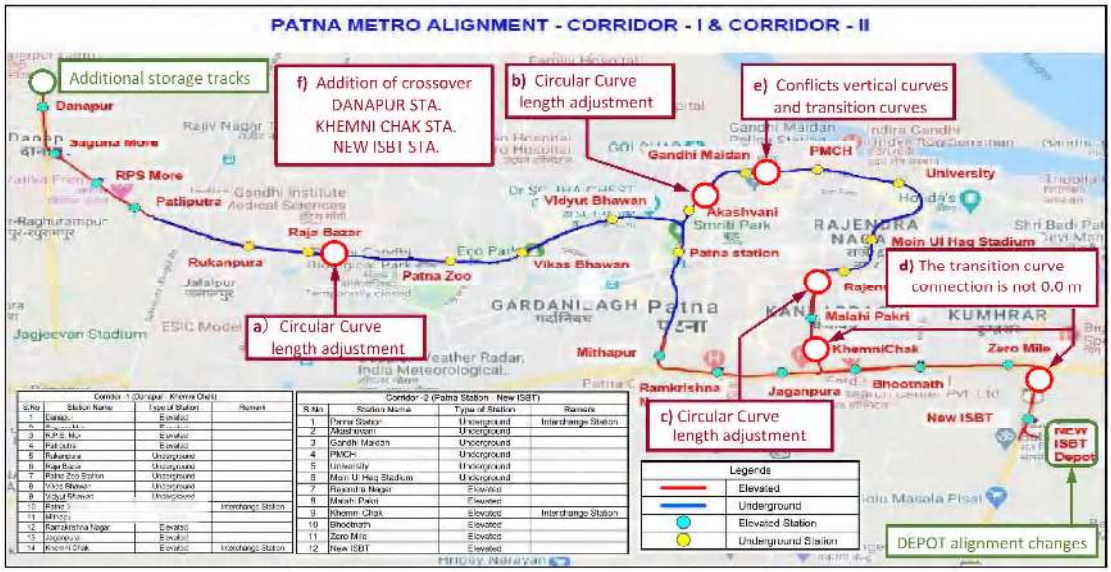
1) Proposal for the main line

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.

Each location covered in this proposal is shown in Figure 5-18.

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



Source: DPR

Figure 5-18: Location map of proposed improvements

a) Corridor 1 CLC-14 circular curve length adjustment

The 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: JST

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 have been resolved.

Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

b) Corridor 2 CLC-3 circular curve length adjustment

The 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: JST

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 have been resolved.

Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

c) Corridor 2 CLC-16 circular curve length adjustment

The 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 Desirable Length	0.72Ca	m	43.200	-	
	0.72Cd	m	38.880	-	
Transition curve Minimum Length	0.44Ca	m	**26.400**	-	
	0.44Cd	m	23.760	-	
Adopted transition curve length		m	**30.000**	-	
Proposed Circular Curve Length		m	**25.354**	-	> 25.0m

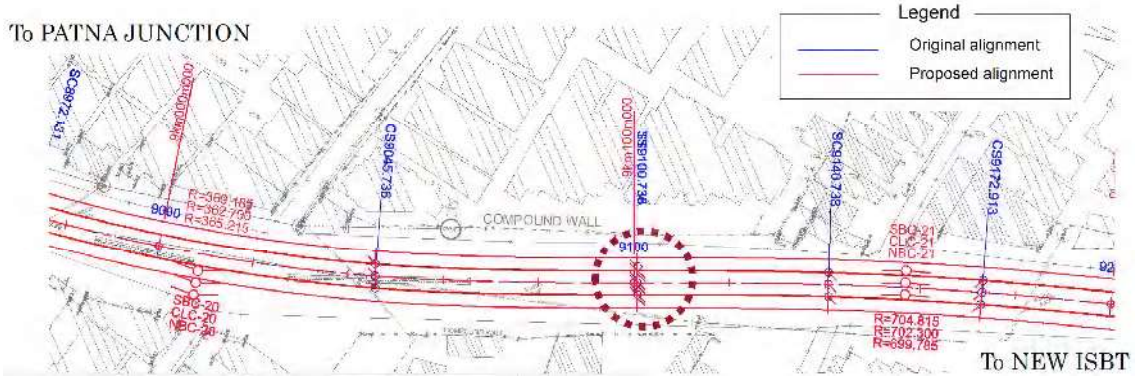
Source: JST

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 have been resolved.

Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

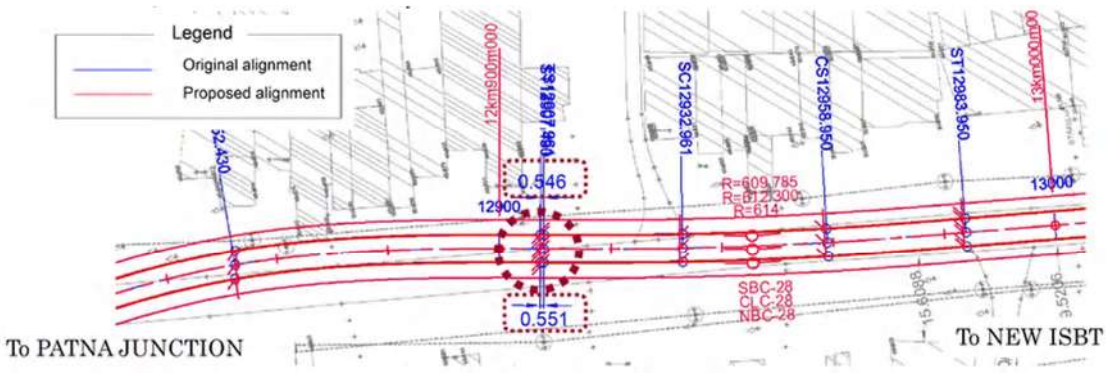
d) Correcting the batted part length of the reversed curve to 0.0 m

In the current alignment, the straight section of batted 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: JST

Figure 5-19: Reverse curve layout between CLC-20 and CLC-21



Source: JST

Figure 5-20: 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

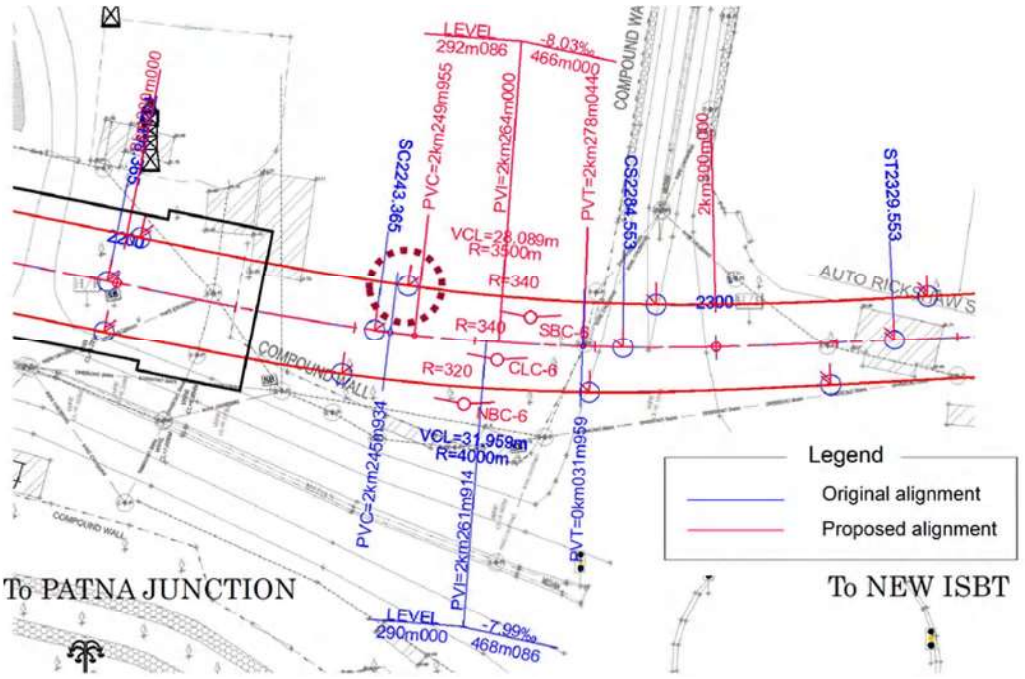
Source: JST

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 have 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: JST

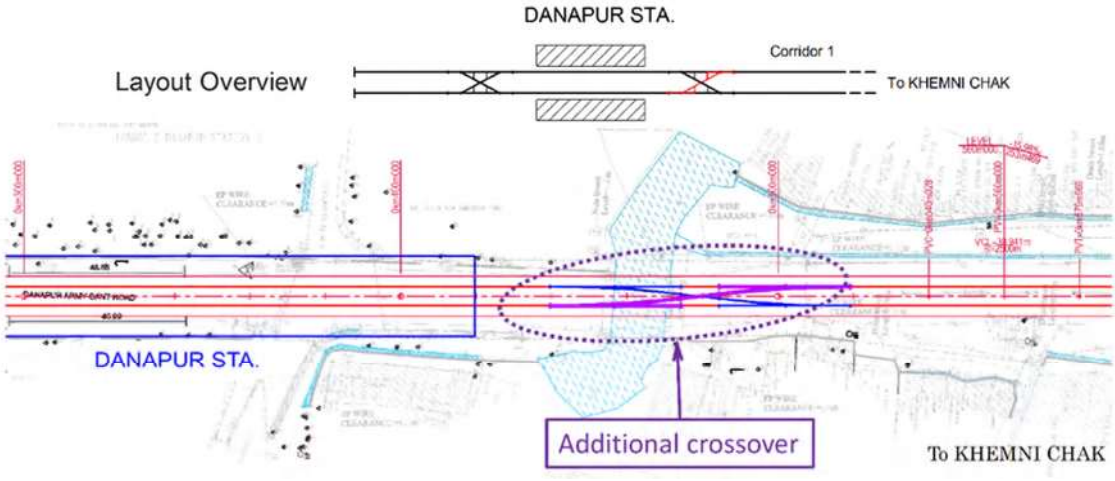
Figure 5-21: Result of adjusting for conflicts between transition curves and vertical curves

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 have been resolved.

Refer to ATTACHMENT 5. ROUTE PLAN AND ALIGNMENT for the revised alignment.

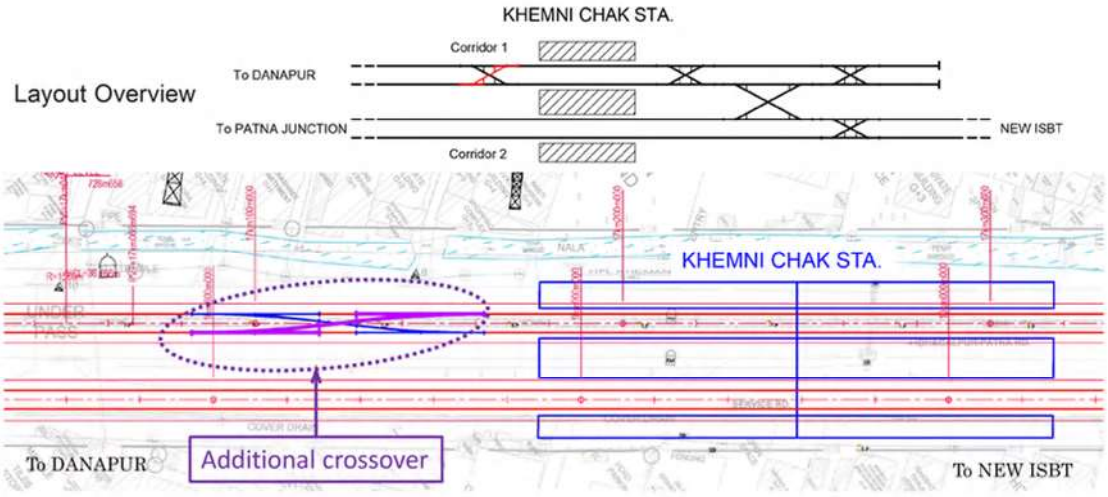
f) Additional crossover to the terminal stations

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.



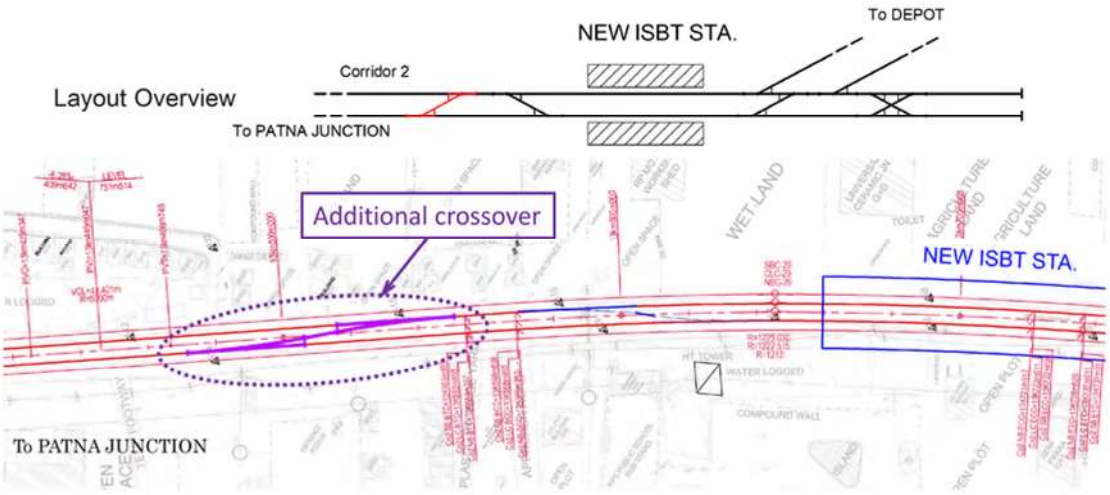
Source: JST

Figure 5-22: Danapur Station Additional Crossover Layout



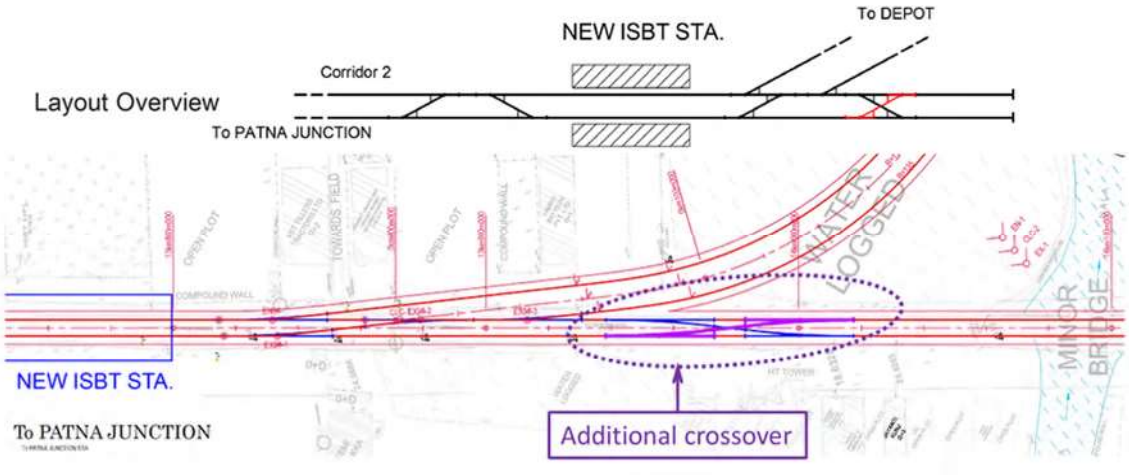
Source: JST

Figure 5-23: Khemni Chak Station Additional Crossover Layout



Source: JST

Figure 5-24: New ISBT Station Additional Crossover Layout (Beginning Point Side)



Source: JST

Figure 5-25: 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 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 the lead tracks becomes unusable. Due to this reason, the proposal for the additional crossover is not adopted.

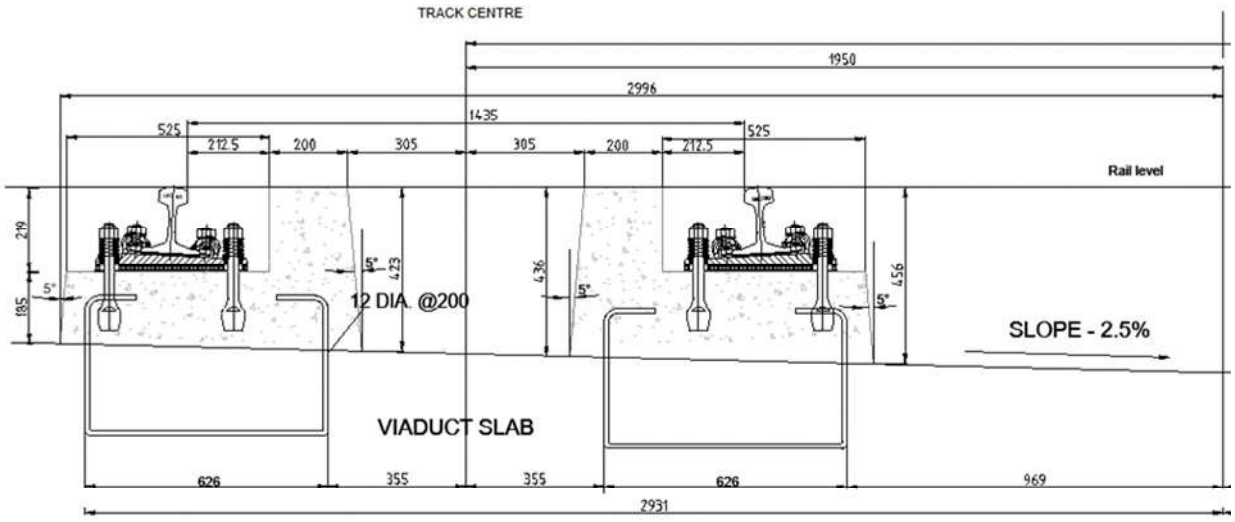
5.2 Track Structure

5.2.1 Overview of Existing Studies

DPR decides its track structure 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

DPR proposes Plinth track 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 5-26: Cross Section of Plinth Track

(2) Ballasted track

DPR proposes the ballasted track in depot sections except for a washing line, inspection lines and lines in a workshop. In general, depot sections use ballasted track because a low-speed operation does not cause much track irregularity, easy-to-fix track settlement and low cost.

(3) Rail

DPR proposes 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.

(4) Turnout

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

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

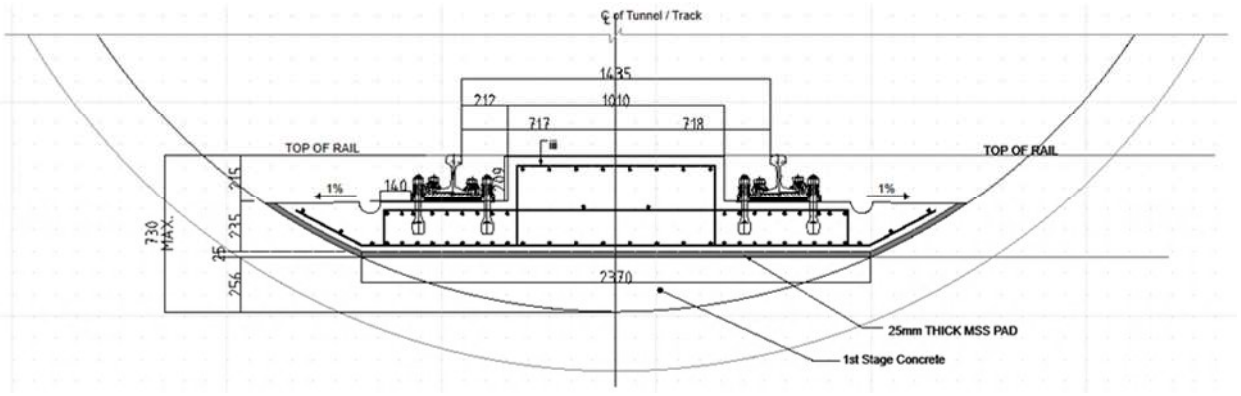
PSTM says that Plinth track has two types of structure: precast and in situ. In India, the former has mainly been used so far, and the latter has been used on a mass rapid transit, MRT Purple line in Thailand. The track structure that will be used for Patna metro has not been decided for the present. 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 an 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 5-27: Cross-section of Mass-Spring System for Plinth track

(2) Rail

1) Rail weight

DPR proposes the 60kg rail for the main line and depot lines. 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

DPR proposes UIC 60 head hardened rail (hereinafter called HH rail) for the entire main line 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.

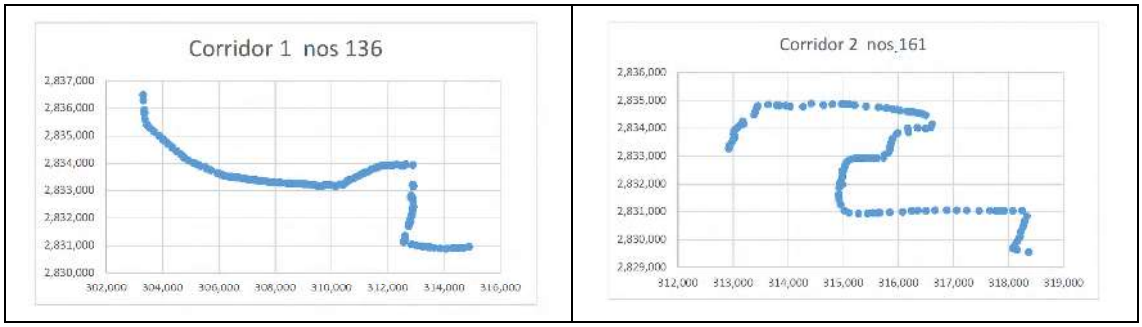
PMRCL states the intention to follow PSTM in the talks during the JICA survey.

5.3 Engineering Survey

5.3.1 Overview of Existing Survey

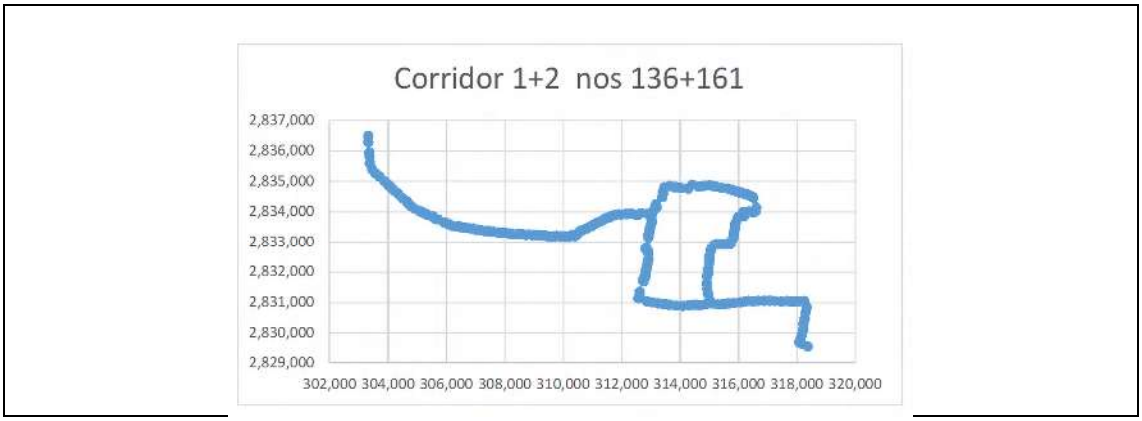
(1) Geotechnical Investigation

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



Source: JST

Figure 5-28: Boring Locations



Source: JST

Figure 5-29: Boring Locations of the Corridor 1 + 2

The geotechnical survey report described the following 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 an additional boring survey at the Depot area.

The summary of geotechnical survey report is shown as below.

1) Strata description

The below table shows the soil layer at the Corridor1 underground section.

Table 5-18: Strata description and coefficient of permeability at Corridor 1 underground section

Soil Layer	Strat Description	Coefficient of permeability k
Fill	Filled up strata	-
Cl (upper)	Brownish, Firm to Stiff, Clayey Silt of medium plasticity	10^{-5} ~ 10^{-4} (cm/sec) order 10^{-7} ~ 10^{-6} (m/sec) order
Cl (lower)	Brownish, Very Stiff to Hard, Clayey Silt of medium plasticity	Ditto
SP-SM	Brownish, Very Dense, Silty Sand	10^{-5} ~ 10^{-4} (cm/sec) order 10^{-7} ~ 10^{-6} (m/sec) order
SM	Brownish, medium dense to dense. Silty sand	Ditto

Source: JST

2) SPT value

SPT 'N' values were correlated with the relative density of non-cohesive soil and with the consistency of cohesive as given below;

Table 5-19: Soil compactness as per SPT N values

Correlation for Clay / Plastic silt		Correlation for Sand / Non-Plastic silt	
Consistency	Penetration Value (N)	Compactness	Penetration Value (N)
Very Soft	0 - 2	Very Loose	0 - 4
Soft	2 - 4	Loose	4 - 10
Medium	4 - 8	Medium	10 - 30
Stiff	8 - 15	Dense	30 - 50
Very Stiff	15 - 30	Very Dense	> 50
Hard	> 30		

Source: Geotechnical Report by PMRCL/DMRC

3) Typical soil parameter

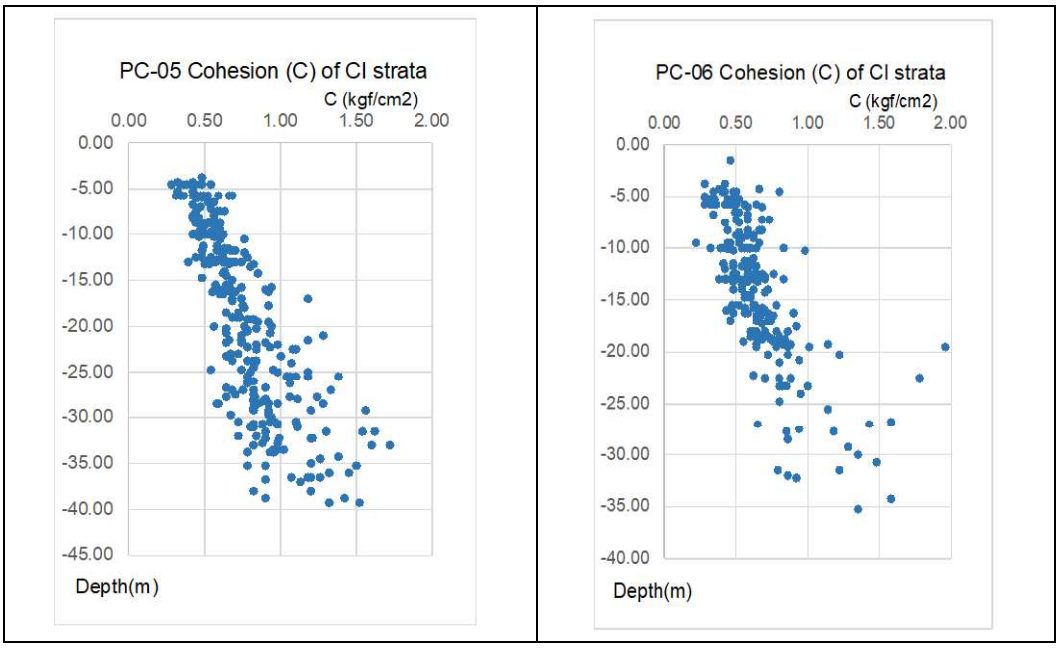
Next, the below table shows typical soil parameter.

And the below figure shows distribution diagram between cohesion value and depth of PC-05 and PC-06 of Cl strata.

Table 5-20: Typical Soil Parameter for Civil Structure Design

Soil Layer	Unit weight γ (tf/m^3)	Cohesion C (kg/cm^2)	Angle of Internal Friction Φ (degree)
Fill	1.8	0.0	30
Cl (upper)	1.9～2.0	0.5～0.6	4～5
Cl (lower)	1.9～2.0	0.6～1.5	4～5
SP-SM	2.0	0	30
SM	2.0	0	30

Source: JST



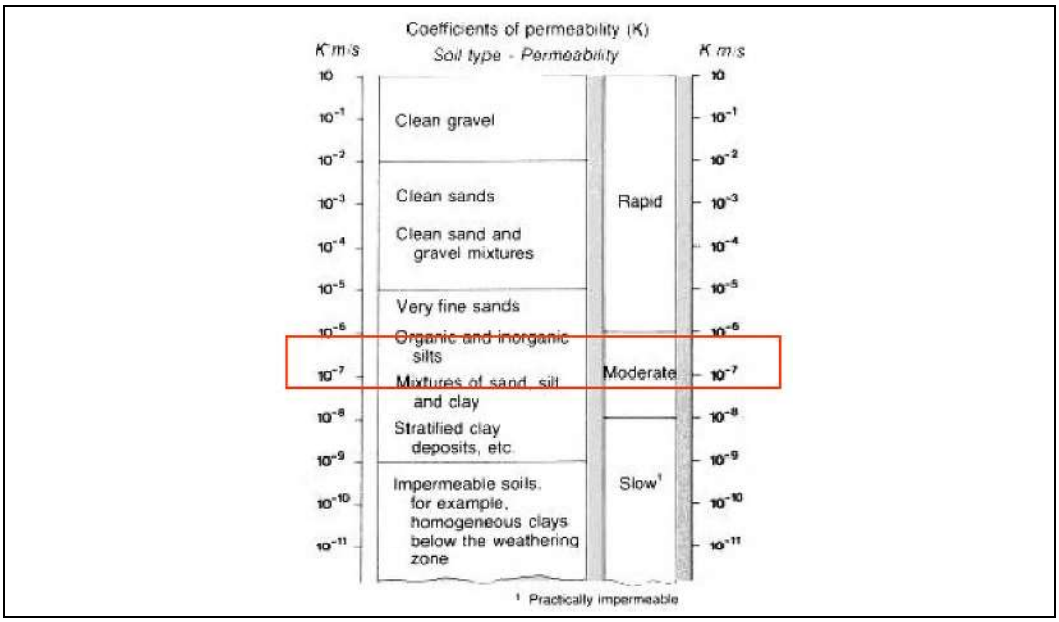
Source: JST

Figure 5-30: Distribution Diagram between Cohesion value and Depth of PC-05 and PC-06 of Cl strata

4) Permeability

Between coefficient of permeability Soil type and Permeability is shown in below figures.

The permeability coefficient of the underground section of Corridor1 is indicated by the red rectangular box.

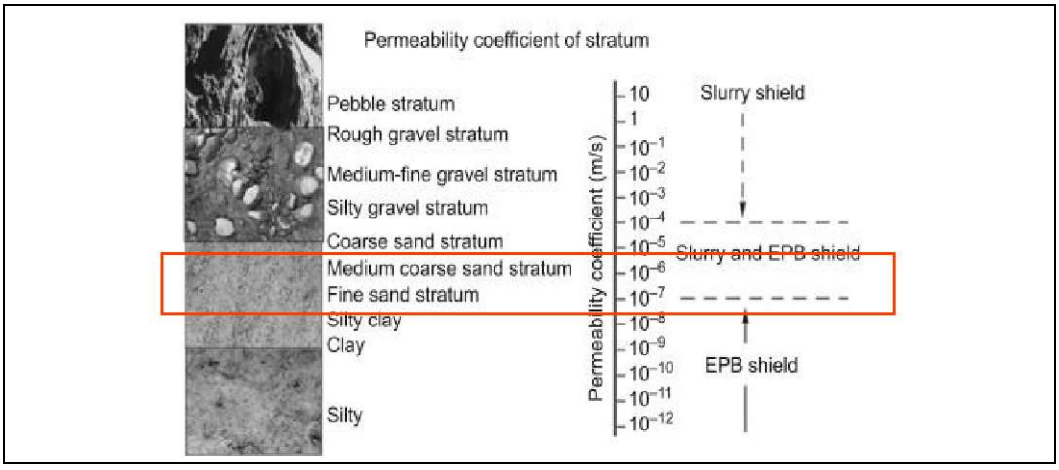


Source: https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e09.htm

Figure 5-31: Coefficient of Permeability Soil type and Permeability

The relation between TBM machine type and the permeability coefficient of strata is shown in below figures.

The permeability coefficient of the underground section of Corridor1 is indicated by the red rectangular box.



Source: https://www.sciencedirect.com/topics/engineering/permeability-coefficient

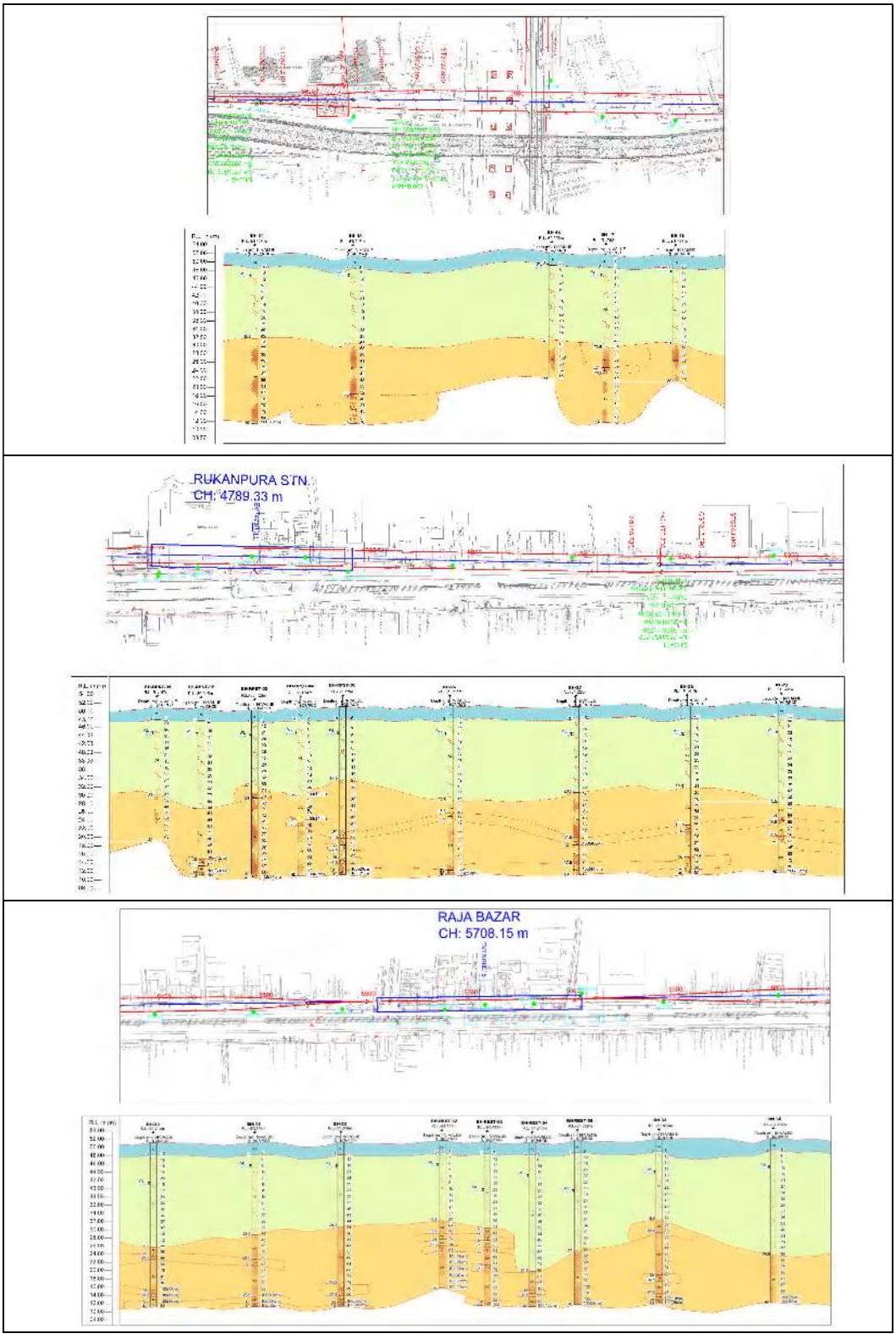
Figure 5-32: The relation between TBM machine type and Permeability coefficient of strata

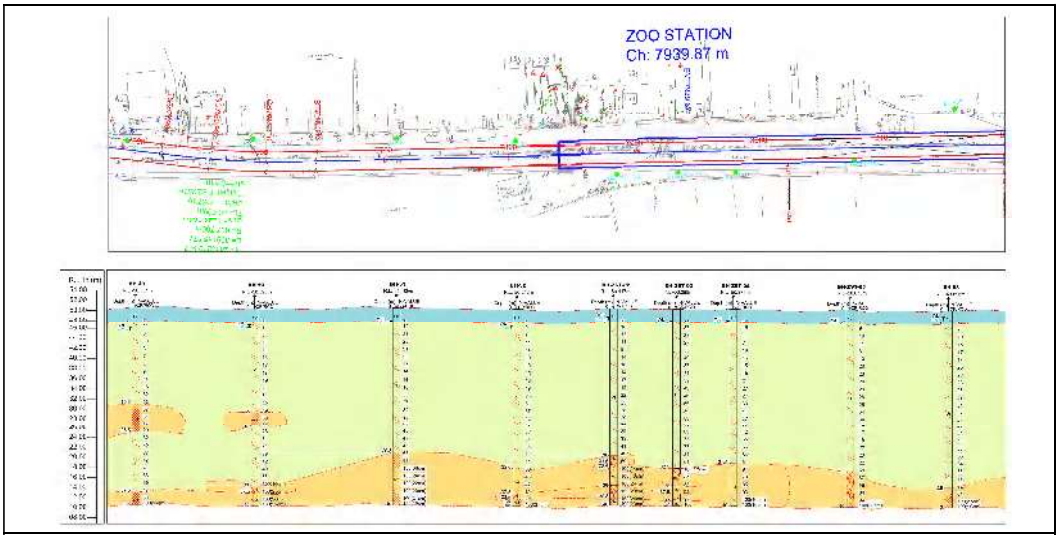
5) Geological longitudinal profile drawings

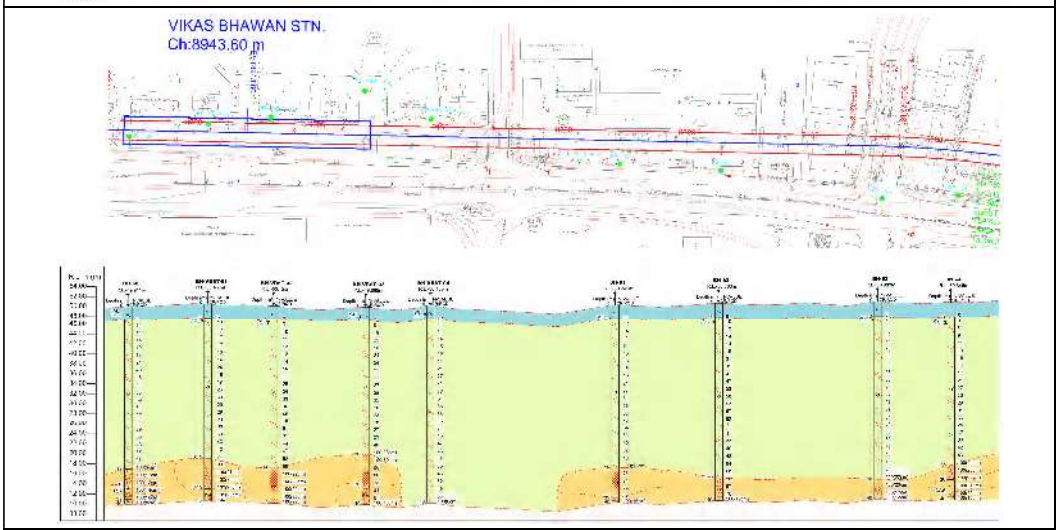
The below figures show Geological longitudinal profile drawings of Corridor 1 underground section.

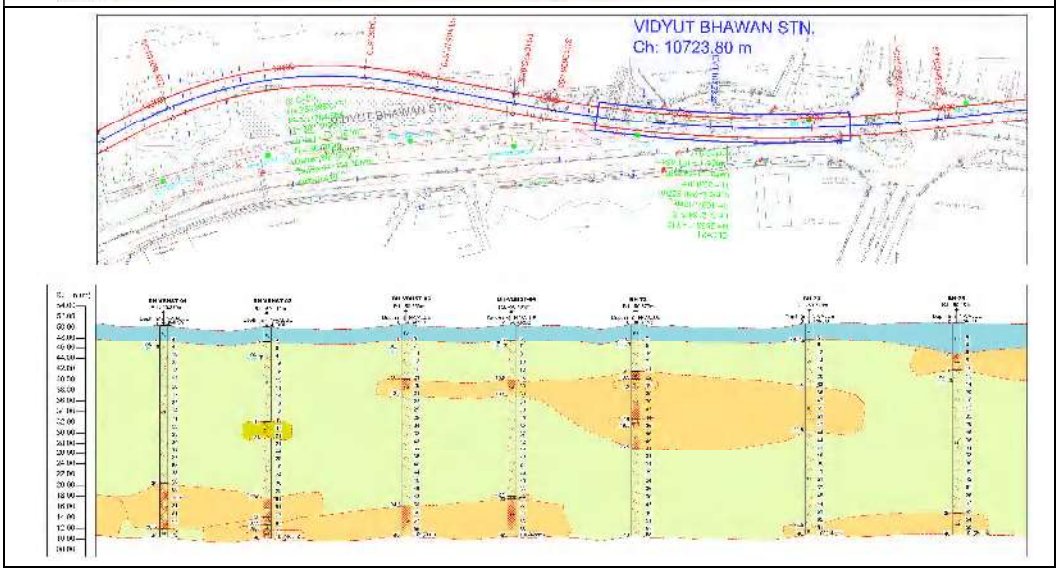
The soil layer pattern is changed at the nearby Zoo station in the Corridor1 underground section.

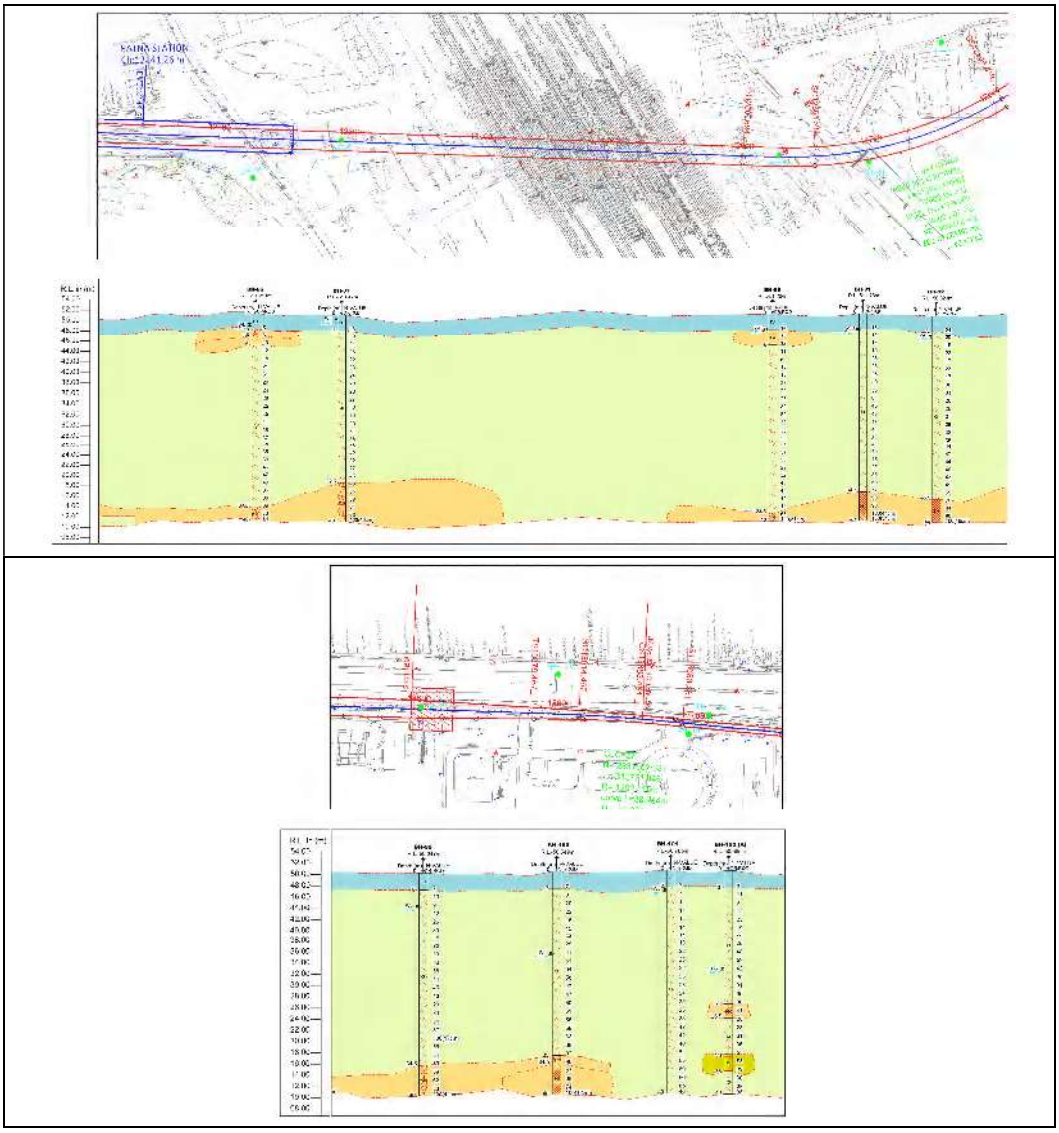
And a lens layer of SP-SM/SM strata appears at Viduyut Bhawan Station.




ZOO STATION
Ch: 7939.87 m


VIKAS BHAWAN STN.
Ch:8943.60 m


VIDYUT BHAWAN STN.
Ch: 10723.80 m



Note; Latest plan alignment has been changed from the above plan alignment.

Source: Geotechnical Report by PMRCL/DMRC

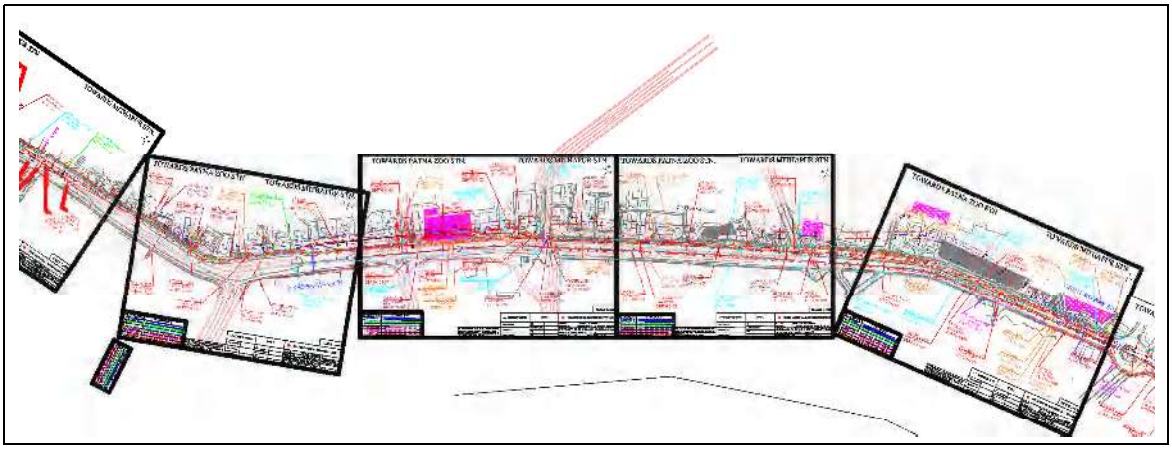
Figure 5-33: Geological Longitudinal Profile drawings at each underground station of Corridor1

(2) Topographic Survey

The construction of viaduct section of the Corridor 1 and viaduct/underground section of the Corridor 2 was 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 5-34: 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 5-35: High Voltage Power Line (Corridor2 ST12 New ISBT Station)





Source: JST

Figure 5-36: Crossing Location between Corridor 2 Elevated Alignment and High Voltage Power Line nearby Corridor2 ST11 Zero Mile



Source: JST

Figure 5-37: 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.



Corridor1



Corridor2

Source: PMRCL/DMRC

Figure 5-38: Existing Survey Report

The Building Foundation Survey Report (Building foundation depth report C-1) described following 1) and 2) Task and method of the existing building foundation survey are shown in bellow.

The Building foundation depth report C-1) described following 1) and 2)

1) Project tittle: Utility Investigation Work for Patna Metro Rail Project from Danapir to Miytapur (Cprridor-1) Subsurface & Foundation depth Analysis

2) Project Objective/Goals; The overall objective of this project is to do Sub-surface Foundation analysis of existing 189 buildings by combination of Non Destructive Testing Technologies by the use of Pile testing, Ground Penetrating Rader (GRP), Earth Resistivity Test and other survey equipment's and Software's for the proposed underground and elevated corridor of Patna Metro Rail Project from Danapur to Mithapur (Corridor1)

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 soil layer pattern is changed at the nearby Zoo station in the Corridor1 underground section. And a lens layer of SP-SM/SM strata appears at VIDUYUT BHAWAN Station.
- 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 is 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.
- Following is the back-calculation of the N value from the C; using the Terzahgi Peck empirical formula C = N/16 (kg/cm^2) C=6.25N (kN/m^2) further details are as follows;
  - Cl (upper layer) C = 0.5 to 0.6
    In this case, N value ranges from 8 to 10
  - Cl (upper layer) C = 0.6 to 1.5
    In this case, N value ranges from 10 to 24

  These N value range correspond to SPT value of geotechnical survey result, and the C value range is on the safe side for the underground structure design, the C value that was achieved through laboratory testing is a sufficient value.
- Next, Φ is usually used as 0 in the design value for clay soil, but small values of 4 to 5 in the laboratory test results may be measured in other cases,

  In sandy soil (SP-SM, SM), Φ = √(20N) + 15 (Osaki's formula) andΦ = √(15N) + 15 gives an N value equivalent to N = 8 to 22 at Φ =27° to 33° which were reported in the geotechnical survey report, but in the field, the ground was also very dense and it was judged that Φ = 30° is adequate value on the safe side for the underground structure design.

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. 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.

B. Suggestions

1. The discrepancy between OCR values and SPT N values needs 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.

The over-consolidation ratio (OCR) allows characterizing the stress history of soils.

OCR is utilized as a soil condition indicator in the design of the embankment construction and the dewatering construction.

When designing an underground temporally stage (such as the excavation of an underground station or cross passage), designers refer OCR derived from a consolidation laboratory test as an indicator for taking consolidation settlement into account when utilizing the dewatering method.

OCR is not directly used in this settlement study; instead, the e-log P curve of the consolidation test results is used.

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

JST requested PMRCL/DMRC to examine OCR test results with the geological survey agency that carried out the testing method, recording sheet that includes the sample circumstances, and how OCR was computed from the consolidation test results as part of the DPR's assessment.

And JST has confirmed result of OCR value of additional geotechnical survey which has been conducted by PC01 Contractor, all OCR result were adequate value.

And, JST requested to PMRCL/DMRC that incorrect data of OCR value not be included in the tender document.

(2) Topographic Survey

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



Source: JST

Figure 5-39: Construction Condition of Guide Wall for Diaphragm Wall Construction at Corridor2 ST05 Moin Ul Haq



Source: JST

Figure 5-40: 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 the 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 the 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 5-41: 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

The below table shows part of the survey result of the foundation depth of existing buildings along Corridor1.

Table 5-21: The survey result of the foundation depth of existing buildings along Corridor1

Report page	Building ID	HEIGHT OF BUILDING	LOCATION/ OWNER	Foundation Depth(m)	
				PIT test	GPR test
30,31	01	B+5	HONDA SHOWROOM	5.84/5.94	5.60/5.70
34,35	03	G+4	SANJIVANI BUILDING	3.90	3.50/3.80
36,37	04	G+3	HIND ENTERPRISES	4.56	4.83
40,41	07	G+4	WOODLAND	15.31	9.56/9.50
44,45	09	B+9	CLUB 10	15.92	9.56
46,47	10	G+3	JALAN SHOP	10.33/9.99	9.50/9.50
48,49	11	G+3	BANK OF MAHARASTRA	10.48	9.60
54,55	14	HEIGHT 15.3m	Under Construction	1.61/1.51	1.19
58,59	16	G+5	KEASHAV PALACE	8.73/8.81	Discard due to Maximum Depth
60,61	17	2B+7	BIG BAZAR	10.67/10.62	9.60/9.56
62,63	18	B+6	SAKET ENCLAVE	4.85/5.15	4.30/4.52
64,65	19	B+3	FAB INDIA	1.83	2.11/2.10
74	27	B+6	PARAS HOSPITAL	Discard due to Maximum Depth	
75,76	29	HEIGHT 18.2m	Under Construction	6.90/6.95	7.10/7.20
133.134	54	G+5+(G+3U/C)	LALIT BHAWAN	7.45	7.30/7.60
135,136	55	G+4	TECHNOLOGY BHAWAN	7.06	7.10/7.30
137,138	56	B+7	PANT BHAWAN	4.33	4.60/4.70
141,142	58	G+2	INDIAN GAS GODOWN	4.61/4.20	4.50/4.50
143,144	59	G+5	GULISTAN APARTMENT	6.8/7.1	6.82/7.10
147,148	61	B+8	JP BHAWAN	12.47	8.0/8.0
149	62	WATER TANK	OLD OVER HEAD TANK	-	7.20/7.20
156,157	67	G+3	MAHAVIR MANDIR	6.77/7.16	7.50/7.30
158,159	68	WATER TANK	OVER HEAD WATER	8.09	7.80
160,161	69	WATER TANK	U/C OVER HEAD WATER	8.27	8.0/8.0
166,167	72	U/C BUILDING	NIFT	5.11	5.80

Source: JST

The below table shows JST's queries and reply comment from PMRCL/DMRC

Table 5-22: The JST's queries and reply comment from PMRCL/DMRC for the Existing Building Foundation Survey

No	JST's queries	Reply comment from PMRCL/DMRC
(1)	Which test either PIT(Pile Integrity Test) or GPR (Ground-penetrating radar Test) test has the highest level of reliability?	It may be impractical or expensive to perform destructive type tests such as core drilling to determine pile lengths of existing foundation elements. (a) Non Destructive methods such as PIT may be used to determine the length of concrete piles. Although this method has some inherent limitations especially for piles which support the superstructure or long piles which exhibit high friction. (b) Ground Probing (or Penetrating) Radar works by sending a radio signal or series of signals into the ground. The returning signals provide information about changing ground characteristics with depth. Basic radar output presents this as patterns of signals at depth against the distance traveled along the ground by the radar. To get accurate depth information, the data will be calibrated for soil conditions on the day(s) of survey. GPR works best when there are well-defined differences in the electromagnetic properties of the materials being surveyed: gradual change is not as easy to detect. The buried structure provides sudden change in dielectric constant from surrounding soil, and hence are a good target to be detected by GPR. Both PIT and GPR testing methods offer a practical, inexpensive and reliable non-destructive test method for embedment depth determination of foundation elements such as shafts, piles or retaining wall. They validates each other's data and reduce the inherent limitations of respective technology, which further limits assumptions in measurement to produce reliable output with increased accuracy.
(2)	What does the test result "Discard due to Maximum Depth" mean?	It means that depth of foundation is out of the range for the method of testing.
(3)	(a) Building survey result by GPR test did not obtained at building ID16.How did you confirm the foundation type and depth of this building? (b) Building survey results by PIT/GPP test did not obtained at building ID 27. How did you confirm the foundation type and depth of this building?	Depth and type of foundation of building nos. 16 and 27 could not be ascertained from this study. However, the outer boundaries of these buildings are approximately 3 meters away from the outer wall of tunnel. Detailed study will be conducted during construction stage by the construction contractor and necessary safety measures will be exercised during the construction near these buildings.
(4)	The building foundation depth of Building IDs 07, 10, and 11 is extremely deep (>10m). There is no basement in this structure. What should this outcome be considered?	This outcome indicate that the buildings have pile foundation with depth as indicated in report.
(5)	The building foundation depth of Building IDs 09 and 17 is extremely deep (>10m). This structure has a basement. Is this the basement depth?	The depth of foundation beneath the basement is indicated by the GPR value.
(6)	Building IDs 3, 4, 16, 54, 55, 68, 59, and 67 have not a basement. What should this result be considered?	These buildings have pile foundation.
(7)	The building foundation depth of ID 14 is very shallow. What should this result be considered?	This is raft/open foundation.
(8)	What kind of foundation is there for each existing/under construction building and water tank? (Is the foundation spread or piled?)	Type of foundation for each existing/under construction building varies from case to case (raft/pile foundation). Depth of water tank could not be ascertained from this study and the detailed study will be done by the construction contractor to get the details of the same

No	JST's queries	Reply comment from PMRCL/DMRC
(9)	Do you have a drawing of the water tank and the building structure?	No
	Will gathering as-built drawing of the water tank and the building structure be done by the contractor while conducting Building Condition Survey before starting the construction after award of the work?	The required details will be obtained by the contractor during the construction stage before the start of work.
(10)	Did you ask the building owner for confirmation of the foundation type in an interview survey?	Yes
(11)	Have you checked/recorded the state of existing buildings for things like cracking and deformation?	No, it will be done by the contractor while conducting Building Condition Survey before starting the construction after award of the work.
(12)	How did you confirm that the TBM alignment stays clear of all pile foundation structures?	Minimum 1D distance have been tried to be kept while fixing the alignment.
(13)	While designing the TBM segment, did you take into account the load from new or existing buildings?	**Yes.** TBM segments will be designed to resist the following loads: • Dead load • Superimposed surface loads from traffic, existing structures over and adjacent to the bored tunnel, and any specified future loads • Appropriate ground loads, water pressure and seismic loads • Railway loads wherever appropriate • Unequal grouting pressures • Adjacent bored tunnelling or excavation • Long- or short-term loads induced by construction • Temperature and shrinkage • Handling loads, including impact, especially in the case of unreinforced segments • Jacking forces, where appropriate • Accidental loading such as fire and derailment
(14)	Do you have the standards for acceptable building/water tank settling, say, during TBM driving?	Settlement during the TBM driving shall be limited, such that any individual structures/buildings shall not suffer damage greater than "Slight" as defined in damage classification table. Settlement to important structures, bridges and heritage buildings shall be limited to "Negligible" as defined in the damage classification table. Damage classification table is shows Table 5-23. Assessment of the effects of settlement on existing building structures is undertaken in stages depending upon the findings at each stage.

Source: JST

Table 5-23: Building Damage Classification

Building Damage Classification[1] (after Burland et al, 1977 and Boscardin and Cording, 1989)				
1	2	3	4	5
Risk Category	Description of Degree of Damage	Description of Typical Damage and Likely Form of Repair for Typical Masonry Buildings	Approx[2] Crack Width(mm)	Max Tensile Strain %
0	Negligible	Hairline cracks.		Less than 0.05
1	Very Slight	Fine cracks easily treated during normal redecorations. Perhaps isolated slight fracture in building. Cracks in exterior brickwork visible upon close inspection.	0.1 to 1	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible : some repointing may be required for weather tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tack-pointing and possibly replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Water tightness often impaired.	5 to 15 or a number of cracks greater than 3	0.15 to 0.3
4	Severe	Extensive repair involving removal and replacement of sections of walls, especially over doors and windows required. Windows and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably, some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	Greater than 0.3
5	Very Severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually greater than 25 but depends on number of cracks	

Source: Received from PMRCL/DMRC

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




Source: JST

Figure 5-42: 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.

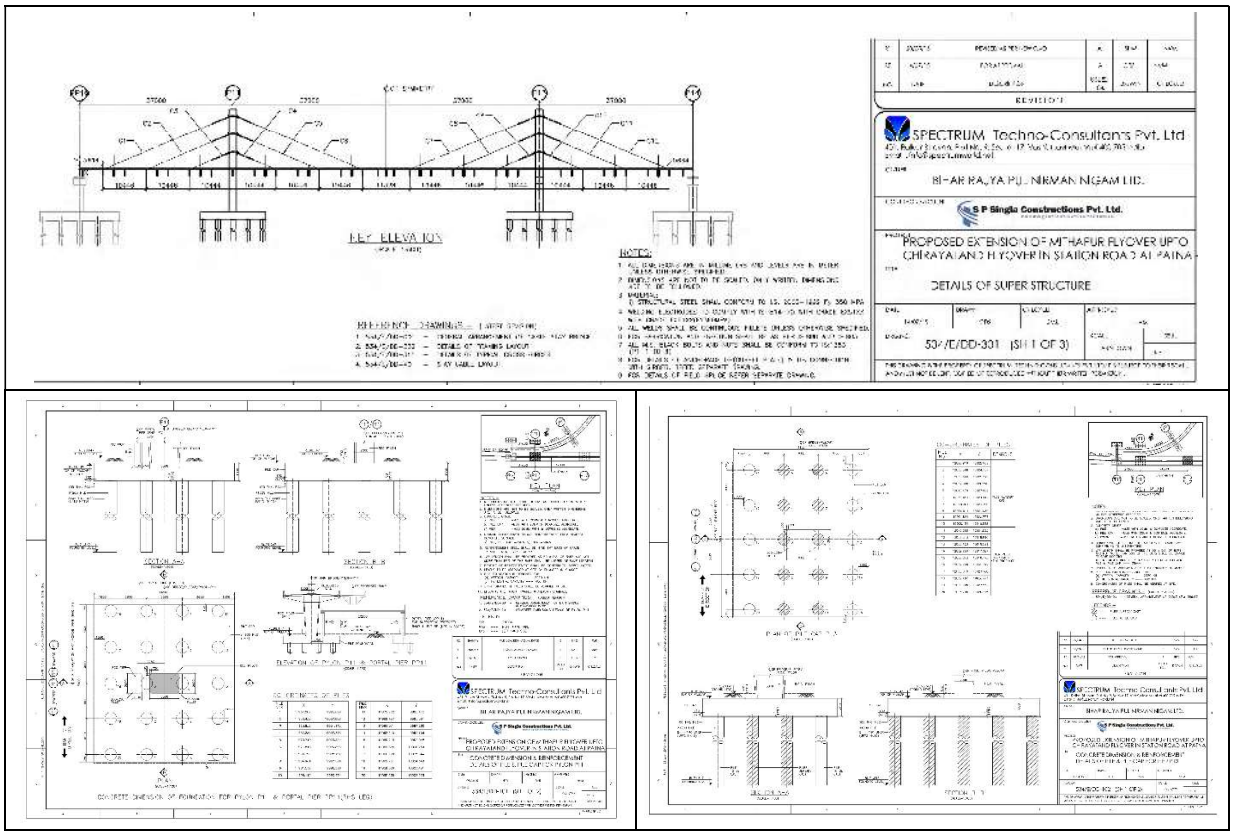
1) Patna Bridge

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 5-43: Patna Bridge

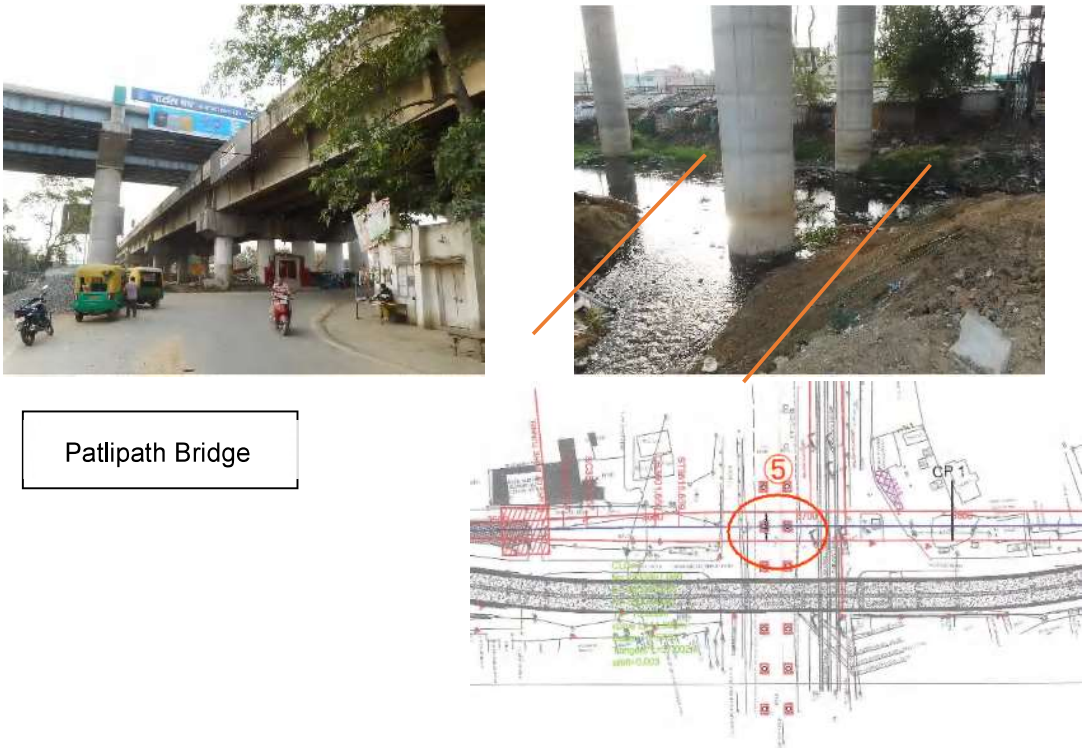


Source: PMRCL/DMRC

Figure 5-44: As-build Drawing of Patna Bridge

2) Patriputra Bridge (From Corridor 1 ST04 Patliputra to ST05 Rukanpura Station):

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



Source: JST

Figure 5-45: Patriputra Bridge