50 years of experience with ballasted track on the Tokaido Shinkansen (Japan)

Masahiro MIWA, **Central Japan Railway Company (JR Central)**

JR Central

- JRC commenced operations in April 1987 upon the privatization and break up of the Japanese National Railways (JNR).
- JRC operates Tokaido Shinkansen and a network of conventional rails around Nagoya and Shizuoka.
- JRC owns the whole railway system, including civil engineering structures, tracks, electric and signaling system, and rolling stock.

Ref[1, 2]

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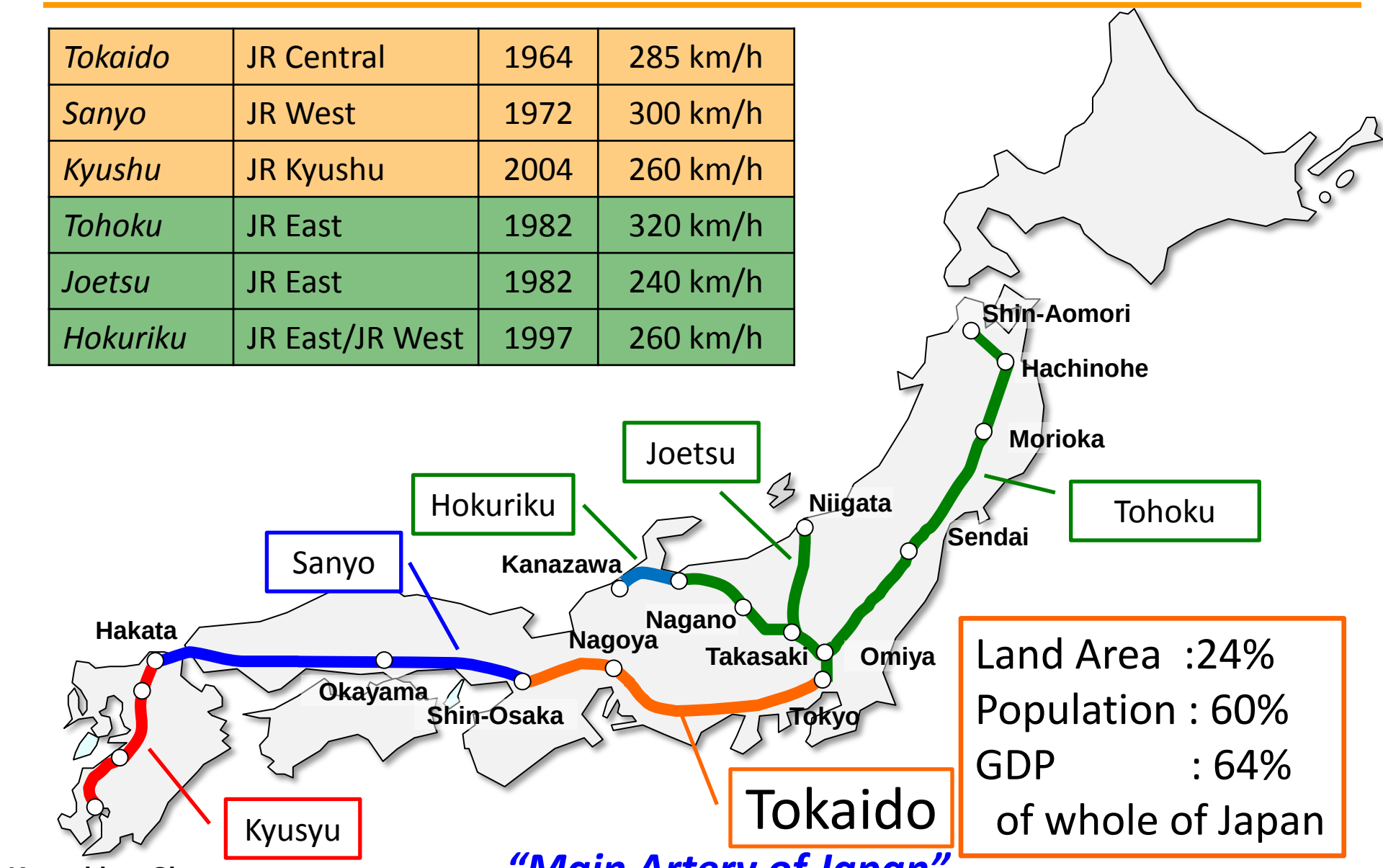
   - Higher speeds and vehicle weight reduction
   - Rail quality management
5. An example of ballasted track issue in the aim for greater maintenance efficiency
6. Slab track in Japan

1. Characteristics and performance of the Tokaido Shinkansen

Shinkansen network

Tokaido	JR Central	1964	285 km/h
Sanyo	JR West	1972	300 km/h
Kyushu	JR Kyushu	2004	260 km/h
Tohoku	JR East	1982	320 km/h
Joetsu	JR East	1982	240 km/h
Hokuriku	JR East/JR West	1997	260 km/h

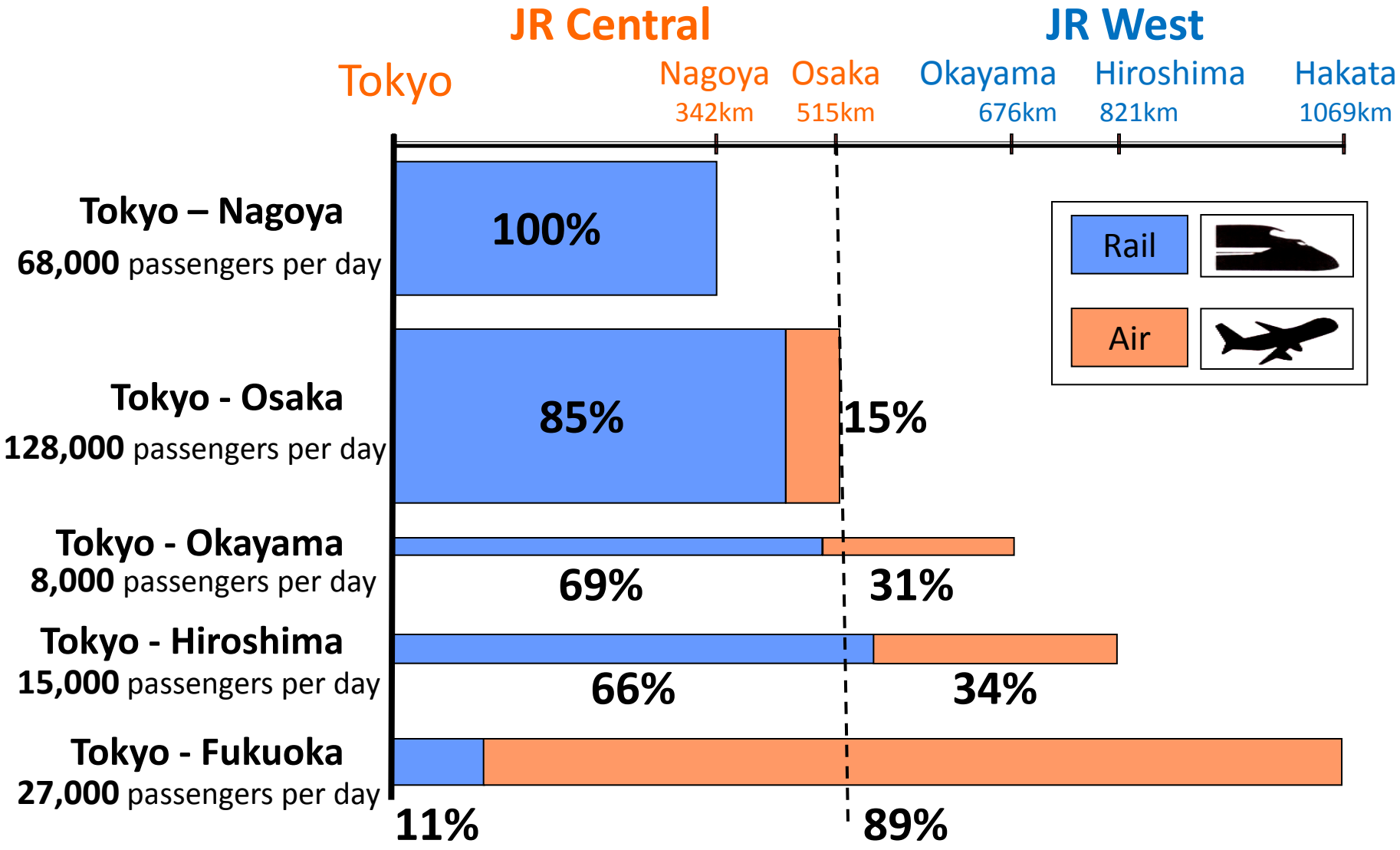


Land Area :24%
Population : 60%
GDP : 64%
of whole of Japan

"Main Artery of Japan"

Ref[1, 2]

Market Share of Shinkansen



Market share is the percentage of all railway and airline services based on the inter-prefectural data of the Inter-Regional Passenger Mobility Survey (FY 2013.3) published by MLIT.

Ref[1, 2]

Key features of Tokaido Shinkansen

Safety and Reliability

- No passenger fatalities or injuries due to train accidents for more than a half century
- Annual average delay: 0.9 minutes per train (FY2013)

Mass Transportation

- High frequency: 342 trips per day in average (Max. 431 trips on August 16, 2015)
- Large capacity: 1,323 passengers per sixteen-car trainset
- Ridership: 424,000 passengers per day, 155 million passengers per year (FY2013)

Environmental Adaptability

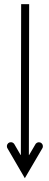
- Low energy consumption, low CO2 emissions
- Low wayside noise
- Small ground vibrations along high-speed lines (Axle load: 11.2 tonnes)

Ref[1, 2]

2. Prior track R&D applied to the world's first high-speed rail

Track for the world's first HSR

- Research and development based on the proven technologies and experiences
  - Japan's conventional lines (≈100km/h)
  - Railways in other countries (120~160km/h)



Theoretical analyses and experiments

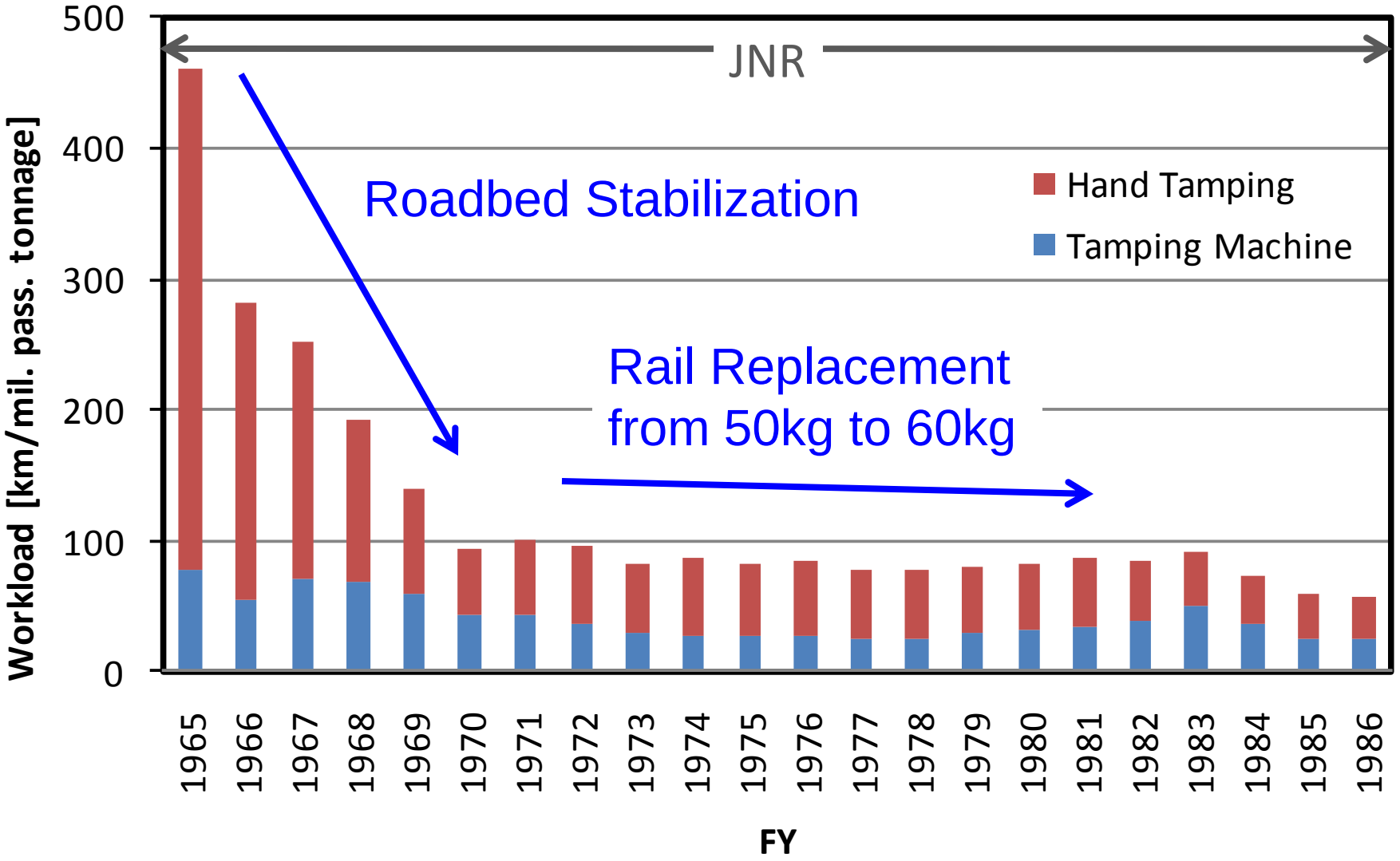
- Ballasted track could be used and also economically maintained under high-speed conditions

- Although the need for slab track was discussed

Ref[3]

3. Track maintenance in the early years (1964-1986; era of JNR)

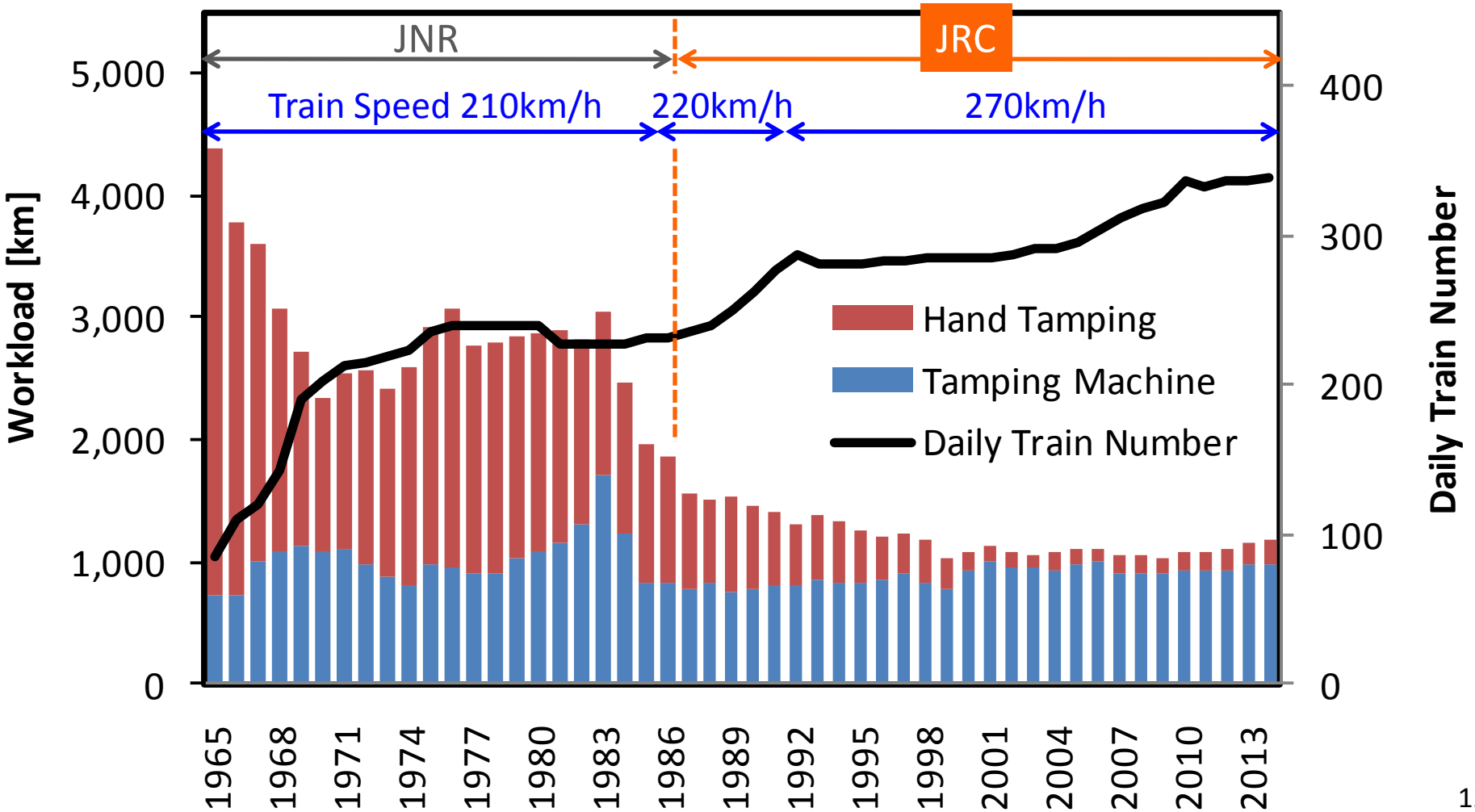
Workload on tamping in the early years



4. Maintenance of ballasted track (characteristically conducted by JRC)

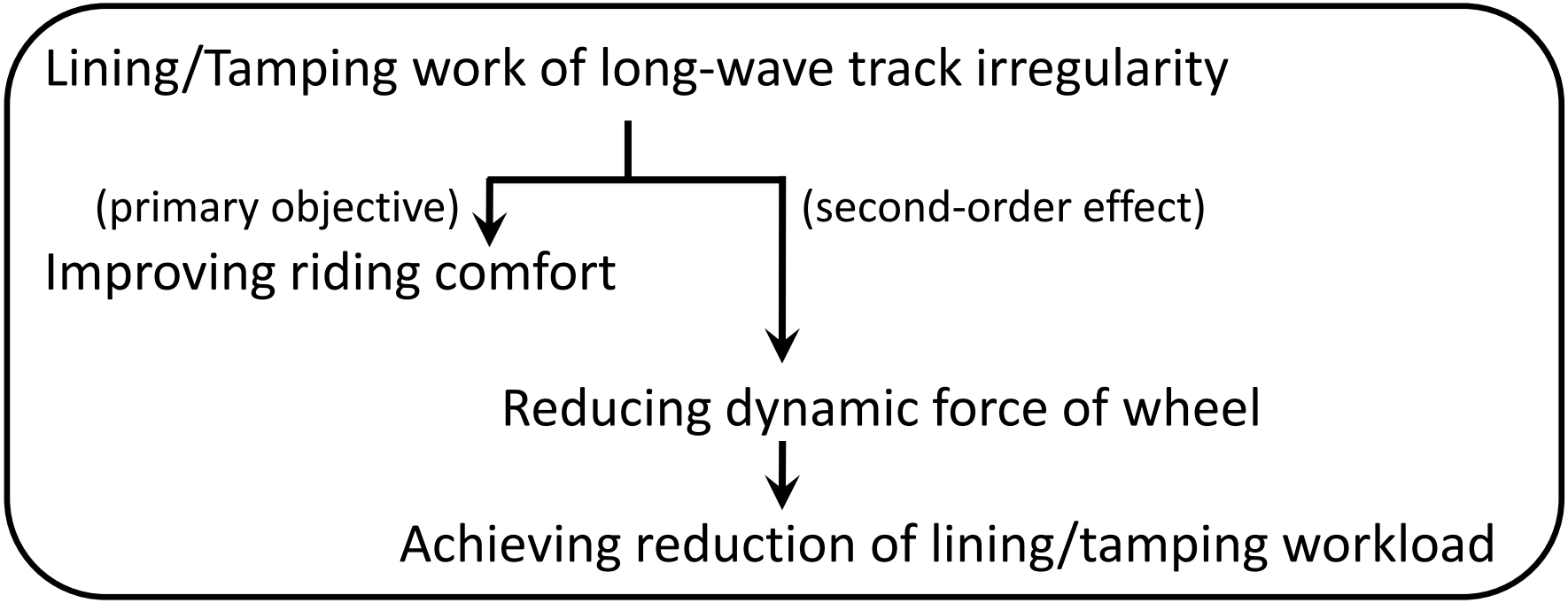
50-year change of Tokaido Shinkansen

- ✓ Train Number : Increasing
- ✓ Train Speed : Increasing
- ✓ Track Maintenance : Decreasing or Roughly Flat



4. Maintenance of ballasted track

— Improvements in riding comfort



Improvements in riding comfort

Repair Planning Using "Estimated Riding Comfort Level" for Reducing Vehicle Lateral Vibration

- In the past, 40m Versine Method was used
- Now, RMS values calculated from track irregularities filtered with characteristics of Fig.3 (= Fig.1 x Fig.2) are used

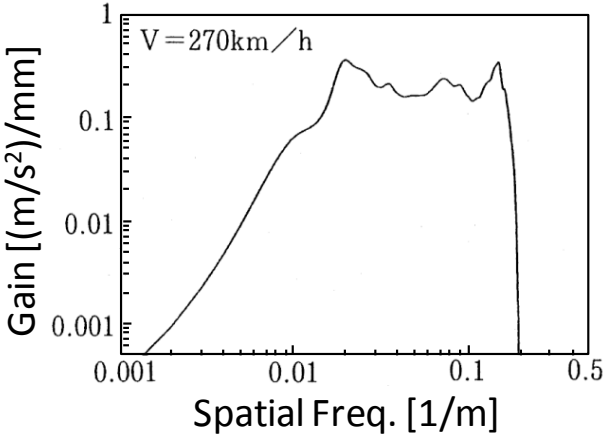


Fig.1
Vehicle Response

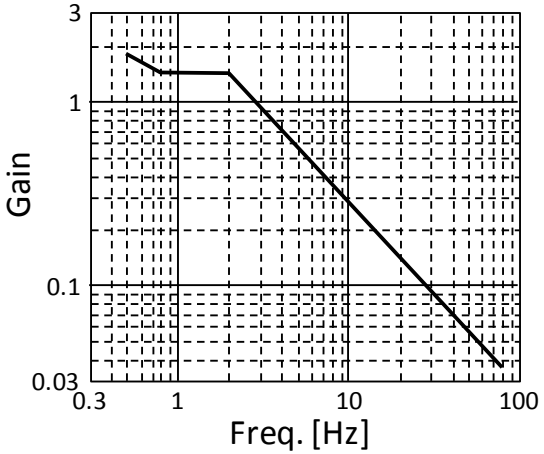


Fig.2
Human Sense Factor

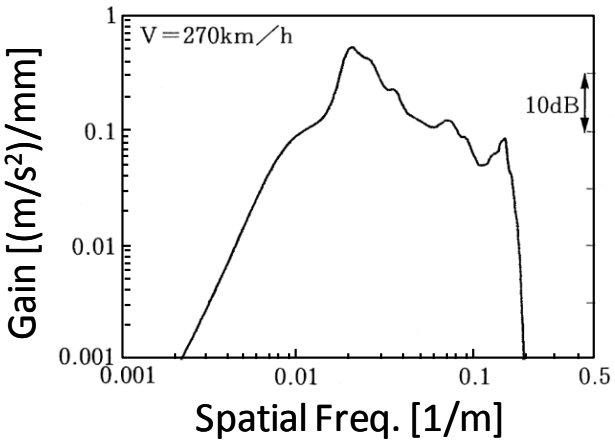


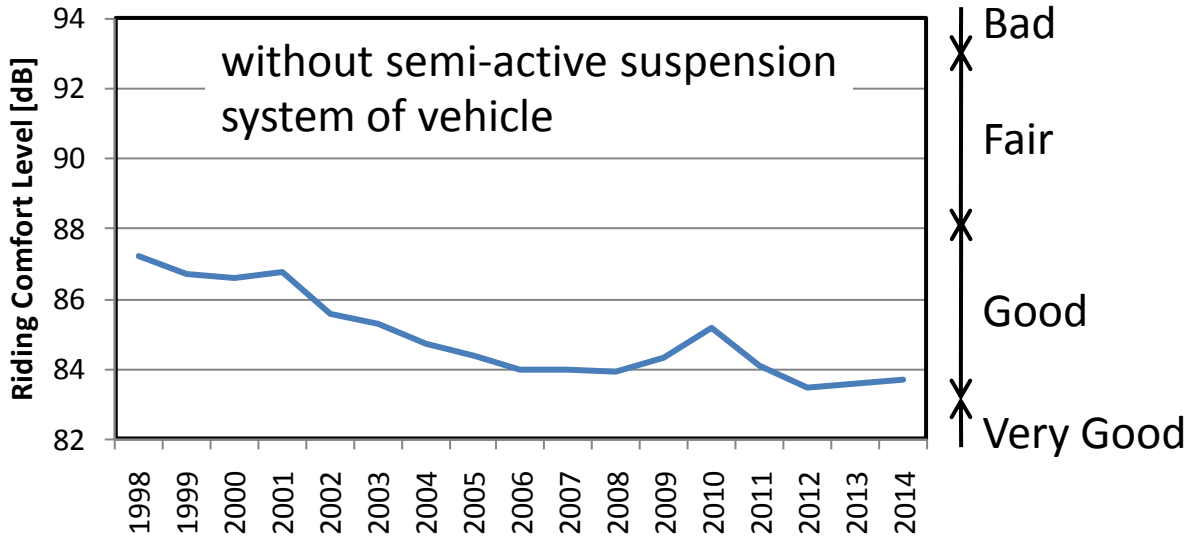
Fig.3
Resultant Weighting Factor

Ref[4]

Improvements in lateral riding comfort decreases lining workload

Lining Work Using "Restored Track Irregularity" Values

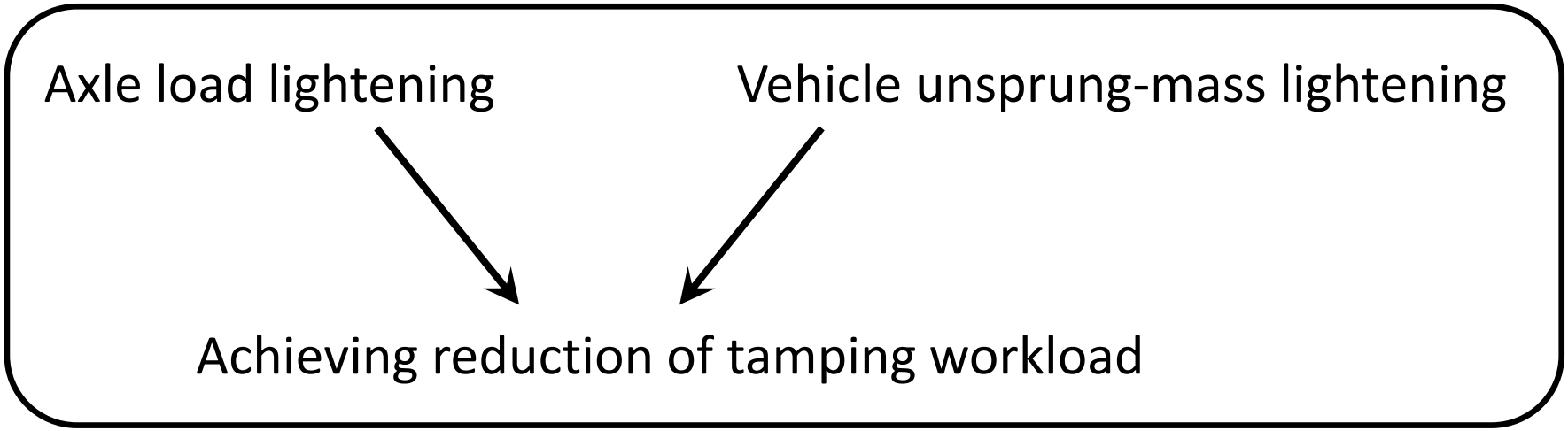
- Flat amplitude values from 5m to 100m wavelengths are suitable for track lining works
- Riding Comfort Levels have improved significantly



- Also, this lining work is effective in decreasing lining work itself, because it suppresses dynamic lateral force associated with lateral and yaw vehicle motions.

Ref[5]

4. Maintenance of ballasted track
— Higher speeds and vehicle weight reduction



Axle load lightening

1964 1985 1992 1999 2007

2006.3

Analog ATC | **Digital ATC**

1st generation rolling stock | 2nd generation rolling stock

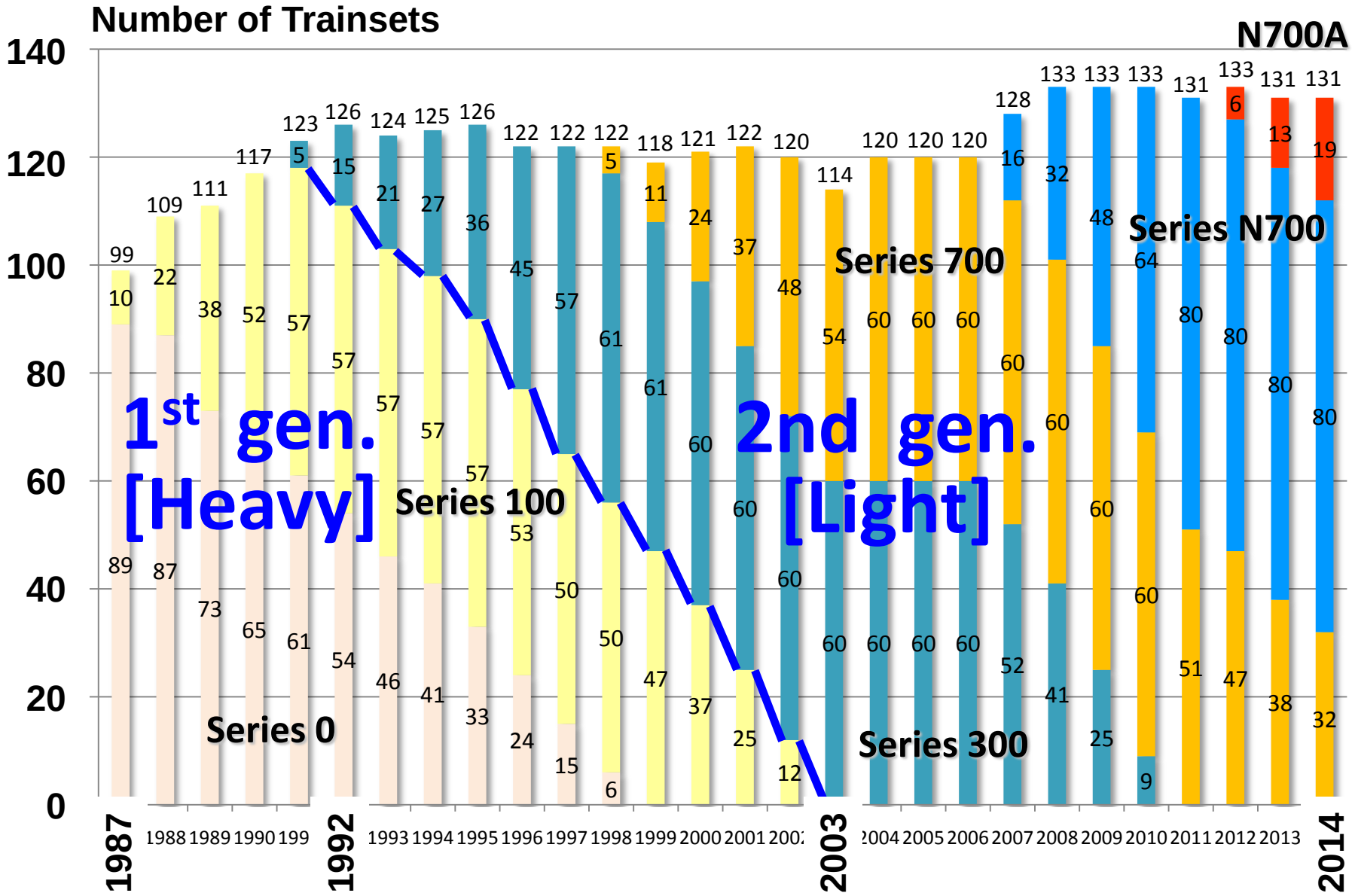
- Steel carbody
- Conventional bogie
- DC motor drive

- Aluminum alloy carbody
- Bolsterless bogie
- Asynchronous motor drive (VVVF control)
- Regenerative brake

	Series 0	Series 100	Series 300	Series 700	Series N700
					
Trainset Weight	972 tonnes	925 tonnes	711 tonnes	708 tonnes	715 tonnes
Max. Axle Load	16.0 tonnes	15.1 tonnes	11.4 tonnes	11.3 tonnes	11.2 tonnes
Operating Speed	210km/h	220km/h	270 km/h	285km/h*	300km/h*

* Sanyo section

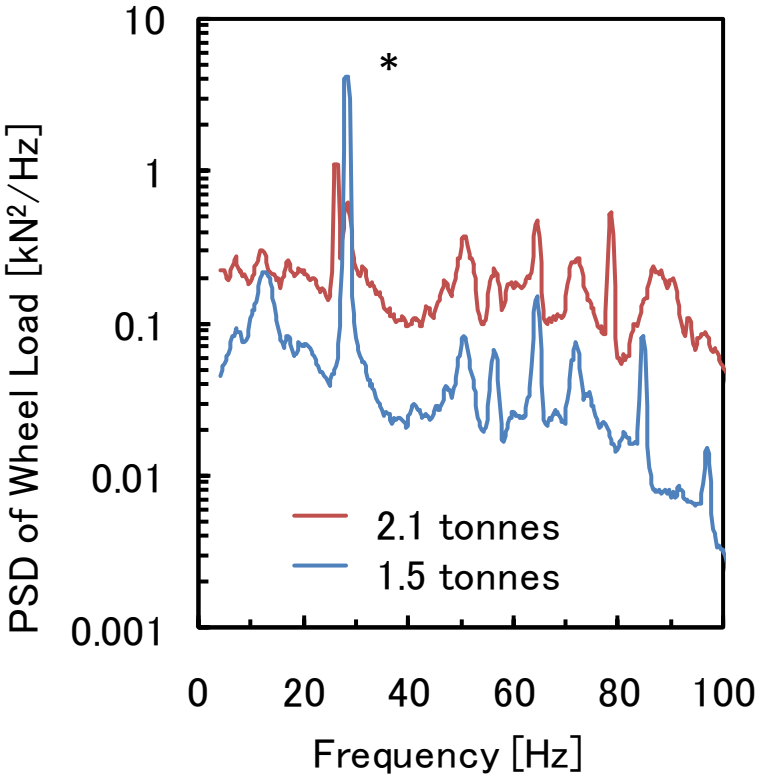
JRC's Rolling Stock



Vehicle unsprung-mass lightening

Unsprung-mass lightening

- Not only was axle load decreased, but unsprung-mass was also lightened
- Wheel-load variation was reduced over the wide frequency by lightening the unsprung-mass



* Peaks around 30Hz are caused by rail surface roughness (to be explained below) and/or vibration caused by wheel rotation.
* Before rail quality management.

Ref[6]

4. Maintenance of ballasted track

— Rail quality management

Reduction of longitudinal roughness

↓

Reducing dynamic wheel load

↓

Achieving reduction of tamping workload

Cross-section re-profiling

↓

Reducing dynamic lateral force

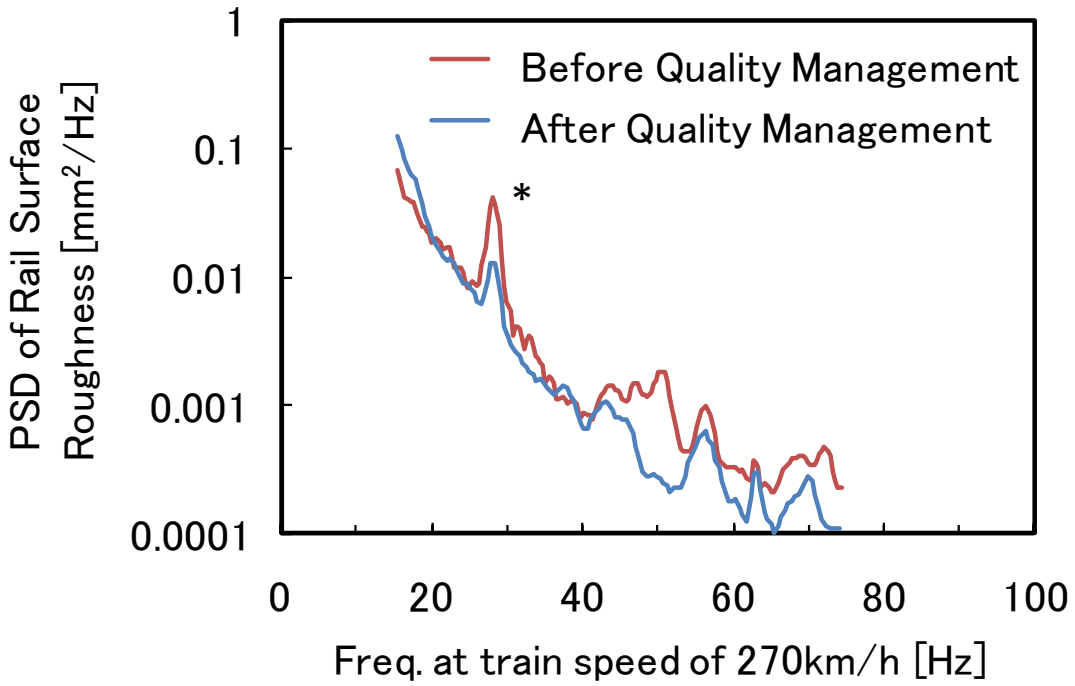
↓

Achieving reduction of lining workload

Rail quality management

Reduction of longitudinal roughness

- has the effect of suppressing track settlement by decreasing dynamic wheel load
- are achieved through rail grinding work and quality management performed by rail suppliers



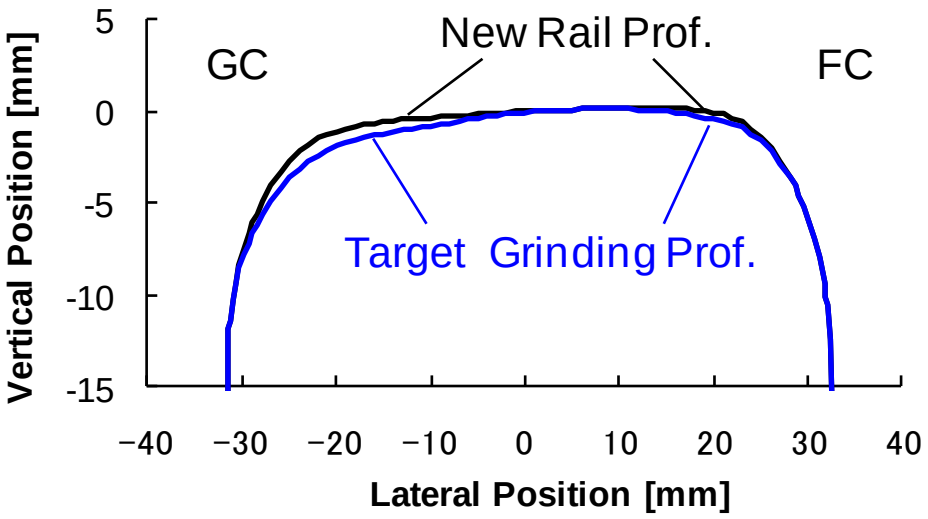
* Peaks around 30Hz cause large dynamic wheel load, as previously explained.

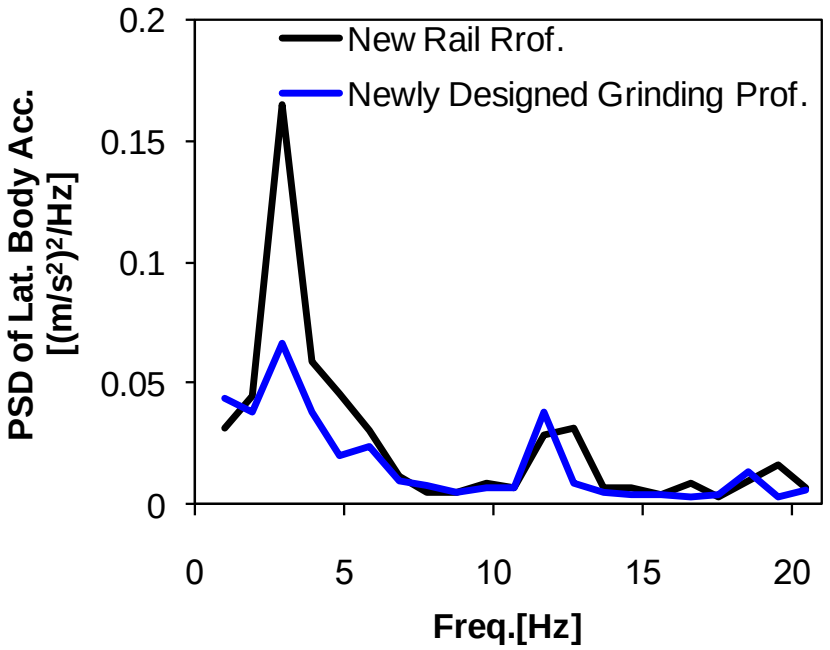
Ref[7]

Rail quality management

Cross-section re-profiling

- inhibits lateral plastic deformation of track by decreasing dynamic lateral force caused by bogie yaw motion
- are achieved through rail grinding work





Ref[8, 9]

4. Maintenance of ballasted track

— High-performance machinery

— Computer-systemized management

Maintenance Machines for Ballast Replacement Work

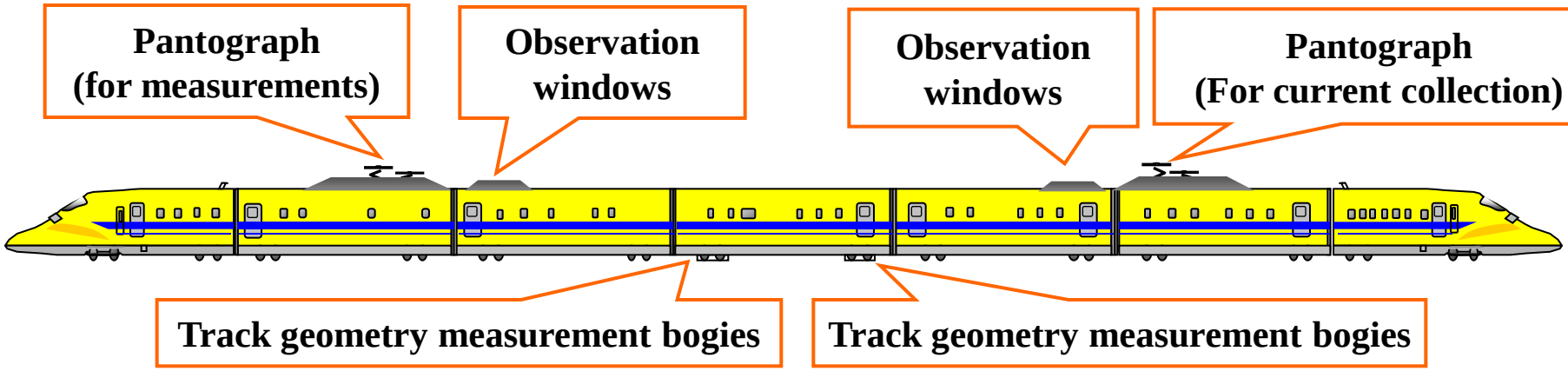
(1) Ballast replacing
(Japanese-Made Machinery)

(2) Tamping and correcting track irregularity

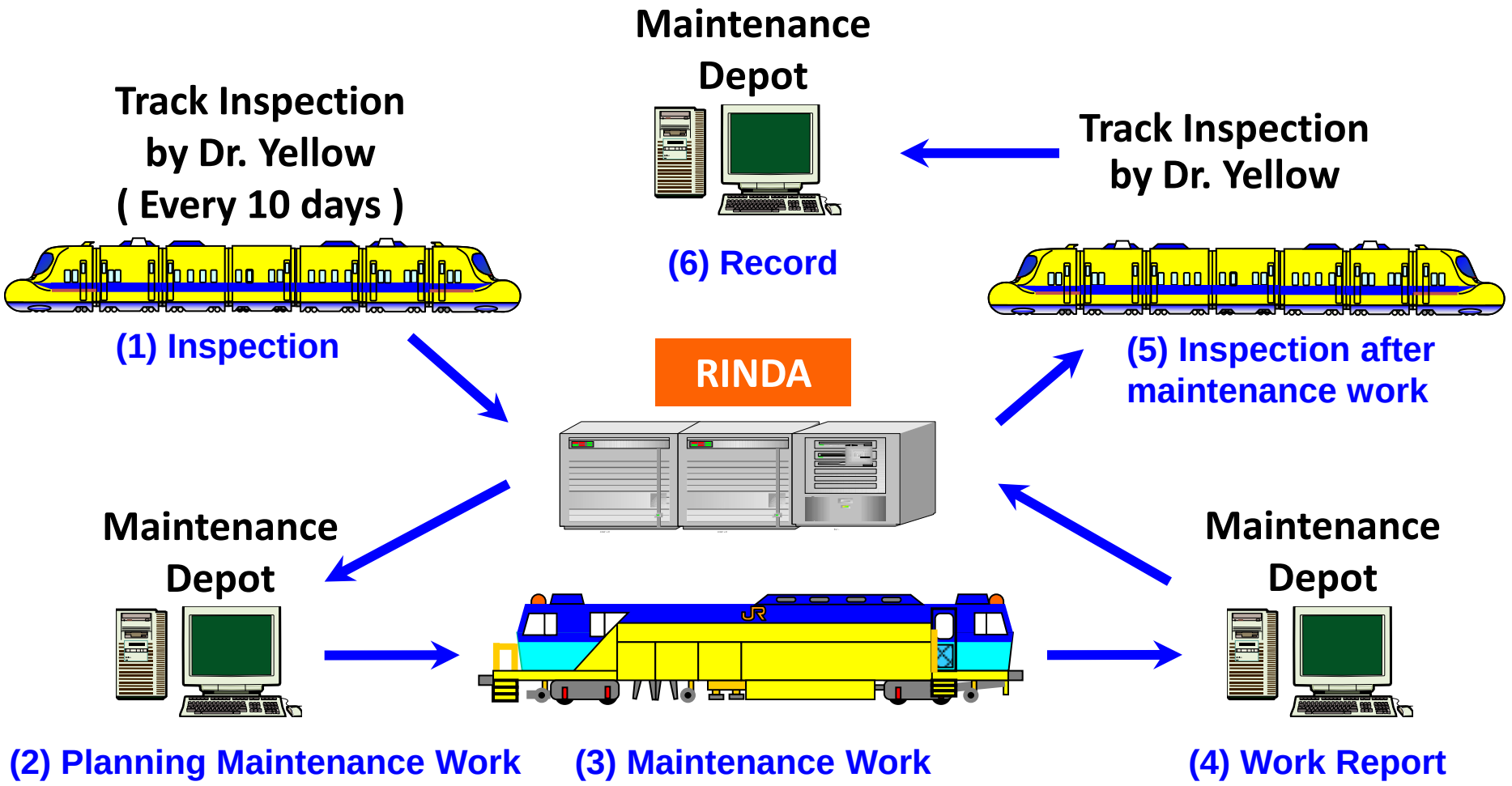
(3) Ballast distributing and profiling

(4) Ballast stabilizing and measuring track irregularity

Inspection Train “Dr. Yellow”



Maintenance Management System



RINDA : Relational & INtegrated DAtabase system for Shinkansen Tracks

- Management of data relating to each type of plan, riding comfort, rail inspection, and maintenance cars and machinery.

Daily Track Inspection by Commercial Trainset

"RAIDARSS" : Real-time Acceleration Inspection Device with Automatic Recording System for Shinkansen

Carbody Accelerometer

Longitudinal Irregularity and Axle Box Accelerometer

On-board Analyzer

General Control Center

Six N700 Trainsets with RAIDARSS

When RAIDARSS finds that measured data exceed limits for immediate work order, the alarm is sent to the general control center by radio system.

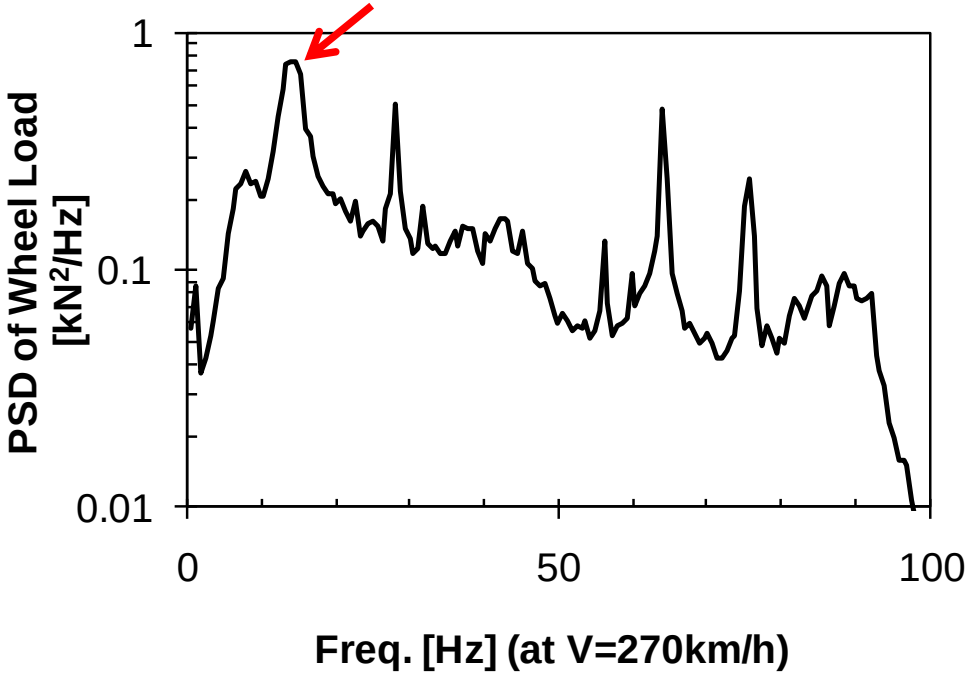
Ref[10]

5. An example of ballasted track issue in the aim for greater maintenance efficiency

Issue in the aim for greater maintenance efficiency

Dynamic wheel load reduction related to short wave track irregularity

- Wheel-load variation of about 15 Hz became more dominant than others (rail roughness, etc)
- Cause of the vibration is bogie pitching motion (analyzed by vehicle/track computer simulation)

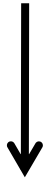


Ref[7, 8]

Issue in the aim for greater maintenance efficiency

Dynamic wheel load reduction related to short wave track irregularity

- This 15 Hz vibration intensifies in a particular location such as soft foundation.
- Then, short wave track irregularities tend to occur and grow larger.



- We are now employing theoretical and practical methods in researching the cause of this phenomenon and developing techniques for reducing tamping work.

Ref[7]

JRC's "KOMAKI" Research Center

Ref[2]

Test equipment “TRADYS”

TRAck and Stractural DYnamics Simulator

Ref[6]

6. Slab track in Japan

Ballasted track? Slab track?

- As well as ballasted track, Japan also has about 40 years of practical experience with slab track.
  - ✓ Initial cost : Ballasted track ≈ Slab track
  - ✓ Maintenance cost : Ballasted track > Slab track
- Newly constructed Shinkansen lines in Japan have adopted slab track for almost the entire length.

Photo:
Japan Railway Construction, Transport and Technology Agency

Ref[11, 12, 13]

Most appropriate track for the Tokaido Shinkansen

Ballasted track? Slab track?

- However, replacing the Tokaido Shinkansen's ballasted track with slab track is unrealistic.

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- ✓ account of the overall economical efficiency
- ✓ difficulty in performing such work while daily train operation is ongoing

- Therefore, we will continue in our endeavor to make further advances with ballasted track.

Concluding remarks

Concluding remarks

- JRC has developed ballasted track maintenance on the Tokaido Shinkansen successfully accomplished with :

  - ✓ Track engineers' strenuous efforts
  - ✓ Technological research and development, especially considering vehicle track interaction
  - ✓ Highly systemized management with computer and work with higher performing track maintenance machinery

Masahiro MIWA, **Central Japan Railway Company (JR Central)**

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