ज्ञान ज्योति से मार्गदर्शन

To Beam As A Beacon of Knowledge

Track Geometry Management on Indian Railways

For Better Ride Quality

An IRICEN Publication

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FORWARD

The recent changes introduced by Indian Railways concerning track recording, analysis and monitoring has entirely altered landscape of track geometry management. Considering the speed policy framework on Indian Railways, various speed bands have been prescribed along with acceptable level of track geometry quality with respect to acceptable ride quality for each of the speed band.

This publication is an endeavor of IRICEN to spread the awareness about the new track geometry management regime on Indian Railway. I hope that it would be of immense help in developing understanding of the topic.

November 4, 2019

(Ajay Goyal)

Director IRICEN

PREFACE

The mechanized monitoring of track geometry has come a long way since introduction of first mechanical TRC during early 60s, followed by Track Recording-cum-Research Car in 70s, Microprocessor based TRCs in 80s and now the High Speed TRCs in use since last 10 years. The routes of Golden quadrilateral and diagonals have already been planned for increase in speeds upto 160 km/h and remaining routes are being planned for speeds upto 130 km/h. Furthermore the high speed corridor is also likely to be commissioned in foreseeable future indicating that the Indian Railways is on the threshold of railway speed explosion, calling for tighter management of Track Geometry.

With the recent changes in the IRPWM, the track geometry management on Indian Railways is now aligned with the latest world practices and follows similar principles as applicable on advanced railway systems and predominantly focused on the ride quality.

This publication has been drafted on the insistence and under guidance of Shri Ajay Goyal, Director, IRICEN as an initial appreciation of the various changes recently brought in IRPWM. It is highly likely that quite a few elements of the new mechanism might change in near future as this new system evolves and creases iron out.

The author is grateful to Shri R. P. Tiwari, Director(TM), RDSO who has rendered immense help in developing understanding and made available the various formats and a lot of contents. The author is also grateful to a large number of individuals with whom various discussions and interactions have taken place and included here in some form or the other.

November 04, 2019

(C. S. Sharma)
Senior Professor (Track-1)

CONTENT

1

Introduction

1. **Railway Tracks:** also known as "Railroad" is an inseparable, and vital sub-system in a rail based transportation system, which needs regular inspections to assess geometrical and structural conditions of the track components and assemblies for its ability to carry the loads and various forces exerted by the rolling stock running over it. The quantum of these loads and the forces depend not only on the design, construction and maintenance condition of the rolling stock but also on the speeds; at which these ply. These loads and forces would further increase or diminish in case of variations in any of the geometrical parameters of the track.

   For safe and comfortable transportation of freight and passengers, it is imperative that both rolling stocks and tracks are maintained well. This endeavour would also prolong the service life of assetsand bring down the cost of operation and maintenance. The Railway tracks needs close monitoring for their proper upkeep i.e. timely maintenance as well as to ensure safety of trains running on them.

2. The Permanent Way (popularly called P.Way) personnel responsible for the maintenance of **"Track"**carryout regular periodic inspections to assess the structural and geometrical health of the track. The regular monitoring of the track condition enables planning and delivering of inputs, as

required, in time for maintenance of Track as well asits renewals. To satisfy the basic principles of track maintenance viz. safety, comfort and cost effectiveness; the optimized track maintenance strategy helps in reducing costs of maintenance by ensuring that maintenance inputs are applied to the identified locations, where these are necessarily required from ride quality considerations. The strategy being that to **"Touch the Track only when required and where required".**

The variations in the geometrical parameters of the track could be either a result of deterioration under regular train operations or an indication of any other underlying issues relating to either condition of various track components or condition of ballast bed, sub-grade,sub-soil etc. individually or combination in varying proportions.

3. Inspection on foot, by trollies, by locomotive, or by rear vehicles enable the P. Way maintenance personnel to carry out realistic assessment of the track conditions and its performance. These inspections, though important, are mostly subjective and enable assessment based on individual's knowledge and experience etc.

The objective assessment of track geometry and track components is possible by Track Recording Cars. The track performance in the form of accelerations generated due to variations in track geometry parameter(s) could be measured by accelerometers in various monitoring equipment.

The acceleration measurements can be used to give an indication of track geometry quality and to detect the local track geometry deviations, which have an influence on the dynamic behaviour of a vehicle. These measurements should be used in conjunction with the main parameter measurements described in the standard.

However, it must be kept in mind that the acceleration measurements are sensitive to the dynamic behaviour of the vehicle and other factors such as climatic conditions, actual position of the vehicle in the train and wheel rail interaction, which restrict liberal comparison under varying recording conditions.

4. Track Monitoring Equipment :

The following track recording equipment are in use on Indian Railways at present:

(a) Track Recording Car
(b) Oscillograph Car
(c) Oscillation Monitoring System

5. Track Recording Car:

5.1. The objective of TRC is to collect data to access the health of the track for:

(a) Monitoring Track Quality and its Performance.
(b) To study the trend of deterioration.
(c) Identifying locations/stretches for maintenance inputs to optimally use limited Maintenance Resources.

5.2. Types of Track Recording Cars:

Two types of Track Recording Cars, one having Contact type sensors and other having LASER based contactless sensors are used on IR. Both the type of TRCs are computerized TRCs, and uses inertial principle of obtaining vertical and lateral profile of individual rails. These TRCs have capability to generate reports of Track Geometry parameters on two user selectable Chord in the range of 2 to 20 m.

One chord of lesser length is termed as short chord while thelonger one is termed as long chord, which are denoted with suffixed 1 & 2 respectively in various reports generated from data collected by TRCs.

5.3. Frequency of Track recording:

All Broad Gauge routes on Indian Railways are monitored by TRC as under :

No.	Route Speed	Frequency
1.	Up-to 100 km/h	Once in 6 months
2.	Above 100 km/h; and up-to 110 km/h	Once in 4 months
3.	Above 110 km/h; and up-to 130 km/h	Once in 3 months
4.	Above 130 km/h	Once in 2 months

5.4. Arrangements for Running Track Recording Car :

For running of the Track Recording Car over Indian Railway routes as per the monitoring frequency, a monthly program for running of TRCs on various zonal railways are issued by RDSO.The zonal railways are expected to arrange for suitable power, crew, consumables, and path to ensure that the Track Recording Car has an uninterrupted run as per the program issued by RDSO. The concerned ADENs & SSEs, who are headquartered at originating/ halting stations,must coordinate for proper placement, watering, charging and other assistance as required for RDSO Special, i.e.Track Recording Carformation.Sectional Sr. DEN/DEN shall ensure proper liaison in the Control office for suitable path and monitoring of the special

5.5. Running of Track Recording Car :

The Maximum recording speed of contact sensor based TRC is 100 km/h and of LASER contact less sensors based TRC is 160 km/h. The measurement of Track parameter recording is independent of speed above a minimum speed of 20 km/h, however, it must be ensured that the Track Recording Cars are run at the maximum speed of Section/TRC. Any recording done by TRC below minimum speeds of 20 km/h is to be taken as "Non-recorded".

Before start of any run, the quick calibration of the system should be done. The track recording car specials must be run during day light hours and should have a through run over the section between two major stations and run on through lines at all stations. The TRC results, printed after completion of each kilometre, should be taken by the P.Way staff; for record and for taking maintenance action.

5.6. Following officials are expected to accompany the TRC run:

(a) For Group 'A' Route-

(i) Zonal Railway headquarter:
A SAG/JAG Officer nominated by PCE/CTE

(ii) Division:
Sectional Sr. DEN/DEN, ADEN and SSE

(b) Other than Group `A' routes-

(i) Railway:
An officer from the Track Cell not below SS/JA Grade

(ii) Division:
Sectional Sr. DEN/DEN, ADEN and SSE

6. Oscillograph Car :

Oscillograph cars are used for monitoring riding quality of track as distinct from actual track geometry recorded by Track Recording Cars. These cars, manned and managed by Mechanical Directorate of RDSO, are instrumented to collect host of data regarding rolling stocks at the maximum sectional speed permitted in the section.

The main equipment in this car is an accelerometer. The recording is carried out at Maximum Sanctioned Speed of the section to assess the track as well as vehicular parameters. It records vertical and lateral accelerations in digital form apart from various other parameters relating to rolling stock.

6.1. Frequency of Track recording:

(a) On routes having speed above 110 km/h and up to 130 km/h - Once in 6 months

(b) On routes having speed above 130 km/h and up to 160 km/h - Once in 4 months

7. Oscillation Monitoring/Measurement System:

7.1. The main equipment in this car is an accelerometer, which collects data of vertical and lateral accelerations at a rate of 100 Hz. (100 samples per second i.e. one sample at every 10 millisecond). The accelerations measured in TRCs are at ever higher frequency of 200 Hz.

7.2. The objective of OMS is to collect data of vehicle response to the track geometry variations and to assess the health of the track as well as suitability of rolling stock movement and define speeds. The OMS can also help in identification of locations/stretches for maintenance inputs.

7.3. Frequency of Recording:

(a) On Indian Railways, the group A, B and C routes are to be covered at-least once a month and other routes can be covered as per capacity and need.However this schedule is only for guidance, which could be altered depending upon the availability of instruments and need for frequent monitoring. The frequency of OMS recording, as prescribed in the IRPWM,for any broad gauge line open for traffic is as under:

No.	Speed Level	Frequency
1.	Speed above 100 km/h	Once every month
2.	Others	Once every two month

7.4. Running of OMS:

(a) As the oscillations of vehicle are heavily dependent on the speed of recording, it is advisable to carry out the OMS recording at the maximum possible speed (permitted sectional speed or nearer to it). In case oflower speed of recording, the oscillation data would not reflect the real vehicle response as would happen at the permitted speed and also the data collected in successive recordings would not be comparable.

(b) On Indian Railways the recording by OMS, on Broad Gauge,are treated as non-recorded, if the speed is lesser than specified as under:

No.	Group of the Route	Speed of recording
1.	"A" Routes	Less than 75 km/h
2.	"B" Routes	Less than 65 km/h
3.	Other Routes	Less than 75% of maximum speed; or 60 Km/h, whichever is less

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2

Factors Affecting Vehicle Response

8. For any track under service, the variations in the track geometry due to consolidation of ballast, if laid on ballast bed, sub-grade/foundation settlement, crushing of edges of ballast particles, wear of track components are unavoidable. However the magnitude of these variations would depend on not only these factors but also on the loads and forces exerted on the track due to traffic climatic conditions as well as maintenance standards.

The variations in track geometry parameters trigger rolling stocks to careen uncontrollably, while moving forward, and generate undesirable accelerations different directions and disrupt the smooth movement. These movements of rolling stocks caused by track geometry variation could also be called parasitic motions of the rolling stock.

9. **Parasitic motions:**

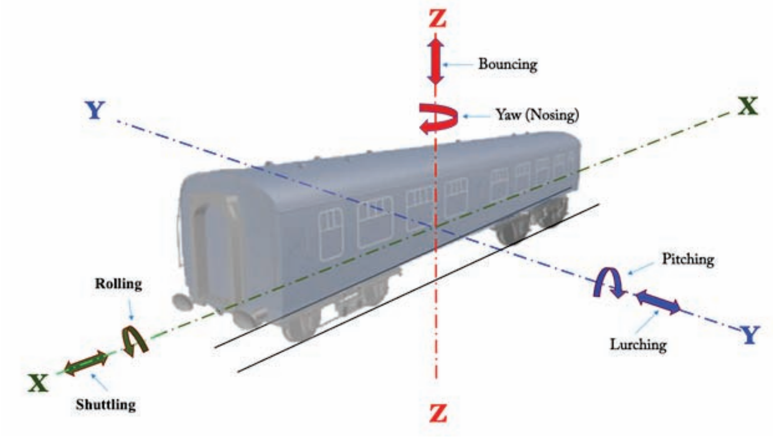
Considering a three dimensional system, the rolling stock could have translational in all the three directions and three rotational movements in the planes formed by the axes system. The X-axis is along the centre line of track in (positive in forward direction), Y-axis is perpendicular to the centre line of track in a horizontal plane (positive towards right in the direction of movement), and Z-axis is perpendicular to the plane formed by the X-axis and Y-axis (positive being vertically downwards).

9.1. The translational parasitic movement along these three axes could be caused by non-vehicular factors as under :

No.	Translational Movement	Identified as	Possible non-vehicular Factor
1.	AlongX-**axis**	Shuttling	Loose shunting
2.	Along **Y-axis**	Lurch	Alignment deviations Gauge variations
3.	Along **Z-axis**	Bouncing	Unevenness of rail-top

9.2. Similarly the rotational parasitic movement in the three planes formed by these three axes could be caused by non-vehicular factors as under :

No.	Rotational Movement	Identified as	Possible non-vehicular Factor
i)	About **X-axis** (i.e. in **Y-Z plane**)	Rolling	Cross level variation Differential unevenness (Twist)
	About **Y-axis** (i.e. in **Z-X plane**)	Pitching	Unevenness
	About **Z-axis** (i.e. in **X-Y plane**)	Nosing (Yaw)	Alignment defect



9.3. Amongst these the important parasitic movements with which a track maintenance engineer is usually concerned are lurching, bouncing and rolling and causes unwanted accelerations. Here the basis assumption is that there is no abnormality in operations and/or defect in the rolling stock i.e. being a perfect rolling stock.

10. Track parameters:

10.1. The track parameters commonly used to define the track geometry are:

(a) Gauge
(b) Twist
(c) Alignment
(d) Unevenness

10.2. Any variation in any of these parameters could trigger deviation from the equilibrium condition and generate accelerations in various directions. The magnitude of these accelerations would depend on the extent of the variations in the parameters as well as the pattern/frequency of occurrence of these variations.

10.3. These accelerations are also responsible for not only poor ride quality but also for increased stresses in the track components like in rails, fastenings etc. leading to overstressing and sub-optimal performance of these components or failure in extreme cases.

10.4. For formulation of comprehensive track maintenance strategy it would be necessary to differentiate between sudden large variations in track parameter at a specific location vis-à-vis occurrence of series of variations at regular interval, might be of relatively lesser magnitude. Although both these kinds of variations in track geometry are un-desirable, but the distinction is necessary as to identification of a specific location as well as continuous patch that might require maintenance inputs.

10.5. An isolated bad spot results in rolling stock getting an isolated jerk, whereas in the case of later ones when variations in the track geometry may not be of appreciable magnitude but presence of a series of these low magnitude variations could cause serious excitation of vehicles and thereby bad running with high amplitude vibrations. It, however, is dependent upon the frequency of the defects, the type of the rolling stock (its natural frequency of vibration) and speed of the vehicle etc. If the frequency of forced vibration of a body equals the natural frequency of vibration, of that body, resonance can occur.

10.6. Therefore regular measurement and monitoring of these parameters are necessary to make sure that the accelerations generated on account of track geometry variations are within acceptable limits.

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3

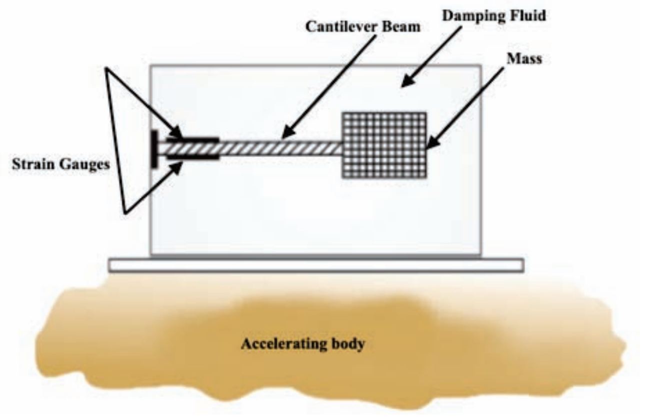
Vehicle Response and Measurement of Oscillations

11. In response to the variations in any of the track geometry parameter the vehicle would get excited and oscillate depending on the quantum of variation and damping system present in the vehicle. Therefore measurement of these oscillation and control thereof becomes the primary for ensuring safe and comfortable ride for any vehicle using railway tracks.

Usually the vertical and lateral accelerations at the coach locomotive/engine floor near pivot point (where maximum oscillations are experienced) are measured using an accelerometer. The acceleration data captured by the accelerometer are thereafter processed for assessment of ride quality and suitability of the vehicle and track conditions. These measurements could also be considered to be objective foot-plate/rear vehicle inspection of the track.

12. Oscillation Monitoring System (OMS):

12.1. The OMS equipment consists of a portable accelerometer having a mass "m" attached to a thin flexible plate whose other end is firmly fixed in casing of accelerometer and instrumented with transducers to convert the oscillations to electrical signals. The space within the casing is usually filled with silicon liquid for damping. Flexible plate has strain gauges to sense deflection of mass "m" which is indicator of acceleration.



12.2. The output from the OMS equipment could be printer based in older machines and laptop based in new machines, which could also be geo-tagged for obtaining precise location and collation.

12.3. As brought out already that the vehicle response is a function of the track geometry variations as well as vehicle parameter and its maintenance & operating conditions. Even the level of accelerations at coach floor varies at different locations within that coach.

12.4. To exclude the affect of factors other than track geometry variations, and compare data captured in successive monitoring, the accelerometer is placed on same location (pivot). In addition the recordings are carried out in the same coach, at similar speed, and same direction of movement.

13. Recording of accelerations:

13.1. Lateral and vertical acceleration peaks exceeding the following values, for broad gauge are considered for track quality assessment.

No.	Route	Threshold value of Acceleration Peaks
1.	Group A & B routes; and Routes with speeds above 110 km/h	> 0.15 g
	Other routes with speeds up to 110 km/h	> 0.20 g

13.2 Classification of Track Quality :

(a) To classify track quality of a continuous section (Section / SSE/P.Way Section / Sub-division / Division), the following criteria can be used on the basis of average number of peaks per km.

Route	Peaks per Km		
	Very Good	Good	Average
Speed above 110 km/h	< 1.0	1-2	> 2
Others	< 1.5	1.5 - 3.0	> 3

(b) If the average numbers of peaks, of vertical and lateral accelerations, exceeding 0.30 g are more than 0.25 per km; or more than one in any particular kilometer, the track would need attention.

(c) However if, at any location, peaks of lateral and vertical accelerations exceed 0.35 g, the track will have to be attended to urgently.

13.3 Sperling's Ride Index:

(a) The OMS collects data of measurement of lateral and vertical accelerations at a frequency of every 10 milliseconds (Sampling Rate of 100 Hz.) and uses these for calculation of Sperling's Ride Index (RI) as explained below.

(i) All the values of accelerations so stored in a buffer, irrespective of these being higher or lower than the threshold value, and are used for computation of RI as per the following formula given by Sperling.

$$RI = 0.896 \times \sqrt[10]{\frac{\sum_{i=1}^{n} b_i^{\,3} \times \frac{F(f_i)}{f_i}}{n}}$$

Where -

b_i	=	Acceleration peak (absolute) value (cm/s^2), calculated for each half wave
n	=	no. of completed half waves (cycles)
f_i	=	Frequency of ithhalf wave in Hz. $f_i = \frac{s}{2N}$ calculated as

Where-

s	=	sampling frequency of the sensors
N	=	number of samples of the ithhalf wave
F(fi)	=	Function of frequency to reflect human response to various frequencies; its value is different for vertical and lateral acceleration Correction factors for various frequency values are as follows:

For vertical mode	For lateral mode
0 for f < 0.5 Hz.	0 for f < 0.5 Hz.
$0.325 \times f^2$for 0.5 < f < 5.4 Hz.	0.8 × f 2for 0.5 < f < 5.4 Hz.
$400/f^2$for 5.4 < f ≤ 20.0 Hz.	650/ f 2for 5.4 < f ≤ 20.0 Hz.
1 for f > 20 Hz.	1 for f > 20 Hz.

(b) Interpretation of RI:

The Ride Index values computed by using Sperling's formula are generally interpreted as under to make it decipherable.

Ride Index (RI)	Ride Index (RI)
1.0	Very good
1.5	Almost very good
2.0	Good
2.5	Almost good
3.0	Satisfactory
3.5	Just satisfactory
4.0	Tolerable
4.5	Not tolerable
5.0	Dangerous in service

(i) The Criteria Committee has recommended limiting Ride Index values for different rolling stocks in use on IR, which is as under:

Stock	Ride Index		Acceleration			
			Lateral		Vertical	
	Preferable	Limiting	Preferable	Limiting	Preferable	Limiting
Coaches EMU & DMU	3.25 3.25	2.00 4.00	0.30g 0.30g	0.35g 0.35g	0.30g 0.30g	0.35g 0.35g
Locomotives	3.75	4.00	0.35g	0.35g	0.30g	0.35g
Wagons	4.25	4.50	Not specified		Not specified	
Breakdown craine	4.25	4.50	-	0.5g	-	0.5g
Departmental vehicles	4.25	4.50	0.55g	0.6g	0.55g	0.6g

13.4 OMS recording modes:

The OMS equipment generally records in three modes as under:

(a) Time mode

(b) Tachometer mode

(c) Combination of Time and Tachometer mode

In Time Mode Ride Index of all blocks are calculated after completion of a kilometre indicated by entering of km for every 200 m blocks.

In Tachometer Mode speed, vertical and lateral acceleration are monitored and exception report is printed along with peak location.

In both cases RI of all the blocks are printed after completion of KM. In case of Tacho mode number of blocks can be less or more than 5, depending upon the length of the km.

13.5 Output from OMS equipment:

A typical sample output of OMS is as under along with explanation alongside, however format may vary depending on equipment/model etc.

04,11,88				Date(DD/MM/YY)
12.56.16				Time(H/Min/Sec) 24 h format
1251	0000		K	Starting location in KM
0100	0.15	0.15	G	Maximum speed, V acceleration limit, L acceleration limit
2.50	2.50		R	Maximum Vertical RI limit and Lateral RI limit
1251	0092		K	Location in KM, Distance from last KM
102	0.16	0.04	G	Speed, Vertical acceleration, Lateral acceleration in 'g'
1251	0320		K	
089	0.19	0.07	G	
1251	0917		K	
095	0.06	0.17	G	
1251				Km switch pressed
092				Average speed during last KM
01	2.93	2.33	R	Block No., Vert. RI , Lat. RI
02	2.91	2.63	R	
03	3.14	2.54	R	
04	3.02	3.30	R	
05	2.97	2.83	R	

14. Analysis of Oscillograph Car Data and Interpretation of Results:

14.1 The Oscillograph Car also captures acceleration data of vertical and lateral acceleration, of which the exceedences beyond threshold values are counted. Track should be attended to at all such locations where peaks above threshold values are reported so as to ensure good riding. Depending on the location of the accelerometer the threshold value of accelerations are as under:

(a) Loco Cab floor–

Threshold value of acceleration in vertical mode is taken as 0.20 g for all locos (Diesel and Electric).

Threshold value of acceleration in lateral mode is taken as 0.20 g for diesel and electric locos with double stage suspension.

In case of locos with single stage suspension, threshold value may be taken as 0.30 g both for lateral and vertical acceleration.

(b) Passenger Coach Floor-

Threshold value of acceleration for both vertical and lateral modes shall be taken as 0.15 g.

14.2 Analysis of Oscillograph Car data is carried out km-wise and results are given under the following heads, on the basis of the peaks counted above threshold values for a particular locomotive:

(i) Station Yards

(ii) Other than Station Yards (Isolated locations)

(iii) Active continuous stretches

(iv) Speed grouping table is also prepared.

Typical Statement prepared in connection with an Oscillograph run are given below as Statement A, B and C. Efforts should be made not only to check the extent of defect but also to find out whether it is occurring in an active patch(active continuous stretches having more than 10 peaks/km above threshold value on an average) as it may lead to excessive oscillations.

STATEMENT 'A'

Total length of Section: 232 kms

Length recorded: 185 kms

Date of recording: 22nd March 2019

Section: BBQ—KZJ

Loco No ....

Type of Loco ....

Oscillograph Results

Station Yards (Peaks above Threshold values)

SN	Name of Yard and Location	Speed in kmph	Vertical acceleration (g)	Lateral acceleration (g)	Remarks
1	SRUR FP-2	100	..	0.26	
2	MCI TP-1 TP-2	100 100	0.22 0.22		
3	PPZ FP-1 FP-2	100 105	0.20 0.20		
4	BGSF 324/10-11	110	..	0.22	
5	OPL 343/5-6	100	0.26		
6	HSP TP-1	100	0.20		

STATEMENT 'B'

Date of recording 22nd March 2018

Loco No.: ....

Type of Loco: ....

Section: BPQ—KZJ (km 367- km 135)

Length recorded: 185 km

Total length: 232 km

Oscillograph Results in Places other than Station Yards

Isolated Locations (Peaks above Threshold value)

SN	Location	Speed in kmph	Vertical acceleration (g)	Lateral acceleration (g)	Remarks
1	146/1-2	100		0.28	Curve
2	148/15-16	110		0.28	Br.
3	149/7-8	110	0.28		
4	149/7-8	110	0.35		Br.
5	151/8-9	110		0.24	
6	151/8-9	110		0.32	
7	151/11-12	105		0.24	
8	160/7-8	110		0.22	Curve
9	164/9-10	110	0.24		
10	168/1-2	100	and so on	0.30	

STATEMENT 'C'

Date of recording: 22nd March 2018

Loco No.: ....

Type of Loco: ....

Section: BPQ—KZJ (km 135-Km 367)

Length recorded: 185 km

Total length: 232 km

OSCILLOGRAPH RESULTS

Active Continuous Stretches

SN	km From	km To	Distance in km	Speed in kmph	Active in mode	Total No of peaks above 0.20g.	Maximum value	No. of peaks between 0.20g. 0.30g.	No. of peaks above 0.30g.	Remarks
						NIL				

Note– If there are on an average more than 10 peaks above the threshold value per km, the length may be included in this statement.

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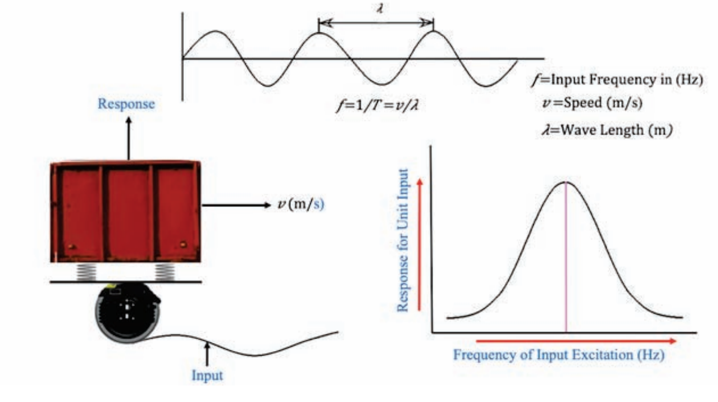
4

Resonance frequency and Chords for Measurements

15. Natural Frequency and resonance:

15.1. The response of a dynamic system depends more on frequency of excitation rather than its amplitude and therefore considered frequency sensitive. From the figure below, a plot of frequency response to unit input excitation of a dynamic system, it can be seen that the response of the dynamic system peaks at a particular frequency. This occurs at an input frequency that matches with natural frequency of the system.



15.2 The vehicle accelerations under such circumstances chiefly depends on frequency response of the vehicle, its speed and the wavelength of the irregularity responsible for input excitations as described below:

$v = f \times \lambda$

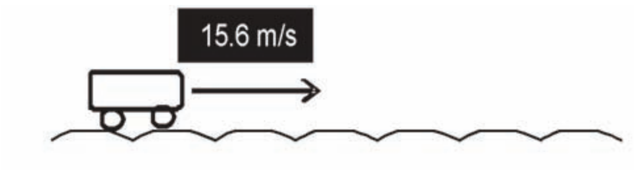
Wherer,

v = Speed of vehicle in m/s

λ = Wavelength of irregularity in m

f = Input frequency in Hz.

15.3 Consider an example of rail joint being low (unevenness of the running surface), in case of fish-plated track, exist at a regular interval i.e. at every 13 m, whereon a rolling stock is moving at a speed of 15.6 m/sec (56 km/h).



Series of low joints - an example of cyclic track defect

The frequency, of vibration induced, will thus be 1.2 cycles/second (=15.6/13). The natural frequency of vibration of a typical ICF coach being 1.2 Hz., it would resonate and experience wild movements at this speed (i.e. 56 km/h).

16. Rolling Stocks on IR:

16.1. The rolling stock plying on IR system are broadly grouped in three category i.e. locomotives (both diesel and electric), passenger coaches and freight wagons.

16.2. The natural frequency of various rolling stocks plying on IR in vertical and lateral mode along-with their maximum speed potential are as under:

(a) Locomotives:

Sl. No.	Type of Locomotive	Speed Potential (km/h)	Natural frequency (Hz.)	
			Vertical (Bouncing)	Lateral (Pitching)
1	WDG2	110	1.56	1.85
2	WAP4	135	2.59	3.57
3	WAP5	180	1.26	1.40
4	WAP7	155	1.35	1.30
5	WDM3A	135	3.45	3.03
6	WDM3D	135	2.17	2.38
7	WDM3E	135	2.44	2.70
8	WDM3F	120	1.36	1.70
9	WDP4	180	1.80	1.72
10	WDP4B	145	1.70	1.92
11	WDG4	115	2.08	1.72
12	WDG3A	115	2.63	2.43
13	WAG7	115	2.19	1.96
14	WAG9	110	1.21	1.35

(b) Passenger Coaches:

Sl. No.	Type of Coach	Speed Potential (km/h)		Natural frequency (Hz.)			
				Vertical (Bouncing)		Lateral (Pitching)	
		Loaded	Empty	Loaded	Empty	Loaded	Empty
1	LHB Generator Car	160	160	1.08	1.408	1.09	1.149
2	LHB AC 2 Tier	160	160	1.19	1.41	1.21	1.19
3	LHB Hot Buffet Car	160	160	1.136	1.19	1.25	1.21
4	LHB AC-III tier	160	160	1.32	1.59	1.47	1.54
5	ICF-SG GS coach	130	130	1.61	1.74	1.68	1.65
6	ICF-SG AC-III tier coach	130	130	1.33	1.12	1.39	1.37
7	ICF- Luggage Brake cum Gen Van	130	130	1.21	1.16	1.23	1.12
8	ICF-1st AC Chair Car	130	130	1.29	1.22	1.27	1.49

(c) Freight Wagons:

Sl. No.	Type of Coach	Speed Potential (km/h)		Natural frequency (Hz.)			
				Vertical (Bouncing)		Lateral (Pitching)	
		Loaded	Empty	Loaded	Empty	Loaded	Empty
1	BOXN	60	80	2.5	-	3.1	-
2	BOXNM1	60	80	1.90	4.54	2.03	5.00
3	BOXNHSM1	75	90	5.50	4.50	4.16	6.25
4	BOXNHL	75	100	3.84	6.25	3.57	5.00
5	BCNHSM1	75	90	2.70	6.25	2.44	3.70
6	BCNAHSM1	75	100	5.00	-	5.00	-
7	BOST	50	80	3.33	-	3.44	-
8	BOSTHSM1	60	80	3.8	8.3	4.8	8.3
9	BOBRM1	70	75	7.14	5.55	4.34	8.00
10	BOBRNM1	70	80	2.77	5.56	3.65	5.88
11	BOBSNM1	45+5	55+5	3.12	5.26	3.22	5.50
12	BCNHL	75	70	2.70	5.00	2.44	5.26

16.3 It could also be established that if the natural frequency of a system matches with the frequency of excitation, the result could be violent excitation of the system (rolling stock or vehicle). In fact under such conditions of matching frequencies, even though amplitude of input excitation may be insignificant, the acceleration build up could be very high. This matching of frequencies of excitation with natural frequency of a system occurs due to presence of the irregularities at regular interval i.e. having critical wavelength. This condition could be avoided if these irregularities having critical wavelength are removed during regular maintenance operation.

16.4 The critical wavelength of irregularities that might cause resonance for any vehicle mainly depends on the natural frequency of vehicle in vertical and lateral mode and speeds. (See Annexure)

16.5 The critical wavelength for various rolling stocks plying on IR, in vertical and lateral mode, at different speed levels are as under:

Critical Wavelength in Vertical Mode

Sl. No.	Rolling Stock	Critical Wavelength at different speeds Vertical Mode							
		90 km/h	100 km/h	110 km/h	120 km/h	130 km/h	140 km/h	150 km/h	160 km/h
1	ICF coaches	15.53 to 20.66	17.25 to 22.96	18.98 to 25.25	20.70 to 27.55	22.43 to 26.85	Speed Potential of ICF Coaches is 130 km/h		
2	LHB Coaches	18.94 to 23.15	21.04 to 25.72	23.15 to 25.98	25.25 to 30.86	27.36 to 33.44	29.46 to 36.01	31.57 to 38.58	33.67 to 41.15
3	WAP-5	19.84	22.05	24.25	26.46	28.66	30.86	33.07	33.27
4	WAP-7	18.52	20.58	22.63	24.69	26.75	28.81	30.86	32.92
5	WAP-4	10.0	11.11	12.22	13.33	14.44	Speed Potential of WAP-4, WDM3A, WDM3D, WDM3E is 135 km/h		
6	WDM3A	7.25	8.05	8.86	9.66	10.47			
7	WDM3D	11.52	12.80	14.08	15.36	16.64			
8	WDM3E	10.25	11.38	12.52	13.66	14.80			
9	WDM3F	18.38	20.42	22.47	24.51		Speed Potential of WDM3F is 120 km/h		

Critical Wavelength in Lateral Mode

Sl. No.	Rolling Stock	Critical Wavelength at different speeds Lateral Mode							
		90 km/h	100 km/h	110 km/h	120 km/h	130 km/h	140 km/h	150 km/h	160 km/h
1	ICF coaches	14.88 to 20.33	16.53 to 22.58	18.19 to 24.84	19.84 to 27.10	21.49 to 29.36	Speed Potential of ICF Coaches is 130 km/h		
2	LHB Coaches	17.01 to 21.01	18.9 to 23.34	20.79 to 25.68	22.68 to 28.01	24.57 to 30.35	26.46 to 32.68	28.34 to 35.01	30.23 to 37.35
3	WAP-5	17.86	19.84	21.83	23.81	25.79	27.78	29.76	31.75
4	WAP-7	19.23	21.37	23.50	25.64	27.78	29.91	32.05	34.19
5	WAP-4	7.0	7.78	8.56	9.34	10.12	Speed Potential of WAP-4, WDM3A, WDM3D, WDM3E is 135 km/h		
6	WDM3A	8.25	9.17	10.08	11.00	11.92			
7	WDM3D	10.50	11.67	12.84	14.01	15.17			
8	WDM3E	9.26	10.29	11.32	12.35	13.37			
9	WDM3F	14.71	16.34	17.97	19.61	-	Speed Potential of WDM3F is 120 km/h		

For more details of critical wavelength at various speeds for various ICF coaches, LHB coaches, locomotives (passenger), locomotives (goods), wagons (loaded) and wagons (empty), the annexure may be referred.

17. Measurement Chords:

17.1. Some of the track parameters viz. Alignment and unevenness are monitored my making measurements based on certain chord length. The choice of size of the chord to be adopted depends on many factors, therefore needs to be selected very carefully to identify the irregularities that are likely to affect the ride quality adversely and may, in extremely rare case, result in compromise on the safe running of the trains.

17.2. The inertial system of measurement for recording of Unevenness, Alignment and Cross-level is in vogue world over, whereby it is possible to acquire absolute profile of track in horizontal as well as in vertical plane. The accuracy of these absolute profile is of-course subject to the measurement accuracy; a function of sensitivity and resolution of the sensors deployed in the data acquisition and processing system. The data acquired are passed through band filter (usually 3-70 m) to exclude very short wave length (high frequency) and very long wave length (low frequency) defects, which are unlikely to adversely affect the ride quality.

17.3. After acquisition of absolute profile in horizontal and vertical plane the data are processed on specific chords.

17.4. Owing to wide variety of both passenger as well as freight stocks, having different natural frequencies allowed on same track at different speeds necessitates handling of wide range of defect wave-length and inter-alia need multiple chords to analyze data, which is usually not practicable. Therefore the data are processed on two chords viz. a short one and a long one; to take care of the passenger and freight stocks having softer and stiffer suspension systems respectively.

18. Transfer Function of Chord:

18.1. The track geometry profile, although complex could be mathematically broken into a number of sine waves of different wavelength and amplitude; few amongst these would have critical wavelengths.

18.2. The measurements using mid chord measurement system vitiates the measurement of actual track irregularity according to the transfer function of the system. The transfer function depends on the chord length selected for measurement and wavelength of irregularity. For pure sine wave irregularity the transfer function has following relationship.

$$H(\lambda) = 1 - Cos\left(\frac{\Pi \times L}{\lambda}\right)$$

Where,

$H(\lambda)$ = Transfer function

L = Chord Length selected for Measurement in meters

λ = Wavelength of irregularity in meters

18.3. Depending upon the value of λ and L the value of transfer function varies from 0 to 2 by which the amplitude, of various wavelengths present in a complex track irregularity gets distorted to varying degree, unless the transfer function is unity.

18.4. The ideal transfer function for exact measurement of track irregularities at critical wavelength (L/λ) would be unity when L/λ are 1/2, 3/2, 5/2 etc. i.e. chord length for measurement is 1/2, 3/2 etc. times the wavelength of track irregularities.

18.5. The study of the transfer function for various chord lengths and critical wavelengths for various rolling stocks plying on IR at different speeds suggests that the critical wavelengths varies in a wide range; moreover the profile of track irregularities also do not follow any well defined pattern. Therefore it is not practically feasible to measure all critical wavelengths with unit transfer function. The chords sizes for measurement, which are having a transfer function in the range of 0.80 to 1.20 for critical wavelengths, considered acceptable.

19. Chord sizes for measurements:

19.1. On IR, till recently chords of 3.6 m & 9.6 m were used for recording of unevenness values and 7.2 m & 9.6 m for recording of alignment values. Similarly for the calculation of the Twist from absolute vertical profile (or from cross level data) a base length of 3.6 m & 4.8 m were used.

19.2. Based on analysis of alignment and lateral ride index; and unevenness and vertical ride index the following chords for speed ≤ 110 km/h and > 110 km/h are identified for UN and AL for different rolling stocks (locomotive and coaches):

Sl. No.	Parameter	Speed	Chord length	Rolling stock
1	Unevenness	≤ 110 km/h	9 m	ICF Coach, LHB Coach, WDM-3F, WAP-7, WAP-5
			18 m	WDM-3E, WAP-4, WDM-3A,
		> 110 km/h	9 m	WDM-3D
			18 m	ICF Coach, LHB Coach, WAP-5, WAP-7
2	Alignment	≤ 110 km/h	9 m	ICF Coach, LHB Coach, WDM-3F, WAP-5, WAP-7
			15 m	WDM-3A, WDM-3E,
		> 110 km/h	9 m	WDM-3F

20. Base for of twist calculations:

20.1. The twist is an undesirable element, in track geometry, for its destabilizing affect on vehicles. The twisting of track, however, is unavoidable in certain situations like transitions to super-elevated curves etc. The wheel base of bogie and centre to centre distance of bogie of various rolling stocks that gets destabilizing affect determines the base for measurement of twist.

20.2. It has been substantiated by studies conducted on IR that the Twist has very low co-relation with ride quality, which is supported by various other studies carried out elsewhere and also finds mention in UIC leaflet, EN code etc.

20.3. The twist is, therefore, not to be used for the characterization of the quality standards of track section, however measurement of track twist on wheel base and bogie center distance is required for testing of vehicles in oscillation trials for dynamic stability of vehicles.

20.4. The wheel base and bogie centres of different wagons, coaches and locomotives on Indian Railways are as under:

(a) Coach

Sl. No.	Type of COACH	Wheel Base (mm)	Distance between centres of Bogies (mm)
1	LHB	2,560	14,900
2	ICF	2,896	14,783

(b) Wagons:

Sl. No.	Type of Wagon	Wheel Base (mm)	Distance between centres of Bogies (mm)
1	BVZI	2,896	9,026
2	BFKN	2,000	9,000
3	BLCA	2,000	9,675
4	BLCAB	2,000	9,675
5	BLLB	2,000	8,812
6	BLCBM	2,000	8,812
7	BLLA	2,000	10,700
8	BLLB	2,000	9,810

Locomotive

Sl. No.	Type of LOCO	Wheel Base (mm)	Distance between centres of Bogies (mm)
1	WDM1	2,073	9,246
2	WDM2	2,108	9,430
3	WDM4	2,020	11,100
4	WDM7	2,108	8,518
5	WDP1	2,800	8,800
6	WDP2	2,120	10,500
7	WDP4	2,134	13,868
8	WDS5	2,650	9,906
9	WDS6	2,108	9,906
10	WDG4	2,134	13,868

20.5. The bases for calculation of twist are fixed on the basis of dynamic stability, which is dependent on wheelbase and distance between bogie centres. Therefore twist values are calculated on two bases i.e. short base and long base. The basic ingredients of twist (viz. unevenness of rails) are considered separately from ride quality considerations.

20.6 Considering the fact that the maximum wheel base for bogies of rolling stocks plying on Indian Railway is 2.896 m and maximum distance between bogie centres is 14.9 m, the short and long bases for measurement of twist are selected as 3.0 meter and 15.0 meter to factor in the sampling interval of 0.30 m / 0.25 m.

21. As per IRPWM the aforementioned chords are classified as Short and Long chords for track parameters as under–

Sl. No.	Parameter	Short Chord / Base	Long Chord/ Base
1	Unevenness	9.0 Metre (UN-1)	18.0 Metre (UN-2)
2	Alignment	9.0 Metre (AL-1)	15.0 Metre (AL-2)
3	Twist	3.0 Metre (TW-1)	15.0 Metre (TW-2)

Annexure (1/6)

Critical wavelength of various ICF coaches at different speeds

Sl. No.	Coach Type	Speed (km/h)	Vertical Mode		Lateral Mode	
			Natural frequency (Hz.)	Critical Wavelength (m)	Natural frequency (Hz.)	Critical Wavelength (m)
1	SG GS	130	1.61	22.43	1.68	21.49
2	SG AC-III TIER		1.33	27.15	1.39	25.98
3	LUGGAGE VAN -ICF		1.21	29.84	1.23	29.36
4	1st AC CC		1.29	27.99	1.27	28.43
1	SG GS	120	1.61	20.70	1.68	19.84
2	SG AC-III TIER		1.33	25.06	1.39	23.98
3	LUGGAGE VAN-ICF		1.21	27.55	1.23	27.10
4	1st AC CC		1.29	25.84	1.27	26.25
1	SG GS	110	1.61	18.98	1.68	18.19
2	SG AC-III TIER		1.33	22.97	1.39	21.98
3	LUGGAGE VAN- ICF		1.21	25.25	1.23	24.84
4	1st AC CC		1.29	23.69	1.27	24.06
1	SG GS	100	1.61	17.25	1.68	16.53
2	SG AC-III TIER		1.33	20.89	1.39	19.98
3	LUGGAGE VAN-ICF		1.21	22.96	1.23	22.58
4	1st AC CC		1.29	21.53	1.27	21.87

Annexure (2/6)

Critical wavelength of various LHB coaches at different speeds

Sl. No.	Coach Type	Speed (km/h)	Vertical Mode		Lateral Mode	
			Natural frequency (Hz.)	Critical Wavelength (m)	Natural frequency (Hz.)	Critical Wavelength (m)
1	LHB GEN CAR	120	1.08	30.86	1.19	28.01
2	LHB AC 2 TIER		1.19	28.01	1.21	27.55
3	LHB HOT BUFFET		1.14	29.24	1.25	26.67
4	LHB AC-III TIER (EOG)		1.32	25.25	1.47	22.68
1	LHB GEN CAR	140	1.08	36.01	1.19	32.68
2	LHB AC 2 TIER		1.19	32.68	1.21	32.14
3	LHB HOT BUFFET		1.14	34.11	1.25	31.11
4	LHB AC-III TIER (EOG)		1.32	29.46	1.47	26.46
1	LHB GEN CAR	160	1.08	41.15	1.19	37.35
2	LHB AC 2 TIER		1.19	37.35	1.21	36.73
3	LHB HOT BUFFET		1.14	38.99	1.25	35.56
4	LHB AC-III TIER (EOG)		1.32	33.67	1.47	30.23

Annexure (3/6)

Critical wavelength of various Locomotives at different speeds

Sl. No.	Type of Locomotive	Speed (km/h)	Vertical Mode		Lateral Mode	
			Natural frequency (Hz.)	Critical Wavelength (m)	Natural frequency (Hz.)	Critical Wavelength (m)
1	WAP5	120	1.26	26.46	1.4	23.81
2	WAP7		1.35	24.69	1.3	25.64
3	WAP5	140	1.26	30.86	1.4	27.78
4	WAP7		1.35	28.81	1.3	29.91
5	WAP5	160	1.26	35.27	1.4	31.75
6	WAP7		1.35	32.92	1.3	34.19
1	WDM3A	100	3.45	8.05	3.03	9.17
2	WDM3D		2.17	12.80	2.38	11.67
3	WDM3E		2.44	11.38	2.7	10.29
4	WDM3F		1.36	20.42	1.7	16.34
1	WDM3A	120	3.45	9.66	3.03	11.00
2	WDM3D		2.17	15.36	2.38	14.01
3	WDM3E		2.44	13.66	2.7	12.35
4	WDM3F		1.36	24.51	1.7	19.61
1	WDM3A	130	3.45	10.47	3.03	11.92
2	WDM3D		2.17	16.64	2.38	15.17
3	WDM3E		2.44	14.80	2.7	13.37
4	WDM3F		1.61	22.43	1.68	21.49

Annexure (4/6)

Critical wavelength of various Goods Locomotives at different speeds

Sl. No.	Type of Locomotive	Speed (km/h)	Vertical Mode		Lateral Mode	
			Natural frequency (Hz.)	Critical Wavelength (m)	Natural frequency (Hz.)	Critical Wavelength (m)
1	WDG2	60	1.56	10.68	1.85	9.01
2	WDG4		2.08	8.01	1.72	9.69
3	WDG3A		2.63	6.34	2.43	6.86
4	WAG7		2.19	7.61	1.96	8.50
5	WAG9		1.21	13.77	1.35	12.35
1	WDG2	75	1.56	13.35	1.85	11.26
2	WDG4		2.08	10.02	1.72	12.11
3	WDG3A		2.63	7.92	2.43	8.57
4	WAG7		2.19	9.51	1.96	10.63
5	WAG9		1.21	17.22	1.35	15.43
1	WDG2	90	1.56	16.03	1.85	13.51
2	WDG4		2.08	12.02	1.72	14.53
3	WDG3A		2.63	9.51	2.43	10.29
4	WAG7		2.19	11.42	1.96	12.76
5	WAG9		1.21	20.66	1.35	18.52
1	WDG2	100	1.56	17.81	1.85	15.02
2	WDG4		2.08	13.35	1.72	16.15
3	WDG3A		2.63	10.56	2.43	11.43
4	WAG7		2.19	12.68	1.96	14.17
5	WAG9		1.21	22.96	1.35	20.58

Annexure (5/6)

Critical wavelength of various Wagons (empty) at different speeds

Sl. No.	Type of Wagons	Speed (km/h)	Vertical Mode		Lateral Mode	
			Natural frequency (Hz.)	Critical Wavelength (m)	Natural frequency (Hz.)	Critical Wavelength (m)
1	BOXNM1	60	1.9	8.77	2.03	8.21
2	BOXNHSM1		5.5	3.03	4.16	4.01
3	BOXNHL		3.84	4.34	3.57	4.67
4	BCNHSM1		2.7	6.17	2.44	6.83
5	BOSTHSM1		3.8	4.39	4.8	3.47
6	BOBRM1		7.14	2.33	4.34	3.84
7	BOBRNM1		2.77	6.02	3.65	4.57
8	BCNHL		2.7	6.17	2.44	6.83
1	BOXNM1	75	1.9	10.96	2.03	10.26
2	BOXNHSM1		5.5	3.79	4.16	5.01
3	BOXNHL		3.84	5.43	3.57	5.84
4	BCNHSM1		2.7	7.72	2.44	8.54
5	BOSTHSM1		3.8	5.48	4.8	4.34
6	BOBRM1		7.14	2.92	4.34	4.80
7	BOBRNM1		2.77	7.52	3.65	5.71
8	BCNHL		2.7	7.72	2.44	8.54
1	BOXNHSM1	90	4.5	5.56	6.25	4.00
2	BOXNHL		6.25	4.00	5	5.00
3	BCNHSM1		6.25	4.00	3.7	6.76
1	BOXNHL	100	6.25	4.44	5	5.56

Annexure (6/6)

Critical wavelength of various Wagons (loaded) at different speeds

Sl. No.	Type of Wagons	Speed (km/h)	Vertical Mode		Lateral Mode	
			Natural frequency (Hz.)	Critical Wavelength (m)	Natural frequency (Hz.)	Critical Wavelength (m)
1	BOXNM1	60	1.9	8.77	2.03	8.21
2	BOXNHSM1		5.5	3.03	4.16	4.01
3	BOXNHL		3.84	4.34	3.57	4.67
4	BCNHSM1		2.7	6.17	2.44	6.83
5	BOSTHSM1		3.8	4.39	4.8	3.47
6	BOBRM1		7.14	2.33	4.34	3.84
7	BCNHL		2.7	6.17	2.44	6.83
1	BOXNHSM1	75	5.5	3.79	4.16	5.01
2	BOXNHL		3.84	5.43	3.57	5.84
3	BCNHL		2.7	7.72	2.44	8.54

■ ■ ■

5

Measurement of Track Parameters

22. The measurement of various track parameters is an integral part of inspections and practiced in all railway system as part of manual as well as by mechanized monitoring systems.

22.1. Manual Inspections and monitoring:

The manual inspections are essential and indispensable, for it enables direct inspection of various components to assess condition and deterioration, measurements/verification of various parameters; quality of work done by gangs; condition of gang tools; inspection of special features of track like curves, points & crossing, LWR & SEJ, bridges etc. and the real conditions to have a first hand feel of the track and its operating environment. These inspections are having certain limitations and constraints; few of which are-

(a) Being Subjective i.e. dependent on the skill of the individual person and there might be significantly different understanding and assessment for issues for which objective assessment criteria are not available/used. The assessment of ride quality and oscillations in footplate inspection is a pertinent example.

(b) Floating Track Condition: The behaviour of the track under load, more often than not, is significantly different than that assessed from its floating conditions. The variations of track parameters in dynamic conditions would play a significant role in the real rail wheel interaction.

(c) Being time consuming, slow and tiring in data collection, and its record keeping being cumbersome prevents deriving meaningful information easily and to undertake complex analysis.

22.2. Mechanized Monitoring:

With the technological advancements and widespread use of computers the storage and handling of huge data became possible; leading to deployment of mechanized measurement system to collect track geometry data.

The different systems/mechanical means available with Indian Railways to assess the track parameters and vehicle response are mentioned in Chapter-1. The measurements of track parameters by the Track Recording Car (TRC) are dealt in this chapter.

23. Track Recording Car :

At present there are two types of track recording cars in use on Indian Railways; viz.

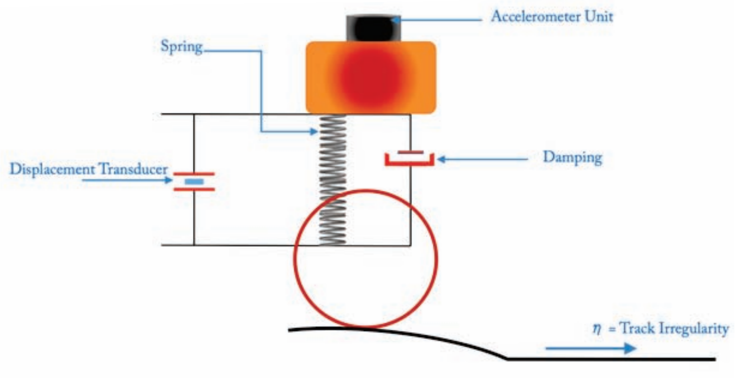
i. With contact type gauge sensors; having contact sensors fixed on measuring frame mounted on the axles of rear bogie of TRC as seen in photographs below; and

ii. With contactless laser based sensors; having LASER based contactless sensors mounted on a sensor beam welded on the rear bogie of TRC; as seen in sketch below.

The Speed potential of LASER contactless sensor based TRCs it is 160 km/h, and it can also record curvature, vertical and lateral rail wear etc. and uses RFID based ALD for location Synchronization. It can also communicate on line; the large peaks to Sectional SSE, Divisional Control etc. in contrast the speed potential of contact sensor based TRCs is 100 km/h due to physical contact.

23.1. Inertial Principle Used in TRCs:

The TRCs measures lateral and vertical accelerations with the help of accelerometers placed at coach floor/bogie frame. The acceleration values obtained are integrated twice to get loci of the location of accelerometers. The relative displacements between rail and accelerometer locations are obtained from displacement transducers (LVDT)/LASER based contactless sensors. The loci of accelerometers are combined with relative displacement obtained from sensors to derive the vertical and lateral profile of the rail. These measurements are further corrected for roll and yaw (nosing) motion of coach using gyroscopes.



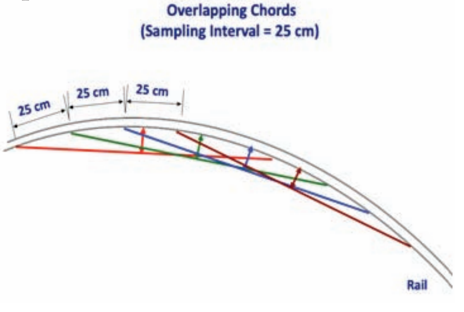
Both types of TRCs are based on inertial principle of track measurements and it is possible to have discrete values of track geometry parameters on selected sampling interval, under loaded condition on two user selectable chords in the range of 2 to 20 meter.

23.2. Parameters Measured:

(a) Unevenness of Left & Right Rail (on two user selectable chords)
(b) Alignment of Left & Right Rail (on two user selectable chords)
(c) Twist (calculated on two user selectable bases)
(d) Variation of gauge (on 50 metre moving average) and/or variation of gauge over nominal gauge
(e) Vertical and lateral accelerations on coach floor above bogie pivot
(f) Curve details
(g) Speed of Recording

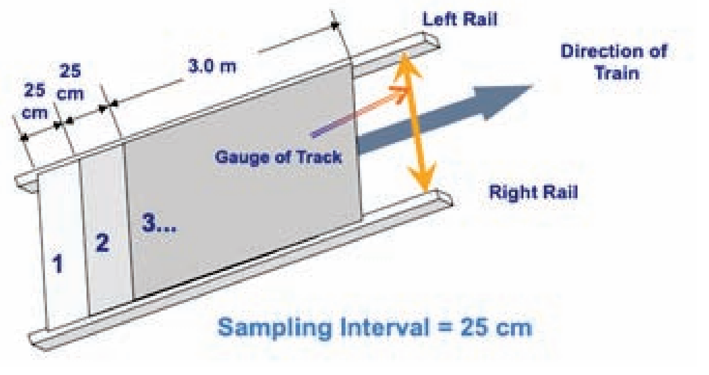
23.3. Sampling Interval/Sampling Distance:

It refers to distance between the two successive data of a track geometry parameter for any stand-alone measurement. However in case of chord based measurement like unevenness or alignment, it is the distance by which the measuring chord is shifted for next measurement; the location of measurement being at the middle of the chord also gets shifted by similar distance. (see sketch) Thereby the measuring chords used in successive measurement would overlap.



Similar principle is used to calculate twist for which the overlapping sliding base length is used.

The sampling interval of TRCs is selectable in the range of 20 cm to 60 cm.



23.4. Concept of Block:

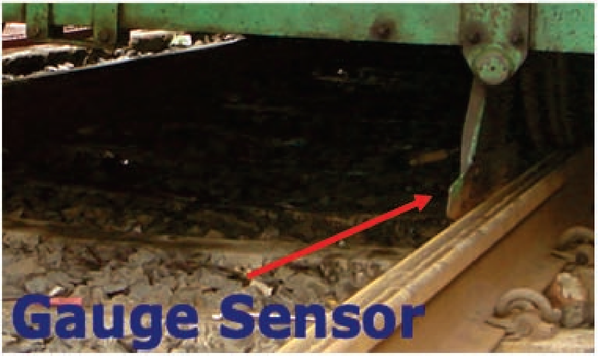
For the purpose of analysis of data and its subsequent attentions as required, the length of track is sub-divided into smaller segments typically of 200 m length. Therefore a kilometre length of track would have 5 blocks, however if the length of any kilometre is longer than 1000 m, then that kilometre would have 6 blocks (the length of sixth block being the length by which that particular kilometre exceeds 1000 m)

24. Measurement of Track Parameters:

24.1. Gauge:

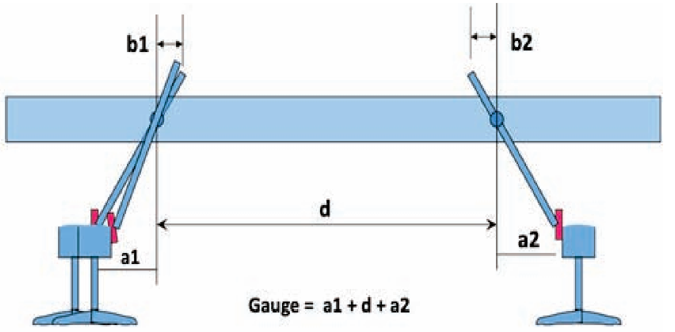
(a) Contact Sensor based measurement-

(i) Gauge is measured by the physical sensors (sword type contact feelers with carbide tips), which are spring loaded to ensure contact with gauge face all the time.



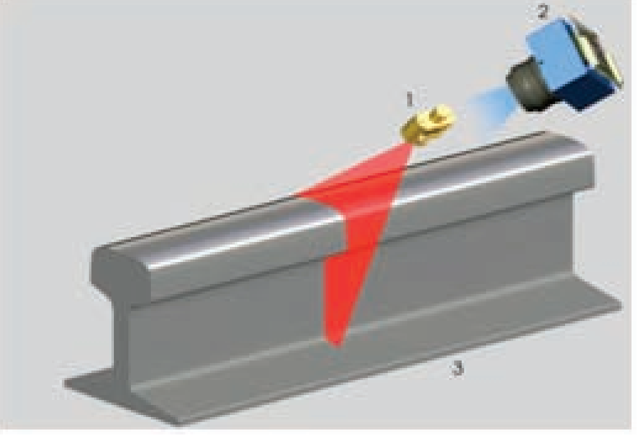
(ii) The Carbide tips are provided on the contact surfaces to reduce the wear of the sensors. (See photo along side)

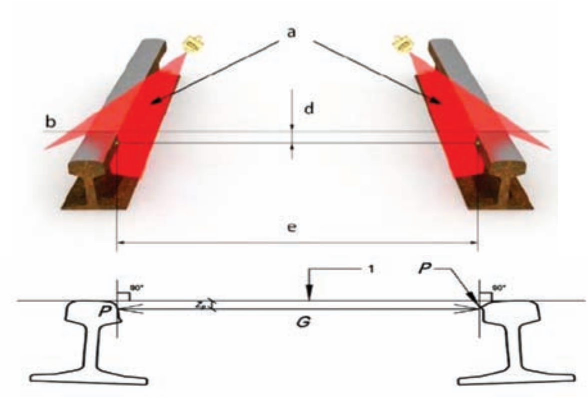
(iii) The gauge value is derived from measurement of movement, with the help of LVDT (Linear Variable Differential Transformer), of the arm attached with the gauge sensor. (see diagram below)



b) LASER based Contact-less measurement:

(i) In case of LASER based contact-less TRC, the gauge face side of the rail (3) is illuminated with a very thin strip of LASER light (1). The special high-speed high-resolution cameras (2) capture this illuminated profile for both left and right rail and the images processed digitally for identification and characterization of gauge value. (See sketches)



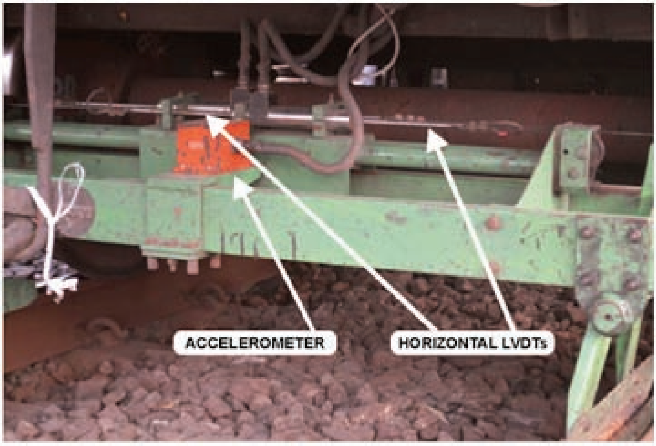


(ii) Based on the sampling distance, of 25 cm, between two successive samples, for a block of 200 m length, there would be 800 readings of gauge gets recorded.

24.2. Alignment:

(a) In the present breed of TRCs, the measurements of alignment deviations are made by inertial system, an indirect method of measurement.

(b) The accelerometer mounted on the measuring frame (See photograph) records lateral accelerations and by double integration of these acceleration values in time domain could define the locus of center line of the track. The distance of the left rail and the right rail from the center line of track are computed with the help of LVDT to define the absolute position of both the rails in plan, which then can be used to derive the alignment deviation values by using appropriate chord.



(c) Based on the sampling distance, of 25 cm, between two successive samples, for a block of 200 m length, there would be 800 readings of alignment for each rail gets recorded.

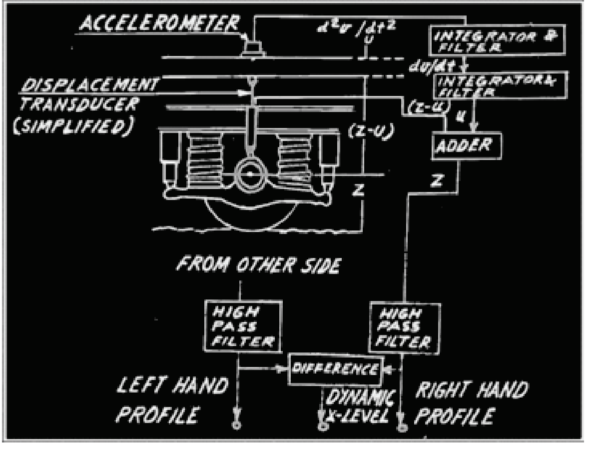
24.3. Unevenness:

(a) In the present breed of TRCs, the measurements of unevenness of rail top are made by Inertial system, an indirect method of measurement.

(b) Two separate accelerometers are mounted on the coach floor (inside the TRC coach) above the left and right axle boxes to records vertical accelerations. The double integration of these acceleration values in time domain gives the displacement of the accelerometer positions.

The dynamic distance (due to suspension system) between the left and right accelerometer position and the centre of axle box is captured by two LVDTs placed between coach floor and axle box on either side. (see sketch and photographs)

Considering that the distance between rail-top and axle box is constant, the absolute profile of rail-top could be derived.



(c) Based on the sampling distance, of 25 cm, between two successive samples, for a block of 200 m length, there would be 800 readings of unevenness for each rail gets recorded.

24.4. Twist:

(a) The twist value is a calculated parameter, from the cross levels measured at two ends of a stipulated base.

(b) Based on the sampling distance, of 25 cm, between two successive samples considering overlapping sliding base, for a block of 200 m length, there would be 800 readings of Twist get recorded.

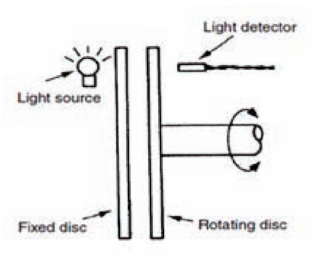
25. Distance measurement:

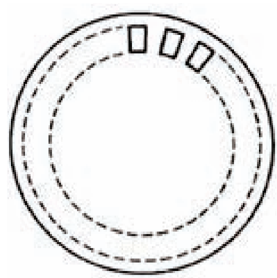
25.1. The distance travelled by the TRC is calculated by the number of, full and part, revolutions of one of the wheels of the rear bogie of TRC coach. For this purpose a tachometer is fixed to that wheel.

25.2. Tachometer consists of a revolving disc with fine slits placed between a light source on one side and a light-sensing detector (diode) on the other side.

25.3. Each time the light passes through the slit, the detector (diode) receives a signal and it corresponds to a known linear distance moved.

25.4. The distance moved will depend on the diameter of the wheel of the coach and angular distance between the slits.





26. Route Data File:

26.1. The section details are collected as a one-time exercise by running a route data measurement equipment to measures the length of each kilometre (distance between two successive kilometre posts) and identify the location of the track features e.g. points & crossings, level crossings, bridge approaches, starting point of curves, SEJs etc.

26.2. During the TRC runs, this data could be utilized directly from the system after initial synchronization of data file with ground position. Subsequent data of track features and km locations are taken from the data file, thus eliminating manual punching of km locations.

26.3. Route data can be created by the methods given below:

(a) Trolley mounted TFMS (Track feature measuring system) now RDPS (Route Data File Preparation System);

(b) TGMS (Track Geometry Measuring System), if available in TRC; or

(c) Track Diagrams.

27. Synchronization of route data in real time during TRC Run:

27.1. Even after using accurately prepared Route Data File, mismatch in distance of ground features recorded; and the actual distance might occur after running of 20–25 km due to-

(a) Wheel Skidding/Slipping

(b) Wheel Wear

(c) TRC travelling on lines not captured in route data

(d) Sinusoidal movement of wheel set etc.

27.2. Synchronization using Automatic Location Detector (ALD) and Ground Transponders fixed on track at intervals of 20-25 kilometres or any RFID based system could take care of the aforesaid mismatch in distances.

28. Calibration of TRC:

28.1. Any measuring system needs to be calibrated regularly for reliability of the measurements; more so when the measurements made are indirect or derived.

28.2. Quick calibration:

Quick calibration is carried out daily before starting the TRC run to check correctness of gauge and level using test piece of known thickness.

Steps involved in quick calibration-

(i) For quick calibration the TRC is brought on a straight and level track and kept in static condition. (Usually outside the platform area)

(ii) After selecting calibration option, the offset counts and input voltage of all transducers, gauge and cross level would be displayed.

(iii) Enter recalibrate option (r); and enter measured value of gauge and cross level

(iv) Message "calibrating" will be flashed till calibration is over

(v) Place 20 mm block in front of all LVDTs – two for the vertical unevenness and two for the alignment measurement (block to be placed between the sword sensor and the gauge face of the rail)

(vi) If the change is 20 mm + 0.2 mm, Save settings.

28.3. Detailed calibration:

Detailed calibration is carried out at-least once in a month, or after replacement of any transducer, or when quick calibration detects any problem.

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6

Data Analysis & Measure of Track Quality

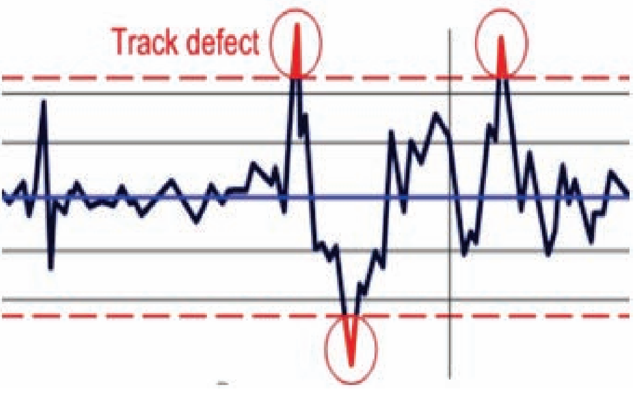
29. In the earlier sections it was mentioned that the TRC collects huge amount of data on track geometry parameters. To derive meaningful information, this huge pile of data needs suitable analytical tools that can indicate about maintenance requirement and possible track degradation pattern.

30. Data analysis approach:

30.1. Identify values beyond acceptable threshold (Peak values):

To identify peak values data are filtered for values beyond a pre-defined threshold limit to identify its locations. The filter values to be used depend on many factors including the expected level of maintenance. This simplistic analysis is suitable for locating specific locations where the parametric values are beyond the acceptable limit; therefore need to be brought back within the acceptable range.

This analysis is quite elementary and does not use the data efficiently, therefore used for identifying the spots only. The peak value reflects the qualitative position of a specific location in respect of considered parameter. It might get co-related with generation of acceleration due to presence of unacceptable value of a parameter, but it has little or no relation with the overall ride quality over a continuous stretch of track.



To assess the quality of track or for that matter any parameter it has to be compared with the benchmark.

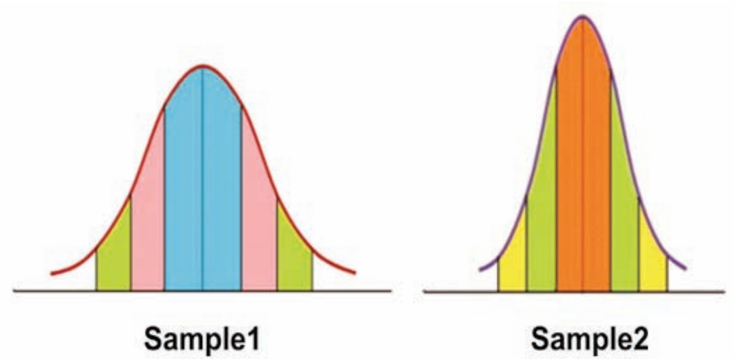
30.2. Statistical analysis:

(a) The ride quality of vehicles on any stretch of track depends not only on the value of any parameter beyond certain limit (as ascertained in peak based analysis mentioned hereinbefore) but also on variation in values, which triggers parasitic motions of vehicle. Simple mathematical tools like average value or maximum & minimum values may not lead to significantly useful conclusion as far as assessment of track maintenance needs are concerned.

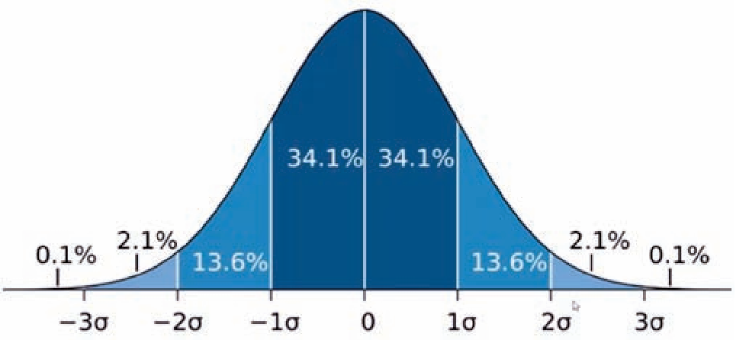
(b) For assessment of quality of the large amount of data of track parameters and its possible linkages with the ride quality over a particular stretch of track, statistical tools (Standard Deviation etc.) are deployed world over, which considers entire data set to indicate characteristics of data and able to reflect the variation in values.

(c) The data of track parameters collected by TRC are at a specified frequency (i.e. at every 25 cm interval) without any bias and are considered random data that follows normal distribution. The normal distribution, also known as the Gaussian distribution, is a probability distribution that is symmetric about the mean, showing that data near the mean are more frequent in occurrence than data far from the mean. In graph form, normal distribution will appear as a bell curve.

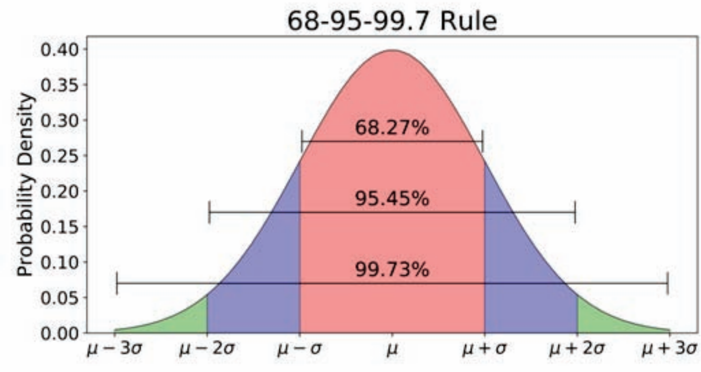
(d) The Standard Deviation (SD) is a measure that is used to quantify the amount of variation or dispersion of a set of data values. A high standard deviation indicates that the data points are spread out over a wider range of values (Sample1 in sketch), while a low standard deviation indicates that the data points tend to be close to the mean value of the set. (Sample2 in sketch)



(e) The probability density function for normal distribution curve could indicate probability of of data distribution along the mean value as shown in sketch.



(f) This implies that approximately 68.2% of the data lies within One SD (±1σ) of the mean (μ), 95.4% of the data lies within Two SD (±2σ) of the mean (μ) and 99.6% of the population lies within Three SD (±3σ) of the mean (μ). This can be seen from the sketch alongside. (also known as 68-95-99.7 Rule)



(g) Applying it for the data of track parameters collected, the lesser the value of the standard deviation (σ) fewer are the number of data points that are likely to be away from the mean value (μ).

31. Evolution of analytics on IR:

31.1. Hitherto the Indian Railways had been using a combination of peak as well as SD based system to analyse and obtain reports from data captured by TRCs. These were-

(i) A, B, C, D categorization of track based on number of peaks exceeding threshold values for each category.

(ii) CTR value based on A, B, C, D categorization.

(iii) Track Geometry Index (TGI).

31.2. The A, B, C, D categorization, and CTR value derived therefrom, had serious limitation of ignoring the magnitude of the irregularities; and rather only number of the peaks were counted in case of exceedences beyond pre-defined limit. Therefore, health of track on any parameter could not be assessed conclusively. Furthermore the CTR value calculated, by assigning equal weightage to all parameters, did not give any proper assessment of the track conditions for undertaking maintenance decisions as no such limits were laid down and had no relation to ride quality.

31.3. In contrast to peak based categorization, the SD based systems considers all data points (magnitude) captured for calculations of SD and in-turn indices values. Further more the SD values of data collected without bias gives probability density of the distribution of data points in terms of departure from mean value.

(a) The Track Geometry Index was based on indices values of alignment, uneven-ness, twist, and gauge; which were calculated using Standard Deviation (SD) values of data collected and benchmark SD values for new track and the track requiring urgent maintenance. The weightage of six (6) and two (2) were assigned to alignment index and uneven-ness index respectively and one (1) each to twist and gauge indices.

(b) The TGI system, introduced in 1996, utilized data for 200 m long blocks and all indices were evaluated for that block only, which in-turn were used for working out TGI value for that block. However the decisions for planning maintenance inputs were based on SD value of measured data and its comparison with the benchmark SD values for planned and urgent maintenance.

(c) The calculation of various indices, TGI, and the maintenance decisions based on benchmark SD values were meant for two speed bands viz. speeds less than and equal to 110 km/h and speeds greater than 110 km/h but less than & equal to 130 km/h.

31.4. Considering the fact that the ride quality has very poor co-relation with the Gauge and Twist indices, keeping in line with the world practice, a new Track Quality Index (TQI) has been evolved on IR. This index considers only alignment and uneven-ness indices and thereby a better reflection of the ride quality. The evolution of new Index, elaborated hereinafter, was also necessitated due to higher speeds on superior track structure (maintained by mechanised means) and better rolling stocks.

32. Track geometry data recorded by TRCs:

32.1. The following data are available from the Track Recording Car reports:

(a) Sampled values of all track parameters on two user selectable chords and acceleration on bogie pivot (on coach floor) at sampling interval of 0.25/0.30 m.

(b) Gauge values are recorded at sampling interval of 0.25 m / 0.30 m as variation from the moving average of last 50 m.

(c) Standard Deviation (SD) values of all track parameters (Unevenness and Alignment of both left and right rail on two user selectable chords, Twist on two user selectable bases and gauge) for each block of 200 meter length in a kilometre.

(d) Ride Index (RI)values in vertical and lateral mode for each block of 200 meter length in a kilometer.

(e) Number of peaks for all track parameters in predefined four bands (A, B, C and D) for short chord and in four bands (W, X, Y and Z) for long chord.

(f) 10 worst peaks, out of the worst peaks recorded for each of the 50 m block (20 such blocks in a kilometer yielding 20 such peaks) for all track parameters as well as of vertical & lateral acceleration in a km.

33. Characterization of Track Quality:

As per UIC, only Unevenness and Alignment reflects the quality of track, whereas the Twist and Gauge parameters are not considered in the definition of Track Quality for its poor co-relation as well as indirect inclusion in the Unevenness (for Twist) and Alignment (for Gauge).

The Track Quality Index (TQI) indicates the overall assessment of track quality based on ride characteristics. For characterization of the TQI, the parameter wise Indices viz. unevenness index (UNI) Alignment Index (ALI) on short and long chord and the Track Quality Index (TQI) for each block of 200 m is computed as under:

33.1. Alignment Index :

(a) On Short Chord (AI_S):

$$AI_S = 100 \times e^{-\left[\frac{((SD_{M\ -AAL-S}) - (SD_{NTL-AL-S}))}{((1.3 \times SD_{NBML-AL-S}) - (SD_{NTL-AL-S}))}\right]}$$

(b) On Long Chord (AI_L):

$$AI_L = 100 \times e^{-\left[\frac{((SD_{M\ -AAL-S}) - (SD_{NTL-AL-S}))}{((1.3 \times SD_{NBML-AL-S}) - (SD_{NTL-AL-S}))}\right]}$$

33.2. Unevenness Index:

(a) On Short Chord (UIS):

$$UI_S = 100 \times e^{-\left[\frac{((SD_{M\ -AUN-S}) - (SD_{NTL-UN-S}))}{((1.3 \times SD_{NBML-UN-S}) - (SD_{NTL-UN-S}))}\right]}$$

(b) On Long Chord (UIL):

$$UI_L = 100 \times e^{-\left[\frac{((SD_{M-AUN-L}) - (SD_{NTL-UN-L}))}{((1.3 \times SD_{NBML-UN-L}) - (SD_{NTL-UN-L}))}\right]}$$

Where

AIS	Alignment Index on short chord i.e. on 9.0 metre chord
AIL	Alignment Index on long chord i.e. on 15.0 metre chord
UIS	Unevenness Index on short chord i.e. on 9.0 metre chord
UIL	Unevenness Index on long chord i.e. on 18.0 metre chord
$SD_{M-AAL-S}$	Average of measured SD value of alignment of left and right rail on short chord
$SD_{NTL-AL-S}$	SD value of New Track Limit of alignment on short chord
$SD_{NBML-AL-S}$	SD value of Need Based Maintenance Limit of alignment on short chord
$SD_{M-AAL-L}$	Average of measured SD value of alignment of left and right rail on long chord
$SD_{NTL-AL-L}$	SD value of New Track Limit of alignment on long chord
$SD_{NBML-AL-L}$	SD Value of Need based Maintenance Limit of alignment on long chord
$SD_{M-AUN-S}$	Average of measured SD value of unevenness of left and right rail on short chord
$SD_{NTL-UN-S}$	SD value of New Track Limit of unevenness of short chord

$SD_{NBML-UN-S}$	SD value of Need Based Maintenance Limit of unevenness on short chord
$SD_{M-AUN-L}$	Average of measured SD value of alignment of left and right rail on short chord
$SD_{NTL-UN-S}$	SD value of New Track Limit of unevenness on long chord
$SD_{NBML-UN-L}$	SD value of Need Based Maintenance Limit of unevenness on long chord

34. Track Quality Index:

34.1. TQI is an indicator for overall assessment of track quality. It could be worked out by expressions given in (a) and (b) below using indices for short chord (for all speeds) as well as long chord (for speeds more than 100 km/h) respectively. Additionally a composite TQI can also be calculated by expressions given in (c) below.

(a) On Short Chord

$$TQI_C = \frac{(UI_S + AI_S)}{2}$$

(b) On Long Chord (For Speed >100 km/h only)

$$TQI_L = \frac{(UI_L + AI_L)}{2}$$

(c) Composite Track Quality Index (For Speed >100 km/h only)

$$TQI_L = \frac{(UI_S + UI_L + AI_S + AI_L)}{4}$$

It must be noted that the TQI values based on the above expressions are only an indicator; the actual maintenance of track has to be planned on the basis of SD values and peak values of different track parameters in comparison to respective benchmark values.

■ ■ ■

7

Tolerances

35. Tolerance Levels:

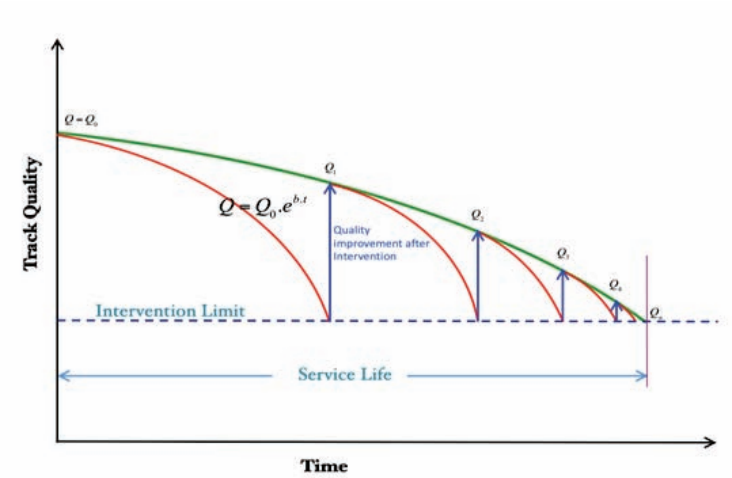
During the service life of track, under the traffic loading, with passage of time it deteriorate structurally and geometrical parameters de-grade, resulting in declining ride quality. The rate of deterioration of the track depends on the quality of track at that point in time. Therefore the rate of deterioration of good track is slower than that of a poor track, which runs down much faster.

Mathematically (P. Veit) it could be expressed as under:

Where, $Q = Q_O . e^{b.t}$

Q	=	actual track quality
Q_O	=	the initial quality
b	=	deteriorate rate coefficient
t	=	time

The deterioration of the track quality, under traffic, would thus necessitate maintenance intervention periodically to make sure that the ride qualities remain satisfactory with no over maintenance. The quality control of track geometry is, therefore, essential not only at the time of laying new track but also subsequently to ensure effectiveness of maintenance operations. See fig. below: (K. Zanakakis)



36. Considering the economic principle for ensuring acceptable ride quality, the maintenance inputsare to be imparted only where required. For guidance of maintenance personnel for objective decision making and plan maintenance interventions accordingly certain limits are to be laid down.

37. Beginning with the installation of new track, till it remains in service limits, various limits are being laid down for different purposes.

38. Speed bands:

38.1. On IR, the broad gauge routes are classified based on the future maximum permissible speeds viz.

(a) Group 'A'– Speeds upto 160 km/h

(b) Group 'B'– Speeds upto 130 km/h

(c) Group 'C'– Suburban Sections of Mumbai, Delhi, Chennai and Kolkatta

(d) Group 'D' Spl.– Speeds upto 110 km/h and the annual traffic density ≥ 20 GMT.

(e) Group 'D'– Speeds upto 110 km/h and the annual traffic density < 20 GMT.

(f) Group 'E' – All other Sections and branch lines with speed upto 100 km/h.

38.2. Keeping in line with the above classification, and the fact that the speed potential of rolling stock is also in the similar slabs, the speed groups are formed to lay down the tolerances as under:

(i) ≤ 100 km/h

(ii) 100 km/h ≤ 110 km/h

(iii) 110 km/h ≤ 130 km/h

(iv) 130 km/h ≤ 160 km/h

39. Chord Applied:

39.1. For initial speed band (≤ 100 Km/h) the standards have been proposed on short chord only as the long chords are not considered to be relevant for rolling stocks running at speeds within this speed band.

39.2. For the remaining three speed bands, standards have been evolved on both short and long chord, as both chords are relevant for different rolling stocks at different speeds. In mixed traffic scenario Freight stock (and other stock) having higher natural frequency would run at speeds below the minimum speed of these speed bands, thereby short chord would also become relevant for these speed bands.

40. Defining Tolerances levels:

40.1. On IR, the tolerances are laid down for standard deviation and peaks in above four speed bands, using data being recorded and stored by Track Recording Cars, on maintainability criteria and then the same are verified with respect to the ride and acceleration criteria laid down under revised 3rdreport of the criteria committee of RDSO.

40.2. In addition certain tolerances are prescribed for guidance of maintenance personnel for manual measurement, in floating condition of track i.e. not recorded by the TRC.

40.3. Based on the requirement at various stages in the lifecycle of the track under service the following tolerances for different track parameters stipulated in order to enable field officials to take objective and well-informed decisions regarding planning of maintenance input based on track monitoring results.

(i) New/Relaying Track Limits (NTL)

(ii) Planned Maintenance Limits (PML)

(iii) Need Based Maintenance Limits (NBML)

(iv) Urgent Maintenance Limits (UML)

40.4. New Track Limit (NTL):

The New Track/Relaying Limits (NTL) are the SD based and peak based tolerances for unevenness and alignment and peak based tolerances for gauge and other parameters, which are required to be attained at the time of construction of new track or through renewal of track with new materials.

40.5. Planned Maintenance Limit (PML):

Planned Maintenance Limit refers to the value, which, if exceeded, requires that the track geometry condition be analyzed and considered in the regularly planned maintenance operations. The Planned Maintenance Limit (PML) are based on SD values of Unevenness and Alignment, which affect the ride quality.

From maintainability considerations the Planned Maintenance Limit SD values of Unevenness and Alignment are stipulated in such a manner that not more than 50% of track falls beyond this limit at any point of time. This limit provides a guidance to plan through tamping of track in a complete block section if majority of track in that block section exceeds the planned maintenance limits. Peak based tolerances are not stipulated for planned maintenance, expected to be undertaken based on the SD based tolerances.

40.6. Need Based Maintenance Limit (NBML):

The Need Based Maintenance Limits are defined to enable apply timely correction before the defect size grows to the level of Urgent Maintenance Limits, which forces traffic slow down till rectification. The philosophy for selecting these limits is that the defect size which is just below the threshold value of NBML and not attended before next monitoring cycle shall not exceed UML in the intervening period. The allowable time for attention to defects exceeding the NBML would depend upon the magnitude of the defect and various factors affecting track geometry deterioration such as sectional speed, axle load, and traffic volume etc. As the analysis of track deterioration pattern is currently not available, these limits are stipulated based on the maintainability of track.

40.7. Urgent Maintenance Limit (UML):

Urgent Maintenance Limit is prescribed in terms of track geometry peaks for twist and gauge only and in terms of exceedences of vertical and lateral acceleration limits (from comfort consideration). Where defects exceed Urgent Maintenance Limit the permitted speed should be slowed down and restored only after attending the track.

41. Identification of tolerance levels:

41.1. SD Based Tolerances for Alignment and Unevenness:

(a) SD based tolerances on maintainability criteria have been worked out on the basis of Cumulative Frequency Diagrams (CFD) of SD values of track parameters being recorded by TRCs at every block of 200 meters in a Kilometer. For plotting CFD of Unevenness and Alignment average SD of left and right rail has been taken.

(i) New Track/Relaying Tolerances:

SD values corresponding to 10% of track on CFD have been taken as New/Relaying tolerances for the considered section. The SD values corresponding to 10% of track on CFD means that 10% blocks of this section are within this SD value.

The CFD of all selected sections (for analysis) in each speed band for all track parameters has been plotted and SD value of each parameter corresponding to 10% on CFD has been worked out. From the plotted graph of 10% SD values of all the sections, 30 percentile values have been taken as New/Relaying tolerance.

(ii) Planned Maintenance Tolerances

From maintainability criteria on account of both alignment and unevenness not more than 50% of track should fall under planned maintenance at any point in time. Practically it might not happen that left and right side values of both alignment and unevenness parameters would be above prescribed limits of planned maintenance at same spot. Thus, to fulfill above criteria while doing parameter wise analysis, 70% of track on CFD has been taken as Planned Maintenance Tolerances for the individual parameters. The SD values corresponding to 70% of track on CFD means that 70% blocks of selected parameter of the section is within this SD value.

The CFD of all selected sections (for analysis) in each speed band for all track parameters has been plotted and 70% on CFD has been worked out. 95 percentile values of all the considered sections in each speed band have been taken as Planned Maintenance Tolerances. The philosophy behind selecting 95 percentile value is to discard abnormally large values.

The PML are stipulated in terms of SD values of alignment and unevenness only, which affect the ridequality. The PML, if exceeded, requires that the track geometry condition be analyzed and considered in the regularly planned maintenance operations.

(iii) Need Based Maintenance Limit (NBML)

From maintainability criteria on account of both alignment and unevenness combined, not more than 10% of track on an average should fall under Need Based Maintenance Limit at the time of measurement. Further, the defect size stipulated should also be such that it should not cause bad riding in terms of ride index/acceleration within the stipulated period of attention during its service life. Practically it might not happen that left and right side values of both alignment and unevenness parameters would be above prescribed limit of NBML at same spot. Thus, to fulfill the above criteria of not more than 10% track under NBML, while doing parameter wise analysis 95% of track on CFD has been taken as Need Based Maintenance Limit for the individual parameters.

The SD values corresponding to 95% of track on CFD means that 95% of the blocks of this section are within this SD value. The CFD of all selected sections (for analysis) in each speed band for all track parameters has been plotted and 95% on CFD has been worked out. 95 percentile values of all the considered sections in each speed band have been proposed as Need Based Maintenance Tolerances.

The NBML are stipulated both in terms of SD value and peak values of alignment and unevenness to identify 200 m long blocks for need based tamping of that particular block, and to identify individual spots, which could be attended by maintenance gangs respectively.

(b) Verification of SD Based Tolerances proposed on Maintainability with Ride Criteria:

For verification with ride criteria the values of preferred and limiting values of Ride Index prescribed by 3rd criteria committee has been used for verification of the hypothesis that stipulated tolerance for NBML would not lead to any bad riding.

To work out SD based tolerances on Ride Criteria the regression analysis between block wise average SD value of Unevenness for left and right rail Vs Ride Index Vertical and between block wise average SD of Alignment values of left and right rail Vs Lateral Ride Index has been performed. The values arrived at corresponding to preferred value of Ride Index (3.25) from regression plots has been compared with Planned Maintenance values and the values arrived at corresponding to limiting value of Ride Index (3.5) from regression plots has been compared with Need Based Maintenance Limits.

41.2. Peak based Tolerances for Alignment and Unevenness:

(a) Peak based tolerances on maintainability can not be laid down on the basis of CFD plots of all peaks in a kilometer as the data of all peaks is not being recorded in TRCs. Therefore the peak based tolerances are stipulated after deriving from SD values.

(b) The track parameter data being recorded by TRC are random data without any bias and therefore considered to be normally distributed. For a normally distributed random data 68.27% data lies within 1×SD value, 95.45% data lies within 2×SD value and 99.74% data lies within 3×SD value. Accordingly the peak based tolerances has been computed on the basis of 3×SD values of the proposed SD based tolerances on maintainability to identify the peak limits.

41.3. Twist:

There are no stipulations made for SD based tolerances for Twist parameter, as it has very poor co-relation with ride quality. Accordingly the Twist parameter has been excluded from characterization of Ride Quality of track.

For Twist parameter the limiting values are defined on most of the railway systems world over. The EN code recommends that the track twist limits including design twist and cross level deterioration for longitudinal base (***a*** in m) should be as under:

$$\text{Track Twist}_{\text{Limit}} = \min\left(7.0;\ \frac{20}{2a} + 3.0\right) \text{ mm/m}$$

41.4. Gauge:

The Gauge also has very poor co-relation with lateral ride quality; therefore it has also been excluded from characterization of Ride Quality of track. On IR no stipulations are made for SD based tolerances for the Gauge parameter also.

42. Stipulation for measurements under floating conditions (Peak based):

On IR the following peak based stipulations have been made for various parameters for measurements under floating conditions.

42.1. New Track/Relaying Limit (NTL):

(a) The standards to be met at the time of construction of new track or through renewal of track with new materials.

(to be recorded by in floating condition, three months after speed is raised to normal)

Sl. No.	Parameter	Value	
1	Gauge	Sleeper to sleeper variation	2 mm
2	Expansion gap	Over average gap worked out by recording 20 successive gaps	± 2 mm
3	Joints	Low joints not permitted High joints not more than Square-ness of joints on straight	 2 mm ± 10 mm
4	Spacing of sleepers	With respect to theoretical spacing	± 20 mm
5	Cross level	To be recorded on every 4th sleeper	± 3 mm
6	Alignment	On straight *(on 10 m Chord)*	± 2 mm
		Variation over theoretical versines: *(On 20 m Chord).* (a) On curves of Radius more than 600 m (b) On curves of Radius less than 600 m	 5 mm 10 mm
7	Longitudinal level	Variation with reference to approved longitudinal sections.	50 mm

(a) Gauge:

For new track and through renewal of track, the tolerances given in Para 403(1) of IRPWM would be applicable, for measurement in floating conditions, as under-

(i) For Straight including curves of radius upto 350 m and more

-5 mm to +3 mm

(ii) For curves of radius less than 350 m

Upto +10 mm

(b) Twist :

No limits are laid down for new track for twist for assessment of quality of new track/relaying.

42.2. Tolerances in service in floating conditions:

For guidance of field officials the Gauge and Twist values are stipulated for manual measurement in floating conditions as under:

(a) Gauge:

While it is desirable to maintain correct gauge, variation in gauge may be there due to age and condition of the rail, sleepers, and fastenings. The limits of gauge as per measurement in floating condition, for the guidance of the Engineering officials regarding condition of track from passenger comfort perspective, shall be as given below, provided that generally a uniform gauge can be maintained over long lengths. In case of exceedences of these limits, the results of last TRC/OMS shall be analyzed for planning suitable maintenance action.

Broad Gauge (Reference nominal gauge of 1676 mm)	
a) On straight	-6 mm to +6 mm
b) On curves with radius 440 m or more	-6 mm to +15 mm
c) On curves with radius less than 440 m	Up to + 20 mm

(a) Twist:

It is desirable to maintain the track geometry for a comfortable ride at Sectional Speed. The limits of twists as per measurement in floating condition, for guidance of the Engineering officials regarding condition of track from passenger comfort perspective, shall be as under (to measured on a base of 3.0 m)

(i) On straight and curve track, other than transition – 3.5 mm/m

(ii) On transition of curve- 2.1 mm/m (Local defects above Designed value)

In case of exceedences of above limits, the results of last TRC/OMS shall be analyzed for planning suitable maintenance action.

43. Stipulation for measurementsby TRC(SD and Peak based):

A summery of NTL, PML, NBML and UML, applicable for processed data based on TRC recordings, is presented in following pages (Annexures 1/5-5/5) for reference.

Annexure (1/5)

Summery of NTL

(to be recorded by TRC three months after speed is raised to normal)

(b) SD based NTL:

Sl. No.	Parameter	SD Values	
		Speeds upto 100 km/h	Speeds above 100 km/h; and upto 160 km/h
1.	UN-1	2.0 mm	1.4 mm
2.	UN-2	-	1.9 mm
3.	AL-1	1.4 mm	1.1 mm
4.	AL-2	-	1.3 mm

1.2. Peak based NTL:

Sl. No.	Parameter	Peak Values	
		Speeds upto 100 km/h	Speeds above 100 km/h; and upto 160 km/h
1.	UN-1	6.0 mm	4.0 mm
2.	UN-2	-	6.0 mm
3.	AL-1	4.0 mm	3.0 mm
4.	AL-2	-	4.0 mm

Annexure (2/5)

Summery of PML, NBML, and UML

(For Speeds upto 100 km/h)

SN	Parameter	Planned Maintenance Limit (PML)	Need Based Maintenance Limit (NBML)	Urgent Maintenance Limit (UML)
1	**Unevenness**			Vertical and lateral acceleration peak of **0.30 g**
1.1	UN-1	SD-5.0 mm	SD-6.8 mm Peak-20 mm	
1.2	UN-2	-	-	
2	**Alignment**			
2.1	AL-1	SD-3.3 mm	SD-4.9 mm Peak -15 mm	
2.2	AL-2	-		
3	**Gauge**			
3.1	**Mean gauge over 200 m section over nominal gauge**			
(a)	Straight	-	-8 mm to +10 mm	-10 mm to + 12 mm
(b)	Curve with radius 440 m or more	-	-5 mm to +14 mm	-7 mm to +17 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-5 mm to +18 mm	-7 mm to +20 mm
3.2	**Isolated defects –Nominal track gauge to peak value**			
(a)	Straight	-	-10 mm to +12 mm	-12 mm to + 15 mm
(b)	Curve with radius 440 m or more	-	-7 mm to +17 mm	-11 mm to +20 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-6 mm to +22 mm	-8 mm to +25 mm
4.	**Twist (TW-1)**		5 mm/m	7 mm/m

Annexure (3/5)

Summery of PML, NBML, and UML

(For Speeds above 100 km/h and upto 110 km/h)

SN	Parameter	Planned Maintenance Limit (PML)	Need Based Maintenance Limit (NBML)	Urgent Maintenance Limit (UML)
1	Unevenness			Vertical and lateral acceleration peak of **0.30 g**
1.1	UN-1	SD-3.8 mm	SD-5.5 mm Peak-17 mm	
1.2	UN-2	SD-5.4 mm	SD-7.5 mm Peak-23 mm	
2	Alignment			
2.1	AL-1	SD-2.5 mm	SD-3.9 mm Peak -12 mm	
2.2	AL-2	SD-4.1 mm	SD-6.7 mm Peak-20 mm	
3	Gauge			
3.1	Mean gauge over 200 m section over nominal gauge			
(a)	Straight	-	-8 mm to +10 mm	-10 mm to + 12 mm
(b)	Curve with radius 440 m or more	-	-5 mm to +14 mm	-7 mm to +17 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-5 mm to +18 mm	-7 mm to +20 mm
3.2	Isolated defects –Nominal track gauge to peak value			
(a)	Straight	-	-10 mm to +12 mm	-12 mm to + 15 mm
(b)	Curve with radius 440 m or more	-	-7 mm to +17 mm	-11 mm to +20 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-6 mm to +22 mm	-8 mm to +25 mm
4.	Twist (TW-1)		4 mm/m	7 mm/m

Annexure (4/5)

Summery of PML, NBML, and UML

(For Speeds above 110 km/h and upto 130 km/h)

SN	Parameter	Planned Maintenance Limit (PML)	Need Based Maintenance Limit (NBML)	Urgent Maintenance Limit (UML)
1	**Unevenness**			Vertical and lateral acceleration peak of **0.25 g**
1.1	UN-1	SD-3.3 mm	SD-4.9 mm Peak-15 mm	
1.2	UN-2	SD-5.1 mm	SD-7.4 mm Peak-22 mm	
2	**Alignment**			
2.1	AL-1	SD-2.5 mm	SD-3.6 mm Peak -11 mm	
2.2	AL-2	SD-3.5 mm	SD-5.3 mm Peak-16 mm	
3	**Gauge**			
3.1	**Mean gauge over 200 m section over nominal gauge**			
(a)	Straight	-	-8 mm to +10 mm	-10 mm to + 12 mm
(b)	Curve with radius 440 m or more	-	-5 mm to +14 mm	-7 mm to +17 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-5 mm to +18 mm	-7 mm to +20 mm
3.2	**Isolated defects –Nominal track gauge to peak value**			
(a)	Straight	-	-10 mm to +12 mm	-12 mm to + 15 mm
(b)	Curve with radius 440 m or more	-	-7 mm to +17 mm	-11 mm to +20 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-6 mm to +22 mm	-8 mm to +25 mm
4.	**Twist (TW-1)**		4 mm/m	6 mm/m

Annexure (5/5)

Summery of PML, NBML, and UML

(For Speeds above 130 km/h and upto 160 km/h)

SN	Parameter	Planned Maintenance Limit (PML)	Need Based Maintenance Limit (NBML)	Urgent Maintenance Limit (UML)
1	**Unevenness**			Vertical and lateral acceleration peak of **0.20 g**
1.1	UN-1	SD-2.9 mm	SD-4.4 mm Peak-13 mm	
1.2	UN-2	SD-4.4 mm	SD-6.6 mm Peak-20 mm	
2	**Alignment**			
2.1	AL-1	SD-1.9 mm	SD-3.6 mm Peak -11 mm	
2.2	AL-2	SD-2.5 mm	SD-4.9 mm Peak-15 mm	
3	**Gauge**			
3.1	**Mean gauge over 200 m section over nominal gauge**			
(a)	Straight	-	-6 mm to +10 mm	-8 mm to + 12 mm
(b)	Curve with radius 440 m or more	-	-5 mm to +13 mm	-7 mm to +15 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-5 mm to +18 mm	-7 mm to +20 mm
3.2	**Isolated defects –Nominal track gauge to peak value**			
(a)	Straight	-	-8 mm to +12 mm	-10 mm to + 15 mm
(b)	Curve with radius 440 m or more	-	-6 mm to +16 mm	-9 mm to +20 mm
(c)	Curve with radius less than 440 m (Permissible speed as per relevant para of IRPWM)	-	-6 mm to +22 mm	-8 mm to +25 mm
4.	**Twist (TW-1)**		3.5 mm/m	5 mm/m

44. Track Quality Index:

TQI being an indicator for overall assessment of track quality is worked out by expressions given in chapter 6.

44.1 The TQI values are calculated by using indices values of Uneven-ness and Alignment. The expression for these indices, has only one variable i.e. measured SD value (SDM); the other two values used in the formula viz. SD value for new track (SDNTL) and SD value for need based maintenance (SDNBML) are having fixed values for any particular speed band. Therefore depending on the the measured SD value (SDM) for few sample cases,the TQI values are calculated and presented in following table:

Speed Band (km/h) / Measured SD value SD_M	TQI Values			
	≤ 100	>100 to ≤ 110	>110 to ≤ 130	>130 to ≤ 160
$SD_M = 0$	133	127	131	134
$SD_M = SD_{NTL}$	100			
$SD_M = SD_{PML}$	66	67	67	75
$SD_M = SD_{NBML}$	50	49	49	50
$SD_M = 1.3\times SD_{NBML}$	37			

44.2 Interpretation of TQI:

Based on the TQI values, indicated in the previous para, a broad interpretation could be as under. However it is to be noted that the TQI is only an overall indicator of riding quality of track and not to be used for planning maintenance of track, which should be planned based on PML/NBML/UML for individual blocks only.

TQI	**General Interpretation***
> 100	**Very Good Track** *(Complying with SD vaues for new track or better)*
75 *(for speeds > 130 km/h)*	**Planned Maintenance required**
66 / 67	
(for speeds upto 130 km/h)	
49/50	**Need Based Maintenance required**
37	**SD_M have exceeded 1.3×NBML**

* - Not to be used for planning maintenance of track

■ ■ ■

8

Deciphering TRC Reports

45. As mentioned in previous sections, for each block of 200 m length, the TRC picks up 800 data points for each of the parameter getting recorded (other than accelerations), which are analysed to characterize quality of that specific parameters and the associated indices.

The result of the data analysis is presented in the form of reports; usually one sheet for every kilometre is presented, by the TRC's in-line software in addition to the reference data used for the analysis. The data recorded could also be used to generate many specific reports, as required, with the help of off-line software.

45.1. The in-line software reports the following details-

(a) Details of every block of 200 m. (refer diagram - area enclosed in blue box)

(i) Standard Deviation value of Unevenness of Left & Right Rail on long chord and short chord.
(ii) Standard Deviation value of Alignment of Left & Right Rail on long chord and short chord.
(iii) Average speed for 200 m block.
(iv) Parameter Indices for Unevenness (UI),

Alignment (AI) on long chord and short chord.

(v) Track Quality Indices (TQI) on long chord and short chord.

(vi) Composite Track Quality Index for Sections having Speed > 100 km/h (TQI-C).

(vii) Maintenance Instructions corresponding to Unevenness and Alignment based on PML and NBML.

(viii) Vertical and Lateral Ride Index

(ix) Average of Variation of gauge over nominal gauge (1676 mm)

(b) Results reported for whole kilometre- (refer diagram - area enclosed in red box)

(i) Number of peaks above Need Based Maintenance Limits (and / or Urgent Maintenance Limit, where available) for alignment, unevenness, twist, gauge and accelerations.

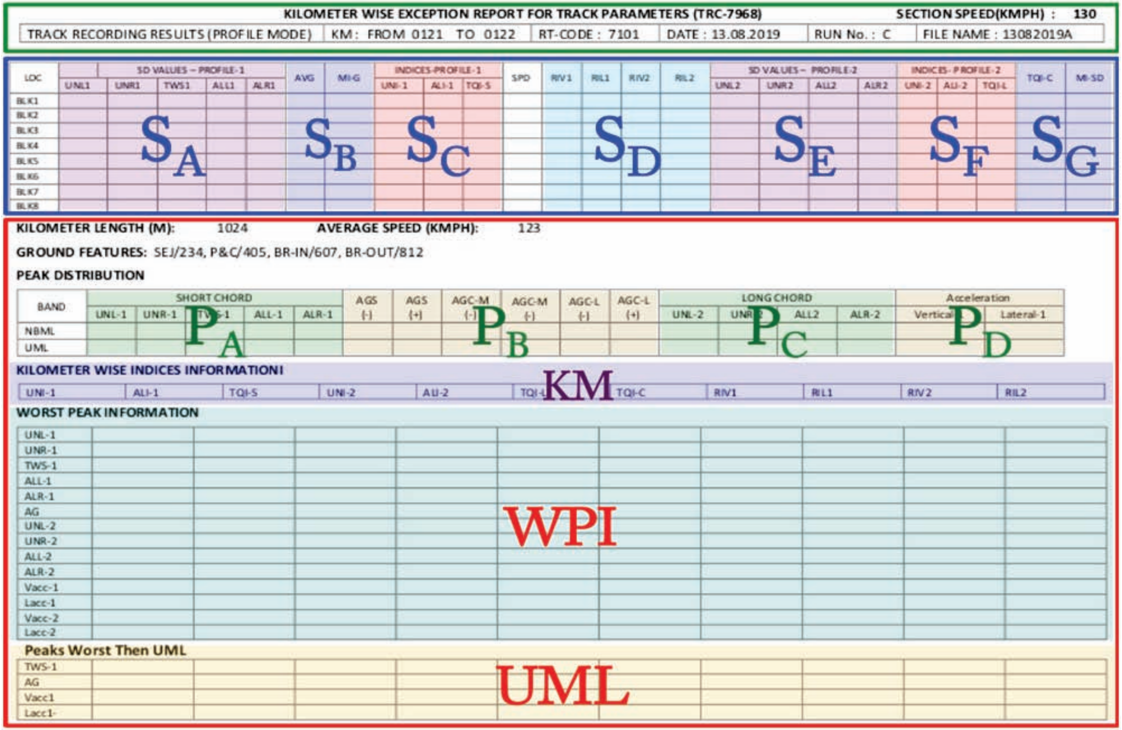
(ii) 10 highest peak values of each parameter with location as obtained from measured worst peaks in each 50 m block of a kilometre.

(iii) 10 highest peak values of twist, gauge and vertical and lateral accelerations exceeding Urgent Maintenance Limits with location.

(iv) TQI (on short and long chord) & composit TQI, and Average Speed.

(v) Unevenness Index, Alignment Index, Vertical and Lateral Ride Index.

45.2. A sample report of a typical report for a kilometre is shown in the figure. The explanations for


KILOMETER WISE EXCEPTION REPORT FOR TRACK PARAMETERS (TRC-7968)
SECTION SPEED(KMPH) : 130
TRACK RECORDING RESULTS (PROFILE MODE)
KM : FROM 0121 TO 0122
RT-CODE : 7101
DATE : 13.08.2019
RUN No. : C
FILE NAME : 13082019A
LOC
SD VALUES – PROFILE-1
UNL1
UNR1
TWS1
ALL1
ALR1
AVG
MI-G
INDICES-PROFILE-1
UNI-1
ALI-1
TQI-S
SPD
RIV1
RIL1
RIV2
RIL2
SD VALUES – PROFILE-2
UNL2
UNR2
ALL2
ALR2
INDICES-PROFILE-2
UNI-2
ALI-2
TQI-L
TQI-C
MI-SD
BLK1
BLK2
BLK3
BLK4
BLK5
BLK6
BLK7
BLK8
S_A
S_B
S_C
S_D
S_E
S_F
S_G
KILOMETER LENGTH (M): 1024
AVERAGE SPEED (KMPH): 123
GROUND FEATURES: SEJ/234, P&C/405, BR-IN/607, BR-OUT/812
PEAK DISTRIBUTION
BAND
SHORT CHORD
UNL-1
UNR-1
TWS-1
ALL-1
ALR-1
AGS (-)
AGS (+)
AGC-M (-)
AGC-M (-)
AGC-L (-)
AGC-L (+)
LONG CHORD
UNL-2
UNR-2
ALL2
ALR-2
Acceleration
Vertical
Lateral-1
NBML
UML
P_A
P_B
P_C
P_D
KILOMETER WISE INDICES INFORMATIONI
UNI-1
ALI-1
TQI-S
UNI-2
ALI-2
TQI-L
KM
TQI-C
RIV1
RIL1
RIV2
RIL2
WORST PEAK INFORMATION
UNL-1
UNR-1
TWS-1
ALL-1
ALR-1
AG
UNL-2
UNR-2
ALL-2
ALR-2
Vacc-1
Lacc-1
Vacc-2
Lacc-2
WPI
Peaks Worst Then UML
TWS-1
AG
Vacc1
Lacc1-
UML

developing an understanding of the report are as under:

(a) Apart from the identification information for the sheet and location, enclosed in green box, the report format has 02 blocks i.e. a block enclosed in Blue box (covering details for every block of 200 m of a kilometre) and another block enclosed in Red box (covering details for whole kilometre).

(b) The blue box, further divided into smaller areas of different colour are marked S_A through S_G indicate SD based block wise analysis report of the data.

(i) The block marked S_A shows SD values calculated for SHORT chord for the following: (the suffix 1 in abbreviations below indicate short chord)

1. Unevenness of Left Rail (abbreviated as UNL1).
2. Unevenness of Right Rail (abbreviated as UNR1).
3. Twist (abbreviated as TWS1).
4. Alignment of Left Rail (abbreviated as ALL1).
5. Alignment of Right Rail (abbreviated as ALR1).

(ii) The block marked S_B shows AVG i.e. Average Gauge; and Maintenance Instructions, i.e. either Need Based Maintenance, marked with ★★★ abbreviated as NI-G (based on Gauge Parameter), or Urgent Maintenance; marked with ★★★★ (necessitating imposition of speed restriction and attention), with reference to mean Gauge over 200 m section over nominal gauge (of 1676 mm).

(iii) The block marked S_C shows Indices values calculated for SHORT chord for the following: (the suffix 1 in abbreviations below indicate short chord)

1. Unevenness Index (abbreviated as UNI-1).
2. Alignment Index (abbreviated as ALI-1).
3. Track Quality Index (abbreviated as TQI-S).

(iv) The column between blocks S_C and S_D indicate average speed of TRC in that block (abbreviated as SPD)

(v) The block marked S_D shows Ride Index values for the block, calculated from acceleration values recorded for that block by the accelerometers (suffix 1 for accelerometers placed near rear pivot i.e. trailing side, of the TRC coach and suffix 2 for accelerometers placed near front pivot i.e. leading side, of the TRC coach) of:

1. Ride Index for Vertical direction (abbreviated as RIV1).
2. Ride Index for Lateral direction (abbreviated as RIL1).
3. ✪Ride Index for Vertical direction (abbreviated as RIV2).
4. ✪Ride Index for Lateral direction (abbreviated as RIL2).

   ✪ Indicate that this information might not be available in some of the contact sensor based TRCs.

(vi) The block marked S_E shows SD values calculated for LONG chord for the following: (the suffix 2 in abbreviations below indicate long chord)

1. Unevenness of Left Rail (abbreviated as UNL2).
2. Unevenness of Right Rail (abbreviated as UNR2).
3. Alignment of Left Rail (abbreviated as ALL2).
4. Alignment of Right Rail (abbreviated as ALR2).

(vii) The block marked S_F shows Indices values calculated for LONG chord for the following: (the suffix 2 in abbreviations below indicate long chord)

1. Unevenness Index (abbreviated as UNI-2).
2. Alignment Index (abbreviated as ALI-2).
3. Track Quality Index (abbreviated as TQI-L).

(viii) The block marked S_G shows:

1. Composite Track Quality Index (abbreviated as TQI-C), based on unevenness indices and alignment indices on short and long chords.

2. Maintenance instructions based on SD value (abbreviated as MI-SD) are based on exceedences of SD values of the alignment and unevenness either on short or on long chord:

a. Exceedences of SD values beyond PML (marked as ★★); and
b. Exceedences of SD values beyond NBML (marked as ★★★).

(c) The red box (indicates various values for the entire kilometre) is further divided into smaller areas of different colour and marked P_A through P_D, KM, WPI, and UML, which displays peak based analysis of the data for that kilometre.

(i) The block marked P_A shows the peak distribution of number of peaks exceeding NBML and UML (1.3 x NBML) on SHORT chord for the following.

1. Unevenness of Left Rail (abbreviated as UNL-1).
2. Unevenness of Right Rail (abbreviated as UNR-1).
3. Twist (abbreviated as TWS-1).
4. Alignment of Left Rail (abbreviated as ALL-1).
5. Alignment of Right Rail (abbreviated as ALR-1).

(ii) The block marked P_B shows the peak distribution of number of peaks exceeding NBML and UML for the following.

1. Gauge on straight being TIGHTER than nominal gauge(abbreviated as AGS(-)).
2. Gauge on straightbeing WIDER than nominal gauge (abbreviated as AGS(+)).
3. Gauge on Medium Radius Curves (radius less than 440 m) being TIGHTER than nominal gauge(abbreviated as AGC-M(-)).
4. Gauge on Medium Radius Curves (radius less than 440 m) being WIDER than nominal gauge(abbreviated as AGC-M(+)).
5. Gauge on Large Radius Curves (radius more than 440 m) being TIGHTER than nominal gauge(abbreviated as AGC-L(-)).

6. Gauge on Large Radius Curves (radius more than 440 m) being WIDER than nominal gauge(abbreviated as AGC-L(+)).

(iii) The block marked P_C shows the peak distribution of number of peaks exceeding NBML and UML (1.3 x NBML) on LONG chord for the following.

1. Unevenness of Left Rail (abbreviated as UNL-2).
2. Unevenness of Right Rail (abbreviated as UNR-2).
3. Alignment of Left Rail (abbreviated as ALL-2).
4. Alignment of Right Rail (abbreviated as ALR-2).

(iv) The block marked P_D shows the peak distribution of number of peaks exceeding NBML and UML on LONG chord for the following.

1. Vertical Acceleration (abbreviated as Vertical-1).
2. Lateral Acceleration (abbreviated as Lateral-1).

(v) In the block marked KM, kilometre wise information of various indices are indicated. These indices are:

1. Unevenness Index on Short Chord (abbreviated as UNI-1).
2. Alignment Index on Short Chord (abbreviated as ALI-1).
3. Track Quality Index on Short Chord (abbreviated as TQI-S).

4. Unevenness Index on Long Chord (abbreviated as UNI-2).
5. Alignment Index on Long Chord (abbreviated as ALI-2).
6. Track Quality Index on Long Chord (abbreviated as TQI-L).
7. Composite Track Quality Index (abbreviated as TQI-C).
8. Ride Index – Vertical for accelerometer on trailing side (abbreviated as RIV-1).
9. Ride Index – Lateral for accelerometer on trailing side (abbreviated as RIL-1).
10. ✪Ride Index – Vertical for accelerometer on leading side (abbreviated as RIV-2).
11. ✪Ride Index – Lateral for accelerometer on leading side (abbreviated as RIL-2).

    ✪ indicates that this information might not be available in older contact sensor based TRCs.

(vi) The block marked WPI shows the 10 (ten) WORST peak information, showing magnitude (in descending order) along with location of the individual peaks, for the following.

1. Unevenness of Left Rail on SHORT chord (abbreviated as UNL-1).
2. Unevenness of Right Rail on SHORT chord (abbreviated as UNR-1).
3. Twist on SHORT chord (abbreviated as TWS-1).
4. Alignment of Left Rail on SHORT chord (abbreviated as ALL-1).
5. Alignment of Right Rail on SHORT chord

(abbreviated as ALR-1).

6. Absolute Gauge (abbreviated as AG).
7. Unevenness of Left Rail on LONG chord (abbreviated as UNL-2).
8. Unevenness of Right Rail on LONG chord (abbreviated as UNR-2).
9. Alignment of Left Rail on LONG chord (abbreviated as ALL-2).
10. Alignment of Right Rail on LONG chord (abbreviated as ALR-2).
11. Vertical Acceleration recorded by trailing accelerometer (abbreviated as Vacc-1).
12. Lateral Acceleration recorded by trailing accelerometer (abbreviated as Lacc-1).
13. ✪Vertical Acceleration recorded by leading accelerometer (abbreviated as Vacc-2).
14. ✪Lateral Acceleration recorded by leading accelerometer (abbreviated as Lacc-2).

It must be noted that these worst peaks are-

(a) Arranged in descending order of the magnitude of the peaks.

(b) Selected from basket of worst peak identified in each of the 50 m sub-blocks (e.g. 1 km of track would have 20 such blocks)

✪Indicates that this information might not be available in older contact sensor based TRCs.

(vii) In the block marked UML, the peak details (magnitude with location), for those peaks, which exceeds Urgent Maintenance Limit are indicated for the following parameters:

1. Twist on Short Chord (abbreviated as TWS-1).
2. Absolute Gauge (abbreviated as AG).
3. Vertical Acceleration recorded by trailing accelerometer (abbreviated as Vacc-1).
4. Lateral Acceleration recorded by trailing accelerometer (abbreviated as Lacc-1).

It must be noted that -

(a) Peaks indicated are arranged in descending order of the magnitude of the peaks along with location.

(b) Only ten (10) peaks exceeding UML would be visible here. In case there are more than ten peaks exceeding UML exist; a star marking at the end of the row for that parameter is made to that affect.

(c) The peaks indicated in block UML would be available in block marked WPI also; unless there are more than one such peak in a 50 m sub-block, when peak having lower value might not find place in WPI for its peak selection criteria.

■ ■ ■

9

Maintenance Planning

46. The various subjective, manual inspections being carried out by various individuals viz. on foot, by trolley, on foot-plate/rear vehicle and the objective inspections by TRCs, in conjunction reveals the health of the track in floating and in dynamic conditions respectively.

    Armed with these enormous inspection data, it is now possible to deploy the strategy to "Touch the Track only when required and where required", wherefore the locations needing attention, as revealed from manual inspections and based on TRC reports, are identified on ground for deployment of maintenance resources.

47. A basic exception report for each recorded kilometre is available, in the form of km wise sheet of TRC output, immediately after the recording.

47.1. A report indicating various values for a typical kilometre for illustration purpose is on next page to appreciate the information being available in the report and using it to make maintenance decisions.

47.2. The route considered in this chart (report) is for a hypothetical section in speed band of 110 km/h to 130 km/h. Accordingly the SD value limits and Peak value limits pre-defined for this speed band are considered and referred.

47.3. Certain labels/values in bold or in coloured font are for the illustration purpose only. The actual kilometre-wise exception report would not have these emphasises.

48. While deciphering various values in the exception report the following steps may also be respected.

48.1. Block attention based on the SD values:

The block-wise exception report indicate the blocks (of 200 m length each) that require Planned Maintenance by marking as ★★, or Need-Based Maintenance by marking as ★★★ in the last column with title MI-SD (Maintenance Instructions based on SD Values of Alignment and Unevenness).

(a) In the present example, the BLK1 require Need-Based Maintenance, marked as ★★★, due to exceedences of measured SD values beyond NBML for following parameters (marked in orange colour font for easy identification in chart):

(i) Unevenness on short chord for left rail ($SD=5.1$ mm against $SD_{NBML} = 4.9$ mm)

(ii) Unevenness on long chord for right rail ($SD=7.7$ mm against $SD_{NBML} = 7.4$ mm)

(b) It may be noted that, for the same block, the measured SD values of the following parameters have exceeded beyond PML for following parameters (marked in blue colour font for easy identification in chart):

(i) Unevenness on short chord for right rail (SD=4.7 mm against SD_{PML} = 3.3 mm)

(ii) Unevenness on long chord for left rail (SD=5.5 mm against SD_{PML} = 5.1 mm)

Based on these exceedences; this block qualifies for Planned Maintenance; however since it is already considered for Need-Based Maintenance, based on more severe conditions, no separate indications are made for Planned Maintenance.

KILOMETER WISE EXCEPTION REPORT FOR TRACK PARAMETERS (TRC-7968)

SECTION SPEED (KMPH):130

TRACK RECORDING RESULTS (CHORD MODE)	KM: FROM 0121 TO 0122	RT-CODE:7101	DATE:13-08-2019	RUN No. :C	FILE NAME :13082019A

LOC	SD VALUES SHORT CHORD					AVG	MI-G	INDICES SHORT CHORD			SPD	RIV1	RIL1	RIV2	RIL2	SD VALUES LONG CHORD				INDICES LONG CHORD			TQI-C	MI-SD
	UNL1	UNR1	TWS1	ALL1	ALR1			UNI-1	ALI-1	TQI-S						UNL2	UNR2	ALL2	ALR2	UNI-2	ALI-2	TQI-L		
BLK1	5.1	4.7	3.9	2.2	2.4	7		49	72	60	113	3.21	2.57	3.02	2.17	5.5	7.7	3.4	3.3	54	69	62	61	***
BLK2	3.2	2.5	2.8	2.4	2.3	13	★★★★	75	71	73	112	2.32	2.82	2.32	2.75	4.5	4.9	3.1	3.3	70	71	70	71	
BLK3	2.7	2.5	2.4	2.4	2.6	11	***	79	68	73	118	2.51	2.99	2.31	2.85	4.1	3.9	3.6	3.2	76	69	72	73	**
BLK4	2.8	2.7	2.6	2.4	2.5	6		76	69	72	112	2.61	2.57	2.37	2.31	3.7	3.8	3.4	3.3	79	69	74	73	
BLK5	3.1	3.2	3.3	2.3	2.4	-5		70	71	70	115	2.51	2.52	2.32	2.35	3.2	3.5	3.2	3.3	83	71	77	74	

KILOMETER LENGTH (M): 1024

AVERAGE SPEED (KMPH): 114

GROUND FEATURES : SEJ/234, P&C/405, BR IN/607, BR OUT/812

PEAK DISTRIBUTION

BAND	SHORT CHORD					AGS	AGS	AGC-M	AGC-M	AGC-L	AGC-L	LONG CHORD				ACCELERATION	
	UNL-1	UNR-1	TWS-1	ALL-1	ALR-1	(-)	(+)	(-)	(+)	(-)	(+)	UNL-2	UNR-2	ALL-2	ALR-2	VERTICAL-1	LATERAL-1
NBML	4	5	6	1	8	1	1	0	0	0	0	2	0	2	5	-	-
UML	1	1	1	0	0	0	1	0	0	0	0	0	0	2	3	3	1

UNI-1 70	ALI-1 70	TQI-S 70	UNI-2 72	ALI-2 70	TQI-L 71	TQI-C 70	RIV1 2.63	RIL1 2.69	RIV2 2.47	RIL2 2.49

WROST PEAK INFORMATION

UNL-1	21/091	-19/165	19/113	-18/765	17/413	14/211	-12/344	10/455	10/581	8/621
UNR -1	22/055	19/130	-19/795	18/303	16/427	-15/909	12/995	10/384	9/425	9/612
TWS-1	6.1/302	5.9/103	5.2/450	4.9/72	4.5/15	4.4/302	4.2/450	3.9/515	3.8/721	3.7/851
ALL-1	12/413	10/501	-10/334	9/445	-9/571	8/601	8/722	-8/864	7/909	6/995
ALR-1	14/522	13/410	-13/865	12/030	12/601	12/995	11/909	11/427	10/864	9/195
AG	15/205	12/068	12/601	11/722	-9/864	7/909	6/995	-4/450	4/515	-4/721
UNL-2	25/041	22/150	21/203	-15/264	15/477	-13/255	13/385	-11/348	11/022	11/822
UNR 2	20/018	18/101	15/314	14/030	12/611	12/985	11/919	11/437	10/866	9/155
ALL-2	24/490	-21/565	16/502	-16/351	-12/091	11/572	10/410	-10/865	-8/824	7/909
ALR-2	26/313	24/429	-21/910	20/990	19/364	17/435	-16/622	16/055	15/130	-15/795
Vacc-1	0.27/035	0.26/457	0.24/116	0.24/852	0.24/310	0.22/423	0.22/512	0.21/609	0.21/762	0.20/262
Lacc-1	0.28/072	0.24/810	0.24/215	0.24/629	0.23/782	0.23/166	0.22/310	0.22/912	0.20/512	0.20/112
Vacc-2	0.27/025	0.24/467	0.23/106	0.23/842	0.22/301	0.22/413	0.22/502	0.21/600	0.21/752	0.20/252
Lacc-2	0.26/062	0.23/800	0.22/205	0.22/619	0.21/772	0.21/156	0.20/300	0.20/902	0.19/501	0.18/101

Peaks Wrost Then UML

TWS-1	6.1/302									
AG	15/205									
Vacc1	0.27/035	0.26/457	0.25/498							
Lacc1	0.28/072									

(c) Further, the BLK3 would require Planned Maintenance, marked as ★★, due to exceedences of measured SD values beyond PML for following parameters (marked in blue colour font for easy identification in chart):

(i) Alignment on short chord for right rail (SD=2.6 mm against SD_{PML}=2.5 mm)

(ii) Alignment on long chord for left rail (SD=3.6 mm against SD_{PML}=3.5 mm)

If there are majority of such blocks in a block section, exceeding PML, on account of either Unevenness or Alignment or both; on either on short chord or on long chord or both; that block section would qualify for Planned Maintenance (through tamping).

48.2. Block attention based on the Average values:

(a) In the same exception report, based on the average Gauge parameter (mean gauge over 200 m section over nominal gauge), the BLK2 require Urgent Maintenance, marked as ★★★★ for the value being beyond UML on positive side, i.e. +13mm against +12 mm, (marked in red colour font for easy identification in chart).

A suitable speed restriction needs to be forced in that block, immediately after such TRC result becomes available to the field officials. This speed restriction can be relaxed only after necessary attention to the track and the affected parameter(s) brought within acceptable range to allow normal speed.

(b) Similarly, based on the average Gauge parameter the BLK3would require Need Based Maintenance, marked as ★★★, for the value being beyond NBML on positive side,i.e. +11 mm against +10 mm, (marked in orange colour font for easy identification in chart)

48.3. Isolated attention based on the Peak values:

The attention to the track based on peak values would be either Need Based Maintenance or Urgent Maintenance only for which the values are prescribed in IRPWM. Since the UML values are not prescribed for Unevenness and Alignment parameters, the peak distribution report considers 1.3 × NBML value as UML for these parameters.

(a) The count for locations, for both Need Based Maintenance (marked in orange colour font for easy identification in chart) and Urgent Maintenance (marked in red colour font for easy identification in chart), in respect of each of the parameterbeing monitored is available under the heading Peak Distribution.

(b) With the total number of locations to be attended being available, the specific details of these individual locations could be found under the heading Worst Peak Information; wherein the defect size as well as the location are mentioned.

For ease in identification the locations needing Urgent Maintenance and Need Based Maintenance are marked in red and orange colour font respectively. The parameter wise locations for

Urgent Maintenance and Need Based Maintenance are summarised below in a tabular form for ready reference along with benchmark values. Wherever the measured value of any of the parameter has exceeded NBML or UML, the respective location is picked up for attention as required for initiation of necessary maintenance activity. These specific locations are to be attended by deploying gangs equipped with off track tampers; or Multi-purpose tamper; or regular tamping machine, as required and feasible.

Parameter	Locations to be attended								Benchmark Values	
									NBML	UML
UNL-1	21/091	-19/165	19/113	-18/765	17/413				15	-
UNR -1	22/055	19/130	-19/795	18/303	16/427	-15/909			15	-
TWS-1	~~6.1/302~~	5.9/103	5.2/450	4.9/72	4.5/15	4.4/302	4.2/450		4	6
ALL-1	12/413								11	-
ALR-1	14/522	13/410	-13/865	12/030	12/601	12/995	11/909	11/427	11	-
AG	~~15/205~~	12/068	12/601						-10 to +12	-12 to +15
UNL-2	25/041	22/150							22	-
ALL-2	24/490	-21/565	16/502	-16/351					16	-
ALR-2	26/313	24/429	-21/910	20/990	19/364	17/435	-16/622	16/055	16	-
Vacc-1	~~0.27/035~~	~~0.26/457~~							-	0.25
Lacc-1	~~0.28/072~~								-	0.25

However for attention to peaks exceeding UML, the section Peaks Worst than UML should be referred for locations and magnitude of the defect for the reasons enumerated below.

(c) Under the heading, Peaks Worst than UML, the magnitude and location of all the peaks that have exceeded UML are listed.

The details of peaks under the heading UML overlaps with the details of peaks reported under Worst Peak Information for a particular parameter. However it is also possible that some peaks reported under Peaks Worst than UML are not finding place under Worst Peak Information, which is due to the specific peak selection process, whereby only one of the peak would be reflected for each sub-block of 50 m.

For an example it could be seen that for Vacc1 there are two peaks, exceeding 0.25g, are listed under WPI, whereas under Peaks Worst than UML, there are three such peaks reported (as can be seen in under Peak Distribution also). The two such peaks (the second and the third one) being in the same sub-block, resulted in omission of second peak, though it exceeded 0.25g.

Parameter	Locations to be attended		
TWS-1	6.1/302		
AG	15/205		
Vacc1	0.27/035	0.26/457	0.25/498
Lacc1	0.28/072		

For this reason; only this section (Peaks Worst than UML) should be referred for initiating immediate action for imposition of the speed restriction and planning of attention on priority before release of the speed restriction.

It may be noted that the acceleration peaks recorded by OMS / Oscillgraph car, which exceed UML, are also to be dealt in similar fashion U/S imposition of the speed restriction and planning of attention on priority before release of the speed restriction.

49. All identified locations based on above data and analysis needs to be inspected to plan for the maintenance inputs depending on the type and extent of deterioration in the parametric values. It needs to be appreciated that the locations noted during foot-plate/rear vehicle as well as that reported by TRC are under dynamic conditions and the fact that locational data might not be vary accurate, owing to the response time of the individuals or the TRC's instruments and sensors.

Furthermore the values of various track parameters reported by the TRC under dynamic conditions are subject to sensitivity of the sensors and other equipment involved in measurement system. Therefore, more often than not, the values of the track parameters and the locations recorded might not match during physical verification of those locations. Nevertheless it being a fact that certain locations have been identified to adversely influence the ride quality i.e. vehicle response, a through inspection and analysis would certainly be required to plan for input requirements.

50. While performing thorough inspection it needs to be concluded as to whether the track parameters are deteriorated under normal traffic movement, or the abnormal values of the track parameters or frequent deterioration at any location are initial manifestation of certain serious underlying issues.

While inspecting such locations the adjacent areas on either side may also be thoroughly inspected to detect possibility of existence of similar conditions. During the inspections all track parameters, as considered relevant, to identify the defect/ abnormality should be measured and compared with benchmark values of those parameters. Here the measurements are taken in floating conditions; therefore, the comparison also needs to be made with those prescribed for floating conditions only.

In addition to the track parameters the condition of rail, sleepers, ERC, rubber pads, ballast cushion (clean/caked), formation etc. that might influence the affected track parameter or the behaviour of track in dynamic conditions should also be inspected.

51. Generally in most cases of deterioration of track parameters i.e. NBML cases or isolated excursions, it would suffice if block/spot attention by deploying a tamping machine were carried out. For repeated cases thorough inspection of the site and corrective action thereafter might be necessary for addressing underlying issues causing deterioration in the track geometry.

52. In the event if the number of blocks needing planned attention in any particular block section exceed 50%, through tamping needs to be planned. The process of planning through tamping has been elaborated in IRPWM, and IRTMM.

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A better-laid &nicely maintained track has longer life to provide comfortable ride and to derive maximum value.

For any suggestions, errors etc, please contact
Email : mail@iricen.gov.in


Z
Bouncing
Yaw (Nosing)
Y
X
Rolling
Shuttling
Pitching
Lurching
Track defect
f=Input Frequency in (Hz)