Some Demands for running on one-and-the-same Route higher Axle-Load (25 t) Freight Trains under a mixed Traffic Scheme plus Passenger Trains of different Speed-Profiles: 80 to 110 kmph Speed-Band ICF Coach Trains and 130 to 160 kmph Speed-Band LHB Coach Semi High-Speed Trains

Part I

Track & Rolling Stock Technologies, Logistics/Infrastructures, Signalling Systems, and Long-Term Capital Investment Schemes

India’s Proud: The Gatimaan Express No. 02050 on its inaugural Run H. Nizamuddin-Agra on 5 April 2016; max. Speed: 160 kmph; Station to Station Journey Speed: 112 kmph

By Dr. Frank Wingler, March 2017
http://www.drwingler.com
“Challenges in Design and Maintenance of Track under Mixed Traffic Regime of Semi High-Speed and heavy Axle-Load”

had been the topic of the International Technical IPWE Seminar held 12th &13th January 2017 at Mumbai.

The topic is an appeal to the ingenuity and skills of Indian Track Engineers and Experts to make tracks fit to match with the increasing strain and stress exerted by increased Axle-Load up to 25 t of Freight Trains running under a mixed Traffic Scheme with Passenger Trains of different Speed Profiles in the 80 to 110 kmph speed-band with ICF Coaches and in the 130 to 160 kmph speed-band with LHB Coaches, latter as so-called “Semi High-Speed Trains”.

The Seminar has revealed again that amongst Indian Track Engineers and Experts the knowledge on technologies, methodologies, standards, schedules, designs and specifications are at hand how to design and achieve High Quality Tracks up to international state-of-the-art and modern standards.

The growing economy in India has led to an increasing need for mobility. India has to improve convenience by higher Train Speed to connect the cities by shorter travelling time. To increase the Speed of Passenger-Trains to 160 kmph on existing routes and to use such routes also for higher Axle-Load Freight-Trains is a long-term corporate objective in India based on ambitious policy initiative.

The technical demands on track structure with its components/constituents are high to run under a mixed Traffic Scheme on one-and-the-same route 25 t Axle-Load Freight Trains together with 80 to 110 kmph speed-band Passenger Trains with ICF Coaches and 130 to160 kmph speed-band Semi High-Speed Trains with LHB Coaches – trains with different Speed-Profiles. The demands on the track structure to meet with the increasing strain and stress exerted by the Axle-Load and Speed Increase are high; the demands on appropriate infrastructures and track-layouts are as well very high.

In the Paper No. 22, Session II (see Annexure II):

Challenges in Design and Maintenance of Track Structure for mixed Traffic Regime on IR

Vipul Kumar and Ajay Kumar, RDSO, argue critically about the increasing strain and stress exerted on the Track Structure components. The authors explain how larger anticipated lateral forces arising out of the 25 t operation coupled with locked up thermal stresses in rails may lead to severe misalignment in track, even leading to derailments bringing Train-Passengers at risk. On the same time, high dynamic vertical load will cause high bending stress in rail causing decrease in fatigue life of track components in general and sudden failure of
weekend section in particular if got combined with large track and other vehicle defects.

The increased loading on track by increased Axle-Load and Train-Speed leads to faster rate of deterioration of track geometry and also decreased fatigue life of rails, welds and other track components thus causing increase in number of rail-weld failures.

Swedish studies on the Heavy Haul iron ore Malmbanan reported in the report ORE, D/141/RP 5, indicate that cost of maintenance increases by 37% for 10 % increase in Axle-Load.

The authors report: Heavy loading on track requires enhanced level of maintenance thus increasing the requirement of maintenance blocks and other resources. But the situation is grim and getting worse day by day. The corridor blocks have practically vanished. There is severe crunch of resources for last so many years. This situation is putting lot of pressure on infrastructure and resulting into huge maintenance arrears, abnormally high in-service failures, increased downtime and causing grave risk to passenger carrying trains.

With the everlasting BUDGED CONSTRAINTS OF INDIAN RAILWAYS there are doubts that within the next decade the envisaged routes can be made fit and adequately maintained at high Quality Level to match with the strain and stress of the traffic load exerted by the envisaged mixed Traffic, and that the appropriate infrastructures and track layouts for running trains with different Speed-Profiles and Speed-Bands can be achieved.

IR has still to fight with Budged Constraints to bring down the increasing number or killed and injured Train-Passengers in unwanted nasty Derailment-Disasters.

The realisation of the ambitiously aspiration of a mixed Traffic-Scheme with heavier axle-load freight trains running together with 80 to 110 kmph speed-band and 130 to 160 kmph speed-band Passenger-Trains on the same routes will need huge capital investment schemes of which IR is already short of.

Politicians should not oversee that in-service failure of assets can lead to devastating consequences at higher speed of operations. Presently there is no other Railway around the globe, from where so many nasty and fatal Train Accidents with such frequent high mortality rates can be reported than from India!

Increase of Traffic Density by increase or Route Capacity is without doubts of paramount importance to meet with the increasing demand of the growing economy. What counts is not so much the max. train-speed but the travel-time from A to B resp. the connecting time between cities. Journey time has
to be cut. The relatively low Route Capacity of Indian Rail Routes ails Indian Railways due to the infrastructure-and track-layout bottle necks and the present signalling system sans Automatic Train Protection. With modern state-of-the-art signalling (ETCS Level 1/Level 2) the route capacity and hence the transport capacity could be increased without the need to increase the Axle-Load of freight trains, in order to meet with the demand for the higher transport capacity.

India’s proud, the Gatimaan Express needs for its 188 km journey between H. Nizzamudin and Agra Cant 1 h and 40 min. Although this so-called “Semi High-Speed” train can run with a speed of 160 kmph it runs from station to station with an average journey speed of only 112 kmph due to route bottle necks.

To eliminate logistic constraints/bottle-necks for the envisaged Mixed Traffic Schemes with trains of different Speed Profiles will become a herculean task and will need a long-term high input of massive capital investment in Infrastructure Enhancements, Adjustments in Track Layouts, Tripling and Quadrupling of Lines, Provision of By-Pass Lines and Deployment of Automatic Train Protection (ETRC Level 1).

IR can learn a lot from British Railways how to reduce station to station journey time by deploying fast accelerating dual-mode Diesel and electric propelled light weight EMU/DMUs with power distribution and by modernisation of the infrastructure as by the West-Coast Modernisation Project; how under this programme over a decade the infrastructure and track layouts got adjusted to meet with the logistic demands for mixed-traffic and higher speed (200 kmph), especially in the conurbations, at the junctions and railway stations.

On Britain’s Railways the culture of systemic maintenance, operating environment and discipline are far more well defined and professionally followed than that on IR. Even the acceptance criteria for freight stocks on BR are far stricter in comparison to IR.

The possibilities and methods to increase the freight transport capacity and to shorten the journey times for train passengers in the Axle-Load Range of 16 to 21.5 t and in the Speed Band of 80 to 130 kmph are not completely outbidden yet.

In order to ease the traffic flow and to keep the trains running at congested sections, the trains can be segregated by speed and priority with fly-over/over-bridge/grade-separator/over- and under-pass/by-pass. This can help that valuable gain in journey-time by speed-increase will get less squandered due to bottle-necks and constraints of infrastructure and track-layout. Enhanced traffic-management can also help to improve the rail-traffic flow. In this respect IR can learn from the railways in Switzerland.
200 kmph dual-mode (bimodal) Electric-Diesel propelled Hitachi Light-Weight Train-Set with Power Distribution for British Railways

Track Segregation with Fly-Over in Switzerland
One can learn from Highway Engineers how to keep by route-segregation the traffic flowing:
Sturdy Concrete Fencing-Infrastructure has to be provided to secure Semi High-Speed Tracks from encroachments and trespassers, especially in conurbations. Only wire-mesh will not do in India:

In the Paper No. 15, Session II, the speaker Mr. N Rangaraj points out that the simulation of mixed Traffic Railway Networks carrying Semi High-Speed Passenger Trains and high Axle-Load Freight Trains with different speed profiles reveals a **Loss of Route-Capacity**, when permitting higher priority Semi High-Speed Passenger trains to overtake slower trains, and when Passenger Trains have to compete for path with higher Axle-Load Freight Trains.

Tracks have to be maintained at **High Quality Level**. This will be only possible with deployment of heavy-duty on-track machinery. To operate track maintenance machines economically and cost-efficient, their full potential needs to be unlocked. This means that for the economical deployment of heavy-duty on-track machinery longer traffic blocks must be made possible, which is a logistic challenge, and which to solve needs also capital investment. The present availability of traffic blocks are mostly too low, and the block times are too short for an economical deployment of such costly machines; see Paper 16, Session II by Pradeep Kumar Garg, Chief Engineer (Track Machines) Central Railway: Issues involved in Maintenance of Track carrying Heavy Axle-Loads in Reference to Deep Screening.

First of all it should matter to bring down the number of killed and injured train-passengers on all routes in unwanted nasty Derailment-Disasters (since 2014 on increase), which have their root in unsafe conditions (often of far reaching history) regarding Track-Defects, -Shortcomings, -Deficiencies and -Flaws. Freedom from Train-Passenger`s bodily harm and injury matters.
The Seminar reveals again that Indian Railways needs:

♦ Certainty for long-term capital investment-schemes for Safety, Infrastructure, Rolling Stock-Renewal, Signalling (Train Protection) and Track-Rectification related works.

♦ Modern proactive Maintenance-Strategies and predictive Maintenance Regimes making use of modern Track Inspection/Detection/Monitoring Technologies and Heavy-Duty On-Track Machineries shaping the future of sustainable Track Maintenance.

♦ Modern Target and Preventive Rail Grinding and Friction Management cum Rail Lubrication in order to extend rail asset live.

♦ Strengthening, Overhaul, Upgrading, Stabilisation and Rehabilitation of Track Sub-Structure Components/Constituents yielding in higher and less fluctuating Stiffness, Bearing Capacity and Support Modulus.

♦ For Super-Structure: Attendance free “fit-and-forget” Rail Fastening Systems (the Pandrol Fast-Clip is an advisable System), thicker Rail-Pads, Heavy-Duty Concrete Sleepers, Under-Sleeper-Pads, long milled and Flash-Butt welded Rails, Rails with increased hardness, new Turnout-Technologies/Designs with canted Rails allowing higher speed.

♦ Automatic Train Controls, something like ETCS Level1/Level 2.

♦ Way-Side Monitoring of flat Wheels, Wheel Impact Load Detectors (WILD).

♦ Track friendlier and faster accelerating Rolling Stocks:

   a) Replacement of track unfriendly running ICF Coaches by more track friendly running LHB Coaches with Fiat Flexi-Coil Bogie,
   b) modern track friendlier Bogies for Freight Wagons,
   c) possibly articulated track- resp. curvature-friendly light weight Talgo Coach-sets (with only one individual spinning wheel-set per coach) for Semi High-Speed Trains,
   d) possibly dual-mode (bimodal) light weight Diesel and electric propelled Rail-Car Trains with power distribution (like Hitachi dual-mode (bimodal) Train-Sets).
1) In his Paper No. 7, Session I, Mr. Gopalakrishnan points out:

“The Indian Mark III ERCs due to various reasons do not sustain designated toe load (clamping force), and it is high time to turn towards modern Fasteners”...” It can be stated, if someone develops a new fastener and if it passes through the tests successfully as prescribed in EN-13481 specification, the fastener is ready to be used on track”.

The Pandrol Fast Clip is indeed in compliance with the European Norm EN 13481:
COMPLIANCE WITH STANDARDS:
PANDROL FAST-CLIP FE 1400 series fastenings are compliant with the requirements of EN 13481-2:2012 and the High Speed Interoperability Directive (TSI). PANDROL FAST-CLIP FE 1500 series fastenings are compliant with the requirements of EN 13481-8:2012 – Fastening systems for track with heavy axle-loads. Some configurations of Pandrol Fast-Clip FE 1400 and FE 1500 series fastenings are compliant with the requirements of AREMA Manual Chapter 30, Part 4.

Note: This reveals that no new fastener has to be developed for IR. The Pandrol Fast-Clip is ready to be used, also on IR tracks. Around the globe this fastener is superseding the Pandrol right-handed e-Brand and left-handed 401-Series self-tensioning elastic rail clips.

See Technical Railway Paper

Rail-Fastening Demands for Semi High-Speed Rail Roads
Demand for Attendance-free “fit-and-forget” Rail-Fastening on envisaged IR “Semi High-Speed” Routes – Pandrol Fast-Clip an advisable Solution

by Dr. Frank Wingler, free to download from the website:

http://www.drwingler.com

PART II
INHERENT TRACK-QUALITY
THE ROLE OF SUBSTRUCTURE COMPONENTS

In his presented Paper No. 2, Session I, of the International Technical IPWE Seminar, held 12th & 13th January 2017 at Mumbai (see Annexure I):

Important Track Design Parameters to cater Semi High-Speed & heavier Axle-Load Trains

Professor Ramesh Pinjani, Institute of Civil Engineering Pune, used the term “Inherent Track Quality”.

A Rail Track of HIGH INHERENT TRACK-QUALITY shows a lower Deterioration Rate
➢ it deteriorates slower over the time under given Traffic Load/Strain; or with other words: It loses its Track Parameters with a slower Rate over the time under given Traffic-Load/Strain after Realigning/Overhaul, and it inherits a longer period until the threshold is reached for the next realignment ( - the outcome of a Track Realignment/Overhaul is long-lasting - )

than a Rail Track of **LOW or POOR INHERENT TRACK-QUALITY**, which shows a faster **Deterioration Rate**

➢ it deteriorates faster over the time under given Traffic Load/Strain; or with other words: It loses the Track Parameters with a higher Rate over the time under given Traffic Load/Strain after Realigning/Overhaul, and it inherits a shorter period until the threshold is reached for the next realignment ( - the outcome of a Track Realignment/Overhaul is short-lasting - ).

A Rail Track of **LOW or POOR INHERENT TRACK-QUALITY** is far more costly to maintain, in order to keep it in good and safe condition, than a Rail Track of **HIGH INHERENT TRACK-QUALITY**. A Rail Track of **LOW or POOR INHERENT TRACK-QUALITY** needs Overhaul in shorter intervals. The Maintenance Expenditures over the Live Cycle can be 8 times higher.

A Rail Track of **LOW or POOR INHERENT TRACK-QUALITY** creates far higher overall **Life Cycle Costs** inclusive the aggregated “**Hindrance Costs**” – the Cost, created and appearing when the trains cannot run or can run only in less density and/or with reduced speed.

**HIGH INHERENT TRACK-QUALITY** cuts not only overall **LIFE CYCLE COSTS** but makes tracks far less prone for **DERAILMENT-DESASTERS** killing and injuring Train-Passengers.

Around the globe there is no other country with so many Train Accidents killing and injuring so many Train-Passengers, other than India.

The Indian Government promotes the Tourism in India worldwide with the slogan:

“**Incredible India**”

The frequent nasty and unwanted Train-Accidents (since 2014 on increase) in India, killing and injuring so many Train-Passengers, is for an outsider really **INCREDIBLE!**
HIGH INHERENT TRACK-QUALITY on all IR Routes should be a MUST not only for economical reason or to allow a MIXED TRAFFIC SCHEME WITH SEMI HIGH-SPEED TRAINS and 25 t AXLE-LOAD FREIGHT TRAINS, but also because

Train-Passenger`s Freedom from bodily Harm and Injuries matters first of all.

Prof. Pinjani mentioned factors, which determine INHERENT TRACK-QUALITY.

The INHERENT TRACK-QUALITY is predominantly governed by the Quality (Stiffness, Support Module, Bearing Capacity, Water Content and Resistance against Stress) of Substructure Components: Subsoil, Subgrade and Formation.

The “Memory” for Track Instabilities/Misalignments is buried mostly in what is under the ballast-bed: Formation, subgrade and subsoil. Fluctuation/Undulations of stiffness/support modulus/bearing capacity as well low stiffness/support modulus/bearing capacity along the track-bed can be made responsible for low inherent track quality. Water is the enemy of the track-bed. Longevity of track overhaul or renewal depends in high extend if Water can be taken out and kept away from the track-bed. Seasonal Water-increase or -decrease is deadly for the stability of a rail road; see Technical Railway Paper BALLAST, FORMATION AND DRAINAGE; Chapter 18: Track Standards, Track Rehabilitation; Guidelines and Specifications for Design of Formation for higher Axle-Load with the INTRODUCTION: FUNDAMENTALS OF MODERN RAIL-TRACK TECHNOLOGY in INDIAN RAILWAY TRACKS – A TRACK ENGINEERING COMPENDIUM - free for download from the website:


In German Federal Railways, if the formation support modulus comes under 10 MPa/m² the threshold for intervention by a FORMATION REHABILITATION will be reached.

In Sri Lanka the author monitors some shining teaching samples of MEMORY for misalignments (at Kandegoda and Hikkaduwa-Tiranagama, Coast Line), which he regularly monitors since over 16 years. Even after the complete track renewal by IRCON INDIA and lifting the rails by 2 feet with sub-ballast and ballast and after up to 6 rounds of Tamping with a Plasser&Theurer Unimat the same misalignment patterns appear after few months; this had appeared already before the track renewal. The cause is the water below, rising and sinking with the season. A comprehensive surface water management had not been possible for IRCON.
A comprehensive surface water management in water affected areas can be helpful to increase the INHERENT TRACK-QUALITY.

Prof. Pinjani underlines:

**The quality of track on initial laying/relaying is the most important factor to affect the rate of track geometry deterioration, therefore track laying quality is to be given due importance.**

Once a subgrade or subsoil mistake is made the mischief can later not be rectified. A Track can be only as good, as what are the properties of the underlying Substructure Components: Subsoil, subgrade and formation.

The increasing stress in the substructure components, caused by higher speed and axle-load, must be addressed by improving their characteristics using FORMATION IMPROVEMENT TECHNIQUES.

It comparison, it will become easier to fulfill the superstructure component demands on

rails, rail-profiles, rail-lubrication, turnouts, rail--fastening systems, elastic pads, rail-welds, sleepers, ballast, blanket-materials

for envisaged mixed traffic schemes with faster running passenger trains and 25 t axle-load freight trains.

But most of the existing tracks in India have been designed before independence. The question is, will the subsoil, subgrade and formation of those existing tracks match with the new demands for higher speed and heavier axle-load trains?; see Technical Paper No.4, Session I: Stress Assessment in Railway Foundation System for Semi High-Speed and high Axle-Loads Train by R.P.Singh and Yerramshetty Srinivas, presented on the International Technical IPWE Seminar, held 12th & 13th January 2017 at Mumbai.

Prof P. Veith and Dr. B. Lichtberger, Austria, speak about INITIAL TRACK-QUALITY, if it comes to the Quality of new, re-laid, renewed, upgraded or overhauled tracks; see RTR Special Maintenance & Renewal, July 2007, ISBN: 978-3-7771-0367-9, eurailpress, Hamburg, Germany.

The author travels frequent in India by rail. He noticed that embankment-fill for the line duplication between Kanjankulam Jn. and Kottayam resp. Allapuzha in Kerala had been laid on marshy land without excavation of the soft, wet and organic material containing subsoil. With such inferior works the
memory for poor inherent track quality of a track, which cannot retain its alignment, is born.

In his presentation No. 8, Session I, R.P. Singh, Asst. Professor/Track/IRICEN, *Issues related with Compaction during Construction of new Railway Embankments for heavy Axle-Loads* points out the required quality of the subgrade, subsoil and embankment fill materials and their compacting.

The author noticed that the recently laid double track between Arsikere and Birur in Karnataka reminds more of a *roller-coaster-line* than of a level and stable railway line. This new track got already spoiled from the beginning for later to come 160 kmph. Same is now with the new BG Track between Miraj Jn. and Pandharpur, Maharashtra, after Gauge Conversion.

**The QUESTION is:**

Is the CONCEPT of an envisaged MIXED TRAFFIC SCHEME with freight trains with increased Axle-Load up to 25 t on routes for 80 to 110 kmph speed-band running ICF coach passenger-trains and 130 to 160 kmph speed-band LHB coach Semi High-Speed passenger-trains prudent? ;

c since most of the alignments are still resting on old Sub-Structures of poor Stiffness, Bearing-Capacity and Support-Modulus!

**ANNEXURE I**

**Important Track Design Parameters to cater Semi High-Speed & heavier Axle-Load Trains**

By Ramesh Pinjani and Sandip Kumar Saha
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Important Track Design Parameters to cater Semi High-Speed & heavier Axle-Load Trains

Ramesh Pinjani*
pinjani@iricen.gov.in

Synopsis

The paper deals with considerations of important track design parameters, i.e. static vertical load intensity, dynamic augment, rate of track geometry deterioration, target defect wave length for track geometry correction, implications of specific locations such as curved track, abrupt change in sub grade stiffness to cater semi high-speed and heavier axle-load trains, including proposed actions to deal with.

1. Introduction:
   A Case of Tokaido Shinkansen

1.1 The loading considered on Indian Railways for calculation of rail stresses (track stresses) are explained in the Fig. below:

```
Stresses at centre of foot = stress due to vertical bending, stresses at edge of foot = a + b - c + d
```

*Sr. Professor/Bridges; IRICEN, Pune*
The magnitude of rail stresses considered on various accounts is as under Tab. 1:

<table>
<thead>
<tr>
<th>SN</th>
<th>Item</th>
<th>Value in [N/mm²] for 90 UTS Rail</th>
<th>% Age of permissible Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ultimate tensile strength</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Yield strength (52% of average value of observed (UTS) i.e. stress at 2% strain (proof strain))</td>
<td>468</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Stress for unforeseen reasons such as flexed laying on curve, uneven heating of rail faces etc. @ 10% of yield strength</td>
<td>48.00</td>
<td>10.2%</td>
</tr>
<tr>
<td>4.</td>
<td>Thermal stresses in LWR</td>
<td>107.50</td>
<td>23%</td>
</tr>
<tr>
<td>5.</td>
<td>Residual stresses in rails</td>
<td>60.00</td>
<td>12.8%</td>
</tr>
<tr>
<td>6.</td>
<td>Induced stresses due to rolling stock (permissible stresses on yield consideration)</td>
<td>252.50</td>
<td>54%</td>
</tr>
</tbody>
</table>

**Note:** The rail stresses for unforeseen reason includes flexed laying of rails on a 4° curve and one sided radiation of sun. However, it does not account for impact of wheel irregularities, rail/weld irregularities being of instantaneous nature. The factor of safety of 1 is considered, i.e. rail is being loaded to full yield strength.

2. The mixed traffic involving semi high-speed passenger trains (with speed of 160 to 200 kmph) and heavier axle-load (with axle-load 30 to 32 t) freight trains pose variety of challenges to the track. The design of track components and evolving track maintenance features/practices for such traffic conditions requires proper understanding of various important track design parameters, these are discussed hereunder.

2.1 **Static Stresses due to vertical Bending**

a) **Static Stresses in Rail**

Considering track as an infinitely long rail (CWR track) with bending stiffness $E_1$, continuously supported on an elastic foundation with track modulus ($\mu$); **Fig. 1:**

![Fig. 1: Infinite Beam Model](image)
The Bending Moment (BM) in rail follows following equation:

\[ M(X) = \frac{QL}{4} \mu(\chi), \text{ where: } \mu(\chi) = e^{-\chi \frac{L}{x}} \left[ \cos \frac{x}{L} - \frac{L}{x} \sin \frac{x}{L} \right] |x \geq 0| \]

Maximum BM under single load = \( \frac{QL}{4} \),

where \( L \) = characteristic length = \( (\frac{AEI}{U})^{1/4} \).

Mean stress in rail \( \sigma_{\text{mean}} = \frac{QL}{4z} \), where \( z \) is section modulus relative to rail foot.

b) **Static Rail-Seat Load for Sleeper:**

Considering track as beam of infinite length supported on elastic foundation, the Static Rail seat load is governed by following equation:

\[ Q_s = QS \left( \frac{U}{64EI} \right)^{1/4} \]

wherein \( Q \) is static wheel load i.e. axle load divided by 2, \( S \) is sleeper spacing

\( U \) is track modulus i.e. load per meter length of track to cause unit deflection in track

\( EI \) – bending stiffness of rail.

c) **Vertical Stress on Ballast-Bed:**

\[ \sigma_{\text{ab,mean}} = \frac{F_{\text{mean}}}{Asb} = \frac{Q}{2L Asb} = \frac{QS}{2 \left( \frac{U}{64EI} \right)^{1/4} Asb} = \frac{QS \left( \frac{U}{64EI} \right)^{1/4}}{Asb} \]

where Asb=contact area between sleeper & ballast bed for half sleeper.

**Implications:** The heavier axle-load means higher wheel-load, which will result into higher B.M. & higher stress in rail, higher static rail-seat load on sleeper & higher vertical stress on ballast-bed & formation; **Tab. 2:**

<table>
<thead>
<tr>
<th>Tab. 2: Increase of Stress with Axle-Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High-Speed Passenger Trains</strong></td>
</tr>
<tr>
<td>(increase w.r.t. 22 t Axle-Load)</td>
</tr>
<tr>
<td>160 kmph</td>
</tr>
<tr>
<td><strong>No change</strong></td>
</tr>
</tbody>
</table>
Action proposed-1:
The fatigue life of track components mainly rail, sleeper, rubber pad, ERC required to be evaluated/assessed for higher stress cycle. Otherwise under higher stress cycle loading, fatigue failures associated with sudden & abnormal rate of failures of track components may take place, posing serious problems of safety of traffic.

2.2 Stresses due to lateral Load

The generation of lateral/flange force will depend upon speed, axle load & conicity of wheel & play. Under semi high speed & heavier axle-load the lateral flange force will increase. The play needs to controlled & conicity of wheel can be 1 in 40 in place of 1 in 20, accordingly rail profile will require to be re-designed.

3. Dynamic Augment

As per Indian Railway Works practice (RDSO guidelines) the dynamic augment is governed by C-100 Report. The dynamic augment reported for various rolling stock at their maximum permitted speed, based on RDSO trials in June-2005, is as under:

<table>
<thead>
<tr>
<th>Rolling Stock</th>
<th>Speed kmph</th>
<th>Dynamic Augment using WILD* (% Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box N</td>
<td>75</td>
<td>55% approx.</td>
</tr>
<tr>
<td>Box NHS</td>
<td>75</td>
<td>50% approx.</td>
</tr>
<tr>
<td>WDM2</td>
<td>110</td>
<td>95% approx.</td>
</tr>
<tr>
<td>BCN</td>
<td>75</td>
<td>50% approx.</td>
</tr>
</tbody>
</table>

*: Wheel Impact Load Detector

Now as per European practice, the Dynamic Augment is based on the following equation:

$$\sigma_{\text{max}} = DAF \times \sigma_{\text{mean}}$$

where $\sigma_{\text{max}}$ is maximum stress in rail/sleeper/ballast bed, $\sigma_{\text{mean}}$ is mean stress in rail/sleeper/ballast bed

DAF is dynamic amplification factor

$$\text{DAF} = 1 + t \phi \left(1 + \frac{\nu - 60}{140}\right)$$

t is multiplication factor of S.D, which depends upon confidence
interval, is a factor which depends upon track quality. The value of t & φ is given here under:

<table>
<thead>
<tr>
<th>T</th>
<th>Probability</th>
<th>Application</th>
<th>Track Condition</th>
<th>φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68.3%</td>
<td>Sub grade Contact stress</td>
<td>Very good</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>95.4%</td>
<td>Ballast bed</td>
<td>Good</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>99.7%</td>
<td>Rail stresses, sleepers, fastening</td>
<td>Bad</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Note:** The maximum stress is generated in rail foot centre due to repeated loading causing fatigue fractures.

**Implications:** The high-speed means higher dynamic augment, which will result into higher BM & higher stress in rail, higher rail seat load on sleeper & higher vertical stress on ballast bed & formation.

<table>
<thead>
<tr>
<th>Higher Speed Passenger Trains (Increase w.r.t 130 kmph)</th>
<th>Heavier Axle-Load Freight Trains</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 kmph</td>
<td>200 kmph</td>
</tr>
<tr>
<td>14%</td>
<td>33%</td>
</tr>
</tbody>
</table>

**Action proposed-2:**
The maximum stress for track components mainly rail, sleeper, rubber pad, ERC under IR track maintenance conditions required to be evaluated/ assessed for higher stress cycle. The concrete sleeper & rubber pad will require to be redesigned. Rails with better metallurgical properties at par with international practices, along with efficient handling practices, needs to be introduced.

4. **Rail Wheel Contact Stress**
The Rail wheel contact stress is governed by Equation:

\[ t_{\text{max}} = 4.13 \frac{Q}{\sqrt{r}} \]

where Q is static wheel load and r is radius of wheel negotiating the track.

**Implications:**

<table>
<thead>
<tr>
<th>Higher Speed Passenger Trains</th>
<th>Heavier Axle-Load Freight Trains (increase w.r.t 22.5 t axle-load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 kmph</td>
<td>200 kmph</td>
</tr>
<tr>
<td>No change</td>
<td>30 t</td>
</tr>
<tr>
<td></td>
<td>32.5 t</td>
</tr>
<tr>
<td></td>
<td>15% increase</td>
</tr>
<tr>
<td></td>
<td>20% increase</td>
</tr>
</tbody>
</table>
**Action proposed-3:**

Rail grinding & efficient rail top profile will help the situation.

5. **Forces due to Wheel-Flat and Weld**

   a) The wheel-flat causes generation of higher dynamic load getting transferred to track. The additional bending moment in rail due to wheel flat is given by the equation: \[ MF = 1.57 \times (10^5 + 11Q) \sqrt{f} \]

   where \( MF \) is additional bending moment by rail in KG-cm, \( Q \) is wheel load in KG, \( f \) is depth of Flat in mm.

   ![Figure: Vertical force under passage of wheel flat](image1)
   ![Figure: P1 & P2 forces under passage of wheel flat](image2)
   ![Figure: Dynamic amplification due to bad weld](image3)

   Note: Forces at frequencies above 500 HZ referred to P1 forces are important as far as wheel / rail contact stresses are concerned. The forces at frequencies below 100 HZ referred as P2 forces are more or less independent of speed.

   ![Figure: Dynamic force amplification versus speed during passage over bad weld](image4)

   Dynamic force amplification versus speed during passage over bad weld.

   b) The dynamic amplification of vertical force during the passage over a poor weld is presented as a function of speed. The dynamic amplification \( (\Delta Q / Q) \) of vertical load is expected to be very high, may be as high as 400%.

   **Note:** IR practice does not account impact of wheel-flat, rail/weld irregularities in rail stress calculations being of instantaneous nature.

   **Implications:** High frequency dynamic loads due to poor welds, corrugation and wheel-flats are very detrimental to the track. Concrete sleepers are very susceptible to these loads. The
properties of rubber pad carries maximum significance. The limiting depth of wheel flat needs to be specified instead of length of wheel flat.

**Action proposed - 4:**
The limiting depth of wheel flat needs to be specified instead of length of wheel flat. Quality of AT welding requires continuous monitoring & updating to keep par with international practices.

6. **Target Defect Wave Length Measurement and Correction**
The target wave length defects are those critical defects, which are required to be measured during track recording & subsequently eliminated during track maintenance operation. The wavelength of critical defects depends upon speed of the train and natural frequency of suspension system of the train. The critical defect wave length for high-speed passenger trains and heavy axle-load freight train is worked out based on following principles:

- The maximum disturbance shall occur when wave length of defect $\lambda c$ is such that at a particular speed of train the forced frequency of oscillation (generated due to defect) matches with natural frequency of suspension system.

- The wave length of defect which shall be critical (in vertical mode only) for various types of rolling stock, i.e. which are required be eliminated while track tamping is given by the Table below:

<table>
<thead>
<tr>
<th>Rolling Stock</th>
<th>Natural Frequency of Suspension (fn)</th>
<th>Speed V in kmph</th>
<th>Critical Wave Length ($\lambda c=V/fn$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box N</td>
<td>3.5</td>
<td>75</td>
<td>5.95 m</td>
</tr>
<tr>
<td>Heavy axle load wagon</td>
<td>3.0 (assumed)</td>
<td>100</td>
<td>9.25 m</td>
</tr>
<tr>
<td>ICF coach</td>
<td>1.2</td>
<td>130</td>
<td>30 m</td>
</tr>
<tr>
<td>High speed coach</td>
<td>1.0 (assumed)</td>
<td>160</td>
<td>44.4 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200</td>
<td>55.5 m</td>
</tr>
</tbody>
</table>

- The small wave length defects (in the range of 5 to 10 m) shall affect
running of goods train and longer wave length defect (in the range of 25 m to 55 m) shall affect running of passenger trains.

- To detect these defects (unevenness) the chord length for measurement should be in the wider range of 3.6 m to 27.5 m (as the chord length for measuring defect should be $\lambda c/2$ to achieve transfer function $TF=1$). Similar exercise needs to be done for lateral mode also for fixing up critical alignment defects.

**Note:** The railway track built on relatively soft subgrade, the critical regime is reached when the train velocity is near the shear wave velocity of subgrade. The magnitude of shear wave velocity is determined by equation, where $Cs=\sqrt{\mu/\rho}$, $\mu$ = shear modulus and $\rho$ is density of material. For subgrade of soft clay, the shear wave velocity lies between 150 to 250 kmph, accordingly, the track response is expected to be amplified when the speed is in the range of 160 to 200 kmph.

**Action proposed-5:**
The track monitoring with defect measurement using appropriate chord length is required, to pick up wider & relevant spectrum of track defects in horizontal & vertical mode.

7. **Rate of Track Propagation due to Fatigue Flaw in Rail/Weld**
The science of fracture mechanics deals with only propagation of cracks & fractures. In linear-elastic fracture mechanics, the crack tip stress intensity factor 'K' is used to characterize the magnitude of the complex stress and strain fields at the tip of a crack.

The magnitude of 'K' is simply a function of the nominal stress (\(\sigma\)) in the cracked structure, the size of the crack (a) and shape factor (Cs), which depends upon the geometry of the structure and the crack, such that

$$K = Cs\Delta\sigma\sqrt{a},$$

where $K$ = the difference between the maximum & minimum nominal stress levels in the fatigue cycle. At fracture, the critical stress intensity $K_p$ is attained with the corresponding critical stress $c$ and the critical crack depth $a_c$. 
Important Points on the Rate of Rail-Crack Propagation

The fracture toughness of rail steel decreases with increasing tensile strength. The values of $a_x$ & RFR (rail fracture resistance) decrease as rail strength increases. The critical crack size obtained using the above stress values works out 5-6mm for 90 UTS rails.

Flaw size smaller than $\lambda/2$ is considered as undetectable. The USFD testing can detect a flaw size $= 1$ mm approx. A crack of 1mm size exists in the rail at the time of detection, then the failure can be apprehended after passage of 8 GMT in 90 UTS rails.

Implications: The rate of crack propagation i.e. fatigue failure will increase under heavy axle load & high-speed trains.

Action proposed-6:
The frequency of USFD testing of rail & weld will require to be increased; the use of spurt car will help to implement it.

8. Location specific additional Factors

8.1 Curved Track Geometry

Presently curves are designed based on maximum & minimum speed of trains running in the section. In order to achieve even wear on both rails under heavier axle load freight trains & to control discomfort under high-speed passenger train, the design cant be worked on the basis of equilibrium speed using following equation (Russian Formula):

$$V_{eq} = \sqrt{\frac{\sum_{i=1}^{m} n_i w_i v_i^2}{\sum_{i=1}^{m} n_i w_i}}$$

where: $n_i$ = number of trains in $i^{th}$ set, $w_i$ = load of each train in $i^{th}$ set $v_i$ = speed of each train in $i_{th}$ set, $m$ = number of sets of trains.

8.2 Abrupt Change in Sub-Grade Stiffness

The change in stiffness causes increased dynamic forces, the extent of which is determined by speed, stiffness ratio, damping and the length of transition. The semi-high speeds trains will require larger transition track to introduce gradual change in stiffness of subgrade
on the approach of girder bridges, level crossings, points and crossings. This will help in controlling rate of track geometry deterioration at locations, where there is abrupt change in subgrade stiffness.

8.3 **Abrupt Change in vertical Alignment**

The changes in vertical alignment of track lead to increasingly pronounced vertical acceleration in the vehicle causing higher dynamic augment and passenger discomfort. The semi high-speed trains will generate higher dynamic forces & passenger discomfort at the locations of abrupt change in vertical alignment such as junction of steep gradients. Therefore to control the dynamic forces & rate of track geometry deterioration at these locations provision of vertical curves with appropriate radius becomes mandatory.

**Action proposed-7:**

The transition tracks at locations involving abrupt change in subgrade stiffness needs to evolved & introduced immediately in new constructions & in phased manner during complete track renewals on existing tracks. In addition better maintenance practices with semimechanized / fully mechanized spot attention for these locations needs to be evolved.

8.4 **Negotiating Points and Crossings Assembly**

The permitted speed on points & crossing assembly is governed by turn out features mainly switch entry angle, lead curve radius having no transition & cant, straight crossing & gap at nose of crossing.

**Action proposed-8:**

Improving speed potential of turnout assembly will require introduction of thick web switch to have sturdy switch assembly, weld able Xing to avoid joints, swing nose Xing / curved Xing to continue curved track in Xing portion. All this will bring adequate improvement in existing 1 in 12 turnout assembly (i.e. without changing yard layout).
9. **Rate of Track Geometry Deterioration**

The mechanism of track geometry deterioration phenomenon is complex. The magnitude of settlement in the ballast depends upon magnitude of axle-load, number of loading cycles, speed & percentage content of fouling material. The Rate of track geometry deterioration is governed by following equation based on ORE study reports No. D141 & D17:

\[ E = K, T^\alpha P^\beta V^\gamma \]

where \( E = \) deterioration since renewal or last maintenance operation, \( T = \) tonnage, \( P = \) axle load (static + dynamic), \( V = \) speed, \( K, \alpha, \beta, \gamma = \) constants.

<table>
<thead>
<tr>
<th>Phenomena</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail fatigue</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Track geometry deterioration</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

**Implications:**

<table>
<thead>
<tr>
<th>Higher Speed Passenger Trains (increase w.r.t 130 kmph)</th>
<th>Heavier Axle-Load Freight Trains (increase w.r.t 22.5 t axle-load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 kmph</td>
<td>30 t</td>
</tr>
<tr>
<td>200 kmph</td>
<td>32.5 t</td>
</tr>
<tr>
<td>51%</td>
<td>137 % increase</td>
</tr>
<tr>
<td>136%</td>
<td>200% increase</td>
</tr>
</tbody>
</table>

9.1 **Characteristics of Track Geometry Deterioration**

1. The track quality i.e. vertical quality and alignment deteriorate linearly with tonnage or time between maintenance operations after the first initial settlement; however, this trend is not always the case for sections with high deterioration rates.

2. The rate of track deterioration is very different from section to section even for apparently identical sections carrying the same traffic.

3. The rate of track deterioration appears to be constant parameter for a section of track, regardless of the quality achieved by the maintenance machine.
4. In general tamping machines improve the quality of a section of track to a more or less constant value; Fig. 6:

![Graph showing Track Quality Changes during Maintenance Cycle]

**Fig. 6: Track Quality Changes during Maintenance Cycle**

### 9.2 Concept of inherent Track Shape
It has been observed that track appears to have an inherent shape, which remains with it throughout its life. This inherent shape appears to be introduced into the track at the time of its original construction. Achieving subsequent changes in the inherent track shape is very difficult. To a large extent, inherent Track Quality is a function of inherent track shape.

### 9.3 Track inherent Quality (Please refer to Fig. 7 next page)
The downward pointing arrow indicates tamping operations. The track shown in the upper part of the sketch has a standard deviation of 1.5 mm and has required 2 tamping operations in 5 years to maintain the track quality at that level. Such a track can be regarded as having a good inherent quality.

The track shown in the lower part of the sketch however, has a standard deviation of 3.2 mm and has required 6 tamping operations in the same 5 years period, to maintain the track quality at that level. Such a track can be regarded as having a relatively poor inherent quality.
Fig. 7 shows two sections of track, 1 km apart, both carrying the same traffic.

Note: The inherent track shape/quality affects the dynamic behavior of track under train loads. It is reported that wheel rail forces for $f = 1$ mm (0-25 m wave band) $\text{DAF95} < 1.67$, $= 1.5$ mm $\text{DAF95} < 2$ according to Euro code.

9.4 Factors affecting Track Geometry Deterioration

The studies undertaken by ORE D-117 & D161, to analyze the effect of different types of traffic, track construction and maintenance machine on the quality of the track & its rate of deterioration, shows that:

The factors governing the rate of deterioration are not obvious and that the unknown factors in the track are the most important in determining both the average quality and the rate of deterioration. While the results of these tests on the effects of these variations were not very conclusive, the committee (ORE D-117) nonetheless felt that:

- The quality of the track on relaying was the most important factor.
- It is very difficult to differentiate statistically for the effects of traffic, track construction and foundation on the rate of deterioration, even for sections of nominally similar track, however in general, a high rate of track deterioration in individual areas of a larger section can be linked to characteristics, which are:
  - Local geometry faults present from the start (inherent track shape & track inherent quality).
  - Singular features (rail bridges, level crossings, etc.) i.e. locations involving abrupt change in the subgrade stiffness.
  - Sub-layers of inferior quality formation.
  - Welds of inferior quality (short wave length defects).
**Actions proposed-9:**

1. The quality of track on relaying is the most important factor to affect the rate of track geometry deteriorations. Track can be constructed such that it has a good inherent quality & the inherent quality of existing track can be improved using design over-lift tamping & high lift design tamping.

2. The surface defects in the rail wheel contact area, i.e. cupped welds, low joints, poor geometry on welds, poor support conditions at the joints, corrugation on rail top, wheel-flat, inadequate availability of clean ballast cushion, poor condition of sub grade, generates higher dynamic forces. These needs to be monitored regularly.

3. Efficient semi mechanized/fully mechanized methods to be introduced for isolated spot attention/slack packing.

4. Proper maintenance of track machines with adequate & proper pre tamping, post tamping attention, for getting satisfactory quality of tamping output is a pre requisite to lengthen tamping cycle.

5. Overloading of freight stock, poor maintenance of rolling stock is causing higher lateral forces. Better bogie designs to have improved rail wheel interaction are required. The bogie with low un-sprung mass, efficient damping characteristics improves rail wheel interaction.

**10. Recommendations:**

1. The fatigue life of track components is required to be evaluated/assessed for higher stress cycle, including maximum stress under mixed traffic of semi high speed & heavier axle load conditions, to avoid & settle issues related to sudden fatigue failures of track components.

2. The quality of track on initial laying / relaying is the most important factor to affect the rate of track geometry deteriorations, therefore track laying quality is to be given due importance.
The concept of design over lift tamping & high lift design tamping needs to be introduced on I.R.

3. The Experience of foreign railways having similar traffic situations including rolling stock design needs to be studied & utilized to plan & cater for heavier axle-load & semi high-speed routes of Indian Railways.

References:


2. Item No. 1078 in REVIEW OF RAIL STRESS CALCULATION METHODOLOGY; 76th TSC Meeting, Jan, 2006.
ANNEXURE II

Challenges in Design and Maintenance of Track Structure for Mixed Traffic Regime on IR

Vipul Kumar*
Ajay Kumar**

1. **Introduction**

Indian Railways operate in mixed traffic regime of passenger and goods operation. The speeds of passenger operations are now being envisaged to be enhanced to 160-200 kmph from existing 100-130 kmph. Simultaneously, the thrust is being given on freight operation with increased axle loads from existing 20.32/22.32/22.9 t to 25 t along with the increase in speed from 75 kmph to 100 kmph. Both of these operations are to be on the same track. This will be unique operational environment on IR hardly being adopted in any of the established world railway systems. British Railways operate under such mixed traffic regime with passenger operations at 200 kmph and 25t axle load at 100 kmph, but the culture of systemic maintenance, operating environment and discipline on BR are far more well defined and professionally followed than that on IR. As we will see later, even the acceptance criteria for freight stocks on BR is far stricter in comparison to IR.

2. **Key Design Parameters**:

Accurate estimation of track-vehicle interaction parameters, like forces and accelerations, is most important aspect of design of the track structure for a particular set of operating conditions i.e. speed and loading. Introduction of heavy axle load operations in mixed

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**Director/Track -II/RDSO  dtd4rdso@gmail.com
traffic regime calls for even more accurate estimation of these parameters considering the safety of passenger operations as heavy axle load operations take toll on fixed infrastructure. There are complexities associated with dynamic forces developed from track-vehicle interactions in mixed traffic regime. Most of the track deterioration is strongly associated to the development of dynamic loads resulting from the wheel-rail contact. These dynamic loads are influenced by many factors. Some important factors are:

a) Axle load.
b) Speed of operation.
c) Characteristics of rolling stock affecting dynamic behavior i.e. wheel diameter, suspension system, unsprung mass, etc.
d) Maintenance standards of rolling stock – permissible size of wheel flat, wheel deformations.
e) Track structure, its geometry and maintenance standards.

The correct estimation of lateral forces is essentially required for deciding the design lateral strength of track structure so as to withstand the loads without conceeding fast deterioration in the track geometry. Larger anticipated lateral forces arising out of the 25t operation coupled with locked up thermal stresses in rail may lead to severe misalignment in track, even leading to derailments. On the same time, high dynamic vertical load will cause high bending stress in rail causing decrease in fatigue life of track components in general and sudden failure of weekend section in particular if got combined with large track and other vehicle defects.

3. Effect of Increase in Axle-Load and Speed:
The increase in speed and axle load increases the static as well as dynamic component of forces coming on the track due to operations. This increase is proportional for static component, but the dynamic augment increases at a much faster rate with speed. The increased loading on track leads to faster rate of deterioration of track geometry and also decreased fatigue life of rail, weld and
other track components thus causing increase in number of rail / weld failure.

Results of some of the studies done in the matter indicate that:

3.1 Increase in axle load from 22.9t to 25t, which is an increase of only 9%, may translate into damage to track structure that could be as much as 20% higher than that caused by current loads*.

(* “Heavy axle load capital needs assessment” – Dr A. M. Zarembaski, PE, President of ZETA – TECH Associates, an American consultancy firm).

3.2 Studies reported in ORE, D/141/RP 1, indicate that increase in axle load from 20t to 22t (10%), the fatigue failure in rails will increase based on the relative increase in mean axle load raised to a power of 3 to 4. Thus, increase from CC to CC+ 8+2 loading culminates into 40-60% increase in fatigue failure of rails. Further increase from 22.9 t axle load to 25 t, the expected further increase in fatigue failure of rails may be 30-40%.

3.3 Studies reported in ORE, D/141/RP 5 indicate that cost of maintenance increases by 37% for 10% increase in axle load.

4. Requirements for Semi High-Speed Operations:
For increasing the passenger operation speed from current band of 100 – 130 kmph to next band of 140 – 160 kmph and subsequently to 160 – 200 kmph, the essential requirements from track point of view are:

- More accurate track geometry than that required at 100/110 kmph in terms of line and level both to provide same degree of ride comfort and stability to stocks at higher speeds.

- Considerable reduction in rail-weld failures as they have more devastating consequences at higher speeds and more hazards for passenger safety.

To maintain better geometry and continuity of track, the ill effects of operations on track i.e. track - vehicle interaction forces -
responsible for distortion of the track geometry and effecting fatigue failures of rails, welds, and track components, need to be contained. Both static and dynamic components of the force need to be taken care of from track loading point of view.

5. **Requisites for Rolling Stocks to operate in mixed Traffic Regime at higher Speeds:**

5.1. The detrimental effects of higher axle load operations at increased speed on track have already been outlined earlier in terms of increased rate of track geometry deterioration and increased fatigue of rails, welds, and other track components.

5.2. So, the primary requirement for heavier axle load stocks to operate at 100 kmph and coaching stocks at semi high-speeds in mixed traffic regime is a track friendly design which imparts such low/moderate forces on track as adopted in the design of track structure. It implies that stress coming on rail and other components shall not exceed the permissible limits during service.

5.3. To check such a track friendly design objectively, a system for testing and acceptance of vehicle at par with international standards also needs to be in place.

6. **UIC Leaflet 724-R deliberates on Design Aspects and Track Equipment for Operation of 25 t Axle-Load on ballasted Track.**

The salient Points of the Leaflet are indicated below:

When considering the phenomenon of track deterioration, some salient aspects of the deterioration needs to be clearly defined; such as

- fatigue of rail and other components,
- wear of rail and other components,
- deterioration of track geometry quality,
- deterioration of track components.

Research, test results, railway literature, reports and experience have shown that the best way to decrease the deteriorating effects on track when operating with high axle loads is through reduction
in dynamic wheel loads. Both the total wheel load and the dynamic part of it have to be considered. Preconditions for reducing dynamic wheel loads include:
- good track geometry quality,
- adapted speed,
- good wheel quality,
- track friendly vehicle design.

7. Experience of 22.9 t and 25 t Axle-Load Operation on IR:

7.1. Indian Railways have started operation of CC+6+2/CC+8+2/22.9 t axle loads at 75 kmph in 2006 on few mineral transportation circuits, which subsequently expanded to many other routes, but majority of these operations are still on mineral routes. Subsequently, very limited operation of 25 t axle load at restricted speed of 50 kmph was started on selected routes, and very limited experience is available on IR particularly regarding the issues and complications arising out of such operations at higher speeds. Based on the limited data captured and provided by zonal railways (ECOR, SCR, SECR) operating heavy axle loads though at limited speed of 75/50 kmph, the track related issues are summarized as under:

- Excessive wear in switches and crossings.
- Crossing zone requires frequent packing.
- CMS crossings required frequent replacement/repair due to wear and cracking of crossing.
- Excessive wear of outer rails of curve and flattening of inner rails.
- Battering of glued joints frequently.
- Increased cases of glued joint failure and fish plate fracture.
- Stretches on weak formation/black cotton soil causing frequent ballast puncture resulting into abrupt cross level variation.
- Fish plate of stock rail joints getting battered, leading to failure of fish plates.
7.2 Experience of KK Line of Waltaire Division:
This route has operated 9944 no. of 25t axle load trains in last nine years. The frequency on an average works out to approximately 1100 trains per year. The maximum number of 25t axle load trains run in a year was 1997, in the year 2013-2014 followed by 1843 no. of trains in 2012-2013. The total GMT of the section is 25 out of which the percentage of 25t axle load trains varied approximately from 10-25% in a particular year. The data of rail fracture/weld failure indicates substantial increase under operation of 25t axle load trains as brought out in the Table 1 below:

Table 1: Data of Rail Fractures/Weld Failures under 25 t Axle-Load Operation

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Year</th>
<th>No. of 25t Axle Load Trains</th>
<th>Total RF+WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2007-08</td>
<td>389</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>(9months)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2008-09</td>
<td>829</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2009-10</td>
<td>832</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>2010-11</td>
<td>796</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>2011-12</td>
<td>1134</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>2012-13</td>
<td>1843</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>2013-14</td>
<td>1997</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>2014-15</td>
<td>1398</td>
<td>57</td>
</tr>
</tbody>
</table>

7.3 South East Central Railway has reported that total 222 IMR were detected in Bilaspur division in the year 2014-15. Out of these, 100 IMR were detected in the 1st round i.e. without being classified as OBS in previous round of testing and remaining 112 IMR upgraded from OBS marked in the previous round. In spite of above detection, 138 rail fractures could not be prevented. The trend is almost same in 2015-16. The rate of detection of IMR and rail fracture in the route under operation of CC+8+2 loads is too high.

8. Experience of British Railways:
Director of Civil Engineering, British Railways, published an important report on the operation of 25t axle loads in a conference held on 11-13 July 1984. British Railways operate mixed Traffic, and during the period of report, they were running passenger trains at 125 MPH (200 kmph) and freight trains of 25t axle load at 60 MPH
(100 kmph). The percentage of passenger train kilometerage was 86% of the total and that of freight train was 13%.

The report brought out following important observations:

a) It is interesting to note that the worst situation occurs on high speed routes where high quality track is maintained.

b) On the heavy weight, slow speed routes, a very low rate of failure exist.

c) One of the significant problem was failure of concrete sleepers on certain heavily worked mainlines. The failures commenced as a transverse crack through the fastening under the rail seat, which progressed downwards. Research showed that in these places considerable wheel flat problem existed. The passage of several flat was shown to cause concrete sleepers to vibrate in the vertical plane. The third and fifth harmonic of this vertical vibration produces substantial transient hogging rail seat bending moments which results in a tensile stress and cause the cracking.

d) It is now becoming clear that a pad thickness of more than 5 mm is necessary, probably at least 10 mm thickness with resilient characteristics.

2. Considering the ill effects of operations of heavy axle loads on track, instructions for effective monitoring of rolling stocks and operational regime were issued from the highest authority on IR while introducing the operations of heavy axle load in 2006. The salient aspects of the instructions are given below:

- Install all sanctioned Weigh Bridges by December, 2006 and ensure that all weigh bridges are kept well maintained and functional.

- NO OVERLOADING must be permitted. Drastic penal action should be taken against defaulters.
- Good train running and adequate powering should be ensured to prevent instances of stalling/wheel slippages.

- Wagons must be well maintained, additional springs as advised be provided during ROH/POH.

- RDSO must expedite development of WILD and it must be installed at selected locations within one year.

- All remaining instrumentations of bridges etc. should be concluded without any further delay.

- Concerned PHODs meeting should be regularly held at General Manager's level to review operation of these heavy axle load.

(Hon'ble MR DO letter No. MR/M/59/2006 dated 10.08.2006)

10. **Major Challenges in Design of Track Structure:**
As indicated earlier, maintaining the good geometry and reliable continuity of track is prerequisite to semi high-speed operation. This necessitates track friendly vehicle design on one hand and sturdy track structure on the other. This also necessitates a well laid comprehensive maintenance regime of rolling stocks and track with adequate occupation time for maintenance, enhanced level of resources, state of art technology and skilled maintenance team to minimize in-service failure of assets, which may lead to devastating consequences at higher speed of operations. Further, it demands a strict discipline in operations with respect to adequate powering, correct loading, enroute monitoring of rolling stocks and detachment of defective ones so as not to cause damage to track structure. But IR is lacking badly on most of these critical issues as indicated below:

A. **Problems with existing Designs and Certification of heavy Axle-Load Wagons**

a) Dynamic forces on rail (track– vehicle interaction forces) are not measured during testing of rolling stocks since required equipments i.e. measuring wheels are not available with RDSO so the actual
dynamic loading on track is not available to work out the stresses on track for designing the rail and other track components.

b) The criteria for certification of freight stocks on IR are very slack in comparison to international standards. It does not mandate the measurement of dynamic forces on rail and any limiting value of it for clearing the stocks for operation. Further, it does not stipulate any limit for accelerations. A comparison is being given in Table 2:

**Table 2: Comparison of Acceptance Criteria (Freight Stocks)**

<table>
<thead>
<tr>
<th>SN</th>
<th>Parameters</th>
<th>IR Limits</th>
<th>UIC-518/EN-14363 Limits</th>
<th>British Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vertical acceleration</td>
<td>Not specified</td>
<td>5 m/s² in body (~0.5g)</td>
<td>should not exceed 0.25g (mean) &amp; 0.44g (max.)</td>
</tr>
<tr>
<td>2</td>
<td>Lateral acceleration</td>
<td>Not specified</td>
<td>3 m/s² in body (~0.3g)</td>
<td>should not exceed 0.2g (mean) &amp; 0.33g (max.)</td>
</tr>
<tr>
<td>3</td>
<td>Vertical Ride Index</td>
<td>4.5 (4.25 preferred)</td>
<td>NA</td>
<td>4.25 (mean) 5.0 (max)</td>
</tr>
<tr>
<td>4</td>
<td>Lateral Ride Index</td>
<td>4.5 (4.25 preferred)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Track loading Limit (Qlim)</td>
<td>Not Specified</td>
<td>(90 + Q₀) Max 210 KN</td>
<td>Not Available</td>
</tr>
<tr>
<td>6</td>
<td>Lateral Force (Hy2m)</td>
<td>shall not exceed 0.85(1+P/3) tonnes; where P= axle load</td>
<td>shall not exceed 0.85(10+Po/3) kN; where Po= axle load</td>
<td>shall not exceed 0.85(1+2Q/3) tonnes; where 2Q= nominal wheel load</td>
</tr>
</tbody>
</table>
Another important issue pertains to the oscillation trials, which are done on new stocks having no regime of oscillation trial of stocks in run down condition before POH for corrective action. This may be needed for preventing high dynamic loading on infrastructure for improved reliability and safety, for mixed traffic regime on IR, as the performance of stock deteriorates as it grows old in service increasing severity of its ill-effects on track.

c) The freight stocks have been cleared with very high acceleration values obtained during oscillation trials much beyond the international norms (see Table 3 and 4 below). High vibrations imparted to track in the high stress state due to high axle load shall reduce the fatigue life and would lead to increased incidences of fatigue as well as sudden failure of rails/welds.

**Table 3 & 4: Acceleration Values of existing Stocks observed during Oscillation Trials:**

**Table 3: 25 t Axle-Load Wagons (loaded Condition)**

<table>
<thead>
<tr>
<th>WAGON</th>
<th>Speed</th>
<th>Max Lateral Acc [g]</th>
<th>Max vertical Acc [g]</th>
<th>C&amp;M-I VOL-I or Other</th>
<th>REPORT NO.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOBSNM1</td>
<td>60/80</td>
<td>0.48</td>
<td>0.65</td>
<td>0.45</td>
<td>0.49</td>
<td>Other 726/2006</td>
</tr>
<tr>
<td>BOXN 25M</td>
<td>125</td>
<td>0.23</td>
<td>0.25</td>
<td>0.69</td>
<td>0.81</td>
<td>C&amp;M 1 1217/2012 (i) UN - AO (ii) 2 degree curve at 80 kmph</td>
</tr>
<tr>
<td>BLC 25M</td>
<td>125</td>
<td>0.21</td>
<td>0.25</td>
<td>0.47</td>
<td>0.51</td>
<td>C&amp;M 1 1288/2013 UN - A0, TW - A0, AL - A0</td>
</tr>
<tr>
<td>BOXNHL25T</td>
<td>85</td>
<td>0.51</td>
<td>0.38</td>
<td>0.36</td>
<td>0.41</td>
<td>Other 1427/2015</td>
</tr>
<tr>
<td>BOXNEL</td>
<td>90</td>
<td>0.66</td>
<td>0.31</td>
<td>0.72</td>
<td>0.65</td>
<td>Other 1437/2016</td>
</tr>
<tr>
<td>BOYEL</td>
<td>90</td>
<td>0.74</td>
<td>0.57</td>
<td>0.73</td>
<td>0.76</td>
<td>Other 1439/2016</td>
</tr>
<tr>
<td>BOXNS</td>
<td>100</td>
<td>0.19</td>
<td>0.42</td>
<td>0.76</td>
<td>0.87</td>
<td>Other 1463/2016</td>
</tr>
</tbody>
</table>
### Table 4: 22.9 t Axle-Load Wagons (loaded Condition)

<table>
<thead>
<tr>
<th>WAGON</th>
<th>Speed</th>
<th>Max Lateral Acc (g)</th>
<th>Max vertical Acc (g)</th>
<th>C&amp;M-I VOL-I or Other</th>
<th>REPORT NO.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Detail run</td>
<td>Long run</td>
<td>Detail run</td>
<td>Long run</td>
<td></td>
</tr>
<tr>
<td>BOXNHL</td>
<td>110</td>
<td>0.64</td>
<td>0.66</td>
<td>0.78</td>
<td>0.73</td>
<td>C&amp;M 1</td>
</tr>
<tr>
<td>BOXNHL (PUC TYPE CCSB PAD)</td>
<td>110</td>
<td>0.53</td>
<td>0.47</td>
<td>0.45</td>
<td>0.41</td>
<td>C&amp;M 1</td>
</tr>
<tr>
<td>BCNHL</td>
<td>110</td>
<td>0.48</td>
<td>0.57</td>
<td>0.57</td>
<td>0.61</td>
<td>C&amp;M 1</td>
</tr>
<tr>
<td>BOXNHL (Series 1)</td>
<td>85</td>
<td>0.23</td>
<td>0.31</td>
<td>0.56</td>
<td>0.56</td>
<td>Other</td>
</tr>
<tr>
<td>BOXNHL (Series II)</td>
<td>85</td>
<td>0.25</td>
<td>0.33</td>
<td>0.5</td>
<td>0.64</td>
<td>Other</td>
</tr>
</tbody>
</table>

**d)** The heavy axle load wagons are now being designed with smaller wheel dia which will have higher contact stress leading to increased rate of generation and propagation of surface cracks thus increased risk of failures. It will also result into increased cycles of impact on track in case of wheel flat/deformed wheel, thus increasing the chances of sudden failure when coupled with track and other vehicle defects of higher degree. Indian Railways is already crippled with inadequate powering of freight load, smaller wheel with increased contact stresses shall result into increased number of wheel burns/scabs leading to more failures.

**B. Major Issues in Operation**

a) It is observed that the basic requisites and operational regime stipulated while introduction of heavy axle load (22.9 t) have not been implemented meticulously and lack of implementation of these instructions coupled with inadequate rolling stock design not being in line with international norms for mixed traffic regime has been causing very high incidences of asset failures. The major issues in the operation are indicated below:

- There is very little monitoring of impact loading on track. It was stipulated to install adequate no of WILD (Wheel Impact Load
Detector) instrument to check the impact loading on track and detach the stocks immediately from the load for which critical alarm is given by the WILD. However, only 15 WILDs have been installed so far against the 260 identified resulting into no monitoring of more than 90% of loads for impact loading on track.

- The second issue is high impact loading permitted during operations. The critical WILD alarm has been set at 35t which is almost equal to 300% dynamic augment for 22.9t axle load. The stress generated with such high vertical load in combination of other stresses such as residual and thermal stresses in rail are estimated to reach up to level of 55.28 Kg/mm² against the permissible limit of 46.8 Kg/mm² in 60 kg/90 UTS rail.

- It is seen from the WILD data that zonal railways are not taking action on WILD alarms as stipulated. Form the data available from limited number of functional WILDS, it is indicated that the detachments of vehicles giving critical alarms have been less than 10%. Alarms up to 50 t (equivalent to Dynamic Augment of 325%) loads are generally ignored and allowed to run resulting into high dynamic forces. Such high dynamic forces of repeated nature with every revolution of the wheel shall continue reducing fatigue life of rails & welds, also leading to sudden failures.

- Instantaneous wheel load upto 59t (DA – 400%) have been recorded by WILD indicating need of tightening of maintenance standards as there can not be any standard and economical track structure designed for such traffic regime, opined by a Swedish Track Expert during discussion for optimised sleeper design project taken by UIC for IR.

- Monitoring of overloading and corrective action thereon is also not being ensured by zonal railways. In many railways, weighbridges have either not been installed or installed at tail
end which are of no use as the load has done the damage having completed the journey.

- Inadequate powering is another important area of concern, particularly in gradient sections, leading to stalling and damage to rails.

b) Heavy loading on track requires enhanced level of maintenance thus increasing the requirement of maintenance blocks and other resources. But the situation is grim and getting worse day by day. The corridor blocks have practically vanished. There is severe crunch of resources for last so many years. This situation is putting lot of pressure on infrastructure and resulting into huge maintenance arrears, abnormally high in-service failures, increased downtime and causing grave risk to passenger carrying trains.

c) Another significant area of concern is the corrosion of rails and fastenings due to human excreta from coaches which leads to severe reduction in sectional area at critical locations as foot in very short span of time and leads to sudden breakage of rails/welds. As per our experience and estimate, this factor alone is responsible for 25% - 30% of rail/weld failures and for burdening the exchequer by hundreds of crores due to premature renewal of rails and other track components. It is important to observe that this arrangement of toilet discharge to tracks exists on no other responsible railway system of the world.

11. Limitations of existing Track Components

11.1 Maximum allowable vertical Load in 60kg/90 UTS Rails:

Permissible rail stress in existing 90 UTS rail due to bending is 46.8 Kg/mm². After factoring in the other stresses in rail like thermal and residual, the maximum vertical load that can be worked with 60 kg rails is 18-22 t depending upon the wheel base of wagons while wheel loads upto 35t are allowed for operations as per WILD alarm stipulations. The range of 20t to 35t has been stipulated as
maintenance alarm in the WILD which has to be checked during scheduled inspections only for any defect. These rail stress calculation does not take into account the increase in dynamic augment due to wheel deformations. The RDSO report no C-100 indicates that a wheel flat of dimension of 18x25x3 mm in ICF coach produced a dynamic augment (DA) as high as 257% at speed of 96 kmph against the normal DA of 57.4%. Therefore, it can be inferred that even of flat of size 10-15 mm or little deformation in wheel, which is very likely for a large number of wheels, will produce an instantaneous wheel load of such order that rail stress crosses its permissible limit in 60 kg rail.

Continuous operation at near limiting magnitude of rail stress could be very severe for the track. This aspect assumes greater importance considering the fact that the flat size up to 60 mm is permitted in the wagons on IR. The option of higher UTS rail giving higher service stresses is open, however, with the prevailing underutilization of available rail grinding machines, it looks unlikely that the mandatory regime of rail grinding needed for use of higher UTS can be implemented effectively. In that case, the use of higher UTS shall be more of a liability than asset as they are prone to higher incidences of sudden failures, wheel scabs/burns leading to rather increased incidences of rail failures.

11.2 Sleepers:

The existing PSC sleeper was designed for 20.32t axle loads and was allowed for 22.9 t axle load operations up to 75 kmph. The suitability was reviewed by committee of officers from RDSO & Zonal Railways. It is concluded that these sleepers will not be fit for regular 25t operations at speed of 75 kmph and above. RDSO has already designed 25t sleepers for DFC. Also, the design of wider sleeper for 25t axle loads has been completed requiring field trial for regular adoption.

The wider sleeper for 25 t axle load has been designed by RDSO keeping provision to accommodate extra foot width for 68 kg rails.
as required through change of liners. The rail seat assembly for wider sleeper has been designed to provide flexibility to adopt UIC 60 kg rail section or 136RE (68 kg/m) rail section.

11.3 Rubber Pads:
As per experience of IR and that of other railways also, the existing 6mm thick rubber pad shall not be able to sustain heavy axle loads. 10 mm thick rubber pads alongwith 25t axle load sleepers have been designed by RDSO and are under trial.

11.4 Other Track Components:
Though the schedule of other track components for heavy axle loads proposed to be operated on IR is under stipulation based on the experience gained so far from limited operation of 22.9 t axle load and 25 t axle load at low speed on some of the zonal railways. The exercise shall, however, only be a hit and trial as an adequate and safe track structure can only be assessed and designed after actual forces the track components are subjected to are known. This requires not only measurement of real time forces with the use of measuring wheel & measuring accelerations at axle box levels but also strict maintenance regime both by fixed infrastructure and rolling stocks owner to keep the dynamic loading low within the permissible limits. **Until then, the introduction of heavy axle-load regime can only be done on IR assuming considerable risk.**

It is interesting to observe that Japanese Railway, which is one of the most advance railway systems in the world, has been reducing axle loads from initially in the range of 20t to now 12t, in order to reduce dynamic forces for increased component reliability and life reducing safety risks even with increased speed of operations. The increase in through-put has been achieved through going for moving train block system instead of absolute train block system at a head-way of 8-10 minutes, keeping low differential of speed among various types of trains on it’s system.
CONCLUSION

The quest of IR to increase through-put with the use of increased axle loads stocks and introducing Semi High-Speed on the same track can be justified to cater to the needs of ever burgeoning population, assuming certain risks. For reducing these risks, various elements and regime of heavier axle loads and Semi High-Speed needs to be conceived and implemented meticulously, including proper design of track structure. In order to design an appropriate track structure, real time measurement of track forces are needed. Even the option of use of higher UTS rails to contain rail stress caused by higher axle loads within limits can only be exercised in a disciplined operating environment facilitating assured track possession for rail grinding, adequate powering of loads, detachment of defective vehicles, etc.

The effort is also needed in the direction of going for a world class freight suspension system with limited dynamic loading of track during operation at higher speed. Even the regime of passing rolling stocks needs a complete relook in order to ensure that rolling stock passes through the track with worn out limits having low dynamic forces so that cost of fixed infrastructure can be economized along with enhanced maintainability and safety of operations.

The way side monitoring, timely maintenance and replacement of both aged rolling stock and fixed infrastructure are also pre-requisites to keep the forces low and long term economical sustainability of heavy axle load operations along with Semi High-Speed passenger operations.
Mixed Traffic Scheme with Mixed Mode Rolling Stock for Passengers plus Freight

Train-Passenger’s Freedom from Bodily Harm and Injury should matter first of all before going for envisaged "MIXED TRAFFIC SCHEME"