Tunnelling Asia' 2023
International Conference on
Climate Change Resilience and Sustainability
in Tunnelling and Underground Space

Execution Strategies in Delivering Sustainable Urban Infrastructure Project of Colaba-Bandra-Seepz (Line 3) in Mumbai

by

S.K. Gupta

Director/ Projects

Mumbai Metro Rail Corp Ltd

subodh.gupta@mmrcl.com

Mumbai Metro Line 3:

- 33.5 km (fully underground)
- Station : 27 (26 U/G+1At-Grade)
- Completion cost : Rs 37,276
- EIRR : 17.93%
- FIRR : 4.20%

	2024	2031	2055
Ridership	14.0 L	17.0 L	31.51 L
Headway	4 min	3 min	2 min
Coaches	248 (8x31)	336 (8x42)	440 (55x8)

Mumbai-MMR

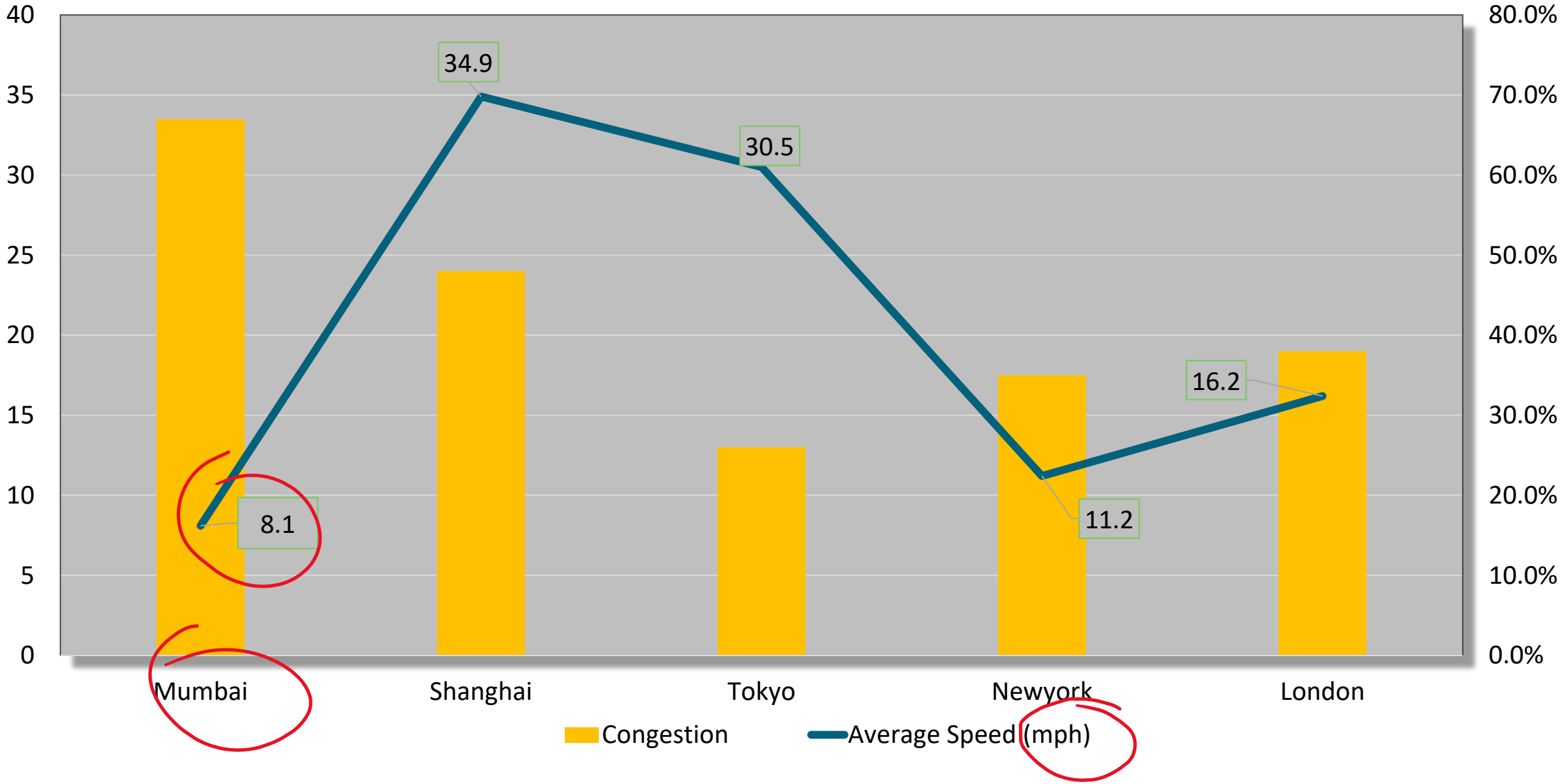
- 6th largest Metropolitan Region in the world in terms of population
- Financial capital of India
- Contributes 6.16% share in India's GDP, over 33% of India's income tax revenues
- The two ports in Mumbai handle 1/3rd of the country's foreign trade
- Handles 38% of international and 28% of domestic air traffic of the country
- Accounts for 25% of Industrial Output

Congestion on roads

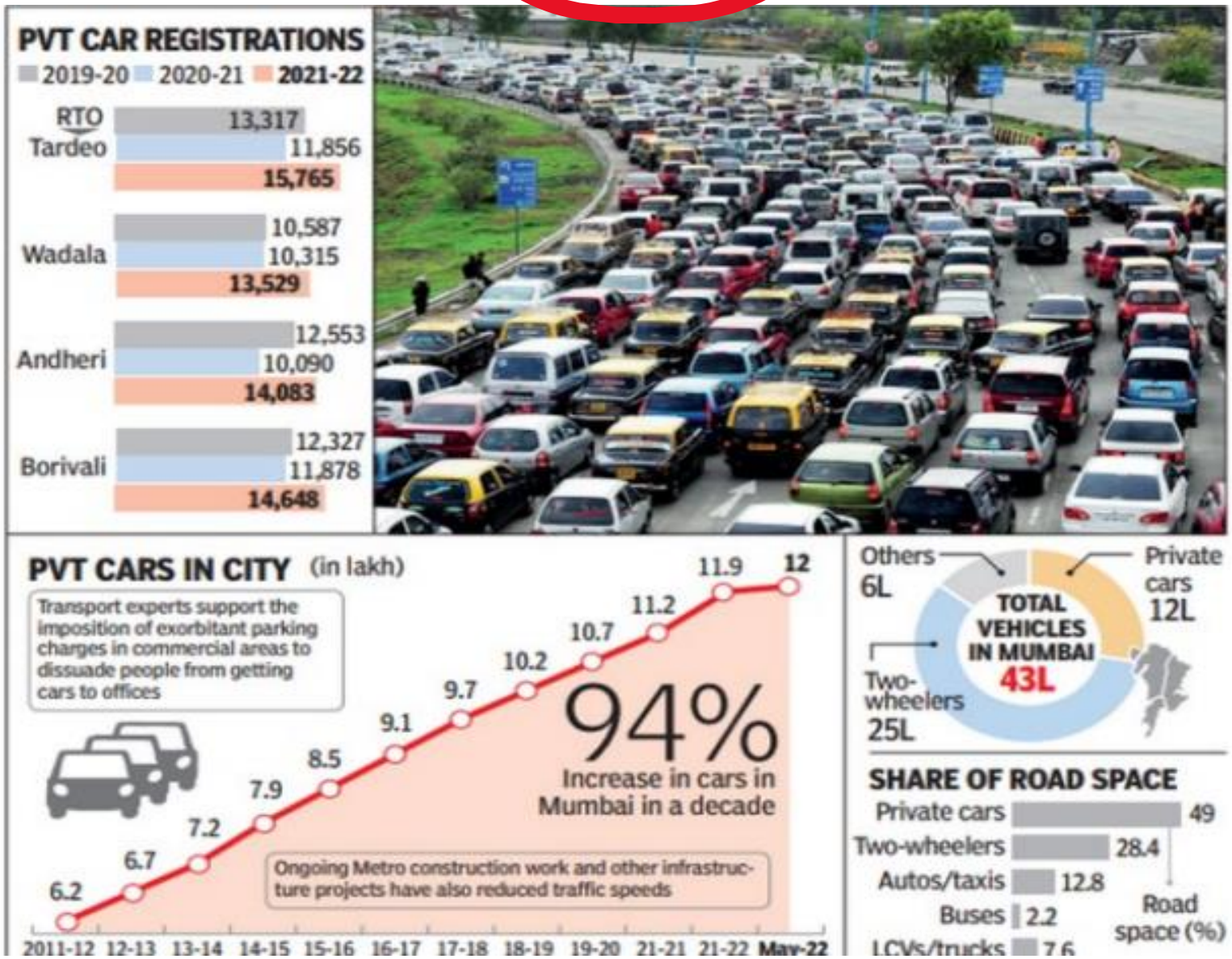
- 56% growth in vehicle count from 2012 to 2017
- Every day 700 vehicles added (2017)
- Public transport buses crawl with less than 10km/hour speed

Mumbai: Traffic Congestion and Average Speed

Comparison with Metropolitan Cities



Mumbai has 12 lakh private cars & 2,150 veh. per km

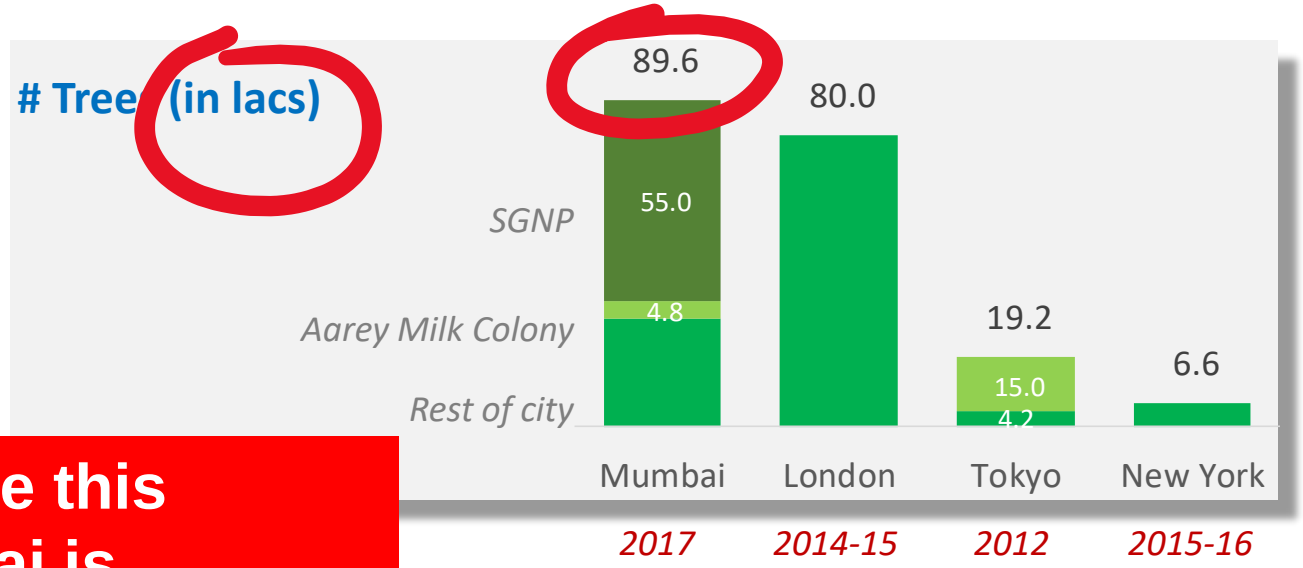


DOUBLES IN DECADE

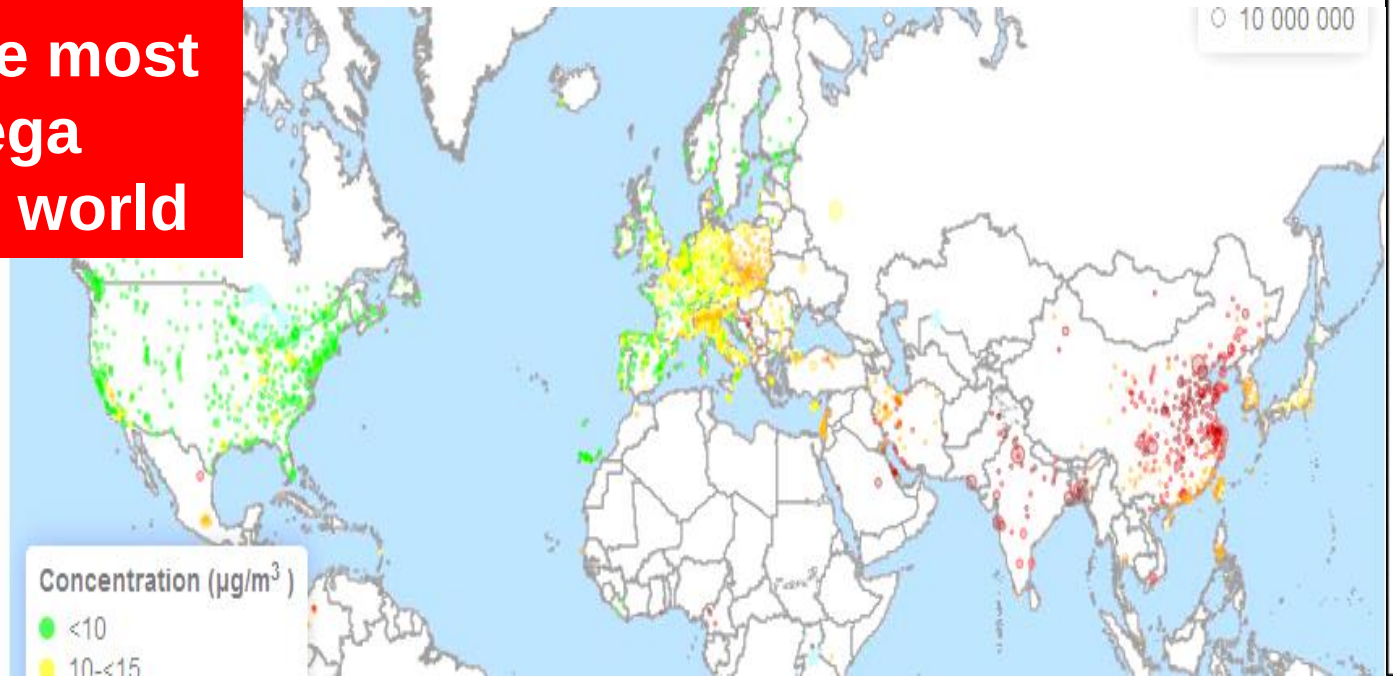
- Number of **private cars** in the city has **grown 94% from 6.2 lakh in 2011-12**
- **Total vehicular popn,** including bikes & buses, **up 112% in a decade to 43L**
- **Pvt cars now occupy 49% of the city's road space** and two-wheelers 28.4%
- Experts **call for reducing private cars by 20%** and two-wheelers by 15% in city

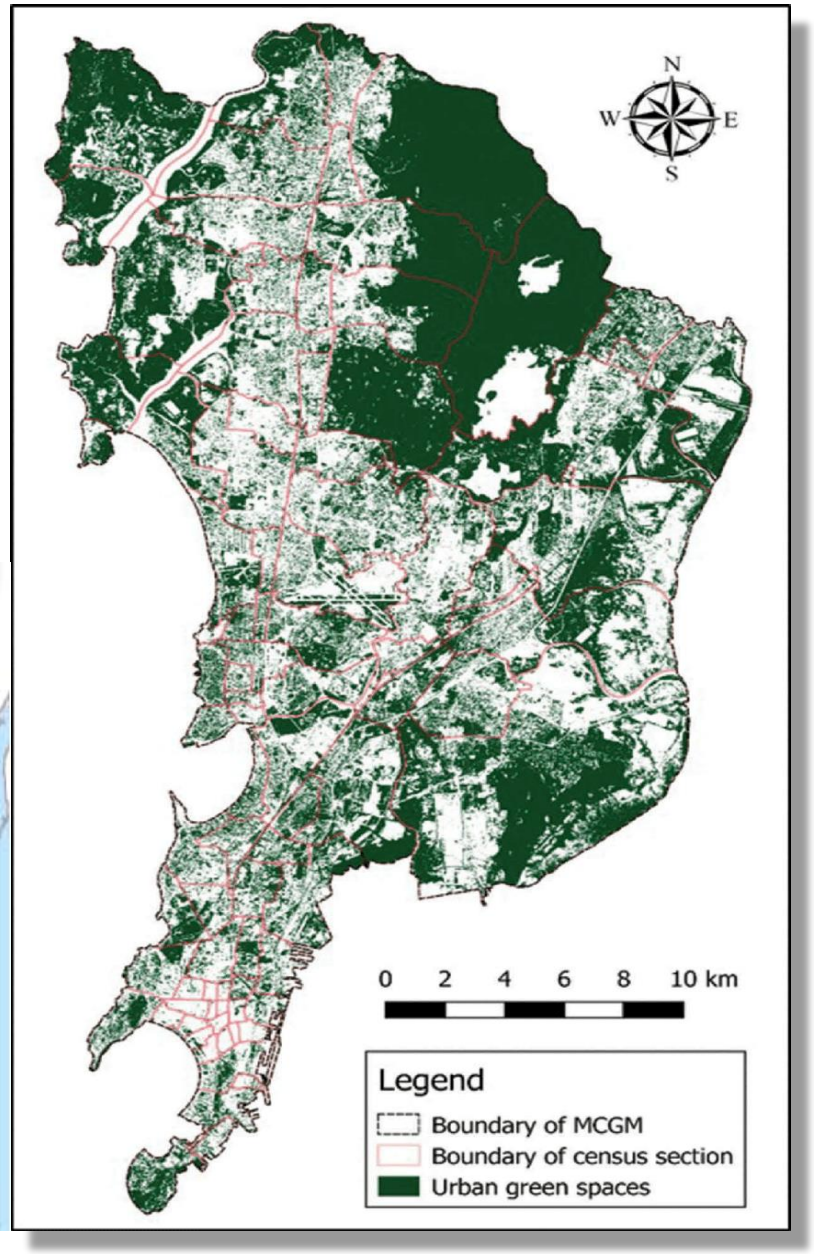
Source: TOI 25 May 2022

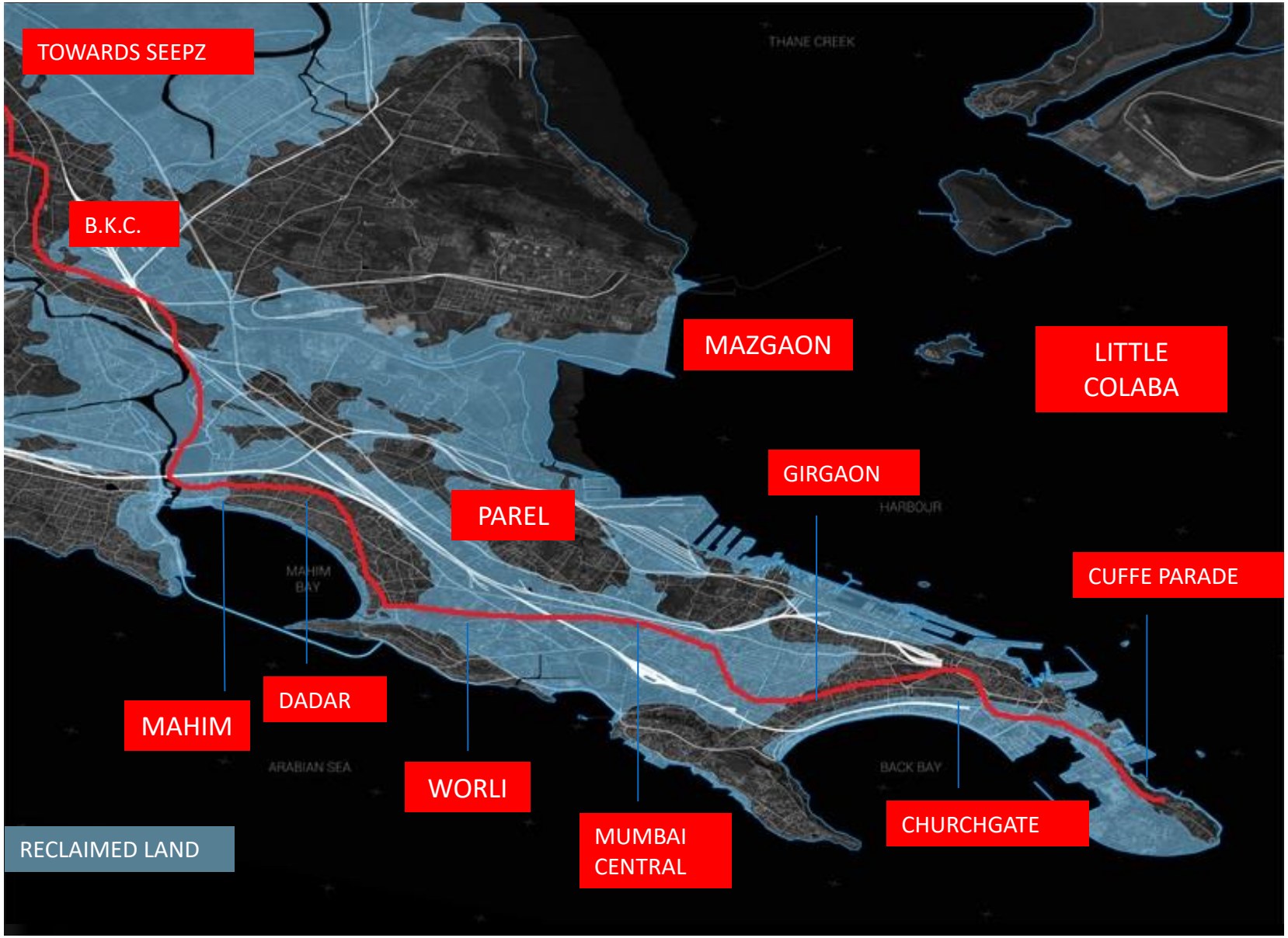
Mumbai has higher green cover than any other mega city



Despite this Mumbai is amongst the most polluted mega cities in the world



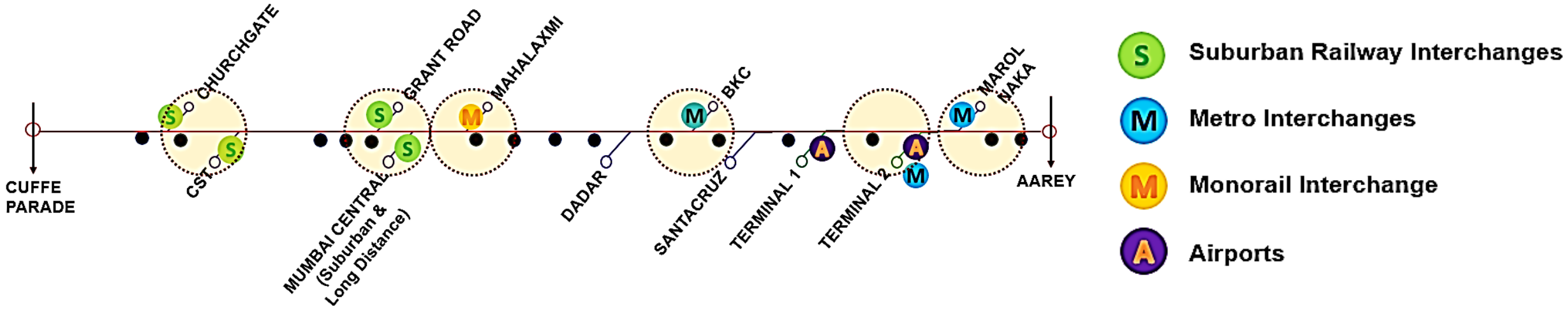




Mumbai was once an archipelago of seven islands which were joined by land filling over period of time.

Mumbai today is a tapered land mass with sea/creek on three sides. It has high population density; and low road space.

The alignment of Line 3 is planned to serve important residential areas, business and employment hubs; multimodal integration including both the terminals of the airport, educational Institutions, major hospitals and many religious & recreational centres.



- Line 3 will be the major arterial line in North - South direction with other lines criss-crossing to provide East-West connectivity.
- 3 million population falls in the influence zone of this Line.
- It touches many slum areas opening new livelihood opportunities to them. Design capacity of the Line is 72,000 PHPDT (highest in India)

Line-3 passes through densely populated and congested parts of the city to serve its intended purpose. It is practically impossible not to have tunnels passing directly underneath, or in proximity of old and dilapidated buildings, heritage buildings, high-rise buildings or a flyover, metro viaduct or railway line. In certain areas the alignment is very close to the coastline or below a water body.

How is the project made sustainable to the community and resilient

- Planned to serve sizable population, to reach closest to their origination and destination
- Planning and construction not to unduly affect the public ie minimum relocation (PAPs), relocation with human touch; construction with minimum effects on -their day-to-day life, civic utilities, traffic ….
- Construction not to unduly affect environment and trees
- Physical safety of public and their establishments
- Technology upgrade to prevent noise and vibration nuisance during operations
- Infrastructure to sustain natural calamities such as earthquakes or events related to climate change-heavy rains/ flooding

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1.Planned to serve sizable population, to reach closest to their origination/destination

~ 30 Employment clusters/ Govt/ Pvt. Offices

~ 12 Education Institutions

~ 11 Major Hospitals

~ 10 Major Transp Hub

~ 25 Religious/ recreation centres

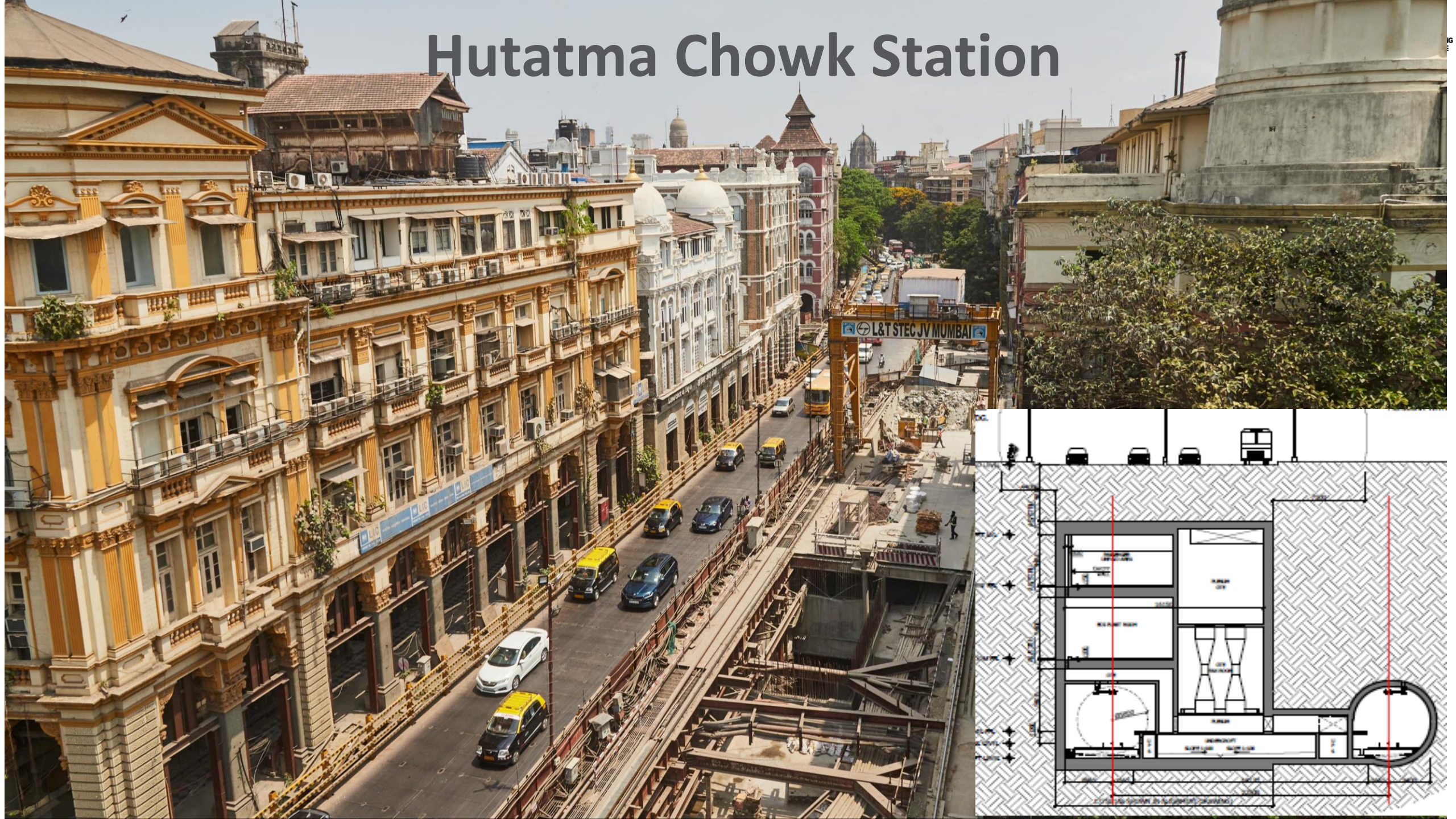
- Connects densely populated localities like Kalbadevi, Girgaon, Grant Road, Worli, Dadar, Mahim, Bandra East, Santacruz, Marol
- Serves 30 Lakhs population in its influence zone.
- Serves six Business Districts: Nariman Point, Cuffe Parade (WTC), Fort, Worli/Lower Parel, BKC, SEEPZ / MIDC
- Interchange with existing public transport -Churchgate(WR), CSTM (CR), Mumbai Central, Marol Naka (Line1), Mahalaxmi (Monorail), Mumbai Central (ST)
- Airport - Domestic Terminal (T1), International Terminal (T2)

- This line has a disproportionately higher component of NATM tunnels than any other urban metro project in India
- 7 out of 26 UG stations have NATM tunnels for PF, Sidings, central cavern
- Two scissor cross-overs have been constructed by NATM tunnels
- Many of our tunnel drives were long with drive-through or drag-through the stations.
- Extensive traffic decking are installed to cater to the traffic.
- Massive civic utilities were supported in-situ

Any other way of working would have impacted city life very adversely, invited opposition and thus would not have been sustainable

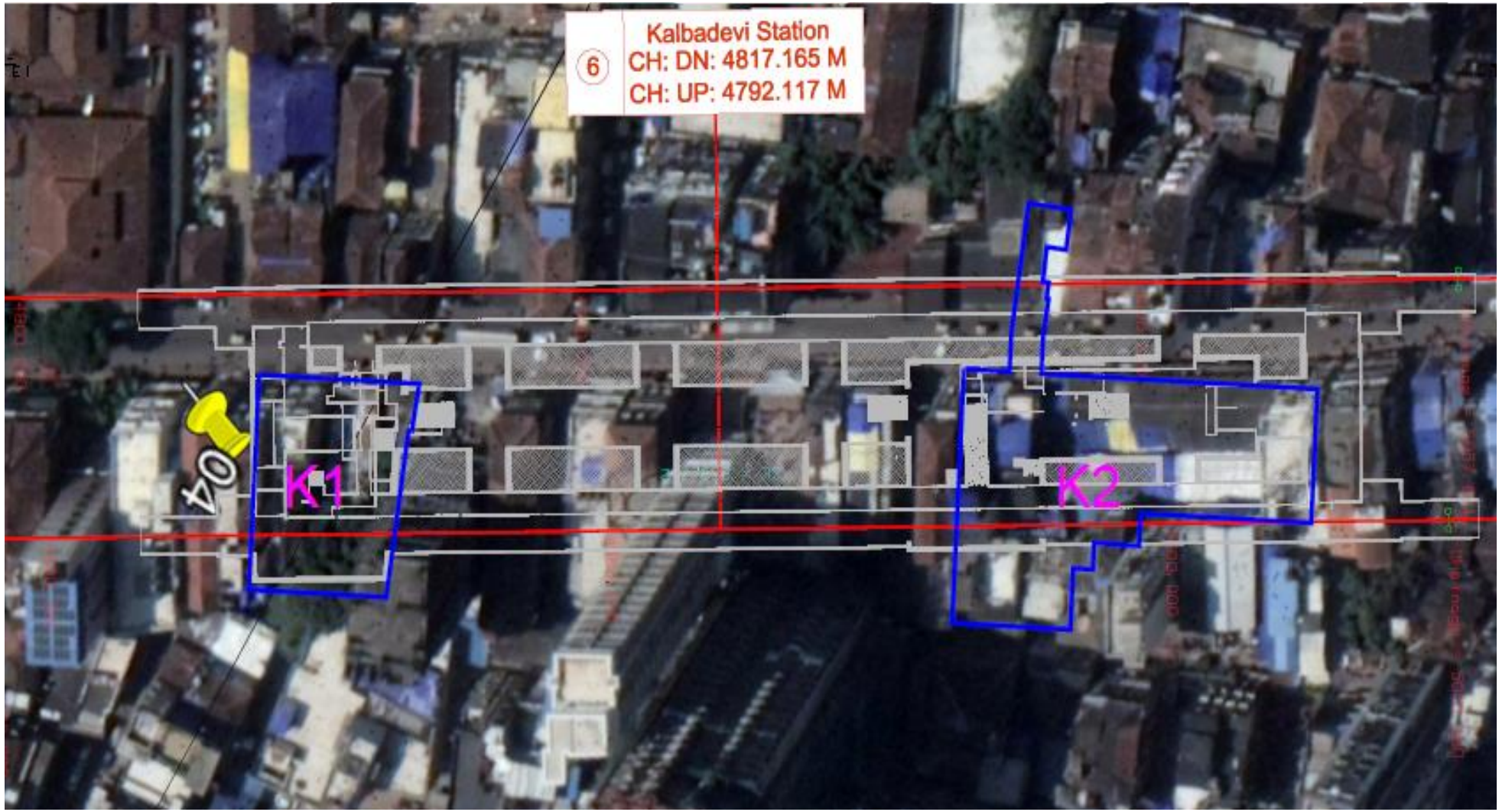
HUTATMA CHOWK STATION – PROXIMITY TO HERITAGE PRECINCT

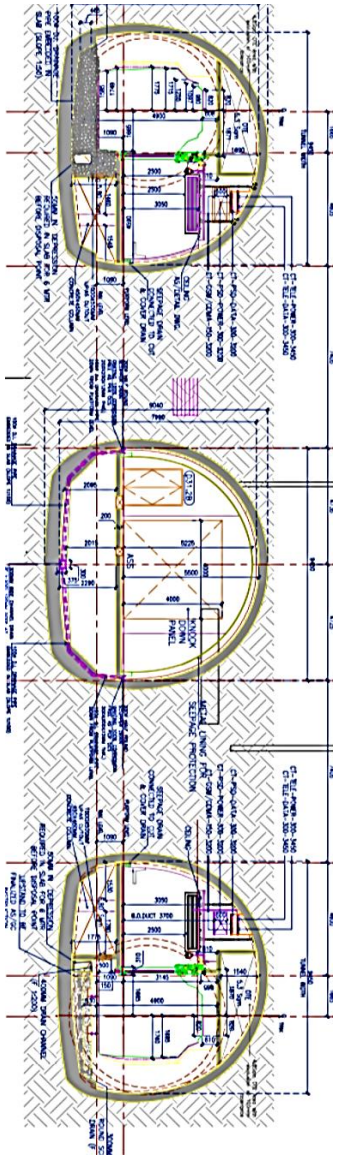
Hutatma Chowk Station



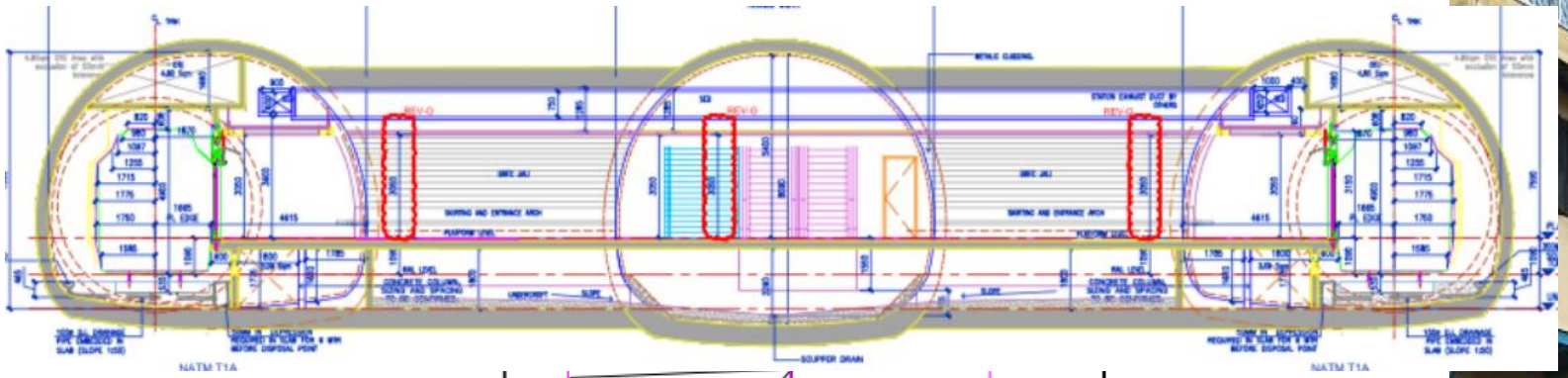
Thousands of micro blasts were carried out below heritage buildings built in stone masonry with no precise foundation details.

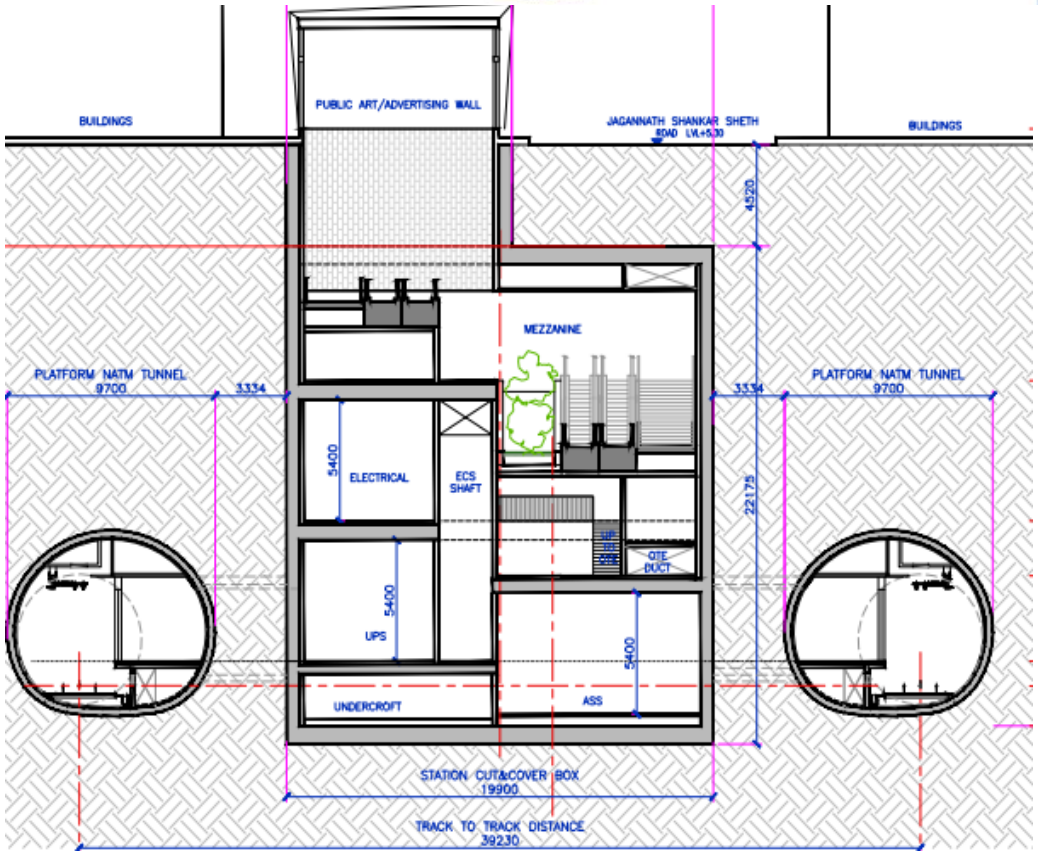
KALBADEVI STATION

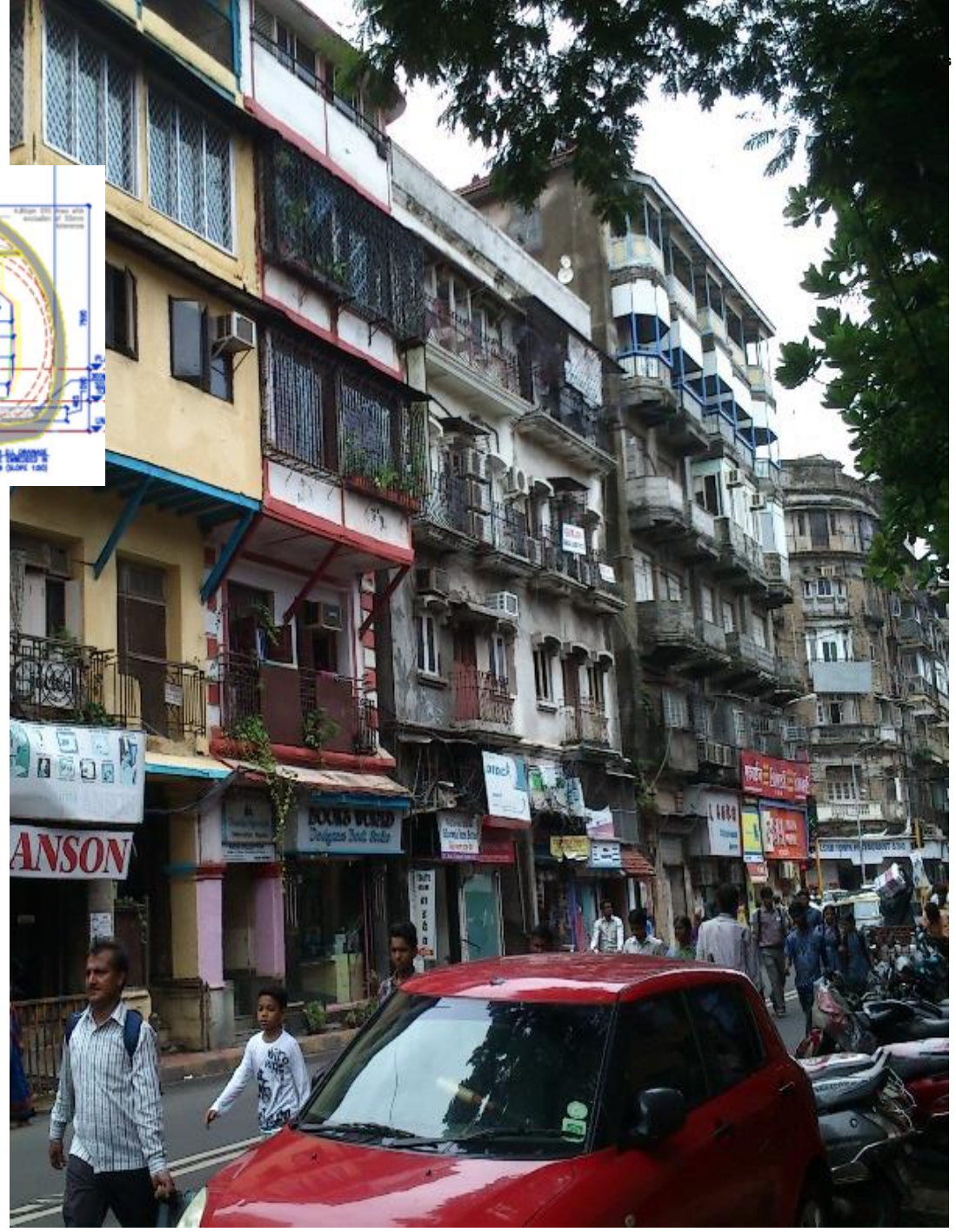




KALBADEVI STATION







KALBADEVI STATION

KALBADEVI – K2 BLOCK

KALBADEVI METRO STATION – OPENING TO CENTRAL CAVERN FROM K2 BLOCK

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KALBADEVI NATM

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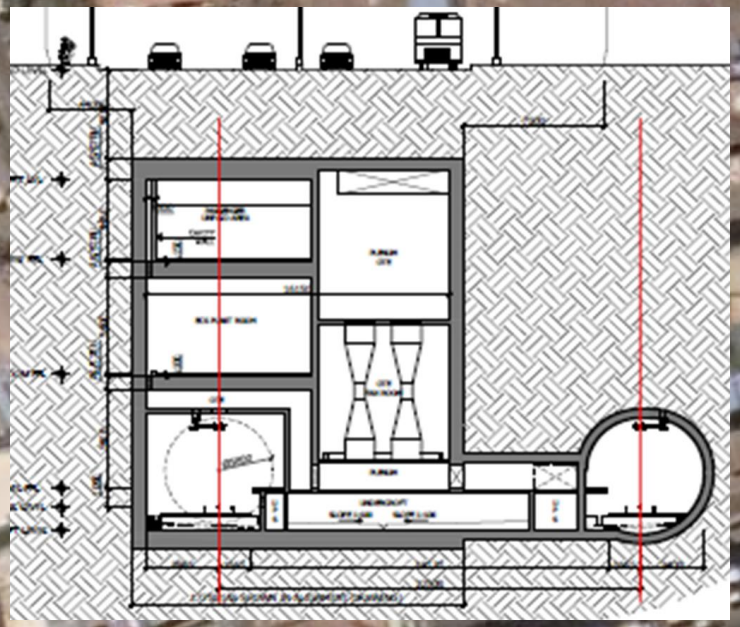
GRANT ROAD STATION



3D

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GRANT ROAD STATION

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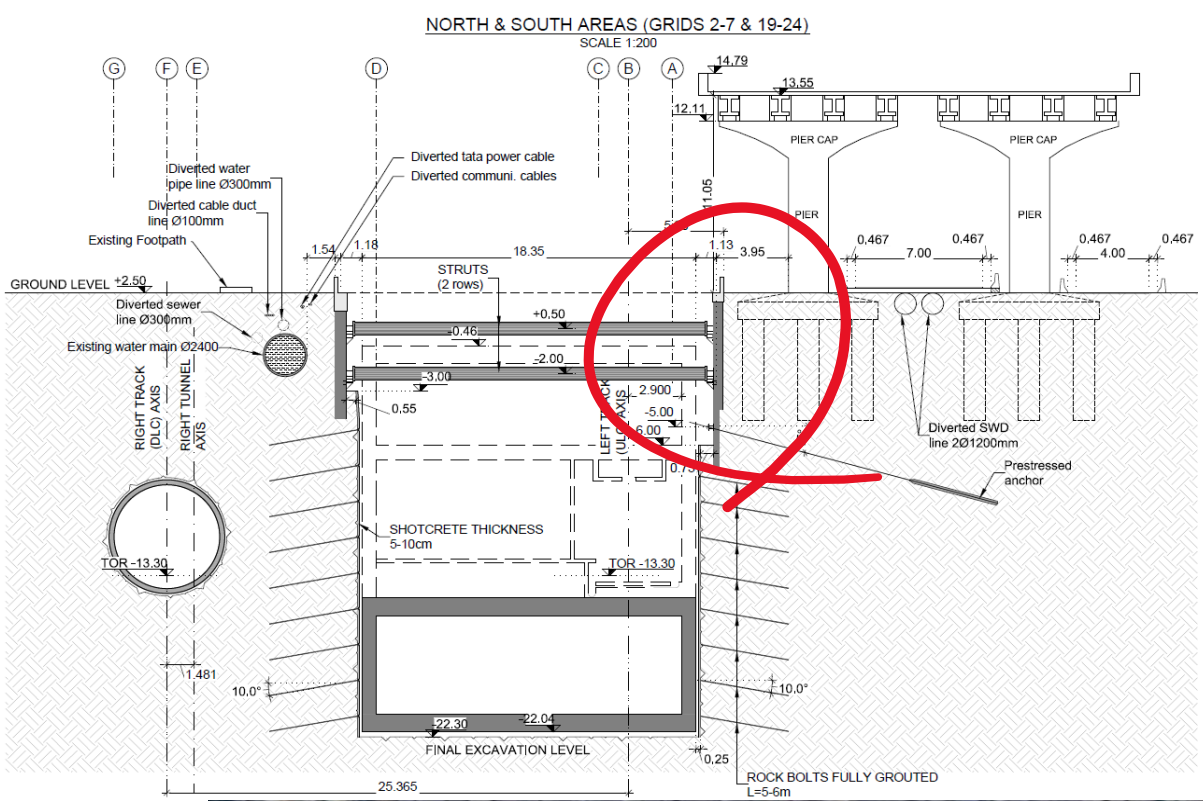
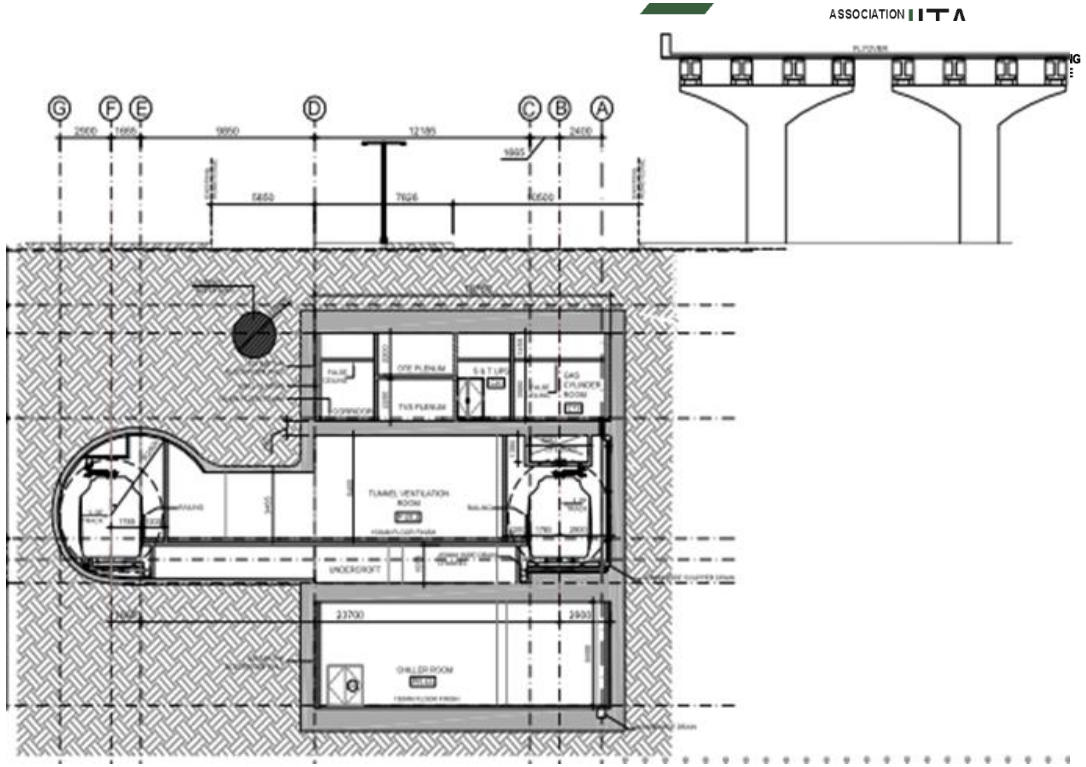
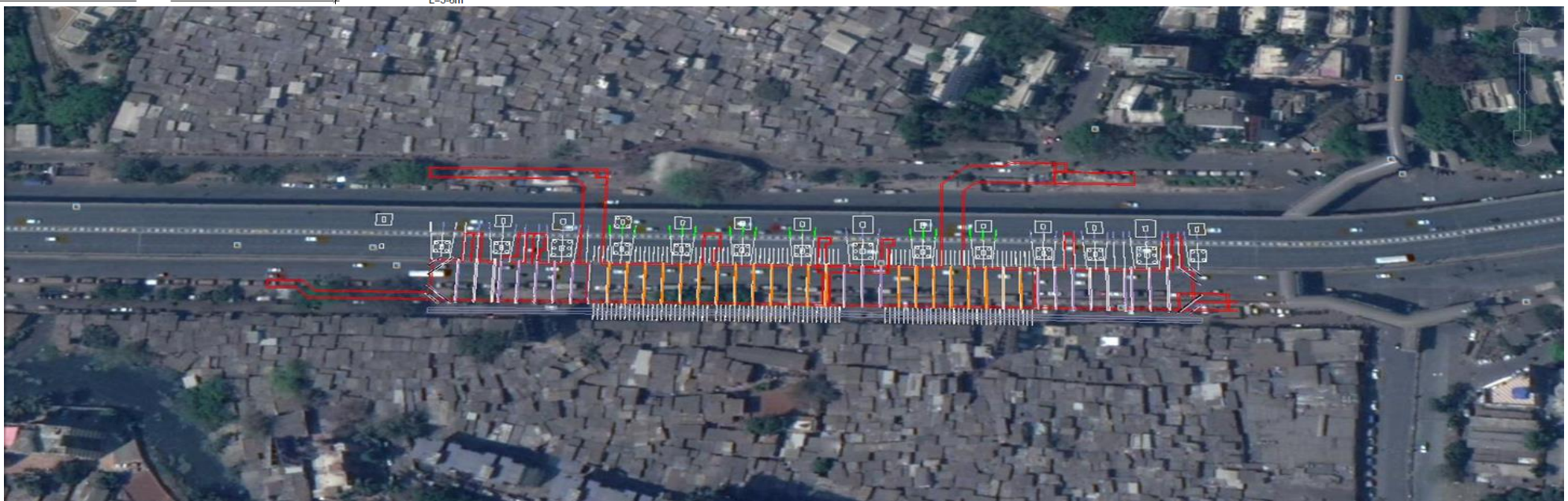
GRANT ROAD NATM

SANTACRUZ STATION NEXT TO WESTERN EXPRESSWAY (VAKOLA) FLYOVER





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SANTACRUZ – NATM PLATFORM WORKS

SANTACRUZ – NATM PLATFORM WORKS

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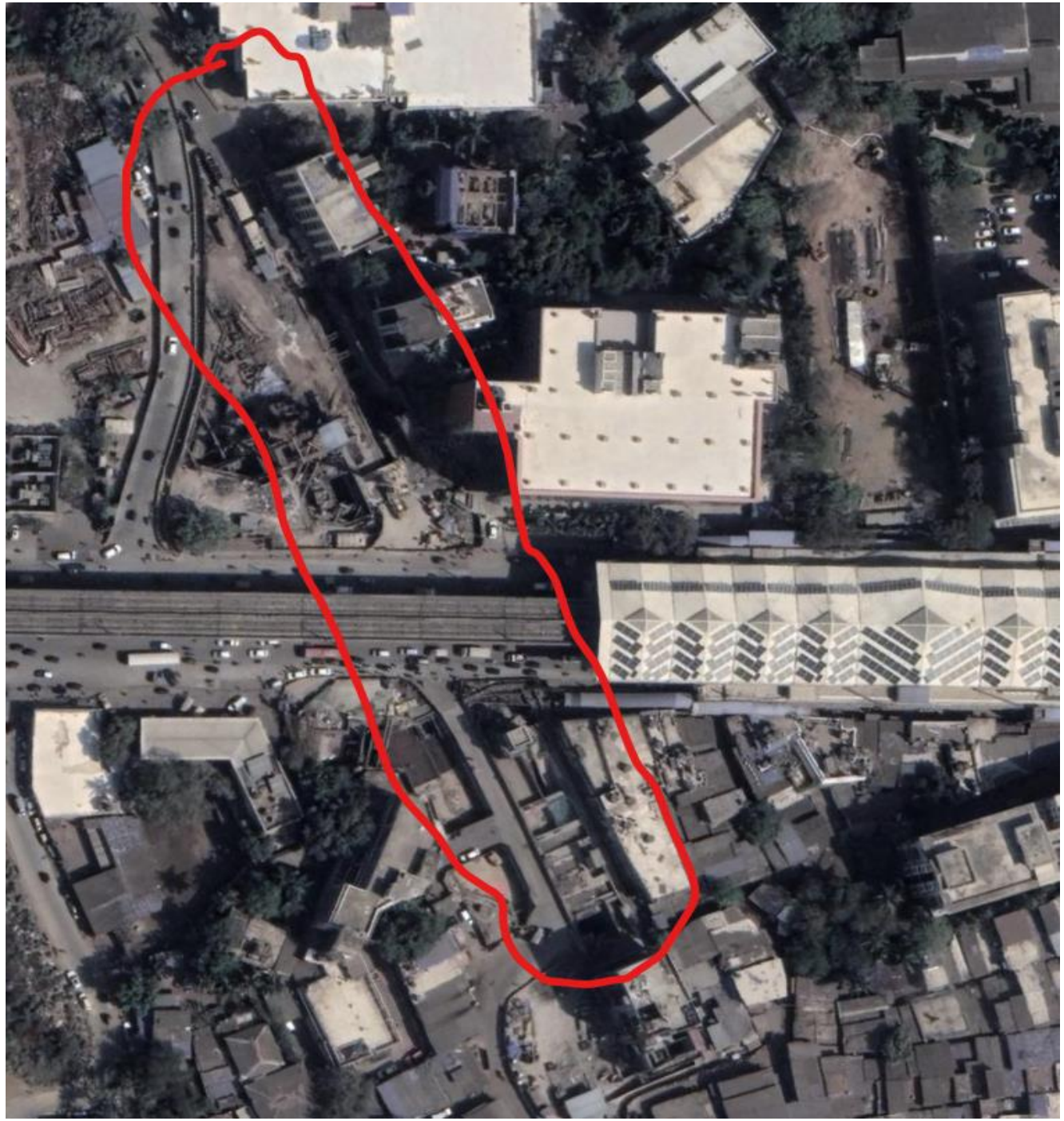
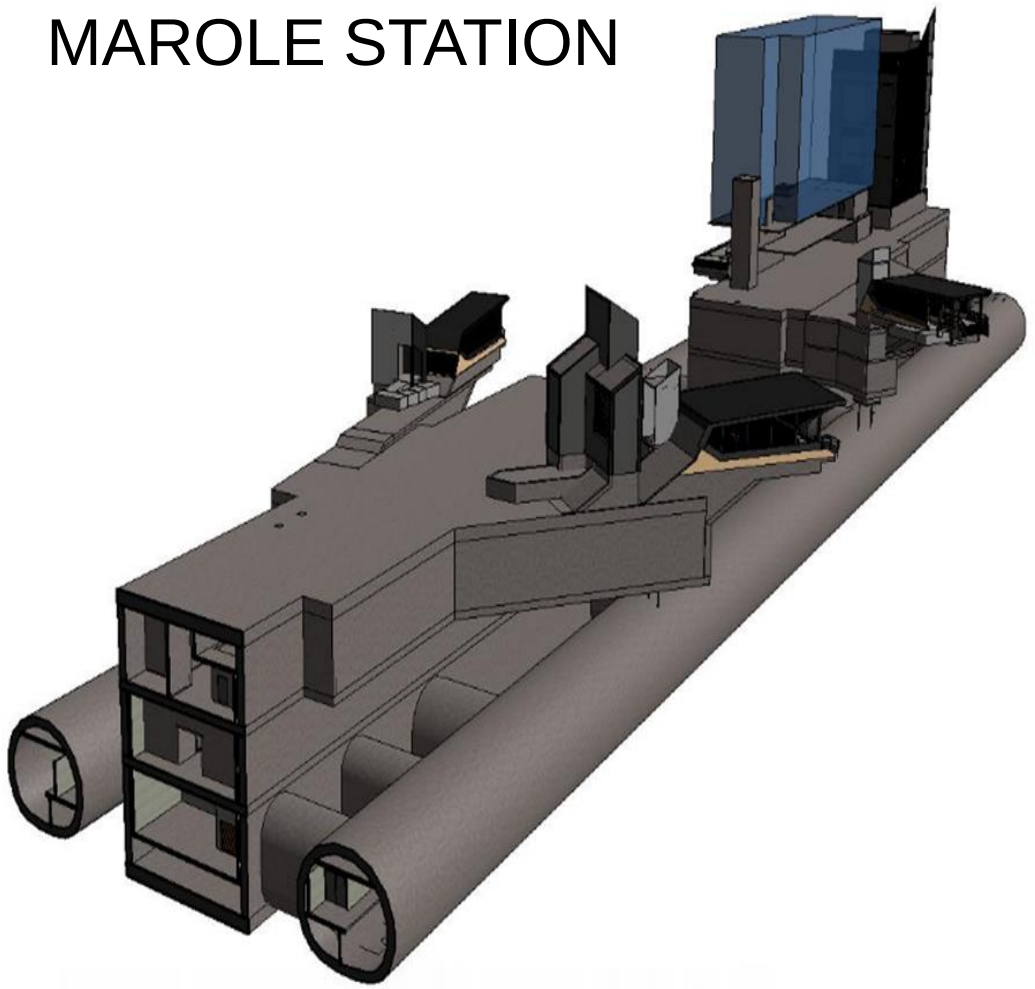
MAROL STATION



MAROLE STATION



Station length interrupted by Line 1, an elevated metro line

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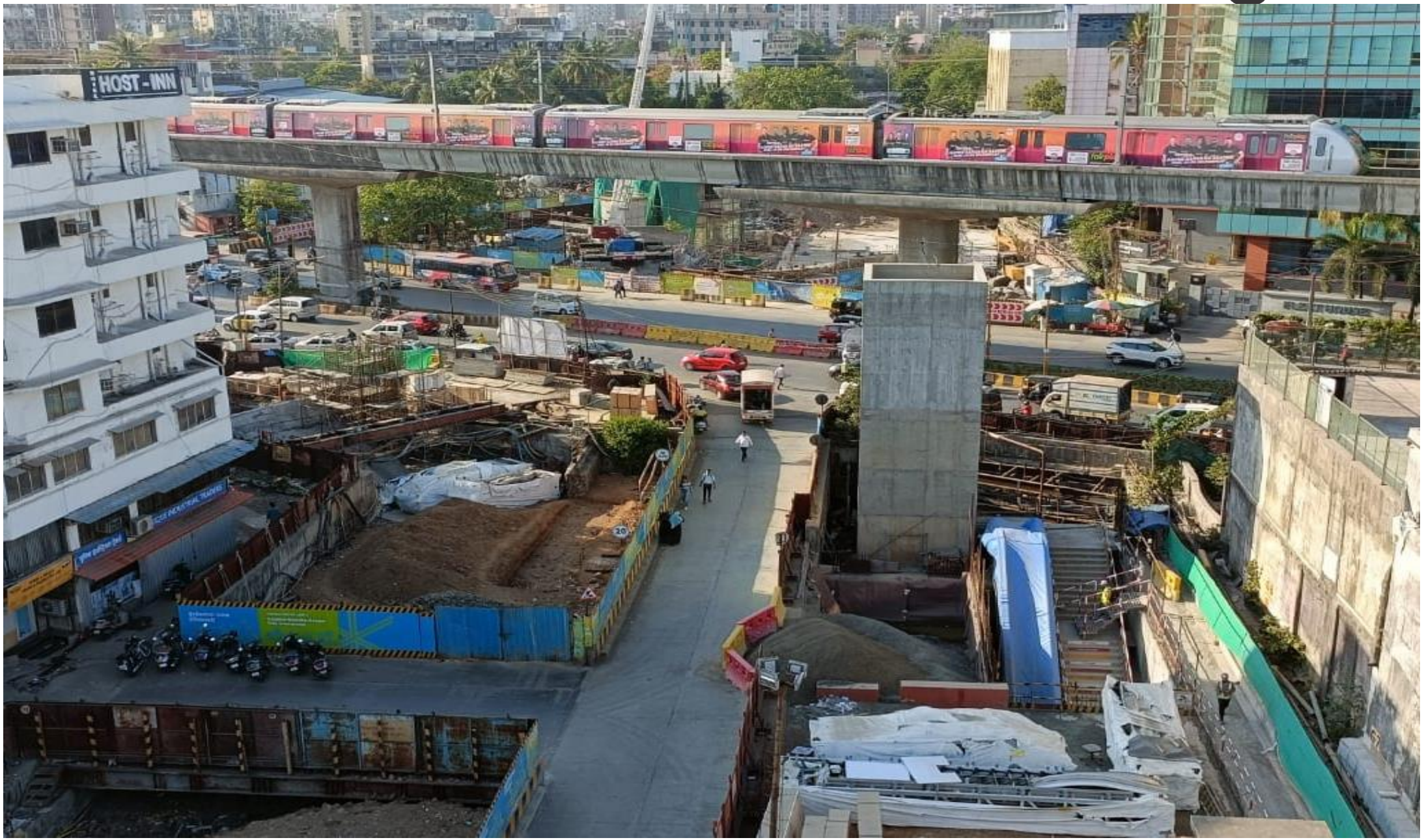
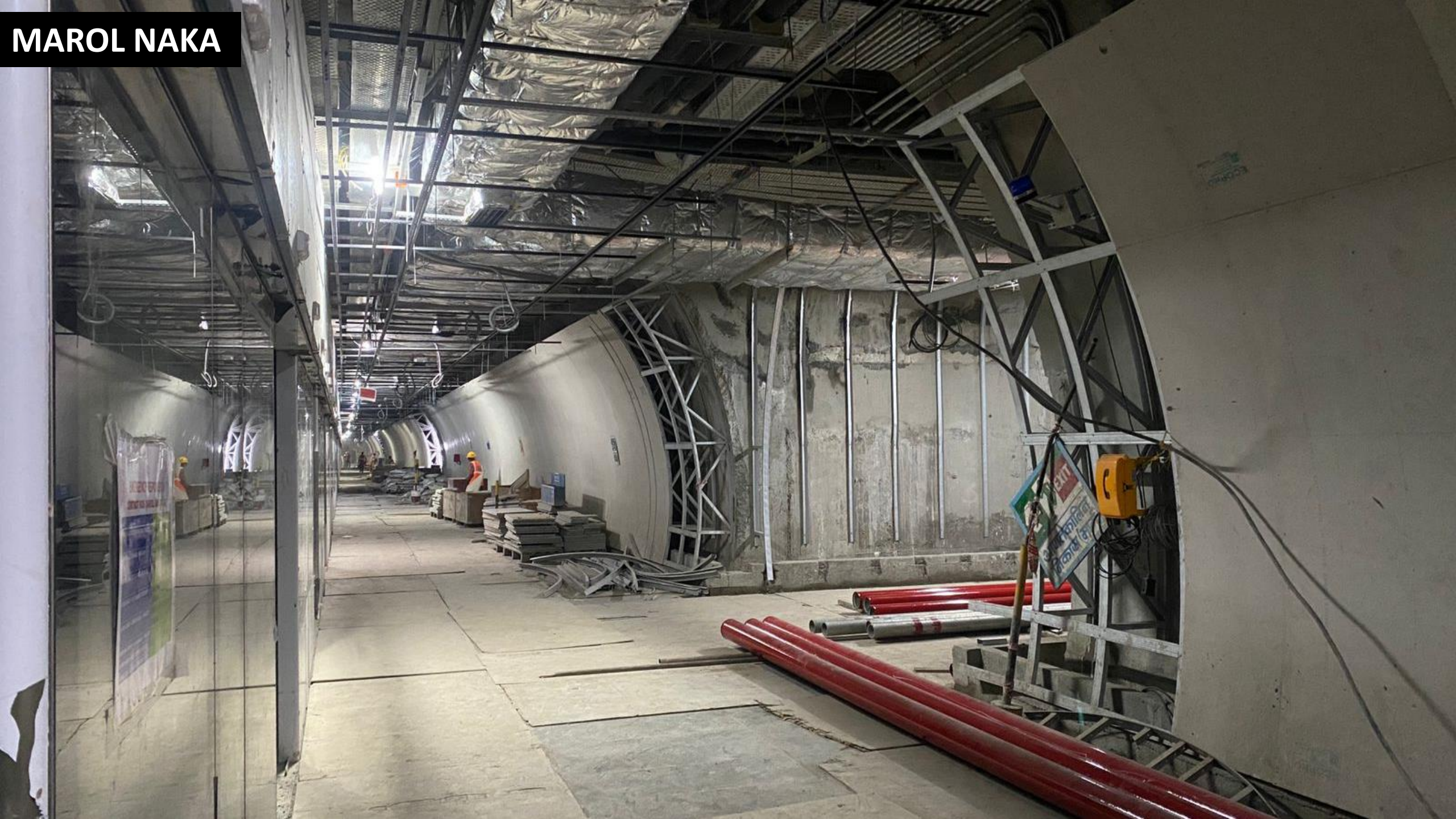
MAROL STATION




Putzmeist
MAROL NAKA NATM


MAROL NAKA
NATM PLATFORM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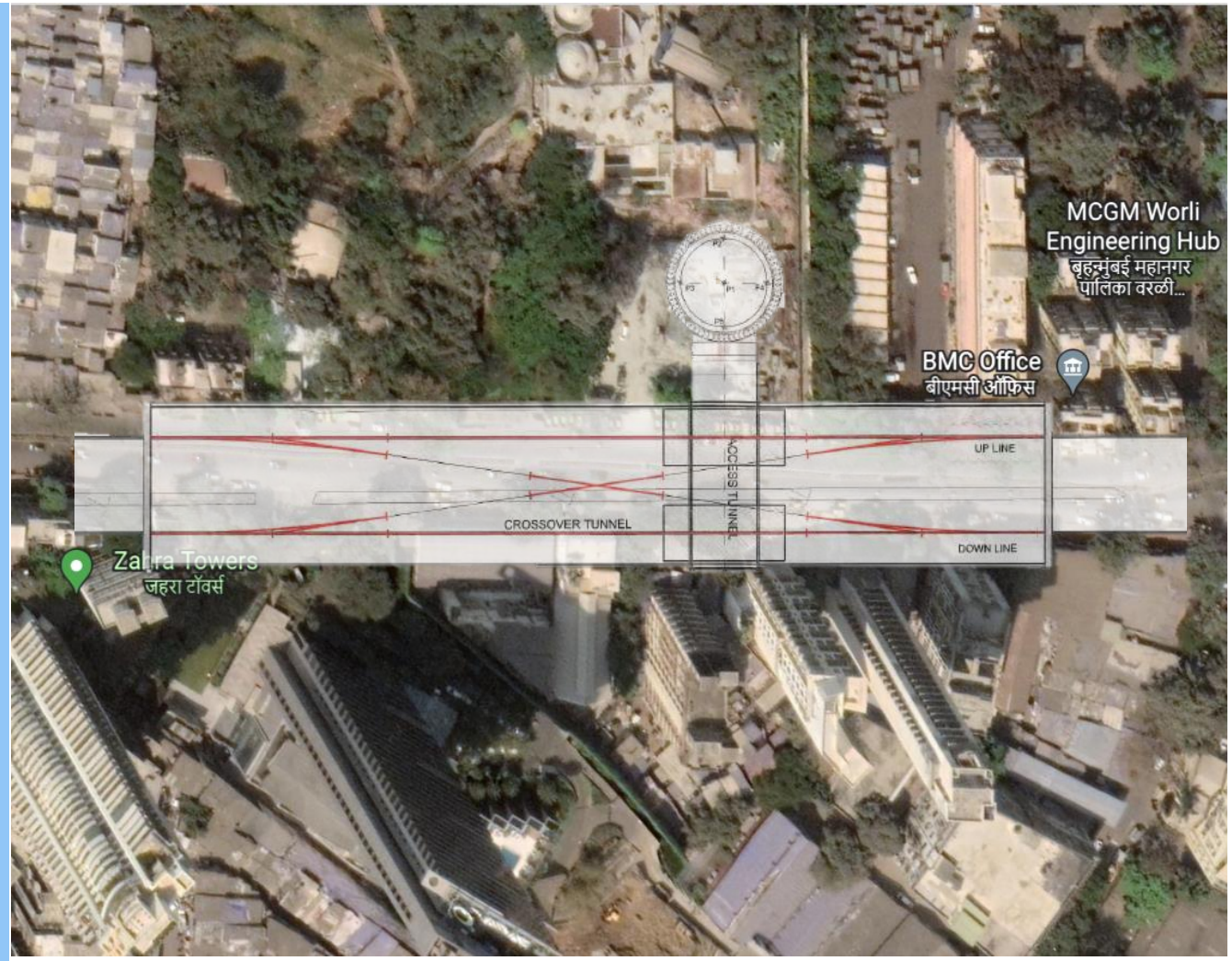
X-Over at Aacharya Atrey



CROSSOVER - ACCESS TUNNEL HEADING

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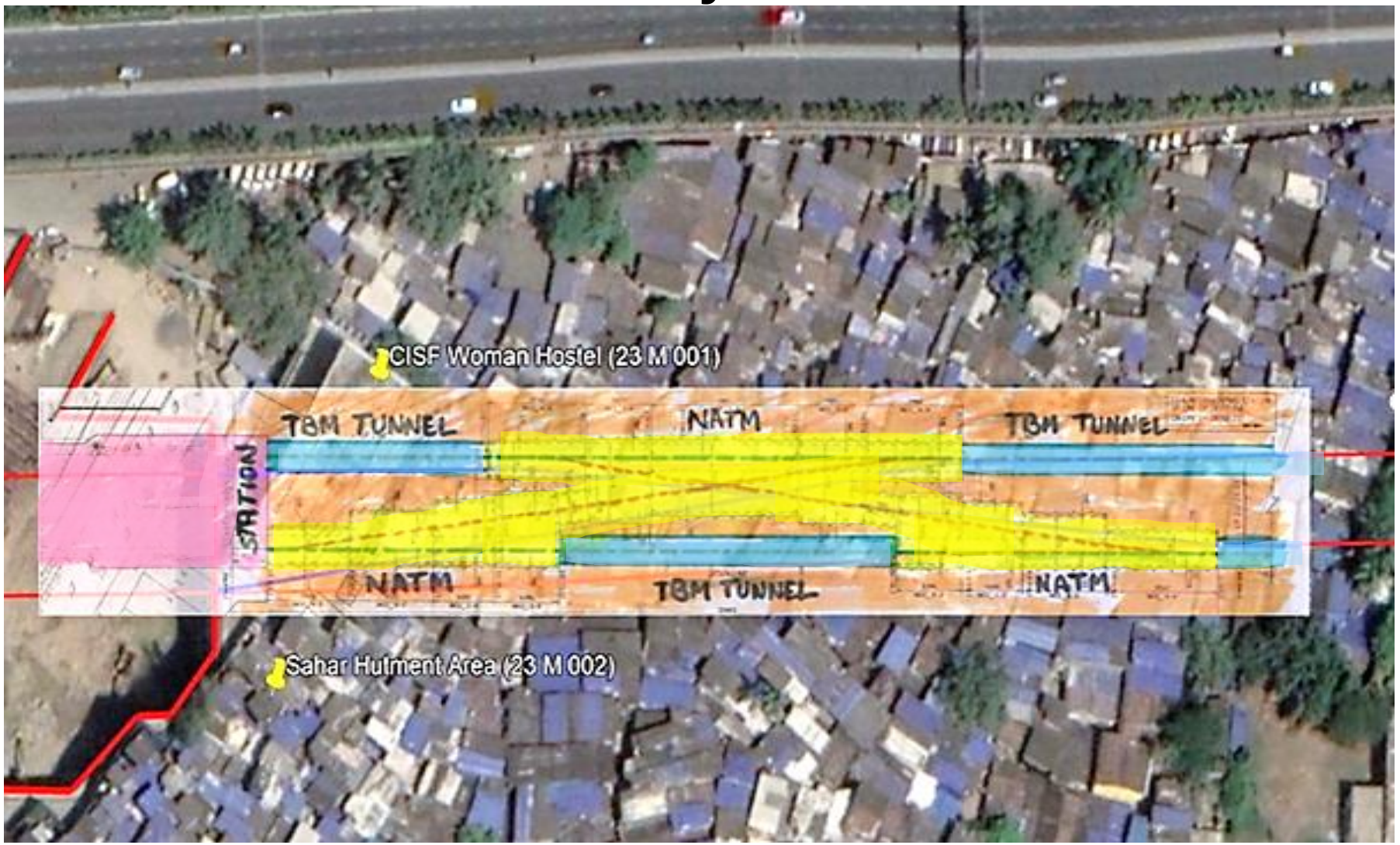
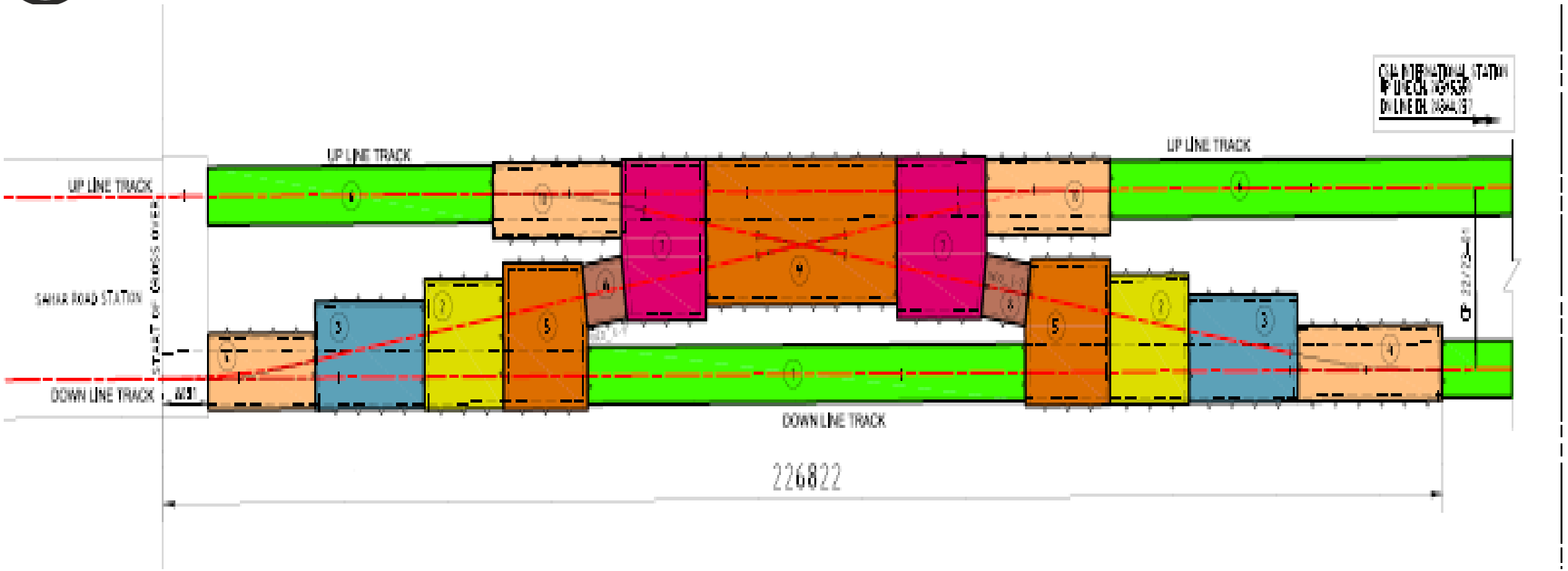
Construction of X-over by NATM below slums



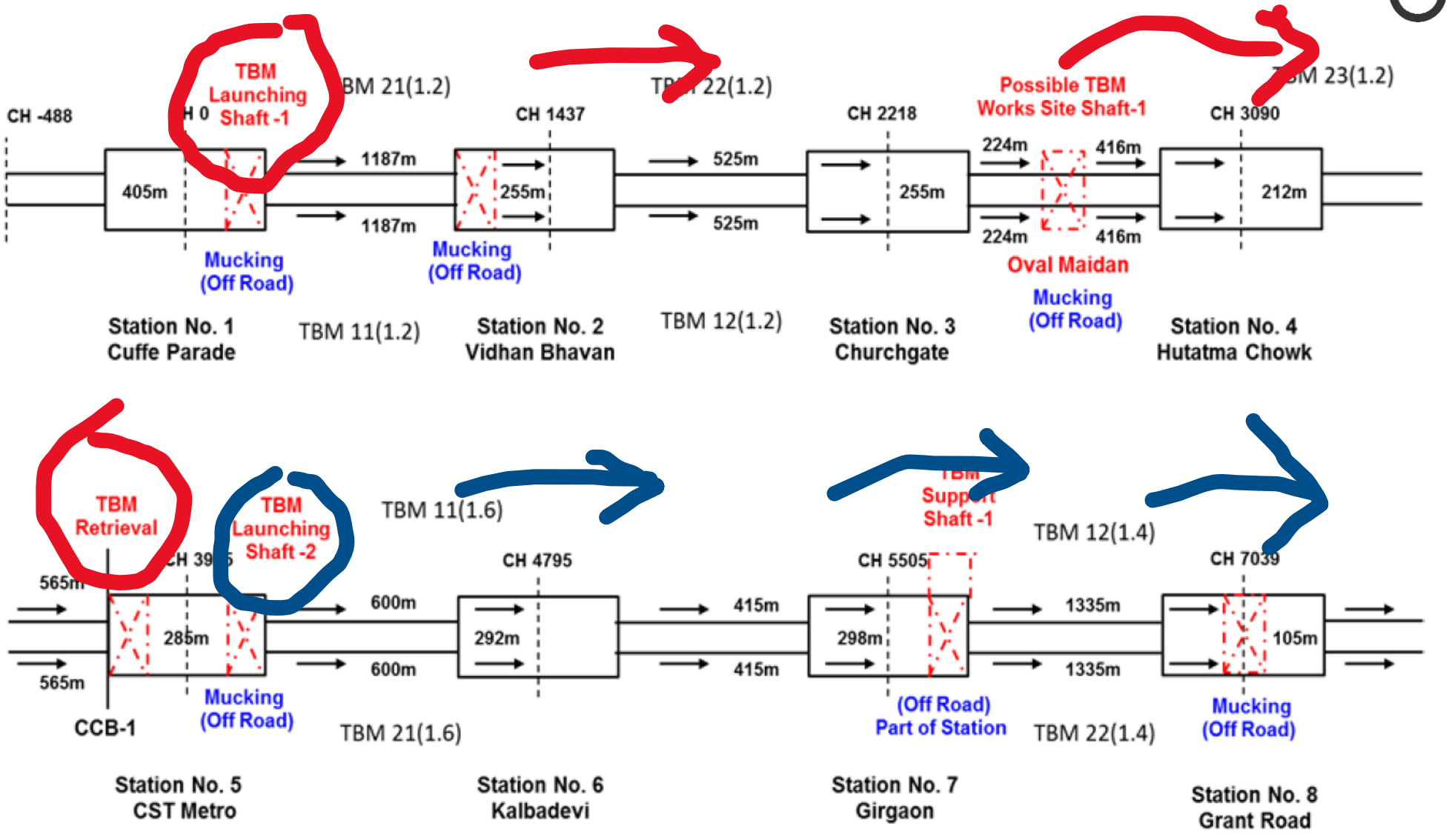
X-Over constructed by first tunnelling by TBM and then locally widening/ joining tunnels by NATM.

X-Over at SAHAR



VARYING PROFILE OF NATM TUNNEL
FIBER REINFORCED SECONDARY LINING TO AVOID SHUTTERING COMPLICATIONS

CROSS OVER AT SAHAR



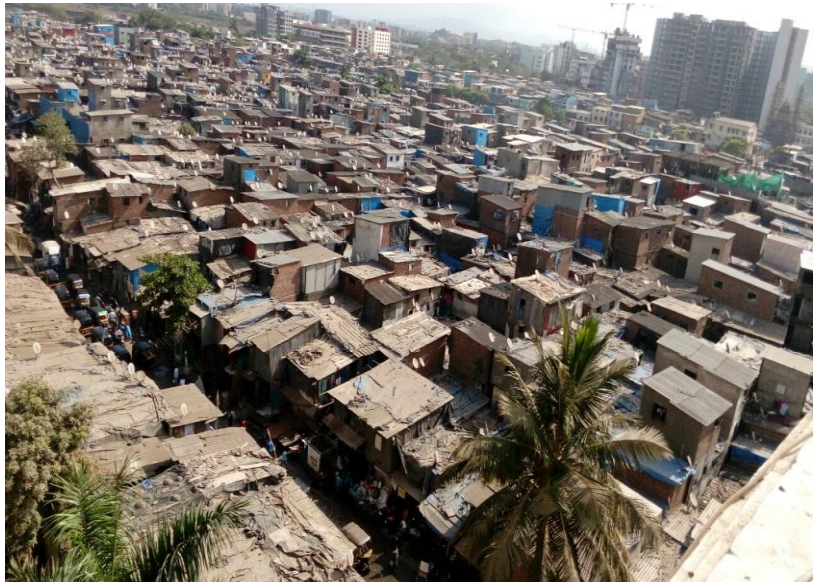
LONG DRIVES OF TBMs

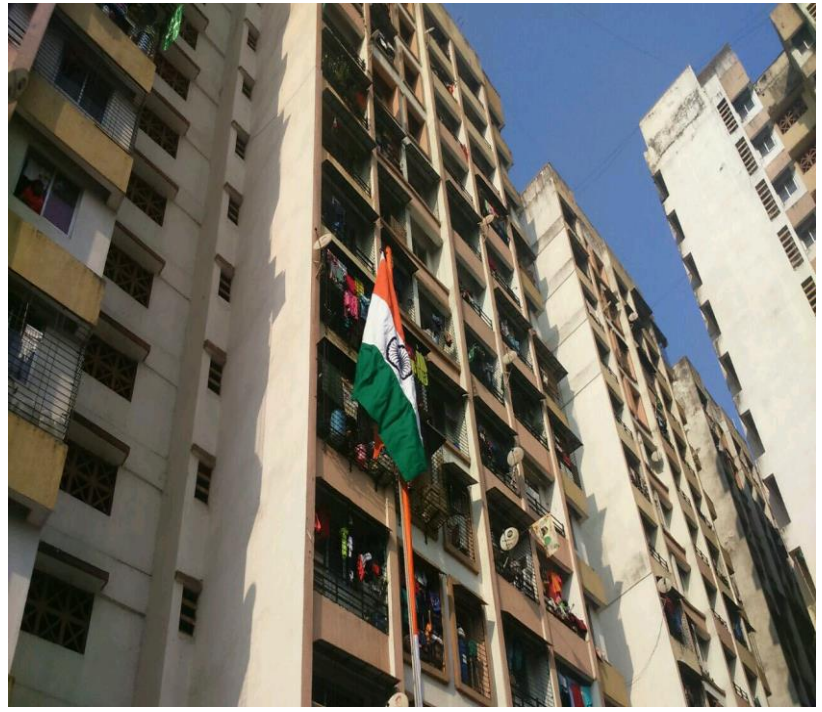
2. Minimum relocation, relocation with human touch

Land Acquisition: Primarily Govt land: 73.14 Ha Govt. Pvt land: 2.56 Ha

Rehabilitation & Resettlement of PAPs: 2125 PAP (Slum) : All rehabilitated in organised housing

733 PAP (protected): Kalbadevi & Girgaon: Temp. rehabilitated. Rent being paid. Permanent in-situ rehabilitation under execution by constructing multistoried buildings





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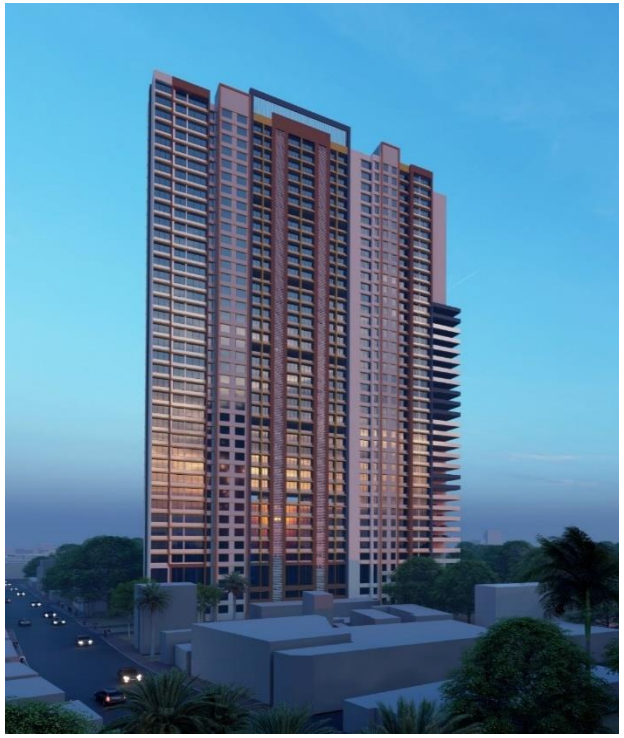
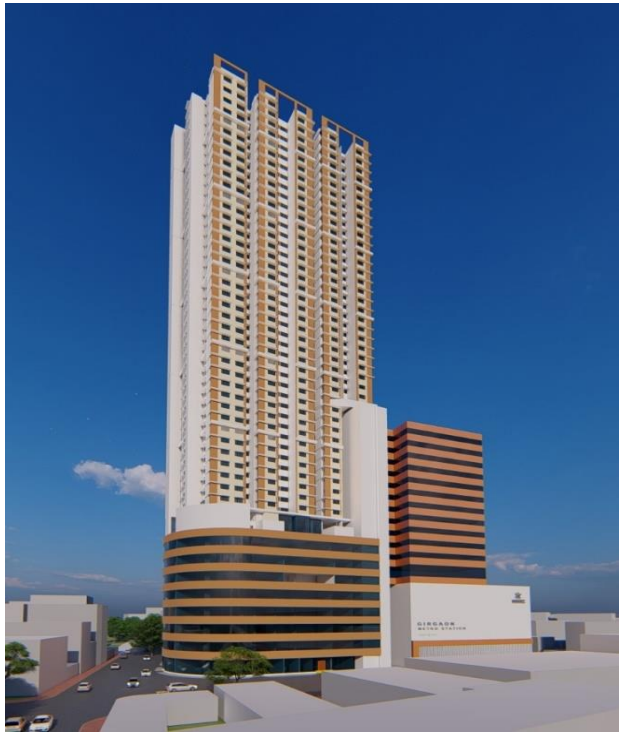
Proposed Carpet Areas for Permanent Alternate Accommodations

Sr. No.	Category	Existing Carpet Area	Proposed Carpet Area of Alternate Accommodation including Fungible Area
1	Category 1	Residential Area upto 18.81sqmt **(upto 202.5 sqft)**	37.63 sqmt **(405 sqft)**
2	Category 2	Residential Area above 18.81sqmt and upto 27.88sqmt (i.e. **Above 202.5 sqft and upto 300 sqft)**	Double the existing area (i.e. **range of 405sqft to 600sqft)**
3	Category 3	Residential Area above 27.88sqmt and upto 41.29sqmt (i.e. **Above 300sqft and upto 444.44sqft)**	**600 sqft irrespective of existing area**
4	Category 4	Residential Area above 41.29sqmt **(above 444.44sqft)**	**Existing area + 35% over and above Existing Area**
5	Category 5	Commercial Existing Carpet Area	**Existing area + 20% over and above Existing Area**

IN-SITU REDEVELOPMENT

733 families to get benefit of in-situ rehabilitation



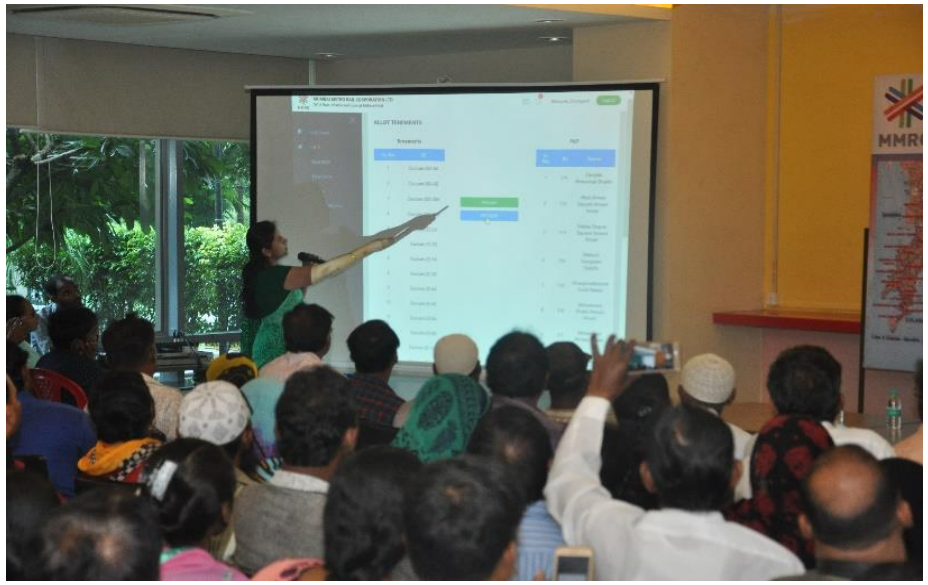


Project Configurations

Blocks	K2 (Kalbadevi Commercial Complex)	K3 (Kalbadevi Heights)	G3 (Girgaon Heights)
Block Area (in sq.mt.)	1,822.3 sq.mt.	1,643.8 sq.mt.	4,613.6 sq.mt.
Metro Building Configuration	G+4 Structure	Ground Structure	G+3 Structure
Redevelopment Building Configuration	• Fully Commercial Building • Basement (Services) • G+2- Fish market • 5th To 10th (Rehab Commercial) • 10th to 16th Floor (Sale Commercial)	• Composite Residential Building • Basement (Services) • G+1 (Commercial & Amenities) • 2nd & 3rd (Services) • 4th To 37th (Residential)	• Composite Residential- Commercial Building • 3 Basements (Parking. & Services) • Ground to7th (Commercial & Part Services) • 8th & 9th (Services & Amenities), • 10th to 48th (Residential) • Ancillary Building (G+4 Metro Structure, next 10 floors commercial)
Redevelopment Building Height	70.0 mts.	119.7 mts.	155.5 mts.

Public Consultation with PAPs

Girgaon & Kabadevi



BKC

Nayanagar

Sahar Road

Traffic Management and civic utilities

- Mumbai has a lesser road area per million population, and a higher population density per Sqkm than any other city in India.
- In absence of alternative roads with spare capacity, daily traffic could have been put to lot of hardship due to construction activities.
- Detailed requirements of traffic decking and traffic marshals were provided in the contracts and implemented
- Massive civic utilities were supported in-situ by installing heavy structural works

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5200 RM of traffic lanes were laid on steel or concrete decking.

Happy to say that the traffic situation never deteriorated at our work sites. This also helped in keeping vehicular pollution levels under control in these areas.

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At locations, working space and traffic diversion were created by concrete decking. Underground work was dealt by small openings left in the decking to reduce construction induced impacts

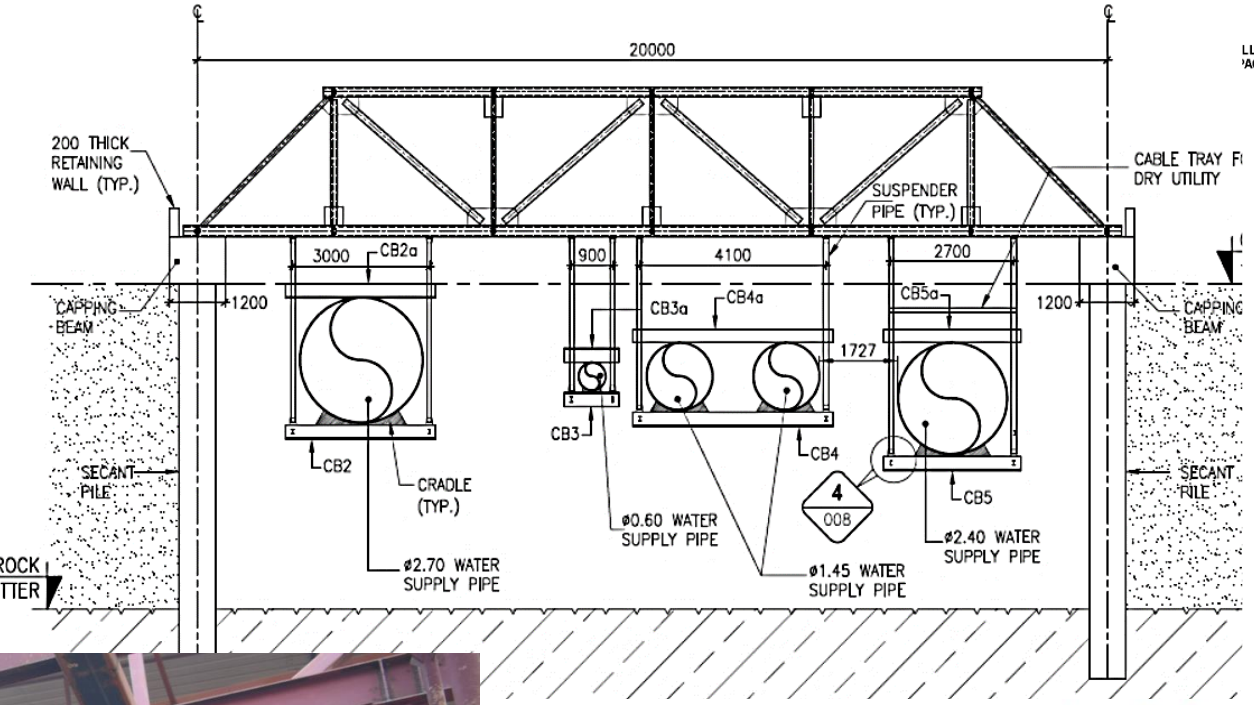
Extent of civic utilities supported in-situ

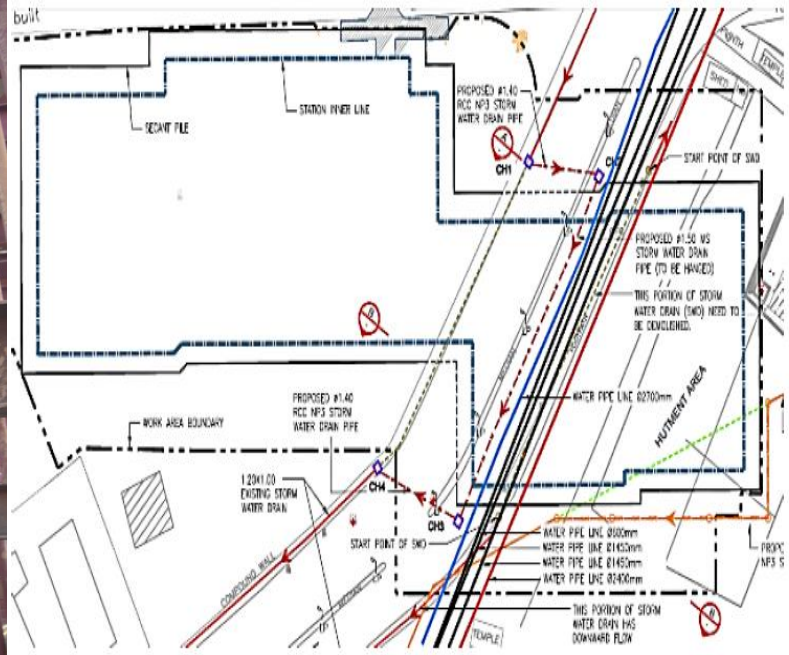
Sr. No	Description	Totalling Kms
1	Water mains > 1m Dia	4.5 km
2	Storm Water & Sewer drains > 1m Dia	3.5 km
3	Electrical Power Cables > 110KV	1.0 km
4	Gas Lines	2.75 km
5	Telecommunication Cables	168.0 km

Some of the larger utilities:

- Water Mains: 2.4 – 2.7m Dia
- Storm Water drains: 2m -3m Dia
- Sewer lines: 2m- 2.4m Dia

SAHAR ROAD STATION : UTILITY SUPPORT BY HANGING- MUMBAI TRUNK WATER PIPELINES





ACHARYA ATREYA CHOWK STATION
UTILITY HANGING INSIDE STATION BOX

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DADAR STATION UTILITY HANGING INSIDE STATION BOX

3. Construction not to unduly affect environment, trees: mitigation measures

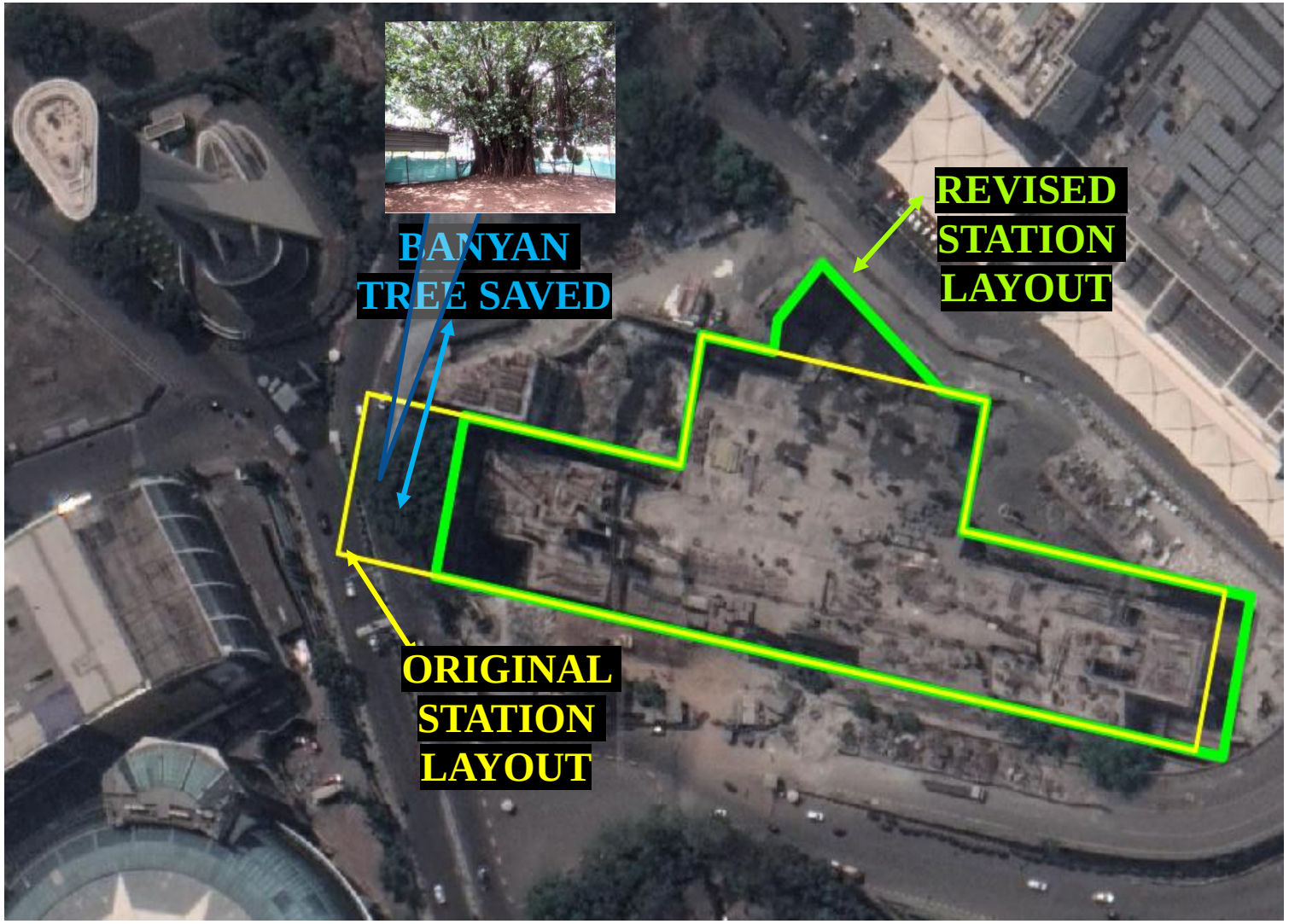
3726 trees have been felled at work sites of stations and about 2265 trees in the Depot.

Actions:

- To **plant 2931 grown-up trees** at respective station sites after completion of works. **Probably a first in India.**
- Planted 22000 saplings in SGNP thru Forest deptt
- Miyawaki plantation in a city park.
- Distributed 25,000 saplings to the residents

We remained conscious during execution to **save any additional trees by changing plans**, if possible.

Saving a Banyan Tree at Domestic Airport station



Top two images:
MIYAWAKI plantation in Goregaon (W), Mumbai

Bottom two images:
Plantation in nurseries

Environmental sustainablity

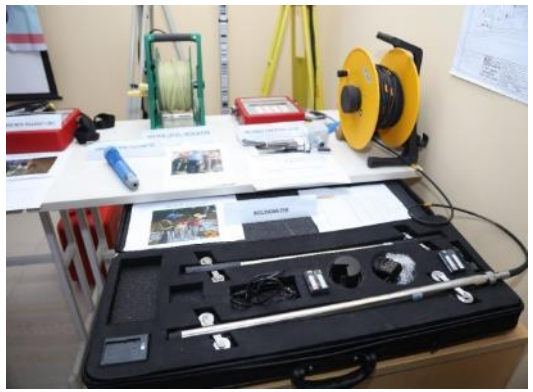
- Line 3 is a registered project under the ‘Clean Development Mechanism’ (CDM) of the ‘United Nations Framework Convention on Climate Change’ (UNFCCC).
- To help reduce 2,61,968 tCO2 (average) every year during a 10-year period of metro operations.
- By an report, metro train operations would out-do the yearly CO2 sequestration by 2702 trees in four days and the lifetime CO2 sequestration in less than three month (80 days). (The study was carried out in reference of 2702 trees being cut at a certain place.)

4. Physical safety of public and their establishments

Sn	Description of item	Total In Nos.
1	**Buildings Investigated**	2416
2	**Heritage Structures**	103
3	**Dilapidated Buildings**	2266
	Very Severe	**48**
	Severe	**436**
	Moderate	**883**
	Very Slight/ Minor	**739**
	Negligible	**160**
4	**Building Supported**	124

Monitoring Instruments

- Building Settlement Marker
- Soil Settlement Marker
- Pavement Settlement Marker
- Crack Meter, Inclinometer
- Rod Extensometer, Piezometers
- Vibrating Wire, Tiltmeter
- Vibration & Noise Monitor/ Seismographer
- Total Stations & Targets, Load Cell & Strain Gauge
- Shotcrete Creep Test Equipment
- Water Stand Pipe
- For heritage and weak buildings 24X7 Online monitoring was undertaken.



5. Technology upgrade for noise and vibration mitigation during operations - **Use of High Vibration Attenuation track structure**

For the first time in India High Vibration Attenuation track structure has been used. This track structure would mitigate 20-22VdB more vibrations than a direct fixation track. This would comply with the stringent requirements set by RDSO and the residents would have no nuisance of trains running beneath them.

6. **Resilient infrastructure - natural calamities such as earthquakes or climate change related aspects- flooding during heavy rains**

- Line 3 designed for earthquake Zone 3 as per IS 1893 for Mumbai
- Openings into stations, be it Entry/Exits, Lifts or vent shafts, all are above the HFL of the area with a margin for a 0.5 m rise in the sea level. All openings generally not less than 1.2 m above ground thus no possibility of ingress of flood water. Removable Flood Barriers to be the second level of defence.
- In the event of flooding of surroundings of one or two stations in the vulnerable areas even then the system will continue to operate keeping such stations closed.
- There are multiple feeding points for the electricity. So even if one or two feeders fail the system can continue to operate.

On resilience front it can be said that the **City is as resilient as it's weakest link.**

Line 3 would continue to operate during any climate change related event, so far as there is electricity in the grid.

Line -3, because of its planning and design features, will prevent any impact of climate change on the public mobility during such an event.

Sustainable System Infrastructure

- LED type intelligent lighting system in station, trains and other installations, optimal lux control in non-peak hours
- About 30% of regeneration of energy in train operations.
- Inverter Air Conditioning System in coaches.
- Full height Platform Screen Doors, estimated 35% reduction in Energy consumed in ECS.
- Variable Speed Drive in Environmental Control System(ECS) and Tunnel Ventilation System(TVF)
- Variable Voltage Variable Frequency drives in Lift and Escalator.
- Use of sensors to reduce the speed and stopping of escalators during no load condition.

Progress Updates

Overall Project Progress- 86.2 %	
➢ Overall Civil works 96.2 % completed ➢ Overall Station construction – 93.1 %	➢ Overall Systems works 62.5 % completed ➢ Depot works – 82.9 %
➢ Tunnelling 100 % completed	➢ Mainline Track works 70.7 % completed

Phase -I (Aarey to BKC) Progress- 92.7 %	Phase -II (BKC to Cuffe Parade) Progress- 80.3 %
➢ Station and Tunnel works 98.7 % completed ➢ Overall Station construction – 96.1 %	➢ Station and Tunnel works 96.6 % completed ➢ Overall Station construction – 91.6 %
➢ Overall Systems works 77.3 % completed	➢ Overall Systems works 49.6 % completed
➢ Mainline Track works 100 % completed	➢ Mainline Track works 54.0 % completed
➢ OCS works 73.7 % completed	➢ OCS works 47.9 % completed

Tunnelling Asia' 2023

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Thanks for your kind attention.

Safe Tunnelling

'Of course I have a car. But I don't have a road to drive it on!'

R.K. Laxman in
'The Times of India'