PROCEEDINGS
MONORAILEX 2021

Milan, Italy
September 24 - 28, 2021

INTERNATIONAL MONORAIL ASSOCIATION

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MAURER

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Monorailex 2021

Carlos' Farewell Speech

Buongiorno!!

For those that do not know me yet, my name is Carlos Banchik, now immediate past-president of the Association.

For those that know me, they know I'm hyper committed, passionate and intense about things. In 2010 working in the São Paulo Expresso Tiradentes Monorail, Line 15 in São Paulo, the idea of helping hundreds of thousands of people a day with effective and reliable transportation seemed at the time an enticing challenge, and one where I could contribute my efforts, seeking to provide life with what the American psychologist Maslow described as Purpose and Meaning. I attended my first meeting in Las Vegas in 2011, and decided to join the Association. By 2012, I became its President. It has been an interesting journey in personal, and professional terms, and I'm grateful for the opportunity.

As humans we have many things in common that we have been evolving for tens of thousands of years. Studies show that the typical human being can sustain relationships with about 150 individuals. So how to create an organization engaged in the promotion of monorails at the time when there were few hundreds of people advocating for it without a unifying voice, and no serious planner would consider one for a client?. How to help the idea reach its true potential? How to create a movement?

The idea that appealed to me was one that came through a great American marketeer and thinker, Seth Godin. In a TED talk in 2009 he reasoned that the Internet ended mass marketing and revived a human social unit from the past: tribes. Tribes connecting people and ideas. A tribe then can now spread our discontent with the status quo and become a unifying force to effect change in the world. Find something worth changing, like the non-acceptance of monorail as a choice for mass transportation and start working changing the world as we know it.

Humbly we have helped since IMA came into existence to deliver on that formula. The results are starting to be seeing in plain view with very long projects in China, Bangkok, Cairo, Panamá, among a few of them. The thought of providing efficient, effective, fast to construct, mass transit solutions for hundreds of thousands of people through monorails is gaining traction.

Are we done? Not by a long stretch. We need to improve the quality of the civil components of the technology, helping it reach increasingly tighter tolerances for structural members to deliver mechanical level accuracy, tackling what is really needed in terms of safety and evacuation, what constitute acceptable means of egress during evacuations, how to make the operation greener with improved tires and mechanical reliability of rolling stock, higher train speeds for long haul monorails. The list goes on and on, however the satisfaction of seeing people improve the quality of their lives through societal effective use of resources is worth belonging to this tribe.

For all of you that are new to IMA and attending a Monorailex event for the first time, welcome to the tribe. This is a place where the exchange of ideas in the next few days will most likely blow your mind, learning from geotechnical engineering, to rolling stock items, to construction observation. You will be hearing the state-of-the-art in the technology by those having active participation in the market. It is our desire that participating at the event makes you decide to be an active participant on this tribe!

Lastly, special thanks to my wife Adriana, Rob Naples and Rosie Lee at Innova for their support all this time and seeing the vision to help shape an industry. And to those that trusted us to be stewards of the association. The list includes Jaap Ketel, Peter and Christina Keller, Peter Witwer, Prof. Eryu Zhu, Peter Timan, Roger Dirksmeier, Marko Kroenke, Tarun Goyal, Matt Hofford, AK. Das, and many others. More recently, thanks to Maxim and Ilga on this endeavor.

I know the Association is in good hands. As our good old friend Kim Pedersen used to say, Upwards and Onwards!

Carlos Banchik

Immediate Past-President

Keynote Speech

Carlo Bianco, Director Safety Metro Systems, Azienda Trasporti Milanesi

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The Benefits of Full Metro Automation

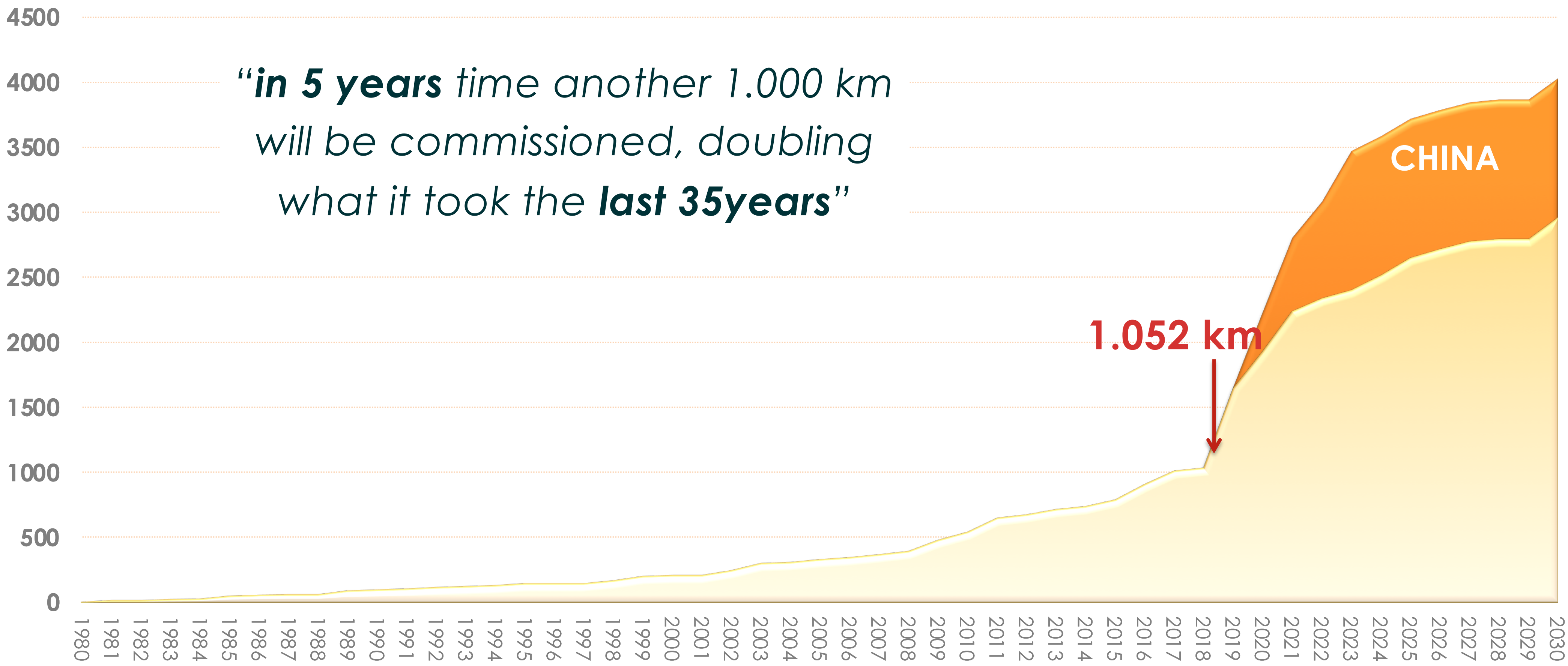
Carlo Bianco
Director of Driverless Metro Operations ATM Milano
Chairman of UITP's Observatory of Automated Metros

MONORAILEX 2021
Milan, Italy
24 September – 28 September 2021

CONTENT

Exponential Growth of Metro Automation

METRO AUTOMATION TOMORROW: EXPONENTIAL GROWTH



CONVERSIONS SPREADING

Nürnberg

U2: 13,5 km

Paris

L1: 16,4 km
L4: 12,1 km

Wien

U2: 9 km

Lyon

LB: 13,5 km

Glasgow

S: 10,5 km

Marseille

M1: 10,5 km
M2; 9,2 km

London

DLR: 38 km

Brussels

L1: 12,7 km
L5: 17,6 km

GETTING THE MOST FROM AUTOMATION

Being automation a clear trend in metro,

how we can unleash its full potential?

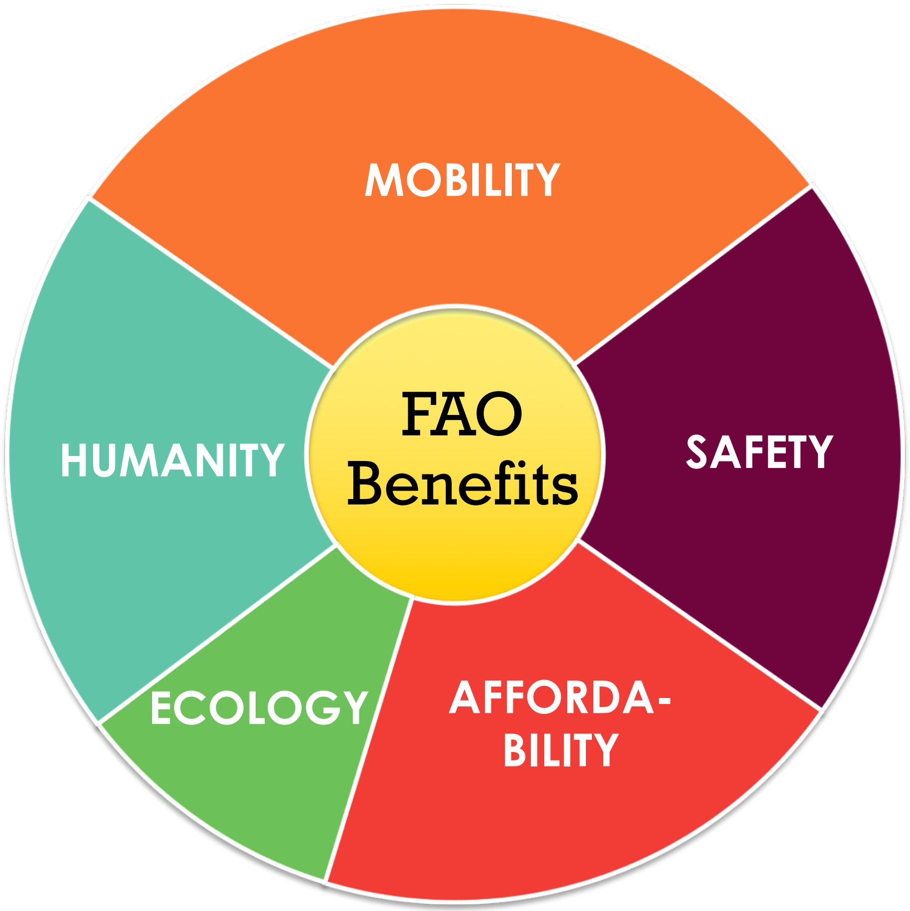
Benefits of Full Metro Automation

“Drivers” of Automation

BENEFITS OF FULL METRO AUTOMATION

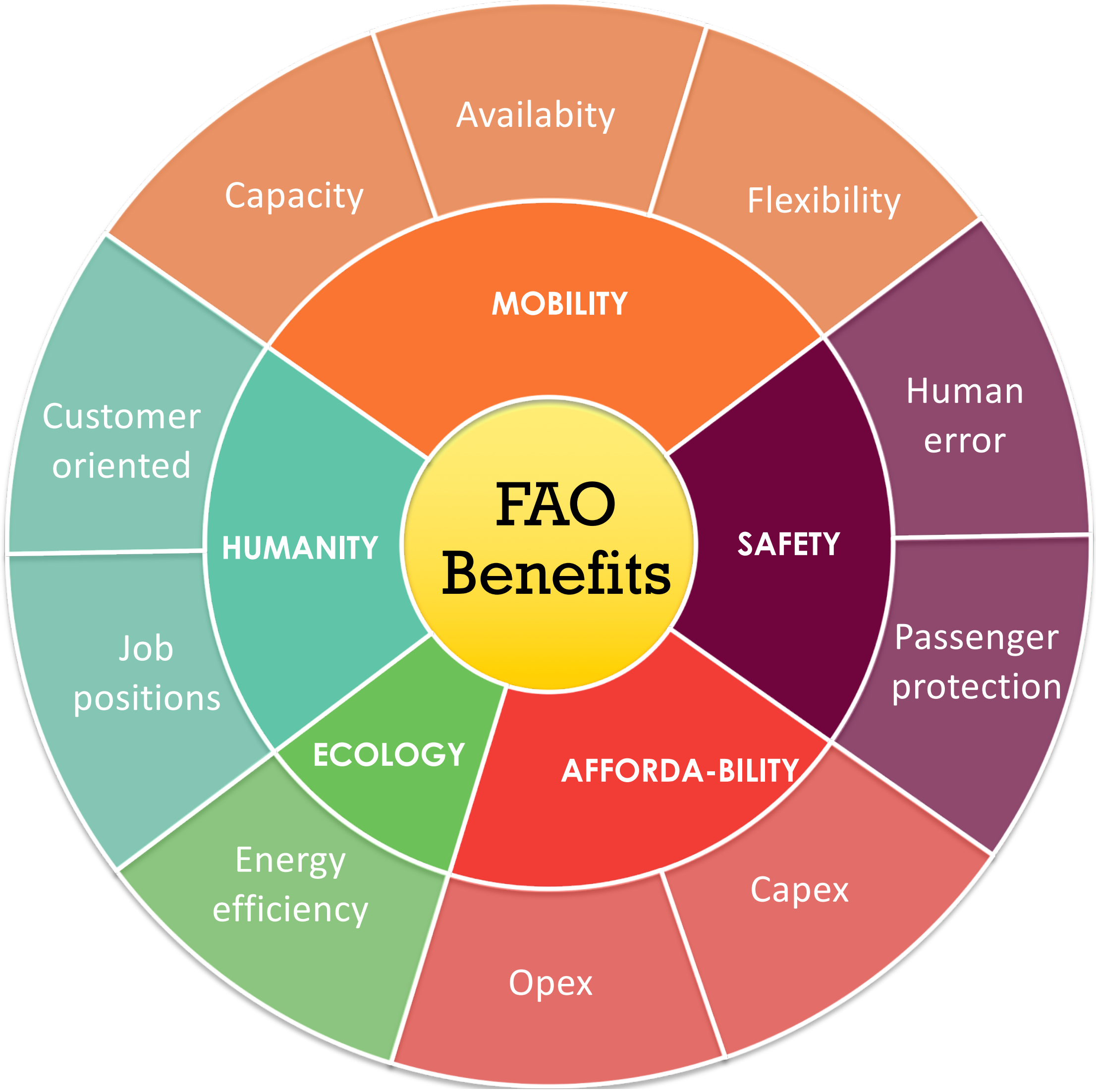
These 5 dimensions are key to any Public Transport System Design

BENEFITS OF FULL METRO AUTOMATION



Fully Automated Operation greatly contributes to the fulfillment of these benefits

BENEFITS OF FULL METRO AUTOMATION



Mobility

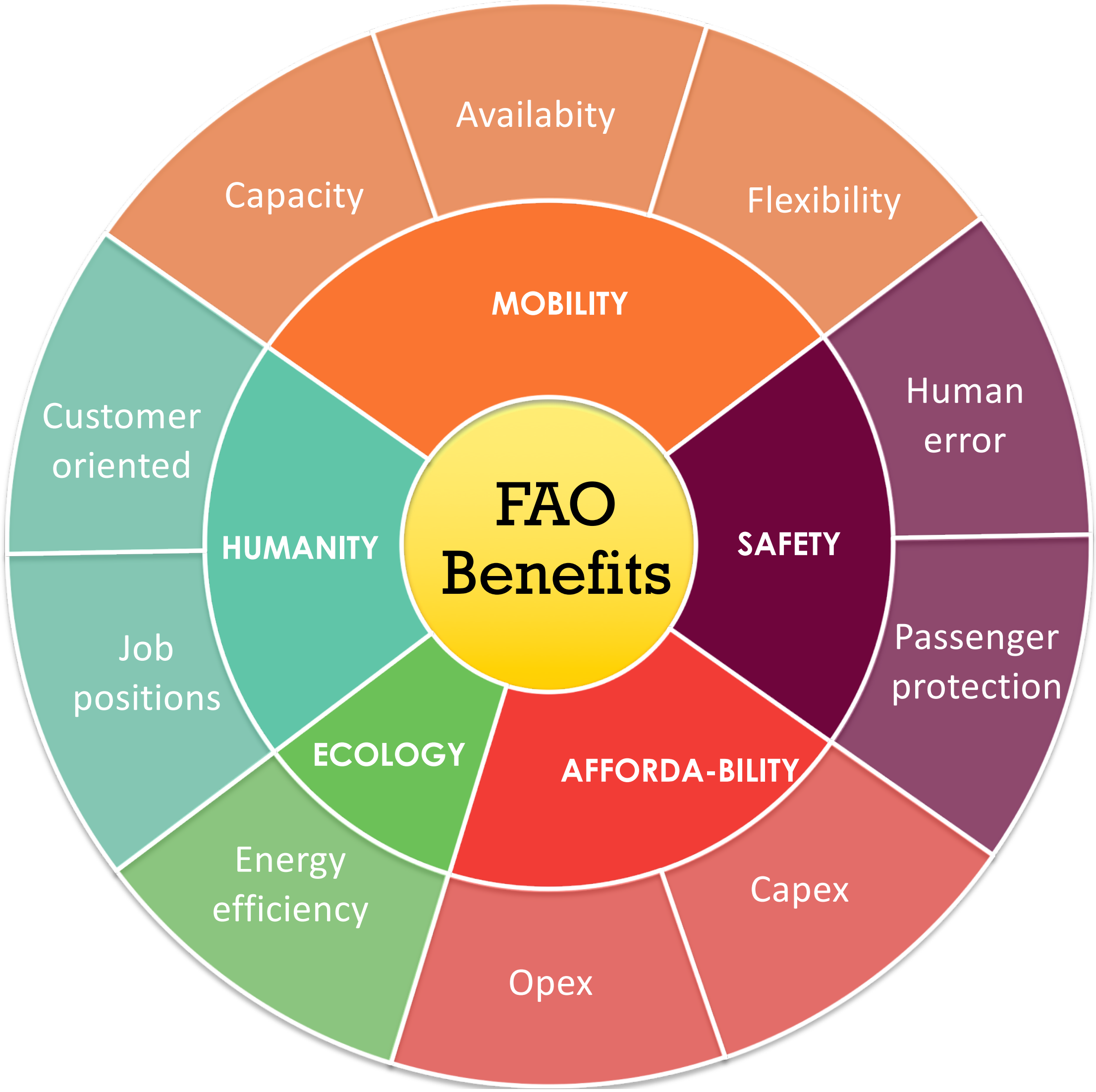
Outstanding services: to **match supply to demand**, optimizing the capacity allocation and fleet size

Higher Capacity; Higher commercial speed (+>10%) + shorter headways (down to 60s)

Flexibility at its core: real time reaction to demand surges or improving off peak service **at marginal costs**

Happier Customers: shorter waiting times and faster rides

BENEFITS OF FULL METRO AUTOMATION



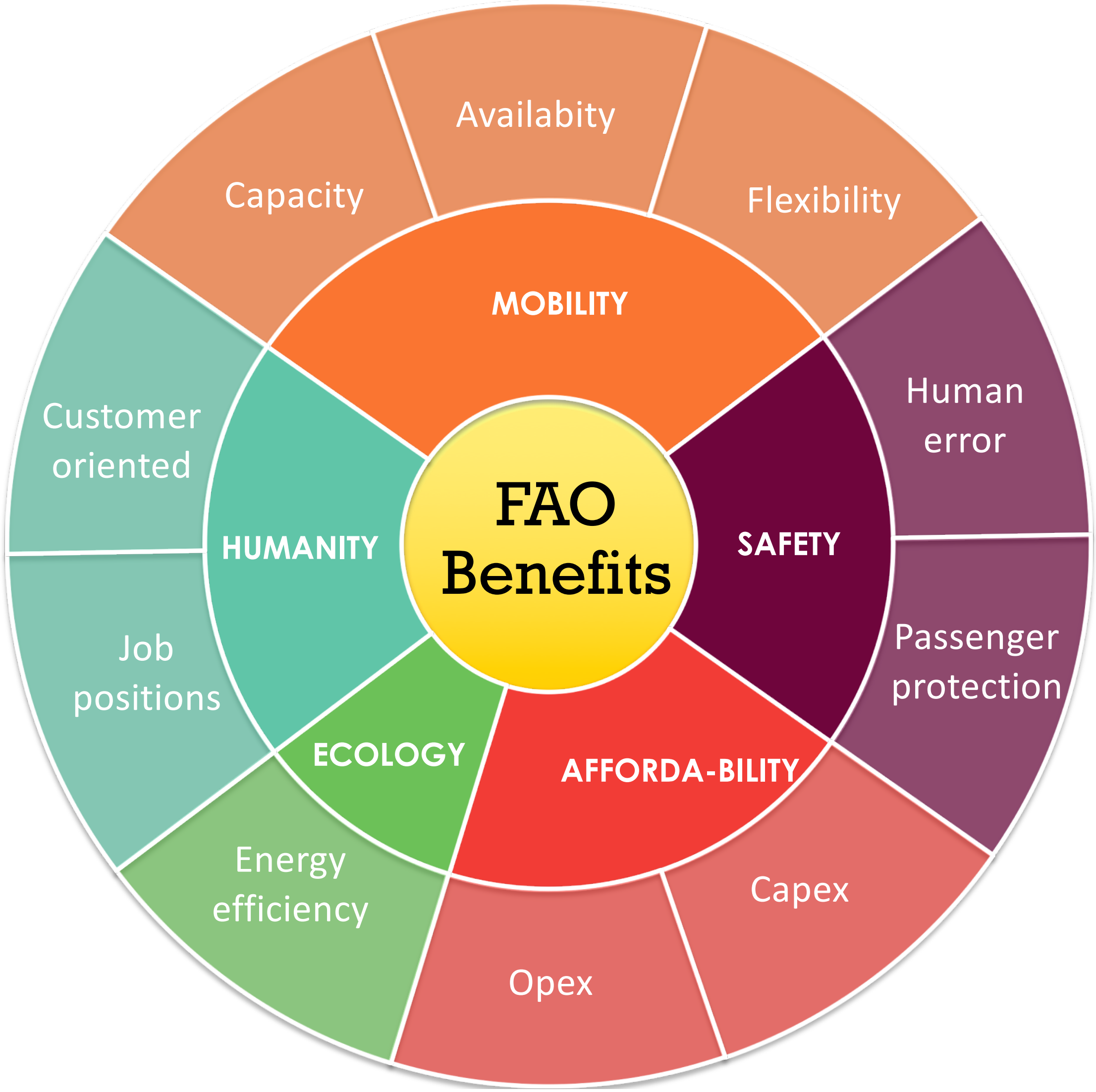
Safety

Free from human error: Vital repetitive tasks are totally automated

“0” accidents in 35 years: metro automation holds and impressive safety record with no fatalities so far

Platform Screen Doors: the top measure (85% systems) to avoid track intrusions and **protecting passengers. PSD increase system performance** (shorter dwell times and higher service availability)

BENEFITS OF FULL METRO AUTOMATION



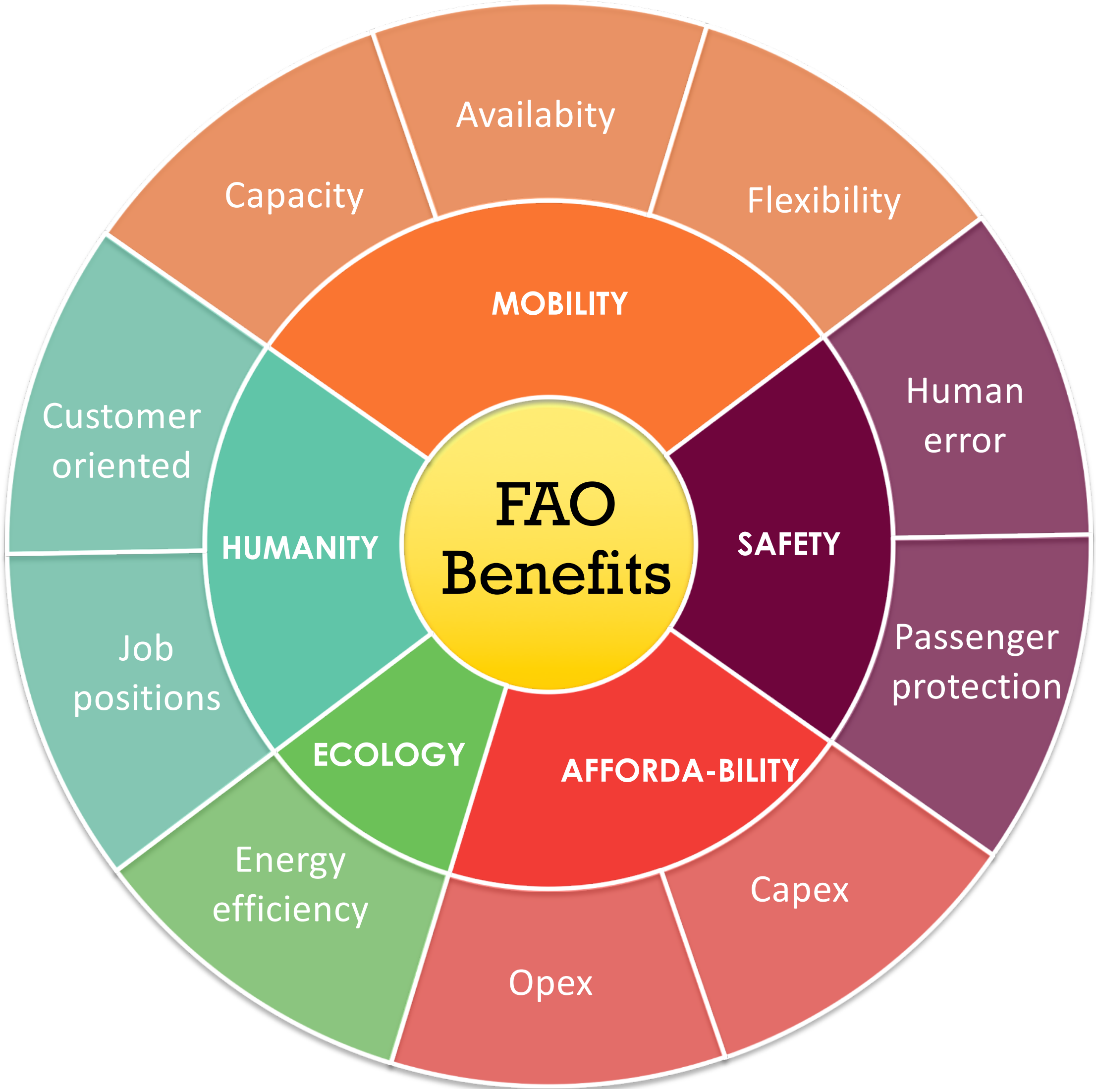
Affordability

CAPEX reduction: the shorter headways allow the use of shorter trains (keeping same capacity) and smaller platforms.

Optimal fleet: the increase in commercial speed combined with flexible services at peak hour help to **reduce the fleet size investment** (>10%)

Lower OPEX: combining energy savings, with more efficient services and lower labor costs, **recurrent expenditures are notably reduced**

BENEFITS OF FULL METRO AUTOMATION



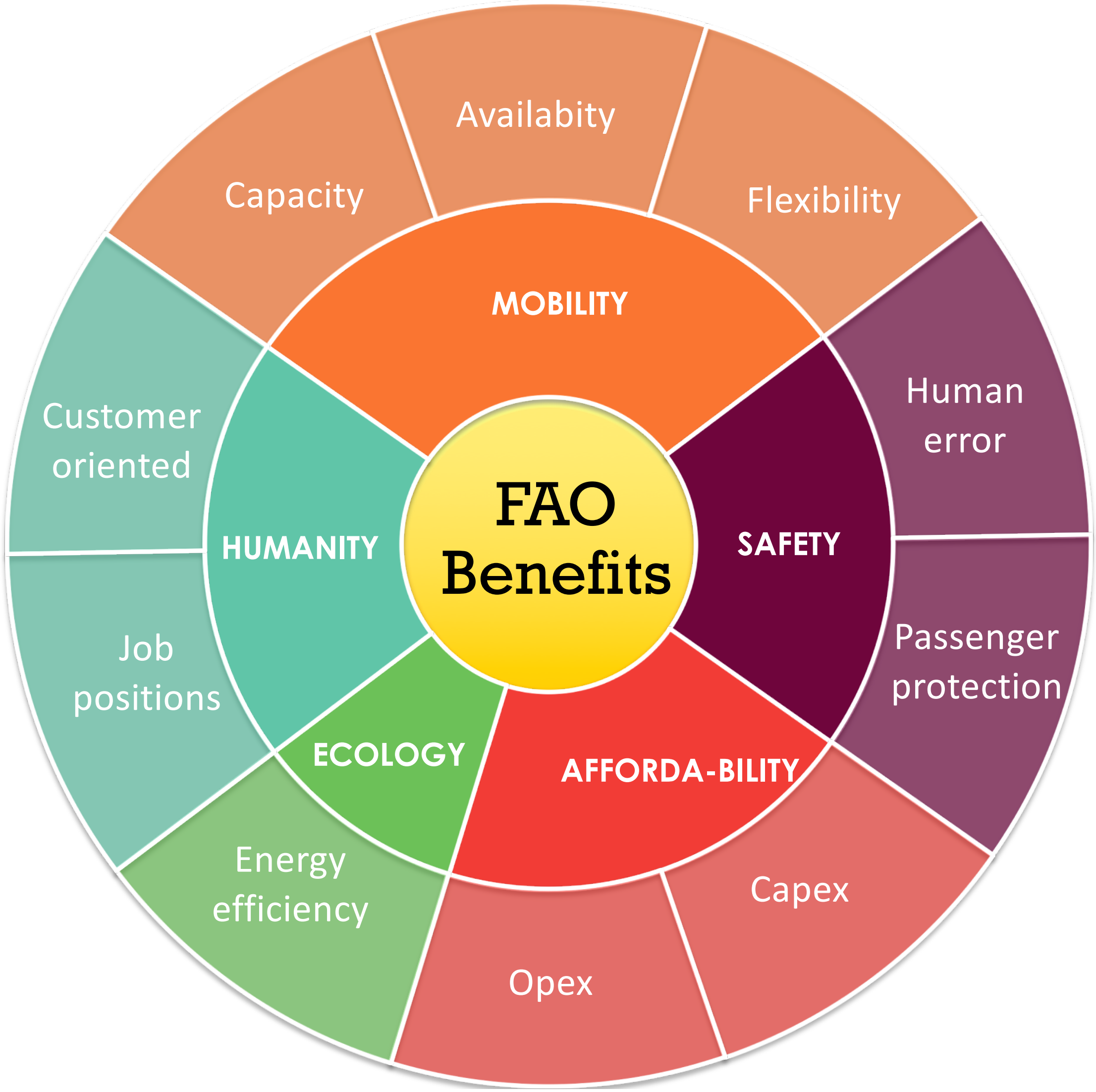
Ecology

Eco driving modes: automation repeatability maximizes the savings from consumption optimized running diagrams at off-peak hours (~80% of servicer time)

Optimal fleet size & Flexibility: matching supply to demand results in lower energy waste.

An even greener metro: By combining these measures up 15% of power can be saved. Automatic train coupling further improves this figure.

BENEFITS OF FULL METRO AUTOMATION



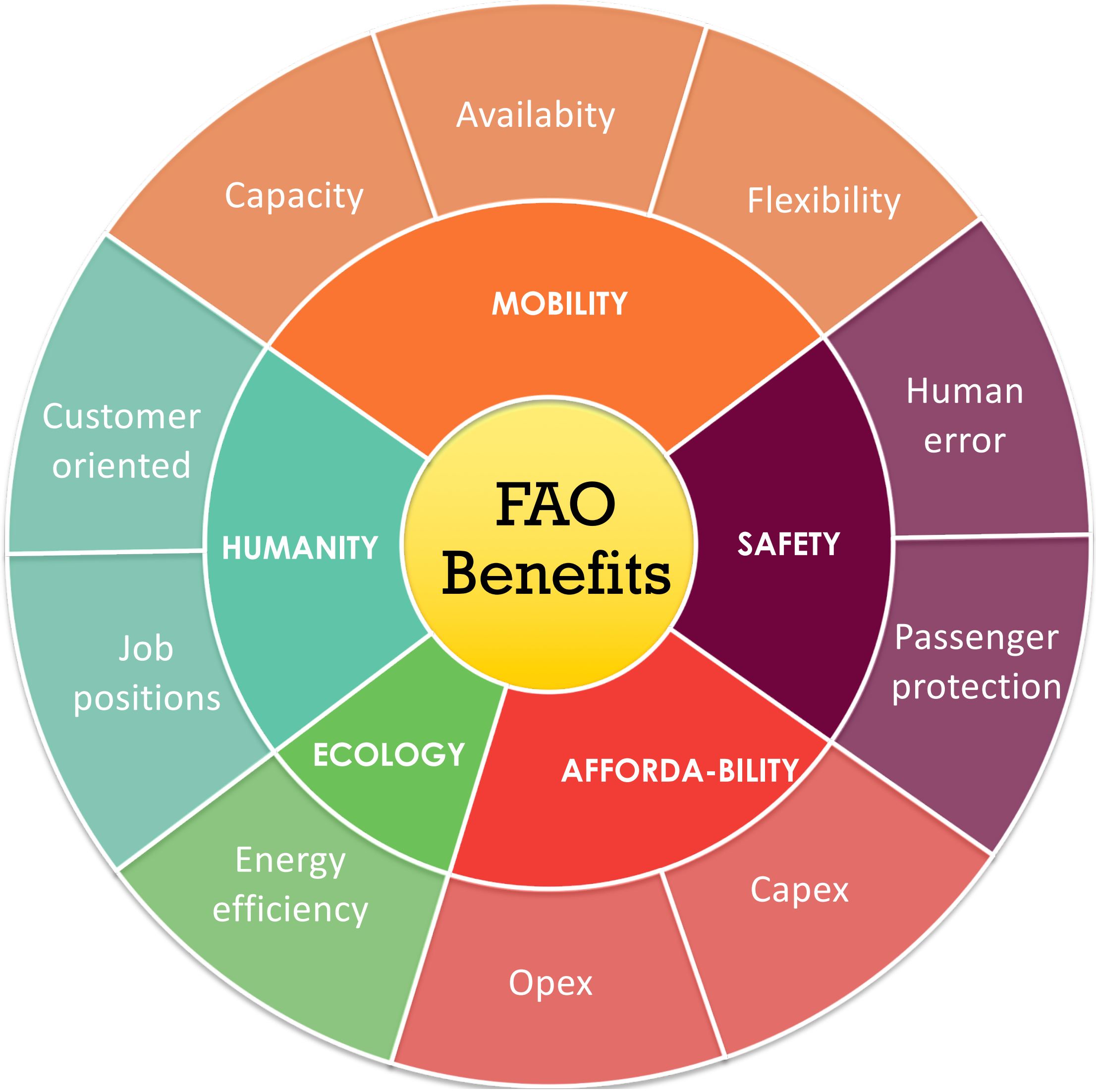
Humanity

Better Customer Service: "unlocked" from cabins, at equal staffing, multiskilled roving staff are closer to customers, improving their travel experience.

Fulfilling Jobs: automation helps improving the organizational model, empowering employees to deliver more value and increasing their commitment (lowering absenteeism)

Better employability: automation enables a new organization that meets the expectations of future labor market

BENEFITS OF FULL METRO AUTOMATION



These 10 levels compile the unrivalled contribution of metro automation

CONCLUSIONS

CONCLUSIONS

In a nutshell…

- ✓ This crosswise approach defines a general framework for any mass public transportation system, although **fully automated metro maximizes its outcomes**

- ✓ Metro is being challenged by a **disrupted and fast changing mobility landscape**. Only by a compelling design in the five dimensions would allow metro to become **the backbone of the future mobility ecosystem**

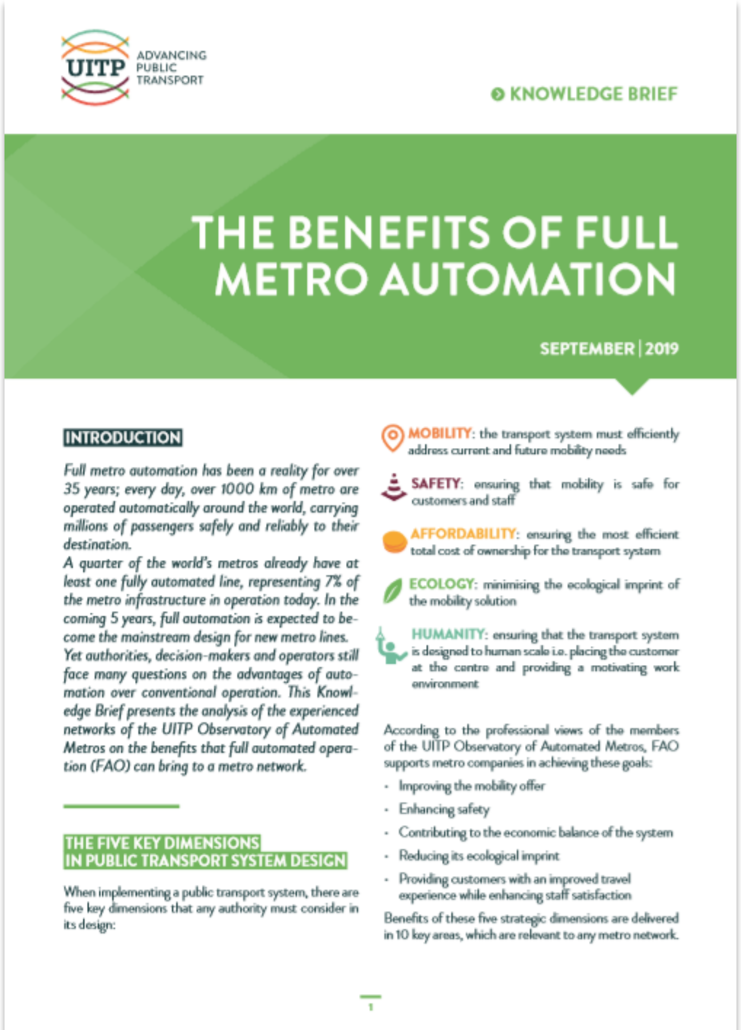
CONCLUSIONS

In a nutshell…

Therefore the question **is not about whether “to automate or not”**, it should framed in:

“how to leverage the automation benefits to deliver the *most efficient*, *safe and rapid metro service* that enables the new mobility context?”

CONCLUSIONS


ADVANCING PUBLIC TRANSPORT

KNOWLEDGE BRIEF

THE BENEFITS OF FULL METRO AUTOMATION

SEPTEMBER | 2019

INTRODUCTION

Full metro automation has been a reality for over 35 years; every day, over 1000 km of metro are operated automatically around the world, carrying millions of passengers safely and reliably to their destination.
A quarter of the world's metros already have at least one fully automated line, representing 7% of the metro infrastructure in operation today. In the coming 5 years, full automation is expected to become the mainstream design for new metro lines. Yet authorities, decision-makers and operators still face many questions on the advantages of automation over conventional operation. This Knowledge Brief presents the analysis of the experienced networks of the UITP Observatory of Automated Metros on the benefits that full automated operation (FAO) can bring to a metro network.

THE FIVE KEY DIMENSIONS IN PUBLIC TRANSPORT SYSTEM DESIGN

When implementing a public transport system, there are five key dimensions that any authority must consider in its design:

MOBILITY: the transport system must efficiently address current and future mobility needs

SAFETY: ensuring that mobility is safe for customers and staff

AFFORDABILITY: ensuring the most efficient total cost of ownership for the transport system

ECOLOGY: minimising the ecological imprint of the mobility solution

HUMANITY: ensuring that the transport system is designed to human scale i.e. placing the customer at the centre and providing a motivating work environment

According to the professional views of the members of the UITP Observatory of Automated Metros, FAO supports metro companies in achieving these goals:

- Improving the mobility offer
- Enhancing safety
- Contributing to the economic balance of the system
- Reducing its ecological imprint
- Providing customers with an improved travel experience while enhancing staff satisfaction

Benefits of these five strategic dimensions are delivered in 10 key areas, which are relevant to any metro network.

1

A new Knowledge Brief has been issued by UITP to help **unleashing the full potential of metro automation** far beyond the technological approach

THANK YOU!

Carlo Bianco
ATM Metro Safety Director and Operations Director for automated metro lines
Chairman of the UITP Observatory of Automated Metros

Carlo Bianco is a highly experienced senior rail Operations Director with railway management roles stretching back to the 1980s. He has extensive international experience across a broad spectrum of rail mobilization, rail operations and maintenance delivery.

He developed his career within the ATM Group, the Public Transport Operator of the city of Milan (Italy). Focusing his activity on driverless metro operations, he worked for five years as Operations manager in the Copenhagen Metro (Denmark), system currently operated by ATM (through the sister company Metro Service A/S).

In 2011 he was responsible for the startup of the automatic people mover of Princess Noura University in Riyadh (Saudi Arabia).

In 2012 he returned to Milan as responsible for the startup of the driverless line M5 which started commercial operation in February 2013.

Carlo's operations experience also extends to the project phase – pre-revenue operations.

He is currently in charge of the mobilization and start up of the new driverless line M4, whose commercial operation is planned for early 2021.

Since 2019 Carlo has been the Chairman of the UITP Observatory of Automated Metros and has been teaching the participants in the UITP Trainings on automated Metros since the first edition.

He is currently working as Metro Safety Director and Operations Director for automated metro lines for ATM Milan.

He is Deputy Chairman of the Board of Metro Service A/S Copenhagen, where he also covers the role of Project Director for the new Light Rail Ring 3 (under construction).

Profile Azienda Trasporti Milanesi

Established in 1931, with a workforce of 10,000 employees, ATM - Azienda Trasporti Milanesi manages the Operations & Maintenance of urban and suburban public transport in Milan and 95 municipalities in Lombardy, the bike sharing service, the car parks and on-street parking. ATM is also in charge of the management of the payment systems and access control for the Milan congestion charge area, Area C, and the LEZ area, Area B.

The Milan transport network is composed of four metro lines – one of which fully automated - covering nearly 100 km, 19 tram lines covering 180 km, 160 bus lines covering over 1,600 km and 4 trolley-bus circular routes. Over 2.5 million people travel every day on the ATM metro and surface network, totalling nearly 800 million passengers per year (pre-Covid data).

ATM also manages, through Metro Service A/S, the four driverless metro lines in Copenhagen and was recently awarded the contract for the Operations and Maintenance of the new Light-Rail line in the Danish capital.

Sustainability and technological innovation are the major company drivers. Among the projects, the ambitious "Full Electric Plan" providing for the transformation of the entire bus fleet – 1,200 vehicles - into full electric by 2030. The company develops cutting edge innovative solutions to improve customer journey, such as contactless payment in the metro network and its Mobility as a Service platform, the official ATM APP, that integrates the smart ticketing system and information to passengers on public transport, car and bike sharing, trains and airports. Improved digital tools enable passengers to forecast occupancy level in the metro stations so as to plan trips in advance.

P1
Monorail – A True Urban Mobility Solution

CLAUDIO TAVELLA / ALSTOM

INTERNATIONAL MONORAIL ASSOCIATION

Monorail – A true urban mobility solution

Abstract

In the past, Monorail technology was considered a niche technology applicable to amusement parks (e.g., Disneyworld Monorail in Orlando and other monorails serving these kind of attractions). Today, it can truly be considered as a real solution for public mass transit system in our cities.

Monorail technology has been around for over a hundred years. This year, you know Monorailex is in Italy. But did you know that Italy was one of the first countries in the world to use this technology? In fact, Genoa and Turin were equipped with monorail systems in 1914 and 1960 respectively!!!

The current trend noticed in the recent years, favorable to the monorail technology, reinforces the choices that many cities made in times when the monorail was seen as a futuristic technology.

Blast to the past…!!!

As mentioned earlier, Italy has shown interest in this technology over 100 years ago. The "TELFER" of Genoa, which came into service operation in 1914, was the first "straddle" type monorail built in the country.

Introduced at the International Marine Exhibition to connect the south-east part of the city to Molo Giano dock. The Monorail system, that was built in 100 days only with a restaurant integrated to the end terminal station, was the showpiece of the exhibition. It was later used to transport coal and then decommissioned in 1918.

Fig.1 Genova "TELFER" Monorail Infrastructure

Fig.2 Genova » TELFER » Monorail alignment

Fig.3 Genova Monorail

Main data:

Type: Straddle type monorail

Manufacturing: BBB (Badoni Bellani Benazzoli)

City: Genova (IT)

Route: Piazza di Francia - Molo Giano (Port area)

Opening: 1914

Closed: 1918

Length: 2.2 Km

Stations: 2

Almost fifty years later, the Piedmontese capital city of Turin introduced its Monorail to the world!!! In 1961, on the occasion of the International Labor Exhibition and the simultaneous celebration of the centenary of the Unification of Italy, a 1.8 Km with 2 stations Monorail system was inaugurated.

The monorail ceased operation a few months after the end of the exhibition, but was used again during the springs and summers of the following two years, especially for the use of school groups, and was definitively decommissioned at the end of November 1963.

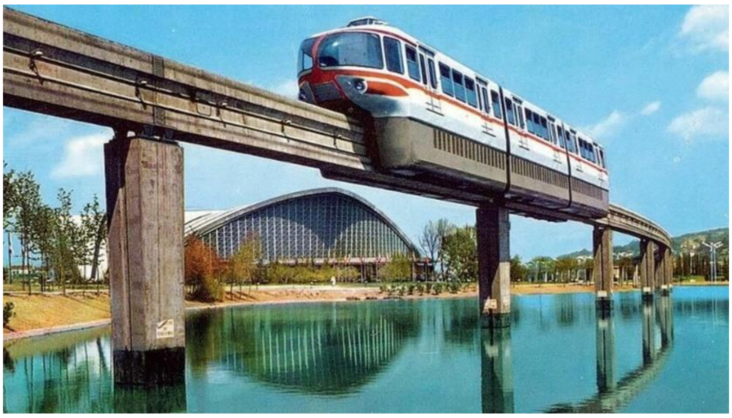


Fig.4 Torino Monorail Alignment

Fig.5 Torino Monorail, Rolling Stock (ALWEG)

Main data:

Type: Straddle type monorail

Manufacturing: ALWEG

City: Turin (IT)

Route: Palavela – Palazzo del Lavoro

Opening: 1961

Closed: 1963

Length: 1,8 Km

Stations: 2

And where are we today?

Can Monorail be truly considered a mass transit technology compared to conventional mass transit systems (subways, tramways, metros, etc.)?

From the examples I described earlier, even 100 years ago, the systems were introduced in conjunction with major national and international events.

This is still the case today. Many Brazilian cities including Sao Paulo selected Monorail as mass transit systems when the country had the opportunity to host the Olympic Games and the football World Cup in a span of 2 years (2012-2014). Monorail technology (new generation) was considered the best solution in terms of construction time and cost of the work.

While planning the extension of the existing metro line 15, Metro Sao Paulo authority realized that by extending the metro with the traditional method, it would not be put into service in time for the events coming to the city. For this reason, it was decided to use the monorail as an alternative, innovative and futuristic technology for Sao Paolo Monorail. Amongst other things, the rolling stock order was the single largest trains purchase in history for this type of technology.
In fact, 54 X 7-car trains (378 total cars) were ordered to meet the 40,000 PPHPD transport capacity (classic heavy metro capacity) along the 24.5 km of elevated guideway fitted with 17 stations.

Fig.6 San Paolo Monorail 7 car train

Market trends today show that **automated systems** will generally grow more and more in the coming years:

Fully automated metro lines represent 7% of the world's metro infrastructure in operation. This comparatively small figure is the outcome of a relatively short time span of exponential growth, especially when considering the 150 years of conventional metro history.

In the 37 years since the implementation of the first automated metro line, their growth rate has accelerated with each passing decade, with 2018 marking a significant inflection point.

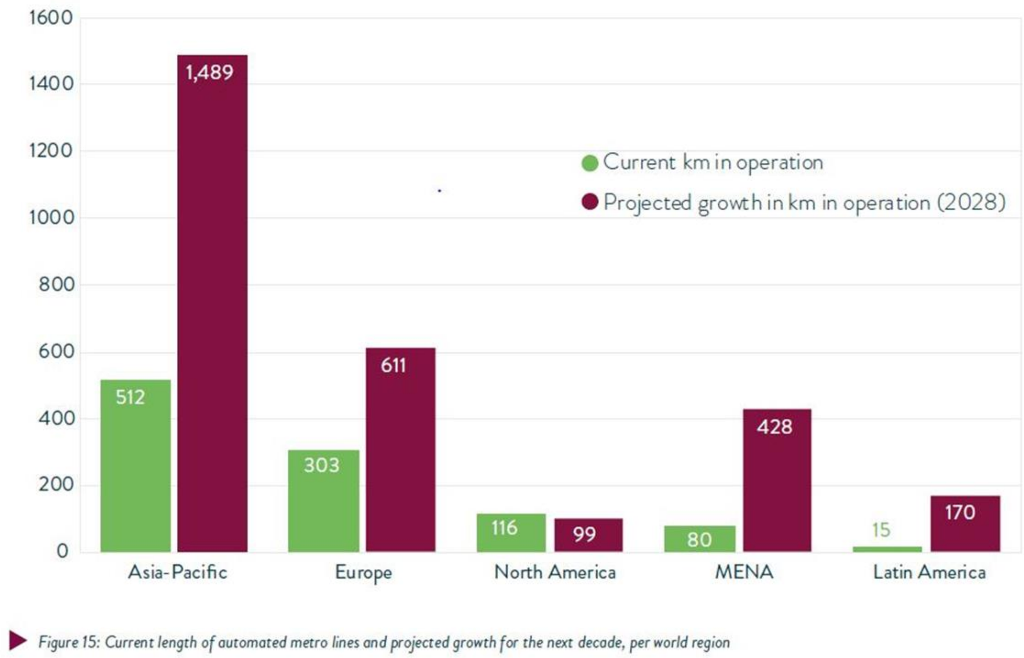


Fig.7 – UITP report 2019

In the next 5 years, a further 2,000km will be commissioned, tripling what took 35 years to achieve so far. (UITP report 2019)

The interest towards monorail transit systems is confirmed by the arrival of new players trying to get their part of a market more and more interested in the monorail technology as observed with a growing number of cities opting for monorail mass transit systems.
Some of the most populous cities in the world have opted for and / or are currently operating monorail mass transit systems:

City Operating Monorail Systems Year entered in Service

- Tokyo 1998
- Shanghai 2002
- Chongqing 2005
- Moscow 2008
- Sau Paulo 2014
- Beijing 2017
- Bangkok 2022
- Cairo 2023
- Panama City 2025

One of the most recent of those opportunities is the Cairo Monorail system, where 2 lines are currently under construction:

NCC New capital City Line **East Cairo-New Administrative City**

Project status : in execution

Revenue service: will begin in June 2022 (NTP+42)

52 km dual-beam alignment

21 stations

160 cars (40 four-car trains)

Designed to carry 45,000 PPHPD

6% maximum grade

Fig.8 New Capital City Alignment

Fig.9 First Cairo Monorail train - Derby Alstom Factory (UK)

6th October line **Giza City – 6th October City (industrial zone)**

Project status: in execution

Revenue service: Revenue service will begin in May 2023 (NTP+45)

42 km dual-beam alignment

12 stations

120 cars (30 four-car trains)

Designed to carry 45,000 PPHPD

6% maximum grade

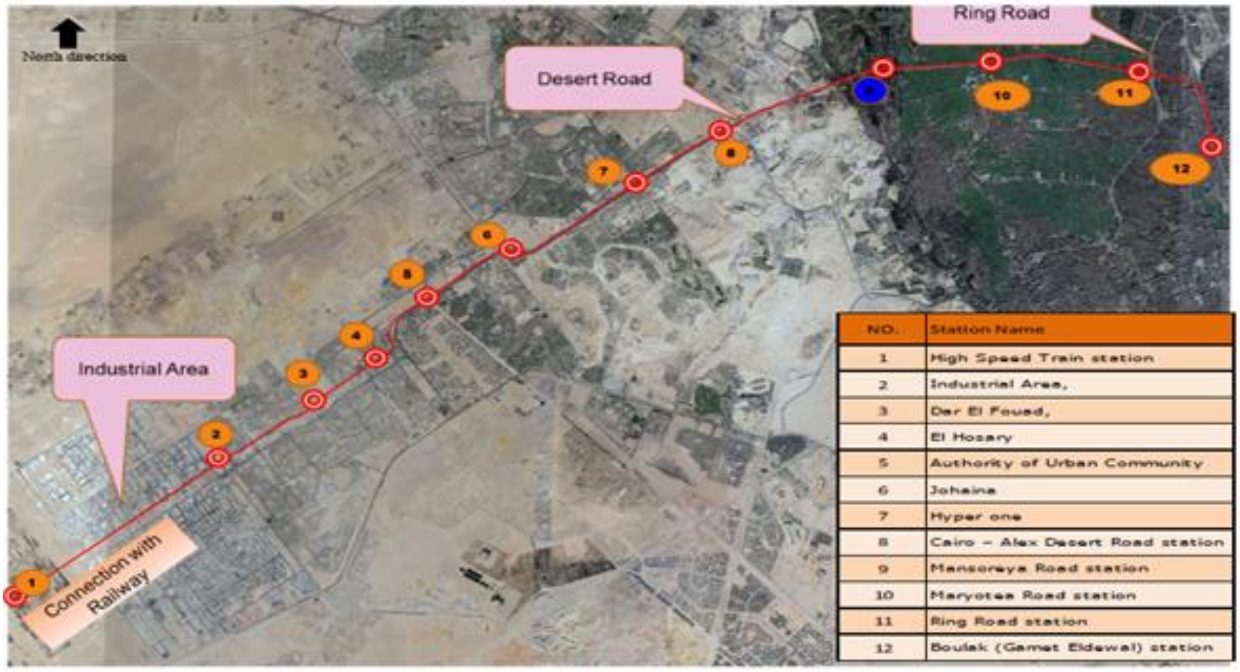


Figure No. (5): 6th. of October City Monorail Stations

Fig.9 6th October Alignment

In Conclusion, one could say that this is the time for Monorail technology, the next challenge will be to introduce the new generation of Monorail Systems in European cities, highlighting the benefit that this technology has to offer compared with other similar mass transit systems and benefit from the experience acquired in other cities around the world in the last years:

- Reliable and Safe (CBTC system and emergency walkway are a must for the new Monorail generation)

  Several questions were raised in the past regarding the safety of Monorail Systems. New generation of Monorail use an emergency walkway that can allow passengers evacuation everywhere along the alignment. In most countries, this is mandatory in order to be comply with the safety requirements.

Fif.10 Monorail emergency walkway example

- Mass transit capacity greater than 40,000 PPHPD
- Quick and easy installation into existing urban environments
- Unobtrusive guideway design
- Cost effective implementation
- Turnkey solution for fully integrated systems
- Efficient and environmentally friendly to operate
- Short headways for superior passenger service

The goal for the next Monorailex is to show you the first Italian/European real monorail mass transit application!!!

Monorail – A true urban mobility solution

Claudio Tavella

25 September 2021

ALSTOM
• mobility by nature •

Agenda

1. About Alstom
2. Blast to the past
3. Where are we today ?
4. Cairo Monorail
5. Conclusion

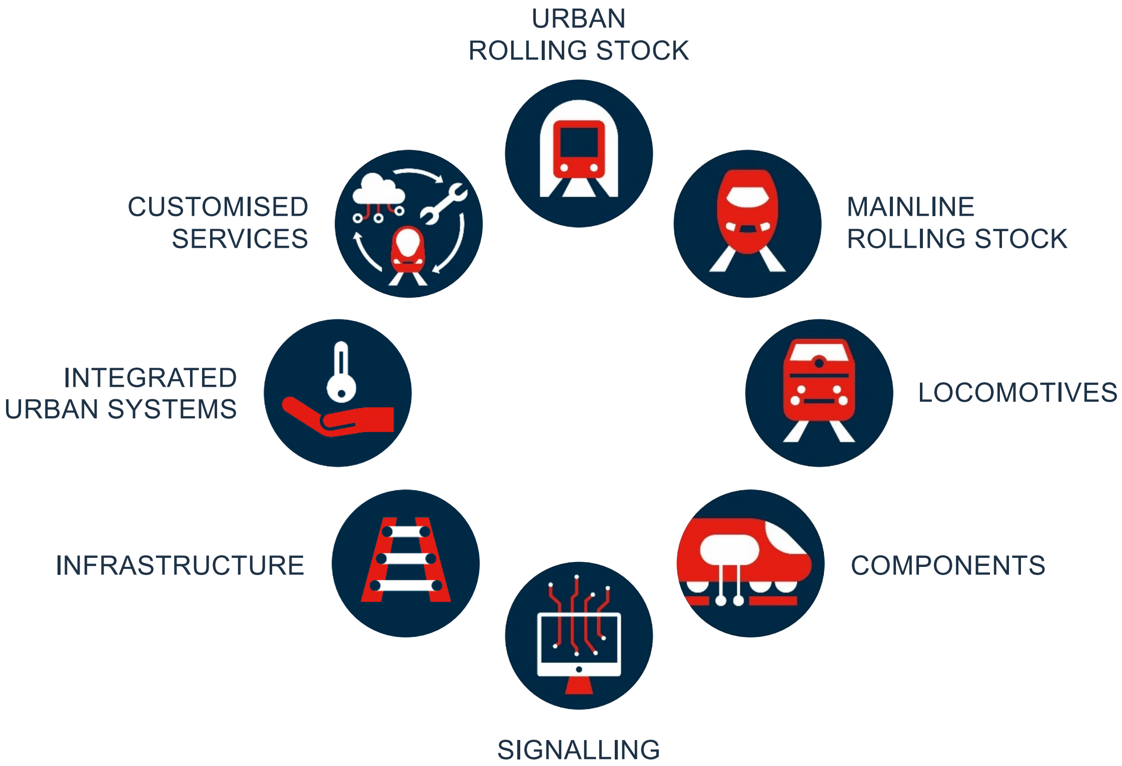
01

About Alstom

A global leader in the transportation sector in the digital age

Leading societies to a low carbon future

Alstom develops and markets mobility solutions that provide the sustainable foundations for the future of transportation. Alstom's product portfolio ranges from high-speed trains, metros, monorail and trams to integrated systems, customised services, infrastructure, signalling and digital mobility solutions.



We are where mobility is needed

Over **70,000** employees worldwide

17,500 engineers

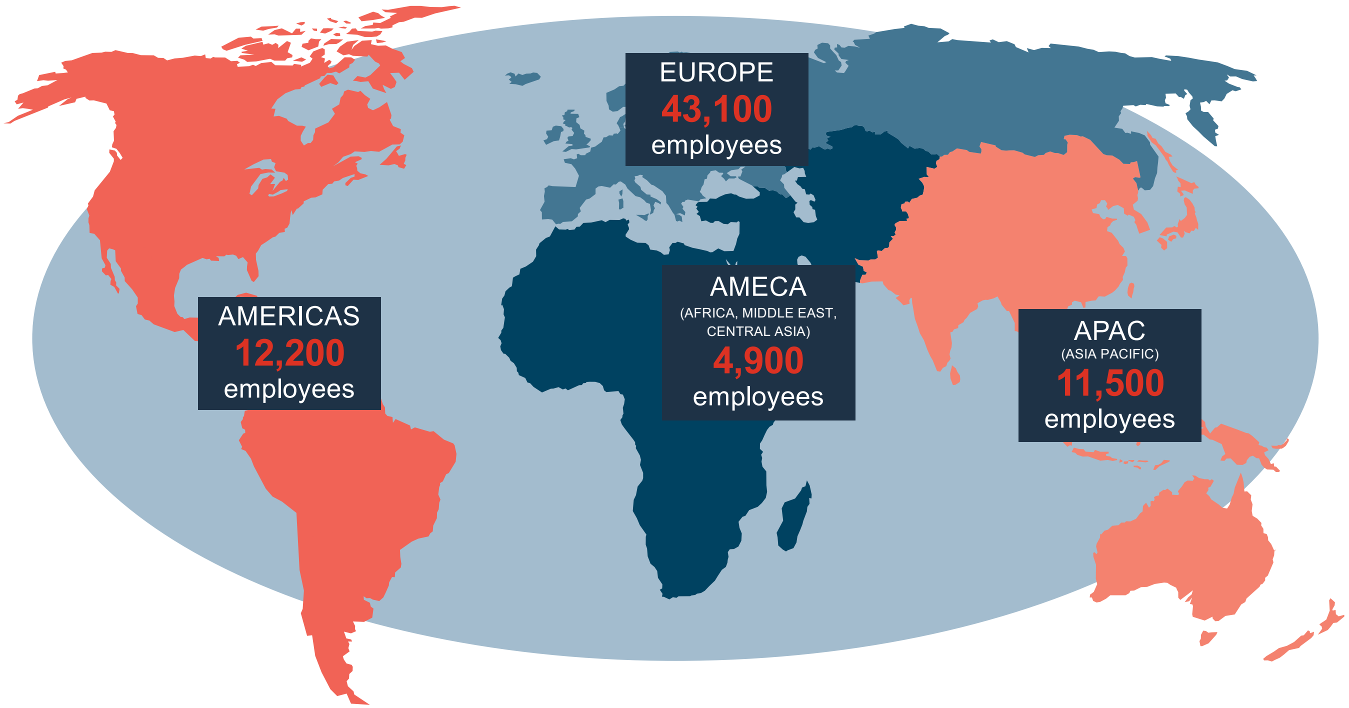
More than **9,500** patents

70 countries

Partner to over **300** cities

Over **250** sites

Over **150,000** vehicles in commercial service



A new complete product portfolio to better serve our customers

Rolling Stock & Components	Digital & Integrated Systems	Services
		
People Mover & Monorail	Urban Signalling	Rolling Stock Maintenance
Light Rail	Mainline Signalling	Asset Life Management
Metro	Turnkey	Parts & Component Overhauls
Suburban	Smart Mobility	Digital Solutions
Regional & Intercity	Cybersecurity	Train Operations & System Maintenance
High-speed & Very high-speed	Signalling & Infrastructure Services	
Locomotives	Infrastructure & Telecom	
Components		

Urban products

- Broad product range from
  - Small capacity lines (~5 000 PPHD) with **Innovia™ Automated People Mover** (APM) or **Monorail** solutions to
  - High-Capacity lines (70 000+ PPHD) based on **Movia™** or **Metropolis™** platforms.
- More than 30 Innovia™ APM systems delivered around the world
- 30 cities worldwide ordered Metropolis cars and transport 10,000,000 passengers daily
- Over 30 years of successful monorail design, build, operations and maintenance

PPHD - Persons per hour and per direction

02

Blast to the past

Genova and Turin Monorail

Blast to the past !!!
Genova Monorail 1914 and Turin Monorail 1961

As mentioned earlier, Italy has shown interest in this technology over 100 years ago. The “TELFER” of Genova, which came into service operation in 1914, was the first “straddle” type monorail built in the country.

Introduced at the International Marine Exhibition to connect the south-east part of the city to Molo Giano dock. The Monorail system, that was built in 100 days only with a restaurant integrated to the end terminal station, was the showpiece of the exhibition. It was later used to transport coal and then decommissioned in 1918.

Fig.1 Genova Monorail

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Fig.2 Torino Monorail

Main data:
Type: Straddle type monorail
Manufacturing: ALWEG
City: Turin (IT)
Route: Palavela – Palazzo del Lavoro
Opening: 1961
Closed: 1963
Length: 1,8 Km
Stations: 2

03

Where are we today?

Where are we today?
Sao Paulo Monorail

- Many Brazilian cities including Sao Paulo selected Monorail as mass transit systems when the country had the opportunity to host the Olympic Games and the football World Cup in a span of 2 years (2012-2014).

- Rolling stock order **was the single largest trains purchase in history for this type of technology.**

- **54 X 7-car trains (378 total cars)** were ordered to meet the **40,000 PPHPD** transport capacity (classic heavy metro capacity) along the **24.5 km** of elevated guideway fitted with **17 stations.**

Fig.3 Sao Paulo Monorail 7 car train

Fig.4 Sao Paulo Monorail 7 car train

Where are we today?
Market trend

Market trends today show that automated systems will generally grow more and more in the coming years:

- Fully automated metro lines represent 7% of the world's metro infrastructure in operation. This comparatively small figure is the outcome of a relatively short time span of exponential growth, especially when considering the 150 years of conventional metro history.
- In the 37 years since the implementation of the first automated metro line, their growth rate has accelerated with each passing decade, with 2018 marking a significant inflection point.

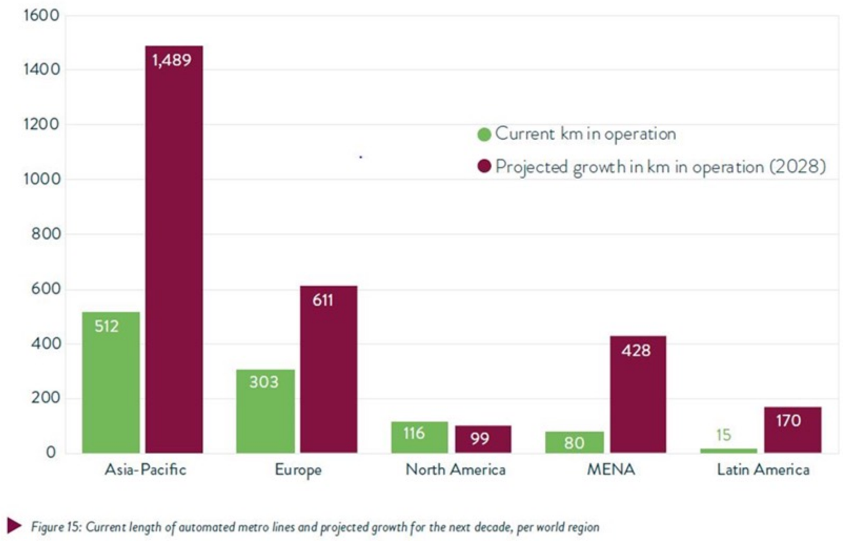


Fig.5 – UITP report 2019

In the next 5 years, a further 2,000km will be commissioned, tripling what took 35 years to achieve so far. (UITP report 2019)

Where are we today?
Market trend

- The interest towards monorail transit systems is confirmed by the arrival of new players trying to get their part of a market more and more interested in the monorail technology as observed with a growing number of cities opting for monorail mass transit systems.
- Some of the most populous cities in the world have opted for and / or are currently operating monorail mass transit systems

City Operating Monorail Systems	Year entered in Service
Tokyo	1998
Shanghai	2002
Chongqing	2005
Moscow	2008
Sau Paulo	2014
Beijing	2017
Bangkok	2022
Cairo	2023
Panama City	2025

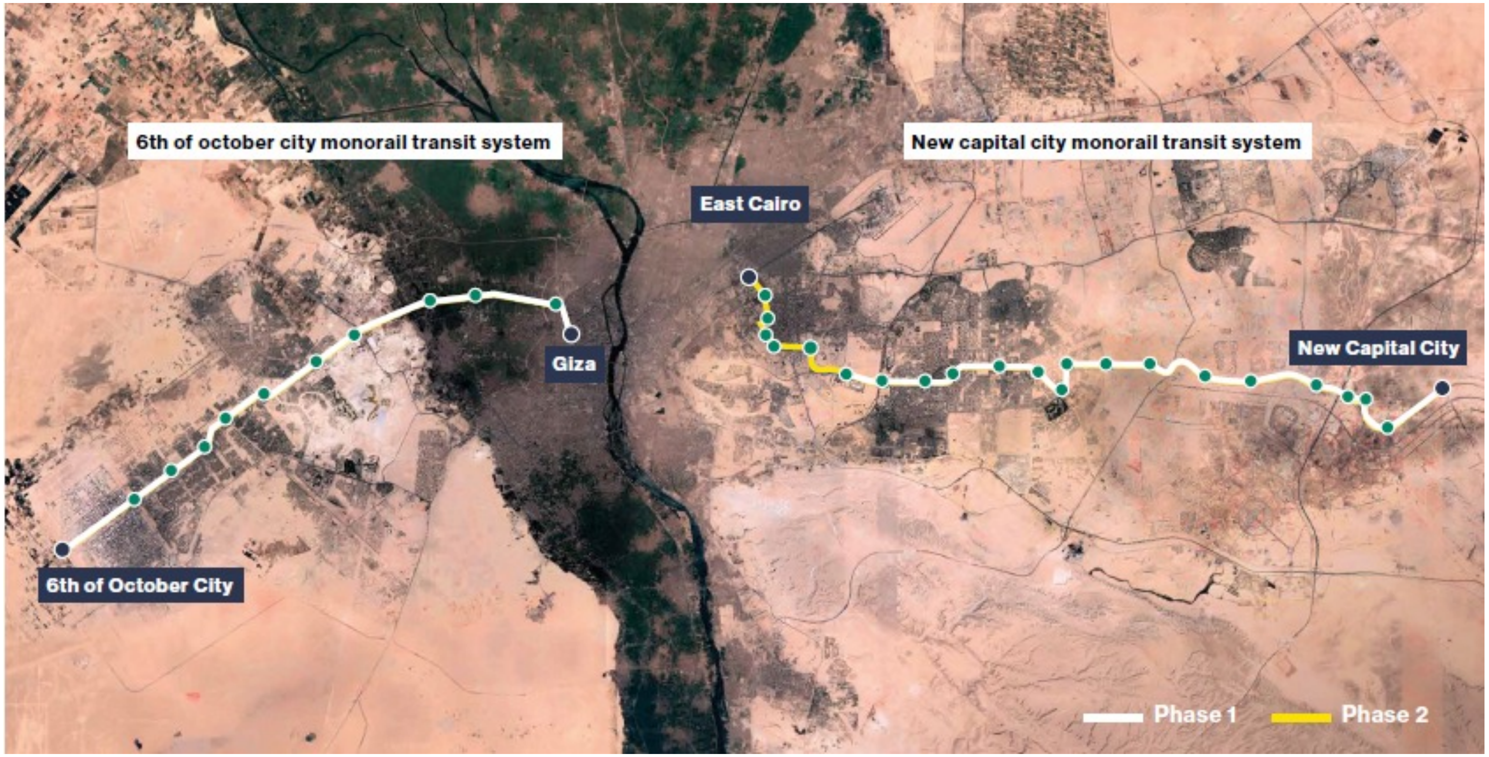
04

Cairo Monorail

Cairo Monorail

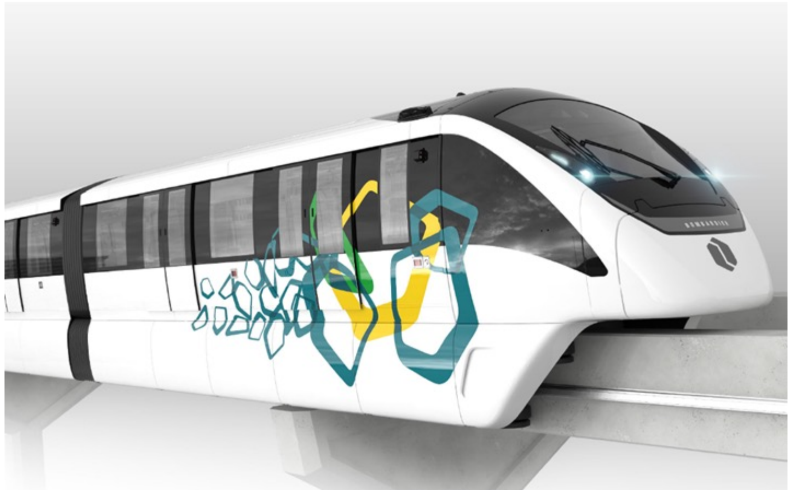
Route Map

One of the most recent of those opportunities is **the Cairo Monorail** system, where 2 lines (total 96 Km) are currently under construction:

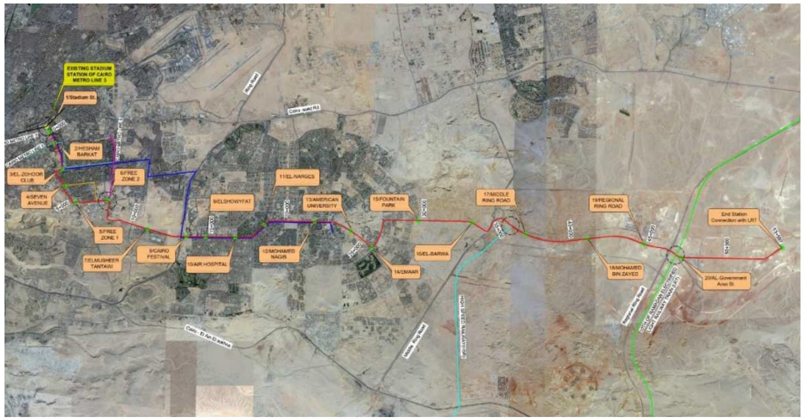


Cairo Monorail

INNOVIA Monorail 300 system – **New Capital City Line** – Contract signed in August 2019



System alignment map:



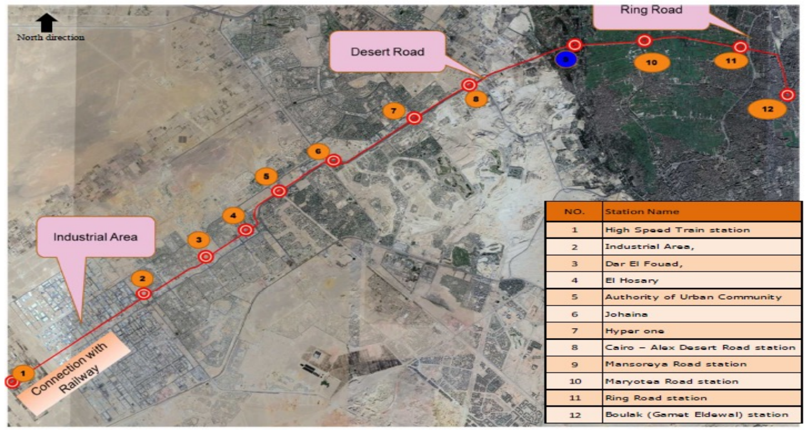
- New Capital City 'NCC' Line
- Revenue service will begin in June 2022 (NTP+42)
- 54 km dual-beam alignment
- 21 stations
- 160 cars (40 four-car trains)
- Designed to carry 45,000 pphpd[1]
- 6% maximum grade
- 750 Vdc guideway-mounted power rails
- East Cairo-New Administrative City
- Alstom will provide Vehicles, Signalling, Wayside Systems, System Integration and 30 years of O&M

(1) Ultimate design with 8-car trains configuration.

Cairo Monorail

INNOVIA Monorail 300 system – **6th October Line** – Contract signed in August 2019

System alignment map:



NO.	Station Name
1	High Speed Train station
2	Industrial Area,
3	Dar El Fouad,
4	El Hosary
5	Authority of Urban Community
6	Johaina
7	Hyper one
8	Cairo – Alex Desert Road station
9	Mansoreya Road station
10	Maryotea Road station
11	Ring Road station
12	Boulak (Gamet Eldewal) station

Figure No. (5): 6th. of October City Monorail Stations

6th Line

- Revenue service will begin in May 2023 (NTP+45)
- 42 km dual-beam alignment
- 12 stations
- 120 cars (30 four-car trains)
- Designed to carry 45,000 pphpd[1]
- 6% maximum grade
- 750 Vdc guideway-mounted power rails
- Giza City to 6th October City (industrial zone).
- Alstom will provide Vehicles, Signalling, Wayside Systems, System Integration and 30 years of O&M

(1) Ultimate design with 8-car trains configuration.

Cairo Monorail

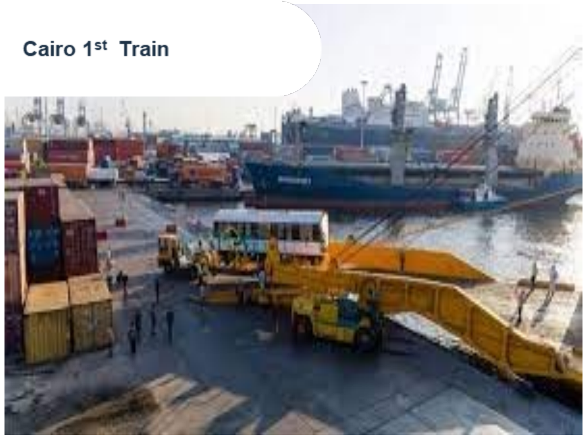
Project in execution - pictures

Cairo 1st train in Derby

Cairo pre-cast field

Cairo NCC guide beam installation

Cairo 1st Train



Cairo 1st Train

Cairo NCC infrastructure

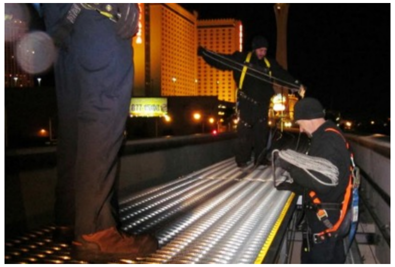
05 CONCLUSION

Conclusion

In Conclusion, one could say that this is the time for Monorail technology, the next challenge will be to introduce the new generation of Monorail Systems in European cities, highlighting the benefit that this technology has to offer compared with other similar mass transit systems and benefit from the experience acquired in other cities around the world in the last years:

- Reliable and Safe (CBTC system and emergency walkway are a must for the new Monorail generation) Several questions were raised in the past regarding the safety of Monorail Systems. New generation of Monorail use an emergency walkway that can allow passengers evacuation everywhere along the alignment. In most countries, this is mandatory in order to be comply with the safety requirements.
- Mass transit capacity greater than 40,000 PPHPD
- Quick and easy installation into existing urban environments
- Unobtrusive guideway design
- Cost effective implementation
- Turnkey solution for fully integrated systems
- Efficient and environmentally friendly to operate
- Short headways for superior passenger service





Monorail emergency walkway example

The goal for the next Monorailex is to show you the first Italian/European real monorail mass transit application!!!

https://www.youtube.com/watch?v=REFa8vZPuwQ

In Memory of Stephane Tavernier

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Author

Claudio Tavella

Claudio works as a Sales Manager for Alstom, following all the turnkey opportunities, with special focus on APM and Monorail systems. He has a 20-year experience in this field, having worked in Rome Airport APM and on the Cairo Monorail project for Bombardier Transportation.

He is not new to participate in conferences as a speaker: in 2012 he presented a paper at ExpoFerroviaria in Turin (Italy) on the San Paolo monorail project (BR).

Company info

Leading societies to a low carbon future, Alstom develops and markets mobility solutions that provide the sustainable foundations for the future of transportation. Alstom's product portfolio ranges from high-speed trains, metros, monorail and trams to integrated systems, customised services, infrastructure, signalling and digital mobility solutions. Alstom has 150,000 vehicles in commercial service worldwide. With Bombardier Transportation joining Alstom on January 29, 2021, the enlarged Group's combined proforma revenue amounts to €14 billion for the 12-month period ended March 31, 2021. Headquartered in France, Alstom is now present in 70 countries and employs more than 70,000 people.

www.alstom.com

P2
An Overview of Railway Transportation Systems for High and Medium Steep Gradients in Operation and Under-construction Worldwide

PROF. CHRISTOS PYRGIDIS / ARISTOTLE UNIVERSITY OF THESSALONIKI

INTERNATIONAL MONORAIL ASSOCIATION

An Overview of Railway Transportation Systems for High and Medium Steep Gradients in Operation and Under-construction Worldwide at the End of 2020

Christos Pyrgidis[1]

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Abstract

In recent years, there has been a continuous and rapid increase in the number of railway transportation systems put into service worldwide. New technologies have been researched, discussed and developed. Consequently, the need for frequent updates of relevant data arises. This paper attempts a systematic recording of railway transportation systems for high and medium steep gradients, with a reference date as at the end of the year 2020. Specifically, the systems that operate on steep grades, greater than 5 %, are examined. Such systems are classified into three major categories; rack railways, cable railways and monorails. Each of the former mentioned systems is defined and classified into sub-categories. For every one of the 357 systems that are operational at a global level (59 rack railways,248 cable railways and 50 monorails), their constructional and operational features are registered in databases after extensive research through both bibliographical sources and the internet. These features are subsequently analyzed and statistical data are derived and presented in comparative tables and figures, in order to acquire a comprehensive insight for each system. Finally, the conditions for application of each railway system and future trends are examined. The resulting databases for each of the above systems are easily accessed and updated by any interested parties, while the methodology suggested could also be efficiently applied in the study of different railway systems.

Keywords: *Railway systems for high and medium steep gradients, rack railway, funicular, monorail*

An Overview of Railway Transportation Systems for High and Medium Steep Gradients in Operation and Under-construction Worldwide (2019 Data)

Prof. Christos Pyrgidis, Aristotle University of Thessaloniki, Greece

The railway as a transport system

The “railway” is a terrestrial mass transport system. Trains move on their own (diesel traction) or remotely transmitted power (electric traction) on a dedicated steel way corridor defined by two parallel rails

Passengers and goods

- Transportation of passengers : 1500 km (2439 km, China)
- Transportation of goods > 3000 km(10000-12000 km, Europe-China)

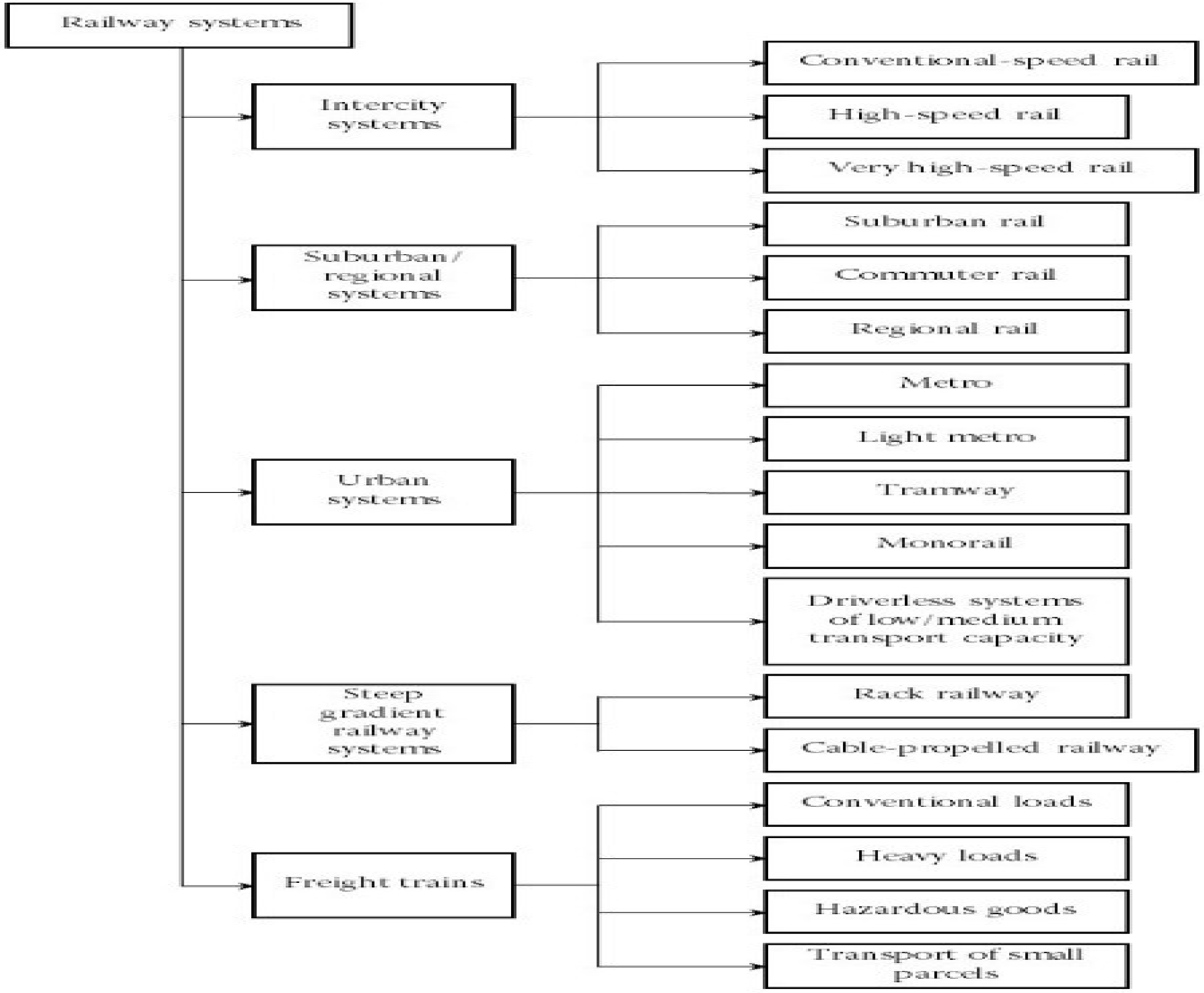
It serves different distance transfers in all kinds of environment (urban, suburban, peri-urban, regional, interurban)

The railway is the only technology that reached its peak, then dropped to nadir and peaked again

1830 - 1950

1960 - 1980

The railway was the means of transport that set the basis for the development of the inland in all continents



Railway systems
Intercity systems
Conventional-speed rail
High-speed rail
Very high-speed rail
Suburban/regional systems
Suburban rail
Commuter rail
Regional rail
Urban systems
Metro
Light metro
Tramway
Monorail
Driverless systems of low/medium transport capacity
Steep gradient railway systems
Rack railway
Cable-propelled railway
Freight trains
Conventional loads
Heavy loads
Hazardous goods
Transport of small parcels

Railways - Characteristic speeds

Characteristic speeds	*Maximum value (km/h)*	*Country*
Rolling stock design speed	400	China
Commercial speed	304.1	China
Cruiser (forward) speed	350 (320)	China (Japan, Europe)
Track design speed	400	Spain
Speed record	574.8	France (2007)

Objective of the work and application field

Railway systems that (can) operate, in a great part of their route, on gradients higher than 5%

- Definition and classification of the systems
- Identification and recording of the systems that are operational at a global level
- Registration in databases, of their constructional and operational characteristics
- Analysis and statistical elaboration of the data
- Future trends
- Reference date: End 2019

- Rack Railways
- Cable-propelled Railways
- *Monorails (medium slopes)*

Rack Railways

Two conventional rails plus a toothed rack rail in-between

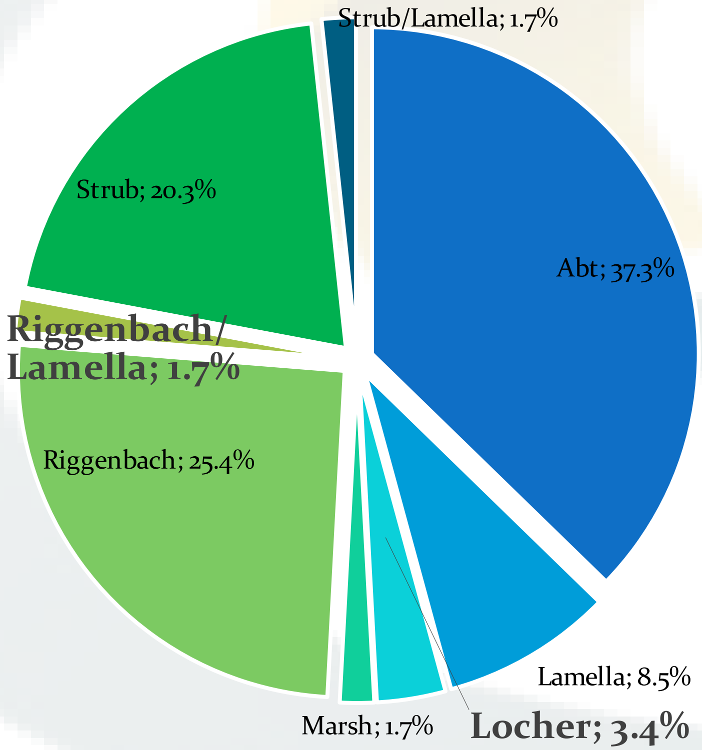
Classification according to:

- Rack system
  Riggenbach, Abt, Strub, Locher, Marsh or Lamella
- Type of adhesion along the line
  Purely racked, Mixed adhesion

Rack systems

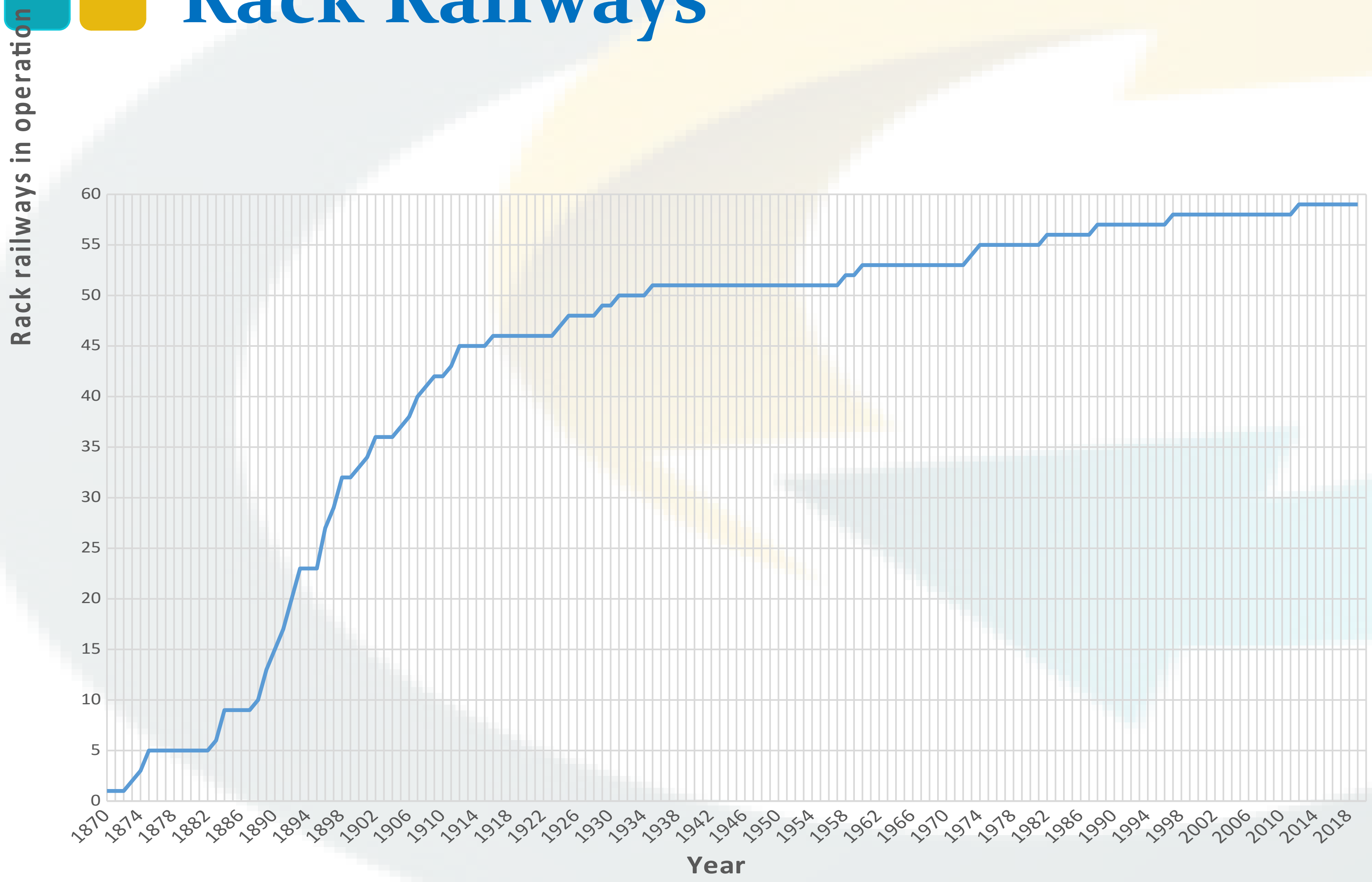
Rack Railways

59 Systems in operation (2019 data)



CONTINENT	COUNTRY	PURELY RACKED SYSTEMS	MIXED ADHESION SYSTEMS	TOTAL
EUROPE(48)	Austria	2	1	3
	France	3	2	5
	Germany	2	2	4
	Switzerland	13	11	24
	Greece	0	1	1
	United Kingdom	1	0	1
	Spain	0	2	2
	Italy	2	1	3
	Hungary	1	0	1
	Russia	1	0	1
	Slovakia	1	1	2
	Czech Republic	0	1	1
AMERICA (6)	Brazil	1	1	2
	United States	3	0	3
	Panama	0	1	1
ASIA (3)	India	0	1	1
	Indonesia	1	0	1
	Japan	0	1	1
AUSTRALIA (2)	Australia	1	1	2
TOTAL		32	27	59

Rack Railways



- First rack railway opened in 1868 on Mount Washington, USA
- Only 3 new rack railways during the last 35 years
- No systems under construction

Rack Railways

Constructional & Operational Features

Route length	Usually 4.5-6km, S_{max}= 19,09km
Track gauge	Usually metric gauge (1000mm or 1067mm)
Longitudinal gradient	>5%, usually i= 20-25% , i_{max}= 48%
Traction system	Diesel, bi0-diesel, steam, usually electric (67.2%).
Commercial speed	7.5–20km/h, V_{max} = 40km/h
Transportation system capacity	Low/medium transportation system capacity

- Infrastructure cost: 10-15 million €/km (single track)
- Mostly used for passenger transport
- Mainly directed towards leisure activities, mountainous areas

Cable-propelled Railways

Moving with the aid of a cable that rolls over pulleys mounted on track

Classification:

- Funiculars (non-detachable cable-propelled vehicles for steep gradients)
- Cable cars (detachable cable-propelled vehicles for steep gradients)
- Inclined elevators

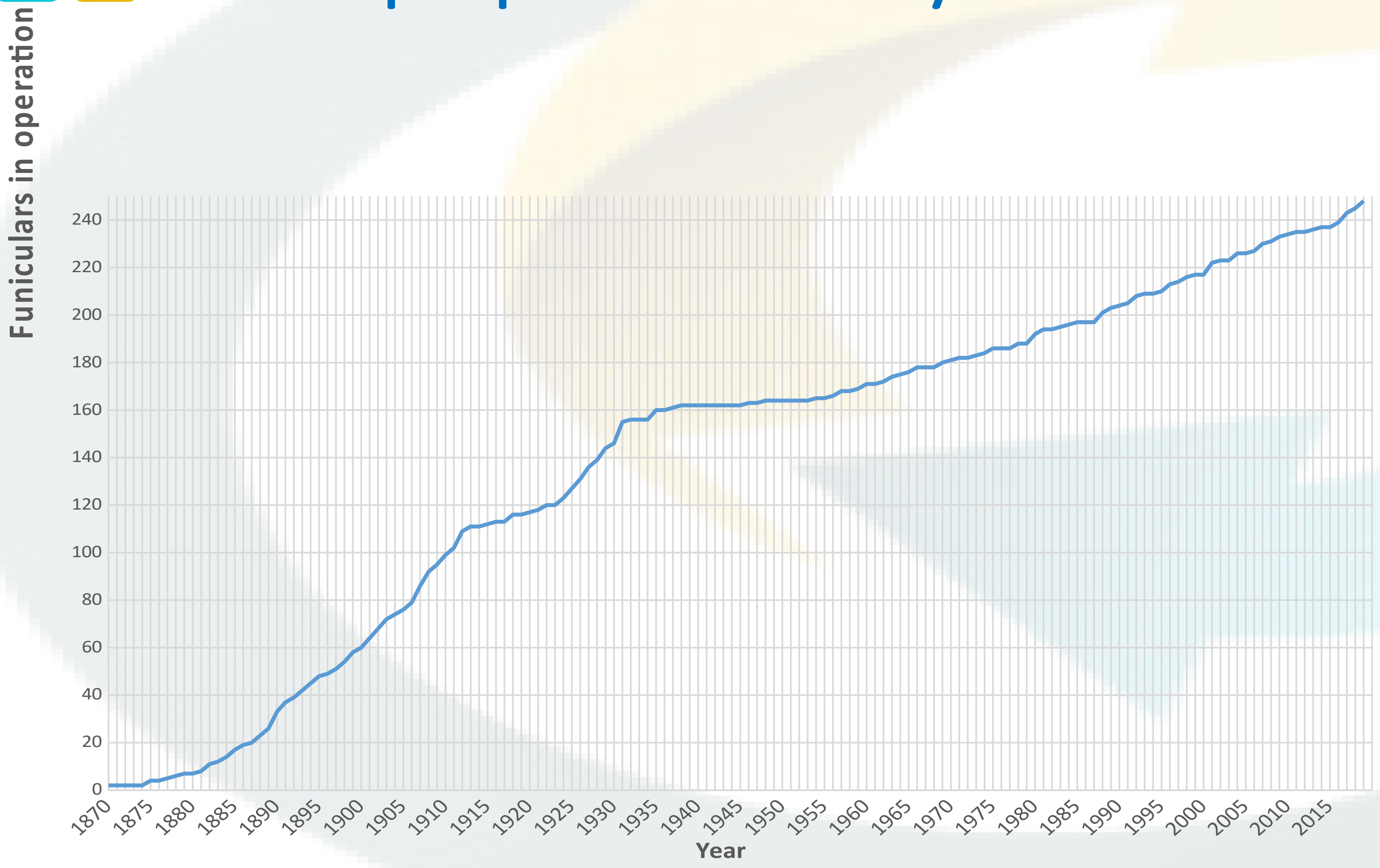
Cable-propelled Railways-Funiculars

248 funiculars in operation (2019 data)

50 of them in Switzerland

CONTINENT	COUNTRY	FUNICULARS
EUROPE (175)	ENGLAND	13
	AZERBAIJAN	1
	AUSTRIA	11
	FRANCE	16
	GERMANY	14
	GEORGIA	1
	SWITZERLAND	50
	GREECE	1
	SPAIN	11
	ITALY	21
	CROATIA	1
	LITHOUANIA	2
	LUXEMBURG	1
	NORWAY	2
	WALES	5
	HUNGARY	1
	UKRAINE	1
	POLAND	3
	PORTUGAL	8
	ROMANIA	1
	RUSSIA	2
	SLOVAKIA	1
	SWEDEN	2
	TURKEY	3
	CZECH REPUBLIC	3
NORTH AMERICA (14)	UNITED STATES	12
	CANADA	2
SOUTH AMERICA (18)	ARGENTINA	1
	BRAZIL	6
	COLOMBIA	1
	MEXICO	1
	CHILE	10
ASIA (39)	VIETNAM	2
	JAPAN	22
	INDIA	2
	ISRAEL	1
	CHINA	4
	LEBANON	1
	MALAISIA	1
	THAILAND	3
	HONG KONG	2
AFRICA (1)	SOUTH AFRICA	1
AUSTRALIA (1)	NEW ZEALAND	1
TOTAL		**248**

Cable-propelled Railways- Funiculars



- First funicular opened in 1862 in Lyon, France
- 14 new funiculars during the last decade
- 1 funicular under construction (Qiddiya Project, Saudi Arabia)

Cable-propelled Railways- Funiculars

Three main superstructure types:

Two-rail superstructure with passing loop

Three-rail superstructure with passing loop

Four-rail superstructure configuration

Cable-propelled Railways- Funiculars

Constructional & Operational Features

Route length	Usually S<1000m, S_{min}= 39m, S_{max}= 4827m
Track gauge	Usually metric gauge (1000mm or 1067mm)
Longitudinal gradient	usually i= 30-50% , i_{max}= 110%
Commercial speed	7.2–14.4km/h, V_{max} = 50.4km/h
Transportation system capacity	1000-2000 passengers/hour/direction

- Implementation cost: 20-30million €/km (infrastructure & rolling stock)
- Used for passenger transport
- Short distances with continuous gradients

Cable-propelled Railways- Inclined Elevators

- Uses a single vehicle, balanced by a counterweight
- Ideal for large continuous and very high gradients (50%-70%)
- Private use in residences (hotels, beach houses, cabins, etc.)
- Low transport system capacity (200–700 passengers/hour/direction)

Monorails

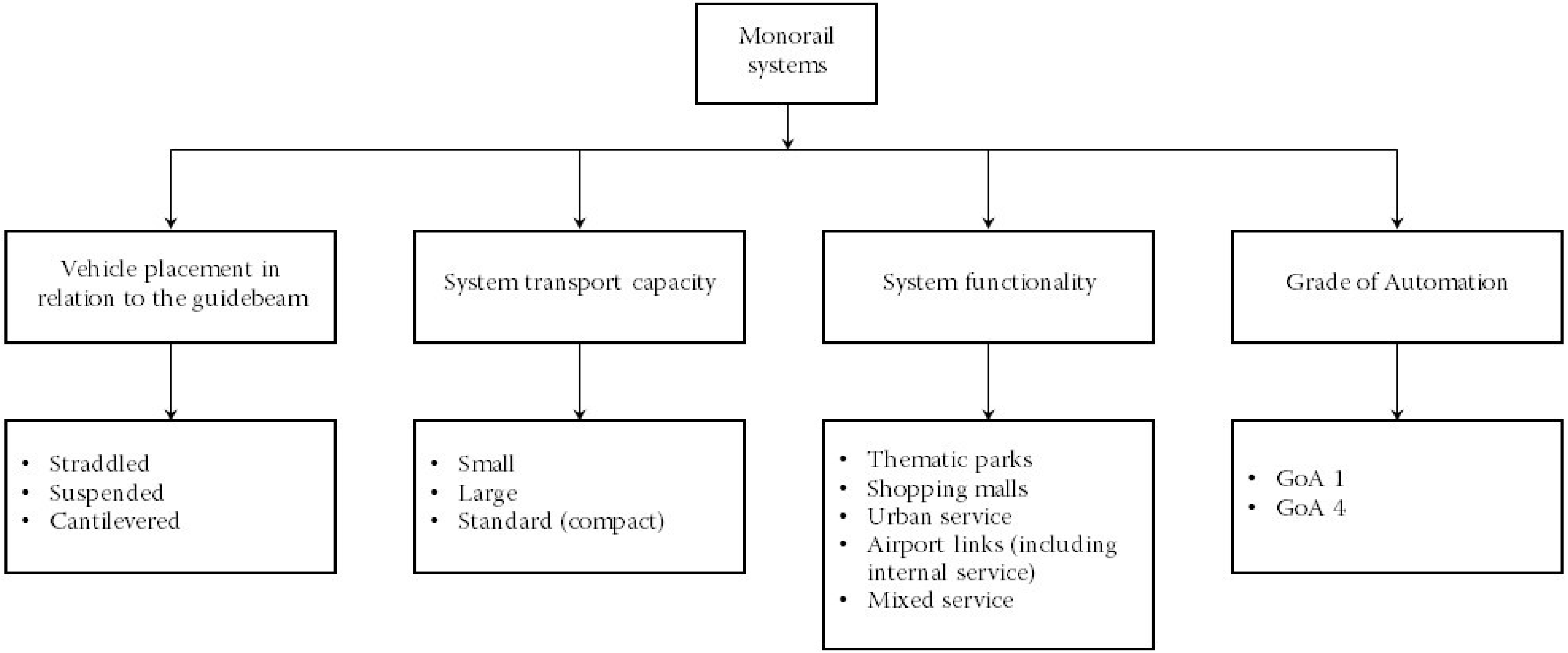
The monorail is an electrified light rail passenger transport system. This transport mode (in a typical manner, an articulated train) is formed of a small number of vehicles (2-6 and rarely 8) and in most cases it moves via rubber-tired wheels, on an elevated permanent way (guideway). The guideway is essentially a beam, which takes over the traffic loads and guides and supports the vehicles (guide - beam)

Small monorails

Large monorails

Standard monorails

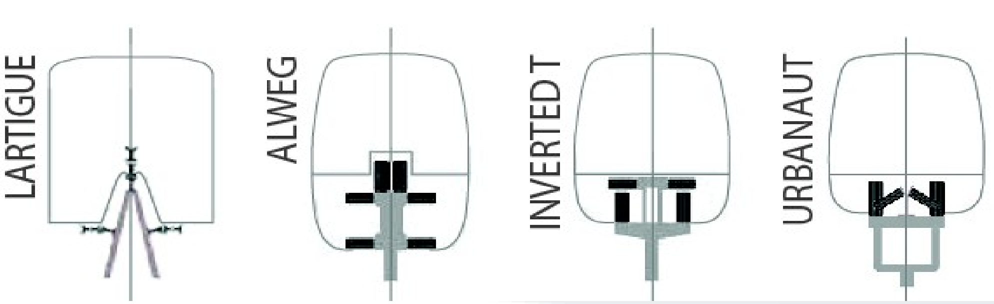
Monorails-Classification

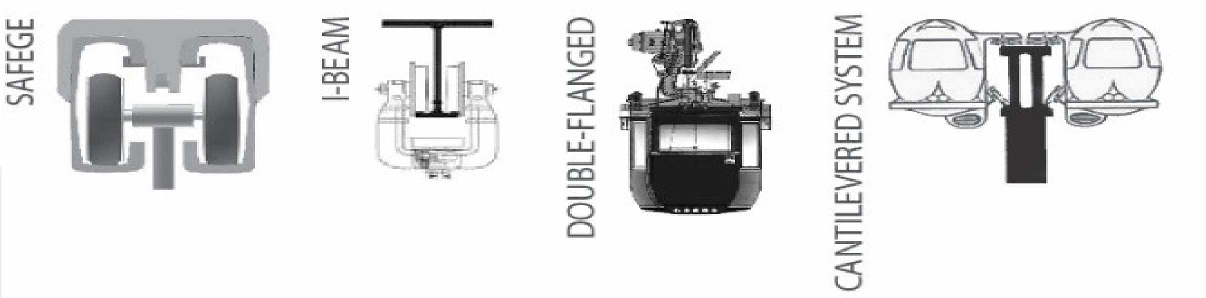


Monorails-Classification

Straddled

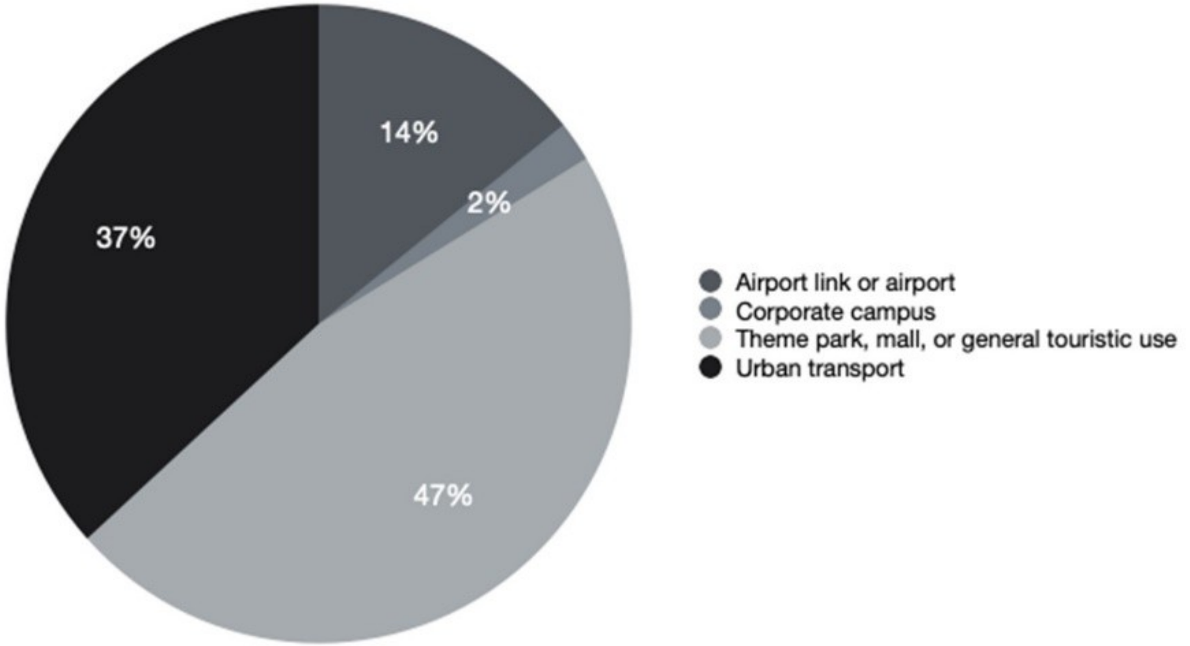
Suspended

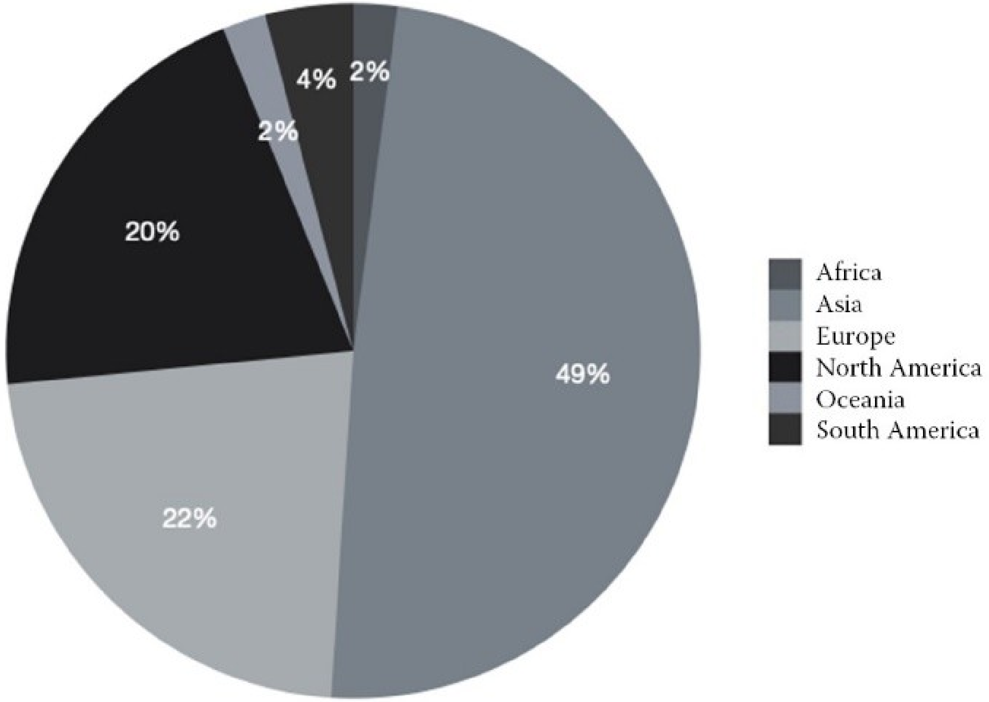




Monorails- Evolution

49 Systems in operation
(2019 data) + 1 (2020)



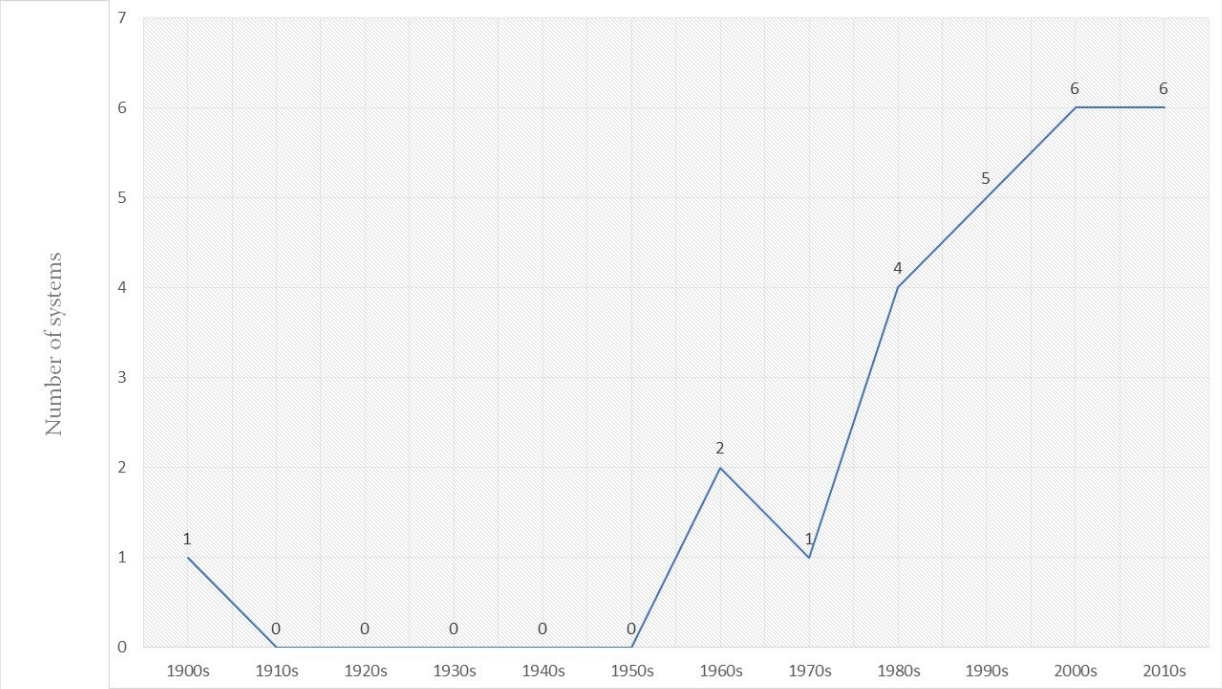


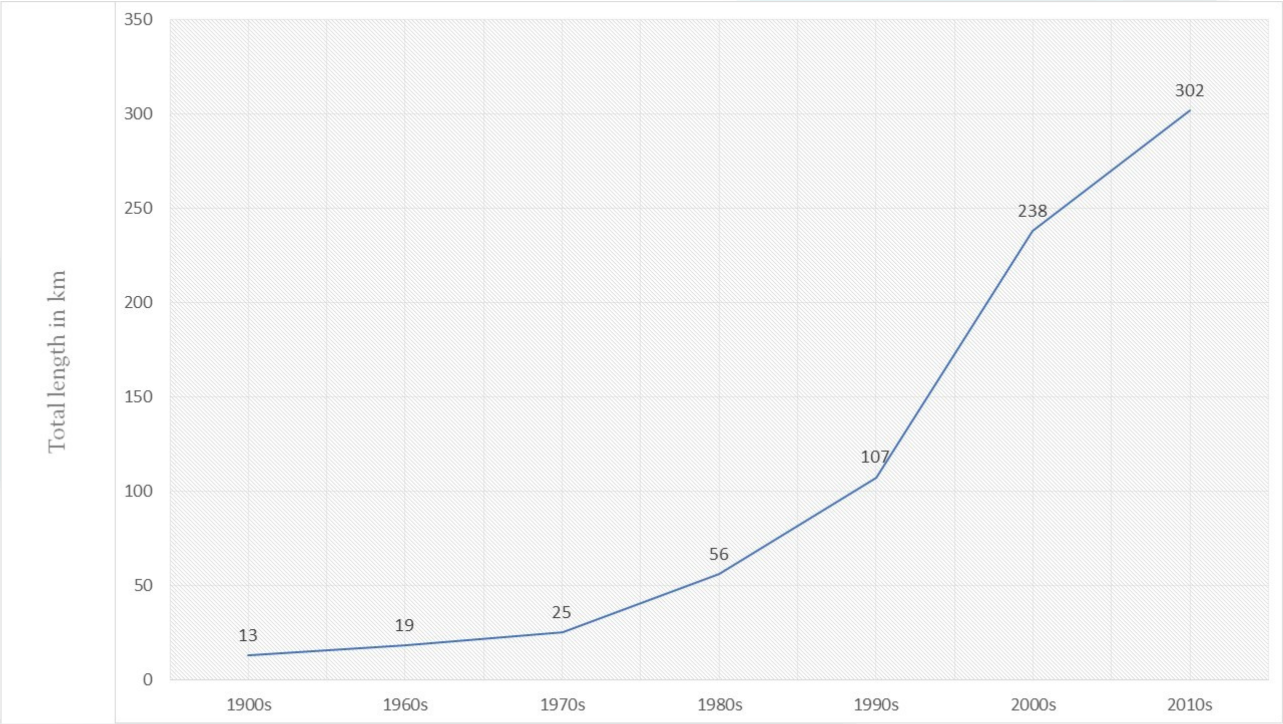
41(+1) straddled)
Total length approximately : 410km

Monorails- Evolution

25 urban use systems (300 km)

8 systems under construction





- **Route length :** 1.5-12 km (When used for public transport, its length may be significantly longer-55.5 km)
- **Maximum running speed :** 60-100km/h
- **Commercial speed :** 15-40 km/h
- **Distance between successive stops :** 800-1,500m
- **Longitudinal gradient :** 0-10% (20%)
- **Implementation cost :** 30-90 mil € / km (infrastructure + rolling stock)
- **Frequency :** 3-15 min (min 60 sec)
- **Maximum transportation work (pphpd) :** Small systems 2,000, Large systems: 12,500,Standard systems 4,800 (20,000-25,000 pphpd)
- **Driverless or not**
- **Axle load :** 8-11t

Area occupied on the ground by the pylons : 1 - 1.5m x 1 - 1.5m
Usually pillars are constructed inside a 2-3 m wide green zone

When there is a need for a transport mode that will serve movement within amusement parks, zoos, and so on

For the transportation of passengers over small distances, and in areas that are particularly interesting in terms of their view

For the connection of urban areas of the same altitude, where there is a natural barrier hindering their connection (e.g., water)

In recent years, monorails are increasingly used not only for recreational purposes but also for urban public transport, for serving connection with airports, movement within shopping malls and so on

Name	Continent	Country	City	Expected Date	Length	Placement	Type	GoA
Cairo Monorail	Africa	Egypt	Cairo	2023	96	Straddled	Urban Service	Driverless
Kai Tak monorail	Asia	China	Hong Kong	2023	9.0	Straddled	Urban service	n.d.
Wuhu Metro	Asia	China	Wuhu	2020	46.2	Straddled	Urban service	With Driver
Zunyi Rapid Transit System	Asia	China	Zunyi	n.d.	50.0	n.d.	Urban service	n.d.
QOM Monorail - Line M	Asia	Iran	Qom	n.d.	7.0	Straddled	Urban service	With Driver
Yellow Line	Asia	Thailand	Bangkok	2022	30.4	Straddled	Urban service	With Driver
MRTA Pink Line "2020"	Asia	Thailand	Bangkok	2021	34.5	Straddled	Urban service	Driverless
Marconi Express	Europe	Italy	Bologna	In operation from November 2020	5.0	Straddled	Airport service	Driverless
Krasnogorsk Monorail	Europe	Russian Federation	Krasnogorsk	2020	13.0	Suspended	Urban service	Driverless

Conclusions

- Construction of rack railways has virtually halted - Evolution of adhesion railways
- Funiculars remain in consideration as an alternative for cases of a complex landscape
- Inclined elevators remain a popular solution for very steep gradients and very short distances
- In recent years, monorails are increasingly used not only for recreational purposes but also for urban public transport, for serving connection with airports, movement within shopping malls and so on

The champions in gradient

Pilatusbahn–Rack (48%)

Stoosbahn–Funicular (110%)

Lotte World Monorail (20%)

Biography

Prof. Christos Pyrgidis

Christos N. Pyrgidis is a professor in railway engineering at the Aristotle University of Thessaloniki (AUTh), Greece. He earned a diploma in civil engineering (AUTh,1981). He specialized for 5 years at the Ecole Nationale des Ponts et Chaussées, Paris, France, in transportation infrastructure (CES), transport economics (DEA), and railway engineering (PhD). From 2004 to 2007 he was the Greek representative to the Administrative Board of the European Railway Agency. Since 2014 he is a member of the Scientific Committee of SHIFT2RAIL.

CV Prof. Christos Pyrgidis

Dr Christos Pyrgidis was born in January 1957 in Thessaloniki, Greece. He is a professor at the Civil Engineering Department of the Aristotle University of Thessaloniki (AUTh).

He holds a diploma in Civil Engineering (AUTh, 1981). He specialized for 5 years at the Ecole Nationale des Ponts et Chaussées (ENPC), Paris, France, in Transportation Infrastructure (1984-85: C.E.S. "Infrastructure et Transports", Transport Economics (1985-86: D.E.A. "Transport"), and Railway Engineering (1986-89: Doctorat (PhD) in "Transport" (Railway Dynamics).

He is in charge of courses on "Railways" (Undergraduate level), "Design and management of railway transportation systems" (Masters level), and "Construction methods of transportation technical structures" (Masters level) in the Civil Engineering Department of AUTh.

He has participated in many research railway projects and studies and has worked as a consultant to several railway organizations. From 2004 to 2007 he was the Greek representative to the Administrative Board of the European Railway Agency (ERA). From June 2015 he is member of the Scientific Committee of SHIF2RAIL Joint Undertaking (S2R JU).

He has published more than 170 articles in scientific journals and international congresses. He is the author of two books entitled a) "Railway Transportation Systems: Infrastructure, Rolling stock, Exploitation", 2nd edition, 2019, pages 864 (in Greek), Editions ZITI, ISBN 978-960-456-155-1 and b) "Railway Transportation Systems: Design, Construction and Operation", (in English),475 pages, March 2016, Editions "CRC Press -Taylor and Francis Group", ISBN 978-1-4822-6215-5.

Hobbies: Fishing, playing bridge, traveling

Name of the company ARISTOTLE UNIVERSITY of THESSALONIKI (AUTH)	
Type of Enterprise	UNIVERSITY
Country	GREECE
CITY	THESSALONIKI
LINK TO WEBSITE	https://www.auth.gr

General description

The Aristotle University of Thessaloniki is a state institution established in 1925 during the First Greek Democracy.

The structure of the university today, its range of activities and its size make it the largest and most complex institution of higher education in the country. More than 65.000 students study in the university and the teaching and research staff (professors, associate professors, and assistant professors) number approximately 2.000. This number is supplemented by about 1.500 administrative and technical support staff.

Its infrastructure consists of a big amount of scientific high-technology equipment, as well as sophisticated data and voice networks.

Funded research

With its 10 Faculties and 44 Departments, the Aristotle University of Thessaloniki offers both new and ongoing educational services at undergraduate and postgraduate level and covers almost the entire spectrum of scientific areas in which funded research projects are conducted. Therefore, it can offer many interesting programs in all of these areas.

The scientific study areas of the research programs vary. The most important of these areas are the following:

- Environment
- Informatics
- Telecommunications
- Industrial Technology
- Transport
- Biotechnology
- Biomedicine and Health
- Agriculture, Forestry and Fishing
- Education and Language
- History and Archaeology
- Social and Economic Sciences
- Humanities

European Collaboration in Research

Within the framework for the implementation of the programs, bilateral of multi-lateral international cooperation is achieved with universities, research centers, and other bodies, both national and European as well as in other countries.

P3
Advantages of Multi-standard Monorail System in Logistics Transportation

PROF. ERYU ZHU / BEIJING JIAOTONG UNIVERSITY

INTERNATIONAL MONORAIL ASSOCIATION

Advantages of Multi-standard Monorail System in Logistics Transportation

Eryu Zhu[1] Teng Li[1] Lei Liu[1]

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Abstract: The research and development Center of straddle monorail system in Beijing Jiaotong University has developed a multi-standard monorail system based on the existing straddle monorail transit and suspended monorail transit. The multi-standard monorail system has the characteristics of safety, environmental protection, simple construction, automation, flexible disassembly, low cost, less land occupation, fast speed and could be prioritized in transportation. In this paper, the characteristics of multi-standard monorail system from the perspective of logistics was explained, and a specific case was investigated to analyze the advantages of multi-standard monorail system relative to the traditional logistics transportation system. The results show that the multi-standard monorail system has obvious advantages in logistic transportation, and could bring huge market values.

Keywords: Straddle monorail; suspended monorail; maglev system; multi-standard monorail; logistics transportation

0 Introduction

In recent years, monorail transit in China has received extensive attention. In addition to the existing two Chongqing monorail lines that have begun operation, the planning, design, and construction of multiple monorail lines in Wuhu, Liuzhou, and other places have begun. At the same time, in some scenic spots, suspended monorails have also come out as amusement facilities in many places; Shaanxi Province also has a suspended line under construction. In addition, the “Belt and Road” International Standard Alliance for Straddle Monorail System (ISAM) was established in Wuhu, China. The organization will publish a series of monorail transport standards and regulations in the form of an alliance. In addition, China's maglev will also be greatly developed, and many places have planned different types of maglev types. In conclusion, the future development prospects of monorail transit in China will be very broad.

1 Multi-standard monorail and its characteristics

Single-standard monorail system includes straddle monorail, suspended monorail, and maglev. The straddle monorail refers to the rail transit from where vehicles sitting on the top of the guideway; the suspended monorail refers to the rail transit form where monorail trains are suspended at the bottom of the guideway; the maglev refers to the rail transit form where vehicles running on the top of the guideway supported by the magnetic force.

Under the leadership of Professor Eryu Zhu, the research and development Center of straddle monorail system in Beijing Jiaotong University innovatively proposed the multi-standard monorail transit system based on the existing monorail system. The multi-standard monorail system is based on the straddle monorail, the suspended monorail and the maglev, which is set up on the road slope or the central reservation belt of highways [1], and uses the resources of low-level channels in the city. The multi-standard monorail system includes the upper straddle and lower suspended monorail system or the upper maglev and lower suspended monorail system (Fig. 1) [1]. The system uses two spaces above and below the beam, thus greatly improving the transport efficiency and better relieving the traffic pressure on the road surface. The system can be located on the middle belt of the road, or the slopes on either side of the road so that it does not occupy existing road resources [1]. Existing beams for suspended monorail transit are rigid rail beams, which can be prestressed concrete beams [2] or prestressed concrete and steel composite beams [3]. Such beams have been verified by experiments on torsion [4] and flexural [5], and at the same time, there have been studies on beam joints overrun [6], linear planning [7], and emergency beam manufacturing [8]. Therefore, the suspended monorail rigid beam has been verified theoretically and experimentally. However, the performance of the multi-system monorail transit rail beam is required to be higher because trains are passing above and below it. Research and development are also underway.

Fig.1 The multi-standard monorail system

The characteristics of multi-standard monorail beam in terms of transportation include the following [1] [9]:

(1) Safe

The traveling mechanism of maglev or straddle monorail and suspended monorail in the multi-standard monorail transportation system is totally different from that of the steel-wheeled rail system in railways or subways. The bogies of the vehicles are all rail-holding structures. There will be no derailment accidents, which fully guarantees the operational safety of the system. In addition, the multi-standard logistics system runs in the air and has a fixed track, so there will be no collisions with other external trains.

(2) Environment friendly

The multi-standard logistics system is powered directly by a catenary and driven by a motor, unlike the truck with exhaust emissions, so it is green and environmentally friendly.

(3) Simple construction

The guideway, pier column and distribution center in the multi-standard logistics system all adopt the prefabricated structure form, which can be prefabricated in the factory in advance and then transported to the site for installation. Therefore, the field construction time is tremendously saved. Furthermore, the pier column foundation adopts the form of reinforced concrete cast-in-place pile, so the earthwork is very small, and the construction has a limited impact on the road traffic. Finally, the construction period is short.

(4) Automation

The maglev train or straddle monorail train and suspended monorail train in the multi-standard logistics system all adopt the whole automatic driverless system. It can ensure a safe, in time and whole-day operation.

(5) Flexible

According to the needs of road and urban development, the multi-standard logistics system can be extended or disassembled at any time and can be moved to other places to be installed and used again without too much waste of resources.

(6) Low cost

The guideway and pier column of the multi-standard logistics system adopts the form of assembled structure, which belongs to the transportation system of small volume and high density. Compared with other logistics systems, its cost is lower and is convenient and fast.

(7) Land use

The multi-standard logistics system for the viaduct structure covers a very small land area and has little demolition work. Lines can be built along city streets or central areas in the middle of roads, greatly reducing the amount of land use.

(8) Fast speed

The multi-standard logistics system is the rail transit system, which is not affected by ground traffic. The maximum operating speed of maglev could reach 200-300km/h; straddle monorail could reach 50-80km/h and suspended monorail system could reach a speed of 50-80km/h.

(9) Prioritized levels

In the multi-standard logistics system, each line is a dual-system traffic mode. The maglev traffic system or straddle monorail system is used on the upper part of the pier cover beam as a fast passage. The lower part of the pier cover beam is a suspended monorail system as a slow passage. The combination of fast and slow channels can be used to assign priority levels to goods for transportation.

2 Analysis of advantages of multi-standard monorail system in logistics

2.1 Transportation cost advantage

For road transportation, the relevant research [10-18] results show that the average ton-kilometer cost is 0.65 yuan (RMB), and the main cost is calculated by the GTC model. The average ton-kilometer cost will increase/decrease 0.0335 yuan when the fuel price increases/decreases by 10%.

The average ton-kilometer cost of railway transit is 0.15 yuan. The main items constituted by freight are: basic operating expenses, miscellaneous expenses, railway construction fund, new road and new price amortized freight and electrification surcharge.

Air transport fees are based on China's current domestic civil aviation freight rates, with the average basic freight (below 45kg) 4.90 yuan/kg and the minimum freight 30 yuan.

The cost of water transportation is low. The cost of coastal transportation in China is only 40% of that of railway. The cost of transportation in the Yangtze River trunk line is only 84% of that of railway.

Pipeline transportation is developed with the growth of oil and gas production, and has become the main transportation mode of onshore oil and gas. Pipeline transportation fee is about 0.15 yuan/square.

Case study：

Assume that a multi-standard logistics transportation line is built on the Beijing-Tianjin Expressway. The total length of the line is about 140km, and each train contains 8 vehicles. It is estimated that the annual freight volume could reach 1,261,400 tons

[10-18], and the transportation cost estimates are shown in Table 1.

Table 1 Logistics and transportation cost breakdown of Beijing-Tianjin high-speed multi-system

The cost of the project	Annual cost per kilometer/Ten thousand yuan	The cost per unit/（Yuan/t.km）
Infrastructure cost	2947.28	0.1168
Operating costs	1198.37	0.0475
Environmental external cost	696.31	0.0276
User cost	3387.47	0.13427
Accident cost	5.3	0.00021
Combined cost (total)	8234.73	0.32638

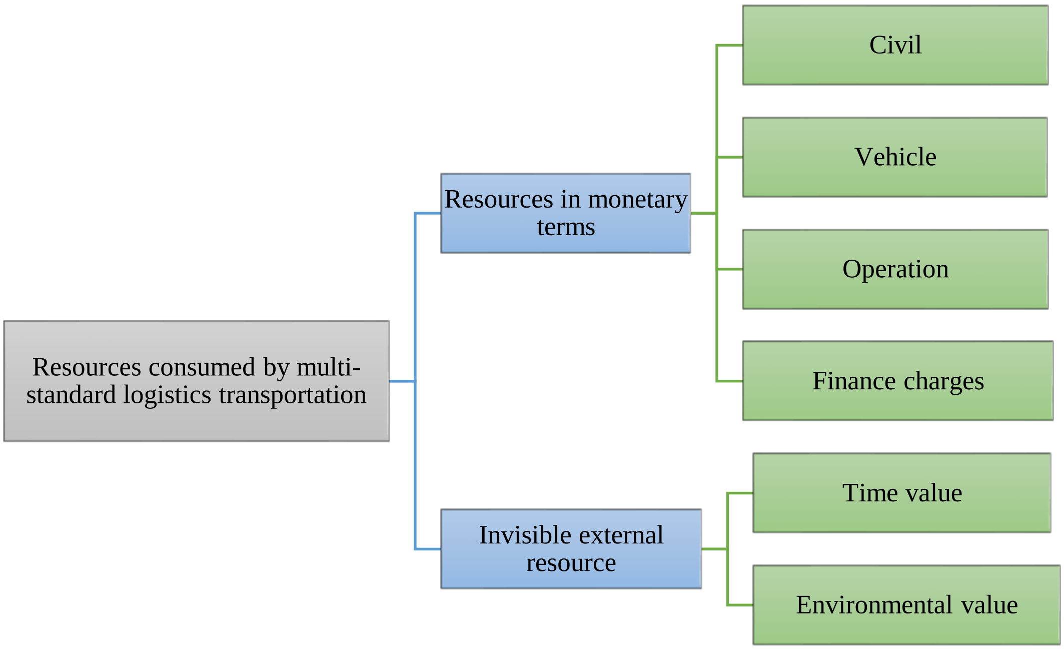

Fig. 2 Resource tree of multi-standard logistics transportation consumption

According to the above analysis, the average ton-kilometer cost of the multi-standard logistics system is 0.326 yuan, and the transportation cost only accounts for half of the road transportation. At the same time, the transportation cost of a multi-standard logistics system is twice that of railway transit, but much lower than that of air transportation.

2.2 Construction cost advantage

According to some statistics [10-18], in the general plain and small hills area, the average cost per kilometer of expressway is more than 30 million yuan. In mountainous areas, expressways cost more than 50 million yuan per kilometer on average. And with the improvement of highway grade, the cost continues to increase.

The cost of an ordinary railway could reach 100 to 300 million yuan per kilometer, while that of high-speed railway could reach 400 to 600 million yuan.

As for the air transportation, construction cost includes the airport, aircraft construction and maintenance, airport service facilities. Construction cost is far higher than other modes of transportation.

The average cost per kilometer for the construction of a multi-standard logistics system (including transport vehicles, logistics distribution stations, and other supporting facilities) on expressways is 30 million yuan, as shown in Table 2. In the tunnel and bridge part, the average cost per kilometer is 50 million yuan.

Table 2 A breakdown of the cost of building a multi-standard logistics system on highways

Project and cost name	Estimated value（Ten Thousand Yuan）				Sum（Ten Thousand Yuan）
	I	II	III	IV	
	Construction cost	Installation cost	Equipment purchase costs	Other construction expenses	
Logistics distribution station	238.56				238.56

Track engineering	743.79				743.79
Power		206.8	126.75		335.55
Disaster prevention alarm, environment and equipment monitoring		43.57	26.86		70.43
Water supply and drainage and fire protection		54.82	63.68		118.5
Distribution station auxiliary equipment		26.84	135.42		162.26
Engineering construction and other expenses				527.81	527.81
Reservation fee				368.52	368.52
Vehicle purchase fee				320	320
Loan interest during construction period				50.86	50.86
Initial working capital				13	13
Total investment	982.35	332.03	352.71	1280.19	2947.28

2.3 Efficiency advantage

Compared with road transportation, the multi-standard logistics system runs faster, and the flexibility of its site setting is no less than that of road transportation, especially in the expressway service area [1]. The site can make the perfect combination of multi-standard logistics and road transportation. Compared with railway transportation, multi-system logistics is more flexible, and the timeliness will be greatly improved. Air transport is the most efficient of all modes of transport right now, but it is expensive and radiates limited areas.

2.4 Safety management Advantages

The safety of highway transportation is affected by weather, road conditions, drivers, and other aspects. The reliability of road transport is also affected by holidays, in general, the reliability of road transport is low. Especially for the transportation of hazardous chemicals, safety management is worth considering.

The safety management of railway transportation should consider aspects such as the system, personnel, equipment, and transportation capacity that cannot be met during peak periods, as well as the impact of natural disasters. The safety of railway transportation is influenced by many factors such as human factors, technical equipment, and the environment.

Air transportation has higher requirements for weather conditions, such as thunder and lightning or severe smog, which is not suitable for takeoff. And air transportation has strict requirements on cargo types and specifications.

Multi-standard logistics is a low-altitude transportation system, and the reliability of transportation is not affected by weather, road conditions, drivers, etc., nor is it affected by holidays. In general, the safety and reliability of the multi-standard logistics system are relatively high.

Table 3 Comparison of the advantages and disadvantages of five logistics systems

	Transportation cost	Construction cost	Speed	Safety management
Roadway	0.65Yuan/ ton-km	0.3～0.5 (one hundred million yuan)/km	60km/h	Severely affected by the weather
Railway	0.15Yuan/ ton-km	Railway 1～3 (one hundred million yuan) /km	80km/h	All day
Aviation	4.50Yuan/ ton-km		800km/h	Severely affected by weather and cargo
Water	0.10Yuan/ ton-km		35km/h	Severely affected by weather and navigation

				channels
Multi-standard system	0.33Yuan/ ton-km	0.30 (one hundred million yuan) /km	200～300km/h	All day

3 Case study of multi-standard monorail logistics transportation system

The Beijing-Tianjin expressway is the second direct highway between Beijing and Tianjin. The main road is designed for eight lanes in both directions. The Beijing-Tianjin expressway has a total length of 140km, and the terrain of the whole line is flat. It is known that the cargo volume of the Beijing-Tianjin Expressway in 2017 was 87.95 million tons. Among them, the proportion of express delivery, fast freight, cold chain, and truckload are shown in Figure 3 [10-18].

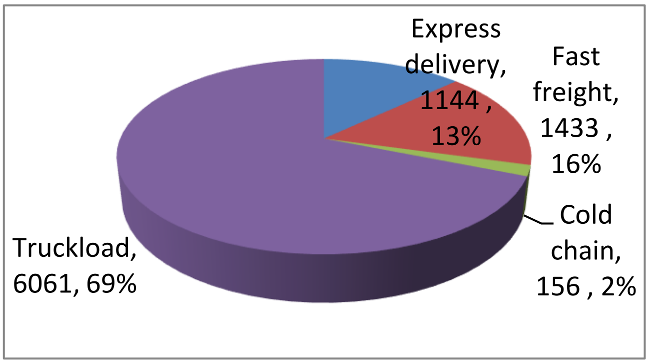

Fig.3 2017 Beijing-Tianjin express delivery, fast freight, cold chain and truckload

It is estimated that the annual growth rate of express delivery and fast freight in China are both 20%, and that of cold chain is 50% [10-18]. Therefore, by 2020, the freight volume of Beijing-Tianjin Expressway reaches 136 million tons, among which the proportion of express delivery, fast freight, cold chain, and whole vehicle are shown in Figure 4.

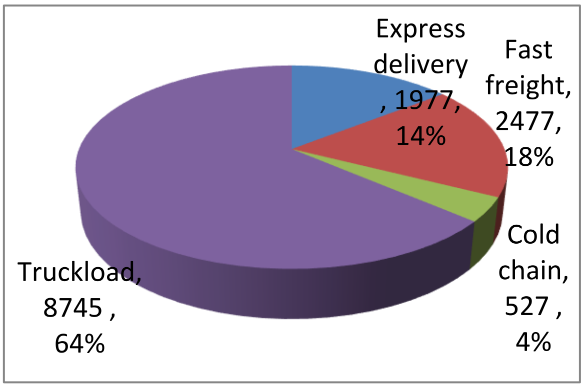

Fig.4 2020 Beijing-Tianjin express delivery, fast freight, cold chain and truckload

It is assumed that the multi-standard logistics transportation line is built on the Beijing-Tianjin expressway. The length of the line is 140km and there are four two-way channels running. Trains leave from opposite directions every five minutes. The upper layer is maglev type, 8 ~ 10 sections a group, each section 0.5 ~ 0.75t, each trainload 4.0 ~ 7.5t, and the charge is 0.6 yuan per ton kilometer. The lower layer is suspended type, 8 ~ 10 sections a group, each section 1.0 ~ 1.5t, each trainload 8.0 ~ 15.0t, 0.3 yuan per ton kilometer charge. The construction cost is about 30 million yuan per kilometer, and the project investment payback period is calculated as follows:

The static payback period is:500000 / (12614.6+18921.6) = 15.85 years.

The payback period and rate of return are shown in Table 4.

Table 4 Static payback period and internal rate of return at different price of multi-standard logistics system

Annual price increase 5%	0.6 yuan/ ton-km	0.3yuan/ ton-km	maglev 0.6yuan/ ton-km suspended 0.3Yuan/ ton-km
Payback period	13.21	17.62	15.85
15-year internal rate of return during operation	6.04%	2.36%	3.66%
20-year internal rate of return during operation	8.96%	5.79%	6.91%

4 Conclusion

The innovative structure form of multi-standard monorail transit makes better use of the space resources of the road and the beam and has many excellent characteristics. Compared with traditional logistics transportation, multi-standard monorail transit has an advantage in cost, efficiency, and safety. The development of the multi-standard logistics system will be an effective means to reduce the transportation cost, especially the cost of the small intercity express. The multi-standard logistics system offers an innovative method to use the expressway resources intensively and make full use of the low-altitude channel to better use the space of the expressway. The application of the multi-standard logistics systems can drive the development of many industries. As a new economic growth point, it will give birth to a huge value market.

Acknowledgement:

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Eryu Zhu

Eryu Zhu, Ph.D, postdoctoral, professor, doctoral supervisor, vice president of the International Monorail Association (IMA). He is now the director of Research and Development Center of Straddle Monorail Transit in School of Civil Engineering of Beijing Jiaotong University. He mainly engaged in the research of straddle monorail, suspended monorail, maglev and other transportation fields. He has trained more than 100 doctoral and graduate students.

Prof. Zhu likes reading all kinds of materials about monorail transit after work. He likes reading all kinds of materials in different subjects. Professor Zhu also likes taking pictures.

Beijing Jiaotong University (BJTU) is a key university specializing in the study of rail transit in China. The history of the university dates back to 1896. BJTU is one of the leaders in China's high-speed rail technology. The discipline of transportation engineering has been ranked the first in the world for three consecutive years. Engineering remains in the top 1‰ of Essential Science Indicators (ESI), and 5 disciplines are in the top 1% of ESI.

Beijiao Tiangui Rail Transit Technology Co., Ltd. (BJTG) is a university-run company, and BJTU owns its shares. Its trademark is . Its brand name is Tiangui. In terms of “Tiangui”, “Tian” means sky and “gui” means rail. Its goal is to create the future of first-class monorail for logistics and passenger transportation, and it has a wide influence in the field of rail transit. BJTG was founded by Professor Zhu Eryu, vice president of the International Monorail Association (IMA). Professor Zhu led the research team to develop more than 200 patented technologies after more than 20 years. BJTG pioneered the concept of "one guideway, two rail transit systems" in the world, that is, to operate two monorail systems on a single guideway. In addition, BJTG has many innovations in straddle monorail, suspended monorail and maglev, including maglev seamless lines and assembly-based monorail technology. BJTG is becoming the world's largest and most well-known first-brand monorail consulting platform. BJTG warmly welcomes investment companies interested in the rail transit field to invest in BJTG and jointly create the future of monorail.

The Research & Development Center (RDC) for Straddle Monorail Transit in Beijing Jiaotong University was established in May, 2014. It is a well-known monorail research and development center in China. The director of the center is Professor Eryu Zhu. The RDC consists of 5 professors, 6 associate professors. RDC has trained more than 100 master students and 10 doctoral students in the field of rail transit.

P4
Energy Consumption Analysis of Straddle Monorail Transit in the Operational Phase Based on Grey Relational Method

TENG LI / BEIJING JIAOTONG UNIVERSITY

INTERNATIONAL MONORAIL ASSOCIATION

Energy consumption analysis of straddle monorail transit in the operational phase based on grey relational method

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Abstract:

Chongqing is currently the only city in China with straddle monorail transits. The operation of two straddle monorail lines throughout the year will bring a certain amount of energy consumption (electricity). To explore the influencing factors of the operational energy consumption of straddle monorail transit lines, this paper first defines four energy consumption indexes and uses the grey relational method to analyze the influence of five factors conforming to the design characteristics of the lines on the four energy consumption indexes of the two lines. In addition, in this paper, the characteristics of the ratio of traction energy consumption to total energy consumption of the two monorail lines were calculated according to the statistical data. The results were compared with metros in Chongqing, Beijing, Shanghai, and Guangzhou. The results show that for all energy consumption indexes, the influence degree of each factor is in the order of average speed > the actual number of vehicles per day > number of stations > length > total passenger volume. The ratio of traction energy consumption of monorail transit is higher than that of the subway.

0 Introduction

The world's first monorail was created in 1820. The modern straddle monorail appeared in the 1950s which is designed by Europeans. At the same time, a German company called ALWEG built its first straddle monorail at Walt Disneyland in California [1]. In Japan, the first straddle monorail, the Tokyo monorail, was officially put into operation in 1964, followed by several Japanese monorails participated by Hitachi [2]. After that, Bombardier, Hitachi, and other companies have introduced new straddle monorail technologies. The major countries that have built or are building monorail for large volume urban rail transit operations in the world include Japan, Canada, China, the United States, Germany, Russia, India, Malaysia, Brazil, South Korea, and so on. At the same time, Egypt, Brazil, Thailand, China, and other countries are actively building new straddle monorail transit lines, and monorail transit is gradually occupying a certain market share in the world rail transit field [3].

Straddle monorail has many advantages due to its structural characteristics, including environment friendly [4], low construction cost [5], little influence on road traffic [6], strong climbing ability [7], small turning radius [8], safety [9], etc., therefore, monorail traffic has attracted more and more attention around the world.

However, the research on the characteristics of monorail traffic energy consumption is not much in the world. To address this gap, this paper adopts the grey relational method to analyze the influence degree of 5 different factors on four energy consumption indexes in the operation process of Chongqing monorail transit line, including the line length, annual passenger volume, the actual number of vehicles per day, average speed and number of stations, which are in line with the design characteristics of the monorail lines. Finally, this paper compares the characteristics of the proportion of traction energy consumption to total energy consumption in the operation of monorail and metro lines in different cities according to the statistical data.

1. Theory and method

1.1 Grey relation theory

Grey correlation analysis is to compare the relationship of statistical sets of each study sequence and analyze the correlation degree among multiple factors through quantitative analysis of each factor in the system. In the system, if the trend of two factors is consistent, the degree of correlation between them is high. Otherwise, it is lower. The calculation steps of grey correlation degree are as follows: determining the analysis sequence, dimensionless sequence, calculating the correlation coefficient, the calculating correlation degree and the ranking of correlation degree. The main formulas are [10]:

$$xi(k) = \frac{X_i(k)}{X_i(l)}$$

$$k = 1,2,\dots,n;\ \ i = 0,1,2,\dots,m. \tag{1}$$

$$\xi_i(k) = \frac{min_i min_k \Delta_i(k) + \rho max_i max_k \Delta_i(k)}{\Delta_i(k) + \rho max_i max_k \Delta_i(k)} \tag{2}$$

1.2 Energy consumption intensity indexes

The energy consumption intensity indexes in this paper include the following four forms:

Total energy consumption index 1 is the total energy consumption per passenger-kilometer:

$$E_1 = \frac{E_{Total}}{PKT} \tag{3}$$

Where, E_1 is the total energy consumption per passenger-kilometer with the unit kwh/passenger-kilometer; E_{Total} is the total energy consumption with the unit of ten-thousand kwh; PKT is the passenger kilometers travelled with the unit of ten-thousand passenger-kilometer.

Total energy consumption index 2 is the total energy consumption per vehicle-kilometer:

$$E_2 = \frac{E_{Total}}{VKT} \tag{4}$$

Where, E_2 is the total energy consumption per vehicle-kilometer with the unit kwh/vehicle-kilometer; E_{Total} is the total energy consumption with the unit of ten-thousand kwh; VKT is the vehicle kilometers travelled with the unit of ten-thousand vehicle-kilometer.

Traction energy consumption index 1 is the traction energy consumption per passenger-kilometer:

$$E_3 = \frac{E_{Traction}}{PKT} \tag{3}$$

Where, E_3 is the traction energy consumption per passenger-kilometer with the unit kwh/passenger-kilometer; $E_{Traction}$ is the traction energy consumption with the unit of ten-thousand kwh; PKT is the passenger kilometers travelled with the unit of ten-thousand passenger-kilometer.

Traction energy consumption index 2 is the traction energy consumption per vehicle-kilometer:

$$E_4 = \frac{E_{Traction}}{VKT} \tag{4}$$

Where, E_4 is the traction energy consumption per vehicle-kilometer with the unit kwh/vehicle-kilometer; $E_{Traction}$ is the traction energy consumption with the unit of ten-thousand kwh; VKT is the vehicle kilometers travelled with the unit of ten-thousand vehicle-kilometer.

2. Energy consumption analysis and data source

The energy sources of straddle monorail are similar to those of subway, mainly traction, lighting, air conditioning, and braking [11].

The energy consumption of straddle monorail or subway operation studied in this paper is mainly divided into two categories: one is traction energy consumption, the other is the other energy consumption, including ventilation, lighting, and other energy consumption. The total energy consumption includes traction energy consumption and other energy consumption. According to the actual characteristics of each project, this paper selects five factors, including the line length, annual passenger volume, the actual number of vehicles per day, average speed, and number of stations.

The annual traction energy consumption, total energy consumption, and other line characteristic data of Chongqing monorail Line 2 and Line 3 in this paper are all from China Urban Rail Transit Almanac 2019 [12]. China Urban Rail Transit Almanac 2019 has compiled the operating data of China's urban rail transit in 2018. Excel and Origin software were used for data statistics and analysis.

3. Study on the influence factors of operational energy consumption of Chongqing Monorail Line 2 and Line 3 based on grey relational method

In this paper, two straddled monorail transit lines operated in Chongqing in 2018 are selected for analysis. The train running diagram is shown in Figure 1, and the energy consumption indexes are shown in Table 1. All the data are from the China Urban Rail Transit Almanac 2019.

Figure 1 Chongqing monorail transit line

Table 1 Operation energy consumption of monorail transit lines in Chongqing

Order	**Name**	E_1 **(kwh/passenger-kilometer)**	E_2 **(kwh/passenger-kilometer)**	E_3 **(kwh/vehicle-kilometer)**	E_4 **(kwh/vehicle-kilometer)**
1	Line 2	0.0703454477	2.926269645	0.04488406457	1.8671126553
2	Line 3	0.062078766	2.959887457	0.03861695	1.841238668

The total energy consumption index 1 is taken as an example to carry out the grey correlation analysis. The initial grey correlation analysis matrix of Chongqing monorail transit Line 2 and Line 3 constructed according to the line conditions is shown in Table 2, and the results are shown in Table 3. In Table 3, the larger the value is, the greater the influence of this factor is.

Table 2 Operational data of straddle monorail transit lines in Chongqing (Energy index 1)

Order	**Name**	**Length(kilometer)**	**Station**	**Annual passenger volume (ten-thousand passenger)**	**Actual number of vehicles per day**	**Average speed (kilometer/h)**
1	Line 2	31.36	25	11547.14	463.29	31.85
2	Line 3	67.09	45	30365.76	825.87	34.80

Table 3 Grey correlation analysis results of energy consumption indexes of straddle monorail transit lines in Chongqing

Index	**Length(kilometer)**	**Station**	**Annual passenger volume (ten-thousand passenger)**	**Actual number of vehicles per day**	**Average speed (kilometer/h)**
E_1	0.5321	0.6001	0.4724	0.6046	1
E_2	0.4495	0.5187	0.3913	0.5233	1
E_3	0.5448	0.6123	0.4851	0.6167	1
E_4	0.4670	0.5363	0.4082	0.5409	1

For all energy consumption indexes, the influence degree of each factor is in the order of average speed > the actual number of vehicles per day > number of stations > length > total passenger volume.

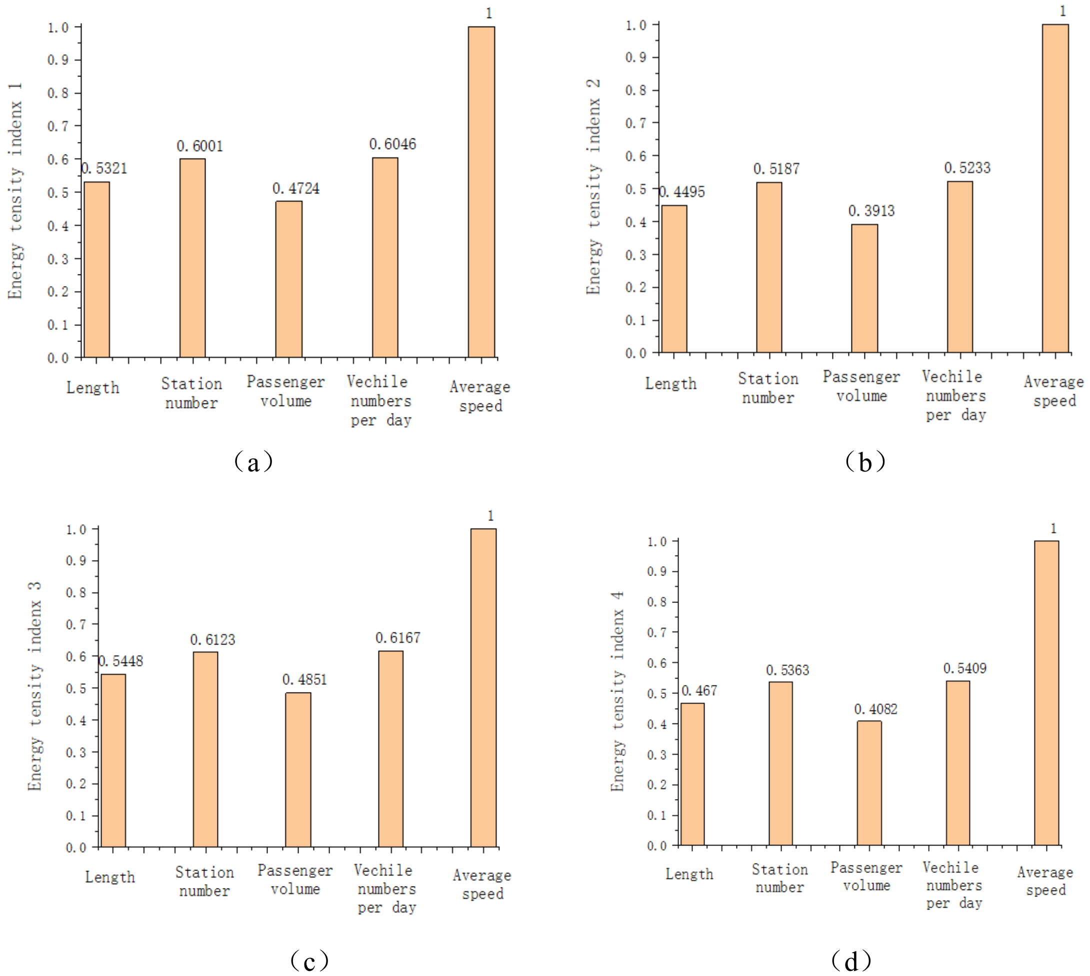

Figure 2 Analysis of grey relational degree of energy consumption indexes of Chongqing monorail transits

4. Analysis of ratio of traction energy consumption

For Chongqing subway, Beijing subway, Shanghai subway, and Guangzhou subway, the ratios of traction energy consumption are shown in Figure 3-6. The average ratios of traction energy consumption of subways in Chongqing, Beijing, Shanghai, and Guangzhou are 51.163%, 60.52455%, 60.43848%, and 50.87223%, respectively. For Chongqing monorail line 2 and Line 3, the ratios of traction energy consumption are 63.8052% and 62.2064%, and the average value is 63.0058%, which is higher than those of all subway lines.

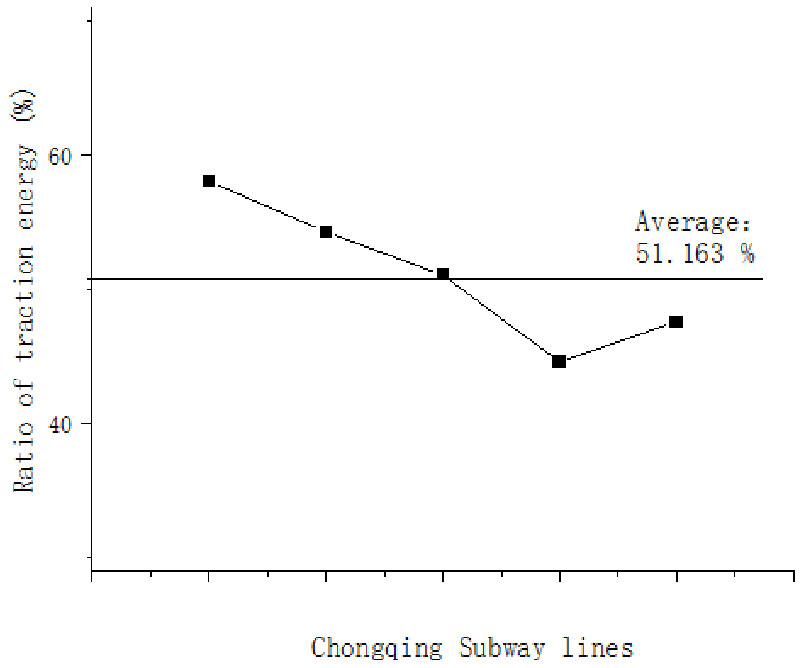

Figure 3 Traction energy consumption ratio of Chongqing subway

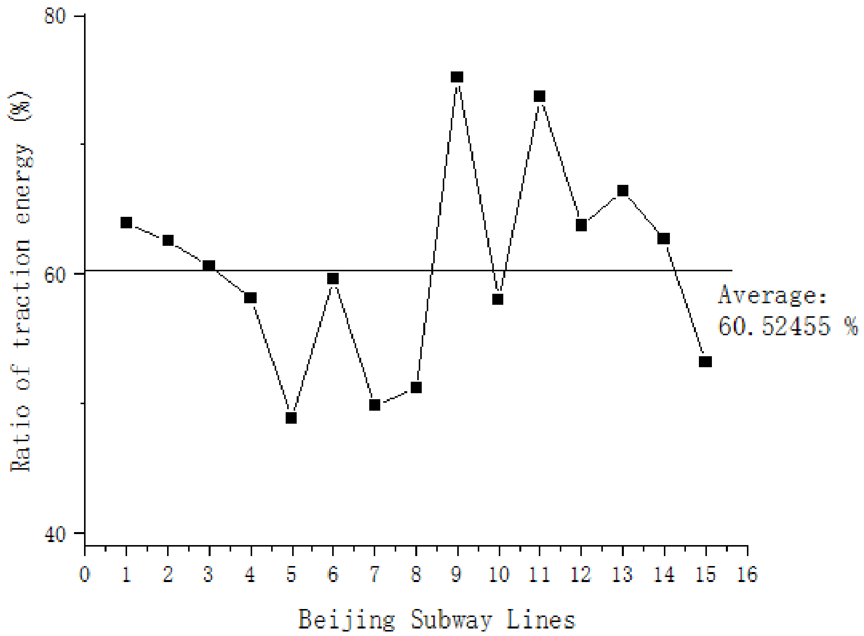

Figure 4 Traction energy consumption ratio of Beijing subway

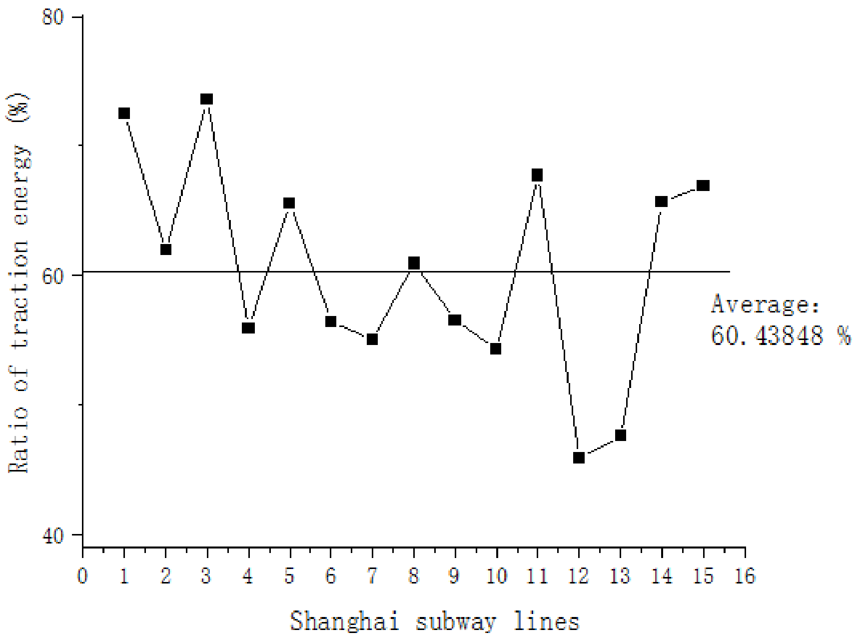

Figure 5 Traction energy consumption ratio of Shanghai subway

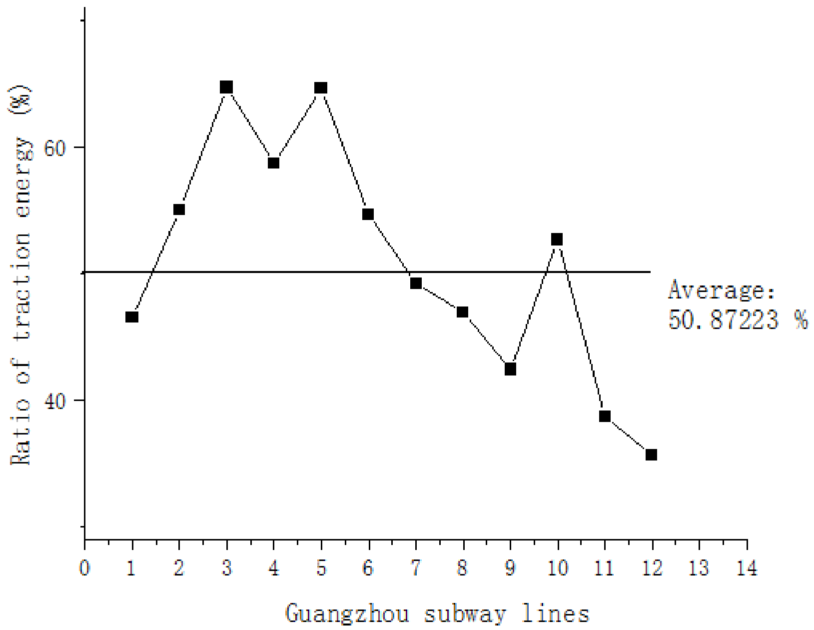

Figure 6 Traction energy consumption ratio of Guangzhou subway

5. Conclusion

In this paper, the energy consumptions of Chongqing monorail lines were analyzed and calculated. Firstly, four energy consumption intensity indexes are defined, E_1, E_2, E_3 and E_4.

Average speed, length, number of stations, actual number of daily vehicles, and total passenger volume were selected as five influencing factors. Through grey relational degree analysis, it is found that for the four energy intensity indexes of Chongqing monorail transit line 2 and Line 3, the order of influence degree of each factor is: average speed > the actual number of daily vehicles > number of stations > length > total passenger volume.

This paper analyzes the ratios of traction energy consumption in the total energy consumption of Chongqing monorail transits and Chongqing, Beijing, Shanghai, and Guangzhou metros. It is found that the average ratio of traction energy consumption of Chongqing monorail transit is 63.0058%, and that of Chongqing metro is 51.163%. The average energy consumption ratio of Beijing metro is 60.52455%, that of Shanghai is 60.43848%, and that of Guangzhou is 50.87223%. Monorail transit has the highest energy consumption ratio.

Acknowledgement:

This work is supported by 2021JBM426 of Beijing Jiaotong University, Beijing, China.

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Teng Li

Dr. Teng Li is a Ph. D candidate in bridge engineering department, school of Civil Engineering, Beijing Jiaotong University. Dr. Teng Li's main research area is whole life cycle carbon footprint, and corrugated duct structure. At the same time, Teng Li also helps Prof. Eryu Zhu with the things from the International Monorail Association, such as the monthly video conference translation, document work, paper writing and so on.

Teng Li likes to watch videos after work. He takes part in various activities to broaden his knowledge after work. Teng Li is interested in reading and playing basketball.

Beijing Jiaotong University (BJTU) is a key university specializing in the study of rail transit in China. The history of the university dates back to 1896. BJTU is one of the leaders in China's high-speed rail technology. The discipline of transportation engineering has been ranked the first in the world for three consecutive years. Engineering remains in the top 1‰ of Essential Science Indicators (ESI), and 5 disciplines are in the top 1% of ESI.

Beijiao Tiangui Rail Transit Technology Co., Ltd. (BJTG) is a university-run company, and BJTU owns its shares. Its trademark is . Its brand name is Tiangui. In terms of "Tiangui", "Tian" means sky and "gui" means rail. Its goal is to create the future of first-class monorail for logistics and passenger transportation, and it has a wide influence in the field of rail transit. BJTG was founded by Professor Zhu Eryu, vice president of the International Monorail Association (IMA). Professor Zhu led the research team to develop more than 200 patented technologies after more than 20 years. BJTG pioneered the concept of "one guideway, two rail transit systems" in the world, that is, to operate two monorail systems on a single guideway. In addition, BJTG has many innovations in straddle monorail, suspended monorail and maglev, including maglev seamless lines and assembly-based monorail technology. BJTG is becoming the world's largest and most well-known first-brand monorail consulting platform. BJTG warmly welcomes investment companies interested in the rail transit field to invest in BJTG and jointly create the future of monorail.

The Research & Development Center (RDC) for Straddle Monorail Transit in Beijing Jiaotong University was established in May, 2014. It is a well-known monorail research and development center in China. The director of the center is Professor Eryu Zhu. The RDC consists of 5 professors, 6 associate professors. RDC has trained more than 100 master students and 10 doctoral students in the field of rail transit.

P5

Hydrogen: New City Energy Concepts

JÜRG FÜRST / BALANCE DRIVE AG
PETER KELLER / DERAP AG

INTERNATIONAL MONORAIL ASSOCIATION

Hydrogen – new City Energy Concepts

By Juerg Fuerst, Balance Drive AG –
Peter Keller, Derap AG

Monorails are becoming more and more popular in modern urban environments that are searching for new more efficient public transport solutions. But the public transport can be also part of a complete new city energy concept.

Hydrogen is one of many options to produce and store clean energy. That provides entirely new perspectives for a city energy concept. Hydrogen can be used as energy for public transport, as a commercial energy for road cars or trucks and busses as well as for the building technology.

Hydrogen –
new city energy concepts

Balance Drive Ltd.

Jürg Fürst,

Derap AG

Peter Keller

Ways to produce hydrogen

from fossil fuels
(e.g. natural gas)

steam reforming
(natural gas or biomass)

from water
(e.g. electrolysis)

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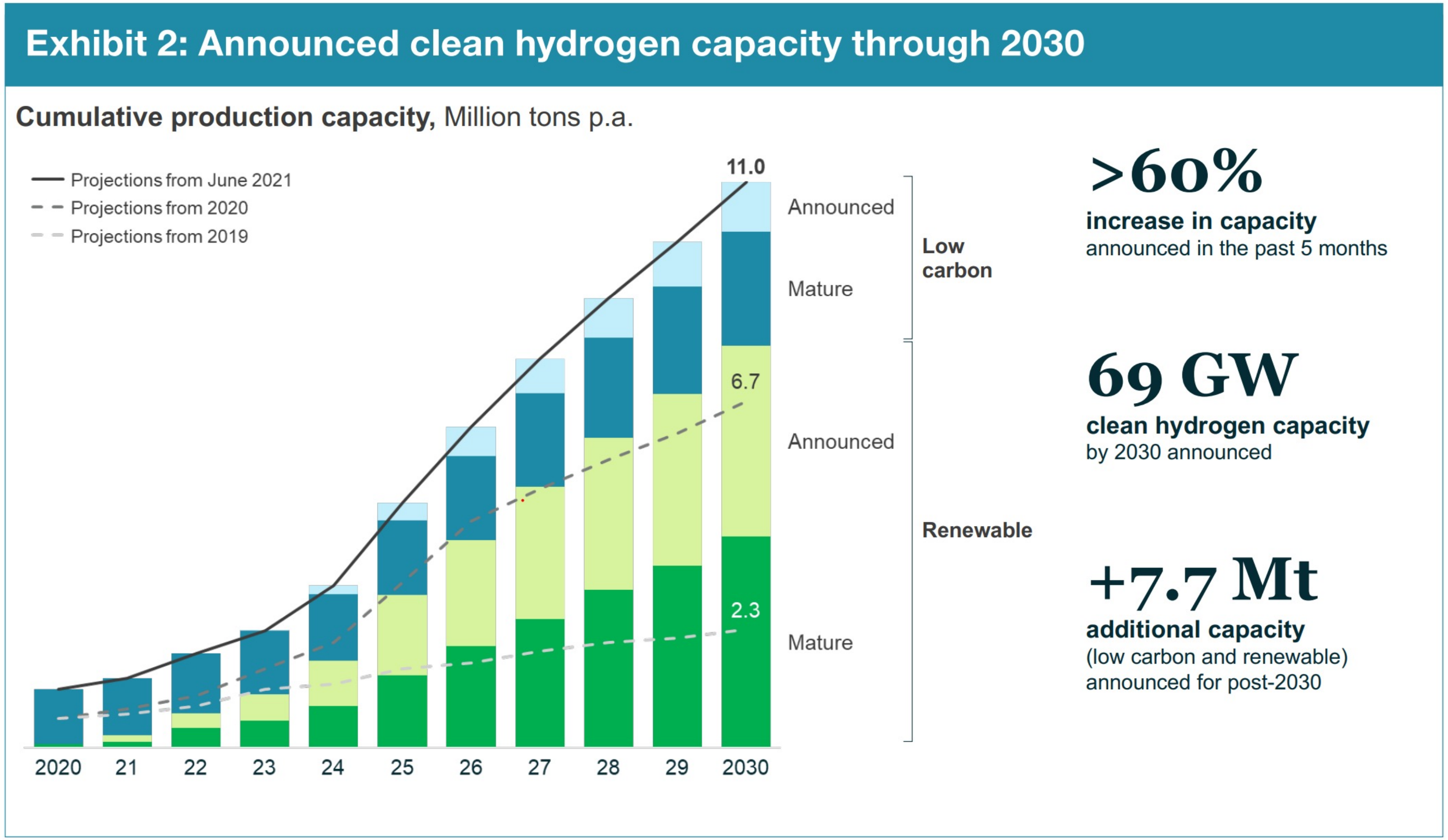

Source: hydrogen council, insights hydrogen July 2021

Hydrogen storage

Compressed hydrogen

Hydrogen gas is compressed.

- 500…700 bar in vehicles
- 30 bar to transport in tanks

Liquid hydrogen

The hydrogen is liquified by reducing its temperature to -253°C.

As a solid

In metal storages, hydrogen is chemically bonded with metals or alloys to form metal hybrides.

Ways to use hydrogen

Converting to electricity and heat

Fuel cells produce electricity and thermal energy

Feeding into a natural gas grid

In EU the natural gas grid can be fed with up to 5% H2

Source: Energie Park Mainz

Energy source

Energy source for vehicles

- Public transport
- Truck
- Cars

For buildings

- Converting to electricity and heat

Production of synthetic fuels

Synthetic fuels (petrol and diesel) made from H2 and CO2.

Green hydrogen

Definition

Green hydrogen is produced out of water with electricity from low-carbon sources.

The most common way of production is with electrolysis, whereby electricity from photovoltaic systems or hydropower plants is used.

Combination with other energy sources

Incineration plants have high energy resources that could be used to produce hydrogen.

- energy storage
- feed of H2 into natural gas grid
- production of methanol or synthetic fuels with H2 and CO2 from the thermal process in the plant

Hydrogen as energy for public transport

Nowadays

Todays public transport is mainly driven by electricity.

Vehicles are running with:

- Battery
- Overhead lines or current lines
- Hybrid vehicles (combustion engine and battery)

Problems:

- Maintenance
- Current peaks
- Lines without electricity grid
- Charging stations

Hydrogen as energy for public transport

New ways with hydrogen

- Fuel cell vehicles using hydrogen as energy source
- Vehicles in public transport can also transport hydrogen from A to B and are a part of the hydrogen supply chain
- The city infrastructure becomes more connected. Waste treatment plants, natural gas grid, wind and photovoltaic plants, electrical grid, public transport and individual transport are all connected and support each other
- Hydrogen production is used to stabilize the electrical grid
- The electrical grid of public transportation will be used for decentralized hydrogen production, right at the place where the hydrogen is needed (fuelling station for Monorail, Bus, Cars, Truck….)
- Sun and wind energy will be stored as hydrogen

Jungfraupark

The “Jungfrau Park” located in Interlaken CH is in need of new activities and attractions due to low attendance figures. It offers an excellent location and infrastructure.

- Near the Interlaken Ost railway station
- Near the freeway entrance
- Large parking
- More space to expand

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BALANCE DRIVE SWISS MOTION

New project

The idea is to add a Clean Energy Resort to the existing pavillions :

- With a hotel for visitors
- With a clean energy Swiss Chalet hotel
- With restaurants and shops
- With pavillions for the touristic spots in the surrounding region
- With a development centre for clean energy and new transport systems (Monorail, Busses, etc.)






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SWISS ENGINEERING SOLUTIONS

BALANCE DRIVE
SWISS MOTION

Attractions

We are in the heart of exciting attractions such as:

Jungfraujoch, Schilthorn, Harder, Giessbachfalls, St. Beatus caves, Ballenberg museum, town and lake of Thun, lake of Brienz and Interlaken.






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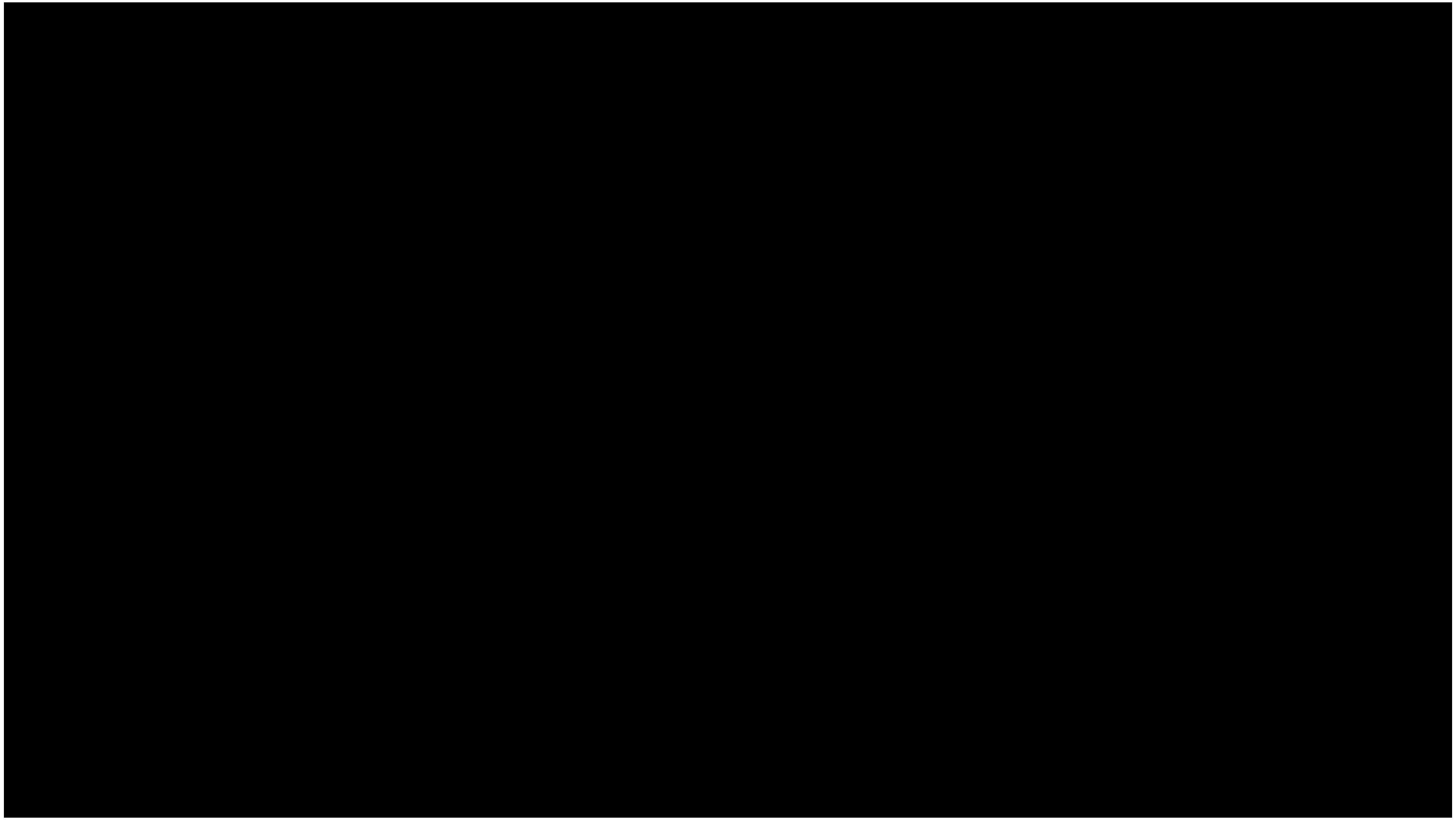
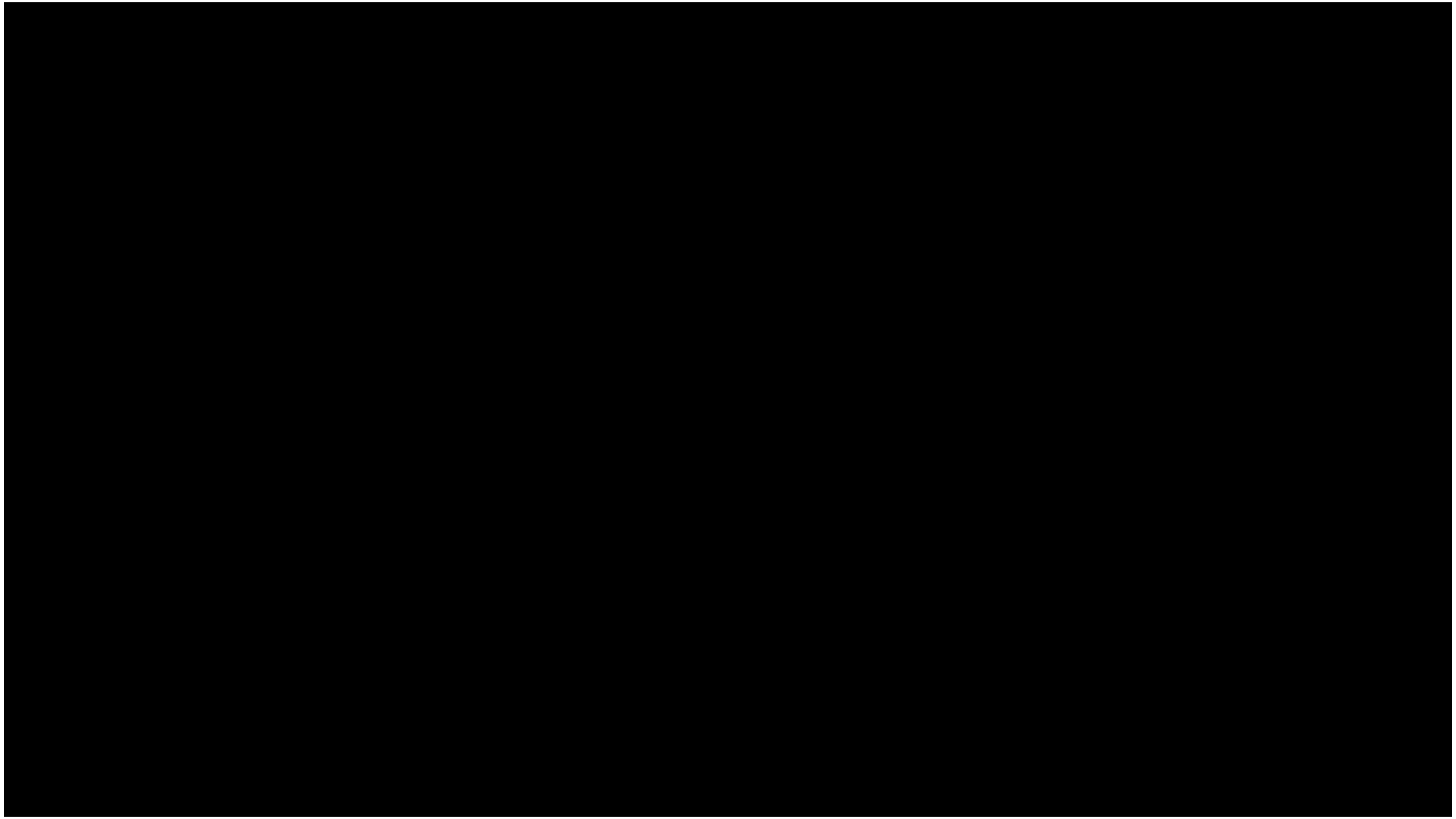
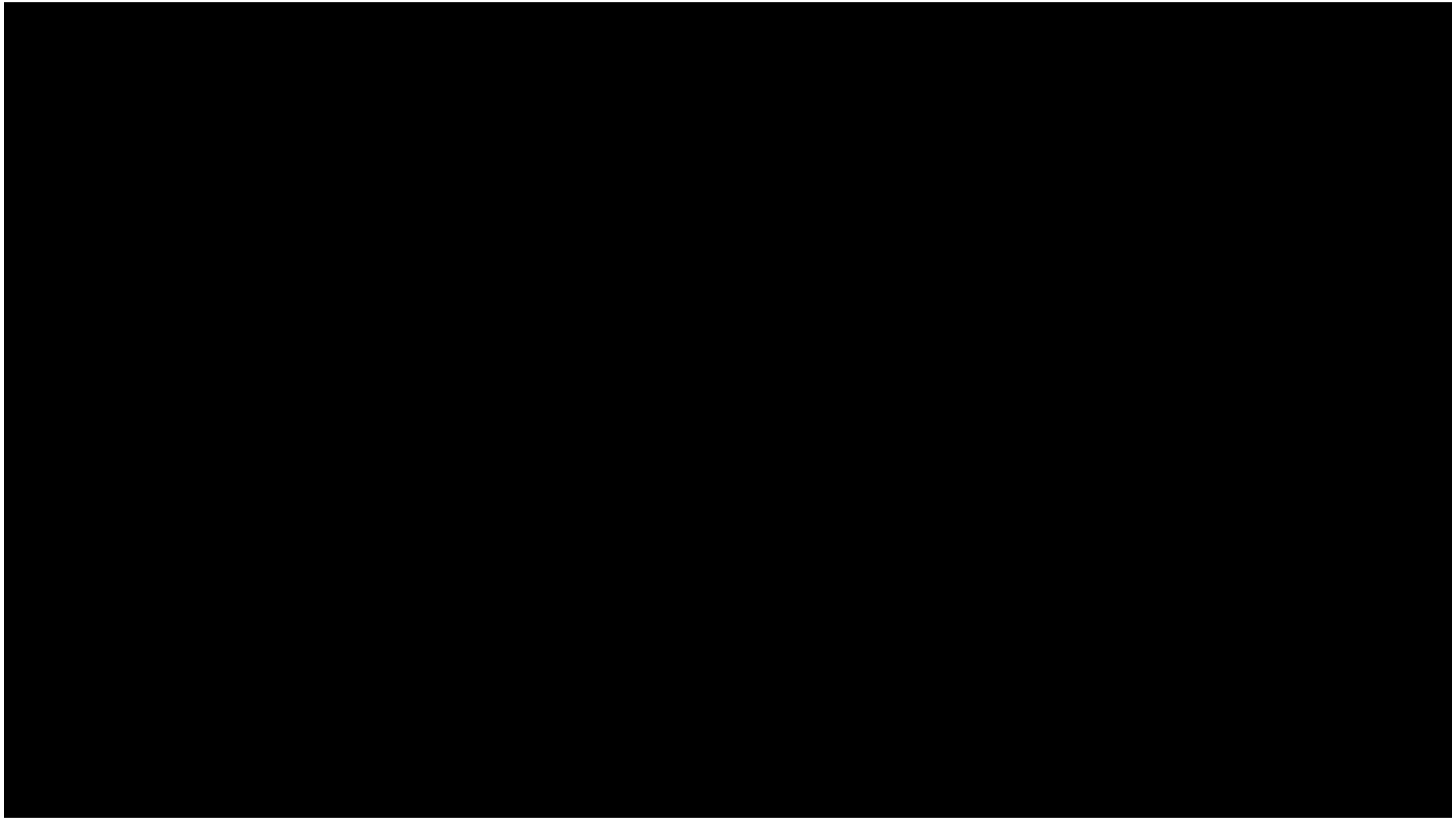
Monorail MRST



Bus SRT Vehicle



City Cable Car - CCC



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SWISS MOTION

Jungfraupark Clean Energy Resort (CER)

Business park for new transport projects

- Electric drives for different projects
- Hydrogen for different transport systems
- Development centre and test field
- Visiting centre and presentation platform for students and companies

Summary

- Hydrogen offers complete new possibilities to store energy and connect different infrastructures
- Public transport running with hydrogen could support the supply chain and help to stabilize the electrical grid
- H2 production can help to reduce CO2 emissions in the industry – synthetic fuel or methanol production
- The Clean Energy Resort Jungfrau Park will be a combination of touristic infrastructure and new technology development
- The resort is also a good opportunity for education, research and technology events

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Thank you for your attention!

P6
Hydrogen Internal Combustion Engines in Rail: A Step Towards a Hydrogen Future

JONATHAN BROWN, MARKO KROENKE / RICARDO RAIL

INTERNATIONAL MONORAIL ASSOCIATION

Abstract

Hydrogen Internal Combustion Engines in Rail: A Step Towards a Hydrogen Future

The transition to hydrogen as a fuel for rail transport has multiple challenges for the industry, requiring significant change to both rolling stock and infrastructure. Implementing these fundamental system-level changes, rolling stock propulsion moving from the internal combustion engine (ICE) to fuel cell (FC) technology whilst concurrent re-developing infrastructure to accommodate hydrogen will require huge levels of investment and highly complex stakeholder & programme management to deliver successfully. However, the use of existing propulsion units, if converted to utilise hydrogen remove one of these two significant barriers. Utilising the remaining value and life of existing assets (engines/locos) and enabling focus on one critical system change (infrastructure) provides a gateway for adoption of this future fuel with a lower risk to the industry and reduces the barrier to entry.

Specifically, within the North American rail industry line-haul locomotives are used for the majority of railroad movements, both passenger and freight, reducing the burden of conversion of these units to hydrogen fuel. There is an established route to market as used for CNG/LNG operation currently with fuel tenders co-located with the locomotive. Hence, transition to hydrogen through conversion of ICEs is a logical roadmap for the industry to follow in this market.

With modern engine control technologies, the conversion of older engines to use hydrogen, either in a dual fuel mode of operation with diesel, or substituted at 100% rates with spark ignition enables flexibility of operation and provides the reserve option that if hydrogen supply is short or unavailable the unit can still operate, providing security of service.

In this paper we focus on the latest technology in hydrogen ICEs that enables this gateway to a hydrogen future and the benefit this offers to the industry in terms of reducing the change required for this transition. This approach is not in competition to fuel cell technology, rather it provides both the rail industry and the new fuel cell technologies time to adapt to the demands of hydrogen operation in rail, spreading investment costs and reducing risks.

Hydrogen Power for Monorail?

Monorailex Conference
Milan, September 2021
Jonathan Brown, Marko Kroenke

Market trends

Why monorail?

Urbanisation and congestion	Automation and digital solutions	Comfort	Environmental awareness	Value for money	Safety / cyber security
• Increasing need for mass transit systems • Space/land resources becoming scarce • 24/7 Operation	• More automation, less manual work • Big data collection and analysis • Virtual reality • Artificial intelligence	• Seamless and integrated transport connections • Physical and digital passenger amenities available	• Carbon neutral, emission-free transport • Higher efficiency and less energy consumption	• Life cycle cost optimization • New revenue possibilities	• Increasing safety and security levels • High availability

Monorail propulsion

Self-powered monorail?

Monorail systems typically operate with 3rd rail electricity

- Close to urban area with good power supply and distribution (PS&D) system
- Use of existing power collector and power rail
- Proprietary track (closed network)

Some niche manufacturers offer battery/self-powered vehicles

- Direct storage of recuperation energy with minimal losses
- Less dependent from availability from traction power station (TPS)
- Cost savings by not using TPS, PS&D, simplified SCADA
- Cost off-set by charging stations

The Metrail Monorail train has something that most monorails don't, a fuel cap and diesel engine! Frazer-Nash has found a way for smaller cities to build monorails without investing an extraordinary amount of money: the Hybrid-powered monorail.

https://www.monorails.org/tMspages/Metrail1.html

The Poços de Caldas Monorail was a monorail system that served the city of Poços de Caldas in the state of Minas Gerais, Brazil. Privately owned, the single elevated line connected the bus station to the centre of the city, a total of 6 km (3.7 mi) and 11 stations.

https://en.wikipedia.org/wiki/Po%C3%A7os_de_Caldas_Monorail#/media/File:Monotrilho_de_Po%C3%A7os_de_Caldas.jpg

Self-Powered Monorail

Niche, potential to fit integrated solutions

Future connected cities

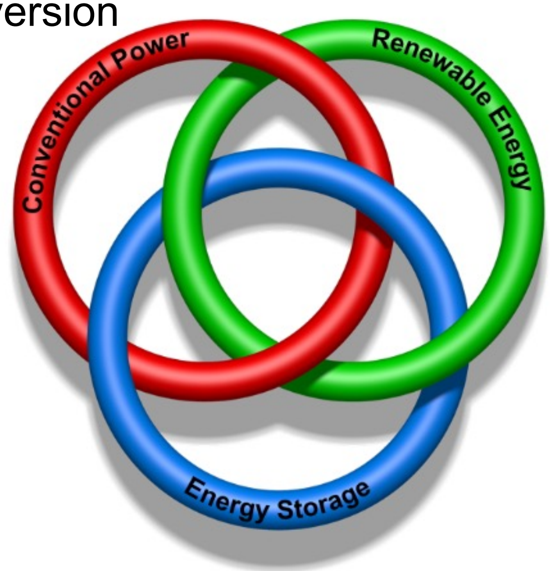
- Localised energy hubs
- Integrated transport systems and modes
- Hydrogen & battery buses
- Private taxis & delivery fleets

Energy Systems

- Electricity / Batteries
- Hydrogen
- Biogas / biofuels
- Mechanical (flywheels, etc)
- Cryogenics

Integrated local renewables

- Wayside energy storage
- Localised generation & conversion

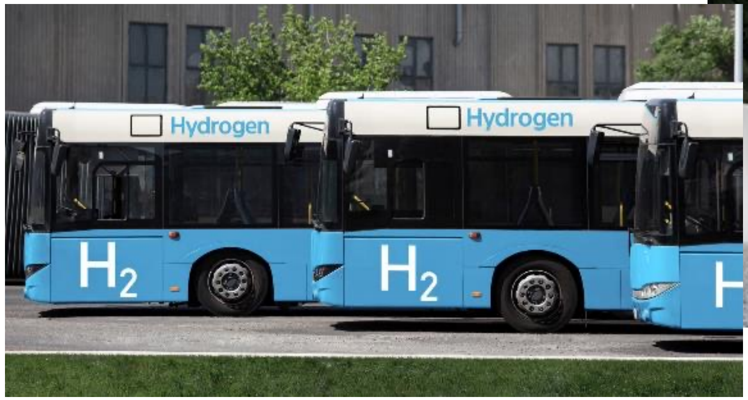


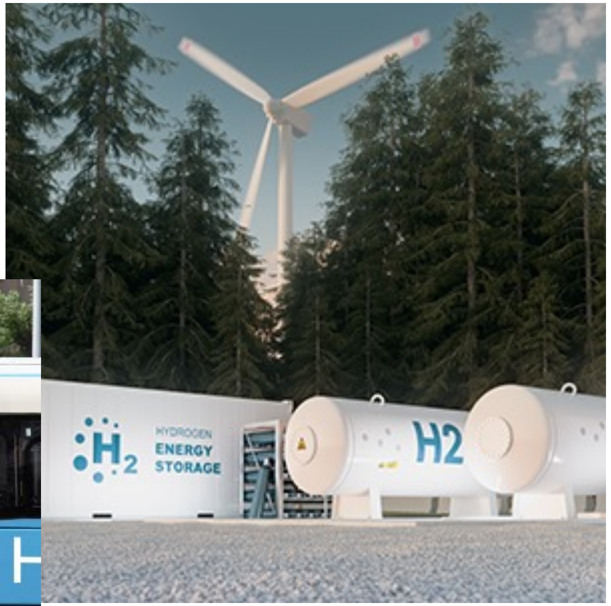
Why Hydrogen?

A flexible energy vector

Global hydrogen economy being developed for core future transport systems

- Long distance/high energy consumption applications (rail, heavy duty trucks, bus/coach, aviation, marine)
- Centralised hydrogen hubs with range of modes likely
- Monorail may be link to de-centralised hubs – airports, ports, out of town destinations
  - Likely to have other hydrogen users





Hydrogen Options

Fuel cells, combustion engines

Fuel Cells (H2FC)

- Generate electricity directly
- Quiet
- “zero” emissions (only H_2O)
- Good efficiency quoted

Technology still immature for rail applications

Combustion Engines (H2ICE)

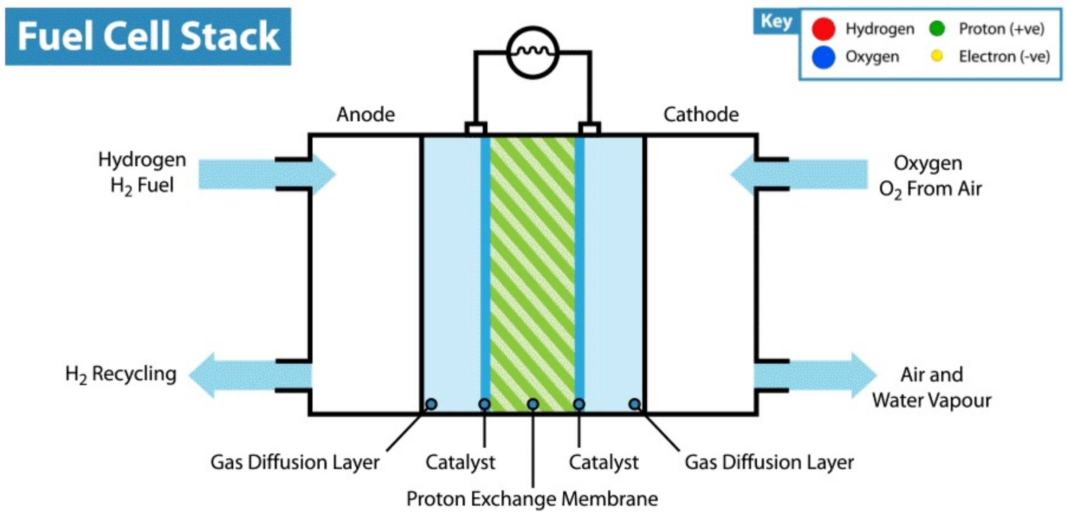
- Stable, known technology
- Tolerant of fuel quality
- Robust to poor air quality
- Durable & reliable

Growing interest across commercial power sectors

H2FC: Hydrogen Fuel Cell
H2ICE: Hydrogen Internal Combustion Engine

How do these systems work?

H2FC and H2ICE – what's the difference?



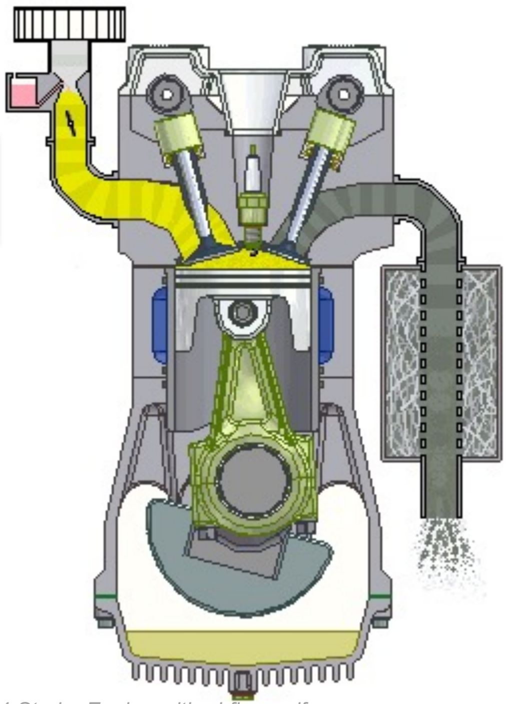
Source: Intelligent Energy, https://www.intelligent-energy.com/our-products/stationary-power/fuel-cells/

Additional parts of the system include

- Balance of Plant (hydrogen/air handling; pumps, compressors, filtration, environmental conditioning)
- Thermal conditioning (cooling, heating for startup)

Multiple difference fuel cell stack technologies. Most common for transport applications is Proton-Exchange Membrane (PEM)

Hydrogen Internal Combustion Engine



Source: https://commons.wikimedia.org/wiki/File:4-Stroke-Engine-with-airflows.gif

Conventional 4-stroke internal combustion engine technology

- Gasoline or diesel-type combustion systems viable
- Dual-fuel operation with diesel-hydrogen or methane-hydrogen possible, but not ideal
- Limited aftertreatment necessary due to NOx formation from combustion temperature and PM from lubrication oils (lower emissions than diesel/gasoline)

The right time for H2ICE?

Many benefits outside the technology

H2ICE has key advantages for a rail environment:

- Proven technology, robust (H2FC not mature)
- Can be retrofitted/converted from existing hardware
- Reduces initial capital cost for system conversion to hydrogen
    - Allows for capital to be invested in *infrastructure & operational logistics*, by reducing cost of vehicle propulsion system
- ‘Stepping stone’ technology
- Increases time for skills transition

H2ICE for rail reduces the initial investment requirements and pain of transition to hydrogen

Challenges, opportunities

Moving forward

Challenges remain for use of hydrogen in rail & monorail systems

- *Safe use and operation*
- On-board storage volume
- Cost
- Supply

INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

$

But, opportunities exist to be realised; hydrogen opening up new markets?

- Reduces requirement for grid connectivity
- Supports business case for multi-modal hydrogen hubs
- Facilitates renewables energy storage & utilisation
- Consistent hydrogen consumer for supply chain

Ricardo

Monorail projects

Examples of Ricardo monorail project work

- **Dubai Monorail:** RAMS Engineering
- **Kuala Lumpur:** Driveline Engineering
- **BYD Monorail:** Brake System Certification
- **Bangkok Monorail:** Independent Verification & Validation
- **Daegu Line Monorail:** Independent Verification & Validation
- **Beijing TCT:** Certification of Monorail CBTC system

Thank you

Questions?

Author

Jonathan Brown
Global Decarbonisation & Sustainability Lead - Rail, Ricardo

Delivering technical engineering projects for Ricardo’s global customer base since 1998, Jonathan’s experience covers the design and development of internal combustion engines and more recently, clean energy propulsion systems in rail. Initially working in analysis and simulation prior to a role as chief engineer in the Large & Industrial Engines team, he has been responsible for leading clean-sheet design and development programmes for OEMs in the automotive, rail, marine, power generation and industrial sectors.

A drive to reduce our impact on the planet coupled with a realisation that public transport infrastructures are required to spearhead a decarbonised future resulted in a switch to Ricardo’s Rail team in 2018. Here the belief that utilisation of cross-industry innovation and technology harvested from life at the forefront of propulsion and energy systems across the globe drives the agenda. Coupled with the supporting environmental science to ensure solutions fit the problem provide a platform for real innovation and change.

Jonathan is a Chartered Engineer with the Institution of Mechanical Engineers and a previous chair of the Automobile Division Southern Centre, where he has spearheaded a number of STEM outreach programmes to inspire the next generation of engineers.

Company Info

Ricardo are experts in critical and complex railway systems, with over 3000 engineers and scientists across the group delivering leading edge R&D, innovation and technology solutions to support the rail industry navigate a rapidly changing landscape. Since 1915 Ricardo have set out on a mission to maximise efficiency and minimise waste

www.ricardo.com

rail.ricardo.com

P7
The Important Factors That Define the Choice for a Transportation Solution

EUGENIO DOTTA, ALLAN IMMEL / HITACHI

INTERNATIONAL MONORAIL ASSOCIATION

Monorailex 2021

The important factors that define the choice for a Transportation Solution”

Milan, 09/25/2021

Mr. Eugenio Dotta
SVP Head of Global Sales and Bidding

Mr. Allan Immel
Turnkey Systems Business Development – North America

Contents

1.TRANSPORTATION SOLUTION MARKET

TRANSPORTATION SOLUTIONS MARKET

HITACHI
Inspire the Next

Transportation options for movement in a city:

Heavy Rail - dedicated right of way metro

Light Rail - shared right of way metro

Automated People Movers – dedicated lines typically used in airports

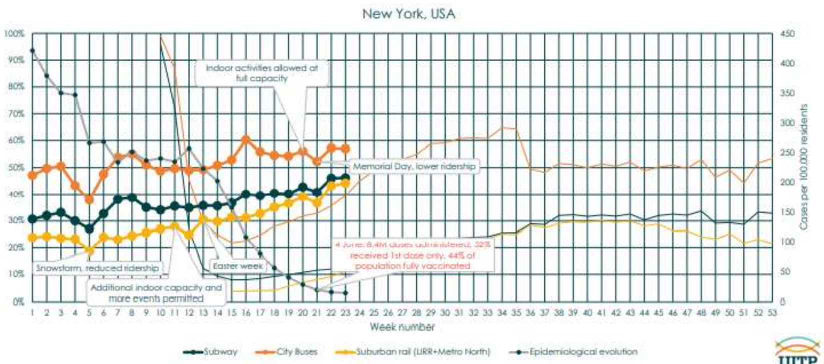
Monorail – Dedicated right of way to serve as an APM or a Metro

TRANSPORTATION SOLUTIONS MARKET

How is moving the transportation solution market after COVID

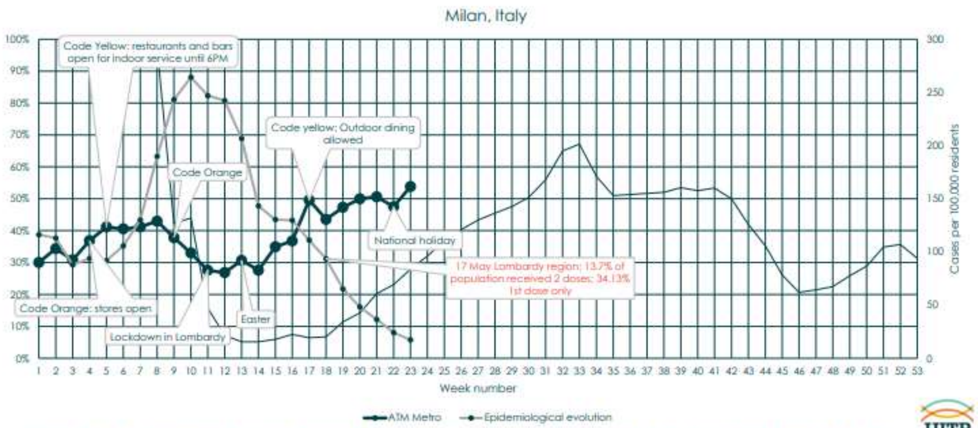
COVID-19 RIDERSHIP EVOLUTION

NEW YORK MTA, USA



*Comparison with 2019 average for corresponding days

MILAN, ITALY



*2020 ridership change is calculated against the relevant corresponding date of 2019. For the first 6 weeks of 2021, the comparison is with the corresponding date of 2020. Starting from w7/2021 the comparison is with the corresponding date of 2019

TRANSPORTATION SOLUTIONS MARKET

HITACHI
Inspire the Next

The importance of public transport as a vital element for the green economy

reduction of pollution and Improvement of the quality of life

The key principles is rethinking streets, public spaces and transport for a post pandemic city

Creating safer street that prioritise public transit, to support local economies and bringing communities into the process

Considering the revolution that the pandemic has brought into our lives

There will be an economic recovery, perhaps the required mobility may not return to pre-pandemic levels

Monorail builders must be ready to see the new opportunity

TRANSPORTATION SOLUTIONS MARKET

Major Transportation request changes:

- No school or partially
- Increase smart working
- Airplane and train travelling important reduction

House	School
House	Airport
House	Factory
House	Office

Italian previdence observatory of 2019, the total Italian workers are 25.5 million.
Private employees (excluding agricultural and domestic workers) are 15.3 million of which 8.5 million workers, from which non-workers should be 6.8 million

The pool of potential workers for smart working is about = 12 million, on the 25.5 million total workers, equal to about 47%.

The audience is large and can certainly determine significant changes in the economic / social relations and movements that are our focus.

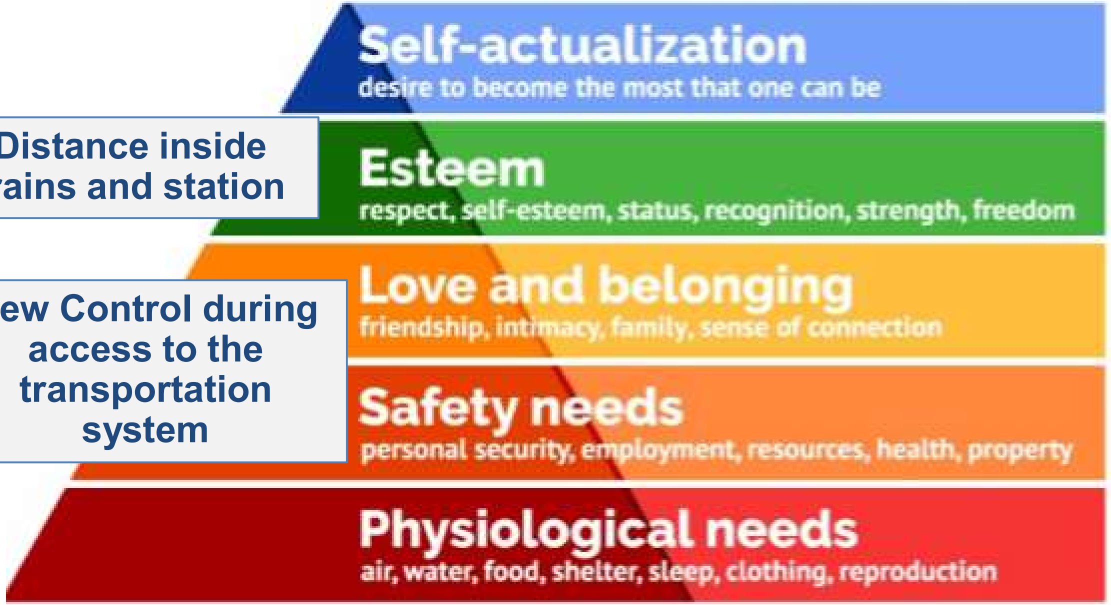
TRANSPORTATION SOLUTIONS MARKET

HITACHI
Inspire the Next

It is possible that the situation that will arise after the pandemic involves considerable variations in the origin and destination matrices of public transport compared to those we knew pre-Covid.

Distance inside trains and station

New Control during access to the transportation system



Investment and timing required new answer to the request: economical and fast implementation

HITACHI
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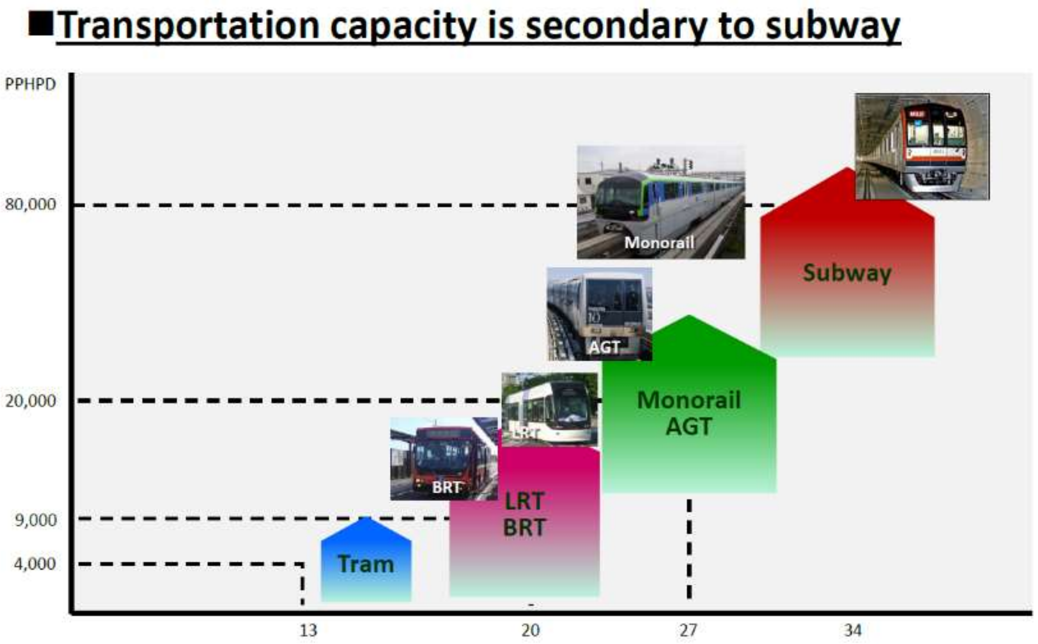
2.KEY FACTOR FOR THE CHOICE

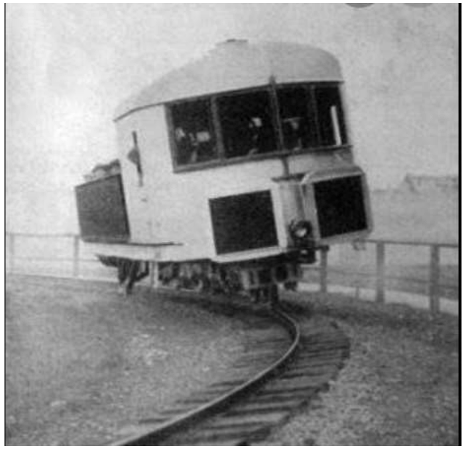
Ridership
Increase City Prestige
Construction time and cost
System Flexibility and Alignment

KEY FACTOR: RIDERSHIP

Turism and improvement of city life and view ---- monorail

Advantage: It Depends





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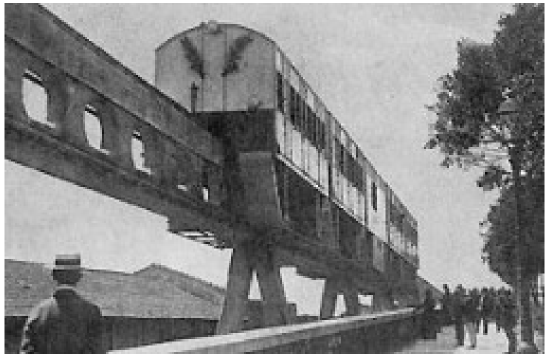


1914 Genoa Exposition

KEY FACTOR: INCREASE CITY PRESTIGE

HITACHI
Inspire the Next

Advantage: Monorail

How long is the line
Impact on the city during construction
New modern development area

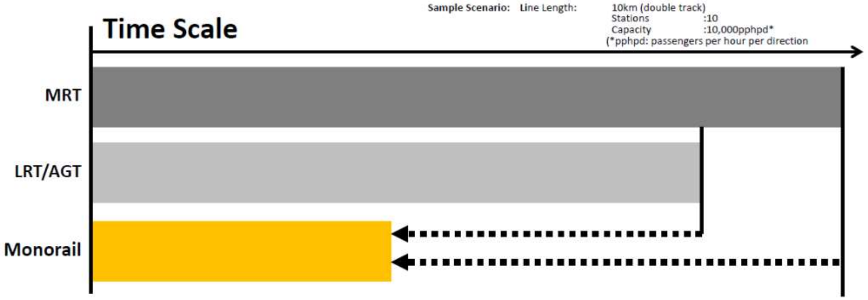
KEY FACTOR: CONSTRUCTION SCHEDULE & COST

HITACHI
Inspire the Next

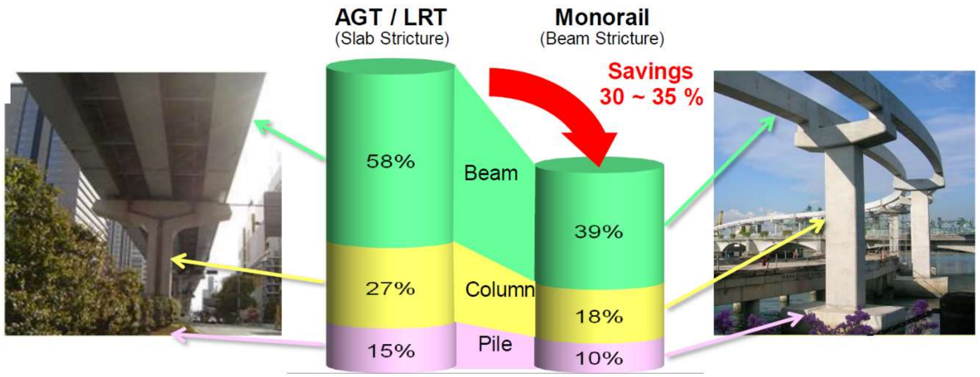
■Benefit of short lead time

- ➢Reduction in overall construction cost
- ➢Increased opportunities in providing public service
- ➢Early start of revenue collection
- ➢Improvement of project viability

Advantage: Monorail



Lower Cost in Track Construction



NOTE: Comparison is based on average construction costs in Japan.

KEY FACTOR: SYSTEM FLEXIBILITY AND ALIGNMENT

HITACHI
Inspire the Next

Advantage: It Depends

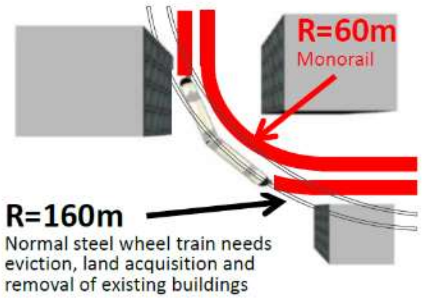
Flexibility for Line Arrangement and Alignment

Sharp Curve Running
(Minimum R=60m)

Steep Gradient Running
(Maximum 6.0%)

Easy to Overpass

- Line planning with less constraints of existing buildings.
- Less eviction and demolition of existing buildings
- Less acquisition for structure.



3.THE EXPERIENCE

Tokyo Monorail

Inauguration in 1964 / ©Tokyo Monorail Co., Ltd.

The Tokyo monorail, which runs from Haneda Airport to the city, is celebrating its 55th anniversary in 2019. It's an example of the transport infrastructure overhaul which Tokyo underwent in the lead up to the Tokyo 1964 Games. The rail is still in operation today, and as fast and punctual as ever.

THE EXPERIENCE

Hitachi Rail is a world leader in monorail vehicles and systems

- First monorail delivered in 1964
- Progressively advanced the monorail design
- More than 50 years of safe operations
- Proven track record of delivery
- 9 systems in service
- Global presence

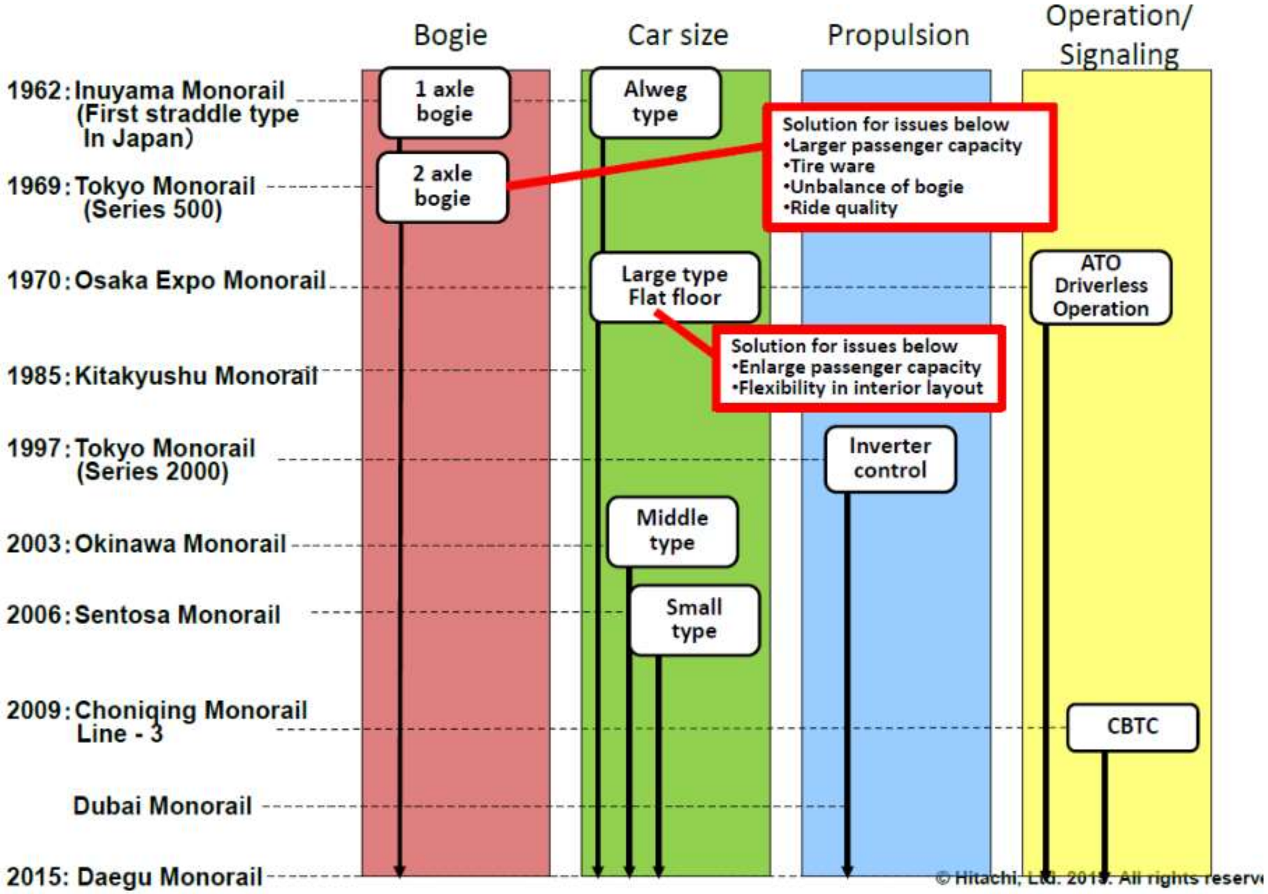
1964 opening Ceremony

Today

THE EXPERIENCE

HITACHI
Inspire the Next

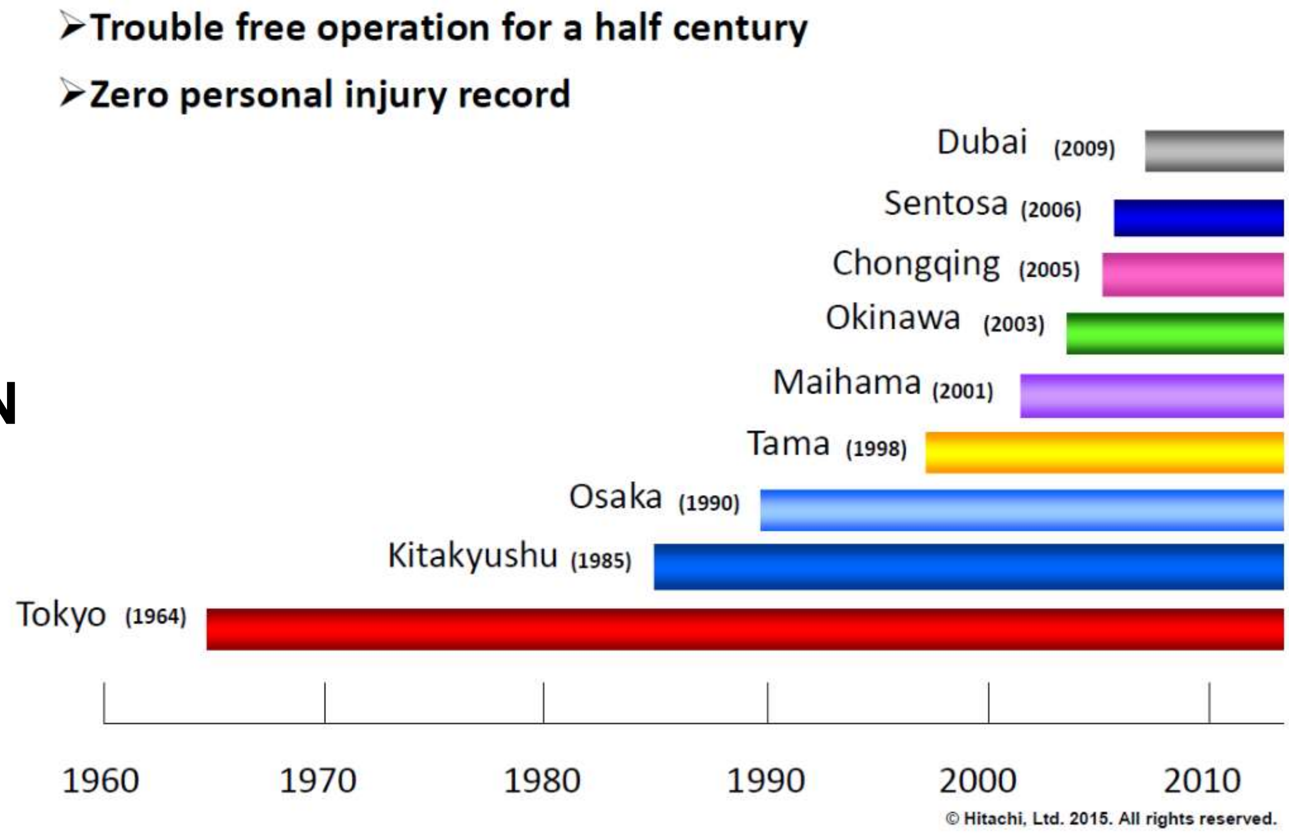
EVOLUTION PROCESSC



THE EXPERIENCE

HITACHI
Inspire the Next

50 YEARS OF SAFE OPERATION



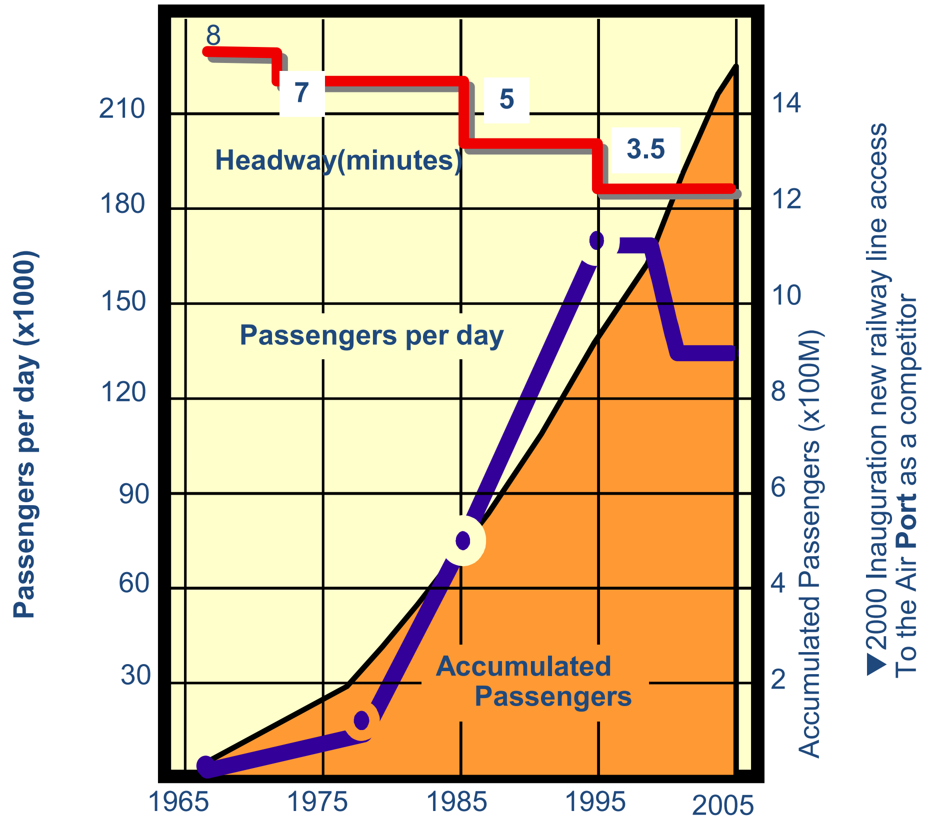
THE EXPERIENCE

HITACHI
Inspire the Next

Passengers	:	310,000	passengers per days	
Total Car N	:	120 cars		station
Line:	1964 ▼ 1993 ▼ 1998 ▼ 2010	13.0 km ▼ 16.9 ▼ 17.8		2 ▼ 9 ▼ 10 ▼ 11

Over 2,000 million passengers Since 1964

SYSTEM FLEXIBILITY EXTENSION AND EXPANSION



THE EXPERIENCE

HITACHI
Inspire the Next

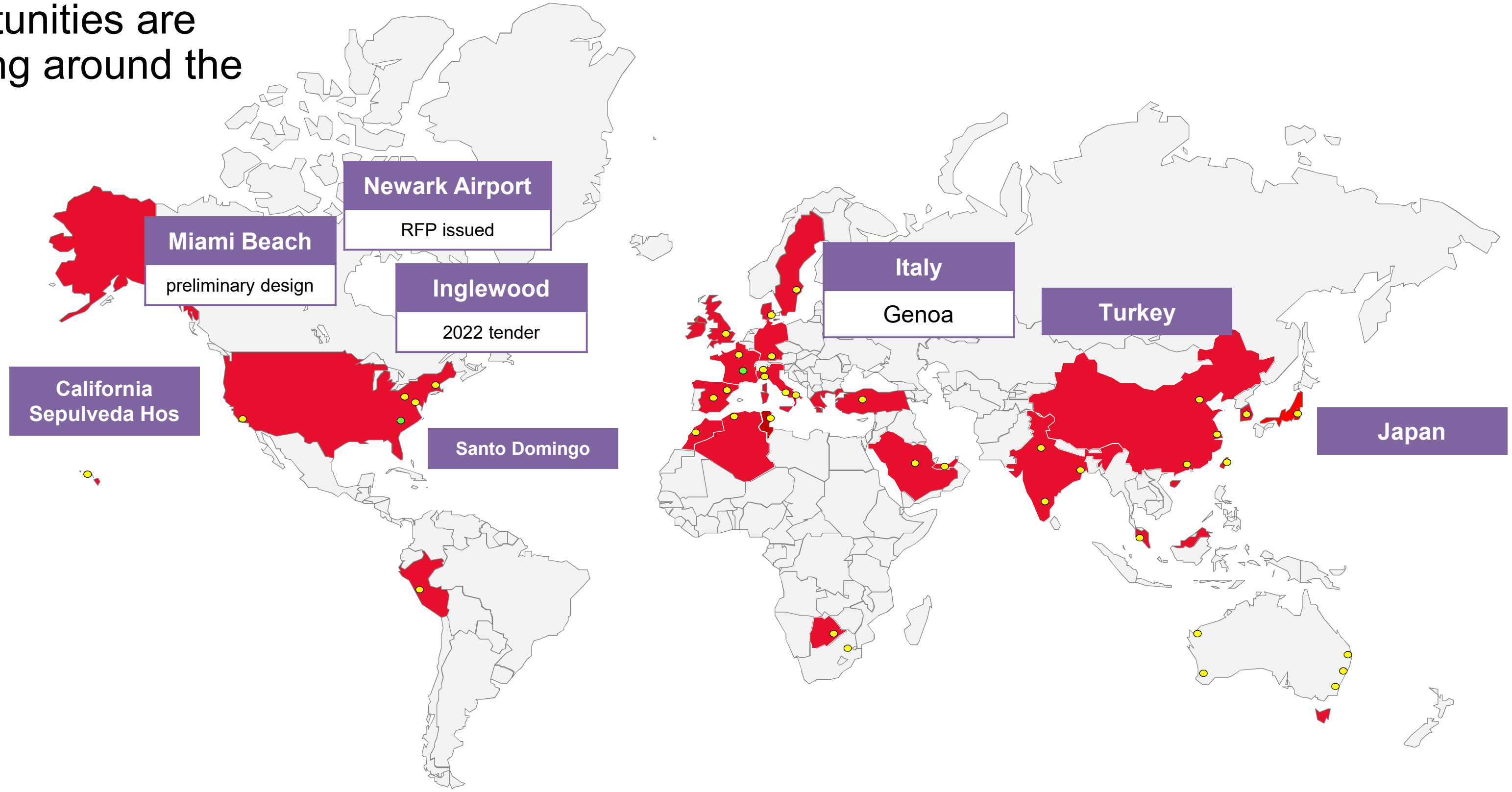
Project	Tokyo	Kita-Kyushu	Osaka	Tama(Tokyo)	Okinawa	Chongqing (China)	Sentosa (Singapore)	Dubai (UAE)	Daegu (Korea)
Purpose	Public Transit Airport Access	Public Transit	Public Transit Airport Access	Public Transit	Public Transit Airport Access	Public Transit	Tourism	Public Transit	Public Transit
Rolling Stock									
Inauguration	1964	1985	1990	1998	2003	2005	2006	2008	(2015)
Line Length	17.8 km	8.8 km	28 km	16 km	12.9 km	19 km	2.1 km	5.3 km	24 km
PPHPD (Design base)	33,000	48,000	48,000	48,000	9,300	48,000	3,000	3,000	25,000
Station	11	13	18	19	15	18	2	4	30
Cars	126 6cars / 21 trains	40 4 cars / 10 trains	80 4 cars / 20 trains	64 4 cars / 16 trains	24 2 cars / 12 trains	84 4 cars / 21 trains	12 2Car/ 6 trains	12 3 cars / 4 trains	84 3cars / 28 trains
Note	No fatal accident in 50 years	Station inside the building	Withstood Hanshin earthquake		Operation in Tropical climate		Operated in tropical climate	Operated in harsh climate	UTO operation Driverless Operation

4. NEXT FUTURE

THE FUTURE

HITACHI
Inspire the Next

Monorail opportunities are growing around the world!



5.CONCLUSION

CONCLUSION

HITACHI
Inspire the Next

Monorail systems are one of the public transportation solution that can achieve very reliable and safe performance

Not just a ride at Disney Park

What is it behind a safe and comfortable trip of our passenger?

The criticism could be that it is a visionary approach, it may be. But only visionaries could invent a system that moves a vehicle on a beam,
So being visionaries is in our DNA.

Clear demonstration that a good implementation can be a reference for transportation solution also after around 60 years of operating service

Technical knowledge and passion for our work have a result a milestone for transportation solution daily used by thousands of passengers around the world

TOKIO, 1964

PANAMA 2026

END

Monorailex 2021
The important factors that define the choice for a Transportation Solution”

Mr. Eugenio Dotta
SVP Head of Global Sales and Bidding

Mr. Allan Immel
Head of Sales and Bid USA

HITACHI
Inspire the Next

SHORT COMPANY PRESENTATION

We are a fully integrated, global provider of rail solutions across rolling stock, signalling, operation, service & maintenance, digital technology and turnkey.

Last year, 18 billion journeys were completed using our technology, delivering social, environmental and economic value.

With revenues of ¥580.3bn in FY19, approximately 80% of which are from outside of Japan, we have a presence in 38 countries, across 11 manufacturing sites on three continents and over 12,000 full time employees.

Our engineering heritage and culture is rooted in Japan, where our first steam and electric locomotives were built in the early 1920s. A major inroad to the field of passenger transport was made in 1964, with the supply of our first Shinkansen 'bullet train' vehicles to coincide with the Tokyo Olympics.

We continue to deliver the our technology and expertise to multiple projects across the globe from high speed, tram, metro, monorail to driverless technologies for passengers and freight.

We are ambitious and continue to seek to expand into new key geographies and to deliver new solutions.

Drawing on the wider Hitachi Group's market-leading technology capabilities and R&D, we strive for industry leading innovations able to deliver value for customers and help build sustainable transportation systems which benefit wider society.

Sustainability is at the heart of our business and we believe that we have an obligation to inspire and build a better and more sustainable future for our employees, customers and all users of our products.

Innovation is key in enabling us to grow our offering for our customers through enhancing existing products, systems and solutions, whilst also harnessing global market trends.

As a business, we are investing in innovation so that we can provide solutions for the megatrends effecting the mobility sector, including sustainability, autonomous vehicles, digitalisation, urbanisation and customer experience - all with a focus to enhance customer satisfaction and increase passenger experience.

Global market trends are also demanding the use of disruptive technologies and we are seeing the introduction of new business models across the mobility sector. For this reason, we are investing in new digital and data capabilities; embedding these across our organisation, allowing us to continue our pioneering status, improve operational efficiency, and maintain our customer and partners' trust through offering products of exceptional quality.

Eugenio Dotta
Head of Global Sales & Bidding Management – Sales & Portfolio Coordination
Hitachi Rail

Eugenio Dotta is a Professional Engineer who holds a Bachelor of Electronics Engineering from the University of Turin.

Columbia University Graduate School of Business and Imperial College Business School.

For more than 35 years I have been working in the transportation market, before as signaling engineer and after manager for commercial proposal as Ansaldo and now Hitachi.

My important result was the acquisition of Copenhagen metro (4 lines).

The Copenhagen Metro contract constituted a turning point in our history and system culture, allowing it to acquire a reference which, having been appropriately exploited, allowed it to replicate this system in four other new contracts, namely: Brescia, Milan Line 5, Thessaloniki and Rome line C.

A Mix of technical competences with commercial attitude allow me to arrive at these important result for my company: the acquisition for important contract are always a merge of several condition but a facilitator is required

In addition to the supply of the so-called "Transportation System" (the electromechanical works and vehicles), the Copenhagen contract also provided for eight years (5 basic + 3 customer option) of operation and maintenance of a totally " unmanned "which, crossing its center, forms the backbone of public transport in the Danish capital.

He assumed responsibility for the Sales Department within this company, contributing with his structure (which also incorporates the SMP office) to the acquisition in the period 2005 - 2020 of contracts for several million.

Among the most significant contracts it is worth mentioning the transport systems of: Riyadh 2 contracts, Taipei 2 contracts, Honolulu, Bart Los Angeles, Horuntario Canada, Brescia, Dublin, Milan Line 4 & 5, Thessaloniki, Naples Line 6, Rome Line C.

He is currently responsible for overall commercial startegy helping the Japan Headquarter to identify opportunities, partners and solution in line with our products and our business plan.In him role, is to define and govern the assessment, proposal, decision-making process, of all initiatives and plans required by the global business.

Key in this role is helping colleagues understand the market and the opportunity, behind the new complete worldwide transportation business so that we can accelerate the changes we need to make again other success for the company.

Allan Immel
Turnkey Systems Business Development lead for North America
Hitachi Rail

Allan leads the development of turnkey systems win and execution strategies for the North American transit market for Hitachi Rail. He works with financial, civil and engineering partners to deliver complex infrastructure solutions, proposals and commercial arrangements to the transit industry.

These rail-based transportation projects may include financing, designing, building, operating, maintaining and delivering the project for the public transit authority.

Allan and the team from Hitachi Rail specialize in signaling and systems integration, as well as rolling stock supply, resulting in the integration of train control, traction power, communications and vehicles into advanced transit solutions that Hitachi Rail can also maintain and operate for its global and US customers.

Allan is a Professional Engineer who holds a Bachelor of Science in Mechanical Engineering from the University of Pittsburgh, a Master's in Business Administration from Winthrop University, and is a certified Project Management Professional. Over the course of his 20 plus-year career with Hitachi Rail and its legacy businesses, Allan has held various positions of increasing leadership and responsibility, tapping into a deep understanding of public transit. During his Hitachi career, Allan has served as a bid manager, a project manager, and he created and led the Project Management Office for North America.

He is currently responsible for turnkey systems business development in North America. Over the past 18 months, Hitachi Rail in North America has earned its largest rolling stock (WMATA), largest signaling (BART), largest monorail (el Metro de Panama) and largest public-private partnership (Hurontario) contracts. A key area of strategic focus is the application of Hitachi's leading-edge monorail solutions for the North American market.

Previously, Allan worked for Westinghouse Corporation to serve the nuclear power industry as a project manager and a product line manager.

P8
An Overview of Norms and Standards for Monorail Systems

MICHELE BARBAGLI / TÜV RHEINLAND

INTERNATIONAL MONORAIL ASSOCIATION

AN OVERVIEW OF NORMS AND STANDARDS FOR MONORAIL SYSTEMS

Michele Barbagli, M. Sc., Assessor and Project Manager, TÜV Rheinland
TÜV Rheinland Intertraffic GmbH
Am Grauen Stein
51105 Cologne, Germany

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1 Introduction

Monorail systems are experiencing a relevant market trend in the last two decades. The once extreme-niche transport system for amusement parks is achieving commercial successes and popularity as urban guided transport solution, as the case of the cities of Bologna, Panama, Bangkok, Wuhan, Sao Paulo, and Cairo.

Currently, no monorail specific international standards or norms are available. International projects adopting monorail as technology must therefore typically use standards from railway, urban transport and people mover origin as reference, which might not be applicable in full.

This paper gives an overview of the railway, urban transport and people mover standards that could be used and are commonly used as reference in a monorail project, and that can constitute a benchmark for new projects worldwide.

The standards are analyzed in regards of their applicability to the monorail systems and not in their detailed technical content.

The paper focuses on the following main areas:
- Safety
- Overall system integration
- Automatic Train Control
- Rolling Stock

From the content of this paper are excluded guideway and civil works. The rationale behind this decision for guideway is that its design is related to manufacturer's own specifications. Civil works are excluded as their design is usually ruled by non-transport specific, national or local, standards and legislation.

While monorails might be designed based on different concepts, such as e.g. suspended or straddled design (1), this paper focuses on the straddled type design, which is the one that has reached relevance in the urban guided transport industry. For ease of communication, the paper uses the generic term 'monorail' instead of 'straddled monorail'.

1.1 Standardization in monorail systems

Lack of a dedicated standardization has been commonly identified as one of the limits to the acceptance and diffusion of monorail systems, with potential risks for the system operator such as low interoperability, difficult obsolescence management and vendor lock-in (1).

Rail-based urban transport systems (tramways, metros) are standardized in such way that, apart from gauge and clearance differences, virtually any vehicle could operate, at least under manual operation and self-propelled, in most of the networks.

In monorails, vehicle and beam design are designed to match to each other, based on manufacturer-specific design solutions. Only by focusing on the monorails of straddled design, several designs for the beam and related designs of the vehicle bogie and carbody can be identified (2) (3).

At the current technological state of the art, guiding beam and bogie design constitute therefore the main constraint to interoperability of monorail systems.

Due to this constraint, interoperability defined by the EN 62290 (5)(6)(7) has a narrower meaning in monorails then in other urban guided transport systems. Based on the definitions of the EN 62290, interoperability in monorail systems is namely interoperability on the same line between:

- “communicating vehicles”, so vehicles equipped with on-board signalling, with “non-communicating vehicles”, such as service and maintenance vehicles, vehicles out of service or vehicles with communication failure;
- two vehicles, one equipped with on-board signalling from supplier A and one equipped with on-board signaling from supplier B (virtually possible, at today not implemented).

Such lack of standardization has impact on the selection of the standards adopted for a new system, which can result in an inconsistent or incomplete normative framework.
Incomplete normative framework means that the chosen selected standards for a system do not cover the complete system and its functionality. Inconsistent normative framework means that the chosen selected standards are introducing overlapping and contradictions in requirements.

1.2 Role of technical standards in the Independent Safety Assessment

The scope of an Independent Safety Assessment is to evaluate and judge, that the required level of safety and quality is achieved by all actors concerned, to ensure a safe implementation of the project to the required safety standards (4).

In particular, the Independent Safety Assessment focuses, amongst other, on the evaluation and judgement on system supplier’s organization and processes and on the evaluation and judgement of the functional and technical safety of the system / subsystem / equipment or component under assessment.

In relation to organizational aspects, processes, and in particular to safety management and functional safety, state of the art technical standards such as EN 50126-1/-2 (8) provide requirements for the supplier / manufacturer on e.g. RAMS management .

In the field of technical safety, state of the art technical standards play a role in constituting a benchmark, based on which a technical solution adopted for a system / subsystem / equipment or component involved in a safety function is chosen and assessed.

While still allowing a system to become operational and performant, an inconsistent or incomplete normative framework might result in difficulties to demonstrate the fulfillment the project requirements, thus affecting the safety assessment and the approval for the operation of the system from the Authority in charge.

The adoption of a consistent and complete normative framework for each subsystem is therefore crucial for the system acceptance.

2 Safety

2.1 EN 50126

The already mentioned EN 50126-1/-2 is the European Norm covering Reliability, Availability, Maintainability and Safety (RAMS) in railways.

The standard is linked with the international standard IEC 62278 (9)[1] and has worldwide acceptance.

The standard provides a methodological approach to RAMS management, having as pillar the lifecycle model (so-called “V-model”) presented in Figure 1:

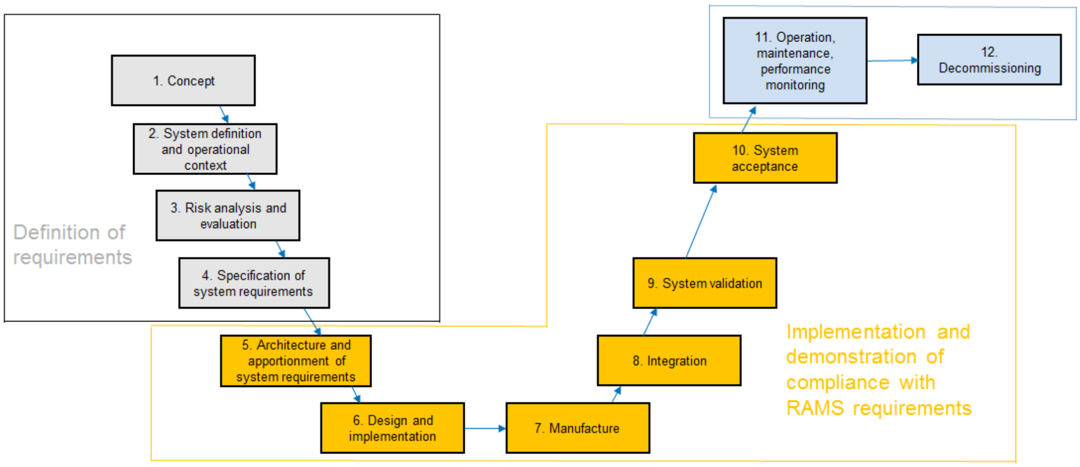

Figure 1: Lifecycle model („V-model“) defined in EN 50126-1

In detail, in regards to Safety, EN 50126-1 provides a safety management process, supported by guidance and methods described in EN 50126-2.

The methodological approach to RAMS adopted by the EN 50126-1/-2 lifecycle approach makes this standard virtually applicable to all type of urban guided transport system and related subsystems.

Applicability to monorail based urban guided transport systems and related subsystems is therefore given without limitations.

2.1.1 Link between EN 50126-1/-2 and specific technical standards

The EN 50126-1/-2 constitutes also the tool, by which technical standards can be defined as requirements for the technical safety of a system / subsystem / equipment or component involved in a safety function.

State of the art technical standards would then play a role in constituting a benchmark, based on which a technical solution adopted for a system / subsystem / equipment or component involved in a safety function is assessed.

[1] IEC 62278:2002 is equivalent to EN 50126-1:1999; however, EN 50126:2017 has now superseded the EN 50126:1999. The overall approach and methodology of the 2017 release is nevertheless consistent to the previous 1999 release.

In detail, adoption of a widely recognized standard for safety requirements definition of a system / subsystem / equipment or component contributing to a safety function, can be a suitable risk reduction measure as per phase 3 ‘risk analysis and evaluation‘ of the lifecycle model of the EN 50126-1.

Specification of system requirements (phase 4) and their apportionment (phase 5) are then conducted by applying the requirements of the selected normative framework to the system / subsystem / equipment or component which are object of the development.

The same lifecycle approach can also be adopted to an urban guided transport system based on monorail technology, in a top-down approach, from overall system level to subsystem level and integration thereof. In that case, the apportionment of overall system requirements constitutes an input for the specification of subsystem requirements (Figure 2).

A future monorail-specific standard (would it exist one day), covering monorail-typical safety relevant features such as e.g. the pairing of the guiding beam and vehicle, would then be identified in lifecycle phases 4-5 and used as of source of requirements to be apportioned to the subsystems.

The specificities of a monorail system and its subsystems, as well as the project specific application conditions, shall be taken into account in this activity for a holistic safety management.

An project specific risk analysis and following activities as per phases 2, 3 and 4 of the EN 50126-1 lifecycle model, taking into consideration the design, the conditions and the risk acceptance principles and criteria applicable to the specific project, are always to be conducted and of primary importance.

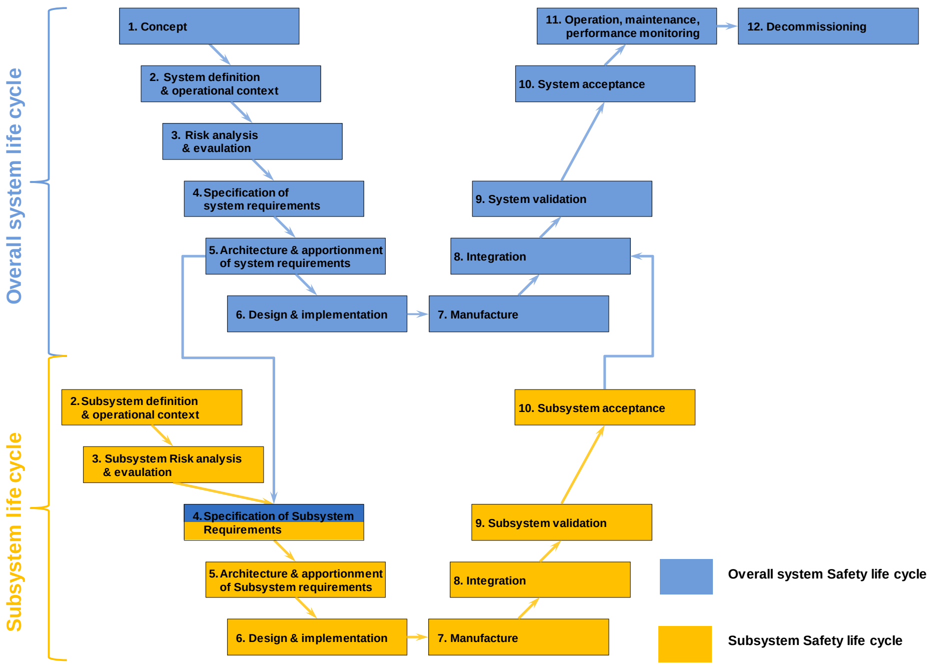

Figure 2: Interaction of Overall System and Subsystem lifecycle

2.2 EN 50128 and EN 50129

The two standards EN 50128 (10)(9) and EN 50129 (11) are to be read in conjunction with the EN 50126.

The standards cover the aspects ‘software for railway control and protection systems’ (EN 50128) and ‘safety related electronic systems for signalling’ (EN 50129).

Same as the EN 50126, also these standards are linked to an equivalent IEC standard, respectively the first editions of the currently valid IEC 62279 (12) for the EN 50128 and of the currently valid IEC 62425 (13) for the EN 50129.

EN 50128 specifies the process- and technical requirements for the development of software for E/E/PE systems / components for use in railway control and protection systems, in areas with safety implications.

EN 50129 defines requirements for safety related electronic systems for signalling and their acceptance.

As per their scope, the standards do not define a limited applicability to a certain guiding technology.

The applicability of both standards to monorail projects is therefore possible without restrictions.

2.3 EN 50657

The European Standard EN 50657 (14) is also to be read in conjunction with the EN 50126 and is an adaptation of the EN 50128 dedicated to on-board software for rolling stock.

The standard provides similar if not identical guidelines as the EN 50128, with the due adaptations necessary to match with on-board software specificities. The relevant difference is the introduction of a differentiated classification of safety integrity levels, including a “Basic Integrity Level”, taking into account that only a part of on-board software is involved in safety functions and therefore safety critical.

The standard provides a set of requirements for the development, deployment and maintenance of any software intended for railway rolling stock applications. No limitation to a certain type of architecture of rolling stock is given.

As per its scope, also the standard EN 50657 does not define a limited applicability to a certain guiding technology.

EN 50657 for the software used on board of rolling stock (with exclusion of the software for on-board signalling, covered by the EN 50128) is therefore possible for application in monorail projects without restrictions.

2.4 IEC / EN 62267

The IEC 62267 (14) is an international standard for safety in automated urban guided transport systems. It is well diffused all over the world and adopted officially also as European Norm EN 62267.

The standard defines Automated Urban Guided Transport (AUGT) systems as systems transporting passengers between stations, using automated trains running on a segregated guideway, and providing conditions of safe train movement. Based on this definition, monorail-based AUGT systems fully belong to the scope of the standard, so allowing its adoption as design base.

The IEC / EN 62267 provides requirements to safety for automated urban guided transport, focused on the functions that are automated and no more conducted by the train driver / attendant staff, such as e.g. train drive and operation, supervision of guideway and passenger transfer or avoidance of collision with obstacles on the trackway.

The approach adopted by the standard can be used as a source of guidance for the phases 2, 3 and 4 of overall project specific lifecycle approach, as per figure below (re-adapted from (14)):

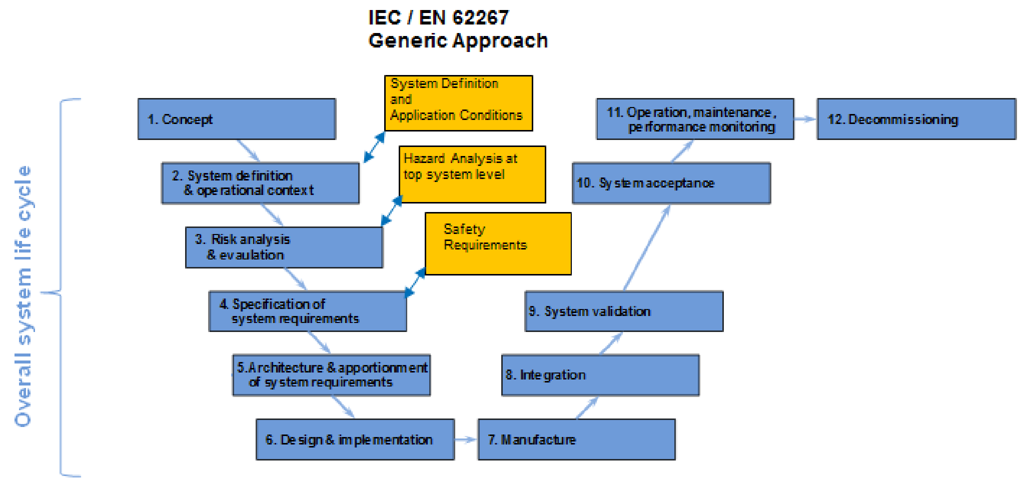

Figure 3: Lifecycle phases covered by the IEC / EN 62267

However and of foremost importance, IEC / EN 62267 is not intended to substitute an application-specific risk analysis. As described for the EN 50126, a project specific risk analysis and following activities as per lifecycle phases 2, 3 and 4 of the EN 50126, taking into consideration the design, the conditions and the risk acceptance principles and criteria applicable to the specific project, is always to be conducted.

The standard is therefore to be intended only as a guidance for minimum requirements, identified by a list of typical hazardous situations, derived from elementary considerations on which functions assumed by the driver and staff in conventional systems are replaced in AUGT systems by automated functions (see 'Introduction' of (14)).

Additionally, the project specific risk analysis and following activities as per phases 2, 3 and 4 of the EN 50126 lifecycle model may demonstrate that some requirements need further modification to take into account some project specific conditions.

In the case of monorail systems, the project specific risk analysis shall also take into consideration the design peculiarities of a monorail system, such as e.g. (non-exhaustive, exemplary list) continuously elevated trackway, critical evacuation possibilities or interference between emergency walkways and train dynamic gauge. This may lead to new or modified requirements related to the characteristics of the monorail environment.

3 Overall system

3.1 ASCE 21-13

The standard ASCE 21-13 (16) for Automated People Movers (APM) is of common application in monorail projects worldwide. .

The ASCE 21-13 is not explicitly dedicated to monorails, however monorails would fall into the definition of APM provided in the foreword ("*An automated people mover is defined as a guided transit mode with fully automated operation, featuring vehicles that operate on guideways with exclusive right-of-way*"). Additionally, the foreword also states that innovative transport systems such as, among other, monorail systems, will also benefit from the standard.
Additionally, its adoption is recommended by the International Monorail Association (IMA)[2].

The standard provides overall system integration but also subsystem specific guidelines and requirements, as well as acceptance criteria for various relevant characteristics.

In practice, several monorail projects around the world have adopted ASCE 21-13 as overall design guidance and standard reference.

The standard can therefore be adopted as overall reference for system integration. A project specific detailed analysis of the applicability should however always be conducted.

4 Automatic Train Control

Technical subsystems for signaling and train operations comprise a variety of subsystems and equipment, capable of implementing basic functions such as train operations and supervision, supervision of track and passenger exchange, detection and management of emergency situations.

A non-exhaustive list of technical subsystems for signaling and operations of a monorail system includes:

- train control systems (Communication-Based Train Control systems, CBTC, are usually adopted in monorail project),
- interlocking,
- track-based train detection system,
- operations and control center,
- interfaces to other relevant subsystems such as PSD (Platform Screen Doors), switches, power supply…,
- wayside signals, if applicable.

The applicability of two internationally diffused and recognized reference standards covering the train control systems is analyzed in this paper: the European Norm EN 62290 (5)(6)(7) and the American standard IEEE 1474 (17)(18)(19)(18)(20).

For completeness of the overview, it is to be mentioned the existence of a third standard covering ATC (CBTC) systems, the Chinese DG/TJ 08-2130-2013 (21). However, this standard is currently not common in international projects and is out of the scope of this paper.

The applicability of the standards EN 50128 and EN 50129, covering software for railway control and protection systems, and respectively safety related electronic systems for signalling, has already been analyzed in section 2.2.

4.1 IEC / EN 62290

[2] See https://monorailex.org/standards, accessed on the 16.09.2021.

The European Norm EN 62290 - Railway applications - Urban guided transport management and command/control systems is a standard covering the management, command and control systems of urban guided transport systems.

Part 1 provides general principles. Part 2 provides guidance on the specification of functional requirements, and Part 3 has as subject the specification of the architecture of the system and the allocation of the requirements. A Part 4, covering interface requirements, is currently in consideration (EN 62290-1, Introduction).

The standard is covering all kind of urban guided transport systems, and has found application in a number of monorail projects as reference for the management, command and control systems.

The management, command and control systems of urban guided transport systems are defined by the standard as Urban Guided Transport Management and Command/Control Systems (UGTMS).

The standard covers a wide range of operation concepts from non-automated (GOA1) to unattended (GOA4) operation – with monorails usually adopting a GOA3 or GOA4 (driverless or unattended) operation concept. It also provides (together with EN 62267) the formal and univocal definition of the term "Grade Of Automation", as the "*automation level of train operation, in which Urban Guided Transport (UGT) can be operated, resulting from sharing responsibility for given basic functions of train operation between operations staff and system*" (EN 62290-1, section 3.1.12).

As per section 1 'Scope' of the EN 62290-1, the standard is applicable to systems using continuous data transmission, continuous supervision of train movements by train protection profile, and localization of trains by external wayside equipment or reporting trains.

Furthermore, EN 62290-1, section 5, defines UGTMS as consisting of:
- Operation control equipment
- Wayside equipment
- Onboard equipment
- Data communication system

The standard is a valid guidance in the specification of functional requirements (phases 4 and 5 of EN 50126-1 lifecycle model) of management and command/control systems of a newly designed urban monorail system or for upgrading existing ones.

While a main objective of the standard is to achieve interoperability, interchangeability and compatibility between equipment, this can only be partially achieved by monorail systems (see section 1 'Introduction', of this paper).

The standard defines basic functions that shall be conducted by the UGTMS (refer e.g. section 6.2.2). Those functions are applicable also to monorail systems.

4.2 IEEE 1474

The standard IEEE 1474 is a standard issued by the Institute of Electrical and Electronics Engineers (IEEE) - Vehicular Technology Society dedicated to CBTC systems.

CBTC systems are train control systems basing their working principle on following key features, as per the abstract of the IEEE 1474:
- continuous, automatic train control (ATC) system
- independence from track circuits;
- train-to-wayside bidirectional data communications
- implementation of automatic train protection (ATP) functions

- optional implementation of automatic train operation (ATO) and automatic train supervision (ATS) functions.

In addition to the requirements of the ASCE 21-13 for Automated People Mover (see section 3.1) the standard IEEE1474 is applicable to Automated People Mover systems (APM) if the ATC is based on a CBTC system.
It is therefore a consistent additional reference standard for monorail systems based on the standard ASCE 21-13 such as in the USA or other Countries adopting US-based standards.

Like the EN 62290, also the IEEE 1474 covers a range of train operation concepts. The standard does not define a 'Grade of Automation', or a classification table such as the EN 62290, but suggests CBTC systems can be used in manned operations, in driverless operations with attendant, and in unmanned mode.

The standard provides an overview of relevant system parameters / reference quantitative performances (Annex C) which can be adopted for CBTC systems and that are also applicable to monorail systems.

Overall functional safety requirements on the CBTC systems are described in section 6.1 of the IEEE 1474-1 and are also applicable to monorail systems.

The standard provides also a typical safe braking model (Annex D) which can be applied also to rubber based systems as monorails.

5 Rolling stock

In a comparison with traditional rail-based rolling stock, following macro-differences can be identified for monorail rolling stock:

- Different bogie design, to pair with a different guiding system,
- No rigid rail/wheel, but flexible tire/guideway contact, with different mechanics affecting braking and vibrations / comfort,
- Technical equipment usually located in the lateral aprons instead of over the roof or underfloor, with different weight distribution,
- Passenger saloon / carbody dimensions have a different geometry, typically wider, due to other dynamic gauge restrictions

Adoption of railway or urban guided transport standards , shall therefore always be approached with an applicability analysis taking into account the design differences.

Based on the identified macro-differences above, the following subsystems and related standards are analyzed in the following sections:

- Brakes
- Bogies
- Carbody strength and crashworthiness

Further monorail rolling stock subsystems such as doors, HVAC, couplers and gangways, power caption (third rail), traction equipment, manual driving units, windows, interiors, PIS, lightning, fire protection, can virtually be identical to the respective ones adopted e.g. in tramways or metros.
Their related specific standards are therefore not analyzed in this paper.

Additionally, also environmental requirements are analyzed.

Note: the applicability of the standard EN 50657, covering on-board software for rolling stock, has already been analyzed in section 2.3.

5.1 Brakes

EN 13452 (22) is a European Norm covering mass transport brake systems and is widely adopted in international urban guided transport projects.

The standard applies among other to *vehicles operating metros on rubber tyred wheels*. Straddled type monorails only might be included in this category, suspended monorails are explicitly excluded by the standard.

Summarizing the standard, it can be stated that the brake system shall:
- decelerate or stop a moving train, without risk to passengers and third parties and with acceptable levels of jerk, without demanding excessive or unrealistic levels of adhesion;
- secure a stationary train;
- control a train's speed on a downhill gradient;
- have a rating consistent with the prevailing gradients and specific operating conditions.

These requirements can be fully applied also to a monorail vehicle and the standard can be adopted as generic design base for the brake system.

The operational conditions formulated for this category (see section 8 of EN 13452-1) should however be analyzed if representative of the monorail project in object.

5.2 Bogies

Bogie for monorail have a design which is substantially different from railway bogies.
Major design differences can be summarized as:
- Often strongly asymmetrical design
- No wheelsets, but cantilevered independent wheels on axle shafts (traction/support wheels)
- Vertical arms for guiding wheels stressing the bogie frame

Two European Norms covering bogies can be mentioned as overall bogie-related international reference standards:
- EN 15827 (23), covering overall requirements for bogies and running gears
- EN 13749 (24), defining methods for specifying structural requirements of bogie frames

EN 15827 is applicable to bogie and running gears for railway vehicles finding application under the European Union railway legislation (Technical Specifications for Interoperability, TSI (25)). EN 13749 is applicable to metros and tramways.

The approach and methodology proposed by the standards is however partially compatible with a monorail bogie, e.g. in the definition of the load cases and fatigue cycles.

Adoption of the EN 15827 and EN 13749 as normative framework for monorail bogie design might therefore be approached, after a due analysis of applicability and necessary adaptation.

5.3 Carbody strength and crash-worthiness

Requirements on carbody strength and crash worthiness focus mainly on:
- Design masses with various load factors, for the carbody strength
- Energy absorption, anticlimbing capability, integrity of the passenger compartment, stability against derailment.

Requirements for carbody strength and crash worthiness in regards of those design features are defined in ASCE 21-13, and in EN 15663 (26) and EN 15227 (27)(26) respectively.

Overall applicability of ASCE 21-13 has already been analyzed in section 3 of this paper.

EN 15663 generically states its applicability to rail vehicles. The standard is of generic nature so application to monorail-type rolling stock is not to be excluded in advance.

EN 15227 is applicable, among others, to passenger rail vehicles such as trams and metros. Monorails might be included in category C-II of the standard, so vehicles designed for operating exclusively in a segregated network, without level crossing and interfaces with other means of transport.

As per section 4.1 of the same standard however, system specific collision scenarios shall be specified, that are due to the peculiarity of the system. This could be e.g. collision with a service vehicle or with obstacle on the guideway.

The standards EN 15663 and EN 15227 might therefore be adopted for a monorail project after a due analysis of applicability and necessary adaptation.

5.4 Environmental requirements

Environmental compatibility standards such as the European Norms EN 50125-1 (28)(22), EN 50121 (29), EN 50155 (30) and EN 61373 (31) provide guidelines related to environmental factors such as e.g. altitude, temperature, humidity, rain, snow and hail, ice, solar radiation and resistance to pollution, dust, and electro-magnetic influences, as well as resistance to shock and vibrations.

All these standards are widely adopted in international urban guided transport projects.

They are a consistent base for the definition of overall and detailed requirements for subsystems, equipment and components of the rolling stock design and due to their generic approach can be fully applied in monorail vehicles.

6 Conclusions

Monorail-based transport systems struggled for their market acceptance, and only in the last decade or less, a relevant adoption of this solution for urban transport could be observed.

The limited diffusion has been caused by, but has also been the reason for, an often incomplete and inconsistent normative framework.

Such incomplete and inconsistent normative framework might negatively impact the safety design and management, the safety assessment and the acceptance by the Authorities.

The paper showed how, despite a lack of monorail-dedicated standards, several existing standards of different geographical and technological origin can be successfully applied to straddled monorail projects and constitute a generic but consistent and complete normative framework.

The publication of a monorail specific guideline, identifying the existing railway and urban guided transport standards to be adopted for monorail systems, could be envisaged by the interested actors in the future and would help formally defining a consistent and complete normative framework, of which the standards presented in this paper can be part of.

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Michele Barbagli	Assessor and Project Manager	 Michele has over 10 years of experience in engineering, quality, safety, sales and project management in the railway industry. He holds a Master of Science in Mechanical Engineering from University of Florence, Italy, with major in Railway Engineering. Additionally, he holds certifications as Lead Auditor (BSI ISO 9001), Six Sigma Practitioner (The Six Sigma Company) and Project Management Professional (Project Management Institute). Michele started his career as trainee and project engineer in the technical office of Italian railway operator TFT. He later joined FOGTEC in Germany, a supplier of rolling stock fire protection solutions, as project engineer and project manager. In the same organisation, he later took over area project and sales manager positions. Since December 2019 he joined TÜV Rheinland AG as Assessor and Project Manager. His fields of expertise are Functional Safety, System integration, Rolling Stock, Fire Protection and CBTC. Key Project experience: • Automated People Mover, Monorails, LRV and Metro systems • CBTC systems, generic and project specific • Rolling stock, conventional and unconventional (monorail, people movers) • System integration and functional safety. • Fire protection for rolling stock

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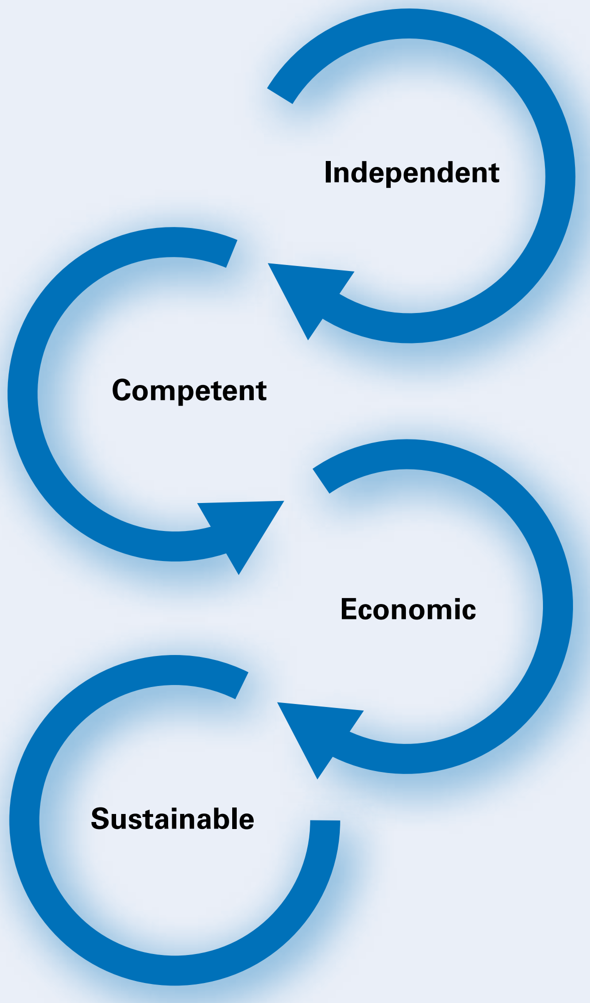

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P9
Catamaran Spherical Bearings for Monorail

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INTERNATIONAL MONORAIL ASSOCIATION

Catamaran spherical bearings for monorail

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Abstract

From the structural bearings special challenges are often required by the Monorail girders.

The often low ratio of live load to dead load increases the issue of fatigue and depending on the concept of the girders; the structural bearings also have to carry moments, which are unusual in conventional bridges.

The aim of the innovative bearing is to take up the challenge and, by a clever arrangement of the spherical bearings, to handle the moments around the longitudinal axis of the girder along with the normal and horizontal forces. All further degrees of freedom shall not be affected or both the serviceability and working life of the spherical bearing with special sliding material shall not be reduced.

Both EN1337 and AASHTO LRFD require the avoidance of a separation of the sliding surfaces of the bearings in service limit state. Conventional concepts often do not meet this requirement, which can lead to limitations in service life, especially if moments to carry. The innovative arrangement of inclined sliding surfaces avoids the harmful separation and allows a design with fatigue strength.

The paper is intended to explain the innovation of the catamaran spherical bearing in this regard. In addition, further advantages should be explained. These include a horizontal clearance free guidance of the girder in the basic/initial service limit state and a perfect centring and alignment of the girder achieved by the inclined sliding surfaces.

Keywords: *Spherical bearings, inclined bearings, bearings monorail, moments on structural bearings.*

1 Introduction

Structural Bearings are designed in US according to AASHTO LRFD, in Europe according to EN1337 resp. appropriate European Technical Assessments. For railway bridges and railroads additional regulations or guidelines (AREMA or RIL 804) are used to adopt the structure and the bearings to the specific needs for the railway track. This paper explains the benefit of inclined installed bearings – “Catamaran Bearings” – in monorail applications with regards to the standards.

The focus is not on the material of the bearing but on the innovative layout application of state-of-the-art spherical bearings with special sliding material, especially for the DEPOT beams used in “New Capital City and 6th of October Lines” in Cairo, Egypt.

2 Bearing layout for monorail bridges

2.1 Monorail bridges

The bearing layout demands for monorail bridges are normally with two connected guideway beams, like the slab tracks of traditional railway bridges. Beside the requirements on the sliding material, it is important to ensure a sufficient lifespan, fatigue and temperature resistance.

Just as for the railway bridges with slab tracks we need the following requirements are:

- The guide system and the alignment at the girder ends shall be with limited transversal clearance.

i.e. the Guideline RIL 804.5401 of the German Railway DB requires for slab tracks spherical bearings with a limitation of the transversal clearance of the guides to ±0.5mm to avoid fatigue damages on the rails.

- To avoid bending deformation of the rails perfect alignment of the girder ends is needed.
- With the requirement for the monorail DEPOT beams the bearing locks the transversal moments M_x. In addition it has to be checked that no partial separation of the sliding elements in SLS appears.

To grant a sufficient working life for the bearings of the monorail guideway beams, the last requirement is of highest priority.

The in chapter 2.2 described catamaran layout can be used in single span or multi span railroad bridges to support the deck, if the stability criteria (2) is given. If not, the in chapter 4 shown application is relevant.

2.2 Traditional Bearing Guides

Traditional guided bearings are equipped whether with internal or external guides. Modern sliding materials are used at the main sliding surface and also in the guides.

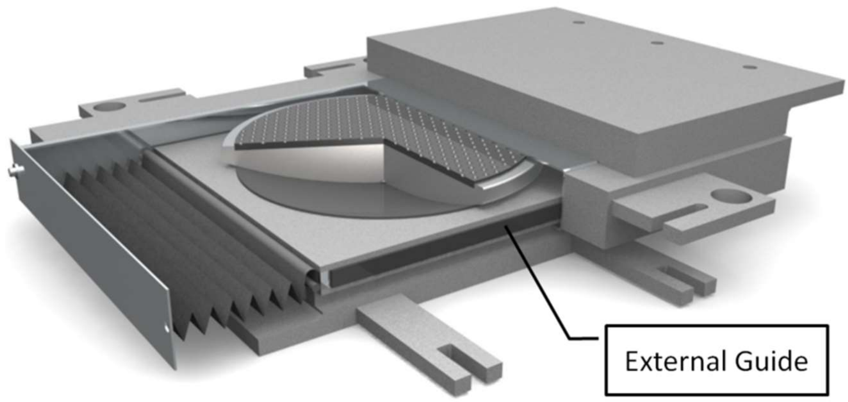

Fig. 1: Spherical Bearing with guides

A lateral clearance is necessary to allow the displacement. EN1337-2 requires the following maximum total clearance:

$$c \leq 1.0mm + \frac{L}{1000}mm \quad (1)$$

The formula (1) limits the initial clearance after assembly and does not consider the setting and wear of the loaded sliding material. Therefore, the maximum clearance must be reduced for slab tracks as well as for the monorail girders due to adjustable guides, which is elaborate and need continuous maintenance efforts. In monorail guideway girders the transversal clearance shall be limited to ensure the comfort and the lifespan of the passing trains and to avoid damages at the finger expansion joints, installed at the top and the two side surfaces.

3 Catamaran Layout for monorail bridges

Structural bearing are designed to minimize parasitic forces and moments. Table 1 of EN1337-1 [Fig.2] shows the degrees of freedom of the different bearing types.

1							2	3	4	5	6	7	8	9	10	11	12	13	14
Relevant parts of the standard							No.	Symbol in the plan view	Symbol in direction		Kind of bearing	Relative movements						Reactions	
												displacements			rotation				
2	3	4	5	6	7	8			x	y		v_x in x-direction	v_y in y-direction	v_z in z-direction	α_x about x-axis	α_y about y-axis	α_z about z-axis	forces	mo-ment
					x		3.1		△	△	Spherical bearing with RS beyond the rotating part	none	none	almost none	sliding	sliding	sliding	V_x V_y N	
					x		3.2				Spherical bearing with rotating part likewise as RS							V_x V_y N	
x					x		3.3		△		Spherical bearing with unidirectional movable sliding part (ext. guidance)	sliding					1)	V_y N	
x					x		3.4				Spherical bearing with unidirectional movable sliding part (int. guidance)							V_y N	
x					x		3.5			△	Spherical bearing with multidirectional movable sliding part		sliding					N	

Fig. 2: Extract table 1 of EN1337-1: Spherical Bearings

In monorail guideways, the bearings are often used to lock the moment around the longitudinal axis M_x (transversal moment) and around the vertical axis M_z (torsion). In dependence of the magnitude the bearings may be affected by fatigue, especially if partial uplift of the sliding elements happens.

The idea is to reduce the number of bearing components and to avoid the risk of harmful separation in the sliding elements.

3.1 Principle of catamaran bearing layout

For the bearing support layout of bridges, the "free movable" Catamaran bearings of one axis are installed inclined in such a way, that both, the normal and the horizontal forces, can be absorbed via them [Fig.2]. The inclination of the bearings in one axis is in opposite direction.

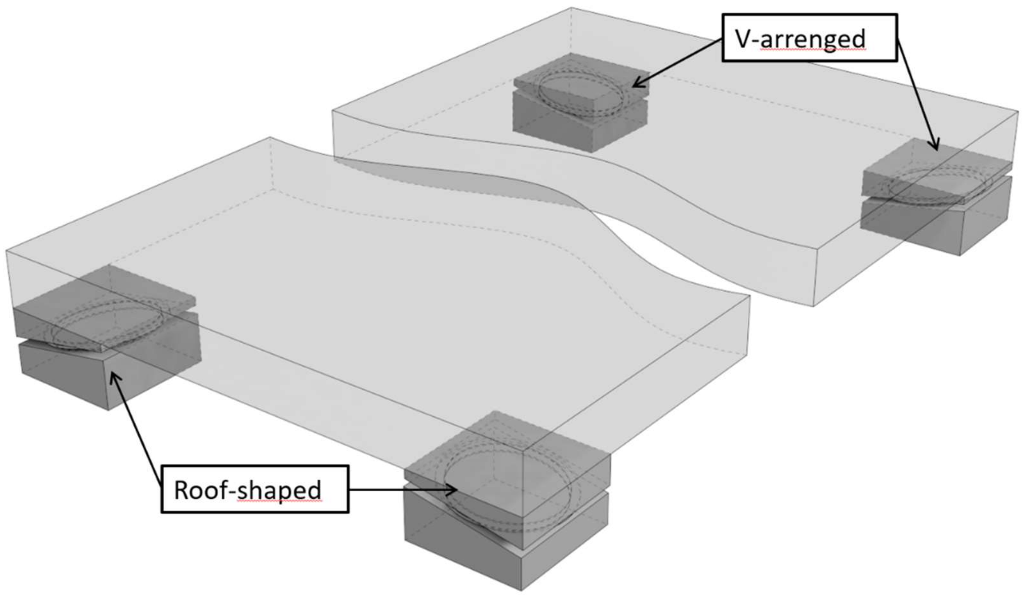

Fig. 2: Roof-shaped / V-shaped arrangement

Since state-of-the-art free movable spherical bearings are used, installed in V-shape with an adjustable angle of inclination, the stability must be checked.

3.1.1 Stability against tilting (h2 > h1)

Normal bridge decks are usually much bigger width than height, so that the center of mass is close to the bearing plane. [Fig.3] illustrates a stable system on the left side. Stability is given when the center of gravity is below the instantaneous center [2].

$h2 > h1$ (2)

If this proof is not fulfilled, the catamaran bearing can be designed to stabilize the system, see chapter 4.

3.1.2 Deck Alignment

The cantilever h2 > h1 ensures a clearance free self-alignment of the bridge deck. By the mass of the bridge deck and the V-shaped arrangement the deck aligns perfectly at the center line of the deck, a benefit for the rails. The alignment in railway/monorail bridges is a matter of comfort and does not at least reduce fatigue impacts.

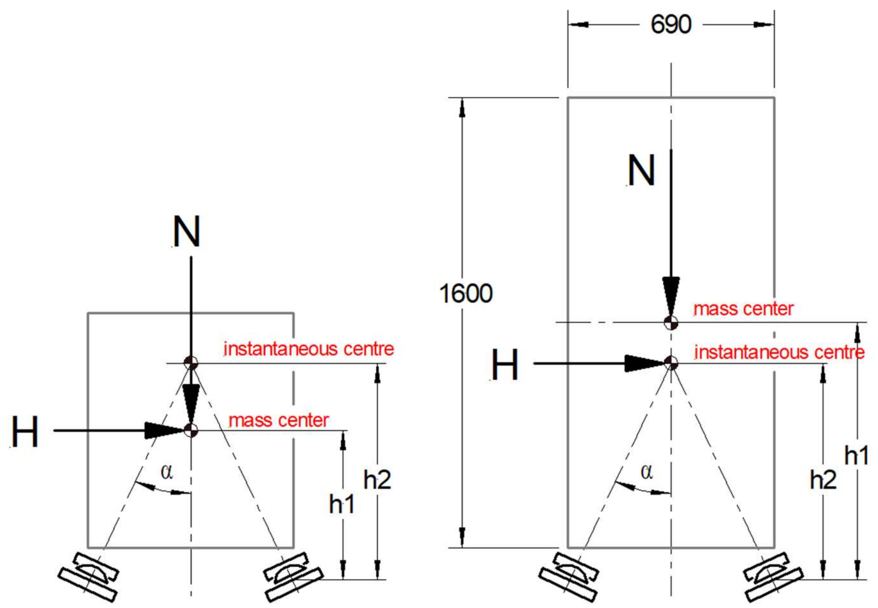

Fig. 3: Stability given: h2 > h1, Stability needs additional provisions: h2 < h1

3.2 Load transfer to the bearings

If the stability test described in 3.1.1 is given, the normal and transversal forces are converted in accordance with the angle α of inclination perpendicular to the sliding surfaces of the bearings. Previously the boundary angle α should be determined, which prevents the sliding surfaces from having a harmful separation (3).

$tan\,\alpha \geq {}^{H}/_{N}$ (3)

The magnitude of α shall adjusted in conjunction to the ratio H/N.

After a positive proof of (2) and (3) the input loads H and N can be transferred to the bearing pair by the force equilibrium [Fig.4].

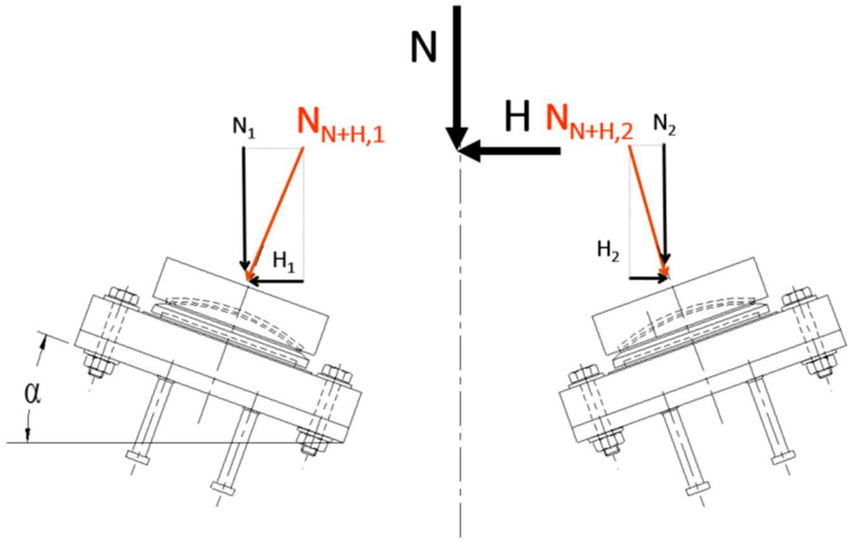

Fig. 4: Load transfer h2 < h1

3.2.1 Normal load on the left bearing

The vertical load on the left bearing is found by formula (4):

$$N_1 = \frac{N}{2} + \frac{H}{2} \times \frac{1}{\tan\alpha} \qquad (4)$$

The coexisting horizontal load by formula (5):

$$H_1 = \frac{N}{2} \times \tan\alpha + \frac{H}{2} \qquad (5)$$

The normal load, which is the design load for the sliding element of the spherical bearing according (6):

$$N_{N+H,1} = \frac{1}{2} \times \left(\frac{N}{\cos\alpha} + \frac{H}{\sin\alpha}\right) \qquad (6)$$

3.2.2 Normal load on the right bearing

The vertical load on the right bearing is found by formula (7):

$$N_2 = \frac{N}{2} - \frac{H}{2} \times \frac{1}{\tan\propto} \qquad (7)$$

The coexisting horizontal load by formula (8):

$$H_2 = \frac{N}{2} \times \tan\propto - \frac{H}{2} \qquad (8)$$

The normal load, which is the design load for the sliding element of the spherical bearing according (9):

$$N_{N+H,2} = \frac{1}{2} \times \left(\frac{N}{\cos\propto} - \frac{H}{\sin\propto}\right) \qquad (9)$$

3.3 Comments

As long the stability is given, the above Catamaran (inclined) layout grants a sustainable and reliable system.

- The spherical bearing parts are reduced to a minimum (standard free movable spherical bearings with special sliding material).
- Only the main sliding surfaces are affected by the vertical and the horizontal load. This grants longest working time.
- NO full or partial separation of the sliding element.
- All loads are transferred by compression through the structural steel. The bearings have fatigue strength.
- Perfect alignment in movement direction.
- Perfect centering.

The inclined "Catamaran" layout with free movable bearings is the most economic and reliable layout for bridges.
The stability against tilting can be increased by different inclinations at the neighbor bearing axes.

4 Catamaran Layout for monorail DEPOT guideway girders

The monorail system has application which cannot fulfil the stability criteria of formula (2) from geometrical reasons: h2 > h1
These applications are different from normal railroads. Especially when the guideway beam lay on only one bearing at each end. i.e. guideway beams at depot and maintenance areas.
The "*New Capital City and 6th of October Lines*" in Cairo, Egypt and their Depot Guideway Bearings are based on the following study.
In contradiction to conventional road and railway bridges, those bearings must be able to restraint moments around the bridge longitudinal axis (transversal moment) and around the vertical axis (torsion). Here are the main additional requirements:

- Restraint of transversal moment M_x
- Restraint of torsional moment M_z
- NO full and partial separation allowed for the main sliding surfaces to ensure the
- Fatigue strength
- Minimised lateral clearance to avoid lateral offset of the girder ends
- Avoid misalignment
- Sufficient working life
- Maintenance cost

The transversal moment is a result of the centripetal forces of the trains and of the curved girders dead load.

4.1 DEPOT bearings

The DEPOT girder height at the Kairo monorail is planned with 1600mm and width of 690mm [Fig5]. The bearing connection to the beam shall not be wider than 690mm.

4.1.1 Stability against tilting (h2 < h1)

To enable the Catamaran bearings to lock the moments of the guideway beams, the angle α is close to 45° and the center of the mass is above the instantaneous center. [Fig.3] illustrates the situation at the right side. Combined with the moment M_x, the stability needs additional devices, as long as the center of gravity is above the instantaneous center [7].

$$h2 < h1 \qquad (10)$$

This result requires for the support on conventional bearings, as well as for the support on Catamaran bearings a careful design verification.

4.1.2 Loading Condition Curved DEPOT beam

The DEPOT bearing stability situation is asking for additional measures at the bearings. Cylindrical or double arranged spherical bearings are faced with accumulated load changes, even in service conditions.
The following tables show the loads for the 23m curved beam. The higher percentage of the moment is a result of the beam dead load and the curvature. To find the minimum transversal bending, the maximum load of the left bearing has to be estimated by the M_x of the straight girders.

Service Limit State:

$V_{SLS,max}$ = 815kN
$V_{SLS,min}$ = 247kN
$H_{y,SLS}$ = 103kN
$M_{x,SLS,max}$ = 665kNm (transversal bending)
$M_{x,SLS,min}$ 1) = 275kNm (transversal bending)
$M_{z,SLS}$ = 125kNm (torque)

1) Considered minimum moment $M_{x,SLS,min}$ = 665kNm – 90kNm = 275kNm

Ultimate Limit State:

$V_{ULS,max}$ = 1041kN
$V_{ULS,min}$ = 163kN
$H_{y,ULS}$ = 179kN
$M_{x,ULS,max}$ = 916kNm (transversal bending)
$M_{x,ULS,max}$ 2) = 723kNm (transversal bending)
$M_{z,ULS}$ = 193kNm (torque)

2) Considered Minimum moment $M_{x,ULS,max}$ = 916kNm – 193kNm = 723kNm

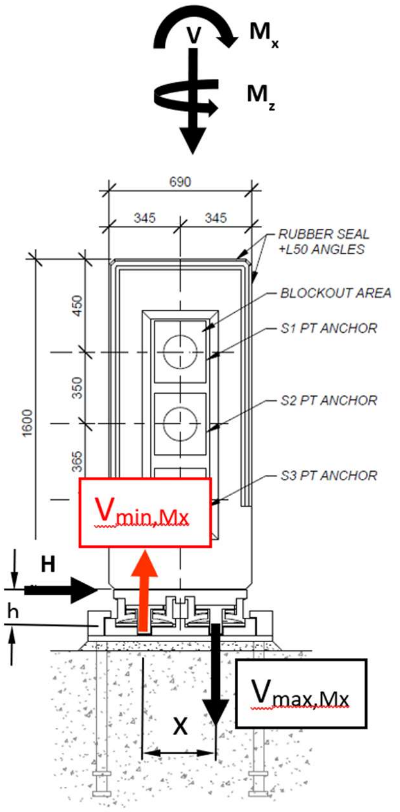

Fig. 5: Girder with horizontal bearing

4.1.3 SLS envelope left bearing

With an assumed distance of x = 0.6m of the bearing centre lines and the cantilever arm of h = 0.05m of the horizontal load, the envelope loads in **S**ervice **L**imit **S**tate are:

$$V_{SLS,min,Mx} = V_{min,SLS} - {}^{M_{x,SLS}}/_{x} - H_{y,SLS} \times h = \text{-866kN} \qquad (11)$$

The main ratio of the curved beam is from the dead load. The straight beam has a value of Mx = 90kNm which we take in consideration for the calculation of:

$$V_{SLS,max,Mx} = V_{max,SLS} - {}^{M_{x,SLS}}/_{x} + H_{y,SLS} \times h = \text{-476kN} \qquad (12)$$

The result is a pulsating tension load in SLS on the left one of the bearing pair, which must be checked for fatigue with the estimated load cycles. Especially the inner bolt connection and the lateral clamp are critical.

To allow the required rotation, the clamp needs a certain vertical clearance in a range of a few millimetres. To activate the clamps a full separation of the sliding element at the left bearing happens. This is contrary to EN1337 part 2, chapter 6.8.7.

Focussing on the sustainability and reliability a solution will be necessary to avoid in SLS the harmful separation, see chapter 4.2.

4.1.4 ULS extreme on left bearing

The extreme uplift load of the left bearing in ULS is:

$$V_{ULS,min,Mx} = V_{max,ULS} - {}^{M_{x,ULS}}/_{x} - H_{y,ULS} \times h = \text{-1373kN} \quad (13)$$

The above magnitude needs strong uplift clamps and many and costly tension anchors to the beam and column.

4.2 DEPOT bearings CATAMARAN

The above-described loading and the pulsating tension load at one side of the girder bearing ask for innovation.
A pair of spherical bearings and their anchorages shall deviate as little as possible from the current standards such as EN1337 or AASHTO LRFD. This ensures that the bearing components have been proven and checked over many years.
To reach above mentioned a pair of spherical bearings with opposite inclinations can be used. However, since the DEPOT beam does not meet the stability condition described in 3.2, the guides are attached at the external side of the bearings.

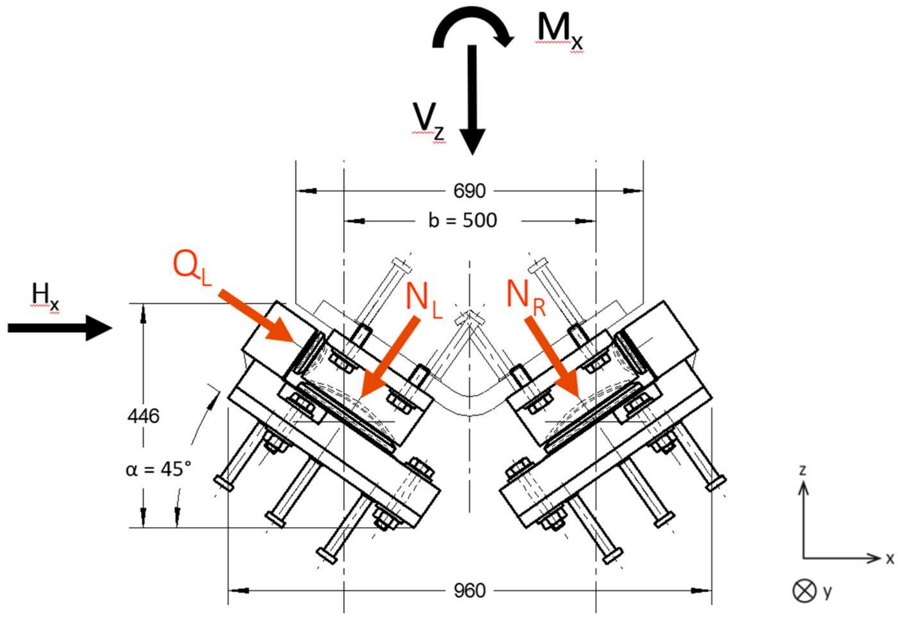

Fig. 6: DEPOT Girder Spherical Bearings principle with inclination

All elements of the bearings are the same compared to the bearing No.3.2 of EN1337-2, table 1 (shown in [Fig.2]).

4.2.1 Load transfer to the Catamaran

The vertical and horizontal loads and the transversal moment are transferred by the inclined bearings. The torsion M_z is carried by torsion keys inside of the bearing, not shown on the sketch.
The curved beam is the one with biggest magnitude of the transversal moment. The moment acts in direction to the curves external side [Fig.6] and twist the beam in clockwise direction. The normal forces N_L and N_R on the bearing and the transversal force Q_L, are determined according to the following formula.

Normal Load on Left Bearing:

$$N_L = \frac{V}{2 \times \cos \propto} - H_y \times \sin \propto - \frac{M_x}{b} \times \frac{\cos(2 \propto)}{\cos \propto} \qquad (14)$$

Shear Load on Left Bearing:

$$Q_L = \frac{2 \times M_x}{b} \times \sin \propto - H_y \times \cos \propto \qquad (15)$$

Normal Load on Right Bearing:

$$N_R = \left(\frac{V}{2} + \frac{M_x}{b}\right) \times \frac{1}{\cos \propto} \qquad (16)$$

The input data of chapter 4.1.2. are transferred to the design loads on the Catamaran Spherical Bearing shown in [Fig.7].

Under SLS and normal ULS conditions, both bearing are compressed. There is no uplift on the bearings itself and with this no element of the bearings are fatigue affected. Even the anchorage is carrying only shear forces. Expensive and space consuming tension anchors can be reduced or avoided.

	LEFT		RIGHT
	N_L [kN]	Q_L [kN]	N_R [kN]
$V_{max,ULS}$, $H_{y,ULS}$, $M_{x,ULS}$	610	2032	4791
$V_{min,ULS}$, $H_{y,ULS}$, 70%$M_{x,ULS}$	-11*	1385	3264
$V_{max,SLS}$, $H_{y,SLS}$, $M_{x,SLS}$	503	1495	3523
$V_{min,SLS}$, $H_{y,SLS}$, 70%$M_{x,SLS}$	102	711	1676

* if negative, neglectable at ULS according to EN 1337-2, 6.8.2.

Fig. 7: Transferred load on the Catamaran Bearing

Only under seismic conditions a small uplift load of N_L = -11kN happens. The tension capacity of the shear studs can carry this small force. In seismic conditions the small value is acceptable. The tilting down of the beam is locked by the geometry of the guide.

4.2.2 Fatigue resistance of Catamaran

The dead load in relation to the live load is relatively small. In addition, the curved beam pulsating loads are high. Fatigue effects are to investigate and to verify.
In conjunction with the loading of the beam, conventional bearing solutions are critical [Fig.5].
The fatigue loads are essential for the bearing design. EN1991-2: 2010-12, chapter 6.9 requires, that vertical actions, as well dynamic effects of centrifugal forces are considered. Most of the structural elements of the Catamaran bearing are compressed, only the connection of the external guide bars to the bottom backing plate are affected by fatigue. The most critical parts of the guide are the welding seams connecting them with the backing plate.
With the detailed stress ranges $\Delta\sigma_i$ in accordance with EN1993-1-9 ANNEX A.5, combined with the number of cycles (17), the damage accumulation shall be carried out.

$$D_d = \sum_i^n \frac{n_{Ei}}{N_{Ri}} \qquad (17)$$

The welding seam of the guides are classified in notch class 63 in accordance to EN1993-1-9 table 8.5.
The fatigue stress verification is analogous to the standard design for railway bridges in curves

5 Conclusion

Monorail applications and requirements on the bearings of guideway beams require specific designed bearings. The Catamaran bearing can fulfill this task, carrying the large moments M_x and M_z without separation - and offers outstanding characteristics in terms of sustainability and reliability.
Since the bearing itself meets the rules of stand-of-the-art bridge bearings, there are no restrictions in terms of service life, they are inspectable from outside and with minimized maintenance cost.
The unusual connection surfaces to the building is compensated by the advantages on the anchorages.

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Curriculum Vitae

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14.07.1968	Born in Gelnhausen, close to Frankfurt, Germany
March 1992	Graduated as a Mechanical Engineer Dipl. Ing.(FH) At the University of Gießen/Friedberg
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During the 29 years' experience in bridge bearings, among others responsible for the following projects:

1. Lehrter Bahnhof in Berlin – Germany
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   Bridge bearings with service uplift loads up to 2700kN - Finished in 2002

2. Viaduc Millau - France
   Design and project manager for

MSM® spherical bearings up to 140,000kN vertical load - Finished in 2003

3. Tsing Ma Bridge – Hongkong
   Project manager and supervisor for the replacement of the failing bridge bearings into MSM® spherical bearings - 2004 to 2012

4. Signature Bridge Delhi – India
   Project manager for
   MSM® spherical bearings up to 230850kN - 2000 to 2012

5. Bridge BOGIBIL over river Brahmaputra, Assam – India
   Senior Sales manager
   MSM® spherical bearings up to 28000kN - 2013 to 2015

6. Mass Transit System Project in Bangkok (Red Line) (1),Bangkok – Thailand
   Technical Sales Director
   >1970pcs. MSM® spherical bearings up to 6570kN - 2014 to 2016

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M A U R E R SPS

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The MAURER Group is a leading specialist in mechanical engineering and steel construction with over 1,000 employees worldwide. The company is market leader in the area of structural protection systems (bridge bearings, expansion joints, seismic devices, tuned mass dampers, monitoring systems). It also develops and produces vibration isolation of structures and machines, roller coasters and observation wheels as well as special structures in steel.

MAURER participates at many spectacular projects worldwide, like for example the world's biggest structural bearings for the Signature Bridge in Wazirabad, Delhi, earthquake resistant expansion joints for the Bosporus bridges in Turkey, semi-active tuned mass dampers for the Donau City tower in Vienna, or uplift bearings for the Zenit-Football-Arena in St. Petersburg. Among the most prestigious steel structures are the BMW World in Munich or the Terminal 2 of Munich Airport. MAURER's most spectacular amusement rides include the world's biggest transportable observation wheel hi-sky in Munich, the Rip Ride Rockit Roller Coaster in the Universal Studios Orlando or the Fiorano GT Challenge in Abu Dhabi.

P10
Structural Bearings for Monorail and Light Rail Bridges

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Structural Bearings for Monorail and Light Rail Bridges

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Abstract

Light Railways are very frequently utilized for Mass Transit Systems to reduce the traffic impact in congested urban areas. Bridges for the Light Railways, even if their static scheme is often very simple, are peculiar structures where the interactions between vehicles, rail and bearings plays a fundamental role. An important aspect of the bearings for Light Rail bridges, frequently requiring special solutions, is also the very high train frequency and the relatively high deformation of the structures under load, implying extremely high performance requirements and fatigue resistance of the bearings . In some cases, as for instance in monorail lines, also uplift forces shall be considered. The author, currently involved in the design and supply of the structural bearings for several Light Rail projects in the world (Thailand, Egypt, Indonesia and others), describes the different solutions of the bearing systems frequently utilized, putting in evidence the fatigue and wear resistance problems.

Keywords: bridge bearings, pot bearings, spherical bearings, sliding materials, fatigue resistance

1 Introduction

Bridges are quite often a very relevant part of Monorail and Light Rail lines.
Bridges, contrary to appearances, are deformable structures, always subjected to small movements: they slowly changes their length due to the creep and shrinkage of the concrete and due to the temperature variations and they are bent by the live loads. The movements induced by the traffic are particularly evident for Monorail and Light Rail lines due to the flexibility of the beams and to the very high frequency of the trains.
Traffic volumes are given for instance in [4] for railway bridges and are of the order of 240 trains per day. Monorails and light railways utilized for mass transit systems however are subjected to a much higher volume. Normally it is considered one train every 3 minutes for 18 hours per day, corresponding to 360 trains per day. In addition to that the weight of the trains for Mass Transit and Monorail lines is much more similar to the design value than that for normal railway bridges.
For the normal railway bridges the design load is referred to the heaviest possible goods train, whilst the average service load includes many much lighter passenger trains so that the average live load in service normally will not exceed 30% of the design load.
For the mass transit trains the vehicles are dedicated to the passengers transportation only so that the average service load is very near to the design load. For the following considerations we will assume an average service load equal to 80% of the design load as will be explained in the next paragraphs.

2 Static schemes of the bridges for light rails and monorail lines

Light rails frequently adopt simply supported spans. This is due to the fact that the rails are normally continuous and the simply supported spans can easily accommodate the different length variations of the rail and the beams with small relative displacements.
For the monorail lines there is no rail and the expansion joints can be used without any negative effect. Therefore continuous beams with 3 or more spans are preferred.
To support the beam of a monorail 2 possibilities are given

1) The beam is supported by columns to which is monolithically fixed (Fig. 1)
2) The beam is connected to the columns by structural bearings (Fig. 2)

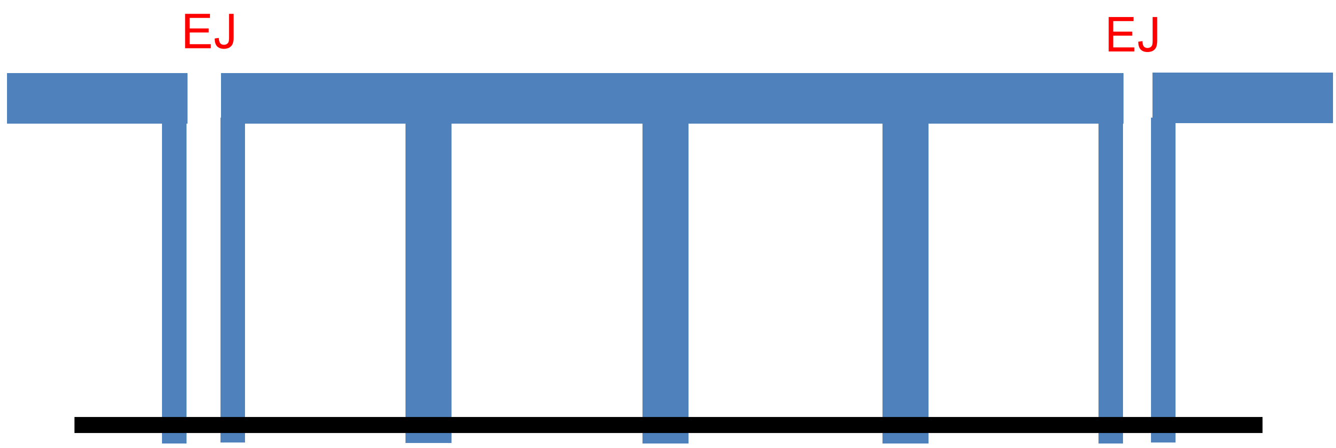

Fig. 1 – Beam monolithically fixed to the column

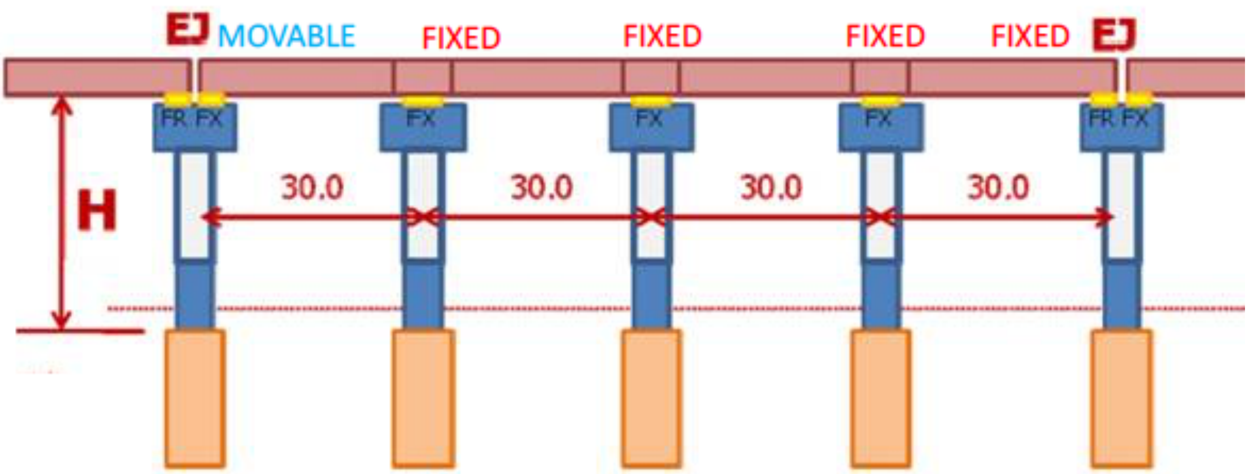

Fig. 2 - Beam connected to the columns by structural bearings (movable and fixed)

Solution 1 has the evident advantage to avoid the structural bearings and consequently:

- Maintenance of the bearings is avoided

- Undesirable relative movements between beam and columns are avoided

Nevertheless the adoption of solution 2 with structural bearings can bring several advantages:

- Twin columns in correspondence of the expansion joints are avoided
- The actions transmitted from the beams to the columns are reduced
- The displacement of the structure due to horizontal actions may be limited adopting stiffer columns
- The distance between expansion joints may be increased, reducing their number
- Foundation settlements may be easily compensated by adding shim plates between the bearings and the structure or adopting injectable bearings

The adoption of structural bearings however requires special attention and the fulfilling of particular requirements in order to assure the proper performance of the monorail throughout its entire service life.
The requirements of the bearings to be adopted in a monorail are shown in the following paragraph.

3 Bearing systems

3.1 Definitions and general requirements

Structural bearings, as defined by EN 1337-1 are elements allowing **rotation** between two members of a structure and transmitting the loads defined in the relevant requirements as well as preventing displacement (fixed bearings), allowing **displacement** in one direction only (guided bearings) or in all directions of a plane (free bearings) as required.
The bearing system for a structure, as defined by EN 1337-1, is the combination of bearings and structural devices which together provide for the necessary movement capability and for the transmission of the forces.
As clearly stated by the European Standard the essential functions of the bearings are to allow:

- rotation
- displacement when required

Essential requirements of the structural bearings are also the following:

- bearings shall be designed to support the specified actions with the minimum possible deformation
- bearings shall be designed to allow the specified movements with the minimum possible reaction
- bearings and the relevant parts of the adjacent structures shall be designed to allow the easy inspection and the replacement of parts of them or the entire bearings.

3.2 Bearing types

We have seen in the previous paragraph that all bearings shall provide one or two functions: rotation and displacement.
To get these functions 3 physical principles only are available: rolling, elastic deformation and sliding.

Fig. 3 – physical principles adopted in the structural bearings

The possible structural bearings, classified in function of their degrees of freedom, are listed in figure 4 where the actions transmitted are in red and the degrees of freedom in green. For the elastomeric bearings the degrees of freedom are limited by the deformation capacity of the rubber and therefore they are shown in red and green.
The bearings commonly utilized for the monorails are evidenced in yellow

FORCES AND MOMENTS	F_z	F_x	F_y	M_y	M_x	M_z	DOF
Cylindrical fixed bearing							1
Spherical fixed bearing							3
Cylindrical sliding guided							2
Cylindrical free sliding							3
Spherical sliding guided							4
Spherical free sliding							5
Elastomeric bearing							5*
Restraint							3
Guide							4
DISPLACEMENTS AND ROTATIONS	Z	X	Y	β	α	γ	

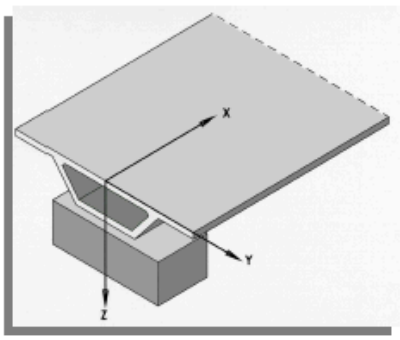

Fig. 4 Classification of the structural bearings in function of their degrees of freedom

The selection of the suitable bearing system for a railway bridge shall always be made taking into consideration the following peculiar requirements:

- Horizontal loads due to braking and traction are very high in comparison with the vertical reactions. This fact requires a special consideration on how horizontal loads are transferred to the substructures. The problem is amplified if also earthquake forces have to be considered.
- The continuous rails are interacting with the structure, especially for the transmission of the longitudinal loads. The bearings shall be able to transfer the longitudinal loads with the minimum possible deformation in order to avoid as much as possible an axial reaction in the rail that may cause buckling and misalignment. Elastomeric bearings shall therefore be excluded, unless combined with rigid restrains.

- In case of earthquake the lateral deflection of the piers may be out of phase, so that the spans may rotate around the vertical axis, requiring the same capability to the bearing system.
- In case of very strong earthquake or in monorail lines the bearings may be subjected to uplift forces as a result of three possible situations: large transversal moments induced by the trains; lateral earthquake with one train on the track; out of phase lateral deflection of the piers when the bridge deck has a very large torsional stiffness. Uplift forces due to the earthquake however are a rare loading condition whilst the uplift induced by the trains may be a frequent one.

In the following paragraphs the behaviour of the different types of bearings will be examined, putting in evidence their performances and their critical aspects.

4 Live loads

We will consider the typical load cases for monorail bridges.
In figure 5 is shown the typical monorail four car train and in table 1 are given the axle loads for different number of passengers per car

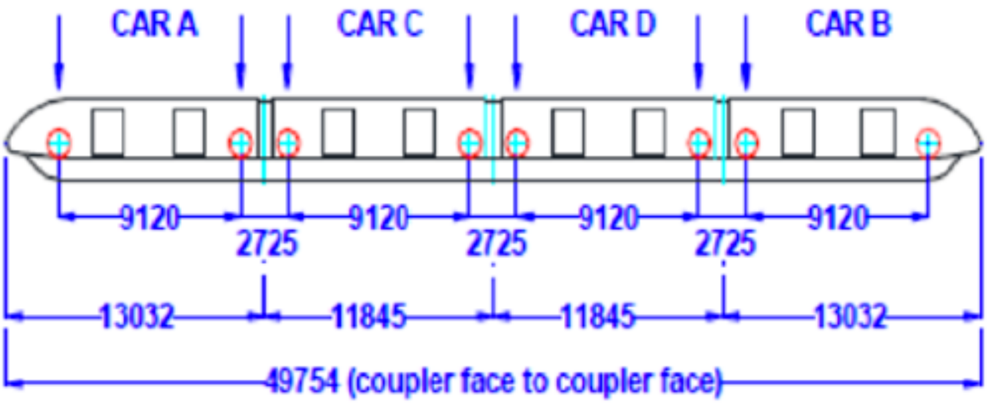

Fig. 5 – four car train axle spacing

Loading condition		Pax/car	Axle load (kN)
AW0	Empty	0	74.3
AW1	Seated	17	80.1
AW2	+ 4 pax/m^2	99	108.3
AW3	+ 6 pax/m^2	140	122.6
AW4	+ 8 pax/m^2	181	136.6
MAX	+ 10 pax/m^2	223	150.9

Table 1 - monorail train axle loads

From table 1 it can be seen that the average loading condition AW3 represents approximately the 80% of the maximum load.
AW3 is also the considered loading condition for the evaluation of the fatigue effects and for the execution of the fatigue tests.

5 Deformation limits

Deformation limits are recommended in UIC 776-3R. UIC is the International Union of Railways and is the most well-known code in the field of railways from which most of the International Standards about railways are drawn.
UIC limits the deflection d of the beams for imposed loads on 30 m spans or more and for speeds up to 120 km/h to the value d ≤ L/800. The same limitation is given for very high speed rails.
This limitation seems very liberal, specially for high speed rails where a deflection of 37.5 mm for a 30 m span seems not to be compatible with the passengers comfort seating in a train running at 300 km/h.

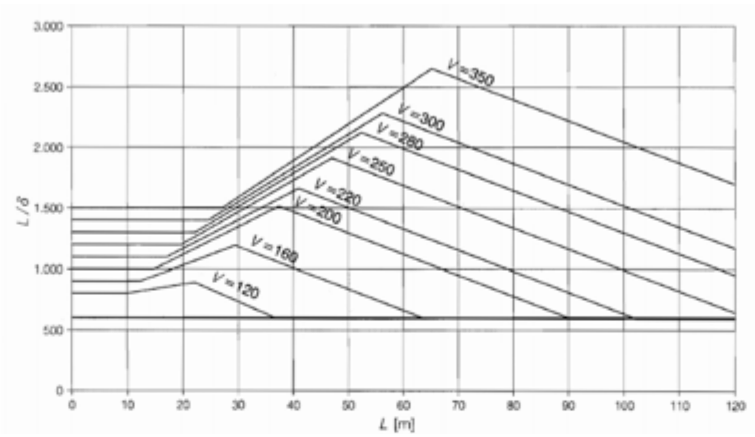

Figure 6 - Deflection limitations in function of the span length, the number of spans and the train speed according to EN 1990

EN 1990 gives a more stringent requirement. The deflection limitations in terms of the ratio span /deflection L/d in function of the span length L, the number of spans and the train speed is given in the graph in Figure 6.
For light railways, where the speed is normally ≤ 120 km/h the limitation is nearly L/d ≤ 800 which is in line with the recommendation of UIC and more or less corresponds to the common design praxis.
For the following considerations we will assume this value of L/d = 800.
This corresponds to a rotation angle of the bearings, assuming a parabolic deformation of the beam:

$$\alpha = \frac{4\delta}{L} = \frac{4}{800} = 0{,}005\ rad \qquad (1)$$

6 Bearings accumulated deformations

We have now all the necessary data to evaluate the accumulated deformations of the bearings during the service life of the structure.

6.1 Accumulated rotation

We will consider the train as defined in Fig. 2 and we will assume that the beams are simply supported with a stiffness such as to generate a maximum rotation of 5 milliradians in correspondence of the supports with the maximum design load as defined in Table 1.
The time history of the rotation at the bearings for the transit of single axles, 2 cars train and 4 cars train at a speed of 60 km/h is shown in figure 7

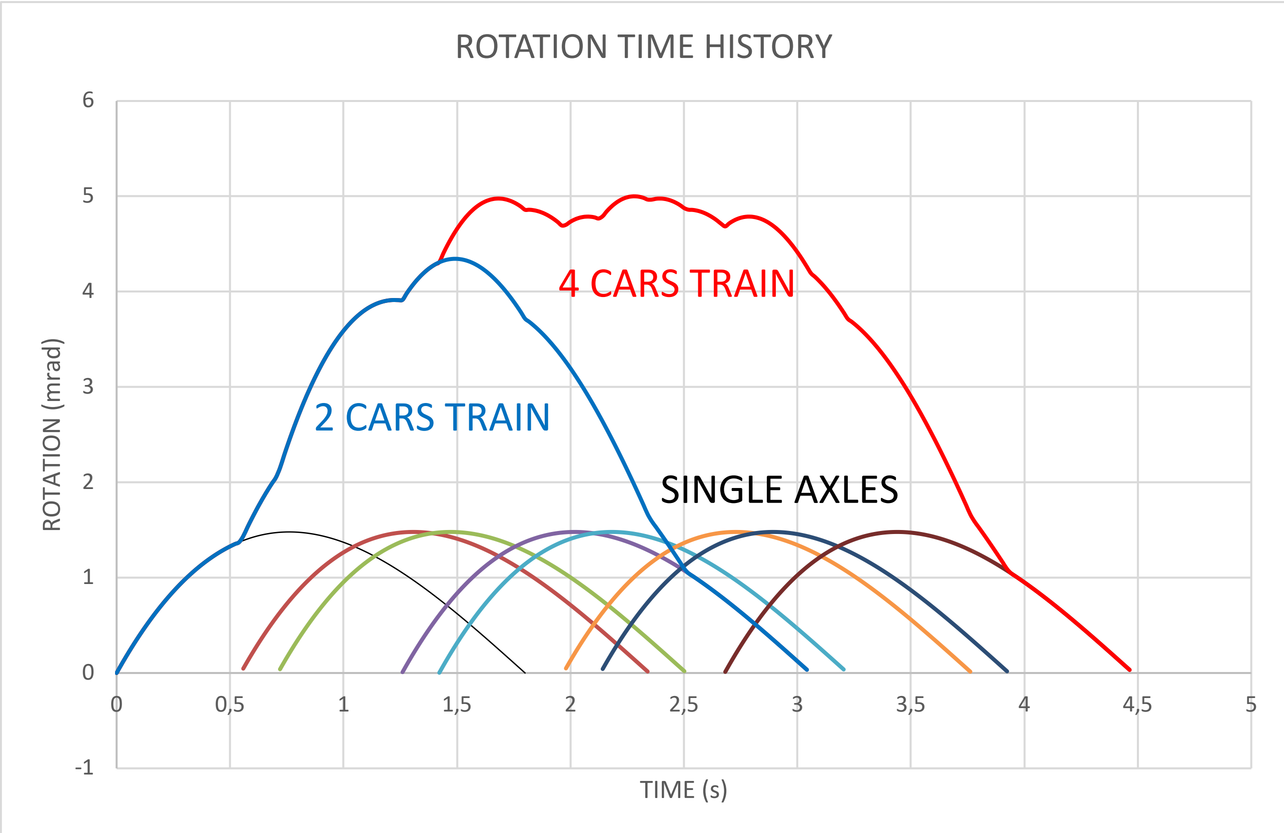

Figure 7 – Rotation time history for the transit of trains at 60 km/h on a 30 m simply supported span

The accumulated rotation for the 4 cars train transit, adding all the partial positive and negative rotations of the time history is:

$$\boldsymbol{\alpha = 10.8\, mrad} \qquad (2)$$

The accumulated rotation per day will be

$$\boldsymbol{\alpha_d = 10.8 \times 360 = 3888\, mrad = 3.89 rad} \qquad (3)$$

6.2 Accumulated displacement

The sliding path in a sliding bearing during its service life can be evaluated through the following assumptions and considerations.

1. The sliding path due to thermal variations represents a minor portion of the total sliding path and will be disregarded
2. The sliding path due to the flexural bending of the beams represents the most important factor

To evaluate the sliding path due to the flexural bending of the beams we consider the same loading conditions assumed for the evaluation of the accumulated rotation at paragraph 6.1

The sliding path of the sliding bearing, as shown in figure 8, is:

$S = \Delta x = 2\alpha(h - y)$ (4)

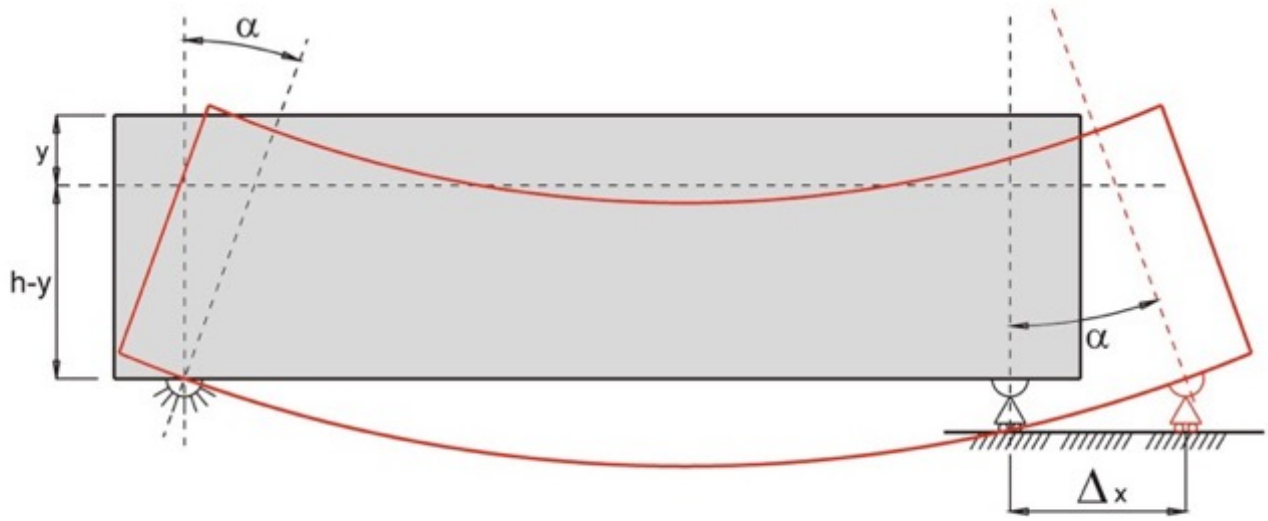

Figure 8 - Flexural bending of a simply supported beam and consequent travel path of the sliding bearing

Considering a typical value for the distance h-y between the neutral axis of the beam and the position of the bearings (as it was the case for the Bangkok Monorail)

$h - y = 2300\ mm$ (5)

we can get the sliding path due to the displacement for each train transit considering the total rotation per train as computed at paragraph 5.1:

$S_{d1} = 2 \times 10.8 \times 10^{-3} \times 2300 = 49.7mm$ (6)

If the sliding bearing is a spherical one, to the above sliding path due to the displacement we shall also add the sliding path due to the rotation, as shown in figure 9

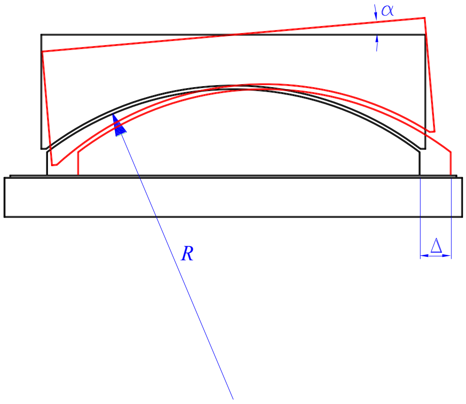

Figure 9 - Travel path due to the rotation in a spherical bearing

The sliding path due to the rotation for each train transit will be:

$$S_{\alpha 1} = 2R\alpha = 2 \times 500 \times 10.8 \times 10^{-3} = 10.8\ mm \qquad (7)$$

Where we have assumed R=500 mm as the radius of the spherical calotte of a typical spherical bearing with a bearing capacity at SLS of 5000 kN
The total sliding path due to the transit of a train with maximum design load in a spherical bearing will be:

$$S_1 = 49.7 + 10.8 = 60.5mm \qquad (8)$$

The accumulated daily sliding path for a spherical bearing, considering 360 trains per day with an average weight equal to 80% of the maximum one will be:

$$S_d = S_1 \times 360 \times 0.8 = 17424mm \qquad (9)$$

These is a very, very important displacement!

6.3 Displacement velocity

The sliding velocity cannot be disregarded because some heat effect may be generated.

If the speed of the train is 60 km/h, considering its length of 44655 mm as given in figure 1 the transit time on a bearing will be

$$T = \frac{44655 \times 3600}{60 \times 10^6} = 2.68s \qquad (10)$$

and the velocity of the displacement on the sliding material will be:

$$V = \frac{60.5}{2.68} = 22.6mm/s \qquad (11)$$

If the trains speed will be doubled to 120 km/h of course the sliding velocity will also be doubled to 45.2 mm/s indeed not a negligible value.

We will now apply the calculated accumulated rotations and displacements to the different types of bearings and evaluate the consequences.

7 Roller Bearings

Rolling has been the first physical principle utilized in structural bearings starting from late XIX century and still used in a limited number of cases.

Figure 10 – Roller bearing for a railway bridge, late XIX century, Germany

They are still used, in particular for monorail lines, especially in Japan and China. Compared with other bearing systems they are normally much more heavy and expensive.
The reason for that is the stress concentration generated by the linear contact between roller and steel plates, require very thick steel plates subjected to bending to reduce the stress at an acceptable level for the adjacent structures.

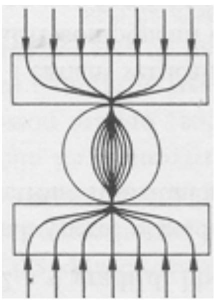

Figure 11 – Stress concentration in a roller bearing

Roller bearings, although expensive in comparison with other types, are very robust and not subjected to wear.
The critical aspects of the roller bearings are the following:

- They don't allow multidirectional movements
- They allow rotation around an axis perpendicular to the movement direction only. This may create a problem in curved or skew bridges.
- When subjected to uplift they cannot totally eliminate the vertical mechanical play.
- To reduce the roller diameter extremely high tensile steel is normally used (as for instance martensitic steel). This kinds of steel may became brittle al low temperature and under dynamic loads.

8 Elastomeric Bearings

Elastomeric bearings are utilized in bridge construction since late 19th century. Their use in railway bridges however is not recommended as they can resist horizontal actions with large horizontal deformations only. This may create misalignments of the rails due to the braking of the trains.
Elastomeric bearings, if utilized in railway bridges, should always be combined with rigid restraints as shown in figure 12

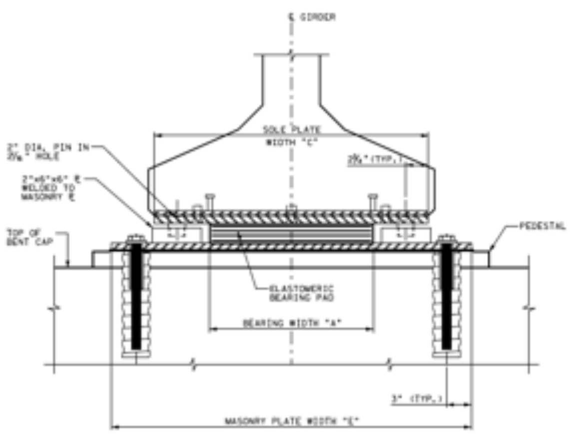

Figure 12 – Typical detail of elastomeric bearings with restraints as used in railway bridges

In alternative, in seismic areas, the restraint may consist in the lead core of Lead Rubber Bearings, however this solution is not recommended because the lead core is not very rigid and will allow a non-negligible deformation before transmitting the braking force with possible negative influence on the rails alignment.
This solution however has been adopted in Indonesia for the Cibubur Mass Transit line.

Figure 13 – LRB adopted by the Cibubur Metro Line in Jakarta, Indonesia

Elastomeric bearings and lead rubber bearings manufactured according to EN 1337 and EN 15129 shall pass very severe prototype tests that also include fatigue tests over 2 million cycles

9 Pot Bearings

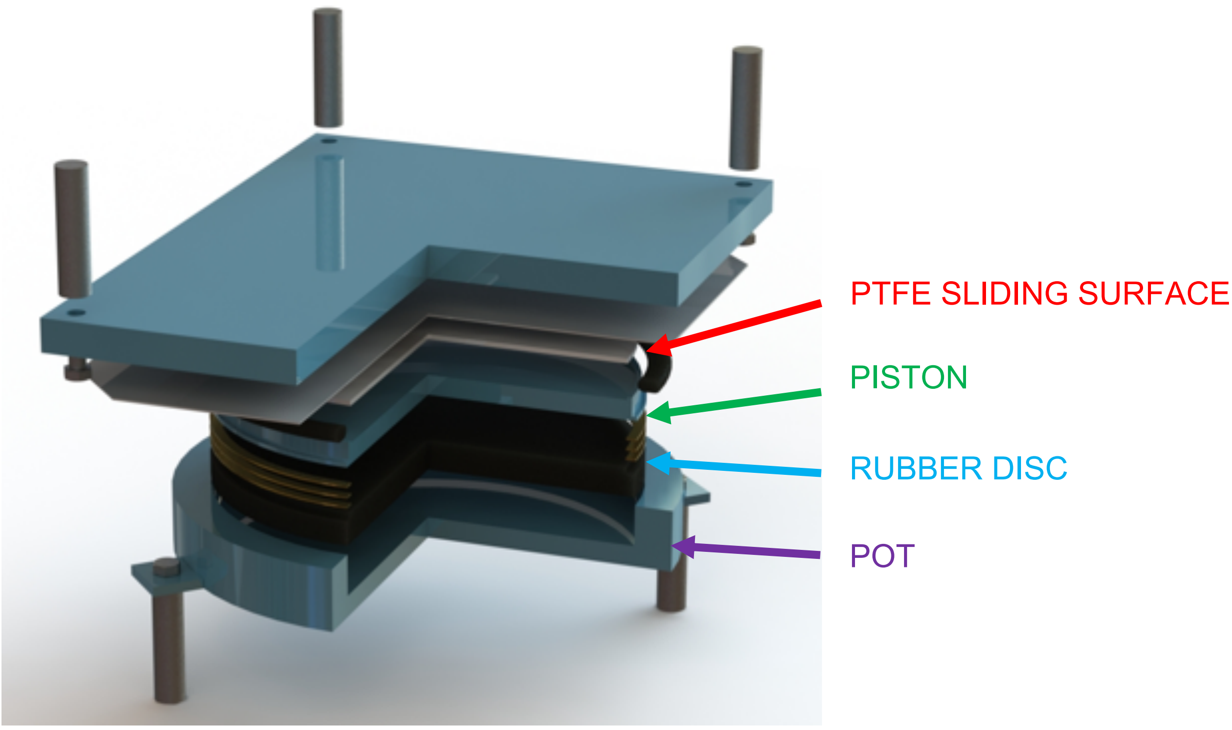

Fig. 14 – Sliding pot bearing

Pot bearings have been invented in Germany in 1960 and for sure, still today after more than 60 years, they are the most widely used structural bearings world-wide. They have been extensively used in High Speed Rail And Mass Transit Systems in all the world.
In the pot bearing the rotation capability is given by the deformation of a rubber disc confined in a steel pot and a steel piston; the displacement capability, if required, is given by a PTFE sliding surface in combination with austenitic stainless steel (see Fig. 14)
However their performance, due to the constant increase of requirements arising from the modern structures, in some cases is not more sufficient as we will see in the following.
The most critical component of the pot bearing is the internal seal.

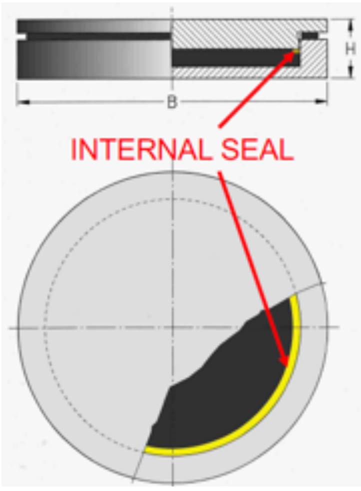

Figure 15 – Typical pot bearing with the internal seal in evidence

In EN 1337-5 are foreseen 4 types of seals, characterized by different wear resistances. Wear resistance is expressed in terms of the accumulated sliding path of the seal against the pot wall generated by the rotation. The foreseen types of seals and their typical wear resistances are shown in table 2

SEAL TYPE	WEAR RESISTANCE (m)	
	TEST	TRAFFIC
Stainless steel	500	2500
Brass	1000	5000
POM	2000	1000
Carbon filled PTFE	2000	1000

Table 2 – Typical wear resistances of internal seals according to EN 1337-5

According to EN 1337.5 the wear resistance for traffic is the test result amplified by 5 to correct the effect between the constant amplitude slide path used in the tests and the variable amplitude movements which actually occur due to traffic
Some manufacturer developed innovative seals based on the use of modified POM, extending the wear resistance to 3200 m.

The wear resistances given by the EN 1337-5 and even the increased one, become insufficient with the requirement of mass transit light rail bridges.
Assuming the traffic volumes and the deformation limits as discussed in paragraphs 4 and 5 we get the accumulated rotation per year in a mass transit bridge:

$$\alpha_{year} = 0{,}75 \times 360 \times 365 \times 0{,}00 = 492{,}75\, rad \qquad (12)$$

For a pot bearing with 5000 kN bearing capacity at SLS the internal diameter of the pot, corresponding to the diameter of the seal will be:

D=460 mm

The accumulated sliding path will be:

$$S_{\alpha year} = \alpha_{year} \times \frac{D}{2} = 492{,}75 \times 0{,}46 = 227m \qquad (13)$$

It means that the limit wear resistance would be reached in 11 years for the stainless steel seal, 22 years for the brass seal (the most commonly used) and 44 years for the POM and filled PTFE ones: in all cases clearly insufficient for a service life that should be 50 or 100 years at least.
When the pot bearing is combined with a sliding surface to allow the displacement the daily accumulated sliding path of the sliding material will be as already calculated ad paragraph 5.2

$$S_d = 2 \times 2300 \times \alpha_d = 2 \times 2300 \times 3.11 = 14306\, mm \qquad (14)$$

The performance limitations of the PTFE sliding surface will be discussed in the following paragraph.

10 Spherical Bearings

Spherical bearings have been developed in the years 60 of last century, after the introduction of the use of PTFE in structural bearings.
In the spherical bearings the rotation capability is given by the sliding of a pair of spherical surfaces respectively plated with PTFE and austenitic stainless steel; the displacement capability, if required, is given by a PTFE sliding surface in combination with austenitic stainless steel (see Fig. 16).

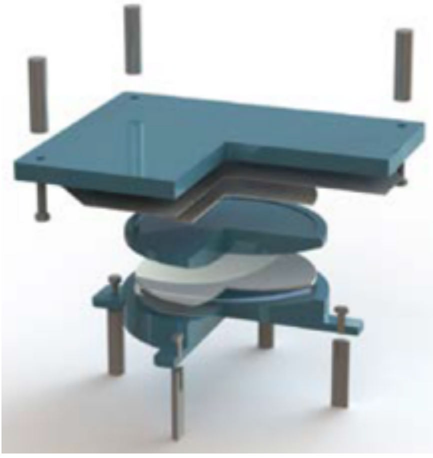

Fig. 16 – Sliding spherical bearing

Spherical bearings can provide a higher rotation capacity if compared with other types of bearings (rotation up to 0.05 rad or more).
Spherical bearings always plaid a minor role in the structural devices due to their higher cost but in year 2000 they became the preferred solution for the Italian High Speed Railways where the high rotation capacity was used to simplify the installation with prefabricated structures, compensating the structural tolerances and the longitudinal inclination of the beams (see Fig. 17).

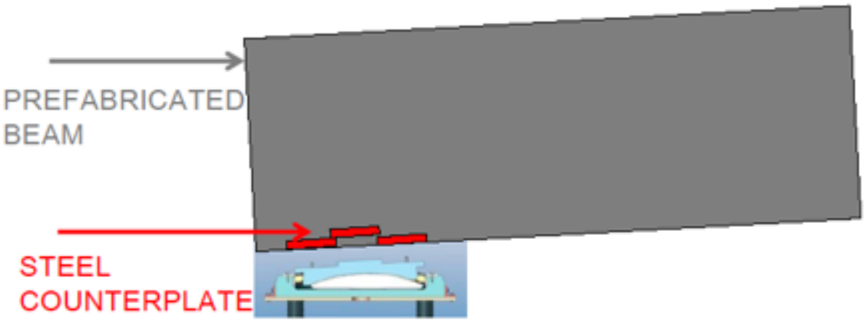

Fig. 17 - Utilizing Spherical Bearings with sufficient rotation capacity it is possible to install the prefabricated beams directly on them. This technique has been widely used in the Italian High Speed Railway

The use of spherical bearings became more and more frequent after the introduction in the market of special sliding materials with much higher performances than PTFE that allowed to extend their service life reducing the cost.
Spherical bearings are now the preferred solution for High Speed Railways and mass Transit Systems in many countries of the world.
Sliding materials are the most critical components of the spherical bearings.
The sliding material foreseen in EN1337 and by many other standards is PTFE.
The performance characteristics of pure PTFE with stainless steel mating surface given in EN 1337-2 are the following:

- Characteristic compression strength up to +30°C: 90 MPa
- Characteristic compression strength at +48°C: 57,6 MPa

- Wear resistance: 10.242 m slide path
- Temperature ranges: -35 ÷ +48 °C

The performance characteristics of PTFE becomes inadequate in the following cases:

- When the temperature range is exceeded. That is a common case in many parts of the world like Arabic Peninsula, several regions of India, Thailand, Africa and others
- When the sliding path foreseen in the useful service life of the bearings is exceeded. This is a common case in many modern projects of high speed railways and Mass Rapid Transit systems as will by explained in the following.
- In addition for some applications it may become impossible to design bearings resisting the specified loads and moments fulfilling the required geometry limitations with a sliding material having a compressive strength of 90 MPa only like PTFE.

In the spherical bearings there are two types of sliding surfaces:

1. The sliding surface allowing rotation only
2. The sliding surface allowing rotation and displacement

This is clearly shown in the following figure 18.

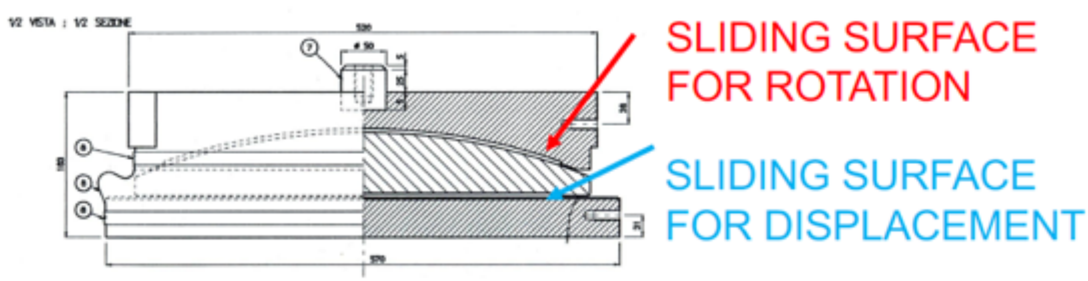

Figure 18 – Functioning scheme of a spherical bearing

Considering the daily sliding paths for a monorail system as computed at paragraph 5.2 we get:

- Daily sliding path for the sliding surface for rotation : 3.7 m
- Yearly sliding path for the sliding surface for rotation: 1350 m
- Daily sliding path for the sliding surface for sliding : 14.3 + 3.7 = 18.0 m
- Yearly sliding path for the sliding surface for sliding: 6570 m

The wear limit of the PTFE would be reached in less than 8 years for the surface 1 and less than 2 years for the surface 2
Where 10242 m is the wear resistance of the PTFE as given in EN 1337-2
Totally unacceptable!

11 Innovative Sliding Materials

The above computation puts in evidence that the wear of the sliding material is a very critical aspect and that PTFE according to EN1337-2 is inadequate to grant a reasonable service life of the bearings without major maintenance.
It is obvious that sliding materials with much higher performances shall be utilized for the bearings of light rails bridges.
In particular are required

- Higher compressive strength
- Higher wearing resistance
- Higher resistance to high temperature.

The basic performances of HI3 and HIM sliding materials developed by Hirun International are summarized in table 3.

PROPERTY	HI-3	HI-M	PTFE	UHMWPE
Compressive strength (MPa)	180	260	90	180
Heat resist. (long term) (°C)	90	120	48	48
Heat resist. (short term) (°C)	120	200	48	80
Wear resistance (m)	50.000	>>50.000	10.000	50.000
Static friction	$\leq 3\%$	$\leq 3\%$	$\leq 3\%$	$\leq 3\%$

Table 3 - Sliding materials performance comparison

In table 3 the basic mechanical properties developed by Hirun International are put in comparison with the performances of PTFE according to EN 1337.2 and with the alternative material UHMWPE

The performance characteristics of the sliding material HI-3 has been tested by a cold-flow test.

The cold-flow test at high temperature is the most severe test to verify the performance of the sliding material in service conditions with long term sliding path.

12 Conclusions

Light Railway bridges, even if their static scheme may appear very simple, are peculiar structures where the actions of the repeated live loads on the bearings shall be evaluated carefully. There are several bearing systems that is possible to apply and the designer shall select the right one in function of the performance required. The aim of the paper has been the review of the possible bearing systems putting in evidence their performances and the problems related to their utilization.

From the review it appears evident that pot bearings may not be suitable for any light rail application and that sliding materials shall provide a much higher performance than PTFE in order to assure a reasonable service life to the bearings without major maintenance

13 References

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THE PAST:

HIRUN INTERNATIONAL is an engineering company having its roots in the deep heart of the most modern and advanced civil engineering technologies.

The core of the company is composed by pioneers that in the last 50 years had a leading position in developing worldwide very important technologies such as: structural bearings, expansion joints, post-tensioning system, anti-vibration and anti-seismic systems.

The Directors of the company in the past years were proudly involved in the definition of international standards or key specifications such as: EN1337 (European standard for structural bearings), EN15129 (European standard for antiseismic devices), special bearings for High speed railway lines (as examples in Italy, Taiwan and China) and Metro lines (as example the Bangkok metro system).

In the past years, the evidence of the strong innovation attitude is represented by several patent issued and this aim is still well alive in the company. Patents and customized unique solutions such as: special dampers, new materials for different applications, customized combinations and applications of different structural devices. This attitude is pushing the company to a never ending improvement.

THE PRESENT:

HIRUN INTERNATIONAL, is now a specialized company for the application, the design, the production, the installation and the testing of **Structural bearings, Anti-seismic devices, Expansion joint, Post-tensioning systems, Anti vibration devices.**

a special attention is dedicated to the quality of the products. We design and produce starting from the control of the internal process; we are qualified ISO:9001 and we got several international qualifications such as the CE marking certificate for our products.

To achieve the above mentioned targets we created a very successful cooperation with partners in many fields such as: industries producing innovative materials, factories, universities and seismic laboratories in many parts of the world. Our partners are diversified for location and capacity in order to create an active and efficient network which can cooperate to match the most challenging needs of all the clients.

WHAT WE ARE:

HIRUN INTERNATIONAL combines the experience coming from more than 50 years in the field with the most qualified, efficient and modern technologies in addition to an extremely dynamic and smart approach granting the successful presence worldwide.

OUR TARGET:

We aim to become the leading specialized company for the most peculiar and important civil engineer projects in the world: **THE ENGINEERING SOLUTION.**

AUTHOR

A. MARIONI - CURRICULUM VITAE

Agostino Marioni graduated in Civil Engineering at "Politecnico di Milano" in 1966 with the title of Doctor Engineer.

He got the specialization in Bridge Design collaborating with Prof. Franco Levi in Turin until year 1973.

He founded Alga in 1969 and became General Manager in 1973.

He has been the Chairman of ALGA S.p.A. Milano from 1985 to 2012. ALGA is operating in the field of structural engineering since more that 50 years and is primarily known in most countries of the world in the sector of bridge bearings, road expansion joints, antiseismic devices and post-tensioning systems.

In this position he developed several kinds of antiseismic devices, most of them patented, and he managed an enormous amount of jobs in various fields of the structural devices in general and antiseismic devices in particular.

He has been the Chairman of CEN TC 167, the European Commission for the standardization of structural bearings since the opening of the works in year 1988 until 2013. CEN TC 167 has been the author of EN 1337.

He has been member of CEN TC 340, the European commission for the standardization of antiseismic devices since the opening of the works until 2013. CEN TC 340 has been the author of EN 15129.

In the years 2013 -2018 he has been Vice President of HIRUN, a very important manufacturer of structural devices such as bearings, post-tensioning systems, expansion joints and antiseismic devices. HIRUN is equipped with a very large manufacturing facility and an updated and very powerful dynamic testing laboratory.

He is currently the Chairman of HIRUN INTERNATIONAL, specialized in structural devices, with main office in Taiwan and branches in China and Italy.

P11
Special Structural Solutions for Longspan Monorail System

TARUN GOYAL / STRUCTURAL CONSULTANTS PVT. LTD.

INTERNATIONAL MONORAIL ASSOCIATION

Special Structural Solutions for Long spans in Monorail system

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Tarun Kant Goyal, born 1976, received his Masters and Bachelors degree in civil engineering from Delhi College of Engineering, Delhi, India. He had worked in Indian railways design department RITES and India's biggest construction group L&T. He was lead structural designer for Mumbai monorail project.

Abstract

Typically monorail beams are slender with typical cross section of 0.7 x 2.0 m and thus can span not more than 30~32m. Often Monorail traverse through congested lanes of cities and need to cross over rivers, road crossings, and railway tracks etc with long stretches more than usual spans of 30~32m. For such situations special structural arrangements are required since the normal beam solutions are not structurally feasible. These structural arrangements are adopted keeping in view the overall construction speed, robustness and aesthetics associated with monorail systems. For longer spans upto 50m, extended pier-cap type solution is adopted, wherein pier-caps are extended to reduce the beam spans. For spans more than 50m Open web steel trusses are adopted wherein guideway beams for monorail pass through the truss.

Keywords: Monorail, Guideway Beam, Long Span Frame, Steel Truss, Extended Pier-cap

1. Introduction

Idea of Monorail as a Mass Rapid Transit System (MRTS) competing against Metro comes from the advantages which it has, i.e, its ability to maneuver along tight horizontal curves upto 60~65m and slenderness of its guideway beams which blends into city's aesthetics without interfering into the landscape as compared to Metro viaduct which does the opposite. However, due to slenderness of Guideway beams, for spans more than 30~32m innovative structural solutions are required so as to traverse the longer span without affecting the city's aesthetics. There are various structural solutions to accomplish this, and will be discussed in this paper.

2. Design of Monorail Guideway Structure

2.1 General

The Guideway Structure design for any monorail is arrived with due consideration to guideway-vehicle interaction, structural efficiency & performance, cost efficiency, and above all constructability of the structural elements with great emphasis on reduction in urban and traffic disruption.

The structural design is always planned to achieve robust & durable structures with minimal requirement of maintenance & simplicity of structural form, layout and construction. This is an important prerequisite for all monorail projects, since the alignment generally is proposed through congested roads and alleys.

2.2 Structural Design Concept

Typical guideway frames substructure (Fig. 1) includes pilecaps and piers which are cast in-situ reinforced concrete elements. The individually precast post-tensioned Guideway beams are erected and stitched together with in-situ concrete and consequently post-tensioned with continuous tendons to form a continuous frame up to five spans. The typical span of the guideway beams ranges from 30~32m. The guideway beams are slender with typical cross section of 0.7 x 2.0 m.

Continuous frames produce more efficient structure both structurally & economically and are more ductile for earthquake resistance. Frame action at expansion joints are obtained through split columns.

In certain circumstances, such as crossing existing railway tracks or wide drains, special spanning arrangements utilizing specially designed long span piers and steel trusses with extraordinary sequences of construction is adopted, in order to minimize disruption to the flow of railway or road traffic.

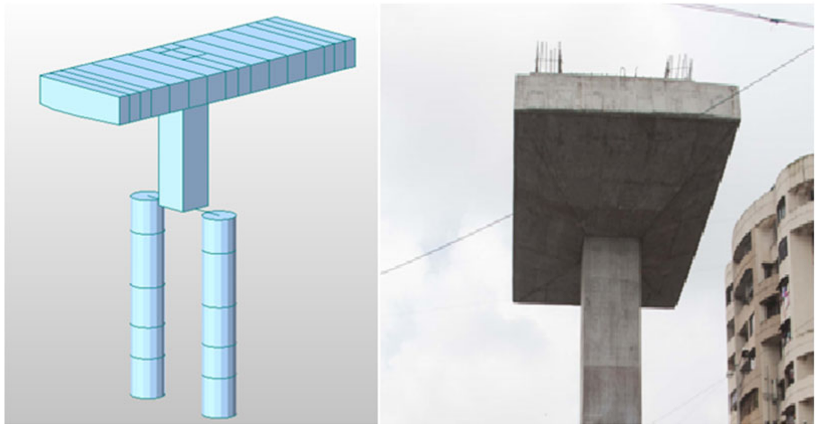
Fig. 1: Typical Frame for Guideway

3. Long Spans with Extended Pier-Cap

This solution is provided when the spans are more than 30~32m but less than 50m. Herein the pier-cap is extended longitudinally (Fig. 2a). Thus, part of longer span of guideway beam rests over extended pier cap thereby reducing the span length for guideway beam.

This solution is proposed for a long span with a horizontal radius of 336m across Koval Tropicana crossing for upcoming Las Vegas Monorail extension.

Extended pier-cap can be precast or in-situ depending upon site conditions, however, precast is always preferred since it reduces site activities and thus reduces construction period.



a) b)

Fig 2:
a) 3-Dimensional FEM model of Extended piercap simulated in Midas-CIVIL
b) Extended pier cap at Mumbai Monorail

Similar solution for long spans adopted in Mumbai Monorail proejcts is shown in Fig. 2b

3.1 Unique structural features of Frame with Extended Pier-cap

3.1.1 Increased Cantilever for pier-cap

This is a unique structural feature for a pier-cap (Fig. 3). Due to increased cantilever length, high values of bending and shear forces are generated. Also higher localized stresses at stitch locations of guideway beams are generated. Since normal Reinforced concrete is not feasible to cater for these high stresses, pre-stressed concrete is adopted for extended pier-caps.

For precast pier-caps, two stage pre-stressing is adopted. 1st stage prestressing caters for dead load of pier-cap during lifting and erection. For 2nd stage prestressing, service loads of guideway beams including live loads are considered.

Fig. 3: Precast Extended Pier-cap

3.1.2 Guideway beam over piercap

Guideway beam of 13~14m are place over top of Extended Pier-Cap (Fig. 4). These are either stitched monolithic at both end or are placed with bearings depending upon the stress distribution of overall frame. In general, due to increase in stiffness of stitch over extended pier-cap compared to normal pier, it's advantageous to use bearing at one of the ends of this guideway beam over extended pier-cap to reduce stresses, particularly due to temperature variation.

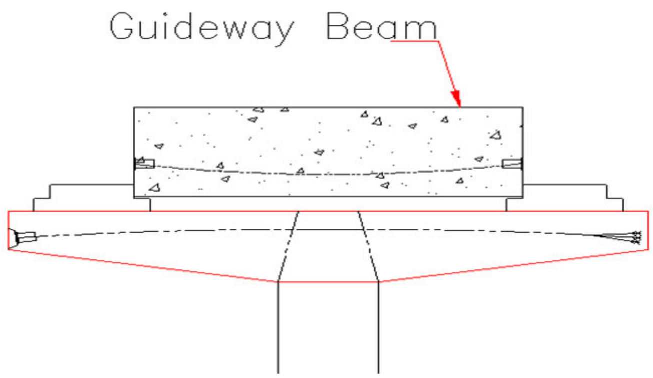


Fig. 4: Guideway beams placed over

3.2 Analysis and design

Analysis of frames with extended pier cap are performed similar to usual continuous frames with the exception of introducing extended pier-cap as member and pre-stressing the same in 2 stages.

Analysis follows the actual construction sequence and time duration to capture time dependent loads and stresses such as creep & shrinkage.

Since monorail structural frame is 3-Dimenional with application of loads in more than one plane, it becomes a complex structural problem. Various loads considered are vertical train loads, lateral loads (Centrifugal, hunting, wind and seismic), longitudinal loads (Braking & Traction) along with thermal, creep & shrinkage and pre-stressed loads.

Due to application such complex loading system in all directions, special structural software with time dependent and non linear analysis capabilities is used to perform design. 3-D FEM models for each frame with exact horizontal radius for Guideway beams along with specified pier heights with piles simulating soil-structure interaction are modelled. Time dependent analysis for creep & shrinkage with age of concrete at each construction stage and prestress loading stages for dead load and live load continuity are modelled. (Fig. 5)

During analysis and design due consideration to deflection and rotation must be given. Since guideway beams are slender, torsional rigidity may be increased with introduction of diaphragm between the beams at the center of main span. This however depends upon over configuration of frame, use of bearings and horizontal radius of frame.

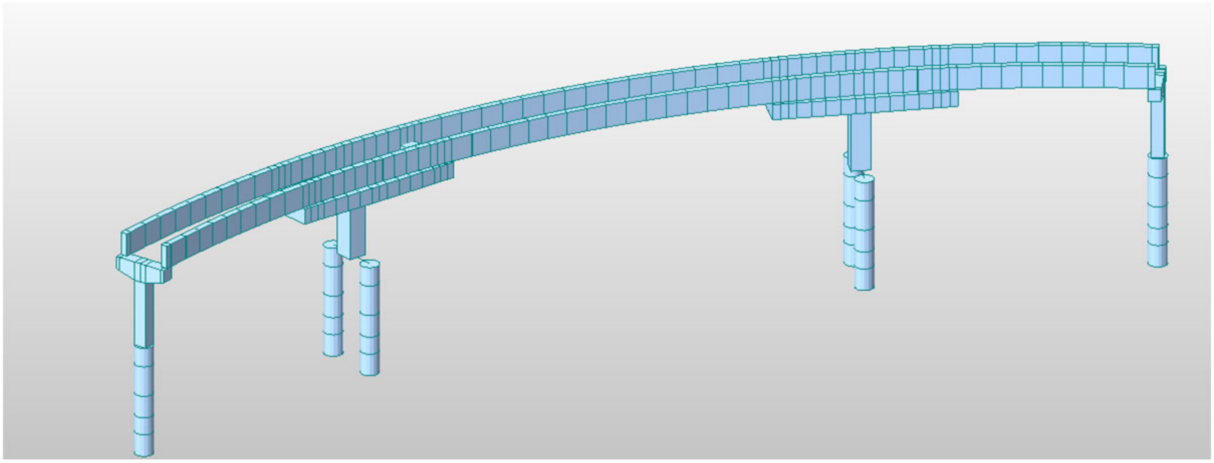


Fig. 5: 3-Dimensional FEM model of Las Vegas Monorail Extension long span frame 28+51+28m, with Extended piercap

3.3 Construction of Guideway frame with Extended Piercap

3.3.1 Precasting of Guideway Beams and Extended Pier-cap

Since Guideway beams are riding surface, special shuttering system for casting guideway beams are used. This is achieved with the usage of turnbuckles mounted on the walls with exact curvature, radius and alignment in tolerance of +/- 2mm tolerance (fig.6).

Extended pier-caps are cast with exact dimensions in the casting yard. Special lifting hooks are designed with special reinforcement to take care of self weight while erection of pier-caps over pier columns.

Fig. 6: Casting shutter for Guideway Beams

3.3.2 Lifting and Transportation of Guideway Beams and Extended Pier-caps

The Guideway beams are of varying curvature, radius and length, which mean no two beams are identical for monorail project. This also means that centre of gravity of Guideway beam varies. As the lifting point need to match with CG of beam specialized adjustable lifting frame with a movable hook is used to lift Guideway beams. This frame ensures that the CG of beam matches with that of lifting frame. Detail structural analysis is performed to ascertain the exact lifting point for each Guideway Beam.

Specialized schemes are devised to ensure smooth transportation of Guideway beams. A separate floater assembly is deployed to ensure that the bolster can carry the Guideway beam of different curvature & different radii.

3.3.3 Construction of Substructure and foundation

Foundation and pier columns are constructed at designated locations. Normal pier-caps are cast along with the pier columns. Precast extended pier-caps are placed over pier columns, held in position and made monolithic with in-situ concrete (Fig. 7)

For Extended pier-caps 1st stage prestessing is done in casting yard and 2nd stage prestressing is done after it becomes monolithic with pier column & before the supporting system is removed.

Fig. 7: Lifting & Placement of precast Extended Piercap

3.3.4 Erection & Placement of Guideway Beams

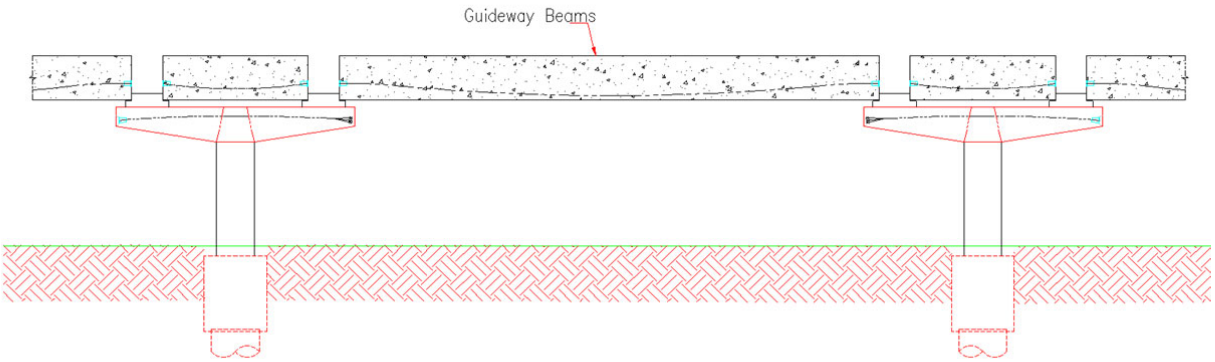


Fig. 8: Precast Guideway beams placed over piercaps

All Precast guideway beams for a frame are erected (Fig. 8) using hydraulic cranes at designated locations over pier caps. Each Guideway beam has a different CG point, therefore special supporting brackets and turnbuckles for alignment control are deployed (Fig. 9).

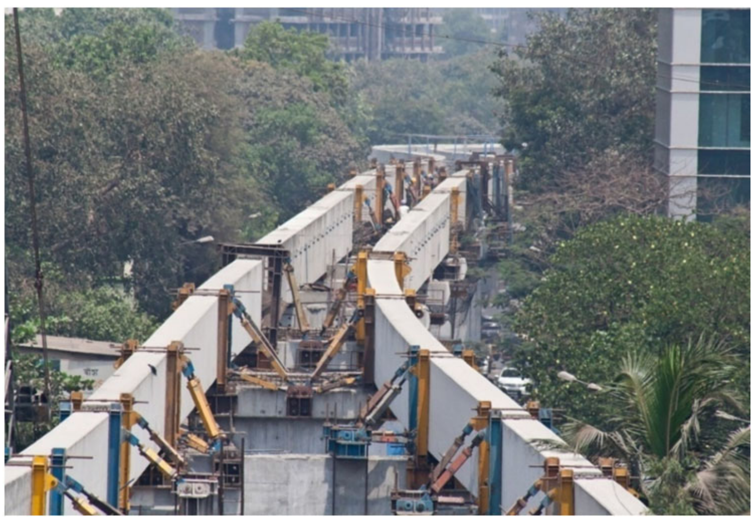


Fig. 9: Supporting System for Guideway Beams

3.3.5 Continuous Pre-stress and in-situ stitching

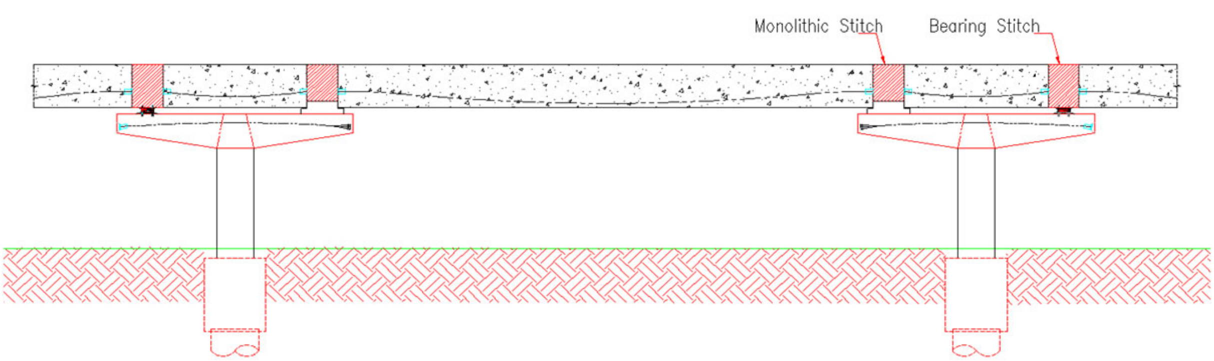


Fig. 10: Supporting System for Guideway Beams

After placement of all Guideway beams for a frame, intermediate in-situ stitching of beams over Extended pier-caps is carried out so as to achieve monolithic joint (Fig. 10). This is followed by both end continuous pre-stressing. Finally in-situ end stitching of Guideway beams with end piers is carried out.

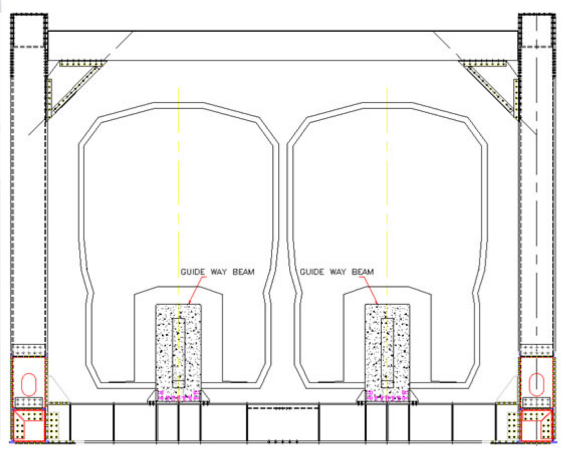
4. Long Spans with Steel Open Web Truss

This solution is provided when the spans are than 50m. Herein steel truss (Fig. 11a) is used to span between railway tracks or rivers etc. Guideway beams are placed inside steel truss and rests over cross girders (Fig. 11b) through special torsional resistant joint.

This solution was employed at 2 locations in Mumbai monorail project.

a) Curry Railway Crossing- Steel truss of 63m span length was used to cross railway tracks (Fig. 11a)

b) Wadala Railway Crossing- 3 consecutive steel truss with configuration 3x 45m was used to cross railway tracks.



a) b)

Fig. 11: Steel Truss

4.1 Unique structural features of Steel Truss for Monorail

4.1.1 Guideway beam connection with Cross Girders

This is special connection between guideway beams and top flange of cross girders (Fig. 12). Angle cleats are placed at bottom faces of guideway beams using shear studs during casting in yard. On bottom side of cleat angles, holes for Bolts are made. Guideway beams are erected inside the steel truss and placed over cross girder and bolted in position. Thus shear studs & bolts transfer shear &force torsional moment. Top flange of cross girder is stiffened to take care of localized bending.

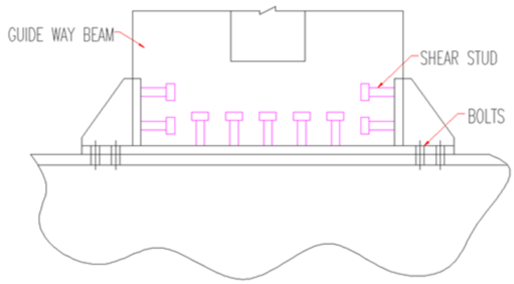


Fig. 13: Torsional resistant connection of Guideway beams with cross girder

4.2 Analysis and design of Steel Truss for monorail

Steel truss is simply supported structure and can have warren or pratt type configuration with top & bottom chords and diagonals. Floor system consists of cross girders, bracings and guideway beams.

3-dimensional structural models are simulated (Fig. 14) with all members properties as specified. Care must be taken that guideway beams are modelled only for taking live loads since after placement of guideway beams local tensioning becomes effective and guideway beams starts to attract axial forces.

Two separate models should be prepared to take care of tensioning effect. One model without guideway beams to analyse for all dead loads and other with guideway beam to analyse for all live loads.

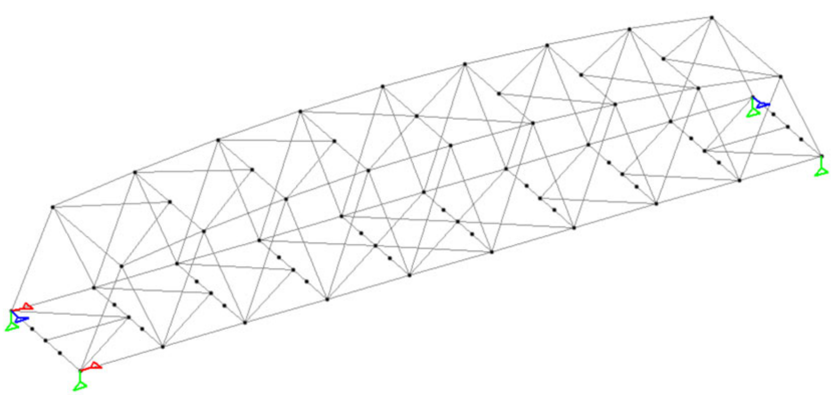


Fig. 14: 3-Dimensional FEM model Curry Railway crossing Steel truss for Mumbai

Various loads considered are vertical train loads, lateral loads (Centrifugal, hunting, wind and seismic), longitudinal loads (Braking & Traction) along with thermal, creep & shrinkage loads.

During analysis & design due consideration to deflection & rotation must be given. Deflection of truss and also local deflection of guideway beams between cross girders must be restricted to minimal within stipulated limits. If required appropriate live load camber should be provided to steel truss so as to reduce deflection.

4.3 Construction of Steel Truss for monorail

4.3.1 Fabrication of members and precasting of guideway beams

Steel members of truss are fabricated according to shop drawings (Fig. 15). Steel templates are used for marking of cutting material and as well as to profile machining for girders. Steel templates are also used for marking of drilling holes in members. The positions and angular setting out lines of all connection holes in the main gussets including the positions of the connection holes in the chord joints and the machining of the ends shall be exactly as shown on the shop drawings.

Precast guideway beams shall be cast in shop as per para 3.3.1

Fig. 15: Fabrication of steel members

4.3.2 Erection of steel truss

Fabricated members of steel truss are brought to the specified site. Usually a platform is constructed using temporary steel trestles to receive fabricated members. The procedure during erection consists of placing camber jacks in position on temporary platform. The camber jacks should be set with their tops level and with sufficient run out to allow for lowering of panel points except the centre by the necessary amounts to produce the required camber in the main girders. It is essential that the camber is accurately maintained throughout the process of erection and it should be constantly checked. The jacks shall be spaced so that they will support the ends of the main girders and the panel points.

The bottom chord members shall then be placed on the camber jacks, carefully levelled and checked for straightness and the joints made and riveted up. The vertical and diagonal web members, except the end posts, shall then be erected in their proper positions on the bottom chords and bolted (Fig. 16).

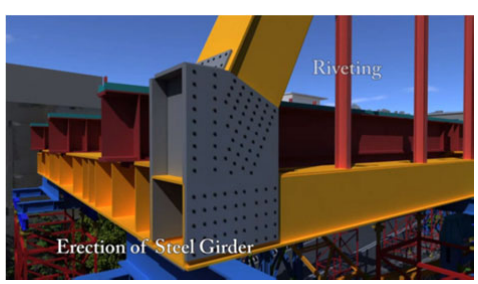


Fig. 16: Member Connections

It is recommended that temporary top gussets, the positions of the holes in which are corrected for the camber change of length in the members, should be used to connect the top ends of the members; this will ensure that the angles between the members at the bottom joints are as given by the nominal outline of the girders. The verticals and diagonals shall then be bolted to the lower chords. All panel points, except the centre, shall then be lowered by amounts to produce the correct camber in the main girders as shown on the camber diagram. (Fig. 17)

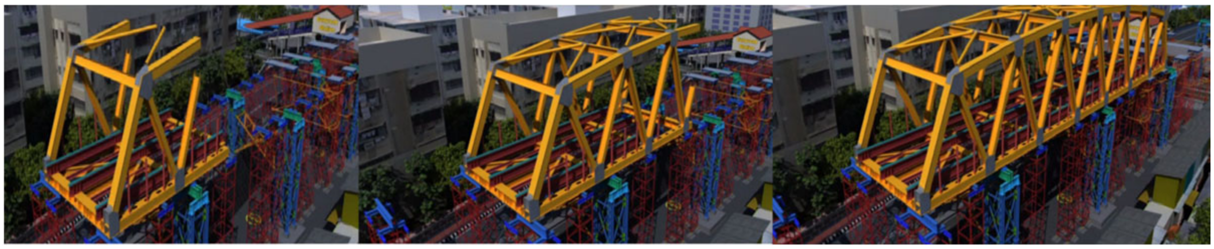


Fig. 17: Erection of Steel truss over temporary platform

4.3.3 Launching of Steel truss

Once the erection of steel truss is complete, a light weight steel nosing is attached in front of the steel truss (Fig. 18). The truss is paced over hilman rollers (Fig. 19) and is then pulled with cable attached at the back of steel truss through a spreader beam. High capacity strand jacks are deployed for pulling.

After one end of truss reaches the opposite end, it is lowered and placed over bearings of designed capacity.

Fig. 18: Launching of Curry Railway crossing Steel truss with nosing for Mumbai Monorail

Fig. 19: Hilman rollers used for launching

4.3.4 Erection of Guideway beams inside steel truss

For erection of guideway beams inside steel truss first working platform along with safety net is placed inside the truss. Guideway beams are hauled inside the truss with erection trolleys and lowered at designated locations. At last, in-situ casting of stitch and connection of guideway beams with cross girder is completed.

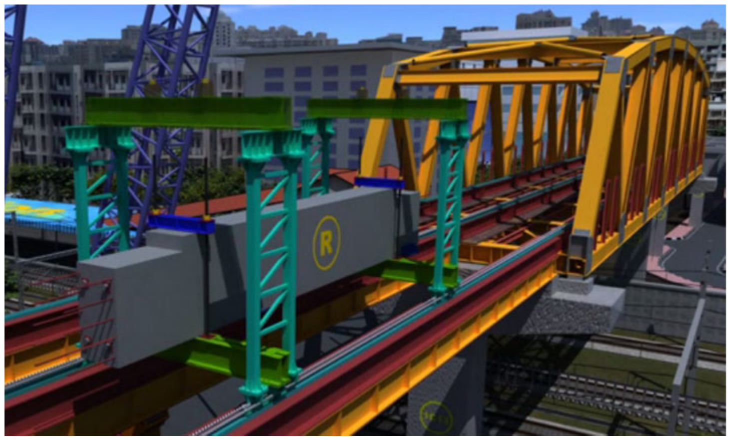


Fig. 20: Erection of Guideway beams

5. Discussion and Conclusion

Structural design of long spans for monorails is a challenging aspect, since the aesthetic appeal of monorail needs to be considered before adopting any of the schemes. There still needs further improvement in solutions for long spans for monorails and these special designs remains a challenge, not only in terms of design but for their constructability.

6. References

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[3] INDIAN RAILWAY STANDARDS "Steel bridge code"

[4] MUMBAI METROPOLITAN REGION DEVELOPMENT AUTHORITY "Employer's Outline Engineering And Performance Specifications"

[5] INDIAN RAILWAY STATNDARDS " Concrete Bridge Code"

Special Structural Solutions for Long spans in Monorail system

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Tarun Kant Goyal, born 1976, received his Masters and Bachelors degree in civil engineering from Delhi College of Engineering, Delhi, India. He had worked in Indian railways design department RITES and India's biggest construction group L&T. He was lead structural designer for Mumbai monorail project.

P12
Evaluation of Pile Axial Stiffness for Large Diameter Monopiles

ANWAR ELKADI, AHMED EBID, AHMED FIKRY, DR. WALAA ELTAHAWY / NECB

Evaluation of Pile Axial stiffness for large diameter Monopiles

Anwar Elkadi, PhD[1], Ahmed Ebid, PhD[1], Ahmed Fikry, MSc[1], Walaa Eltahawy, PhD[2]

[1]Nile Engineering Consulting Bureau (NECB) / [2]Innova Technologies, Inc.

Abstract

Piled foundations are usually used to transfer the structure loads down to strong deep soil through weak surface one and due to its negligible settlement, its design is governed by the capacity requirement. However, for special projects that have a restricted settlement requirements such as Monorails, the design is dominated by settlement criteria. Pile settlement could be estimated using a wide range of techniques started with simple closed form equations and ending with very sophisticated 3D-nonlinear FEM soil-structure interaction models, but the most common used technique in design is the axial stiffness method where the pile is modeled as vertical spring with linear (constant) stiffness. This technique is favorable in design due to its simplicity and compatibility with superstructure models. Pile head settlement could be estimated mathematically based on pile configuration and soil properties or measured experimentally in field using pile load tests. The Axial stiffness considered to be the ratio of imposed load to resulting settlement. Cairo Monorails New Capital City and 6th of October Lines have been taken as a case study to evaluate the design approach values for the pile axial stiffness. Several nonworking vertical pile load tests were conducted along monorail alignment for both lines in various types of soil. The vertical non-working pile load test were loaded up to 300% of the design-working load. Further on, the actual piles axial stiffness had been calculated and compared with theoretical ones which concluded to be conservative under working loads.

INNOVA TRANSPORTATION

NILE ENGINEERING CONSULTING BUREAU

Evaluation of Axial stiffness for Large Diameter Monopile

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Contents

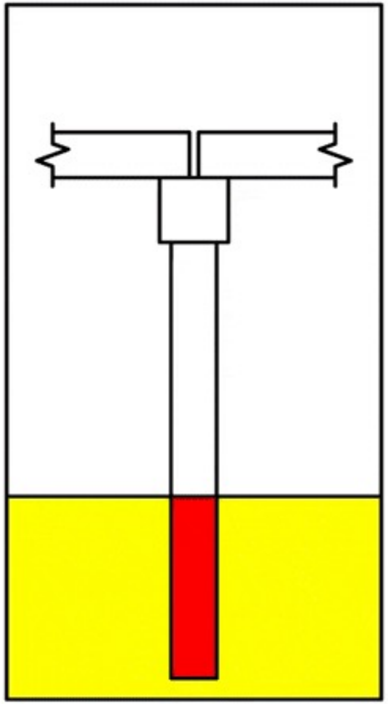
Definition Axial Pile Stiffness

$$K_V = \frac{P_w}{\Delta_w}$$

K_V: *Axial Pile Stiffens*

P_w: *Working Pile load (Given by the structural Engineer Design)*

Δ_w: *Pile Settlement at Working Load*



Introduction

Definition Axial Pile Stiffness

$$K_V = \frac{P_w}{\Delta_w} = K_b + K_s + K_b$$

$K_V: Axial\ Pile\ Stiffens$

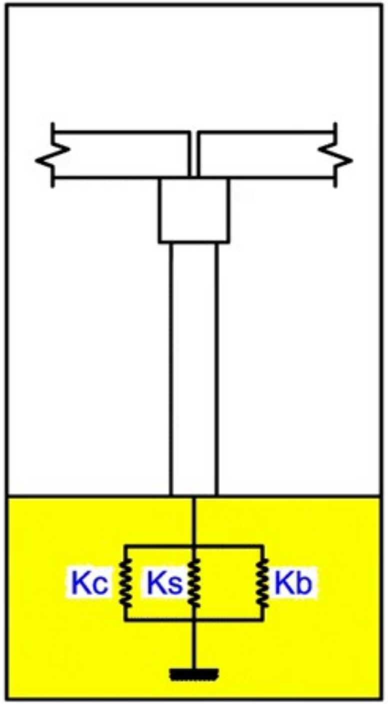
$P_w: Working\ Pile\ load\ (Given\ by\ the\ structural\ Engineer\ Design)$

$\Delta_w: Pile\ Settlement\ at\ Working\ Load$

$K_c: Axila\ Pile\ Stiffens\ due\ to\ elastic\ deformation\ of\ concrete$

$K_s: Axila\ Pile\ Stiffens\ due\ to\ Skin - Friction$

$K_b: Axila\ Pile\ Stiffens\ due\ to\ End - Bearing$



Introduction

Definition Axial Pile Stiffness

$$K_V = \frac{P_w}{\Delta_w} = K_b + K_s + K_b$$

$K_V: Axila\ Pile\ Stiffens$

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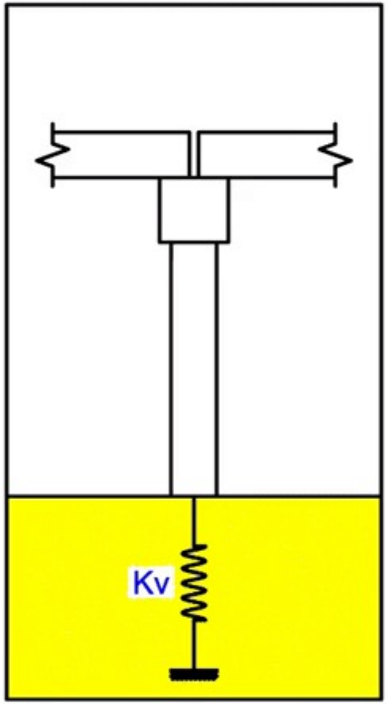
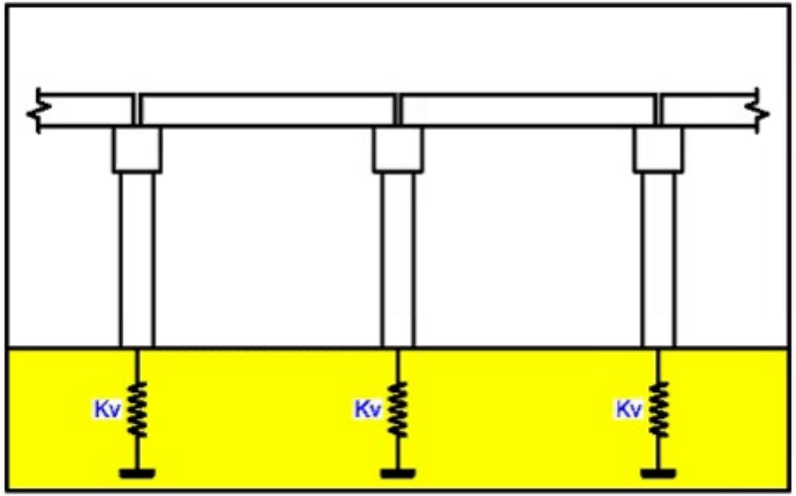
$K_b: Axila\ Pile\ Stiffens\ due\ to\ End - Bearing$



Definition Axial Pile Stiffness

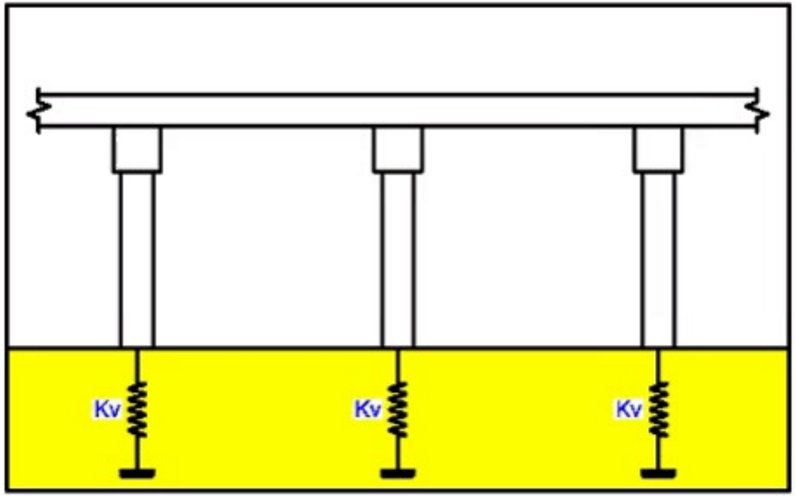
Simply Supported Beams System



Structural Engineer Design (Superstructure not affected)

Mechanical Engineer Design (Monorail vehicle is affected)

Continues Beams System

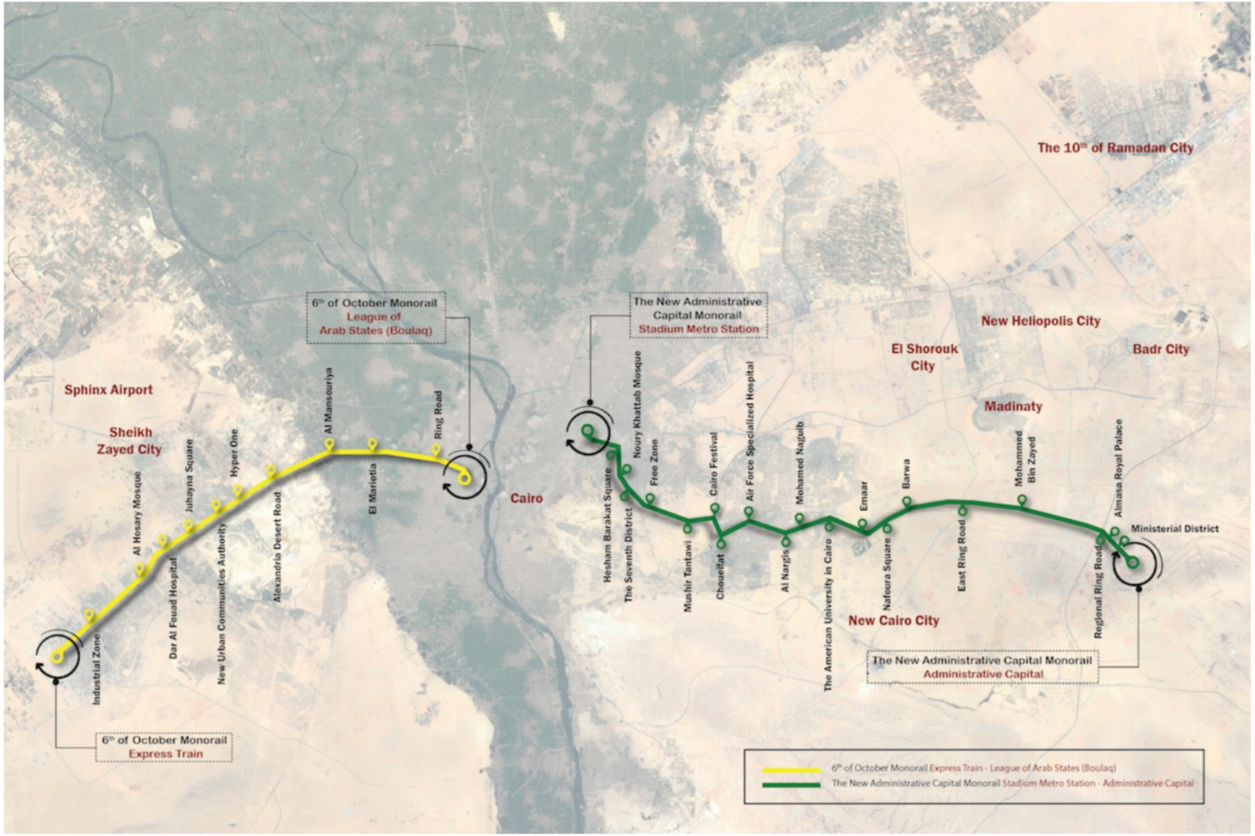


Structural Engineer Design (Cracks in the Superstructure)

Mechanical Engineer Design (Monorail vehicle is affected)

Introduction

Case Study (Cairo Monorails New Capital City and 6th of October Lines)



Introduction

Line Segment	Segment Length (m)	Non-Working Vertical Pile Load Test
NCL00	270	
NCL01	997	🟢
NCL02	1,128	🟢
NCL03	1,985	🟢
NCL04	1,506	🟢
NCL05	1,613	🟢
NCL06	4,572	🟢
NCL07	2,502	⚫
NCL08	2,411	
NCL09	2,914	⚫
NCL10	2,977	🟢
NCL11	3,188	🟢

Line Segment	Segment Length	Non-Working Vertical Pile Load Test
NCL12	2,591	🟢
NCL13	2,636	⚫
NCL14	3,186	⚫
NCL15	4,626	⚫
NCL16	3,137	⚫
NCL17	2,532	🟢
NCL18	3,738	🟢
NCL19	1,855	🟢
NCL20	1,646	🟢
NCL21	2,444	🟢
NCL22	1,986	🟢

🟩 Executed PLT = 15 from 21 PLT

⬛ In Progress PLT = 6 from 21 PLT

Total Length = 56.00 km

Introduction

Line Segment	Segment Length (m)	Non Working Horizontal Pile Load Test
6OL00	1,562	🟢
6OL01	5,217	🟢
6OL02	5,029	
6OL03	2,013	🟢
6OL04	4,024	⚫
6OL05	2,110	⚫
6OL06	3,933	🟢
6OL07	4,011	⚫
6OL08	4,739	🟢
6OL09	3,083	⚫
6OL10	4,176	⚫
6OL11	2,591	🟢
6OL12	414	

Executed PLT = 6 from 11 PLT

In Progress PLT = 5 from 11 PLT

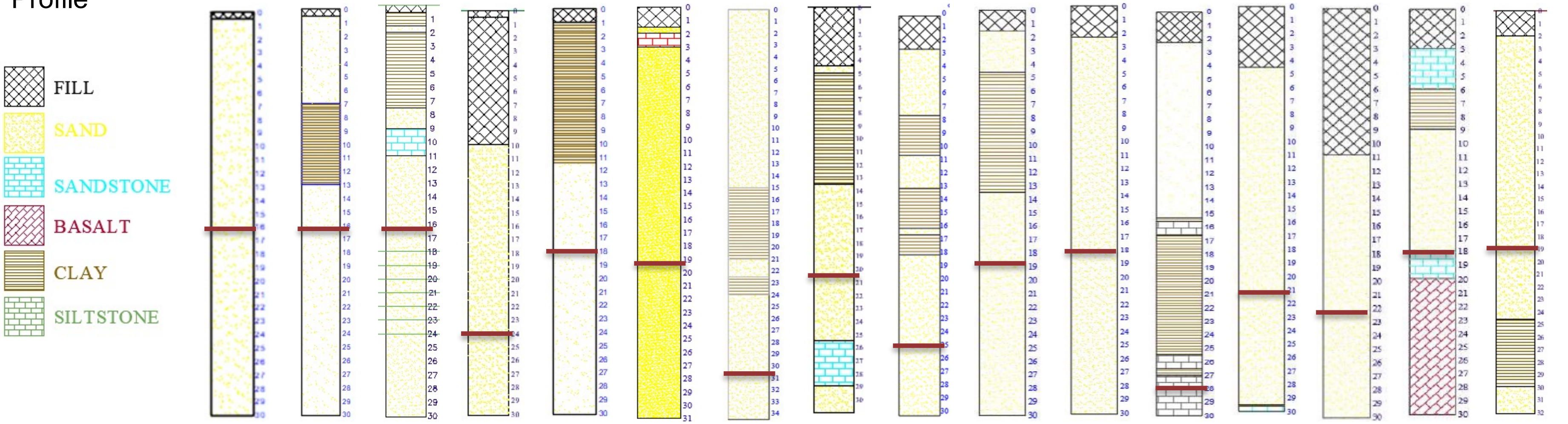
Total Length = 43.00 km

Total Segment Length (km)	Executed VPLT	In Progress VPLT	Total VPLT
99	21	11	32

Introduction

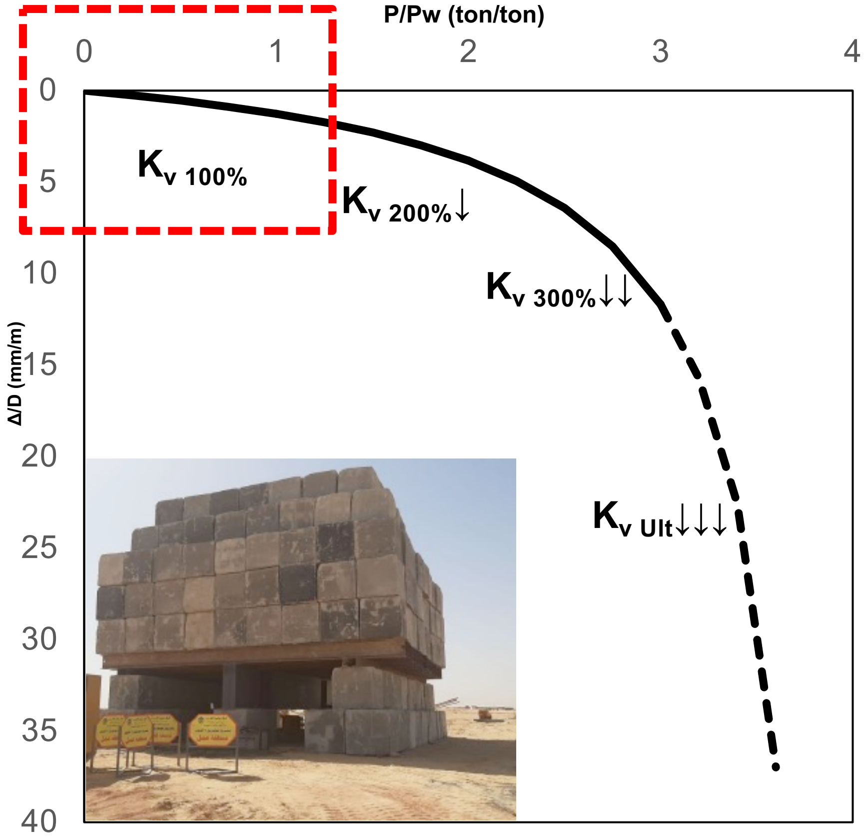
Line Segment	6OL00	6OL01	6OL03	6OL08	6OL11	NCL01	NCL02	NCL03	NCL04	NCL05	NCL06	NCL10	NCL11	NCL12	NCL17	NCL19
Diameter (m)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Length (m)	16	16	16.5	24	18	19	30.5	20.3	24.7	18.7	18.3	28	20.35	22.3	18.4	18.65
Settlement (mm)	1.21	1.78	0.97	0.24	4.24	1.55	0.67	1.16	0.64	0.89	1.01	0.68	1.27	0.75	0.42	5.07

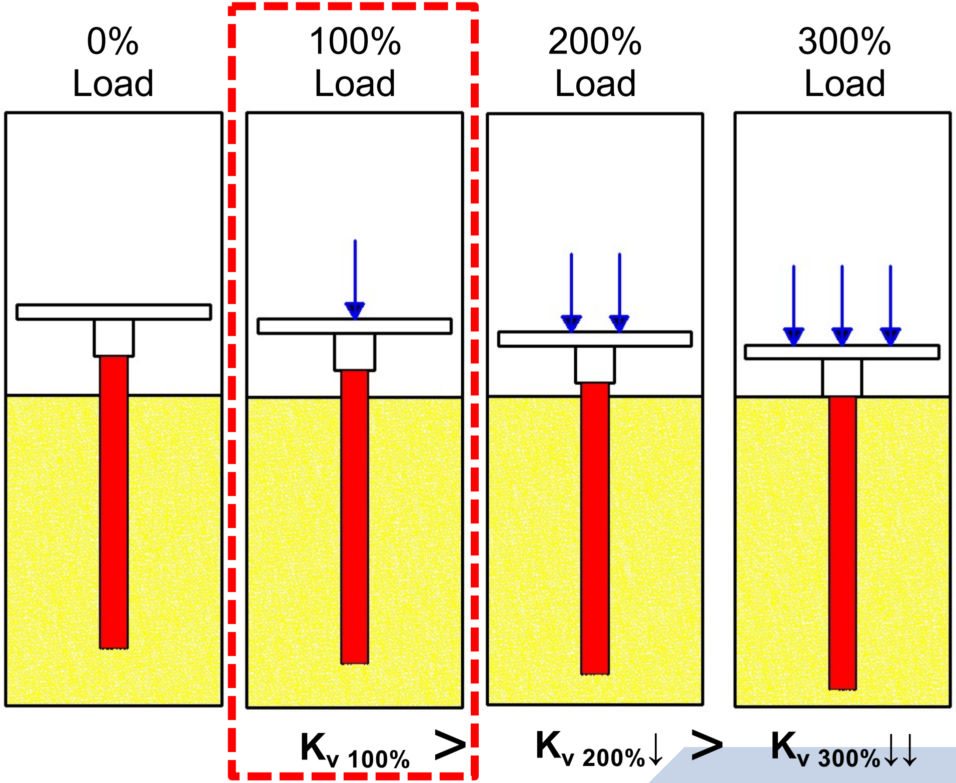
Profile



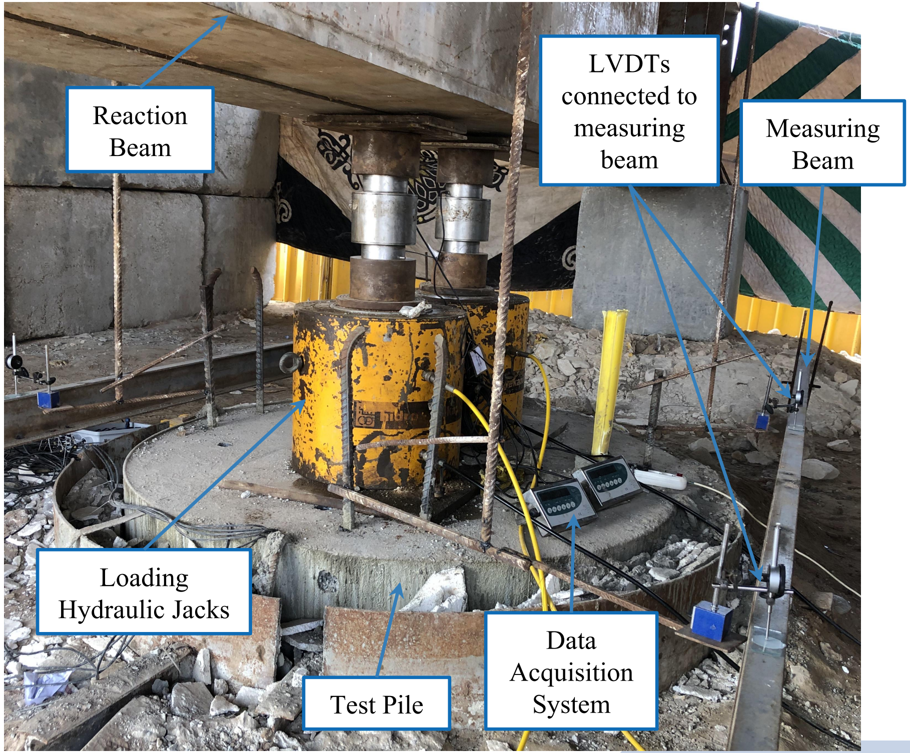
Total No. = 16 VPLT

Experimental Static Pile Load Test

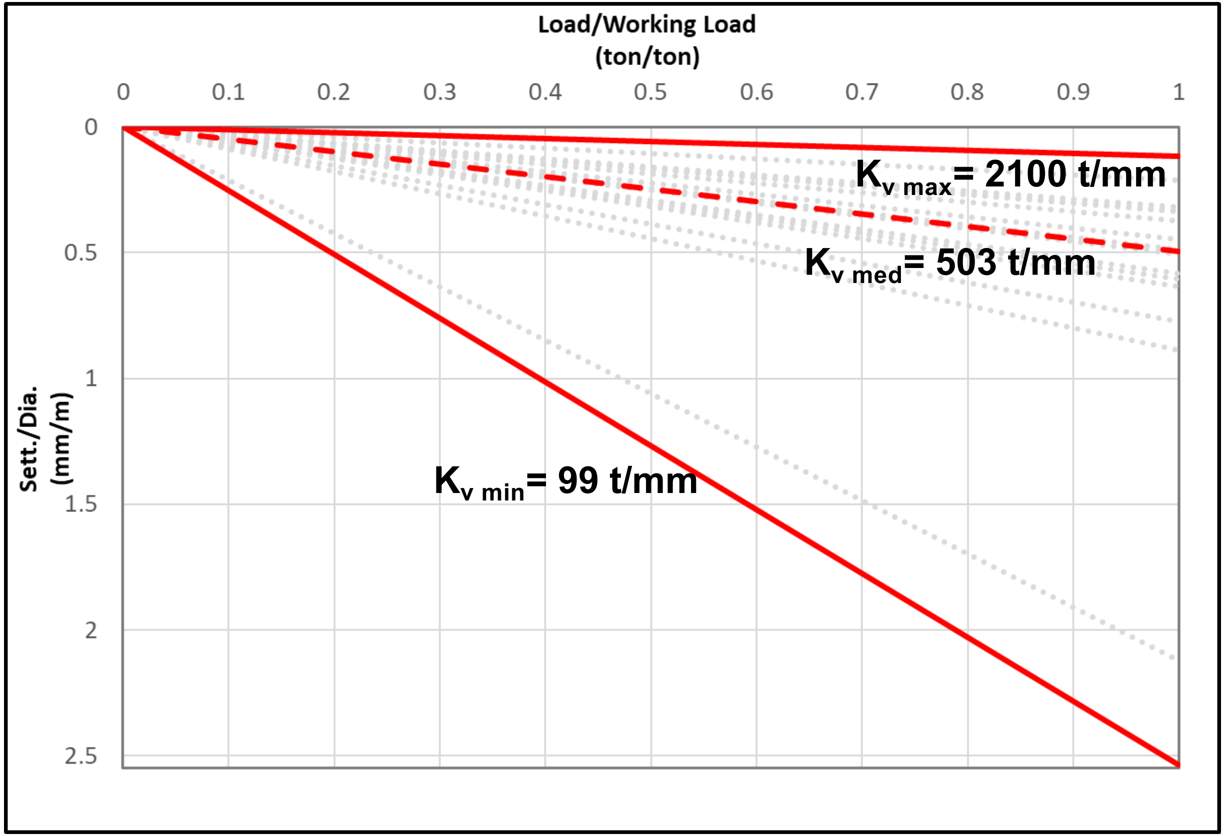




Experimental Static Pile Load Test



Experimental Static Pile Load Test



Simple Theoretical Formula

According to “Navfac DM-7.02 (ECP 202/4)” Vesic 1977

$$K_V = \frac{P_w}{\Delta_w}$$

$$\Delta_w = \Delta_c + \Delta_{bb} + \Delta_{bs}$$

Δ_c: *elastic compression of the reinforced concrete shaft*

Δ_{bb}: *Settlement of the base due to load transferred to the base*

Δ_{bs}: *settlement of the base due to load transferred along the sides*

Δ_c	Δ_{bb}	Δ_{bs}
$\Delta_c = (Q_b + \alpha\, Q_s) * \dfrac{L}{A\, E_p}$	$\Delta_{bb} = \dfrac{C_p Q_b}{D\, q_{ult}}$	$\Delta_{bs} = \dfrac{C_s Q_s}{L\, q_{ult}}$ $C_s = \left(0.93 + 0.16\sqrt{\dfrac{L}{D}}\right) C_b$

Q_b: point load transmitted to the pile tip in the working stress range

Q_s: shaft friction load transmitted to the pile tip in the working stress range

L : Pile length

A : Pile Area

E_P: modulus of elasticity of the pile

D : Pile Diameter

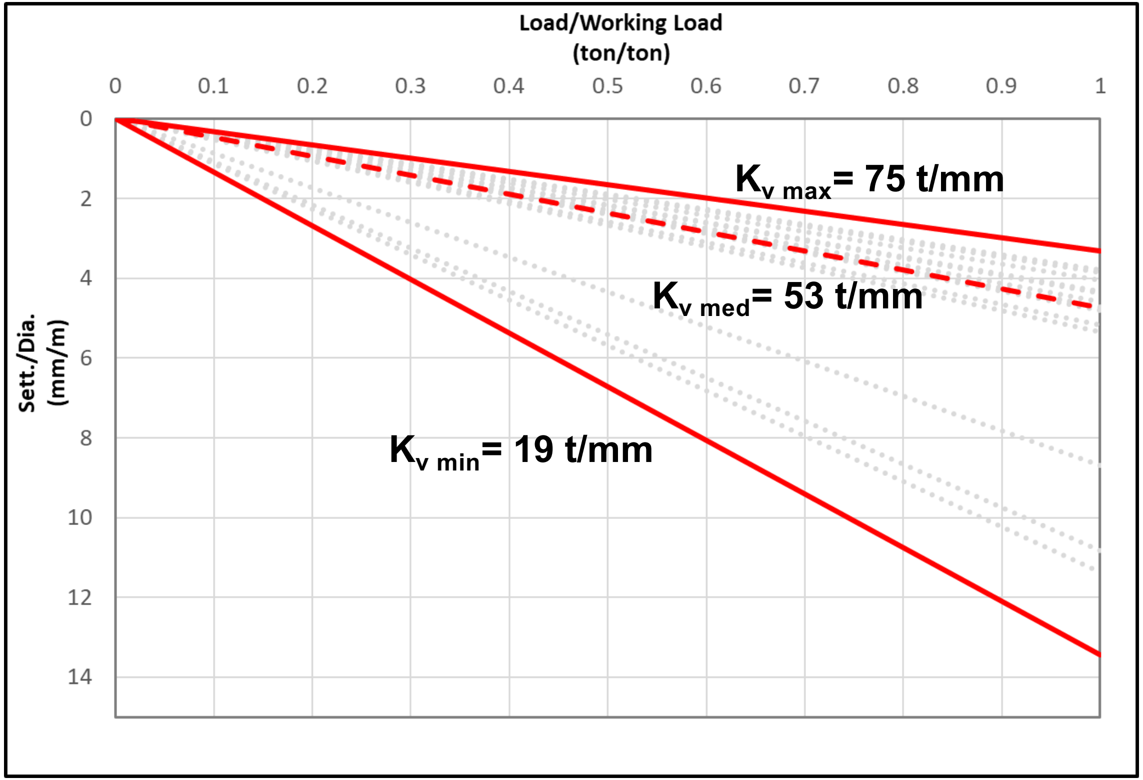
q_{ult}: ultimate end bearing capacity

α : Factor depending on friction distribution on shaft

C_p: Empirical coefficient depending on soil type and method of construction

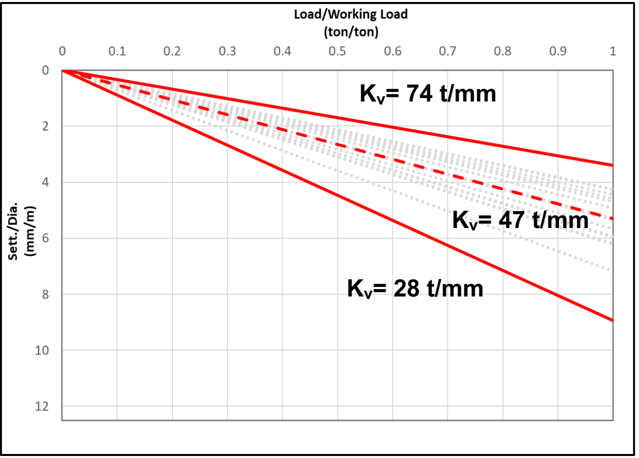
Simple Theoretical Formula

According to “Navfac DM-7.02 (ECP 202/4)” Vesic 1977

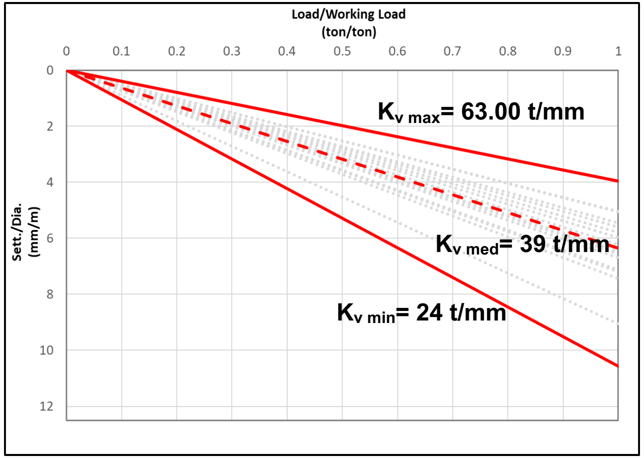


Empirical Load Settlement Curves

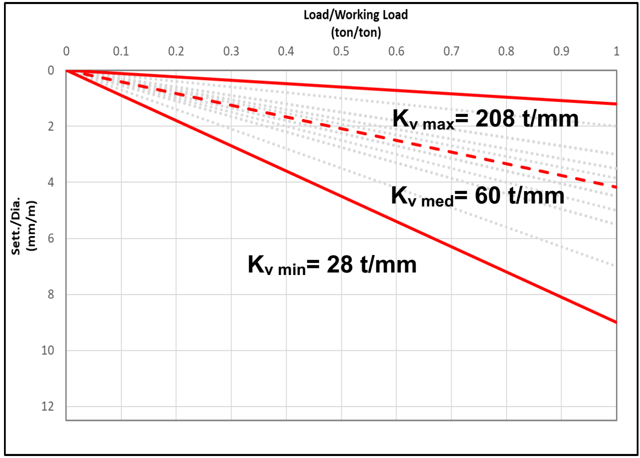
Navfac DM-7.02 (ECP 202/4)



DIN 4014 (ECP 207/8)

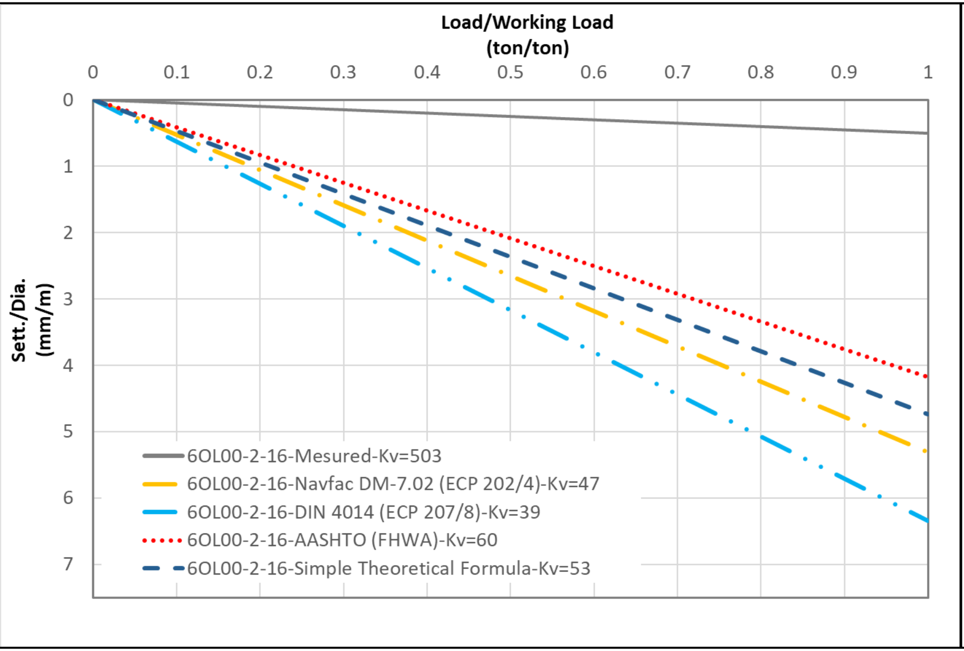


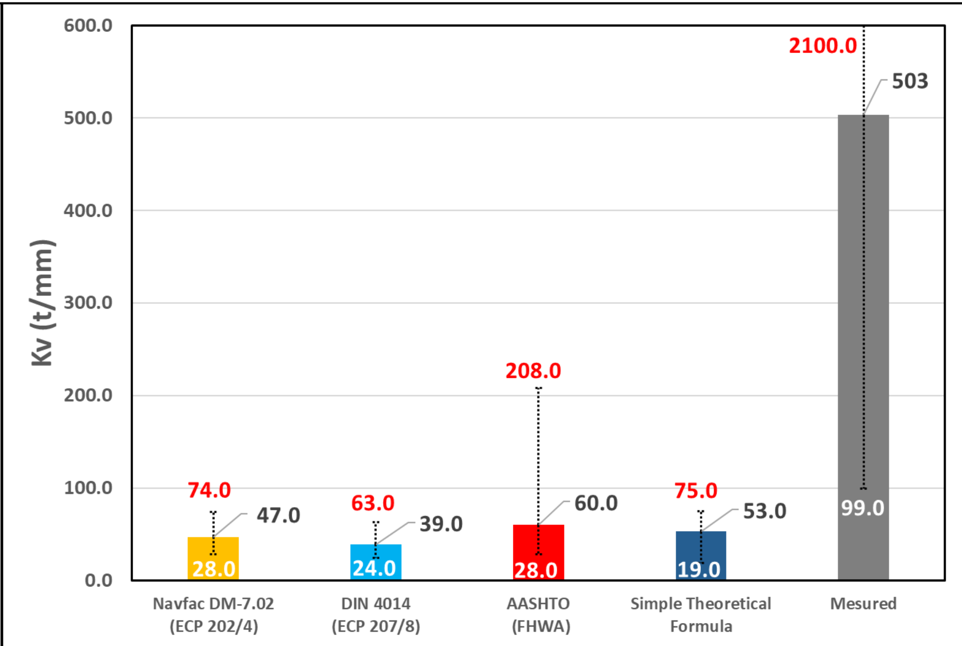
AASHTO (FHWA)



Normalized Load Settlement Curves

Conclusion

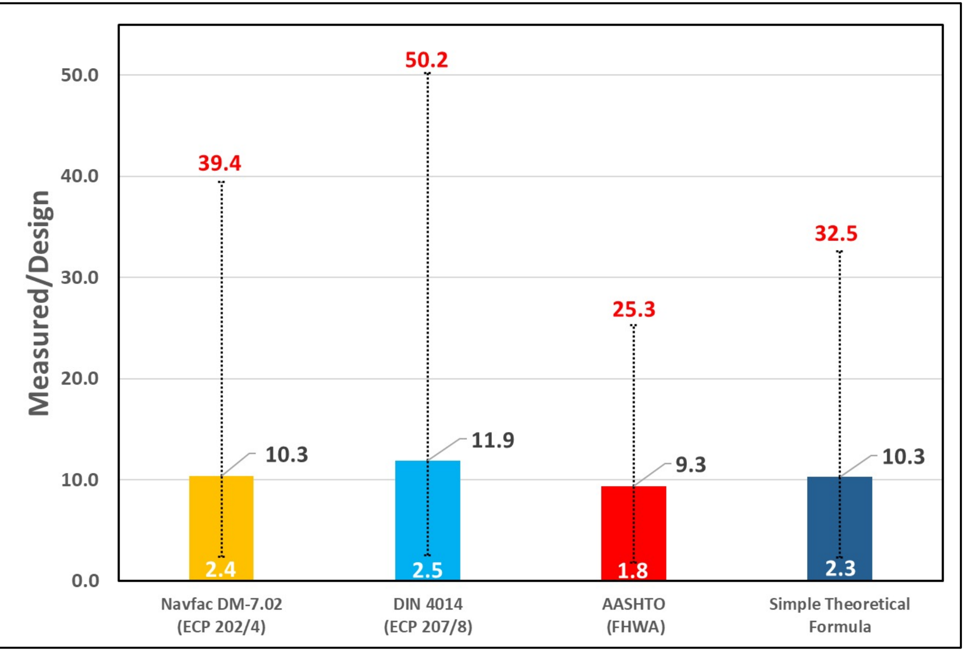


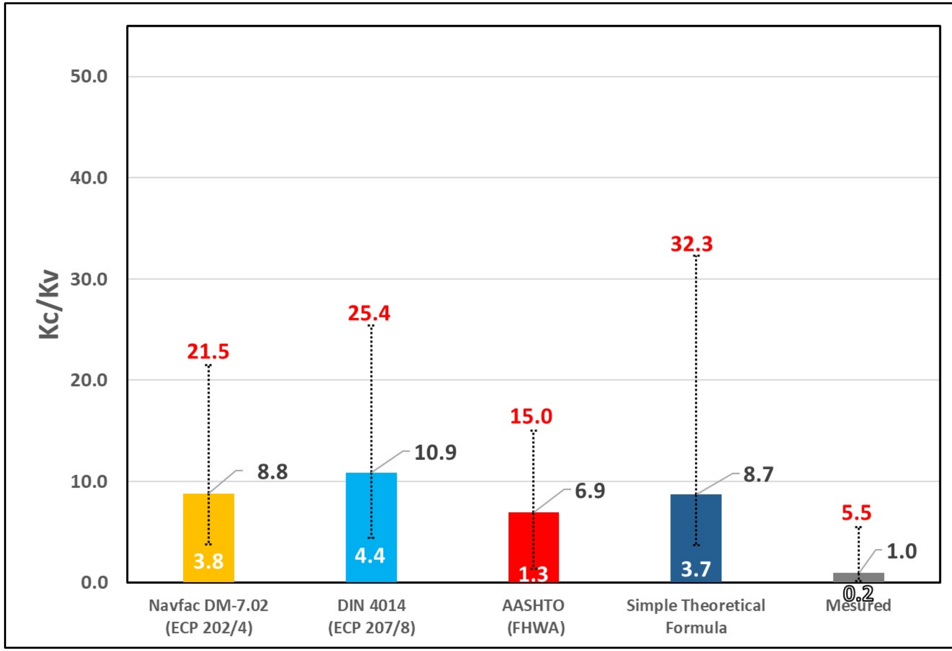


Normalized Median Load Settlement Curves for all Evaluation Cases

Vertical Stiffens values for all Evaluation Cases

Conclusion





Measured Vertical Stiffness Divided by the Design Stiffness for all Evaluation Cases

Concrete Stiffens Divided by Vertical Stiffness values for all Evaluation Cases

Acknowledgments

الهيئة القومية للأنفاق

NATIONAL AUTHORITY FOR TUNNELS
(NAT)

وزارة النقل

ORASCOM CONSTRUCTION

ALSTOM

المقاولون العرب عثمان أحمد عثمان وشركاه

The Arab Contractors
OSMAN AHMED OSMAN & CO

P13

Cairo Monorails – Comparison Between Actual and Theoretical Lateral Pile Stiffness and Effect on Monolithic Monorail Guideway Structures

ANWAR ELKADI, DR. WALAA ELTAHAWY, DR. A. FARGHAL MAREE / INNOVA & NECB

Comparison between actual and theoretical lateral pile stiffness and effect on monolithic monorail guideway structures

Walaa Eltahawy, PhD[1], Ahmed Farghal Maree, PhD[1], Anwar Elkadi, PhD[2]

[1]Innova Technologies, Inc. / [2]Nile Engineering Consulting Bureau (NECB)

Indeterminate structures performance is affected by the stiffness of the base supports. In case of structure supported by monopiles, both axial and lateral stiffnesses of the piles determines the distribution of forces between elements (Beam - Column Straining actions distribution). The monolithic guideway structures are indeterminate structure that are affected by the supporting piles stiffness. The actions based on equilibrium of deformation are significantly affected by the support stiffness, including creep, shrinkage, post-tensioning, and temperature.

Cairo monorail projects contain more than 4000 monopile supporting monolithic guideway structures. The design was performed based on theoretical lateral stiffness obtained from design codes including stiffness reductions due to cyclic load effects. On the other side, lateral pile load tests were conducted, which presented significant differences from the theoretical load values for different soil types. The actual stiffness was implemented in the analytical model to assess the performance of using the actual values on guideway structure under different loading conditions.

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NILE ENGINEERING CONSULTING BUREAU

Comparison Between Actual and Theoretical Lateral Pile Stiffness and Effect on Monolithic Monorail Guideway Structures

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Walaa Eltahawy, PhD, EI, ENV SP - Innova Transportation
Anwar Elkadi, PhD, PE - Nile Engineering Consulting Bureau (NECB)

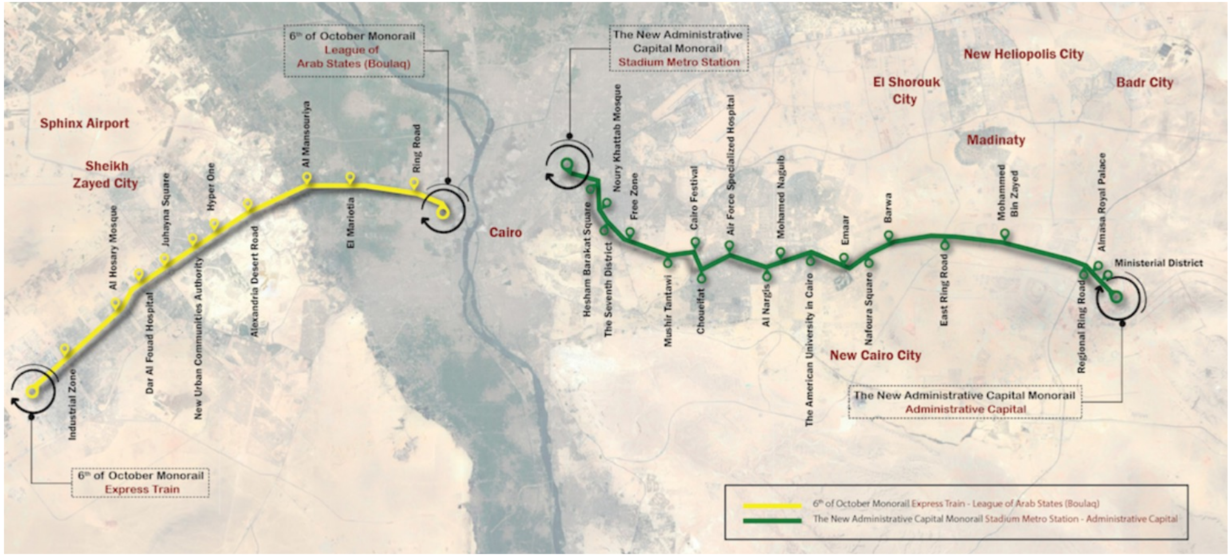
MONORAILEX 2021 – Milan, 26 Sept. 2021

Contents

Introduction

Cairo Monorail Projects consist of two monorail lines east and west of the Greater Cairo metropolitan area:

- **New Capital (NC) Line** connecting Nasr City, Cairo and the New Capital City (56.5 km route length),
- **6th of October City (6O) Line** connecting 6th of October City to Wadi Al Neel Street – Giza (42.5 km route length).



Owner: The Egyptian National Authority for Tunnels (NAT)

Contractors: Alstom with the Civil Works Joint Venture (composed of a joint venture between Orascom Construction and Arab Contractors)

Non-Working Pile Load Test

INNOVA TRANSPORTATION

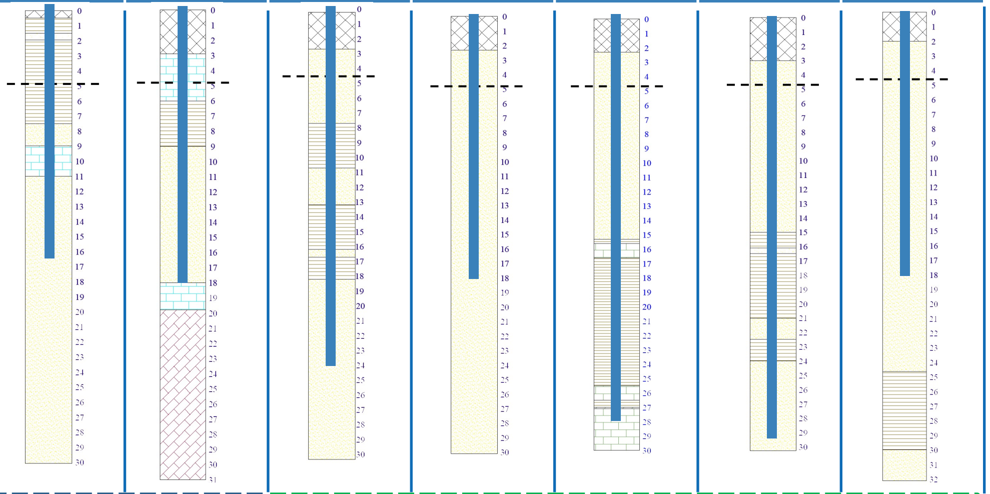
Line Segment	Segment Length (m)	Test Pile Diameter (m)	Test Pile Length (m)
NCL00	270		
NCL01	997	2.0	18
NCL02	1,128	2.0	29
NCL03	1,985	2.0	25
NCL04	1,506	2.0	24
NCL05	1,613	2.0	22
NCL06	4,572	2.0	18
NCL07	2,502	2.0	25
NCL08	2,411		
NCL09	2,914	2.0	22
NCL10	2,977	2.0	28
NCL11	3,188	2.0	20
NCL12	2591	2.0	26
NCL13	2636	2.0	18
NCL14	3,186	2.0	31
NCL15	4,626	2.0	22
NCL16	3,137	2.0	26
NCL17	2,532	2.0	18
NCL18	3,738	1.8	26
NCL19	1,855	2.0	18
NCL20	1,646	1.8	16
NCL21	2,444	2.0	24
NCL22	1,986	1.8	22

Line Segment	Segment Length (m)	Test Pile Diameter (m)	Test Pile Length (m)
6OL00	1,562	2.0	16
6OL01	5,217	2.0	16
6OL02	5,029		
6OL03	2,013	2.0	16
6OL04	4,024	2.0	29
6OL05	2,110	2.0	22
6OL06	3,933	2.0	17
6OL07	4,011	2.0	20
6OL08	4,739	2.0	24
6OL09	3,083	2.0	24
6OL10	4,176	2.0	25
6OL11	2,591	2.0	18
6OL12	414		

Data as of September 2021

- Total Length of Monorail Lines outside Depots = 99 km
- Number of vertical Non-Working Pile Load Test (PLT) = 32, one / line segment
- Executed Non-Working PLT = 21
- In Progress Non-Working PLT = 11
- Horizontal Non-Working PLT in the Study = 7

Non-Working Pile Load Test

Line Segment	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Profile FILL SAND SANDSTONE BASALT CLAY SILTSTONE							
Dominant Soil above Fixation Depth	Stiff Clay	Sandstone	Sand	Sand	Sand	Sand	Sand
Maximum Deformation (mm)	1.43	0.82	1.33	1.88	1.848	1.655	2.71
Length (m)	16	18	24	18	28	29	18
Rate of Increase of Lateral Coefficient of subgrade reaction ,n (t/m3) - Actual	36560	61050	27280	15325	15770	18950	8400
Rate of Increase of Lateral Coefficient of subgrade reaction ,n (t/m3) - Design	642	638	822	822	822	722	822
Depth of Fixation, t (m)	4.5	4.5	4.2	4.2	4.2	4.3	4.2

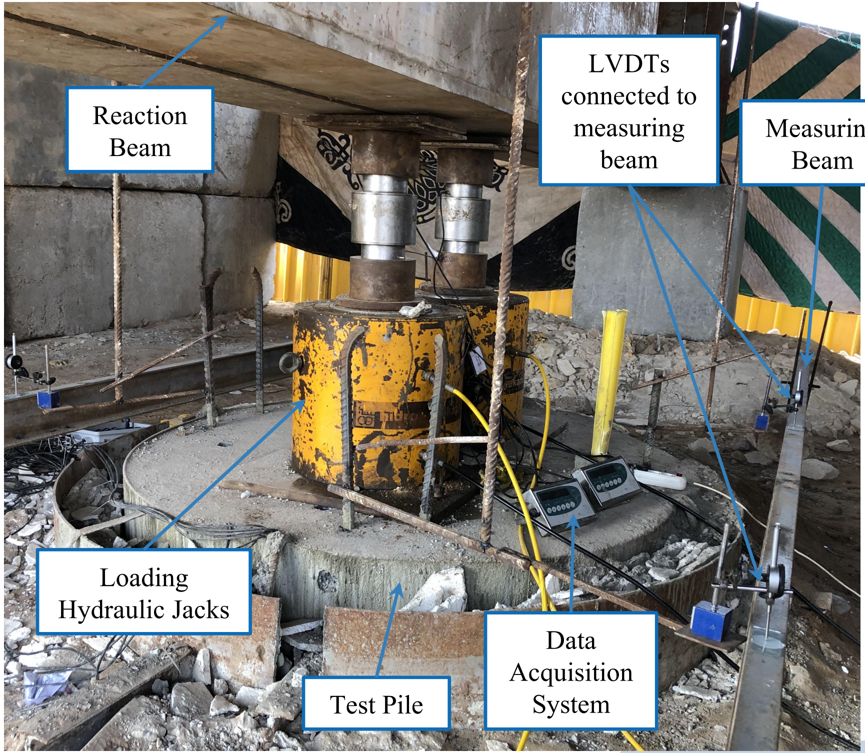
Stiff Soil

Medium Soil

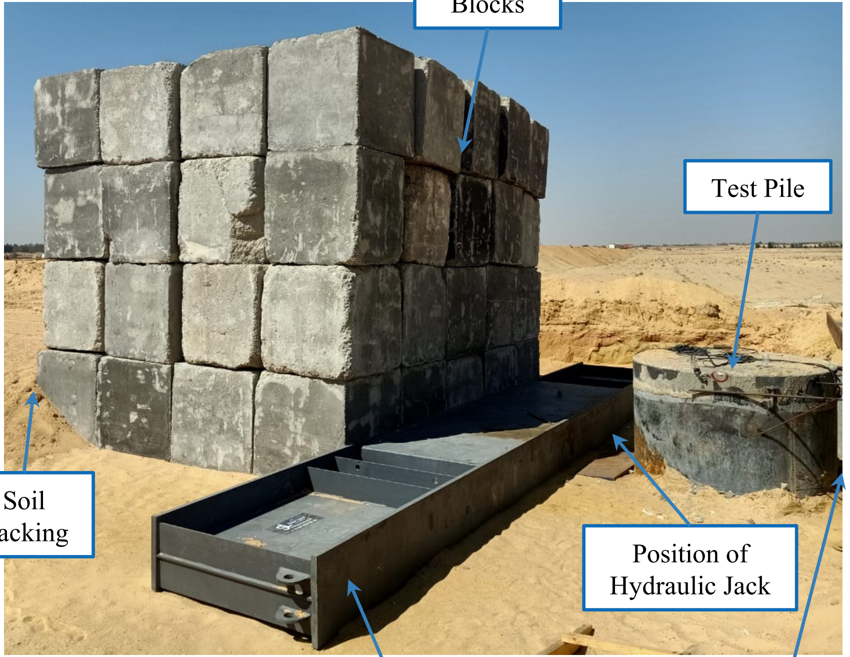
Fixation Depth

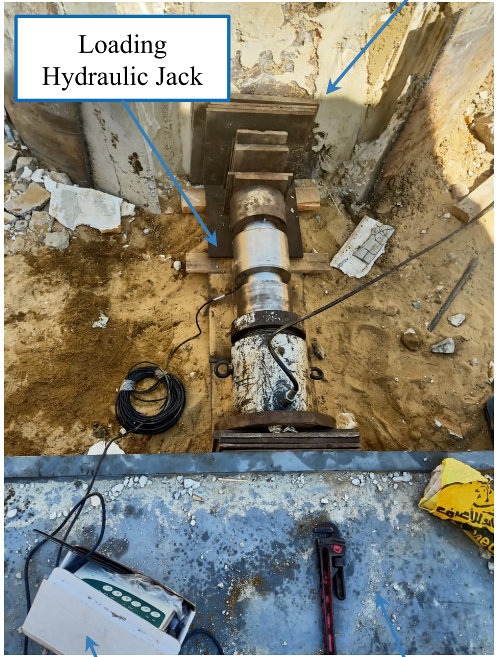
Executed Pile

Vertical Non-Working Pile Execution



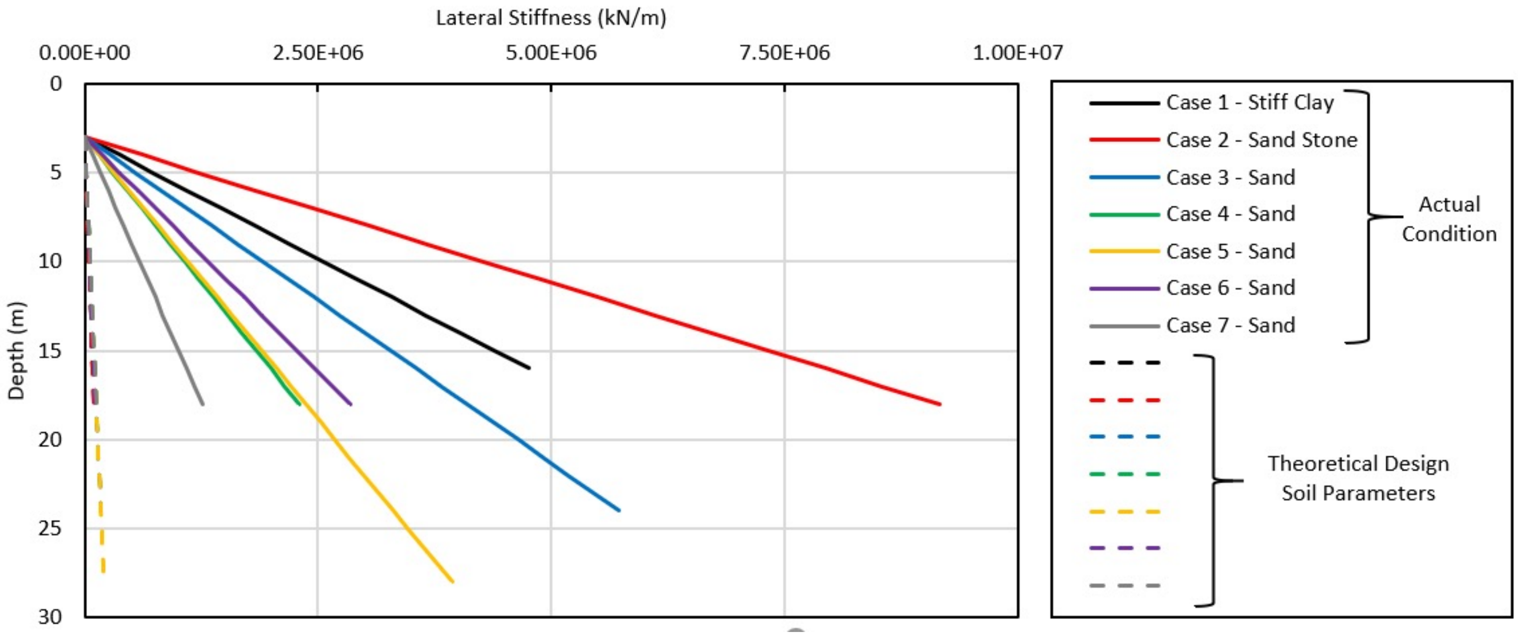
Horizontal Non-Working Pile Execution





Pile Lateral Stiffness

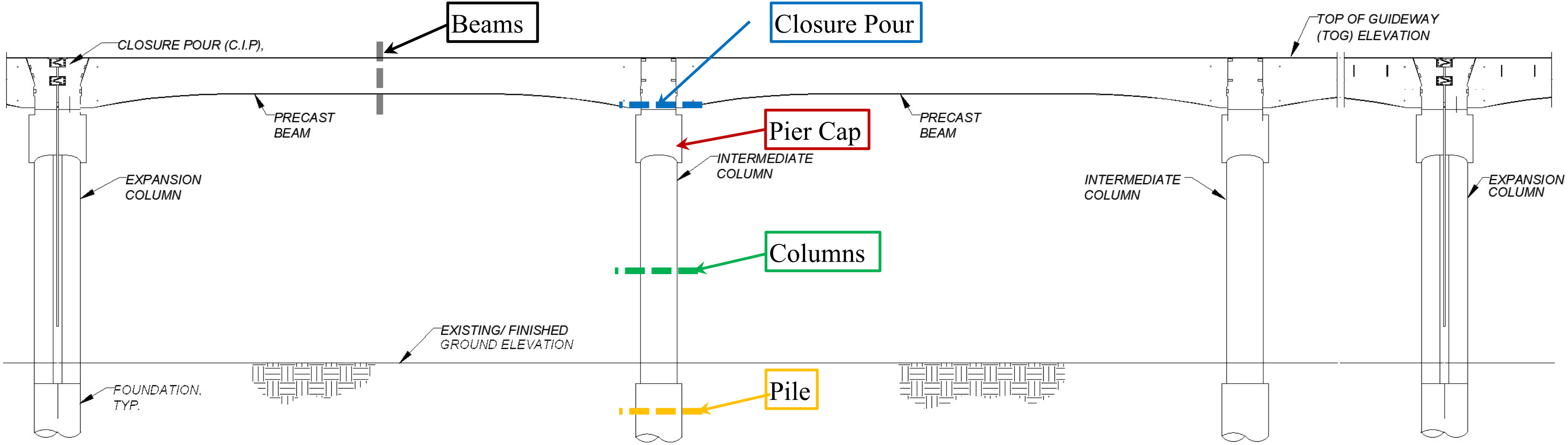
Comparison between Theoretical and Actual Pile Lateral Stiffness



Actual pile stiffness = 10 to 95 times theoretical pile stiffness

Monorail Guideway Structures

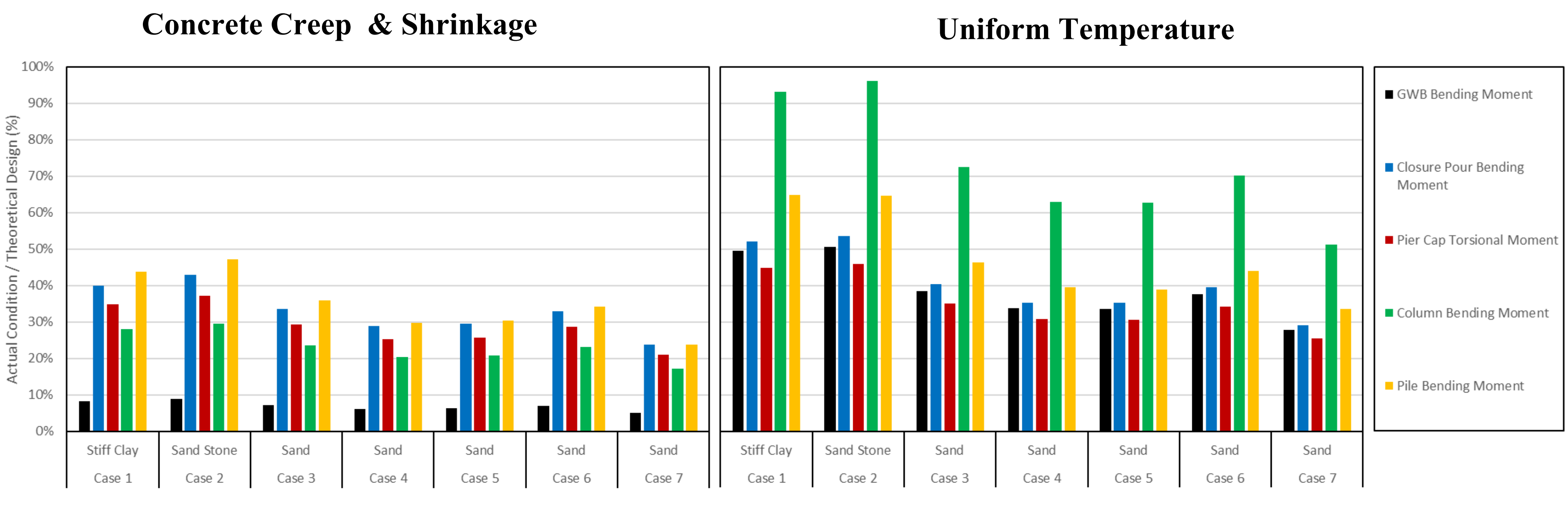
Investigated Design Elements



Assessed Loads Cases:

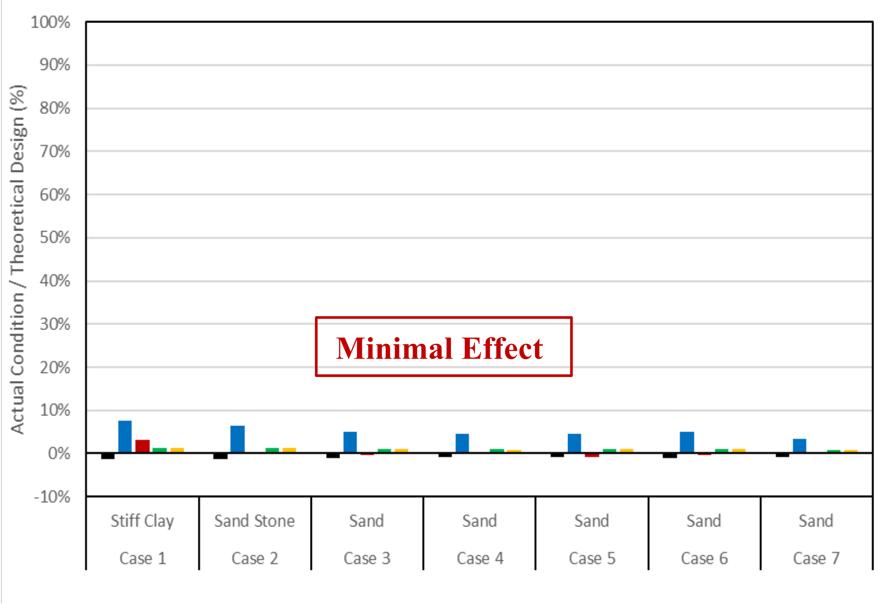
- Concrete Creep & Shrinkage
- Uniform Temperature
- Live Load (Train Load)
- Earthquake
- Post-tensioning (2^{nd} Stage - Continuity)

Effect of Pile Lateral Stiffness on Members Behavior

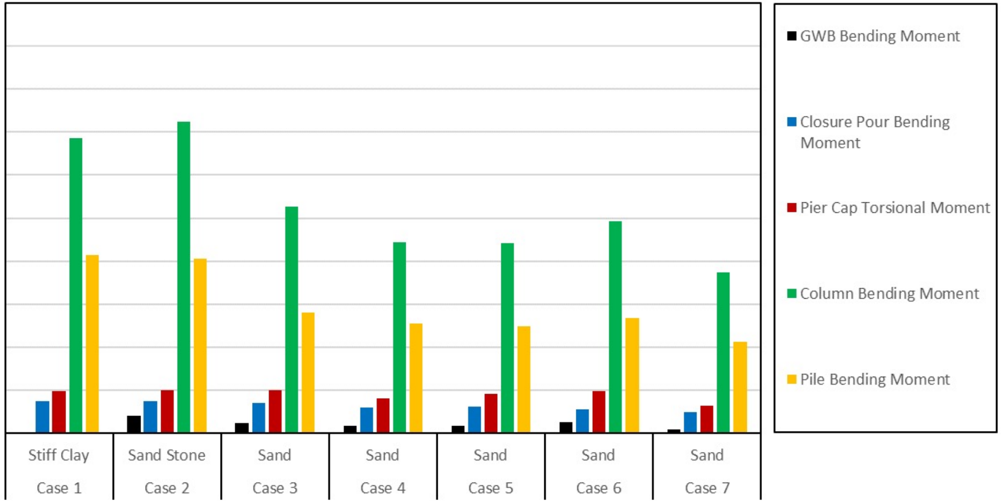


Effect of Pile Lateral Stiffness on Members Behavior

Live Load (Train Load)

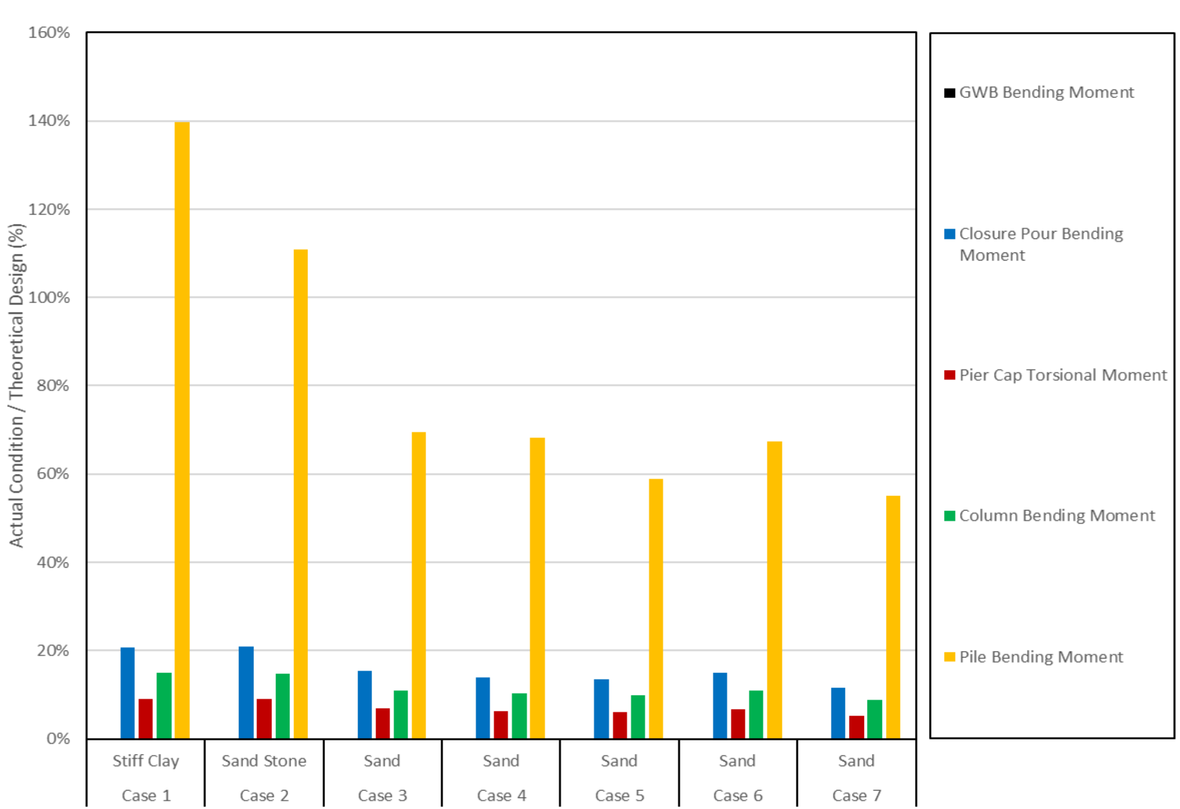


Earthquake



Effect of Pile Lateral Stiffness on Members Behavior

Post-tensioning (2nd Stage - Continuity)



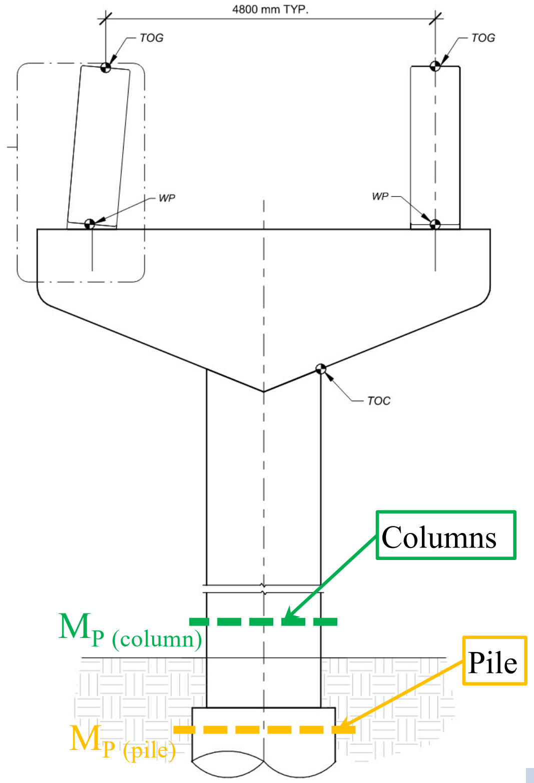
Foundation Design Concept

Pile Design Requirements as per AASHTO for Seismic Zone 2

AASHTO 2017 Section C3.10.9.3

"If seismic forces do not govern the design of columns and piers there is a possibility that during an earthquake the foundations will be subjected to forces larger than the design forces. For example, this may occur due to unintended column overstrength which may exceed the capacity of the foundations. An estimate of this effect may be found by using a resistance factor, ϕ, of 1.3 for reinforced concrete Columns."

$$\boxed{M_{P\ (pile)} > 1.3\ M_{P\ (column)}}$$



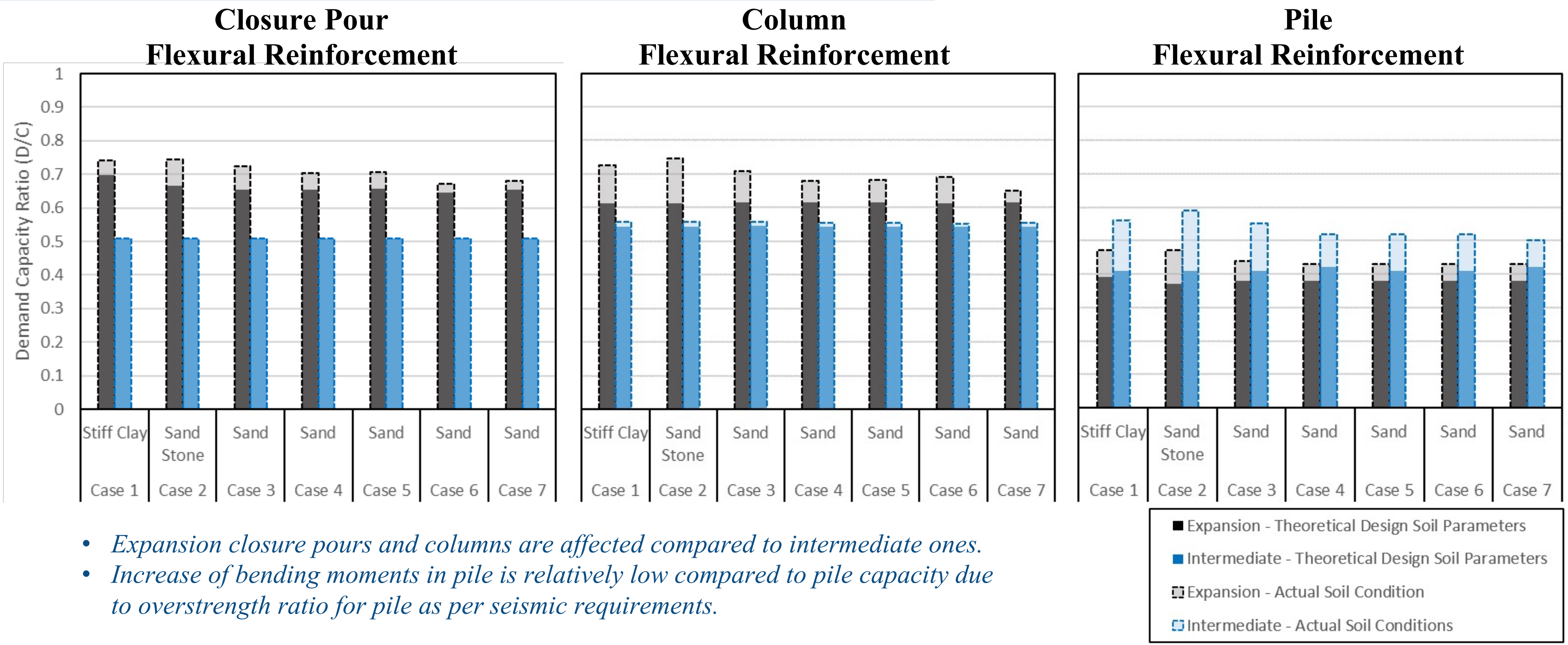
Guideway Structures Members Design

Load Combination as per Design Criteria
(AASHTO with slight modifications for monorail applications)

Load		User	AASHTO LRFD				
		U4*	Strength II	Strength III	Strength V	Extreme I	Extreme II
Dead load	D	1.0	1.25/0.9	1.25/0.9	1.25/0.9	1.0	1.0
Superimposed dead load	DL	1.0	1.25/0.9	1.25/0.9	1.25/0.9	1.0	1.0
Prestressing	PS	1.0	1.0	1.0	1.0	1.0	1.0
Creep and shrinkage	CR & SH	1.0	1.0	1.0	1.0	1.0	1.0
Train vert. live load + impact	L+I	1.35 AW0/AW3	1.35 AW4/SL		1.35 AW4/SL	1.0** AW3	1.0** AW3
Centrifugal force and hunting	CF, H	1.35 AW0/AW3	1.35 AW4/SL		1.35 AW4/SL	1.0** AW3	1.0** AW3
Wind load on structures	WS	1.0 75 km/h		1.0 120 km/h	1.0 75 km/h		
Wind load on live load	WL	1.0 75 km/h			1.0 75km/h		
Emergency braking	Lfe		1.35 AW4/SL		1.35 AW4/SL	1.0** AW3	
Temperature	TU		1.2/0.5	1.2/0.5	1.2/0.5		
Thermal gradient	TG						
Collision	CT						1.0
Seismic load	E					1.0	
Emergency walkway Live	EW	1.35					
Differential settlement	DS		0.0/1.0	0.0/1.0	0.0/1.0		

Check Design Safety
Demand Capacity Ratio (D/C)

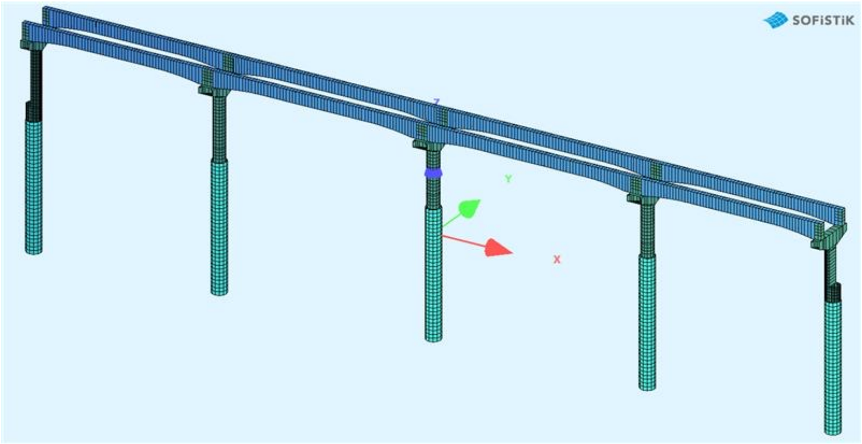
Effect of Pile Lateral Stiffness on Members Design



- *Expansion closure pours and columns are affected compared to intermediate ones.*
- *Increase of bending moments in pile is relatively low compared to pile capacity due to overstrength ratio for pile as per seismic requirements.*

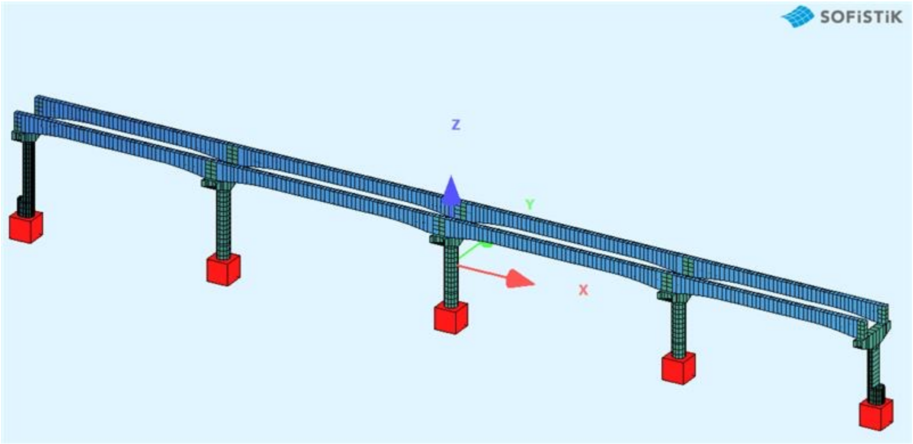
Infinitely Rigid Conditions (Fixed Support)

Soil Structure Interaction

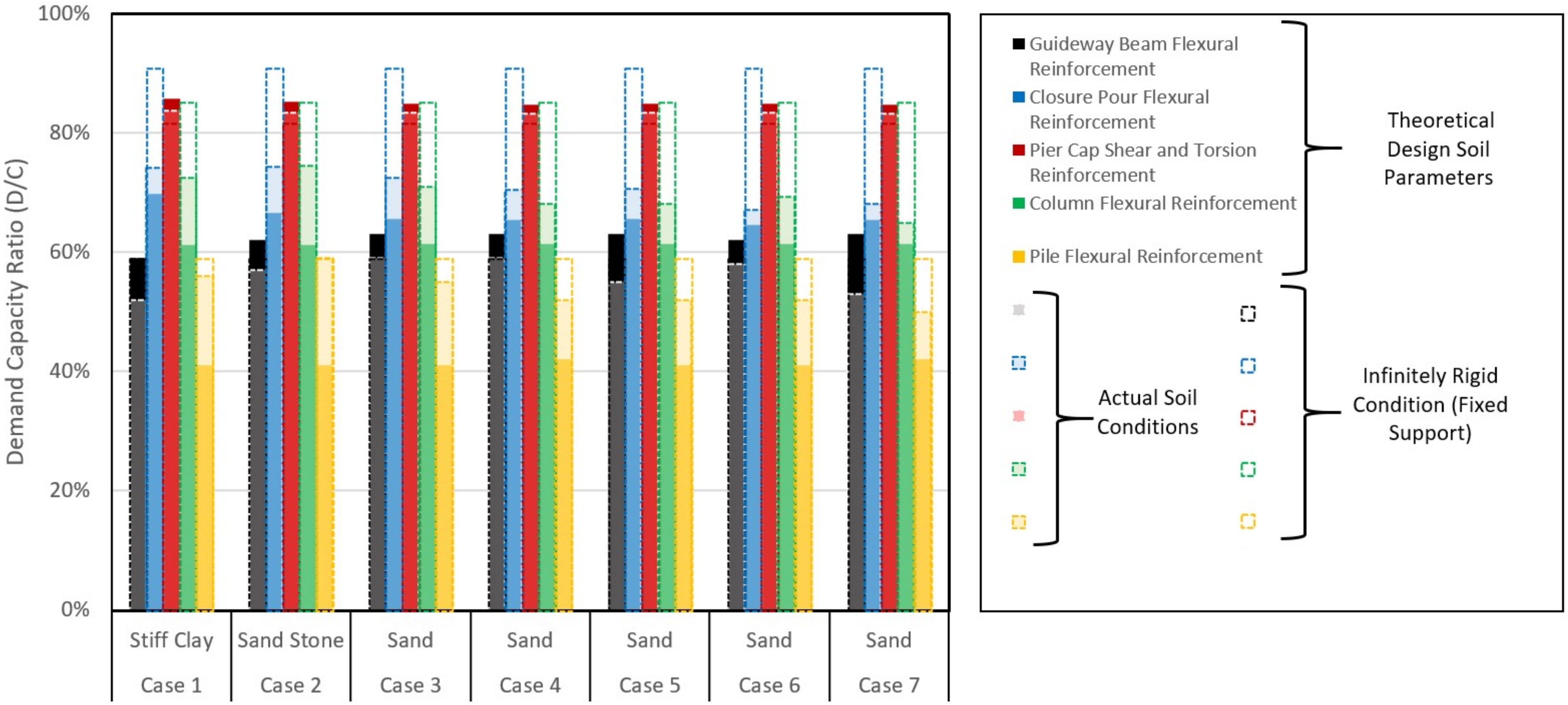


VS

Infinitely Rigid Condition

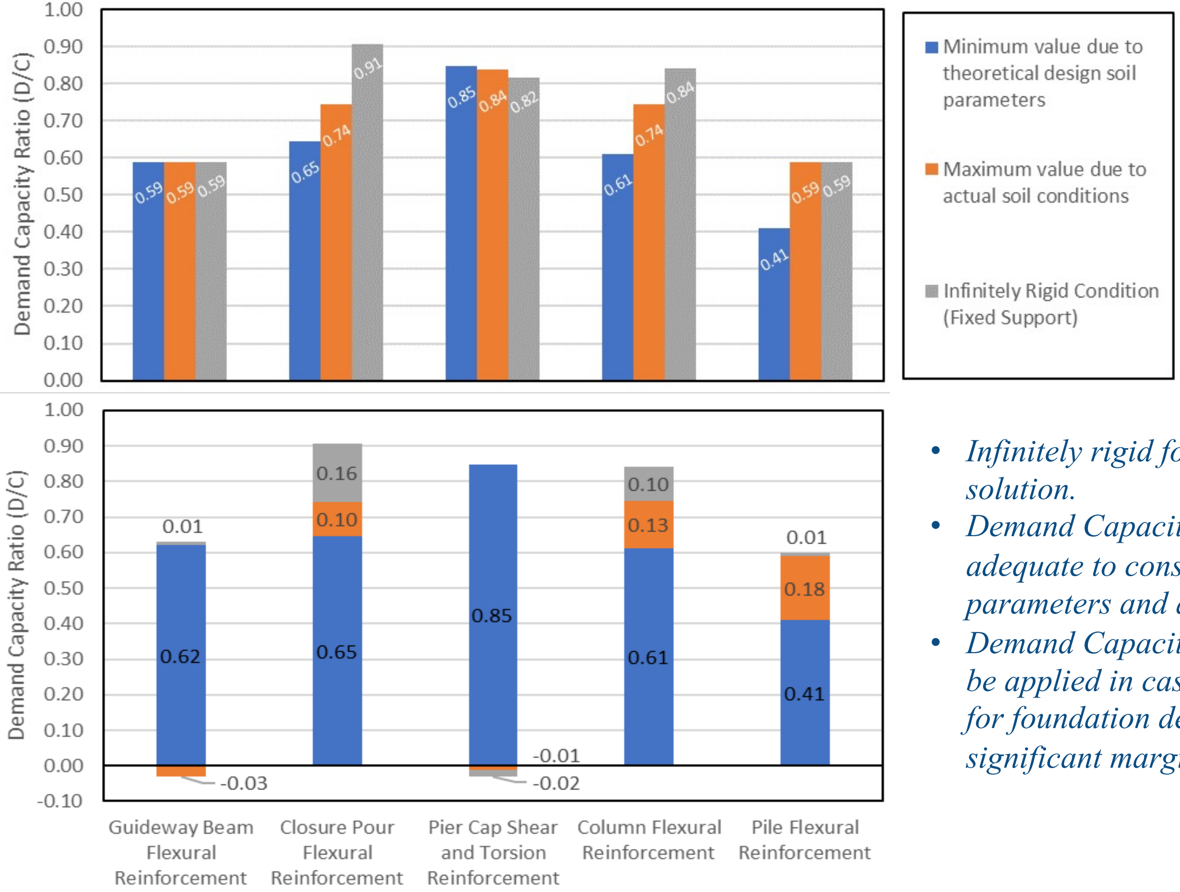


Infinitely Rigid Conditions (Fixed Support)



Significant effect occurred only for closure pours, columns and piles

Effect of Pile Lateral Stiffness on Members Design



- *Infinitely rigid foundation is considered a conservative solution.*
- *Demand Capacity Ratio Safety Margin larger than 18% is adequate to consider variation between design soil parameters and actual soil condition.*
- *Demand Capacity Ratio Safety Margin larger than 13% can be applied in case of implementing overstrength ratio concept for foundation design, which consequently provides significant margin of safety for foundations.*

Conclusions

- In the Cairo Projects, actual soil parameters obtained based on pile load testing are significantly higher than design soil parameters based on codes and standards.

- Adequate margin of safety shall be considered in structural elements to accommodate the variation between design soil parameters and actual soil condition.

- Load cases affected by changes in soil stiffness are:
  - Creep & Shrinkage and Temperature affecting all design elements.
  - Earthquake loads affecting columns and piles.
  - Post-tensioning affecting piles only.

- Design using an Infinitely rigid foundation (Fixed Supports), neglecting soil structure interaction, is a conservative solution of analysis.

Acknowledgments

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ORASCOM CONSTRUCTION

ALSTOM

المقاولون العرب
عثمان أحمد عثمان وشركاه
The Arab Contractors
OSMAN AHMED OSMAN & CO

P14
Cairo Monorail Project Structural Design – Construction Observation Interface

DR. A. FARGHAL MAREE, LUCAS B. MOREIRA / INNOVA

International Monorail Association

Cairo Monorail Project Structural Design – Construction Observation Interface

By: Dr. Ahmed Farghal Maree & Eng. Lucas Bernardi Moreira

Innova Transportation LLC.

Cairo Monorail Projects consist of two monorail lines in Greater Cairo metropolitan area, one between the New Capital City and Nasr City – Cairo (56.5 km route length), and the other from the 6th of October City into Wadi Al Neel Street – Giza (42.5 km route length). The Egyptian National Authority for Tunnels (NAT) is in charge of the development of the two monorail lines. A consortium composed of Alstom with the Civil Works Joint Venture (composed of a joint venture between Arab Contractors and Orascom Construction) is tasked to develop the project. Innova has conducted the design for the guideway structures. A new methodology was performed by integrating the structural design with the construction observation. Through this type of interface, several construction issues were solved through detailed structural analysis and adjustment of construction methodologies. Several Case studies will be presented among them:

1. Use of flowable concrete for monorail beam applications.
2. PT Grout strength for monorail beams and how to assure reaching the target quality for the final produced beams.
3. Guideway beam closure pour connection and different ways of splices executions (Lessons Learned)
4. Variation of guideway beam deformation in the precast yard, which was adjusted by regulation for post-tensioning, concrete curing and beam supports.
5. Control of top riding surfaces for monorail beams.

Integrating Structural Design With the Construction Observation

A. Farghal Maree, PhD, PE, ENV SP
Lucas Bernardi, PE
Carlos Banchik, PE

MONORAILEX 2021, Sunday Sept. 26th, 2021

Presentation topics

INNOVA TRANSPORTATION

Design & Construction Observation Topics

Structural Engineering is the key to obtaining durable and safe monorail structures with ride comfort

Construction observation

- Tasks
- Work Flowchart
- Production Phases

Challenges & Experiences

- Use of Flowable Concrete
- Control of Top Riding Surface
- Post-tensioning Grout strength
- Guideway Beam Deformations
- Closure Pour Connections

Presentation summarizes more than 20 years of civil monorail design and construction observation experience and presents some lessons learned

Construction Observation

Tasks during the design phase

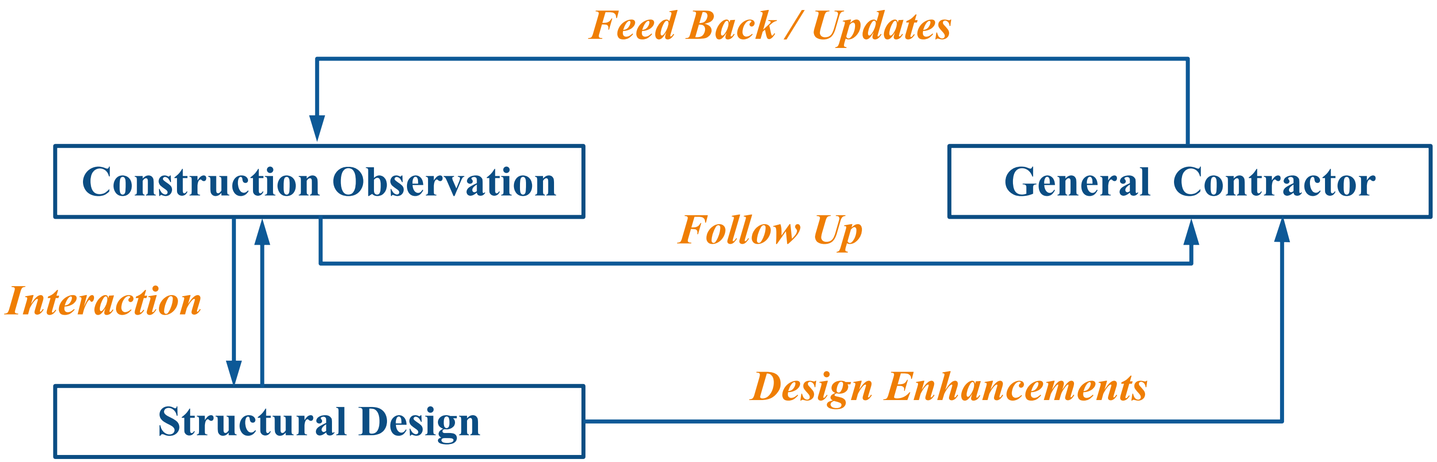
- Review (Documents, Means and Methods)
  - Guideway beam interfaces with mechanical and electrical systems,
  - Temporary supports,
  - Emergency walkways,
  - Precast yard layout and,
  - Guideway beam fabrication, handling, and installation.
- Develop the necessary devices to provide adequate assurance on the QA/QC plan.

Tasks during the construction phase

- QA/QC supervision at the casting yards and installation at sites.
- Monitor guide beams deflection and construction tolerances.
- Train contractors' personnel for the tasks above.

Construction Observation

Work Flowchart



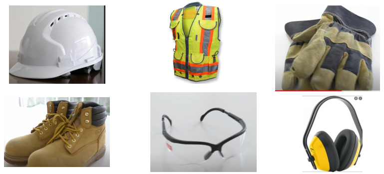
Construction Observation

Production Phases

The Contractor is in charge of the site and defines the rules which apply to all job site personnel and guests.

Training Courses

PPE - Personal Protective Equipment



Observation Report Template

Construction Observation

General Rules

Consider yourself a guest

Attend the job site safety class

Always wear the proper PPE

Fill out an observation report

Construction Observation

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On-Site Etiquette and Procedures

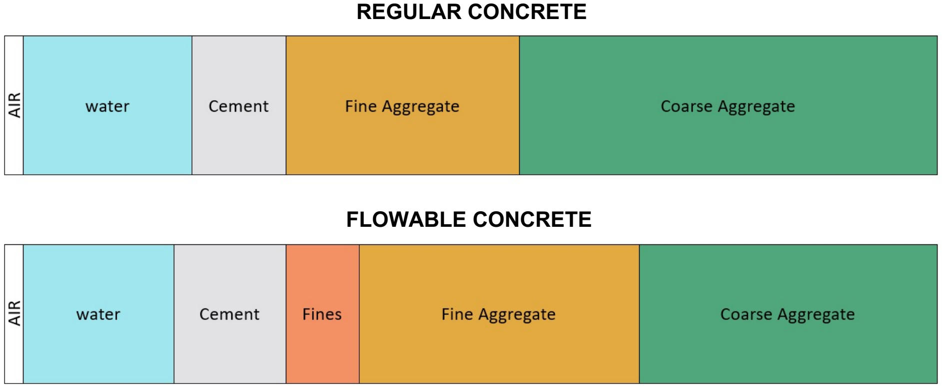
- Safety
  - Be aware of your surroundings
  - Keep food in designated areas
  - Obey construction site signage
  - Be aware of auditory warnings
  - Do not look directly at a weld
  - Practice proper ladder etiquette
  - Give workmen the right of way
- Report non-compliant work immediately
- Follow up after the visit to verify the corrective steps have been taken

Use of Flowable Concrete

Flowable concrete has self-leveling capabilities

Advantages:

- Fast placement.
- Reduced permeability (Potential higher durability)
- Minimizes surface voids
- Reduces labor costs
- Creates smoother surface finishes
- Allows easier pumping
- Resistant to segregation



The volumetric ratio proportions of regular concrete versus those of flowable concrete

Disadvantages:

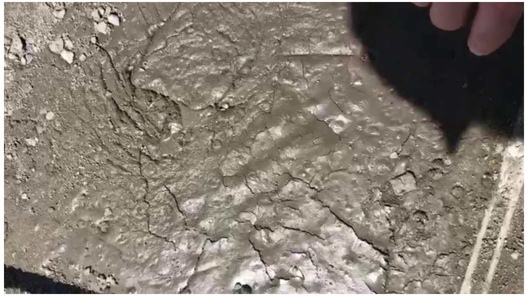
- Material selection is stricter
- Higher construction costs
- Many trial batches and laboratory tests are required to use a designed mixture (Demanding work).
- Higher precision is required when measuring and monitoring
- Formwork must be designed to withstand higher pressures
- Requires increased quality control
- Higher Creep and Shrinkage
- Lower resistance to wear (Decreased amount of coarse aggregate)

Use of Flowable Concrete

Challenges of using self-levelling concrete in monorail guide beams

Concrete with different colors

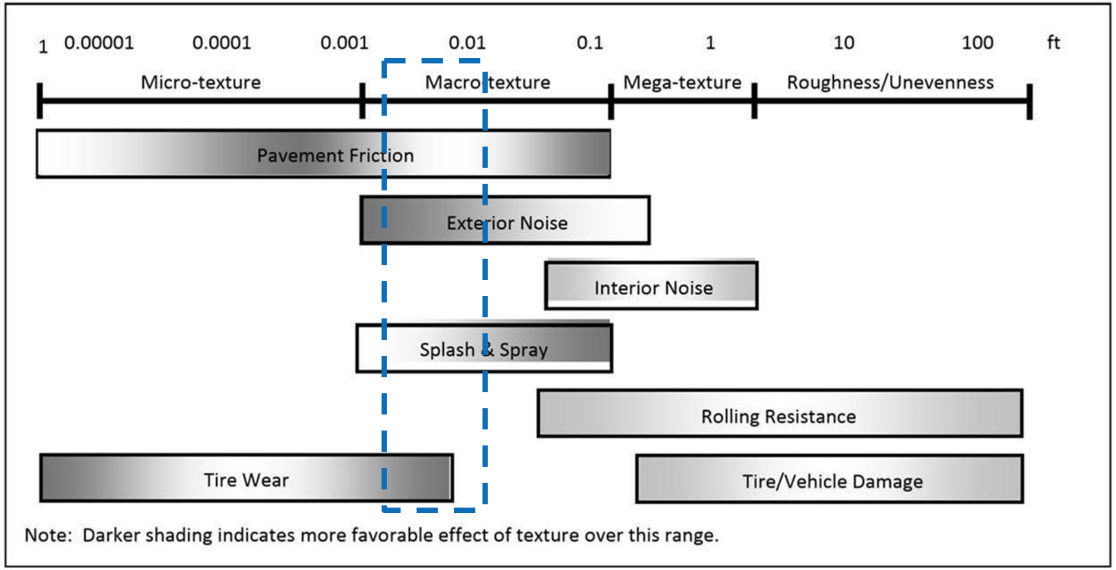
Sticky concrete surface



Control of Top Riding Surface

Top surface texture

Texture wavelength influence on pavement–tire interactions



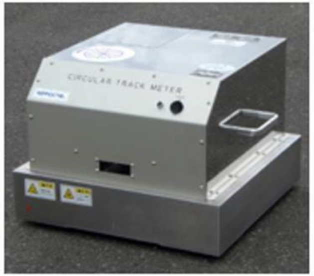
Rolling Stock Supplier Specifies Concrete Surface Micro and Macro Structure and approves samples

Control of Top Riding Surface

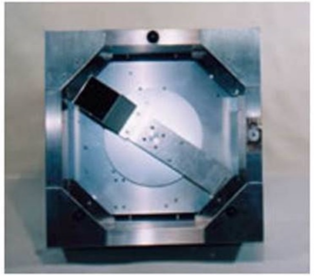
Sample Measuring Equipment to assess Concrete Micro – Macro Texture

- Circular Track Meter – ASTM E 2157-01 Measure surface macrotexture profile - Reports MPD (Mean Profile Depth)
- Dynamic Friction Tester – ASTM E 1911-98 - Measure the frictional characteristics of paved surfaces

Circular Track Meter



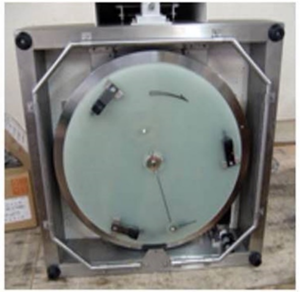
FRONT VIEW



BACK SIDE

Dynamic Friction Tester

Main Body



Back Side

Post-tensioning Grout Strength

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The grout strength of 35MPa is used in most of the world for bridges, and professionals would consider its applicability as common practice, however for monorail guideway beam, grout strength needs to match the concrete strength and be no shrink or shrink compensated.

Codes	Grout Strength at 28 Days (Cylinders)
BS EN 447:2007	30 MPa
PTI M55.1-12 / ASTM C942	35 MPa
FIP Guide to Good Practice	30 MPa

INNOVA DESIGN	40 MPa

Post-tensioning Grout Strength

Design Properties of Critical Sections for the Typical Beam

Concerns that shall be addressed for structures with long design life (100 years):

1. Durability Requirements:

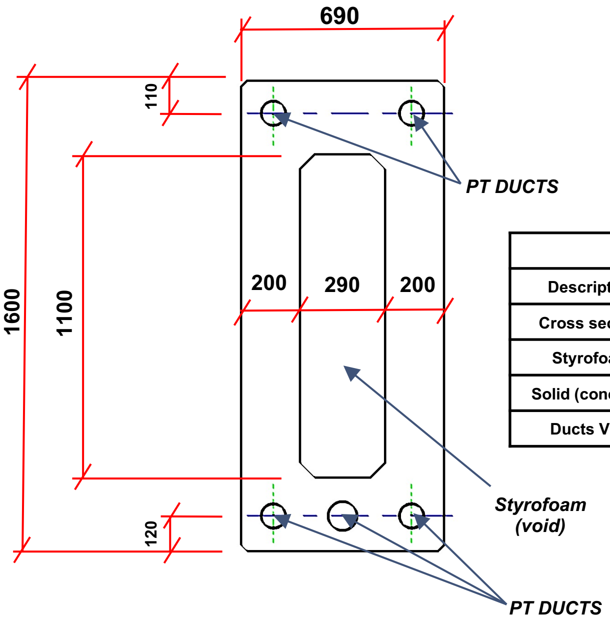
- Usually, local codes and specifications are not based on slender structural elements, where the ducts make up 12.6% of the cross-sectional area .

2. Running surface close to the PT ducts

- The top PT ducts have about 60mm of cover.
- High-strength grout is recommended to maintain the integrity of the grout under the service and impact tire loads from the daily operations of the train.

3. The ultimate flexural capacity of prestressed sections.

- To assure the flexural ultimate behavior of cross-sectional area at the hollow mid-span, maintaining the strength of the grout is a must.



Legend	
Description	Area (m²)
Cross section	1.10
Styrofoam	0.32
Solid (concrete)	0.78
Ducts Void	0.10

12.6 %

Post-tensioning Grout Strength

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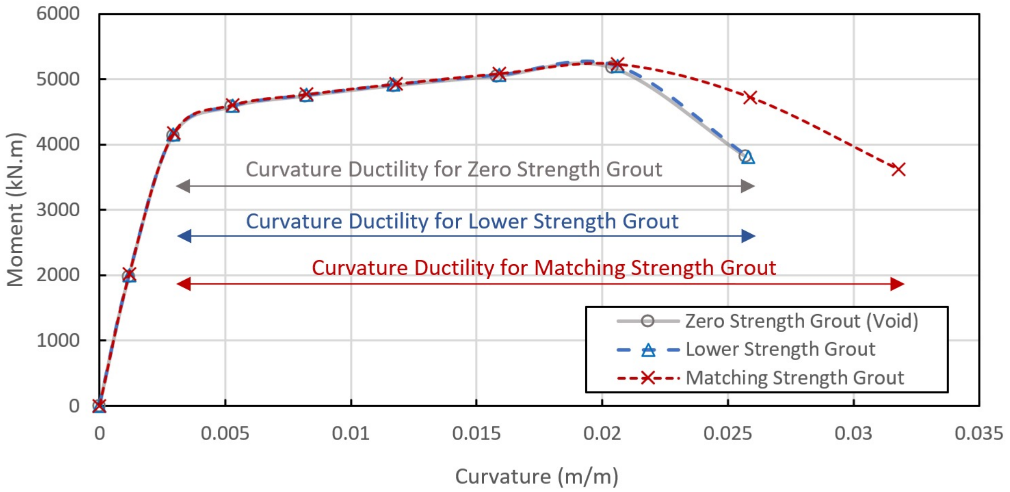
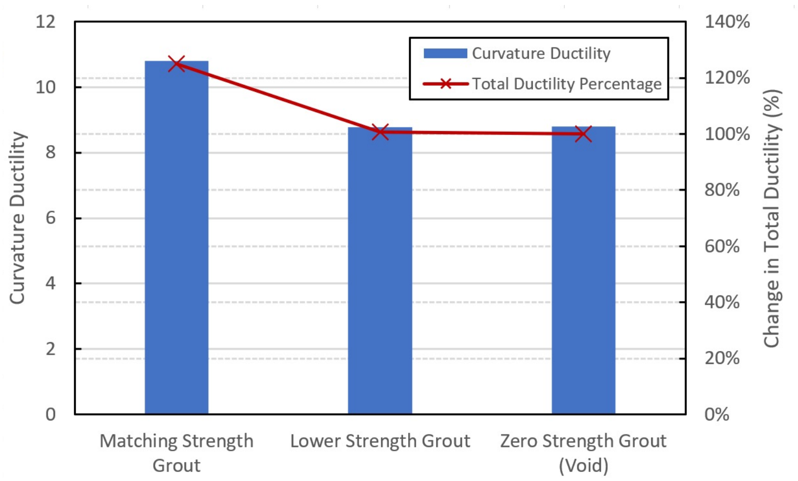
The ultimate flexural capacity of prestressed sections

Moment Curvature Analysis for different grout strength conditions





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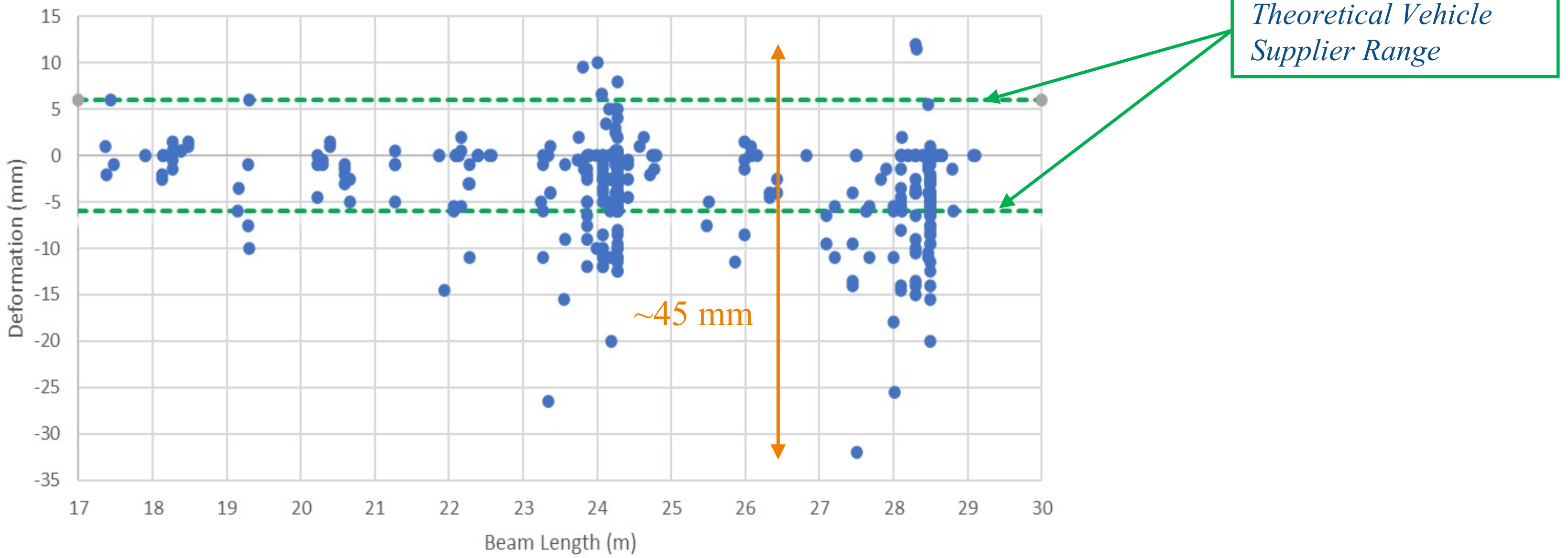
Problem Statement

Sample Precast Yard Guideway Beams Deformations Scatter



Concrete Behavior at Early Age for sample mix with W/C = 0.329

- Tensile Strength
- Elastic Modulus

} Deformation

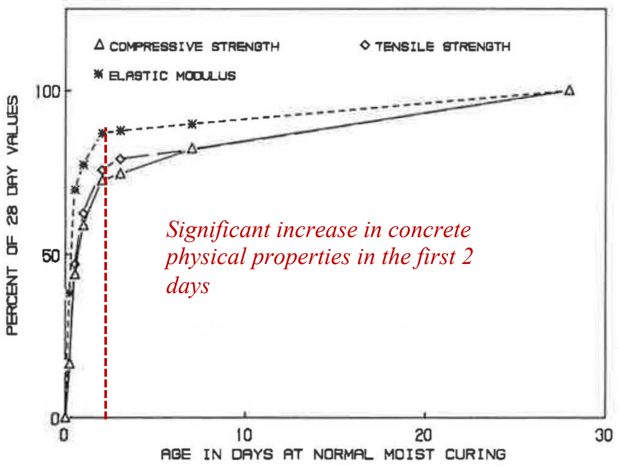


FIGURE 4 Comparison of physical property development using normalized values: Mix D.

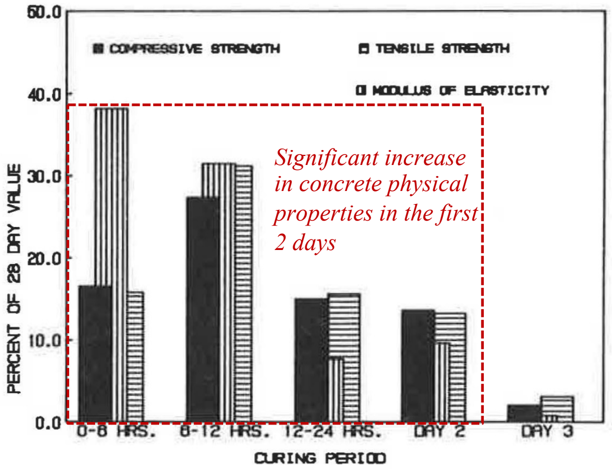


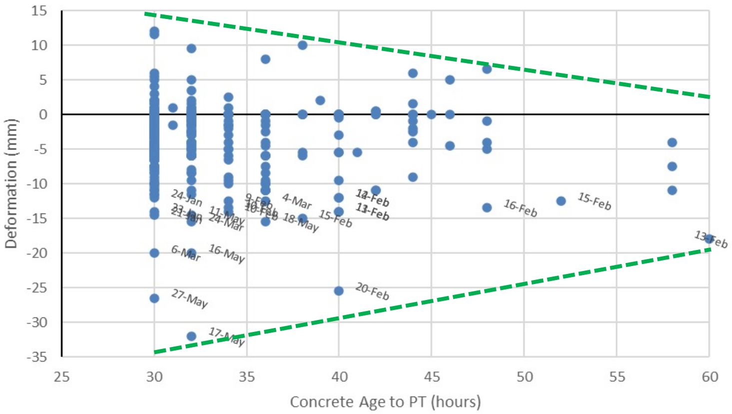
FIGURE 7 Periodic development of physical properties: Mix D.

Oluokun et al., "Rates of Development of Physical Properties of Concrete at Early Ages, " TRANSPORTATION RESEARCH RECORD 1284, 1984.

Guideway Beam Deformations

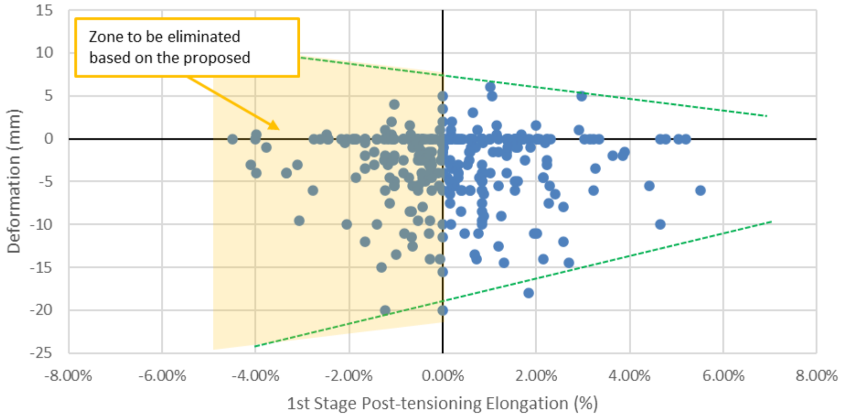
Major Parameters Affecting Guideway Beam Deformations

- ***Early age of concrete at post-tensioning***



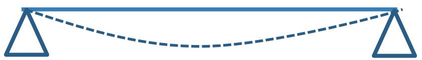
Early Strength → *Deformation*

- ***Quality control of post-tensioning process***



Consistency of Prestressing Elongation → *Scatter in Deformation Results*

- ***Change Support Location***



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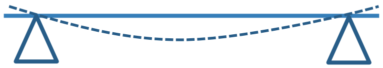
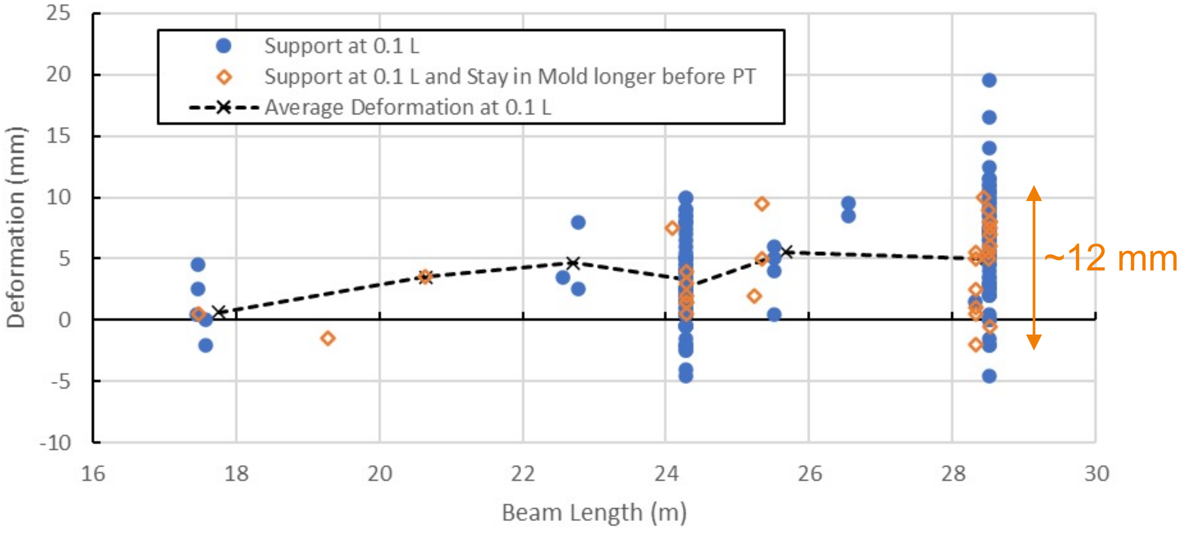


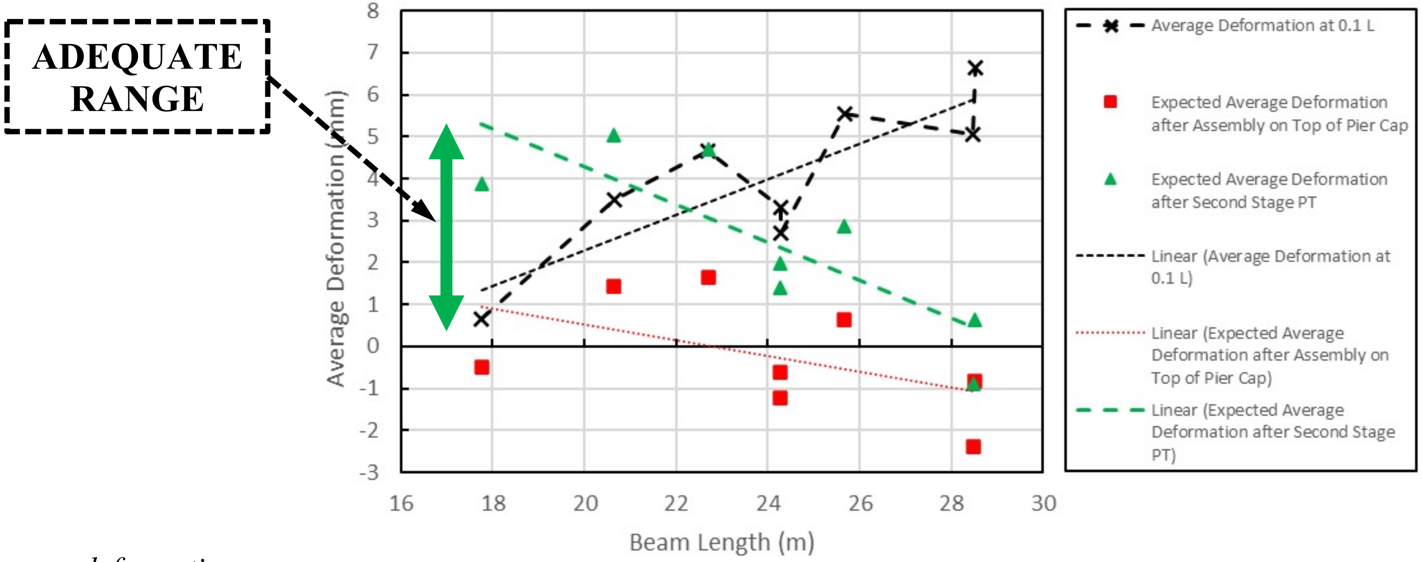
Guideway Beam Deformations

Adjustment Procedures Outcome



Guideway Beam Deformations

Assessment of guideway beam deformation through all construction stages

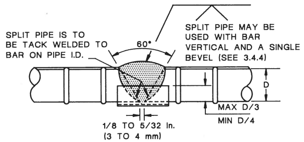
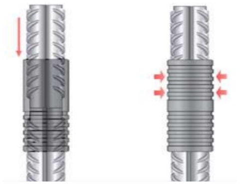


Average deformations:

1. *Support at 0.1L*
2. *After support change to ends*
3. *After second stage PT*

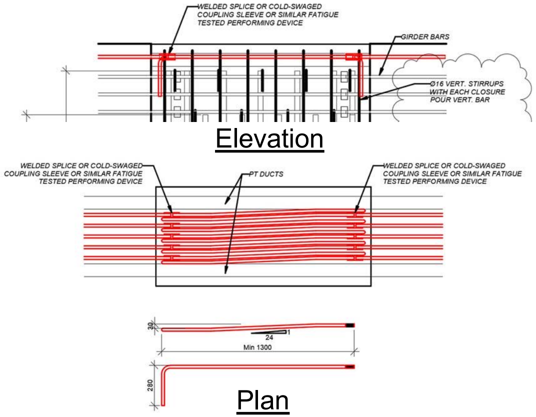
Closure Pour Connections

Ways to execute rebar splices (1/2)

Rebar splices		Advantages	Disadvantages
Welded Splices		• For large jobs welding may be more economical	• Accessibility limitations • Require qualified welder • Time-consuming / Laborious • Increase quality control • Requires special rebar and preparation
Cold-swaged couplers		• No special rebar end preparation needed • Time saving and cost reduction • No reduction of rebar original cross-section or rebar length • Widely used in many countries with time tested practice.	• Require special equipment's • A minimum rebar spacing is required
Position Coupler		• Installs quickly • Slim design frees up space in congested areas	• Require special equipment's • The bars need to be threaded • Limited tolerances

Closure Pour Connections

Ways to execute rebar splices (2/2)

Rebar splices		Advantages	Disadvantages
Lock Nut Couplers		• No special rebar end preparation needed • Time saving and cost reduction • No reduction of rebar original cross-section or rebar length • Widely used in many countries with time tested practice.	• A minimum rebar spacing is required • Expensive type of couplers
Special Lap Splice		• Cost reduction	• Conflicts with the mold bulk heads. • Coupler may be required. • Time Consuming • Low strength • No special rebar end preparation needed

Lesson Learned Example for Positioning Coupler

The challenges of using position couplers to connect guide beams are listed below:

- ✓ If the distance between the two edges is not exact, or an almost exact multiple of the pitch, the threading will not fit properly.
- ✓ Slight misalignment between top bars prevents the coupler smooth fitting.

NOTE: Given the factors above, a great deal of force was needed to assemble the couplers, as the couplers re-thread the rebar affecting its effectiveness.

Conclusion

All Parties on a project are responsible for its success:

- *Owner, Owner Representatives,*
- *Rolling Stock /Systems and System Design Professionals*
- *Contractors and Design Professionals.*

Not two projects are alike.
Experienced design & construction observation teams shall continually assess design and means and methods to ensure quality products and minimize problems and maintenance issues ahead of commissioning and operations

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P15
Line 15-Silver: Seven Years in São Paulo Subway - Activities, Expansion and Challenges

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INTERNATIONAL MONORAIL ASSOCIATION

International Monorail Association

Line 15-Silver: Seven Years in São Paulo – subway activities, expansion, and challengers

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Abstract

São Paulo Subway has increased substantially its line system during last years and among its expanding lines, two were designed using the Monorail System. Line 15-Silver is the only one in operation, which rolled out in 2014, and started operating between the stations Vila Prudente and Oratório and Oratório Maintenance Depot, covering approximately 2.7 km. In April 2018, its length has increased to approximately 8.8 km by the addiction of four stations and one primary substation. Since 2019, after the inauguration of four other stations, Line 15 operates with an extension of almost 13 km. The rolling stock fleet is 27 trains of 7 cars each, and the system is designed to work with Communication Based Train Control (CBTC). Its operation is designed to be UTO, with platform screen doors, cameras inside the trains, image recording, air conditioning and free passage between cars. Currently, one station and a another primary substation are under construction and will start operating in 2021. Actual plans propose three other stations and a train depot. Therefore, the goal of this paper is to present how Line 15 was developed, its construction phases, its system implementation and its expected demand. It will cover lessons learned, its advances, obstacles and challenges after seven years of operation, as well as its expansion project into a high-density region that lacks transportation capacity.

Keywords: Monorail; Line 15

1 Introduction

São Paulo State has a metro rail network that is constantly expanding. Most of this network is concentrated in the metropolitan region of São Paulo, with a population of 20.8 million inhabitants, which corresponds to 47.5% of the population of the State of São Paulo, occupies an area of 7,947 km², with a GDP of approximately US$ 176.3 billion (SEADE, 2021) being one of the most important economic centers in the country.

The Metropolitan Rail Transport Network of São Paulo has a total length of 370 km with approximately 230 km within the limits of the city of São Paulo (STM-2021), shown in Figure 1.

Metrô-SP, whose lines are part of the Metropolitan Rail Transport Network of São Paulo, is responsible for the operation and maintenance of Lines 1-Blue, 2-Green, 3-Red and the Monorail of Line 15-Silver, totaling 69.7 km in length and 62 stations, as well as for the design, expansion and construction of new metro and monorail lines.

Both Lines 4-Yellow, with 11.4 km and 10 stations, and Line 5-Lilac, with 20 km and 17 stations, were built by Metrô-SP, but are currently operated and maintained by Private Operators.

Metropolitan Transport Network

Figure 1: Metropolitan Transport Map (METRÔ; 2021)

Considering all lines currently in operation and expansion and/or construction, only lines 15 and 17 were designed using the Monorail System.

2 Line 17-Gold

Line 17-Gold was conceived aiming at the compatibility and compliance with the guidelines of the state planning to connect Congonhas Airport to the Metropolitan Rail Transport Network. Also, according to Metrô (2011), this line will expand the accessibility and mobility of the population using the airport and the surrounding region.

The line demand was initially estimated at around 480 thousand passengers/day, so this line has medium capacity. This was one of the reasons why the line was designed with the monorail system.

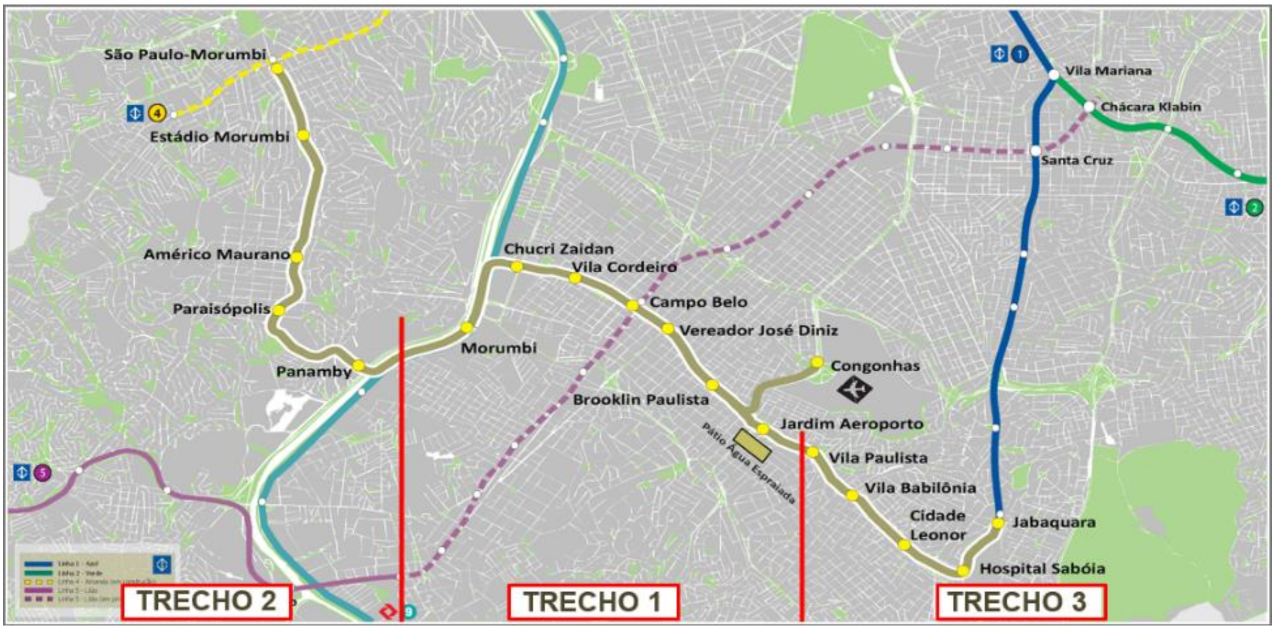

Figure 2: Line 17 – Gold

This line is divided into three sections, but only section 1 is under construction. This first phase will include 7.7 km of operational tracks, 8 elevated stations, 1 maintenance depot and 1 electrical substation.

14 trains will be supplied for this line operation, which will be powered by electric traction. It is designed to use the Communication Based Train Control (CBTC) with UTO automation level and 80 second project headway. The first phase is expected to start operating in November 2023.

The estimated demands for this section of operation are shown in the figure 3:

Estação / Via / Pátio	Demanda (pass/dia 2020)
Jardim Aeroporto	14.190
Congonhas	18.540
Brooklin Paulista	8.800
Vereador José Diniz	9.430
Campo Belo	76.590
Vila Cordeiro	2.990
Chicri Zaidan	12.910
Morumbi	41.260
Pátio Água Espraiada	-

Figure 3: Line 17 2020 Estimated Demand

Both Sections 2 and 3 are waiting for government directives to start their implementation.

3 Line 15 – Silver

Line 15-Silver was conceived aiming at the compatibility of two public transport projects developed for the southeast region of São Paulo: parts of Metro Line 2-Green and the BRT Expresso Tiradentes.

Line 2-Green, a line in operation which uses conventional metro technology, was designed to construct 2 more stations and 1 Maintenance Depot but it was re-evaluated to avoid overlapping with the BRT Expresso Tiradentes design.

The BRT Expresso Tiradentes is an exclusive public transport bus corridor that connects the Line 2 Vila Prudente station with the city center, which also would provide an extension to the Cidade Tiradentes district, in the far east of the city.

The projects compatibility avoided the overlapping of public transport services, large-scale expropriations and major interferences in the region's road system resulting from the implementation of a BRT corridor, and in return, ensured sufficient transport capacity to meet the demands of both modes previously projected, increasing the estimated demand from 240 thousand passengers/day (bus corridor) to 550 thousand passengers/day when adopting the monorail system (METRO; 2011).

São Paulo is a populous city that lacks public transport. In 2017, the average time for commuting from Cidade Tiradentes, located in the extreme east of the city, to the city center, was approximately 2 hours and forty minutes (SMUL; 2019).

In addition, the monorail had the improvement of the urban requalification process requirement, with favorable insertion by using a thinner and less impactful structure when compared to the implementation of the BRT at level (METRÔ 2011).

The Line 15-Silver project was conceived with 17 stations inserted in a layout of a medium line in the Southeast region, approaching neighborhoods and housing complexes, favoring the accessibility of the neighboring population, as shown in Figure 4. This line is also integrating with bus lines.

After the implementation and based on new demand assessments, it was necessary to design one more station (Ipiranga Station) at the west of the line, which will integrate with a railway line. This new integration will alleviate the demand for the 2-Green line, a subway system, which receives most users of the 15-Silver line in the integration with Vila Prudente Station, thus working as an alternative for passengers who wish to travel to the city center.

Figure 4: Line 15-Silver Layout

3.1 Implementation Phases

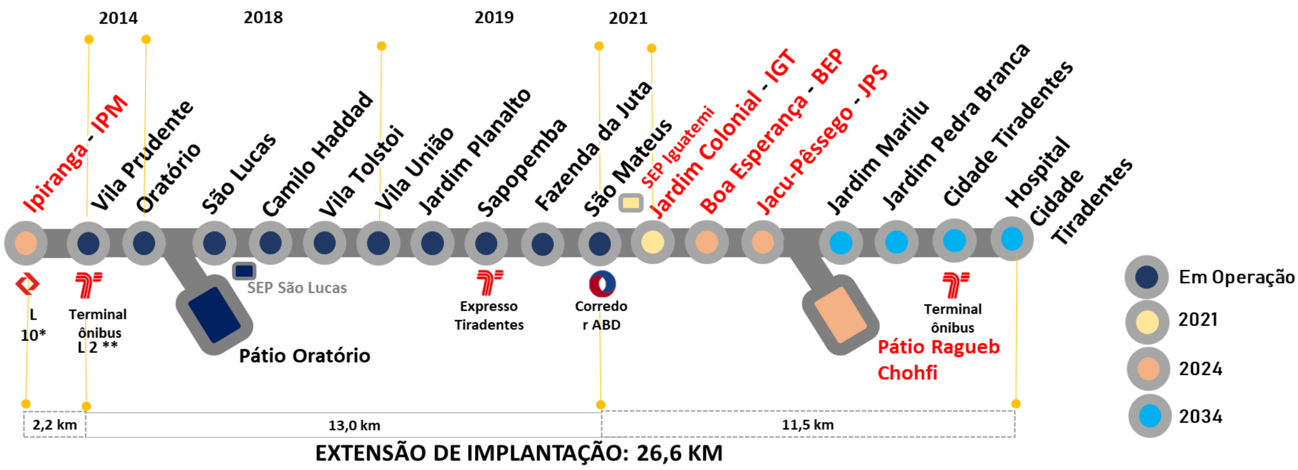

Figure 4: Layout Schematic and finishing estimative date of expansion activities

This line is being implemented in phases in accordance with the strategies of São Paulo State government and completion of the works.

The first phase, comprising the Vila Prudente and Oratório stations and the Oratório Maintenance Depot. It started the assisted operation on weekends, with passengers, at 2014 and entered full Commercial Operation in October 2016, covering 2.9 km of line.

The second phase, consisting of 4 stations (São Lucas, Camilo Haddad, Vila Tolstoi and Vila União) and 1 Primary power substation: assisted operation at 2018 and full Commercial Operation in January 2019.

The third phase, consisting of 4 stations (Jardim Planalto, Sapopemba, Fazenda da Juta and São Mateus): assisted operation at 2019 and full Commercial operation in January 2020.

The fourth phase, comprising the Jardim Colonial station and 1 Primary Energy Substation, will be completed by the end of 2021, totaling 14.8 operational km and 11 stations.

3.2 Demand

This line is being implemented in phases and its demand increases as it expands.

In addition to local users, many users that live in the extreme southeast of the city started to get off the bus and board the monorail to reduce the time to travel to their destination.

Figure 5 reinforces the idea of increase transfer to end line stations and to stations near other modes due to the presence of large bus terminals.

Recordes - Linha 15 - Prata			
Estação	**Entradas**	**Passageiros Transportados [1]**	**Data**
VPM	15.469	48.514	06/06/2019
ORT	12.816	12.816	07/04/2017
SLU	5.776	5.776	14/02/2020
CAD	4.164	4.164	19/02/2020
VTL	5.423	5.423	20/02/2020
VUN	13.688	13.688	21/08/2019
JPL	15.237	15.237	29/11/2019
SAP	7.943	7.943	18/02/2020
FJT	3.854	3.854	19/02/2020
MAT	17.081	17.081	19/02/2020

[1] Inclui transferências da Linha 2 - Verde para a Linha 15 - Prata na Estação VPM.

Figure 5: User records by day and station

However, the beginning of 2020 was marked by the COVID-19 Pandemic, which caused a significant impact on demand, affecting not only the Monorail, but the entire metro-rail transport system. This worldwide phenomenon has posed many challenges for transport system operators, who have been seeking to adapt to the new reality and prospects projected in this new scenario.

In the first half of 2020, the reduction in demand reached approximately 55%

The second half of 2021 has been showing a slight but consistent increase in passenger demand on Line 15-Silver, with projections indicating that demand will reach approximately 75% of the pre-pandemic period by the end of 2022.

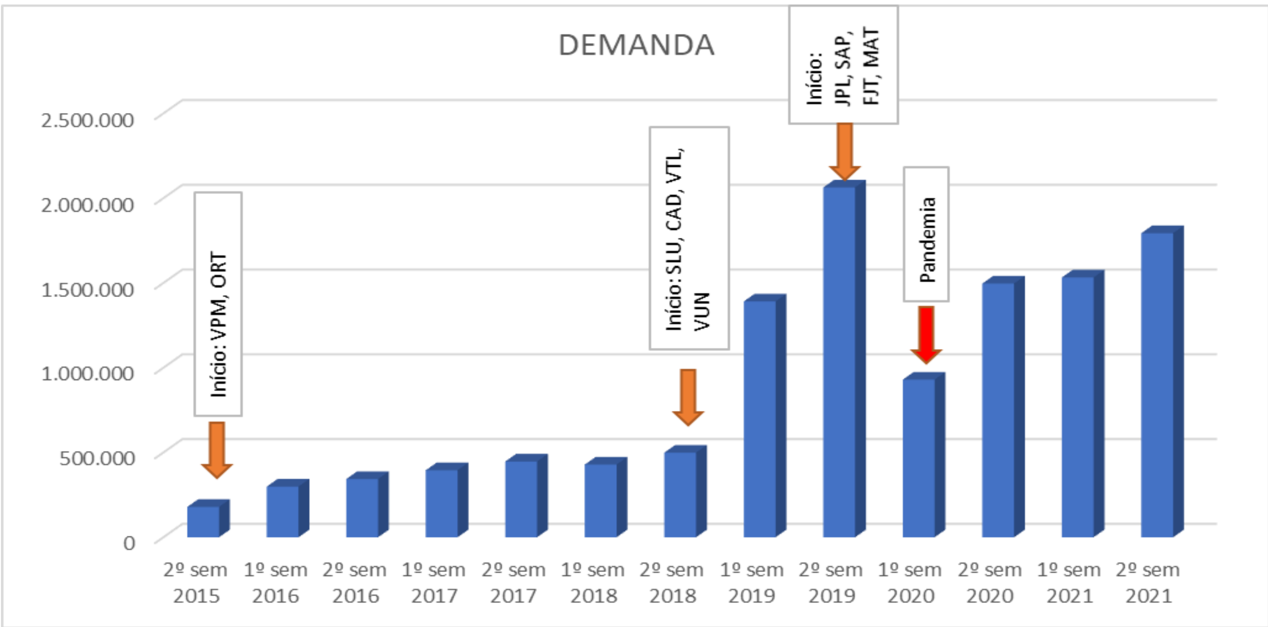

Figure 6: Line 15 - Evolution user demand and station operation start

3.3 Urbanization

Line 15 - Silver, installed at the center of Avenida Professor Luiz Ignácio de Anhaia Mello and Avenida Sapopemba, cuts through the districts that form the Vila Prudente/Sapopemba Subprefecture and São Mateus Subprefecture, which is the second most populous in the city of São Paulo (IBGE 2002).

The stretch covered is in a zone of polar centrality, which provides for the transfer of constructive potential and additions to the built-up area, thus providing for the densification in the centrality points and axes of the neighborhoods and around mass transport stations, as map of the São Paulo Regional Strategic Plan, figure 7.

Over the years, it is already possible to notice the change in the type of construction and occupation of space in this region. What was predominantly made up of one-story houses and popular housing developments is currently being modified by residential buildings and revitalized commerce.

Another important point in the implementation of the Line -15 monorail is the installation of landscaping and a bike path, under the rolling beams, along the entire length of the line. It is noticed that the population adopted this bicycle path as a place of leisure, turning the function of a bicycle path into a central median area for family, sportspeople, among others.

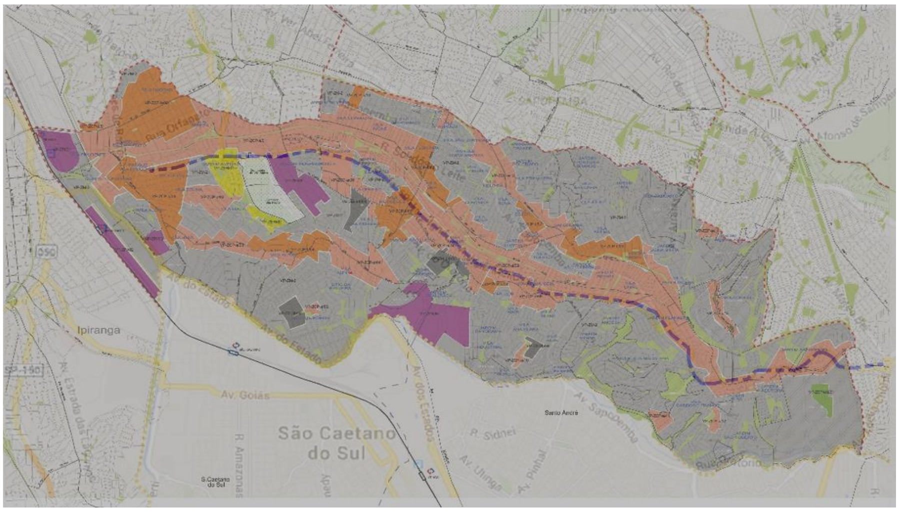

Figure 7 - Land Use and Occupation Map (modified) (PMSP; 2021)

3.3.1 Architectural and Landscape Design

All stations located between Vila Prudente and Jardim Colonial stations maintain the architectural design. They are characterized by having their implantations elevated in a central median along the avenues. They present aesthetic solutions in exposed concrete and steel with large glass fences, guaranteeing public spaces full ventilation and natural lighting, where the platform, technical walkway and mezzanine are developed, forming a single linear set. The platforms are central, 90m long and 9.90m wide to accommodate two operational ways, except for the São Mateus station which has two central platforms with the same dimensions for three operational ways, have a roof with an arched metallic structure, walkways emergency doors at the ends, automatic platform screen doors system for boarding/disembarkation throughout its length, escalators, fixed stairs and elevators. This equipment takes users to the mezzanine level, where accessible public restrooms, ticket gate lines, ticket booth, technical/operational area and connection to access bridges, technical building and, at Vila Prudente station, interconnect with Line 2-Green and Bus Terminals.

Station accesses are located on both sides of the avenues. They are equipped with escalators, fixed stairs, elevators, and bicycle racks.

Technical Buildings have functional configurations of the Master and Satellite types, that is, “ETO” for Technical/Operational Building (equipped with technical and operational rooms) and “ET” for Technical Building (equipped with technical rooms). These buildings accommodate the consumption and fire water reservoirs, medium and low voltage rooms, auxiliary transformer and rectifier rooms, diesel generator room, battery room, auxiliary ventilation engine room, offices, changing rooms, cafeterias and, on the roof, the resistor bank of the AARU Automatic Assured Receptivity Unit system. The external coatings are composed of paint, ceramic tiles and metallic “brise solil”.

The stations adopt Reurbanization-Landscaping concepts that integrate the surrounding landscape with architectural elements. Enabling the improvement of the quality of public spaces through integration with other modes - walking, bike paths and buses - generating environmental comfort and beauty, to ensure convivial "living" areas and green areas between the access stations and the road system adjacent.

Figure 8 – Oratorio Station - Line 15-Silver

3.4 CONSTRUCTIVE CHALLENGES

As previously mentioned, the Line 15 monorail operation began in 2014, with 10 stations only completed and enteraopened in 2019. Apparently, this is a long period for a line implementation, however, some local characteristics make this process more complex than planned.

3.4.1 Expropriation

One of the advantages of the monorail system is the reduction of expropriation when compared to other surface systems. On line 15, the main expropriations were made in the region of the stations and in specific adjustments to adapt the road system to ensure the minimum width required.

Although punctual, expropriation processes can become lengthy due to the legal processing time, the time to release the land if the resident is vulnerable or judicialization of the process due to financial discussions on the property's value.

3.4.2 Environmental Licensing

Brazilian regulations, monitoring and control of environmental licensing and activities throughout constructions are quite strict, sometimes bureaucratic, and can become an impediment in cases of archaeological assessment, as occurred at Vila União station, or on land with soil contamination.

3.4.3 Interference Relocation

Monorail is a typical elevated system modal and does not face the common problems and difficulties of underground works, however, there is a great risk of encountering interferences of various types, aerial or allocated a few meters deep.

Every subway project includes an interference registration phase, in which all registrations are searched through consultations with the companies or concessionaires that own and by evaluation through surveys and with the use of a ground penetrated radar.

Some interferences, known or not, can only be reset by their owner. This dependence on external activities, without the direct control of the Metro, can generate uncalculated delays for the project.

Despite all the effort to register, interferences that are not known are often found and that need to be reorganized to implement the work. In these cases, there is additional work to assess the best solution and proceed with the approval of this activity in the companies or concessionaires that own the interference founded.

3.4.4 Constructive characteristics

There are several constructive issues that must be considered as challenges in the implementation of a monorail system.

3.4.4.1 Transport and guide beams launching

The monorail guide beams are precast concrete pieces with a width of 0.69 m, a length ranging from 15 to 30 meters and a variable height from 1.60 m in the middle of the span to 2.05 m in the support (GIACOBBE et. al.; 2012). They are long and heavy pieces that require large equipment and vehicles to lift and transport them. This process involves extensive logistics for traffic in the city of São Paulo and authorizations from the Traffic Engineering Company.

The launch process must also be carefully studied to avoid any type of accident during its execution.

3.4.4.2 Restrictive tolerances / track regularity

Some requirements are very important for the monorail system. The permanent way in this system is the concrete beam that supports the entire modal. The dimensional tolerances applied to concrete parts are extremely strict to avoid damage to the undercarriage and discomfort to passengers. The main restrictions are related to width, superelevation, leveling and counter arrow.

These strict tolerances are not common in the usual activities of civil construction, used to working with limits above 5 mm, and can make it difficult to accept the permanent way when we assess undercarriage and passengers comfort requirements, causing rework or studies for a solution of potential problems.

This topic will be dealt with in greater detail in a specific article for this event.

3.4.4.3 Other Challenger

Other challenges in civil construction are related to high-performance precast concrete parts, finger plates and monolithizations.

Concrete parts can present, during operation, specific defects due to train movement, passage of tires through the beams, such as bubbles, cracks and displacements that must be treated to avoid loss of the useful life of the track structure and material undercarriage.

Fingers plates and their fixings are also elements that can cause problems in the systems operation due to leveling, concreting and screw failures.

These themes will also be dealt with in greater detail in a specific article for this event.

3.5 OPERATIONAL CHALLENGES

The monorail system poses specific challenges for operation and maintenance when compared with our expertise at conventional subway system. Among the challenges we highlight:

3.5.1 Train

Conceived to operate with tires on concrete beams, it presents new challenges for maintenance, whether in strict control of tire wear or in monitoring its operating conditions.

The interdependence of the correct functioning of the electric braking system with the operational performance of the trains, coupled with the technical limitations of the continuous use of the friction brake system, also impose strict operating requirements.

Issues related to the Monorail's dynamic envelope also impose strict control parameters with fixed installations along the track, this envelope has many different variables compared to the conventional subway (wind, tire, and others).

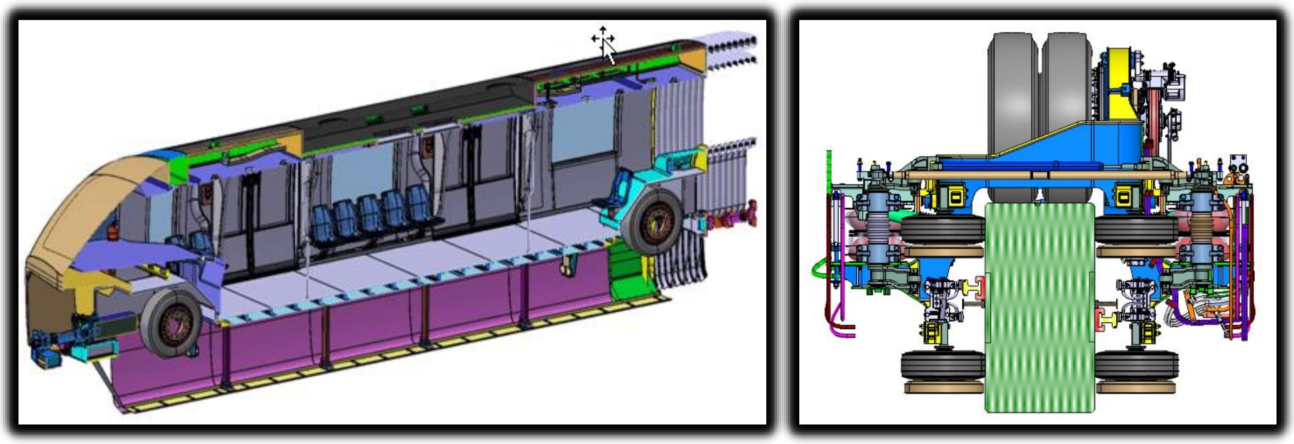

Figure 9 - Sectional view of a train car and detail of the bogie and track

3.5.2 Track Switches

The operational availability of the Track Switches, is essential to guarantee full commercial operation, and issues associated with the time to restore this equipment in case of failure are extremely critical for the operation. Because they are located on slabs along the track, with access only through emergency walkways, and with limitations imposed by the dynamic envelope and proximity to the power rails, the maintenance team actuation is sometimes only possible with the interruption of train circulation, causing inconvenience and cancellation of trips.

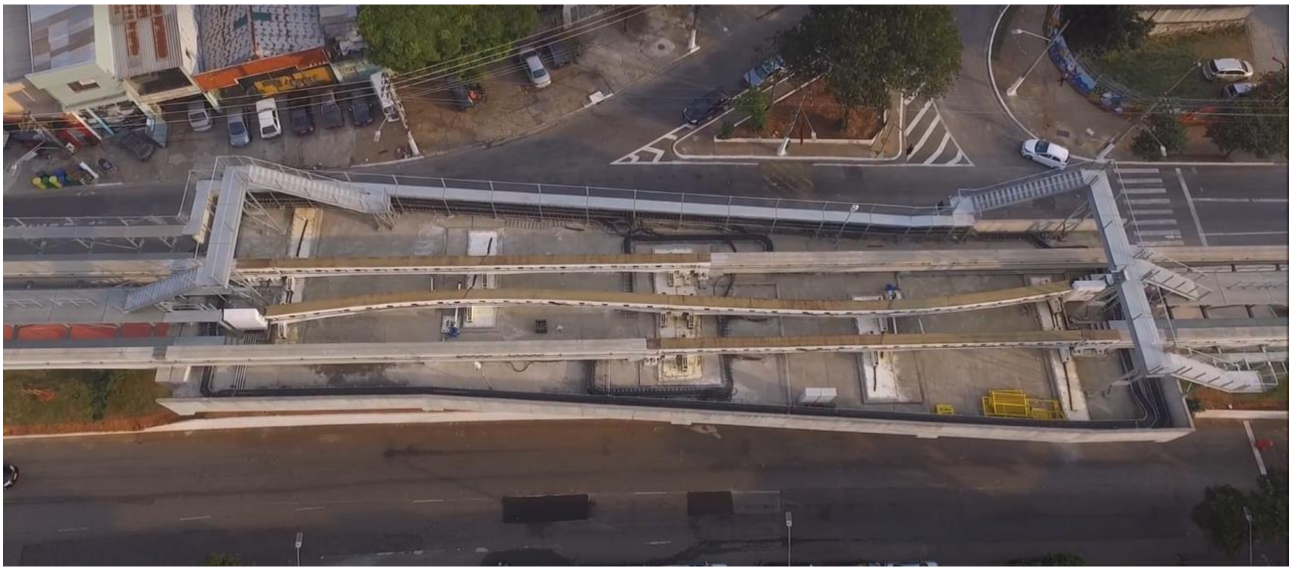
Figure 10 - Aerial View of the Trach Switch

3.5.3 Power Supply Rails

Given the constructive characteristics of the track and the electric power supply rails of the monorail, great challenges are imposed for the maintenance of this system, since there is a dependence on vehicles and special tools to enable periodic inspections on the rails on the external side of the beams, where there is no walkway for maintenance.

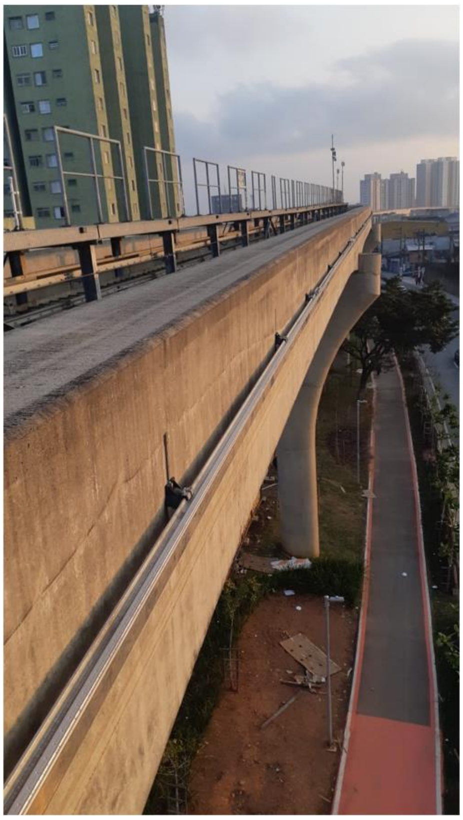
Figure 11 - Power Supply Rail – side without protection


Figure 12 - Power Supply Rail - maintenance protection

Maintenance must be extremely rigorous as the facilities are 15 meters high, on a busy avenue and cycle path.

3.5.4 Wind Monitoring

Another aspect of the Line 15-Silver monorail is the influence of wind action on the system's operation. For that, there is a wind speed monitoring system along the line, depending on the calculated values, there are actions and operating strategies that can, in the limit, interrupt train circulation.

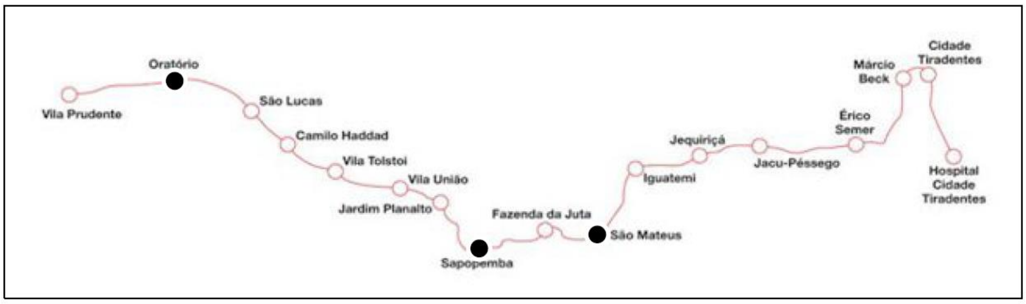

Figure 13 - Installation of Wind Monitoring Stations on Line 15-Silver Location

3.6 EXPANSION CHALLENGERS

By the end of 2024, we plan to open another 3 stations and a depot.

On the west side, the Ipiranga Station will be built, which connects to the railway line. The challenge of this stretch is related to the resettlement of part of a vulnerable community.

These processes are not common expropriations as they involve needy neighbors.

To the east, there are plans to build 2 stations and a depot. In this stretch, the avenue does not support the monorail implementation, for this reason, it will be necessary to carry out a greater expropriation to accommodate the modal and ensure the road system within the dimensions required by responsible authorities.

4 CONCLUSION

The seven years of monorail operation in São Paulo brought a great improvement in residents´s life quality of the city southeast. Travel time to the center has been significantly reduced.

According to the evaluation of users in a survey carried out by Metrô, 77% rated the services provided by the Line 15 monorail as very good and good.

The experience shows that we must pay attention to the care and strict requirements during the execution period, whether the construction and system's implementation, and the restrictions and challenges during the operation and maintenance period of this elevated system.

5 Acknowledgments

This work would not be possible without the valuable collaboration on several themes of friends and colleagues Ricardo Novaes, Débora Regueiro Gramani and Wilson Mitt.

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Company

Companhia do Metropolitano de São Paulo – Metrô

Website: http://www.metro.sp.gov.br/en/metro/about-us/index.aspx

Companhia do Metropolitano de São Paulo – Metrô was founded on April 24th, 1968. It is controlled by the State Government of São Paulo under the management of the Metropolitan Transportation State Secretariat (STM). It is responsible for the operation and expansion of the metro network and the planning of metropolitan passenger transportation in the Metropolitan Region of São Paulo.

The metro network of the city of São Paulo is composed of 6 lines, totaling 101,1 km of extension and 89 stations. It is integrated to several railway stations and the other modes of transportation in the city of São Paulo. It is currently operated by three different companies:

Metro São Paulo is responsible for the operation of four lines, totaling 69.7 km of extension and 62 stations.

There are 2 lines constructed by Metro São Paulo but operated under concession or PPP regime, totaling 31,4km and 27 stations.

In 2017, the metro network reached the mark of 1.3 billion passenger boardings, and Metro São Paulo was responsible for transporting 1.1 billion of those, standing out worldwide for the results obtained in the production and the quality of the public railway transportation of passengers.

To increase revenues, Metrô São Paulo structured a subsidiary and began to prospect consultancy services and services for the planning, implementation, and operation of public transport projects.

P16
Lessons Learned at Construction of Straddle Type Monorail of São Paulo – Line 15 Silver

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Civil Lessons Learned at Construction of Straddle Type Monorail of São Paulo – Line 15 silver

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ABSTRACT

The structure of São Paulo Monorail is basically composed of reinforced and prestressed concrete elements that are always susceptible to pathological manifestations of different origins and whose therapy will vary in complexity depending on the type. Additional challenges are identified when concerning about inspection and repairing of guideway beams, closure pour and accessory elements (finger plates and locking pivot) of monorail: lack of time for carrying out activities – only three hours in the early morning are available; restrictions on modifications to the original sections of the elements and, eventually, difficulty in accessing the damaged region for inspection and/or repair. Cracks, track misalignment, poor performance of accessory elements are the main problems that required the elaboration of correction procedures detailed along this paper. This experience was consolidated by recording a set of lessons learned that allows us to suggest some improvements in execution and design processes in order to minimize occurrences. With regard to concrete, could be identified the need of a better control of dimensional tolerances, temperature in the concreting process, and deflections in guideway beams. Some details were modified in the design of finger plates to make easier the casting of it (holes added to the base plate) and executive processes were changed to ensure alignment between base plate and finger plate, between finger plate and beam surface and between adjacent finger plates. It was evidenced the relevance of a prior study of define torque/tension ratio for bolts to guarantee the set performance.

INTRODUCTION

Line 15 - Silver of the Companhia do Metropolitano de São Paulo - Metrô was conceived in 2009 to be executed in the straddle type monorail modal with all the permanent track in concrete structures composed of guide beams and closure pours. The first section of this line was inaugurated in 2014, then with 2 stations, a maintenance and service yard and 2.9km long. Currently the line is 13 km long and 10 stations in operation and has another station under construction with an opening forecast for Oct/21. There are three more stations and a train parking lot in hiring.

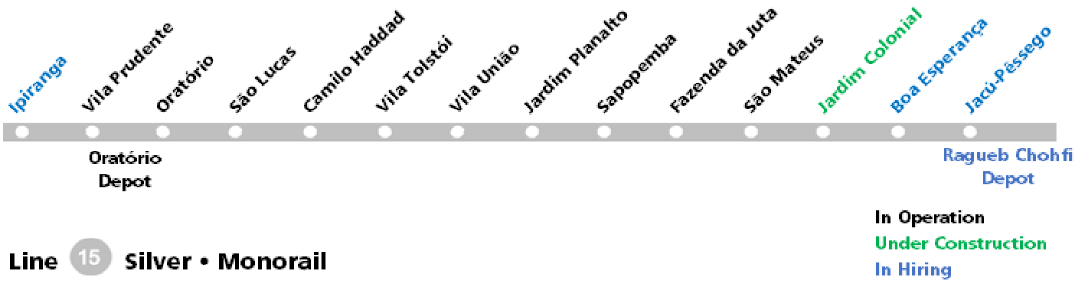


Figure 1: Stations of line 15 - Silver

The structure of the monorail track is made up of 120 m long modules separated by structural joints capable of accommodating longitudinal movements as a function of temperature and shrinkage. In these joints, we highlight the importance of two devices: the locking pivot, which minimizes the relative displacement, vertical and transverse, between adjacent modules and the finger plate, which promotes a better support condition for the cars when passing over the joint. Each module is usually composed of 5 columns and 4 beams that span the average span of 30 meters between them. For the execution of the module pathways, precast beams are used, initially positioned in isostatic condition on the columns and later joined together by concreting the closing sections and by prestressing the second phase. The width of the beams is defined as a function of the undercarriage in 69 cm and the concrete strength specified for its manufacture is 50 MPa.

Reinforced and prestressed concrete structures are susceptible to pathological manifestations of various origins and whose treatment will vary in complexity depending on the type. For the concrete and metallic elements that constitute the permanent route of the monorail, this complexity reaches a more advanced degree in view of the difficulties existing in carrying out any necessary repairs in these structures, such as:

- Short deadline for performing repair activities: the system operates every day of the week with night access "windows" from 00:30 to 03:30, thus preventing repairs carried out in the interface region with the lanes that require longer execution/cure time to be carried out;

- Restrictions on modifications in the original sections: because of the interface between the permanent track and undercarriage, it is not possible to change dimensional characteristics in the leveling (due to the impact with comfort, the interface of the undercarriage with the section of the track and with the energy rails, and impacts with the leveling of the platforms of the stations) and the width (due to the restrictions imposed by the trick of the undercarriage);

- Difficulty in accessing the damaged region for inspection and/or repair: lift platforms are required to inspect the external and lower face of the guide beam, whose assembly deals with restrictions due to the road and the central median under the line. We point out that Line 15 – Silver has metal walkways for lane maintenance, which allow access to the upper and inner side of the permanent lane. Inspection of finger plates sometimes requires disassembly made difficult by the weight of the plates.

Even with the executive care applied in the execution of the permanent pathway certain pathologies were observed in the executed tracing, such as cracks, concrete detachment, bubbles, punctual misalignments in the track, construction defects and performance deficiencies in accessory metal elements.

These pathologies required the elaboration of specific correction procedures that will be detailed throughout this article. Lessons learned within the PMO process implemented in the São Paulo Metro for treatment were also recorded, which generated improvements in reviews of projects and executive procedures that are being applied in the new stretches of track to minimize new occurrences.

MAIN TEXT

1 - CONCRETE

The project instruction IP-9.00.00.00/1A0-001 specifies a fck greater than or equal to 45 MPa with a cement water ratio of less than or equal to 0.45, having been adopted in a fck project of 50 MPa with a slump test of 220 ± 20mm, achieved by applying superplasticizer additives to the concrete still in the plant and before the release on site.

Based on IP-9.00.00.00/1A0-001 and projects, Executive Procedures are developed, and for the execution of the new excerpts, the procedures were revised to contemplate the lessons learned from the previous excerpts having incorporated several executive care and solutions applied in the operational stretch.

Some specificities relating to concrete will be addressed according to the type of verification and importance for the permanent pathway of the system.

1.1 - Bubbles

The existence of bubbles in the concrete occurs by trapping air in the mixture of the mass during the concreting process. An excess of bubbles can create voids in reinforced concrete and larger dimensions can affect the covering of steel bars. In the monorail system, bubbles can also affect the passage of undercarriage, wearing the train's tires and decreasing their durability.

Many bubbles are totally hidden by the cement cream of the concrete, however when the passage of the undercarriage begins in the concrete guide beams and closure pours, these shells break discovering the existing bubbles.

Figures 2 and 3: Appearance of concrete before after train passage

Even some bubbles that are already exposed on the concrete surface have in their perimeter a bark of cement cream that ends up being broken when the passage of the train begins, eventually causing bubbles that had a small opening when surveying the guide beams and closure pours after their disform end up having enlarged openings.

Thus, for the manufacture of new guide beams and concreting closure pours, a much more accurate control was carried out in the realization of the vibration of the concrete, so that it does not occur too much or with a short duration, in order to obtain a surface as free as possible from this pathological manifestation.

After the deformation of the concrete elements, a check is made on its surface with the realization of percussion along the entire region of the lane of the train tires on the sides of the guide beams and closure pours, in order to discover hidden bubbles and / or break the cream corners in the existing bubbles.

It was defined in a service execution procedure that all bubbles with a diameter greater than 37.5 mm should be treated on the concrete surface, and that in the lateral bearing tracks of the track the diameter to be treated should be from 12.7 mm, the maximum permissible value for apparent concrete bubbles, according to the presented in the initial technical proposal of the building consortium.

The repair procedure consists of the surface disruption of the inner bubble region and application of polymeric mortar. It is important to note that, after the application of the mortar, it is necessary to cure the repair (by means of wet or chemical cure), to avoid cracking in the mortar and creation of a new pathological manifestation.

1.2 – Cracks

The concrete has good strength to compression forces, however it is a material that has little competence to tensile forces, which are commonly predicted around 10% of its compressive strength. Thus, due to the various types of efforts that concrete structures are subjected to, there are rare cases where the structures do not undergo any cracking.

The structures of the permanent monorail track do not escape this rule, since when the guide beams are taken from the concrete forms, they undergo efforts when they move that generate some vertical cracks located in the region of its lower half, in view of the tensile forces that act at the time of movement, beams are hoisted by handles near each upper end.

In the production yard and storage of guide beams, they receive a first load of stress, which should close most of the cracks until then opened and, after the release of the beams and execution of the closure pours, a second load of pretension is applied for the consolidation of the modules.

However, several types of cracks were observed along the surface of the guide beams and closure pours with varied directions and openings. To evaluate the necessary treatments in these fissures, a study was elaborated that resulted in a technical report (RT-15.00.00.00/6J2-501), where the fissures were classified and the type of treatment was considered according to the opening of the fissures.

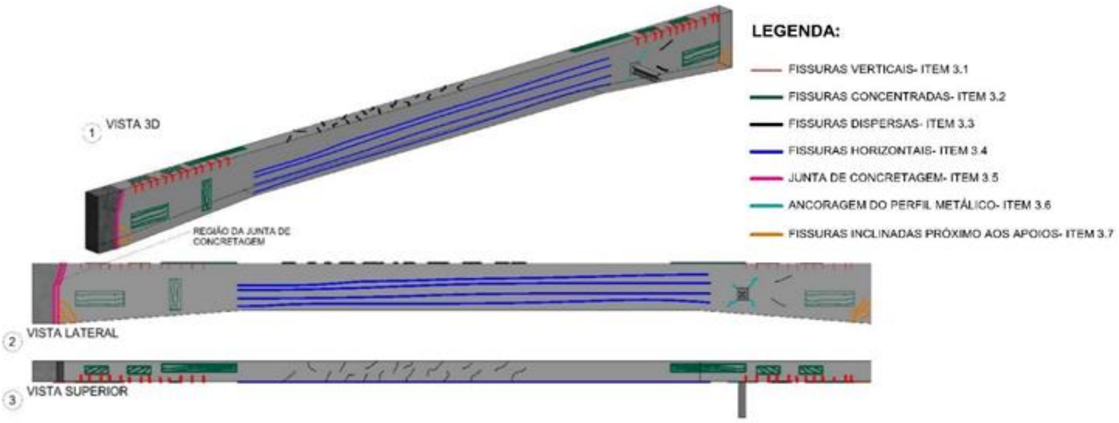


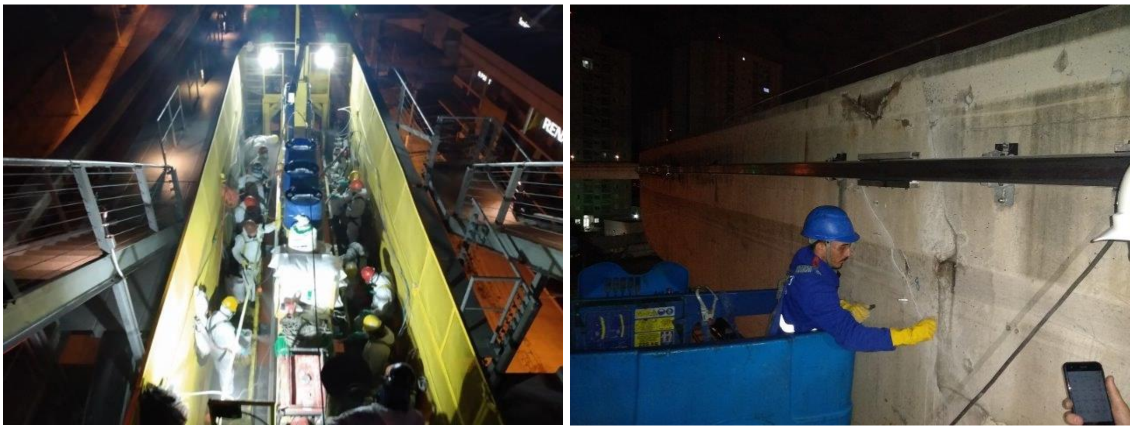
Figure 4: Types of cracks found in the permanent pathway as per RT-15.00.00.00/6J2-501

The actions to be taken were based on the opening of the cracks, where openings up to 0.2mm are considered small opening, requiring no treatment, openings from 0.2 to 0.6mm are treated with application of calcium acetate and liquid waterproofing based on silicates and resins that fills porosity by crystallization effect, and openings above 0.6mm are treated with the use of injection.

For the application of calcium acetate and waterproofing along the operational pathway, two structures were used on the pathway where the first structure contained drums with calcium acetate for application (cleaning and opening of concrete pores), and then the second structure brought the application of the liquid waterproofing agent.

Due to the difficulty of mapping all cracks along the 26 km stretch of roads (2 lanes with 13 km), the application was performed along the entire upper and lateral surface of the permanent track, with the care of protecting the insulators of the third and fourth rail, in view of the risk of loss of insulation and occurrence of electric arc.

For the execution of injections, it was necessary to verify the best positioning of the injector nozzles so as not to interfere in the passing region of the tires of the undercarriage.



Figures 5 and 6: Treatment of cracks from 0.2 to 0.6mm and above 0.6mm

For the manufacture of the new guide beams, a control of the cracks is being carried out when the post beams are stocked, after the first pretension with the beams still in the factory, and after closure pours and modulus prestressing to obtain a better knowledge of the causes of cracking.

A study that was initiated is the verification of the temperature of the concrete during its hydration, because high temperatures (above 70°C) may favor the occurrence of cracking by late ettringite, due to different hydration times of the cement, which can cause point tensile forces in the structure, since the guide beams are precast elements that use high performance concrete, which favors this occurrence.

Thus, before the concreting of the beams, thermocouples were installed to measure the temperature of the concrete during its hydration to evaluate the possible need for temperature control measures.

Figures 7 and 8: Control of hydration temperature of reinforced concrete

Preliminary results showed that the hydration temperature of the concrete reached values above 65°C in some thermocouples for times between 2h and 8h. With the prediction of the execution of new guide beams for the stretches Jardim Colonial – Jacú-Pêssego and Ipiranga - Vila Prudente, temperature studies should be deepened with the use of control measures, such as the use of ice in concrete, application of ice water by the sheaths during the curing of concrete, controls of exposure of the beams concreted to the sun, among others.

1.3 – Detachments

The concrete detachments observed in the permanent track of line 15 – Silver arose basically due to two situations: detachments in corners of the guide beam during the processes of moving the parts in the beam factory and at the time of its release on the columns, and detachments verified with the beginning of the passage of the undercarriage, concentrated in lifting handles and concrete corners in the joint with the plates of the finger plates.

Figures 9 and 10: Examples of detachment at the beam factory (left) and with the passage of the train (right)

To avoid detachments in the operations of moving the guide beams, special monitoring has been carried out in these activities, however due to the efforts to which the parts are subjected when removed from the shapes and/or hoisted, this type of problem can hardly be avoided. The repairs are performed with cementitious mortar application on the sides of the beams and with application of sulfoaluminate concrete in the top corners due to the loads of the undercarriage.

Lifting handles are devices composed of steel strands exposed to the top of the guide beams that are concreted next to the parts. Its application is the lifting of the guide beams of the shapes, and after this movement is carried out the cutting of the strands and filling the niches on the surface of the top of the guide beams.

In the first batch of guide beams the lifting handles were located in two lines along the upper surface of the guide beams, and the repairs of handles were carried out with the application of cementitious mortar, however after the release of the beams on the elevated track and beginning of the passage of the undercarriage, repairs began to undergo displacements, further repairs are required.

Considering that the São Paulo Metro lines operate every day of the week from 4:40 to 00:30, and considering the time of de-energization and energization of the track, there is a working time of approximately 3 hours to perform the breakage of the unplacated material, surface breakage, cleaning, application of bridge of adhesion and application of the material, there was no useful time for cement mortar to achieve satisfactory resistance to resist the passage of undercarriage.

Thus, tests were performed on the track with products that could meet the following characteristics: short curing time, high initial compressive strength, pullout resistance and that allowed the execution of the surface with a timely groove until the passage of the undercarriage. Epoxy and polyurethane materials, despite having good structural behavior and rapid healing, could not be applied due to the impossibility of performing the grooved surface on their surfaces. The only product that was able to satisfy all the conditions was a sulfoaluminate concrete.

In the new batches of guide beams manufactured, due to the impossibility of installing lateral lifting devices in front of the shape operating system, the lease of the handles was made by positioning them as centralized as possible on the axis of the top surface of the guide beams with cross-fixing in order to reduce the number and the repair surface required and seeking to leave the smallest repair surface in contact with the passage of the undercarriage possible.

Figures 11 and 12: New positioning of lifting handles and repair detail performed

2 – DIMENSIONAL

One of the most important aspects for the execution of a permanent pathway of a monorail system is the fulfillment of dimensional tolerances applied to concrete, which are extremely restrictive, since generally in the construction of concrete artifacts the Brazilian technical standards that deal with concrete are accustomed to working with tolerances equal to or above 5 mm.

In the manufacture of the guide beams were imported metallic shapes that have a system of millimeter adjustments by means of amounts topographically located by the measures provided in the project, which allow the conformation of spirals and horizontal and vertical curves, as well as execution of super elevations and different heights of sections as needed.

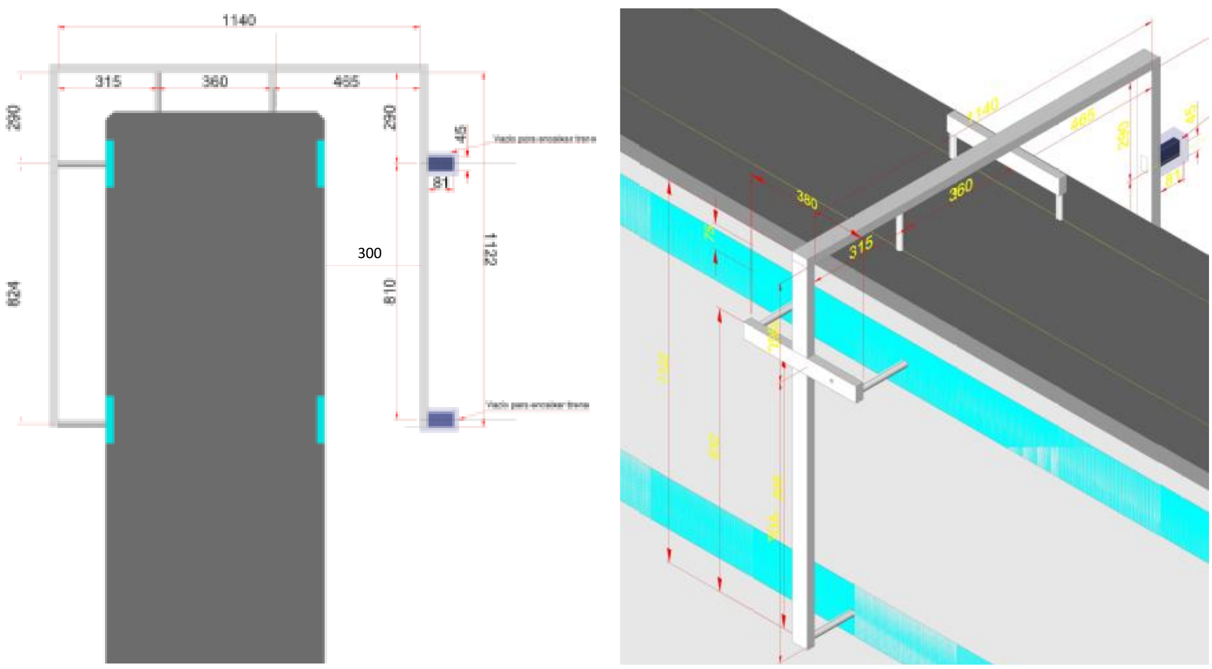
For the verification of dimensional conformity, specific procedures were elaborated for each type of measurement, culminating in approximately 450 dimensional measurements per guide beam and 60 measurements by closure pour, which are registered in a database for evaluation of correction measures in the concreted elements, evaluation of the quality of the shapes of the guide beams and closure pours, as well as creation of a qualitative evaluation of production.

2.1 – Width

The permanent track of Line 15 - Silver was designed with a width of 690mm with dimensional tolerance of ±3mm. To verify this measurement, a structure consisting of a measuring arm with laser tape measure coupled to the heights of the two side bearing bands was elaborated. This arm is leaning against one of the faces of the permanent track while the trains clear the measurements from the opposite side.

The verification is performed every 1.00 m in the guide beams and every 0.20 m in the closure pours and has geometric importance considering that its non-attendance can create additional efforts in the tricks of the undercarriage, thus reducing its useful life.

Another usefulness of this verification is the evaluation of the quality of the forms applied in the concreting, considering that variations in the values along the same range may indicate surface deviations in the sheet metal, as well as variations between values of different bearing ranges indicate a lack of parallelism of the plates of the shapes, thus being subject to interventions before the concreting of new guide beams and closure pours.



Figures 13 and 14: Measuring arm for checking the width of the permanent track

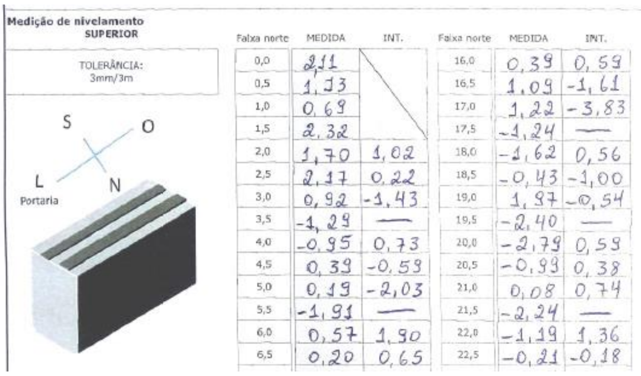
When width deviations are found beyond what is foreseen in the tolerance slate project, an internal evaluation is carried out to assess repair needs, which should take into account issues of amplitude of non-compliance with the stipulated values, location of the defect in the pathway (whether in tangent stretch, spiral curve or circular curve), if it is in the closing region between guide beams, considering that depending on the repair site there is a risk of creating a new problem.

For width defects measured above the expected upper limit, thinning is foreseen on the concrete surface by sanding along the bearing tracks. For measures smaller than the expected lower limit, an evaluation is made with the undercarriage supplier, and there has not been a need for repair so far.

2.2 – Leveling

The leveling of the guide beams has a tolerance of ±3 mm every 3 m and has as its basic function to avoid shakes in the undercarriage that may affect its durability and the comfort of the passenger's trip.

Its verification is being carried out with the use of a metal ruler next to a calibrated digital caliper, where the ruler is positioned on the surface along the upper and lateral bearing tracks of the permanent track (through which each line of tires passes) and the measurement is done by checking the distance between the bottom of the ruler and the concrete surface in the region where the largest opening is observed.



Medição de nivelamento
SUPERIOR

TOLERÂNCIA:
3mm/3m

Faixa norte	MEDIDA	INT.	Faixa norte	MEDIDA	INT.
0,0	2,11		16,0	0,39	0,59
0,5	1,13		16,5	1,09	-1,61
1,0	0,69		17,0	1,22	-3,83
1,5	2,32		17,5	-1,24	—
2,0	1,70	1,02	18,0	-1,62	0,56
2,5	2,17	0,22	18,5	-0,43	-1,00
3,0	0,92	-1,43	19,0	1,97	-0,54
3,5	-1,29	—	19,5	-2,40	—
4,0	-0,95	0,73	20,0	-2,79	0,59
4,5	0,39	-0,59	20,5	-0,99	0,38
5,0	0,19	-2,03	21,0	0,08	0,74
5,5	-1,91	—	21,5	-2,24	—
6,0	0,57	1,90	22,0	-1,19	1,36
6,5	0,20	0,65	22,5	-0,21	-0,18

Figures 15 and 16: Guide beam leveling check and verification record

To obtain more reliable leveling results, measurements are performed by interspersing the aluminum ruler, thus obtaining the evaluation throughout the alignment of each lane of the track.

This verification also allows to evaluate the quality of the shapes of the guide beams and closure pours, considering that variations in the top surface indicate a probable deviation of installation and alignment of the corners in the shapes, as well as may indicate failures in the execution of the grooved surface. When deviations in the leveling of the lateral surface are verified, these indicate deviations of flatness of the shapes that must be adjusted before the concreting of a new guide beam or closure pour.

The correction of leveling problems goes through two applications: when the variation is small the leveling can be corrected by means of a thinning of the surface with the use of sander. It should be noted that thinning on the top surface of the track can cause the loss of the groove, and its execution should be evaluated in advance with the supplier of the undercarriage.

When the grooved surface cannot be lost, or the repair amplitude is too large with the risk of loss of frame cover thickness, cutting, breaking and resetting of the surface is performed to meet the design parameters.

Figures 17 and 18: Roughing leveling correction (left) and with concrete fill (right)

2.3 – Superelevation

Superelevation is an inclination performed on a stretch of railroad track that has the function of equalizing the loads generated by the centrifugal force of the undercarriage when entering a curve stretch at a certain speed. In monorail systems this measure is also applied in the permanent track, having the guide beams and closure pours tipping percentages according to the radius of the curve and maximum speed allowed in the stretch.

The superelevation values are indicated in the executive projects of each guide beam by axes that are transmitted to the amounts of the concreting forms. The tolerance allowed in superelevation through the executive project is ±0.17° (±0.3%). Up to 15 superelevation measurements per guide beam are performed, depending on their length. In the closure pours, the superelevation checks are carried out with the guide beams positioned before the concreting of the closures, and after the new concreting verification is performed to evaluate the attendance to the design parameters.

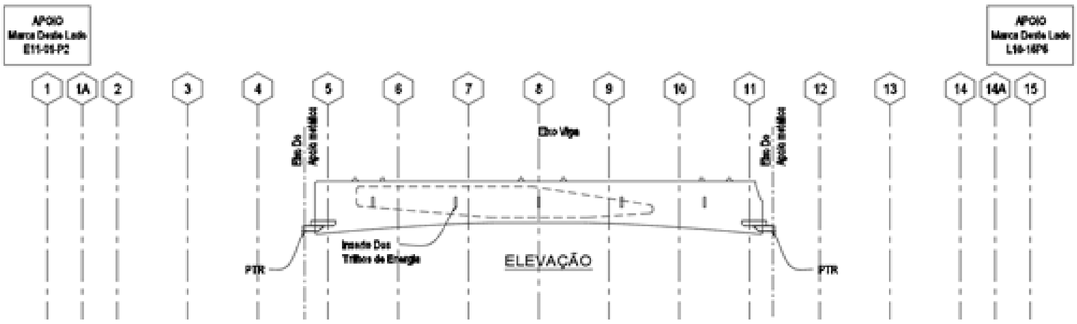


Figure 19: Example of amounts for superelevation check

Before concreting the beams, the shapes are checked with the help of a topography team with the use of a total station, and after concreting the verification is done using a digital inclinometer of 120cm in length and angular accuracy of ±0.05°. The superelevation check can detect possible problems of locking the forms of concreting, which must be corrected before the concreting of the next guide beam.

If any deviation is found in relation to the superelevation values, a check is performed with the designer and the supplier of the undercarriage for evaluation of correction and/or mitigation measures.

2.4 – Counter-Arrow

Counter-arrows occur in concrete structures due to the action of stress forces applied to meet the need to overcome larger spans with slender parts. This need is applicable in the permanent track of the monorail, where a set of prefabricated guide beams is located that must have limited sections to allow the passage of the undercarriage.

Although there are maximum values of counter-arrows provided in Brazilian technical standards for prefabricated elements of L/250 concrete (ABNT NBR 9062), this limit allows a maximum counter-arrow of 120mm in a beam of 30m length. Although the manufactured beams met this limitation of norm, there was a need to further limit these values, due to the impact that these counter-arrows cause on the undercarriage, considering that it causes greater vibrations.

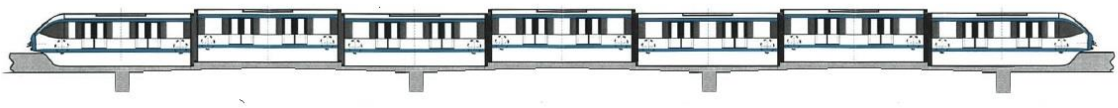


Figure 20: Distortion in the leveling of a composition due to the counter-arrow effect

Thus, the limitation of counter-arrows was adopted in 20mm, accompanied in 3 phases of execution of the permanent track, the 1st after the concreting of the guide beams before the looting of the form, the 2nd stage performed after the pretension cable was made in the beam yard, and the 3rd stage being carried out with the guide beam launched, after concreting the closure pours and longitudinally pretension.

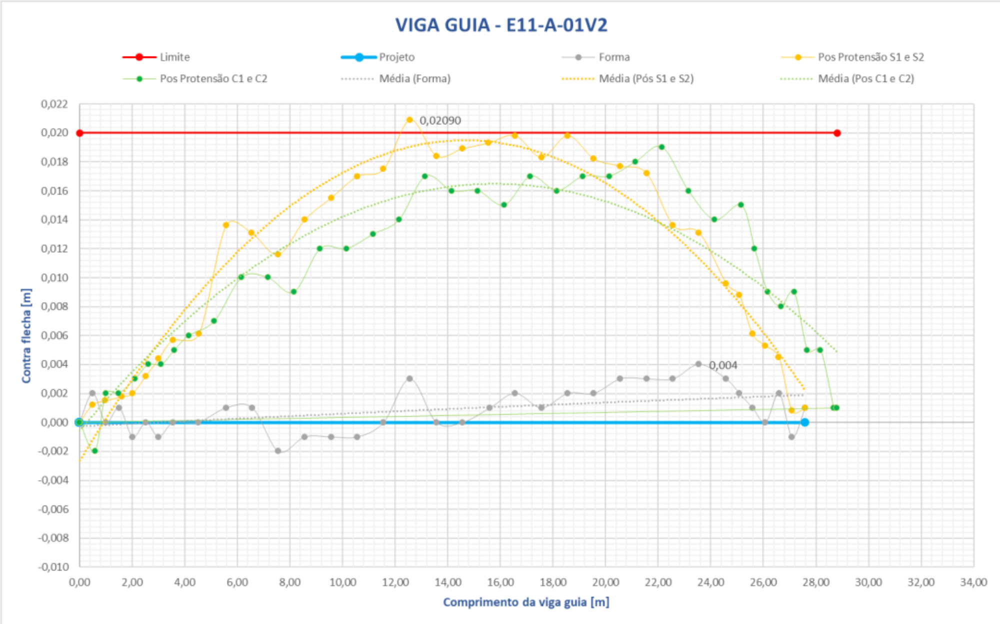


Figure 21: Counter-arrow tracking chart on new guide beams

If values above the limit established after the permanent pathway are verified, a counter-arrow repair is performed, which consists of cutting and breaking the surface concrete of the track, being filled with sulfoaluminate concrete, which has high initial resistance, fast curing and resistance to detachment, having a minimum fill layer of 10mm.

3 – FINGER PLATE AND LOCKING PIVOT

3.1 – Finger Plate

The finger plate consists of a set of metal parts that form a base box and toothed plates that has as function to allow the passage of the train with the necessary comfort in the regions of expansion of the permanent track. In the first stretch of track of Line 15 - Silver was applied a finger plate design that demonstrated that it could be improved, considering some difficulties encountered with the parts executed after the beginning of the passage of the undercarriage.

Thus, for the new stretches of route, a new project of this device was elaborated that contemplated the learning obtained until then.

Figures 22 and 23: Overview of the mounted finger plate set (left) and without the toothed plates (right)

In the boxes that contain the base plates of the assembly, angles were added to their sides that have as function to protect the edges of the concrete that interface with the finger plate, since some detachments of the concrete corner were observed in the joint with the plates toothed with the passage of the undercarriage, which had to be replaced. A hole has been included in the top plate of the upper finger plate assembly to allow the vibrator to enter, thus enabling the complete densification of the concrete under this assembly.

The nail architecture of the toothed plates applied on the monorail of Line 15 – Silver predicted plates with longer teeth while have greater spacing between the plates, since, as there is a massif of 120m track that suffers the effects of dilation and contraction due to thermal variation in the concrete, the values of the expansion joint can vary between 8 and 120mm.

The factory inspections of the new parts were carried out with much more dimensional criterion, especially in the verification of the flatness of the contact surface between the toothed plates and baseplate boxes, in order to avoid voids between them that could culminate in additional efforts in the anchorages with the passage of the undercarriage, as well as the alignment of the assembled assembly, that could not go more than 1mm.

This value was necessary since the tolerance of the track allows a variation of up to ±3mm, however it should be evaluated that there will be accumulated errors of manufacture and installation of the plates in the field, thus the smallest possible margin of error in the manufacture of the assemblies was sought.

It was observed that the weld applied to fix the anchoring assemblies on the plates of the base plate boxes created tensions on the surface of the plates that caused point elevations, culminating in voids between base and toothed plates and misalignment of the assembled assembly. Thus, after welding the anchoring assemblies, the surface of the plates is machining to ensure flatness.

An always constant concern of the São Paulo Metro is about the durability of its assets and facilities. Thus, in order to obtain a longer service life of the finger plate component, the parts have a surface treatment by means of hot zinc plating, yet it was possible to observe a point of improvement in this process, performing a previous blasting with iron shot on the surface of the parts that will suffer wear with the passage of the undercarriage, since the sandblasted surface allows for better zinc adhesion and a greater surface protection layer.

Another aspect in the case of galvanization was the inspection of the contact surfaces of the parts after bathing with a surface thinning to remove point residues of zinc on the surface of the parts that could contribute to voids between the plates and the misalignment of the set.

After the execution of the first track runs and the beginning of the passage of the undercarriage, constant torque losses were verified in the bolts of the finger plate assemblies, with little time of use. Specific studies were conducted aiming at the types of fixations of finger plates, which culminated in changes for the new stretches.

The sets of bolts with washers initially adopted were replaced by bolts with shorter length, longer thread length and with flanged heads to eliminate the use of washers and allow greater contact area of the bolts with the plates of the toothed plates. In the procedure of installation of the bolts, the application of friction reducer in the threads and base of the bolt heads was adopted to reduce the influence of friction on torque and final union force. To protect the interior of the upper anchorage assemblies from any water accumulations, a sealing material was applied between the base and toothed plates in the hole region, and after the installation of the bolts its contour was filled with the same material.

In the fixation of the parts was adopted the process of application of torque x angle using a digital torque wrench that has a program, where graphs of the torque application are generated, which are analyzed to evaluate the service to the union force provided for in the project.

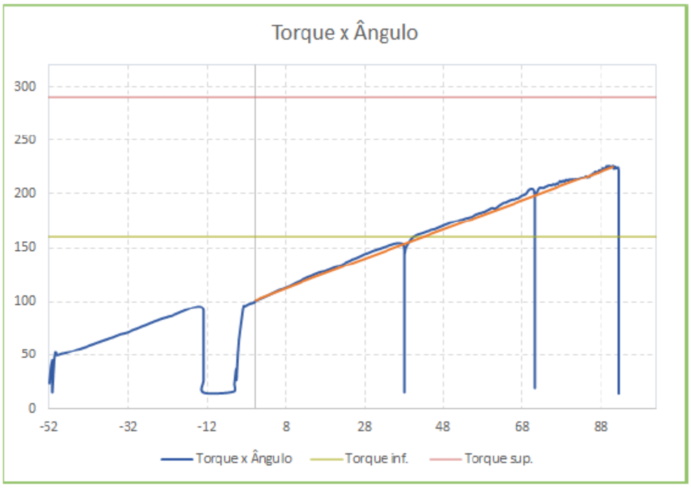
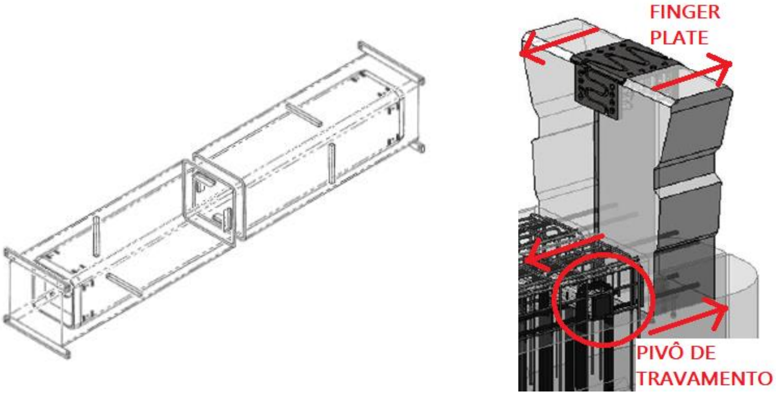


Figure 24: Torque graph x angle for fixing finger plate bolts

3.2 – Locking pivot

The system of execution of the permanent track of the monorail line 15 - Silver provides for the execution of concrete closure pours between spans of guide beams, and every 120 meters are provided the expansion joints that are born at the base of the columns, creating modules consisting of separate gantries. Thus, when the undercarriage travels through a given module, it suffers a vibration, while the next module remains at rest. In the passage of the train between two modules there is a risk on that moment there is a difference of position between them that can affect the structures of the train trick and consequently the comfort of the journey.

To soften this passage, devices are installed on the jointed columns, which perform the transverse locking of the track while allowing the amplitude of opening and closing of the joint due to the effects of the dilation/contraction of the concrete due to temperature variations. These devices, called locking pivots, consist of two gloves, each positioned on each side of the joint column, and an internal core composed of a metal glove filled with Graute.



Figures 25 and 26: Three-dimensional view of the locking pivot components and their dimensional effect on the pathway

The importance of dimensional control of the transverse clearance between the gloves and the internal core, which has a range limit of 0mm +0.5mm, is due to the fact that there is a risk of problems listed above with the passage of the undercarriage, as well as the risk of shock between the teeth of the upper toothed plates of the finger plate. In this way, the inspection work on this equipment has been strengthened, especially in the verification of this clearance.

CONCLUSION

The implementation of the Straddle Type monorail system in the city of São Paulo brought several challenges to the engineering and construction team of the São Paulo Metro, however, it is observed the success that this project represents, given that the monorail had the highest satisfaction score in a survey conducted with the public that uses this transport.

As they constitute a path for a system that requires precision, the design and fabrication of beams and joint elements require greater control and more restrictive tolerance limits than usually employed in concrete structures. Despite all the difficulties and needs for adjustments described, it was possible to meet these needs along the executed stretch and the distrust that initially existed in relation to this proved to be unjustifiable.

At all times the techniques of construction and execution of reinforced concrete of guide beams and closure pours are improved, yet there is always a risk of occurrence of pathological manifestations that require treatment to ensure the durability of the system, and they are recorded and treated according to the available techniques and availability of access to the route for repairs.

Regarding dimensional aspects, the verification is being carried out in all new guide beams and closure pours performed, thus creating a quality database, and allowing the evaluation of possible problems in the forms or procedures applied.

The metal components that are installed on the permanent track must be manufactured and inspected in the greatest possible detail, since manufacturing deviations are aggravated in the installation of the components, and the dimensional limits imposed by the project must always be observed.

The application of the torque x angle methodology with analysis of torque curves allowed greater success in achieving the necessary joining force in the fixation components of the finger plates, in view of the cyclic efforts to which they are subjected with the passage of the undercarriage.

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SPEAKERS AND COMPANY

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MBA-Railway Engineering/ IPOG, São Paulo (Studying)
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I´ve been working since 2010 on civil construction of Line 15 - Silver at Companhia do Metropolitano de São Paulo, responsible for checking civil works, quality monitoring of guide-beams and closure pours, and component factory inspection of finger plates and locking pivots.

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Company

Companhia do Metropolitano de São Paulo – Metrô

METRÔ

Website: http://www.metro.sp.gov.br/en/metro/about-us/index.aspx

Companhia do Metropolitano de São Paulo – Metrô was founded on April 24th, 1968. It is controlled by the State Government of São Paulo under the management of the Metropolitan Transportation State Secretariat (STM). It is responsible for the operation and expansion of the metro network and the planning of metropolitan passenger transportation in the Metropolitan Region of São Paulo.
The metro network of the city of São Paulo is composed of 6 lines, totaling 101,1 km of extension and 89 stations. It is integrated to several train stations and the other modes of transportation in the city of São Paulo. It is currently operated by three different companies:

Metro São Paulo is responsible for the operation of four lines, totaling 69.7 km of extension and 62 stations.
There are 2 lines constructed by Metro São Paulo but operated under concession or PPP regime, totaling 31,4km and 27 stations.
In 2017, the metro network reached the mark of 1.3 billion passenger boardings, and Metro São Paulo was responsible for transporting 1.1 billion of those, standing out worldwide for the results obtained in the production and the quality of the public railway transportation of passengers.
To increase revenues, Metrô São Paulo structured a subsidiary and began to prospect consultancy services and services for the planning, implementation, and operation of public transport projects.

P17
Panama L3 Monorail Project: A New Extensive Transportation Solution for Growing Cities

ENZO CARPANETTI, HIRABAYA YOSHITAKI, GIANLUCA GALLO, MARINO TORRE / HITACHI

INTERNATIONAL MONORAIL ASSOCIATION

PANAMA L3 MONORAIL PROJECT: A NEW EXTENSIVE TRANSPORTATION SOLUTION FOR GROWING CITIES

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Abstract

The Monorails system are modern elevated automated Transportation solutions.

This solution has been adopted for a new important passenger communication in Panama City.

To alleviate this problem the Government of Panama established the Secretaria del Metro de Panama (SMP) who has drawn up a metro network plan consisting of new metro lines, one of these is the: .

- *Line 3 is for the west side of the Panama Canal, to connect Panama City and the suburban areas such as Araijian and La Chorrera.*

The Metro Line-3, is to connect the east and west of the canal and is expected to improve the public transport system.

Lying east and west and linking three districts of Panama Province: Panama District, Arraijan District and La Chorrera District, Line-3 reaches a total length of more than 30 km.

Line-3 is divided into two stages:

- *Phase-1 is a 26 km section from Albrook station to the Depot with 14 stations*
- *Phase-2 is an extension of the line toward La Chorrera with 3 stations*

The first phase line is approximately 26 km in length with 14 stations.

The system is designed to allow a transportation capacity of 20,000 passengers/hour, with a train configuration consist in a 6-car solution, with CBTC control and this solution will be the state of the art a modern monorail technology.
Technical difficulties and solution will be

INDEX

Acronym

AC	Alternating Current	MVB	Multifunction Vehicle Bus
AMCP	Panama City Metropolitan Area	MPSA	Metro de Panama
ATC	Automatic Vehicle Control	NMS	Network Management System
ATO	Automatic Train Operation	OCC	Operation Control Centre
ATP	Automatic Vehicle Protection	O&M	Operation and Maintenance
ATS	Automatic Vehicle Supervision	PA	Public Announcement
BCU	Braking Control Unit	PID	Passenger Information Display
CBTC	Communications Based Train Control	pphpd	Passengers per hour per Direction
CC	Carbon Controller	PS&TP	Power Supply and Traction Power
CCTV	Closed Circuit Tele Vision	PSD	Platform Screen Door
CCU	Central Control Unit	PSIS	Passenger Security Information System
CU	Control Unit	RAM	Reliability, Availability and Maintainability
DCS	Data Communication system	RAMS	Reliability, Availability, Maintainability and Safety
DCP	Driver Control Panel	RTT	Round Trip Time
DCU	Door Control Unit	RTU	Remote Terminal Unit
EB	Emergency Brake	SA	Service Availability
ECP	Emergency Call Point	SIG	Signalling
EDC	Emergency Driving Console	STES	Station Train Emergency Stop
EPCH	Emergency Power Cut Off Handle	SW	Software
ESS	Emergency Station Stop	TIS	Train Information System
ESP	Emergency Stop Plunger	TLC	Telecommunication
FDC	Field Device Controller	TOD	Train Operator Display
GoA2	Grade of Automation 2	TPS	Traction Power Substation
HW	Hardware	TSR	Temporary Speed Restrictions
I/O	Input/Output	TTC	Train Traffic Controller
IDS	Intrusion Detection System	UPS	Uninterruptible Power Supply
ICCS	Integrated Communications and Control System	VHMI	Vital Human Machine Interface
IXL	Interlocking	WS	WorkStation
KVM	Keyboard Video Mouse switch	WSP	Wayside Standard Platform
LAN	Local Area Network	ZC	Zone Controller
LCD	Liquid Crystal Display		
LCP	Local Control Panel		
LRU	Line Replaceable Unit		

1 GENERAL DATA

1.1 GENERALITIES

Due to current population levels in the AMCP (Panama City Metropolitan Area), the very restricted growth capacity of the existing AMCP road system, due, in part, to its narrow/elongated configuration and the continuous increase in its motorization rate, Metro de Panama (MPSA) conceptualized the monorail type system as a modern, efficient, safe and environmentally friendly mass transit system for the AMCP.

The mobility conditions in the western sector of the AMCP (from Albrook Station to Arraiján District) are currently very precarious, especially in peak periods, it is necessary to continue the integration of the aforementioned mass transit system.

Therefore, MPSA has proposed and defined as one of its priority goals the investment and implementation of management measures to serve and provide the eastern sector of the AMCP with a monorail-type public transit system, with a level of service and capacity adequate to the demands and growth of the western sector of the AMCP.

This gives rise to the Line 3 project of the Panama Metro, which in its first stage will have a length of twenty-four (24) kilometers of elevated track and will have fourteen (14) stations, located in the points of greatest concentration, such as Albrook, Balboa, Panama Pacifico, Loma Cová, Arraiján, Arraiján Mall, Burunga, Nuevo Chorrillo, Cáceres, Vista Alegre, Vista Alegre 2, Nuevo Arraiján, San Bernardino and Ciudad del Futuro.

MPSA has opted to implement a high capacity Monorail type component oriented towards to the West sector of AMCP, integrated physically and tariff-wise, to the rest of the public collective transportation system of Panama City for the flexibility of the Monorail system in its slopes and curves.

The mass transit system foreseen for the Metro de Panama-Line 3 project is an elevated two-way straddle-type monorail system. Such system consist of highly automated trains, with the on-board presence of a ride attendant (GoA2 automation level according to European Standards).

The operating system is based on a fully automatic vehicle control system known as the **C**ommunication **B**ased **T**rain **C**ontrol (CBTC).

The regular operation service of Panama-Line 3 monorail will be 365 days-per-year, 19-hours-a-day (from 5.00 a.m. to 0.00 a.m.).

The system is approximately 24 kilometres, elevated at approx.20 m from ground level and in tunnel to underpass the channel.

The Metro de Panama-Line 3 connection includes 14 stations (2 terminal, 12 intermediate stations), and 2 evacuation towers.

The design include 5 additional stations that will be delivered during the second-and third phase of the project.

A side track located past the 14^{th} station leads to the depot/workshop building area that is at ground level.

The system presents the following essential features:

- the transportation capacity is up to 18.000 ppdph;
- each vehicle is set with couplers; the revenue service configuration is composed by a total of six car per train;
- the total train length is around 90 m.

The entire system will be controlled from an Operational Control Centre (OCC), which is located along side that of Line 1 and Line 2, Albrook. A back-up OCC will be provided closely to Panama Pacifico Station.

Control Operators have the facilities to overview the system conditions and have access to the detailed status of apparatus and vehicles.

The technological subsystems are distributed along functional areas with the aim of ensuring the automation of the entire System.

For this purpose, the automatic train control system assures the efficiency and the safety of the movement of vehicles through the combination of elements located on the trains, wayside (stations and line) and at remote central facilities.

Within the above mentioned subdivision, each area is composed of several subsystems in charge of train control, data acquisition and supervision, platform gates control, along with the transmission networks used to communicate within the entire monorail system and allowing the safe movement of the vehicles.

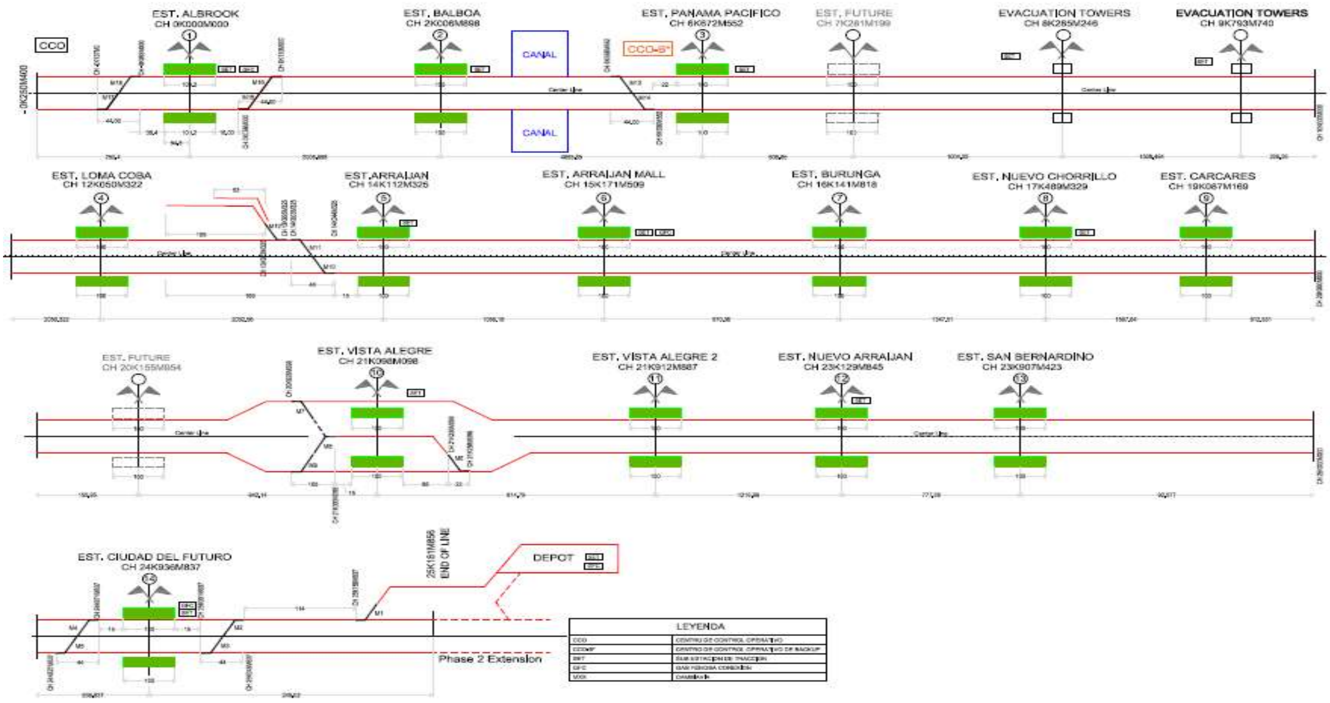


Figure 1 Track Schematic Plan

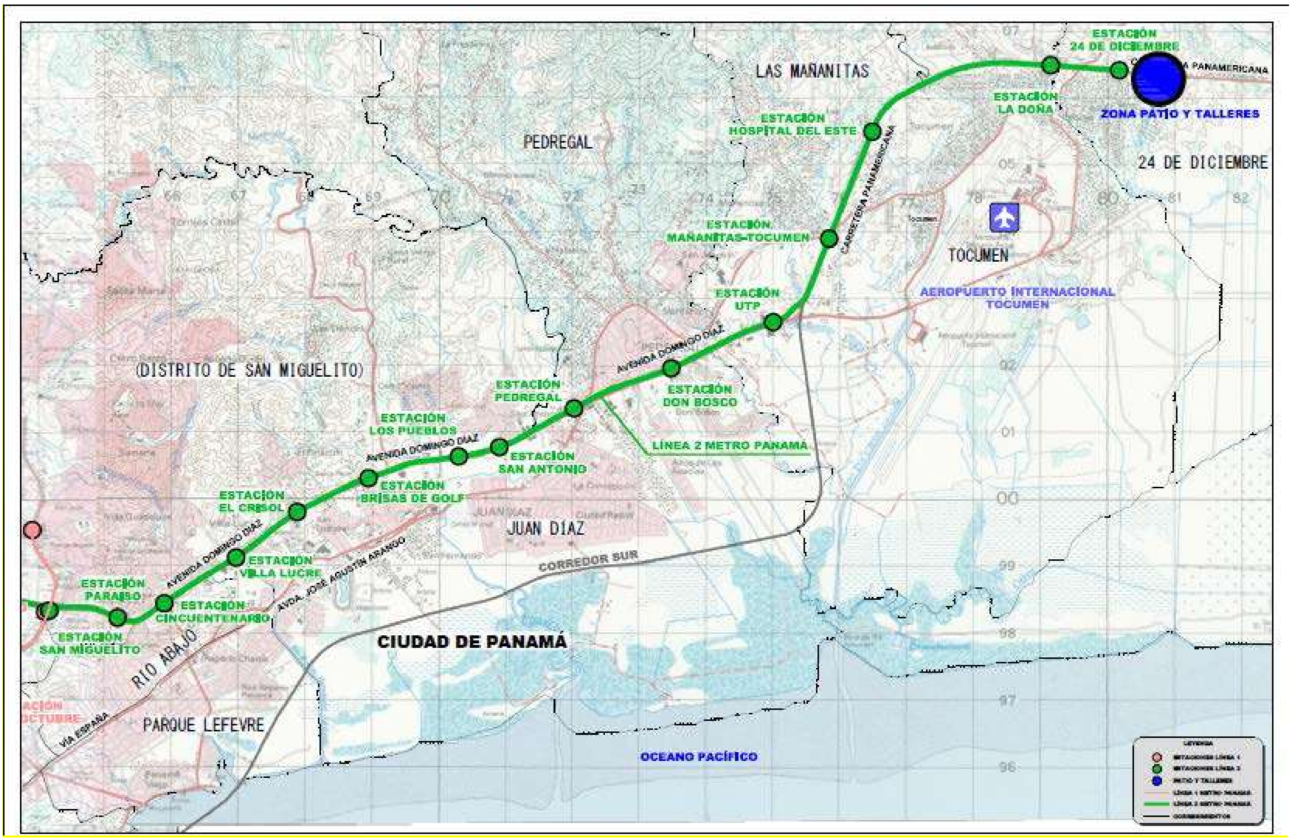


Figure 2 Site Plan

The centralized control is achieved through 3 main control sub-systems:

- ATC - Automatic Train Control;
- SCADA – Supervision Control Data Acquisition
- TLC - Integrated Communication Control System (ICCS).

The implemented hardware and software architecture of the operational components of each system shall be capable of future expansions and further technological development.

The maintenance and storage functions will be executed at the Depot area.

1.2 OPERATION

An "automatic operation" is provided due to the high requirements concerning reliability and performances, in particular:

- stopping accuracy+/- 35 cm a pre-defined distance limit, due to the presence of platform screen doors in the stations;
- Optimized travel times.

Solutions to ensure passengers safety are:

- automatic sliding half-height doors are part of the system delivery;
- doors control system certified SIL4.

In case of inaccurate positioning of a train in a station (over or undershoot), the vehicle and station doors may only be opened automatically when a minimum opening width is left between vehicle and platform doors.

The six cars service train configuration is:

- One trailer car (head car);
- Five motor cars (including tail car).

The proposed system is designed such that the requested passenger capacity can be met with the requested operational headway using the six cars train composition.

By definition, the headway is the elapsed time between the same part of consecutive trains (both running in the same direction on the same guideway), measured at any given point on the guideway.

During normal operation, all trains on the same route will operate at a continuous and nominally equal headways; the same will be valid for all trains on different routes that share a common guideway track section.

The required basic line operation concept sees trains running from station 1 to station 14, and back (i.e. whole route, or Large Loop Operation).

The requested operational headway ranges from 3.30 minutes during rush hour (time slot: 6 to 7 a.m.) to 12.00 minutes during the supposedly least congested hours (from 11 p.m. to 0.00 a.m.).

In addition to the whole route operation, a shorter route operation "Small Loop" can be executed, namely from station 1 to station 10 (Vista Alegre Station): such is indicated as the Eastern route, or the Small Loop Operation.

1.3 DEPOT AND STABLING AREA

The depot area is located on the upland area close to the Ciudad del Futuro station in order to avoid criticalities connected to flooding events. This will permit potential future eastbound expansion.

From a global perspective, the depot area layout has been defined by keeping the following main criteria into account:

- allocation of different Depot functions to physically separate sites;
- optimization criteria for movement schedule both inwards-outwards and within the area;
- separation between circulation routes in automatic and manual mode;
- access to the different functional areas made possible via redundant access routes; reduce the condition of single point of failure prevent train movement toward the mainline.

1.4 GENERAL ARCHITECTURE

From the conceptual point of view, the System Architecture is organized in 3 main areas, namely:

- Centre;
- Wayside;
- Vehicle.

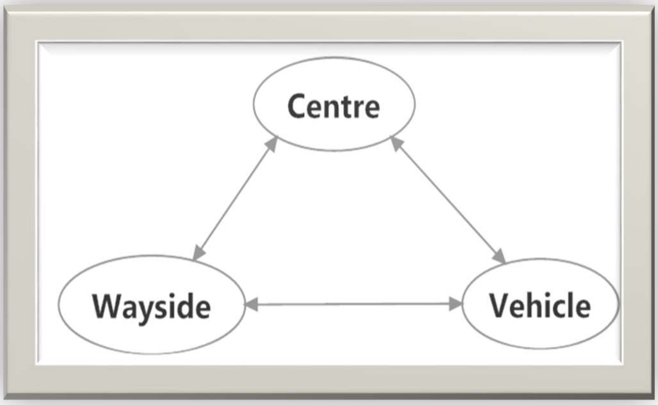


Figure 3 Architecture

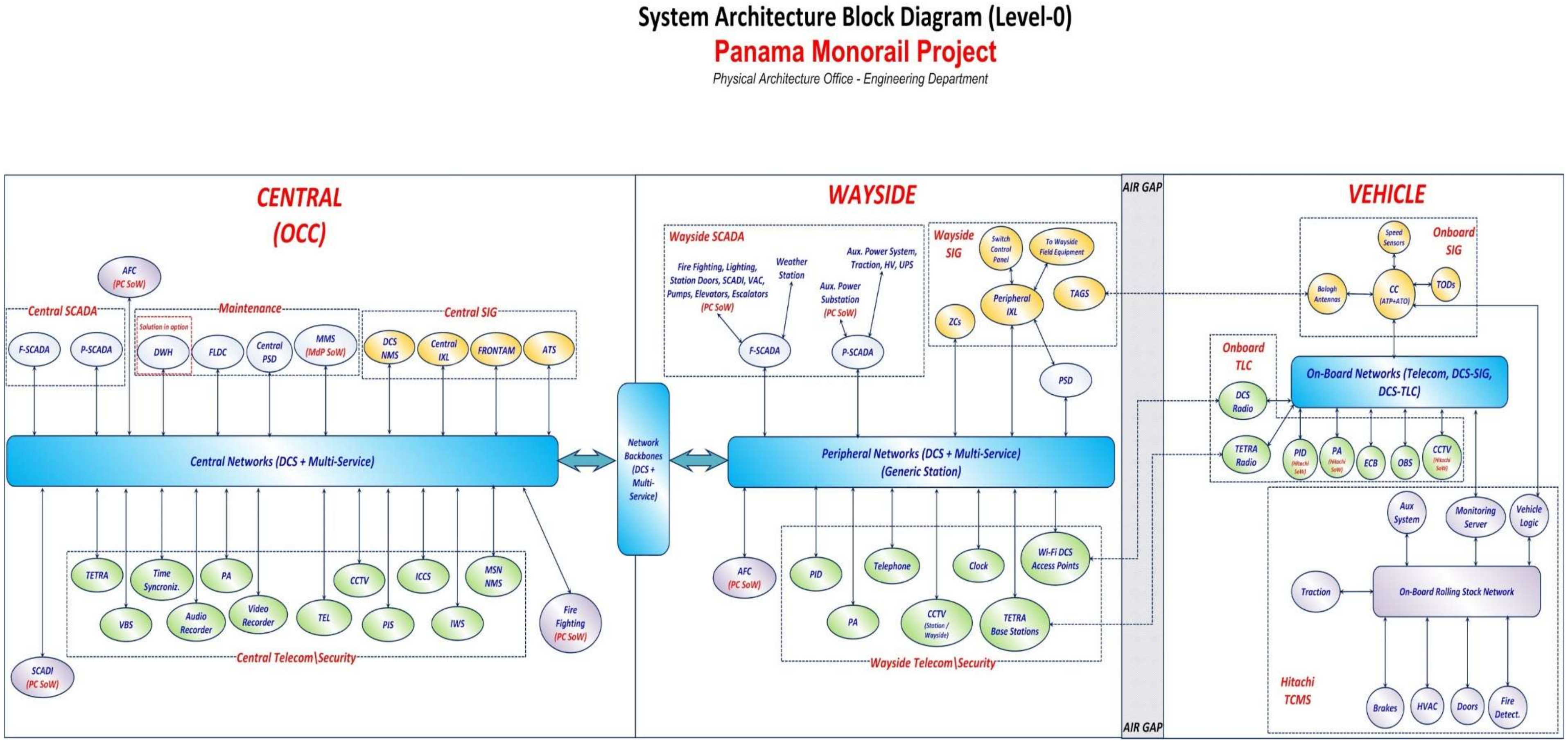


Figure 4 System Architecture Block Diagram

1.5 PERFORMANCES

The Inter-station trip times and turn-back times have been evaluated based on propriety Hitachi software "Presto". The software platform enables the development of a model for the network and traffic characteristics.

The algorithm is based on the dynamical analysis of vehicles' motion and it allows the continuous simulation of the "mechanical state" of the trains in any point of the line for all the phases of motion.

The results of the mechanical simulations are referred to vehicles running at the normal load (AW3) and stopping at each station using the defined dwell times.

In order to calculate the RTT, the running times have a regulation margin. The minimum headway will be evaluated by using those running times and considering a vehicle fleet of 24 operation vehicle.

The Round Trip Time is composed by different parameters: the total dwell time, the turn-back time and running time.

Total Dwell Time is:

$$\textit{Total dwell Time}_{E1\text{->}E14} + \textit{Total Dwell Time}_{E14\text{->}E1} + \textit{Dwell Time at terminals} = 850\ s$$

Total time necessary to complete the turnback operation is calculated with the following formula:

Turn-Back Time = ArrivalTimeT2-ArrivalTimeT1=DepartureTimeT2-DepartureTimeT1= 120 s

Namely, the turn-back time is defined as the minimum distance, in terms of time, between two consecutive trains at the terminal station.

With reference to the values reported in previous sections the round trip times for Line 3 is the following:

RTT = total dwell times + trip times + turn back times = 5252 s

Considering the fixed size of 24 operation vehicles fleet, it is possible to evaluate the Peak Hour Headway during the first stage of operation as follows:

RTT/OperationFleet=PeakHourHeadway= 219 s

The Peak Hour Headway value is rounded up to 220s.

Considering that for AW 3 load (6 passengers/m^2) at the train capacity is 1000 passengers, the line capacity related to this headway is equal to:

*3600/PeakHourHeadway*TrainCapacityatTheNormalLoad (AW3)= 16,363 pphpd*

The commercial speed is the average speed of trains from departure (start of the train movement) from one terminal to the arrival (train stopped at platform) to the opposite terminal, during business day peak hour and under normal weather conditions.

The commercial speeds (E1-E14) are:

- ~ 37 Km/h considering a regulation margin of 5 sec/km;
- ~ 38 Km/h considering a regulation margin of 5 sec for each interval between stations.

2 VEHICLE

2.1 VEHICLE CONFIGURATION

The following figure shows the Panama Line 3 Vehicle solution main characteristic:

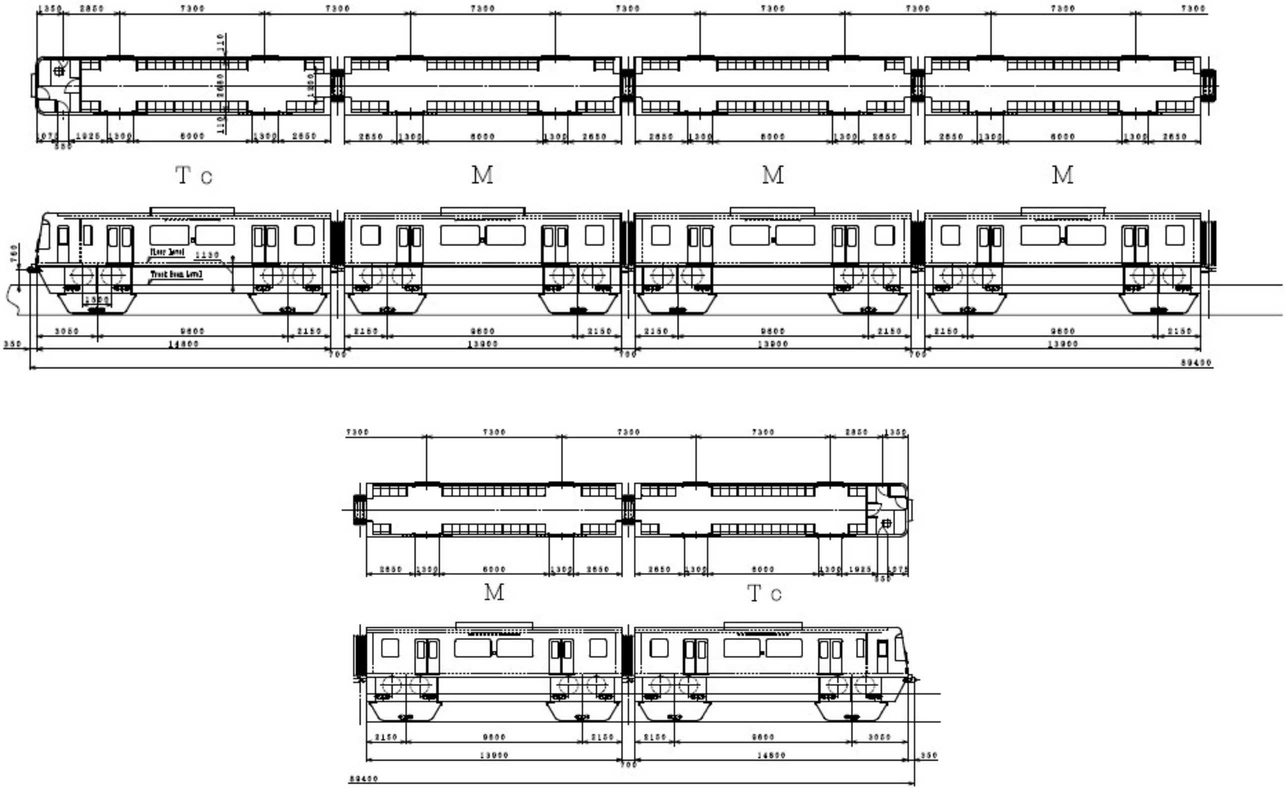


Figure 5 Panama Vehicle Layout

The proposed vehicle consists of 6-cars-double-ended vehicles articulated type with doors on both sides, with passenger capacity of ~**1000 passengers** in AW3 load configuration.

The system is automatic moreover the vehicle is fitted with a drivers cab at each end so it can be driven, in case of particular conditions, in both the running directions.

One manual coupler at each end allows two vehicles to be used only in case of rescue operations.

The following scheme shows the bogie vehicle configuration:

TC1		M1 –M2 – M3 - M4			TC2
Trailer bogie		Motor bogie	Motor bogie		Trailer bogie

Table 1 – Panama Vehicle Bogie Configuration

2.2 OVERALL PHYSICAL DIMENSION

The Panama Vehicle overall dimensions are:

Longitudinal length of car (length between centre of gangway)

Tc cars (Tc1 and Tc2): 15,500 mm   M car (M1, M2, M3 and M4): 14,600 mm

Length & Width of train (length between contacting surface of coupler)

Trainset of 6 cars: 89,400 mm

Width of car body: 2,900 mm

Maximum width: 2,980 mm

Height of top of car from running surface of track beam: less than 3,810 mm

Total height of car: less than 5,550 mm

Height of passenger room: 2,050 - 2,200 mm

Side sliding doors of passenger room

Number of side sliding doors: 2 doors per side of each car

Width of side door: 1,300 mm

Height from floor to doorway top: 1,900 mm

2.3 CARBODY

The car body is extruded aluminium and aluminium plates.

These aluminium materials are jointed to each other by welding for comprising light weight car box structure.

The car body is full comply with the functional and technical requirement required by the Metro of Panama Line 3.

The sub-assemblies, components and parts designed by modular concept for easy construction and maintenance.

Protections in the passenger doors for the raindrops are provided.

2.4 BOGIE

The monorail car has two independent, straddle type, tandem axle bogies.

The bogie frame is a structure of steel-welded.

All axles have the double running rubber tires to support the required load capacity.

In case of pressure loss by one tire, the remaining one will allow the vehicle movement at low speed; in case of pressure loss by two tires, the emergency solid tire, which is hard plastic, will allow the vehicle rescue procedure at low speed.

The pressure of all running rubber tires are monitored by pressure sensors.

Information in case of pressure loss of running rubber tires will impose train speed reduction.

Each motor bogie is equipped with two traction motors, which transmit torque via reduction transmission units.

Each bogie is equipped with two friction brakes, which is installed with the running wheel axle and will be driven by compressed air.

Each bogie is equipped with six horizontal tires.

They are four side mounted guide tires and two sides mounted stabilized tires in horizontal arrangement. These tires guide the monorail car laterally and vertically to provide the vehicle running control.

All tires have the emergency solid tire which is made from urethane, which will run almost 30 km at the speed of 10km/h and it will provide lateral and vertical support in case of tire failure.

The air spring suspension system is installed between the bogie frame and the car body of monorail and it will provide excellent travel comfort, isolation of vibrations from bogie to car body and automatic levelling to assure vehicle floor level to station platform floor for all passengers in loaded conditions.

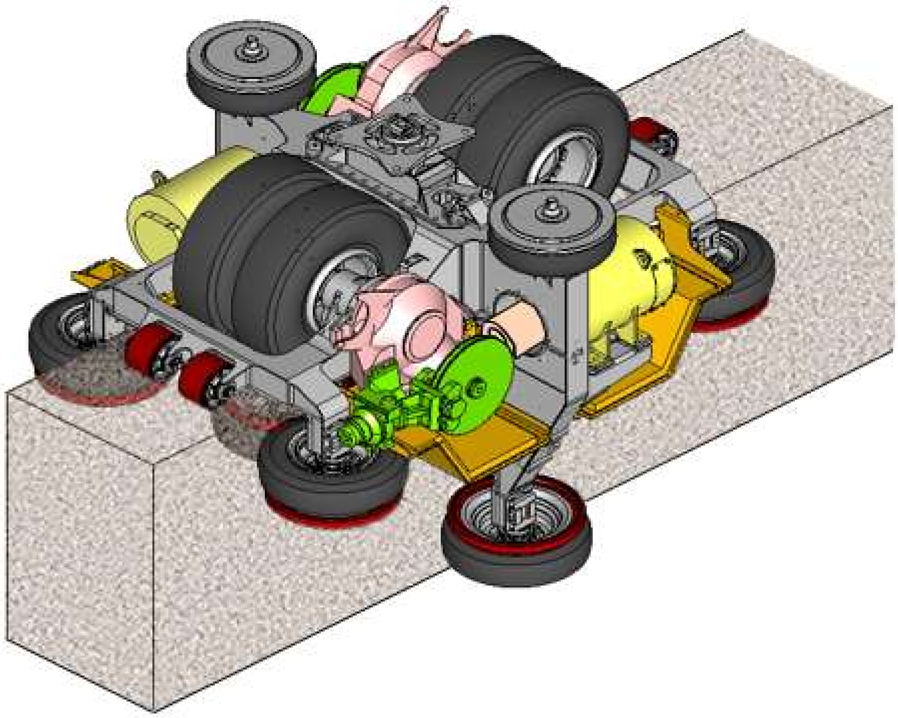


Figure 6 Bogie Solution

2.5 ON-BOARD ARCHITECTURE

The on board technological subsystems are Vehicle Control Unit, Telecommunication Unit and Signalling Unit.

These subsystems are designed with several redundancy solution to allow a very high availability performance.

No a single point of failure can drive to a stop of the train circulation.

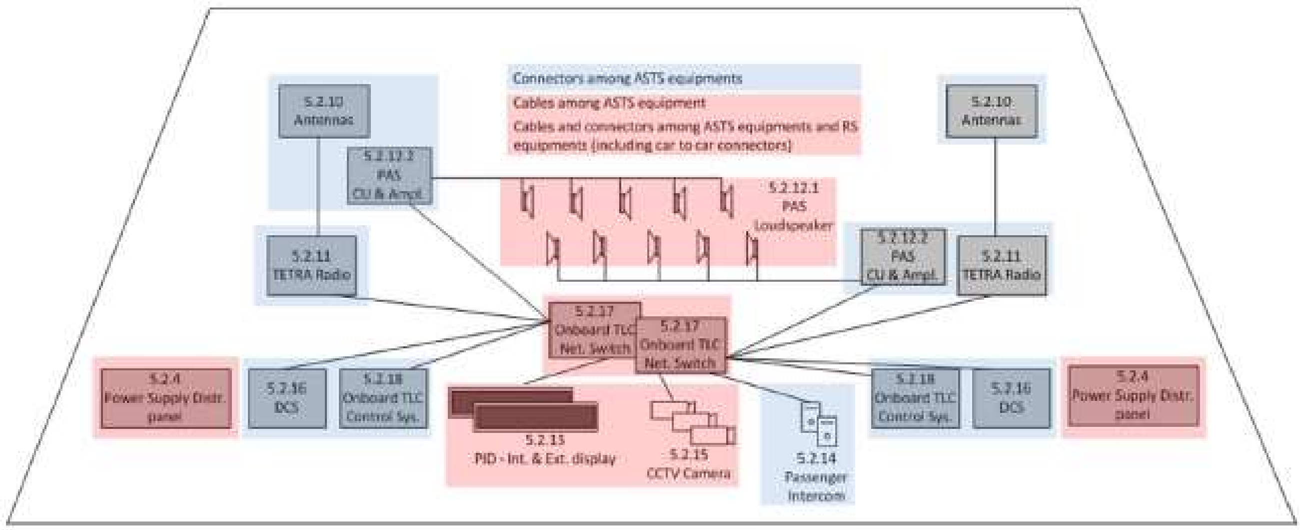


Figure 7 TLC On-board Architecture

The following scheme shows the on-board equipment architecture as regards the signalling.

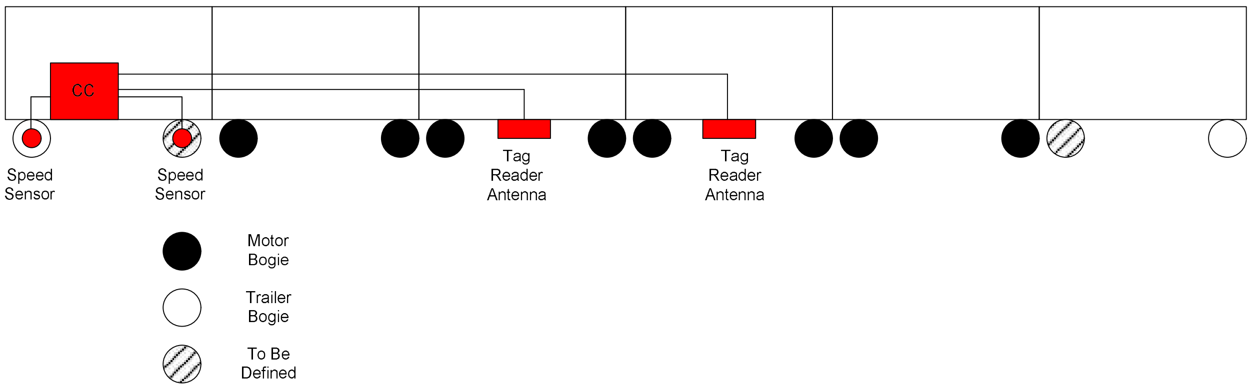


Figure 8 Signalling On board Architecture

The Carborne Controller [CC] installed in car TC1; The carborne controller is in configuration 2oo3 (two of three).

The two Speed Sensors are installed both on the trailer bogie of car TC1.

Two Antennas & Readers are installed in car M3 and in car M4.

Two Serial RS485 Links for the CC-TIS communication see Figure 9.

Two Train information System [TIS] Display Units (one per cab-end) installed in the addition to the SIG Train Operator Display [TOD]. Such displays will show train diagnostic data.

One of important design criteria is the length of the cable between CC and the furthest antenna, that is lower than 60 m which is in the range of signalling functionality requirement.

Protective solutions applied to protect this cable against EMC perturbations.

Considering the 6-cars-train configuration, the Train Information system architecture is showed in figure 9 and the number of on board TLC equipment is in the following table.

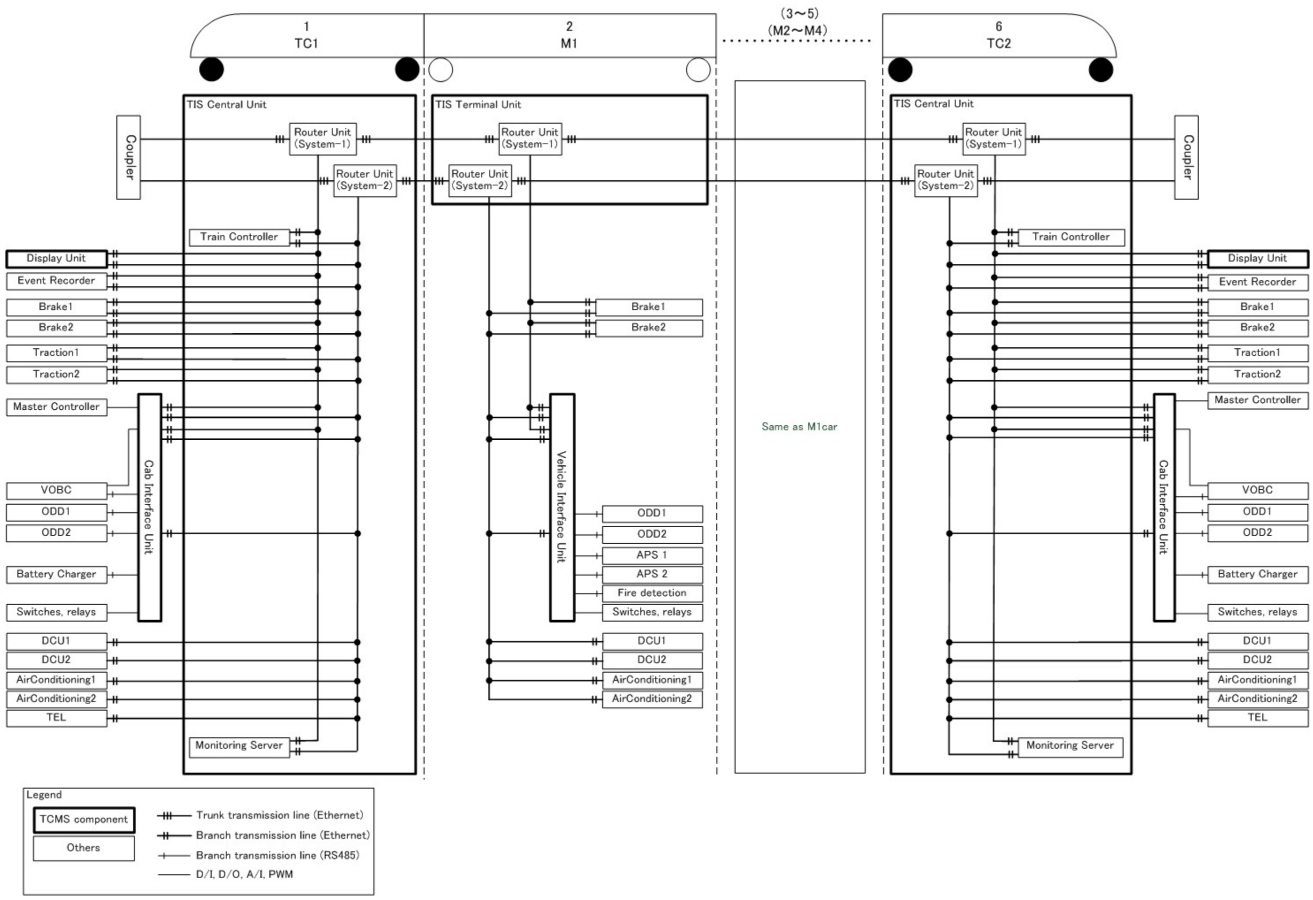


Figure 9 On board Connection Scheme

No.	Equipment	Tc1	M1	M2	M3	M4	Tc2	Total
1	Central Unit	1					1	2
2	Cab Interface Unit	1					1	2
3	Terminal Unit		1	1	1	1		4
4	Vehicle Interface Unit		1	1	1	1		4
5	Driver's Display Unit	1					1	2

Table 2 – Train Information System

Traction/braking commands through a Serial-Ethernet converter.
The Train Controller Unit send/receive commands to the train equipment (e.g. Traction/Braking units).
The Train Controller will work in hot-standby configuration.

2.6 BRAKE SYSTEM

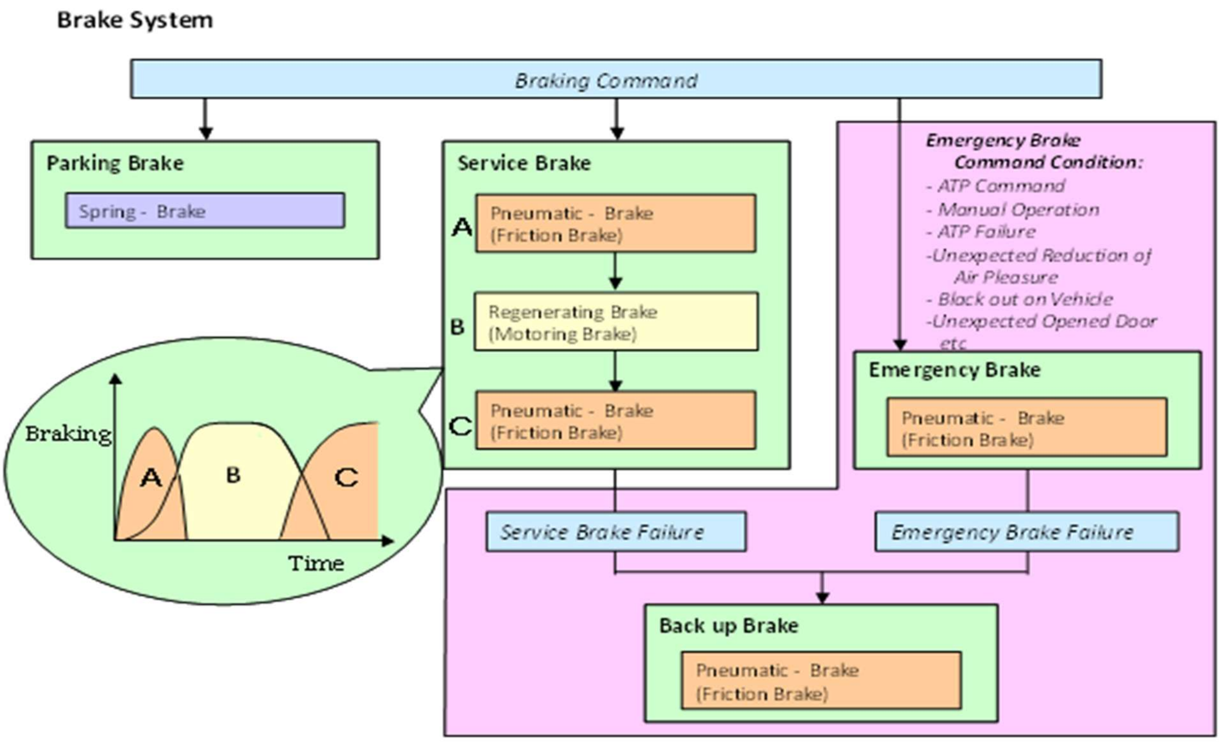


Figure 10 Brake Functional Scheme

Friction brake system
The friction brake disks are installed in each axle and the solution is a pneumatic system with proven performance for supply the required service braking function, emergency braking function and parking brake function.

Service brake system
The service brake system is composed of regenerative brake system (electrical brake) and friction brake system (mechanical air brake), operating in complete coordination. The service brake use mainly the regenerative brake.
The anti-slide control function is controlled by the propulsion system (regenerative brake system).
The service brake system is effective in all load conditions and have an average maximum deceleration of 1.0 m/s^2.

Emergency brake system
The emergency braking is supplied by the pneumatic friction brake and applied in a fail safe manner.
The nominal deceleration will be 1.25m/s^2 under all load conditions.

Back-up brake system
Service and Emergency brake system have a Back-up brake system that is automatically activated in case of Service and Emergency brake system failure.

Parking brake
The parking brake is provided by the spring loaded brake calliper which is similar to the ones used for service and emergency brakes. The parking brakes is installed in 12 axles to achieve the required capability to stop with AW4 (8 passenger m^2) train load at a 6 % grade.

3 SIGNALLING SYSTEM

3.1 OVERALL SIGNALLING ARCHITECTURE

The signalling solution is Communication-Based Train Control (CBTC) for a GOA2 solution and it is derived from the latest evolution of the Hitachi rail CBTC automatic system.

The overall signalling system architecture is reported below.

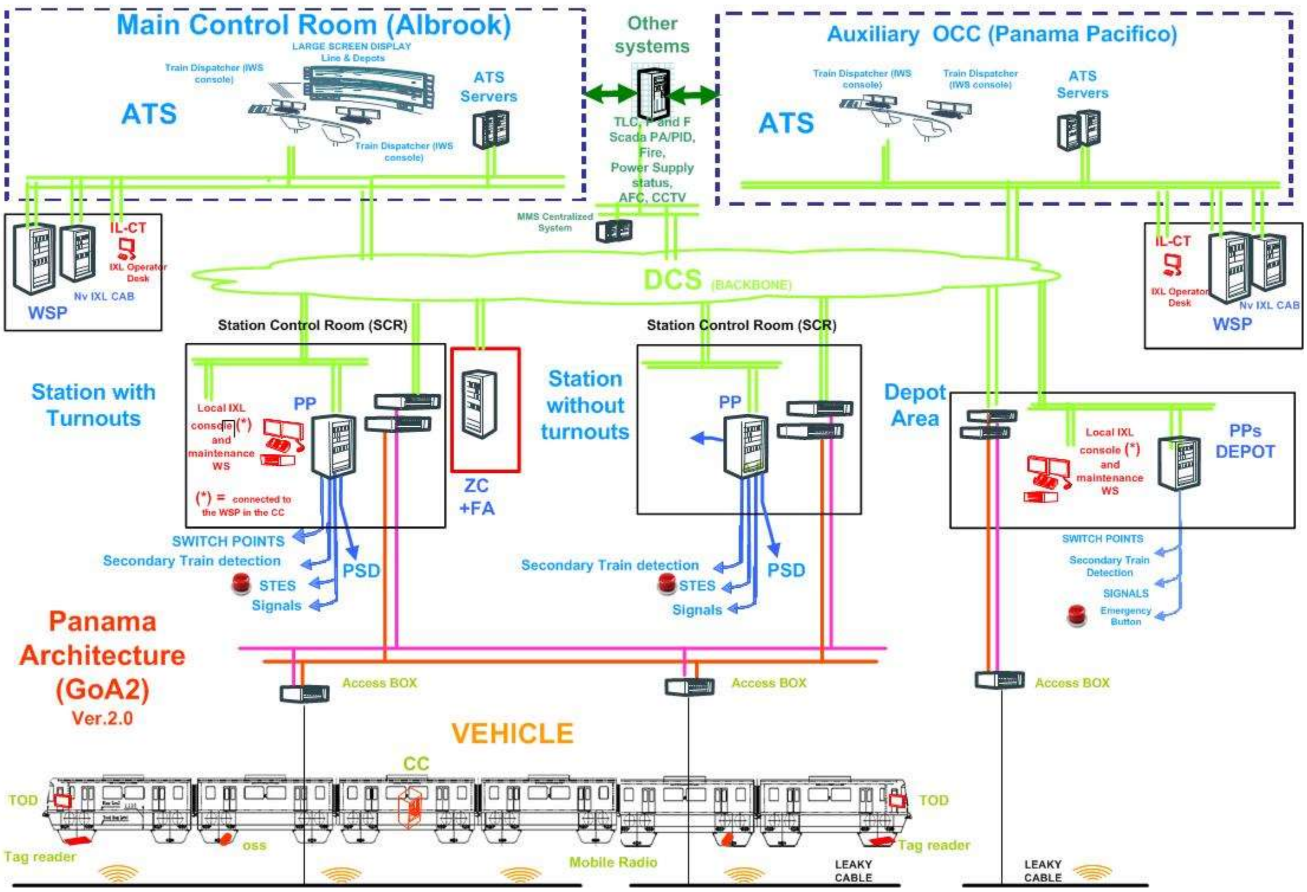


Figure 11 Signaling Architecture

CBTC <u>**Goa2 solution**</u> should foresee:

- an IXL **Centralized Solution with Standard WSP** Solution;
- **a Single CC on Board** for a 6-car (fixed consist);
- Zone controllers [ZC] along the line in different stations and in depot
- Interface control with switch machine;

The centralized System will supervise both the main Line and the Depot.

The Central Post configuration is:

1. main OCC located in Albrook with WSP, IXL Non-Vital interfaces and ATS servers;
2. back-up OCC located in **Panama Pacifico Station (6 Km far from the OCC)** that have the same equipment but it will be managed as **Hot Stand-By;**
3. Integrated Operator Desk (IWS) for the Control room activities;
4. ZCs will be located in some Station along the line (e.g. in the two terminal stations) with a FrontAm in each one (in cold stand-by).

We have also included in our solution an additional independent train detection, called **Secondary Train Detection** (requested SIL4) that has to be used in case of severe failure of the CBTC.

The solution identified is the **"NEGATIVE SENSORS"** installed along the wayside.

The Peripheral Post are Signaling PP solution and installed **in each station** and in Depot.

There are three different typology of PPs:

- PP for Station with Switches
- PP for Station without Switches
- PP for Depot

Two PP are equipped with **Signaling Operator and Maintenance Desk**, connected to the Central WSP, that allow an Operator to manage "remotely" the station, without ATS functions.

A Peripheral Post controls the wayside equipment:

- SWITCHES;
- SIGNALS;
- Platform Screen Doors;
- STES buttons in platform;
- Secondary Train Detection Devices.

The interfaces with other Subsystems SCADA, TVCC, Power Supply, are managed at central level at OCC/ B-OCC.

Only the Traction Power control, and a command as power cut off, is not under signaling command.

The Depot vehicle movement is in ATP RM mode. This solution can be optionally upgraded in ATO/ATP mode (excluding Maintenance Area).

The Signalling System consists of the following major subsystems:

- Interlocking Subsystem (IS);
- Train Control Subsystem (TCS);
- Automatic Train Protection (ATP) Subsystem;
- Fibre Optic Communication Network (FOCN) Subsystem.

The signalling system interfaces:

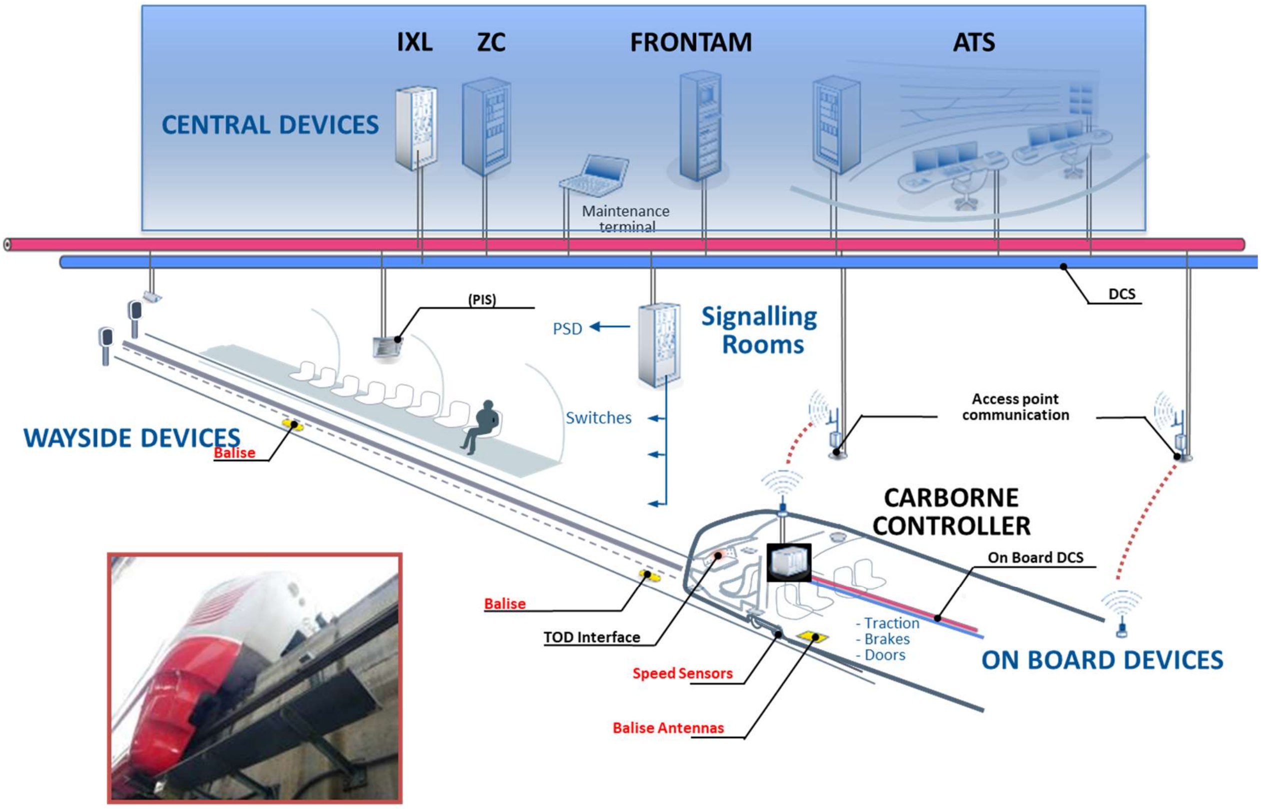
- Master Clock;
- System Overview Display;
- Passenger Information System;
- Location Report Server;
- Beam Switch Equipment;
- On board Traction & Braking System;
- Train & Depot Controllers;
- Station Masters.

The following block diagram presents a functional overview of the major components of the subsystems that make up the Panama Monorail Signalling System and identifies the primary internal interfaces between those components as well as the external interfaces to other systems and to operators.

3.2 ATC FUNCTIONS

ATP Functions (Vital)	ATO Functions (Non Vital)
Train Localization	Speed Regulation
Train Speed and direction control	Dwell Control
Train Consist & Vehicle Identification	Programmed Stopping, Station Skip Stop
Driving Modes	Door Opening
Speed Limit Enforcement	Train Operator Display (TOD)
Movement Authority Limit (MAL) Enforcement	Readiness States
Over-speed detection	Performance Modification
Emergency Braking Control	Departure Testing
Vital Propulsion Cut	Turn-back
Vital Door Control	System diagnosis monitoring
Platform Emergency Handles	

Table 3 – ATC Functions Allocation



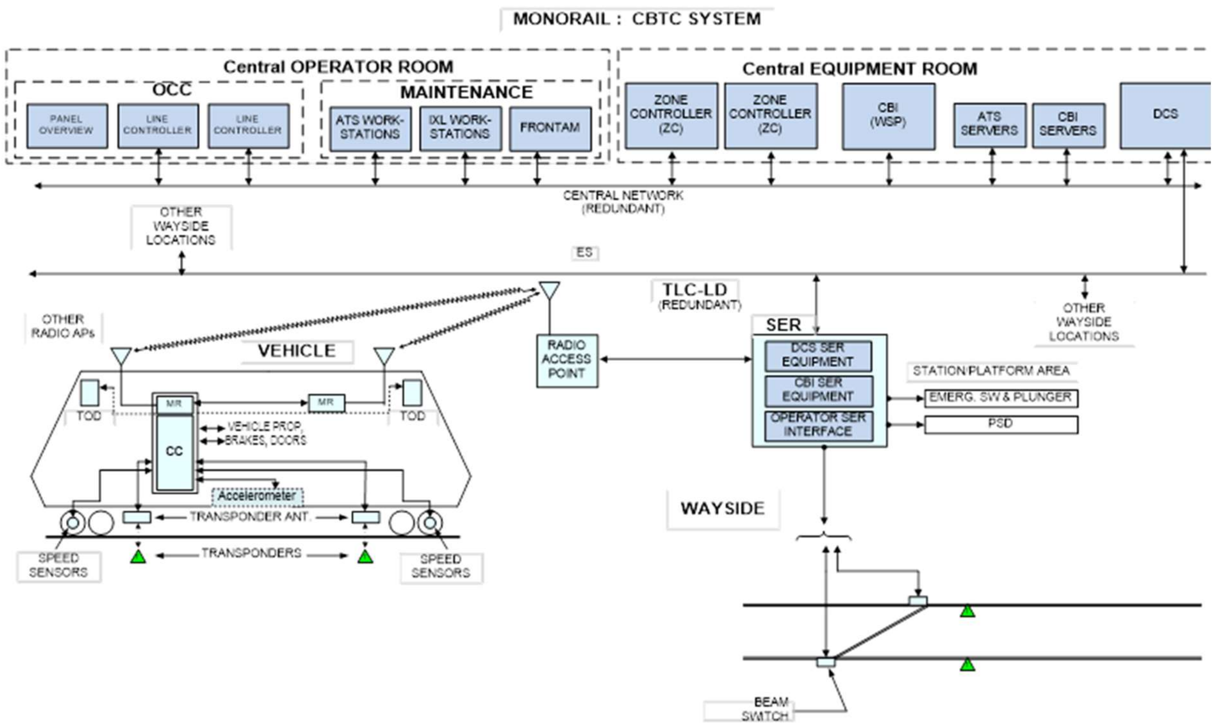


Figure 12 & 13 Signaling Devices Map & Interface Block Diagram

4 SAFETY

4.1 EMERGENCY PUSHBUTTONS-CONTACT LINE

Emergency pushbuttons will be installed to permit to local cut-off the contact line power feed. Their use is assigned to staff and firefighters in case these need to access the line. There is one pushbutton inside Control Centre, which allows cut-off the power feed of the contact line along the whole main line and another for the depot.

Activation of power cut-off push button is accomplished via hardwired circuit.

One power cut-off mushroom button is also be installed at the entrance of each traction substation.

Every station platform a pushbutton is installed (namely the Emergency Stop Plunger [ESP]); it prevents trains entering the area where the alarm has been raised or to blocks trains already in the area.

4.2 FIRE DETECTION

In case of fire alarm, the following actions are executed:

- activation of the passenger compartment monitoring in the Control Centre;
- train automatically reaches the next station and stopped;
- announcements and instructions are broadcast on board and, subsequently, on the adjacent vehicles, in order to avoid a possible panic;
- activation under control of the fire-fighting system for the area affected by the fire.

It is applied for the train to reach the next station and then stop, and for this purpose the Automatic Train Control (ATC) enforces the so-called train movement in accordance with a pre-programmed schedule.

The ATC allows operators in the OCC to trace the train movements in case of emergency conditions. Additionally, the events on station platforms may be monitored via the video system, to see that the arriving trains are safely evacuated and passengers do not board them again.

After activation of a fire alarm the following automatic emergency measures are enforced immediately:

- the affected train travels until the closest station, where it stops with the doors opened. The passengers are instructed to leave the train and not to board again;
- Upon triggering of the fire alarm, if a train is already at a station it is to be held there with the doors open.

When the fire detection system is triggered inside a station, trains in said stations may not be able to come to a halt until the hazard nature is clarified. In such cases, they must be brought to predetermined distances in order to prevent the entry of smoke into the passenger compartments. If a stop at an intermediate station is no longer possible because the train has already approached the station to a distance that is less than the braking one, the train is to pass through the station without stopping and therefore without opening the doors.

4.3 AUTHORIZE DOOR OPENING

This function sets train immobilization supervision for passenger exchange and authorizes door opening for the appropriate side when the following vital conditions for passenger exchange are verified:

- Train is correctly positioned and berthed at platform;
- Speed zero is detected;
- Train Door Controller health synthesis status is positive;
- The correct opening side is determined in the “Determine Door Opening Side function”

or

- A Train Operator opening request is detected, and
- Null speed is detected

4.4 EMERGENCY WALKWAYS

As a safety precaution for passengers, a steel emergency walkway is foreseen. Such walkway shall run along the entire line, and shall be located in the space between the beams.

The emergency walkway shall be used by passengers in case both of the following conditions are met:

- a vehicle breaks down on the open track and train movement (either self- or assisted by a rescue vehicle) to the closest station is not more possible (e.g. passengers cannot evacuate by alighting the faulted train onto a station platform);
- both faulted- and rescue train movement along the line is not possible (passengers cannot evacuate by boarding a rescue train).

The emergency walkway shall be accessible from passengers by means of a ladder to be put in place by the ride attendant after electric power has been cut off.

5 TRACTION POWER SYSTEM

5.1 GENERALITIES

The aim of the Power Supply System for MPSA Line-3 monorail system transportation and auxiliary systems is to distribute the electrical power for the trains, the entire line, including the stations, depots and other facilities, in order to ensure a transportation service with high availability, minimizing the impact to the public.

Metro de Panama Line-3 shall have an exclusive network of 34.5 kV @60Hz. that shall be fed by the Local Energy Provider Company from 3 substations located in the vicinity of the Line-3 alignment.

From the connection cubicle (entrance point of the the Local Energy Provider Company cable) an exclusive main line 34,5 kV CA, three-phase, 60 Hz power supply circuit (3 single cables) will be distributed for supplying power, in a radial manner, to the Traction and Auxiliary substations of MPSA Line-3.

In these sub-stations, the connection shall be made to the Traction and/or Auxiliary equipment transforming to an adequate voltage that is necessary for providing power to the Traction System and Auxiliary System.

The Electric Power Supply System shall be classified in three types of voltage, and each equipment and/or system shall include the following:

34,5 kVCA system:	Power Receptor Equipment and Transmission Line System, 3-phase and 1 loop
1.500 VDC system:	Traction Substation, Contact Line System and Station Circuit breakers
Low voltage 480 VCA system:	Low voltage transmission for auxiliaries

The Medium Voltage Supply system of Line 3 includes:

- **3 Incoming from** the Local Energy Provider Company to supply the full 34,5 kV Medium Voltage Network;
- **12 Substation for Traction (SET). 11** of main line plus 1 SET located at depot which have the primary function to provide the 1500 V_{DC} traction power to the vehicles to be operated on the Metro Panama System;
- **14 Auxiliary Substations (SEP)** which have the primary function to provide power at 60 Hz - 480 V_{AC} to the various equipment and auxiliary loads at these locations;
- **1 Depot** which have the primary function to provide power for auxiliary purpose to ensure the vehicles stabling, maintenance, washing and cleaning.

5.2 DESIGN CRITERIA

The Power System should keep the voltage within the appropriate range for each function and should not affect the power supply at any critical moment N-1, except in the situation of a double failure.

The Power Supply System should maintain the capacity for electric power transmission for any failure of a single point (criteria N-1). Therefore, the Power Supply System should have the following characteristics.

- The network should be configured for maintaining the continuity of the power supply in case of any simple failure.
- All the cables and equipment of the Electric Power Supply System should support the current caused by the failure of a single point.
- The Power Supply should absorb any fluctuation of the supply system caused by the occurrence of a failure of a single point (criteria N-1) and/or the elimination of the failure zone.

The entire 34,5 kV power supply system will be able to operate with one connection to Local Energy Provider Company out of service without load reductions (N-1 criterion). No parallel connection of the Local Energy Provider Company incoming will be accepted.

To ensure the redundancy the 34,5 kV power supply system will be formed as a closed ring, with the possibility to handle effect flow in both directions in order to ensure a high degree of reliability to the traction power system and related installations.

From this 34.5 kV network, the Traction Substations (for trains) and the Auxiliary Services (for Stations, Depot and Workshop, and other structures) shall be supplied.

The loads shall be shared among 3 power supply points that Local Energy Provider Company shall provide in the substations:

- Albrook;
- Arraijan Mall;
- Ciudad del Futuro.

The separation of the loads shall be done with circuit breakers in the open position in the Panama Pacifico substation (Arraijan Mall side) and in the Nuevo Chorrillo substation (Depot side). More details about the location of the normally open position of the mentioned circuit breakers shall be verified during the design phase in order to ensure the best way for the optimum functioning of the electric power supply system.

Operative Conditions of the Medium Voltage Network

The general criteria shall be to maintain the normal operation of the system even with the loss of 1 of the power supply points of 34.5 kV of Local Energy Provider Company. The operative conditions and their effects on the electric power supply network are described below.

Normal Situation

This is the situation where both the functioning of the electric supply and the operation of the trains are going as planned.

All the substations are functioning normally and the trains circulate as planned according to the time table established in the Operation Plan; the loads that are carried by each substation in normal function are transmitted with the circuit breakers in the Panama Pacific substation (Arraijan Mall side) and in the Nuevo Chorrillo substation (Depot side) in the open position.

More details regarding the AC load flow analysis will be provided during the preliminary design stage.

Degraded Situations

In case of a failure of a Local Energy Provider Company substation, the electric power supply network should allow the circulation of the trains in normal conditions according to the criteria N-1. condition of Normal Situation.

In the case of failure of all of Local Energy Provider Company power supply points, it should be possible for all the trains that are stopped between stations to move (one at a time) to the nearest passenger station. To do this, dedicated battery banks (ESS system) are provided with the capacity to store energy from regeneration produced when the trains are breaking.

Operative Conditions of the Traction Substations

Normal Situation

- All the substations operate in normal situation and ensure the electric power to the power strip so that the operation of the trains is as indicated in Table 1-4 of the main contract.
- The loss or the shutting down of one (1) traction substation shall not affect the normal operation of the trains. In this case the adjacent substations shall take up the load of the trains that are in this section (criteria N-1). In this case it is allowable the operation of the group of the adjacent substations within the overload rating without exceeding the Class VI temperature limits in accordance with IEC 60146 standard.
- The system shall have sufficient availability of electric power with the aim to satisfy criteria N-1 for all the available failure scenarios, except for mechanical problems in the Contact Line.

Degraded or Disrupted Situations

- The disrupted situations for the loss of **more than one (1) traction substation,** in this case the circulation of the trains should be regulated according to the section where the failure occurred.
- A set of simulation studies of the power supply system considering the failure of more than one (1) traction substation shall be provided during the preliminary design stage.

5.3 SIMULATION TOOL

The simulation results will be evaluated acceptable if the following conditions will be verified:

- the loads of each SET, teaking into account the contribution of the B-Chop system, shall always be able to guarantee the nominal performances of trains according to the operation scenarios;

- the minimum line voltage measured at trains' current collector shall always be greater than 1000 VDC, according to IEC 60850 standard that is indicated for a traction system with nominal voltage equal to 1500 VDC.
- the current loads measured on the contact line are lower than its maximum current capability which corresponds to 2300 A @40°C.

If all the above conditions are always verified, then it is possible to confirm that substation equipment is capable to support this calculated maximum electrical load and guarantee nominal train performance both in normal operation of the traction power system and for 2 hours continuosly with the total failure of any one traction substation

The used tool is an integrated electro-mechanical simulator for metro systems; it is able to perform mechanical and electrical simulation in integrated or independent way.

The modular approach allows the realization of the system model by means of "objects" linking the subsystems involved:

- overhead contact or third rail lines and rails or contact line system;
- track profile;
- electrical substations;
- vehicles.

Traffic with different type of vehicles may be considered. Various approach to be defined for traffic types:

- fixed headway;
- timetable;
- train entering to track at fixed frequency;
- input and output positions with relative speed.

The conductor feeding system is represented by a resistance that includes the contribute of contact line/third rail, in the same way the return circuit conductor includes the contribute of running rails.

The characteristic of line are defined by:

- curves length and radius
- slopes length and relative gradient;
- position of substations
- speed limits.

The Electrical Substations are inserted in system model according to their position and they are defined by means of following characteristics:

- number rectifier groups;
- rectifier group characteristics;
- transformer nominal power, short circuit impedance and transforming ratio;

Every vehicle is modeled by:

- tractive and braking effort diagrams at wheels;
- auxiliary power system characteristics;
- efficiency diagram;
- maximum speed and acceleration;
- convoy weight;
- Davies Equation parameters for dynamic resistance evaluation;
- maximum voltage drop allowed;
- regenerative braking capability;
- type of speed regulation (constant maximum speed or coasting with speed band limits).

The electrical network model used for the simulation is defined assigning:

- electric nodes;
- electric load variable or static position;
- feeding substation type and position;
- electrical characteristics of every track between nodes and of every subtrack.

Load-flow techniques are utilised to solve the system equation.

The railway network model used for the simulation is defined assigning:

- traffic nodes;
- planoaltimetrical characteristics of every track between two nodes;
- speed limits in every track;
- mechanical characteristics of every train;
- the behaviour of every train in every node.

Electromechanical integrated simulation may be utilised to verify system capability: current collector shoes' voltage drop is able to interact with the tractive effort evaluation.

The two approaches described may interact step by step to generate an integrated system solution.

5.4 SIMULATION RESULT

The traction substations are located within passenger stations according to the location provided in the contract as follows.

<table>
<tr><th>Location</th><th>Number of rectifier</th><th>Rectifier Rating</th></tr>
<tr><td>Est. Albrook</td><td rowspan="12">1</td><td rowspan="12">4500 kW</td></tr>
<tr><td>Est. Balboa</td></tr>
<tr><td>Est. Panama Pacifico</td></tr>
<tr><td>Evacuation Towers (ch. 8+285)</td></tr>
<tr><td>Evacuation Towers (ch. 9+793)</td></tr>
<tr><td>Est. Arraijan</td></tr>
<tr><td>Est. Arraijan Mall</td></tr>
<tr><td>Est. Nuevo Chorillo</td></tr>
<tr><td>Est. Vista Alegre</td></tr>
<tr><td>Est. Nuevo Arraijan</td></tr>
<tr><td>Est. Ciudad del Futuro</td></tr>
<tr><td>Depot (only)</td></tr>
</table>

Table 4 – Substation location and Rectifier

Traction transformers are compliant with IEC 60146 class 6; rectifiers are compliant with the same overload class than transformers. Both transformers and rectifiers are compliant with EN50328.

Furthermore each traction substation (with the exception of Est. Nuevo Arraijan and Evacuation Towers) shall be equipped with the B-Chop (or SESS) system suitable for the optimization of the braking energy available.

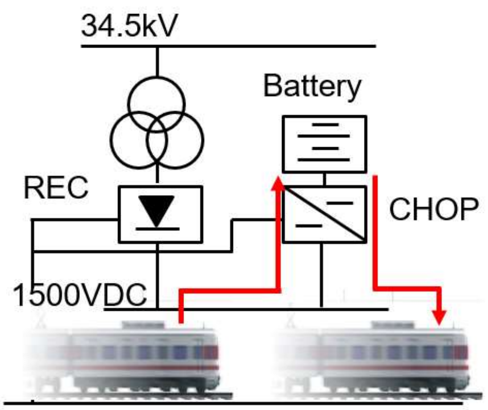


Figure 14 B-Chop scheme

6 CONCLUSION

In conclusion, in this paper an overall presentation of the main characteristics of Panama Monorail Line 3 project.

This is a result of several month of tender design activities executed together with the final Client to define and solve all request identified.

Several years of experience of Hitachi in Monorail world and on driverless metro has been used to identify the best technological solution for this exciting project.

Applying a system and product comparative and experience-based approach, the Panama solutions will be considered as an interested modern Monorail Industrial Solution.

Solutions are proven in similar applications, already in passenger service and are known to be reliable.

Solutions are cost-effective within the monorail solution.

Consolidated system integration with the core technologies of signalling and passenger vehicles to form an overall core system supply contract that will enhance the design approach and reduces interface issues.

Early engagement of the Operating competences by final Client provide important support to system design (procedures, functionalities, etc.) that will enhance the overall final efficiency.

This is how the Hitachi solution and product will inspire the "Monorail Technological Future".

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CENELEC 50126
CENELEC 50128
CENELEC 50129
IEC 62267
IEC/TR 62267-2
IEC 62278
NFPA 130
Hitachi Technical Documentation

SHORT COMPANY PRESENTATION

We are a fully integrated, global provider of rail solutions across rolling stock, signalling, operation, service & maintenance, digital technology and turnkey.

Last year, 18 billion journeys were completed using our technology, delivering social, environmental and economic value.

With revenues of ¥580.3bn in FY19, approximately 80% of which are from outside of Japan, we have a presence in 38 countries, across 11 manufacturing sites on three continents and over 12,000 full time employees.

Our engineering heritage and culture is rooted in Japan, where our first steam and electric locomotives were built in the early 1920s. A major inroad to the field of passenger transport was made in 1964, with the supply of our first Shinkansen 'bullet train' vehicles to coincide with the Tokyo Olympics.

We continue to deliver the our technology and expertise to multiple projects across the globe from high speed, tram, metro, monorail to driverless technologies for passengers and freight.

We are ambitious and continue to seek to expand into new key geographies and to deliver new solutions.

Drawing on the wider Hitachi Group's market-leading technology capabilities and R&D, we strive for industry leading innovations able to deliver value for customers and help build sustainable transportation systems which benefit wider society.

Sustainability is at the heart of our business and we believe that we have an obligation to inspire and build a better and more sustainable future for our employees, customers and all users of our products.

Innovation is key in enabling us to grow our offering for our customers through enhancing existing products, systems and solutions, whilst also harnessing global market trends.

As a business, we are investing in innovation so that we can provide solutions for the megatrends effecting the mobility sector, including sustainability, autonomous vehicles, digitalisation, urbanisation and customer experience - all with a focus to enhance customer satisfaction and increase passenger experience.

Global market trends are also demanding the use of disruptive technologies and we are seeing the introduction of new business models across the mobility sector. For this reason, we are investing in new digital and data capabilities; embedding these across our organisation, allowing us to continue our pioneering status, improve operational efficiency, and maintain our customer and partners' trust through offering products of exceptional quality.

Enzo Carpanetti
Head of Latin America, Sales and Projects
Hitachi Rail

Enzo Carpanetti is responsible for the successful leadership and management of Hitachi Rail's growing Latin America sub-region.

Mr. Carpanetti leads Hitachi's efforts to strengthen the company's market position, build collaborative opportunities with regional stakeholders, and optimize project profitability and compliance.

With more than 15 years of mobility industry experience and a focus on Emerging Markets, Enzo's career includes global assignments in China, the US, Russia, Africa, the Middle East and Latin America. Prior to joining Hitachi, Carpanetti worked for the biggest railway construction company in the world.

Enzo is a Professional Engineer who holds a Bachelor in Science in Electrical and Mechanical Engineering, a M.Sc. in Robotics & Artificial Intelligence and an Executive Global Master in Business Administration. He is fluent in five languages.

Together with Mr. Dotta, Mr. Torre, Mr. Gallo and Mr. Hirabaya, Enzo participated in the company's Panama Line 3 project proposal, which resulted in securing the contract for the first Monorail in the Latin America region – a project that he is now proud to lead as a key part of his Latin America portfolio for Hitachi Rail.

As part of the Hitachi family, Enzo is a true believer in generating social, environmental and economic value for the company's stakeholders particularly at a time when we can explore the potential for new market growth and utilize Hitachi Group's strengths in Digital and IoT -- with our LUMADA platform -- in order to improve people´s quality of life.

Hirabaya Yoshitaka
Monorail General Manager
Hitachi Rail Japan

For more than 30 years Hirabaya has been working in the transportation market, railway and metro at Hitachi Ltd., Tokyo following the graduation from the university, during such period, he has worked as a member of business development team which involves the locomotive project in India and Pakistan, EMU project to Indonesia, Taiwan and other Asian countries.

As far as the monorail business is concerned, he played a following roles in each project;

- Chonqing monorail, China as a business developer
- Sentosa monorail, Singapore as a business developer and project manager
- Dubai monorail, UAE as a business developer and contract manager
- Daegue monorail, Korea as a business developer and risk assessor

From the upstream business development and feasibility study, finance proposal, bidding work, contract management, interfacing coordination with the civil structure, project management and execution, warranty service and risk assessing service, he has an extensive and a throughout hands-on experience as far as Hitachi monorail technology is concerned.

He is registered a member of Japanese monorail association administrated by Ministry of Transportation, government of Japan.

Gianluca Gallo
Senior Project Engineer, Regional Technology EMEA
Hitachi Rail

Gianluca Gallo is a Professional Engineer who holds a Bachelor of Civil Engineering for Transportation from the University Federico II of Naples.

For more than 25 years, I have been working in the transportation market, railway and metro first as structural associated engineer then I joined in 2001 Ansaldo, an historical Italian company that now has been acquired by Hitachi Rail.

In Hitachi/Ansaldo I spent several years in the infrastructure department as track work designer ensuring in the same time the complete integration between the civil works and the electro-mechanical plants during the design phase. Since 7 years I'm a senior Project Engineer for Turn-Key systems.

As structural Engineer I worked on design for several bridges and buildings in Italy.

As Civil work Interface manager, I have been involved in more than 10 project around the world. During delivery phase have been the Project Engineer and Design Manager for Thessaloniki metro.

Together with Marino Torre, Eugenio Dotta and Enzo Carpanetti I participated, as Project Engineer, to several tenders activities that has been contracted by Ansaldo/Hitachi as Panama Line 3 and Hurontario LRT (Mississauga CA). In my role of PE in turn key project, I acquired several competencies on systems like Signal, Telecommunication, Traction Power and all the auxiliary plants that are part of a complex system like a Metro.

As per my role Project Engineer in Hitachi a strongly promote the team collaboration as I guess is the key for the success.

Marino Torre
Head of EMEA METRO PROJECT ENGINEERING PROJECTS,
Hitachi Rail

Marino is a Professional Engineer who holds a Bachelor of Eletromechanical Engineering from the University of Genoa, Technical Fellow inside Hitachi company and awarded as Master of Labor by the President of the Italian Republic.

For more than 30 years I have been working in the transportation market, railway and metro first in Ansaldo, a company that is fully part of the history of the Italian electromechanical industry, now following the acquisition in Hitachi Rail.

After years spent in engineering lines, I had the opportunity to be the System Engineer of the first automatic metro built by Ansaldo in Copenhagen and opened to passenger service in 2002. From this experience we have built many metro system around the world.

Together with Eugenio Dotta participate in several tenders activities that has been contracted by Ansaldo/Hitachi as Milan projects, Taipei and Riyadh Metro, Honolulu metro and recently Los Angeles Bart new signaling system.

Today I cover the role of Head of Project Engineer (technical contract leader) for the EMEA area providing my expertise for the technical and management coordination activities of projects and offers, collaborating with 20 engineers allocated on projects in the different countries of the EMEA area.

I expand my curiosity to other transportation solution and for that I study the monorail application and in detail the Hitachi solution.

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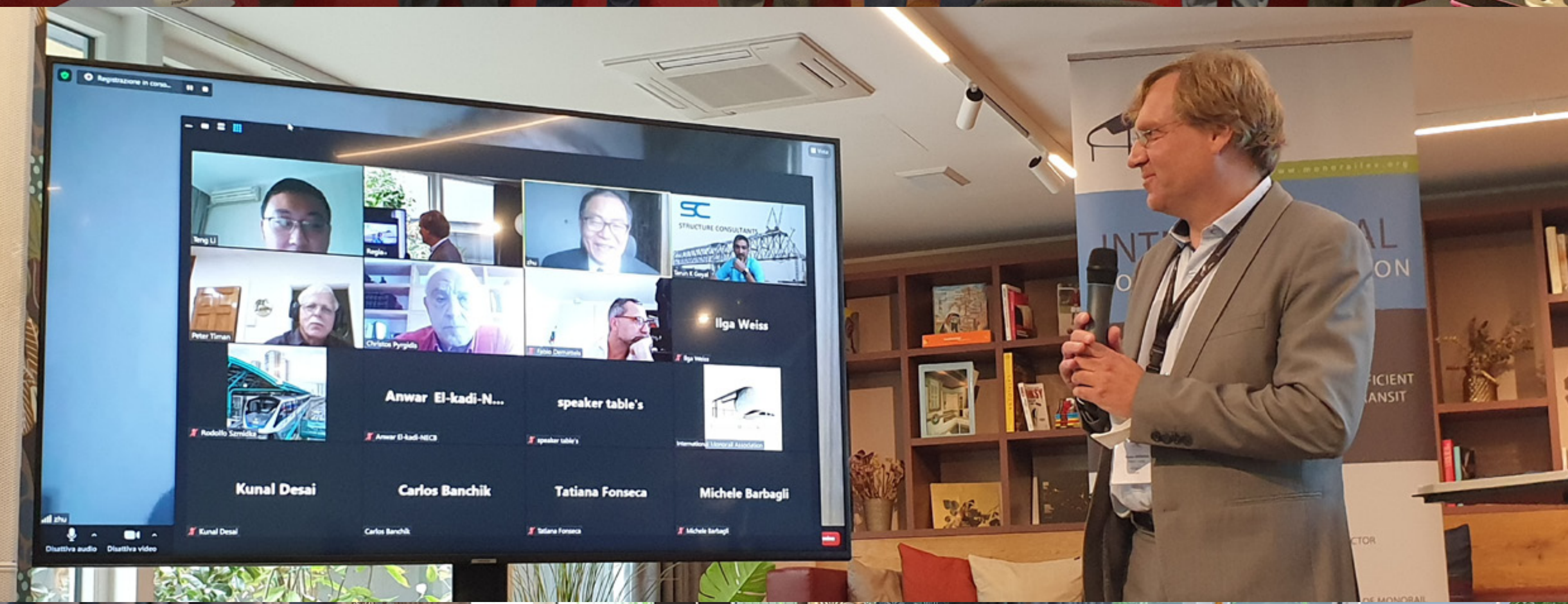
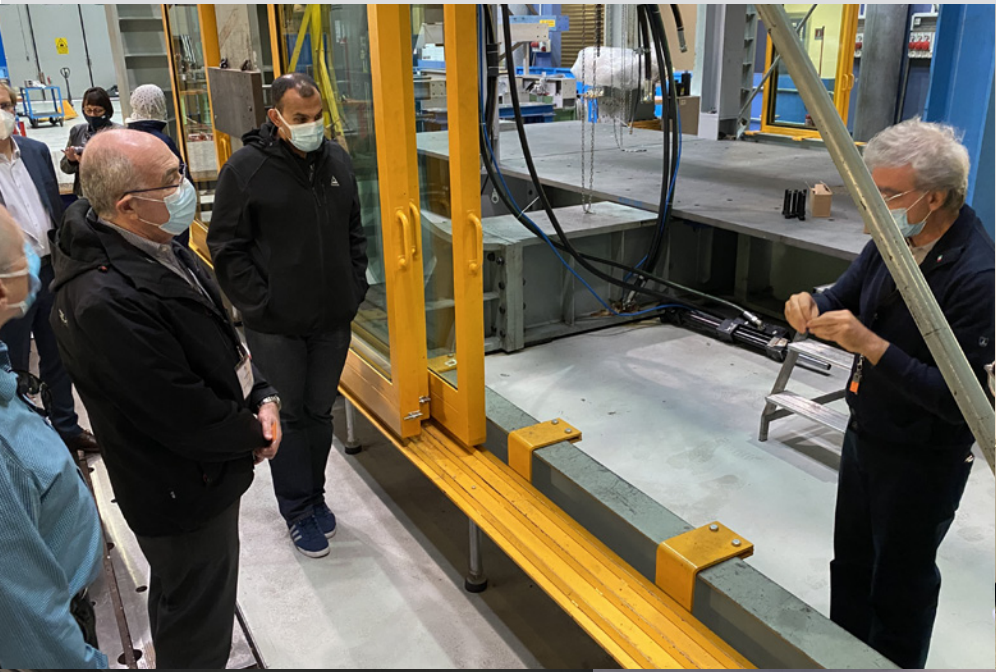


Technical Visits

Politecnico Milano, Mechanical Department



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