Challenges In Design & Maintenance Of Track Structure For Mixed Traffic Regime On IR

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1. Introduction

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

2. Key Design Parameters:

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

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

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

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

3. Effect of increase in axle load and speed:

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

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

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

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

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

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

4. Requirements for semi - high speed operations:

For increasing the passenger operation speed from current band of 100 – 130 kmph to next band of 140 – 160 kmph and subsequently to 160 – 200 kmph, the essential requirements from track point of view are;

- More accurate track geometry than that required at 100/110 kmph in terms of line and level both to provide same degree of ride comfort and stability to stocks at higher speeds
- Considerable reduction in rail-weld failures as they have more devastating consequences at higher speeds and more hazards for passenger safety

To maintain better geometry and continuity of track, the ill effects of operations on track i.e. track - vehicle interaction forces -

responsible for distortion of the track geometry and effecting fatigue failures of rails welds and track components, need to be contained. Both static and dynamic components of the force need to be taken care off from track loading point of view.

5. Requisites for rolling stocks to operate in mixed traffic regime at higher speeds:

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

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

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

6. UIC leaflet 724-R deliberates on design aspects and track equipment for operation of 25 ton axle loads on ballasted track. The salient points of the leaflet are indicated below:

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

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

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

- good track geometry quality
- adapted speed
- good wheel quality
- track friendly vehicle design"

7. Experience of 22.9t & 25t axle load operation on IR:

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

- Excessive wear in switches and crossings
- Crossing zone requires frequent packing
- CMS crossings required frequent replacement/repair due to wear and cracking of crossing.
- Excessive wear of outer rails of curve and flattening of inner rails
- Battering of glued joints frequently
- Increased cases of glued joint failure and fish plate fracture
- Stretches on weak formation/black cotton soil causing frequent ballast puncture resulting into abrupt cross level variation.
- Fish plate of stock rail joints getting battered, leading to failure of fish plates.

7.2 Experience of KK line of Waltaire Division:

This route has operated 9944 no. of 25t axle load trains in last nine years. The frequency on an average works out to approximately 1100 trains per year. The maximum number of 25t axle load trains run in a year was 1997 in the year 2013-2014 followed by 1843 no. of trains in 2012-2013. The total GMT of the section is 25, out of which the percentage of 25t axle load trains varied approximately from 10-25% in a particular year. The data of rail fracture/weld failure indicates substantial increase under operation of 25t axle load trains as brought out in the table below:

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

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

8. Experience of British Railway:

Director of Civil Engineering, British Railways published an important report on the operation of 25t axle loads in a conference held on 11-13 July 1984. British Railway operates mixed traffic and during the period of report, they were running passenger trains at 125MPH (200 kmph) and freight trains of 25t axle load at 60MPH

(100 kmph). The percentage of passenger train kilometerage was 86% of the total and that of freight train was 13%.

The report brought out following important observations:

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

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

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

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

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

- Install all sanctioned Weigh Bridges by December, 2006 and ensure that all weigh bridges are kept well maintained and functional.
- NO OVERLOADING must be permitted. Drastic penal action should be taken against defaulters.

- Good train running and adequate powering should be ensured to prevent instances of stalling/wheel slippages.
- Wagons must be well maintained, additional springs as advised be provided during ROH/POH.
- RDSO must expedite development of WILD and it must be installed at selected locations within one year.
- All remaining instrumentations of bridges etc. should be concluded without any further delay.
- Concerned PHODs meeting should be regularly held at General Manager's level to review operation of these heavy axle

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

10. Major challenges in design of track structure:

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

A. Problems with existing designs and certification of heavy axle load wagons

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

(ii) The criteria for certification of freight stocks on IR are very slack in comparison to international standards. It does not mandate the measurement of dynamic forces on rail and any limiting value of it for clearing the stocks for operation. Further, it does not stipulate any limit for accelerations. A comparison is being given in Table -1.

Comparison of acceptance criteria (Freight stocks) (Table-1)

SN	Parameters	IR Limits	UIC-518/EN-14363 Limits	British Standards
1	Vertical acceleration	Not specified	5 m/s^2 in body (~0.5g)	should not exceed 0.25g (mean) & 0.44g (max.)
2	Lateral acceleration	Not specified	3 m/s^2 in body (~0.3g)	should not exceed 0.2g (mean) & 0.33g (max.)
3	Vertical Ride Index	4.5 (4.25 preferred)	NA	4.25 (mean) 5.0 (max)
4	Lateral Ride Index	4.5 (4.25 preferred)	NA	
5	Track loading Limit (Q lim) – track fatigue criteria	Not Specified	(90 + Q_0) Max 210 KN	Not Available
6	Lateral Force (Hy2m)	shall not exceed 0.85(1+P/3) tonnes; where P=axle load	shall not exceed 0.85(10+Po/3) kN; where Po=axle load	shall not exceed 0.85(1+2Q/3) tonnes; where 2Q= nominal wheel load

Another important issue pertains to the oscillation trials which are done on new stocks having no regime of oscillation trial of stocks in run down condition before POH for corrective action. This may be needed for preventing high dynamic loading on infrastructure for improved reliability and safety, for mixed traffic regime on IR, as the performance of stock deteriorates as it grows old in service increasing severity of its ill- effects on track.

(iii) The freight stocks have been cleared with very high acceleration values obtained during oscillation trials much beyond the international norms (see table 2 & 3 below). High vibrations imparted to track in the high stress state due to high axle load shall reduce the fatigue life and would lead to increased incidences of fatigue as well as sudden failure of rails/welds.

Acceleration values of existing stocks observed during oscillation trials

25 T AXLE LOAD WAGONS (Loaded condition)

WAGON	Speed	Max Lateral Acc (g)		Max vertical Acc (g)		C&M-I VOL-I or Other	REPORT NO.	Remarks
		Detailed run	Long run	Detailed run	Long run			
BOBSNM1	**60/80**	**0.48**	**0.65**	0.45	**0.49**	Other	726/2006	
BOXN 25M	**125**	0.23	0.25	**0.69**	**0.81**	C&M 1	1217/2012	(i) UN- A0 (ii) 2 degree curve at 80 kmph
BLC 25M	**125**	0.21	0.25	**0.47**	**0.51**	C&M 1	1288/2013	UN - A0 , TW - A0, AL - A0
BOXNHL25T	**85**	0.51	0.38	0.36	0.41	Other	1427/2015	
		0.47	0.4	0.42	0.37	Other		
BOXNEL	**90**	**0.66**	0.31	**0.72**	**0.65**	Other	1437/2016	
BOYEL	**90**	**0.74**	**0.57**	**0.73**	**0.76**	Other	1439/2016	
BOXNS	**100**	0.19	0.42	**0.76**	**0.87**	Other	1463/2016	

22.9 T AXLE LOAD WAGONS (Loaded Condition)

WAGON	Speed	Max Lateral Acc (g)		Max vertical Acc (g)		C&M-I VOL-I or Other	REPORT NO.	Remarks
		Detailed run	Long run	Detailed run	Long run			
BOXNHL	**110**	**0.64**	**0.66**	**0.78**	**0.73**	C&M 1	929/2009	
BOXNHL (PU TYPE CCSB PAD)	**110**	**0.53**	**0.47**	0.45	0.41	C&M 1	936/2009	
BCNHL	**110**	**0.48**	**0.57**	**0.57**	**0.61**	C&M 1	1007/2010	
BOXNHL (Series 1)	**85**	0.23	0.31	**0.56**	**0.56**	Other	1341/2014	
BOXNHL (Series II)	**85**	0.25	0.33	**0.5**	**0.64**	Other	1342/2014	

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

B. Major issues in operation

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

- There is very little monitoring of impact loading on track. It was stipulated to install adequate no of WILD (Wheel Impact Load

Detector) instrument to check the impact loading on track and detach the stocks immediately from the load for which critical alarm is given by the WILD. However, only 15 WILDs have been installed so far against the 260 identified resulting into no monitoring of more than 90% of loads for impact loading on track.

- The second issue is high impact loading permitted during operations. The critical WILD alarm has been set at 35t which is almost equal to 300% dynamic augment for 22.9t axle load. The stress generated with such high vertical load in combination of other stresses such as residual and thermal stresses in rail are estimated to reach up to level of 55.28 Kg/mm^2 against the permissible limit of 46.8 Kg/mm^2 in 60 kg/90 UTS rail.

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

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

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

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

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

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

11. Limitations of existing track components

11.1 Maximum allowable vertical load in 60kg/90 UTS rails:

Permissible rail stress in existing 90 UTS rail due to bending is 46.8 Kg/mm^2. After factoring in the other stresses in rail like thermal and residual, the maximum vertical load that can be worked with 60 kg rails is 18-22 t depending upon the wheel base of wagons while wheel loads upto 35t are allowed for operations as per WILD alarm stipulations. The range of 20t to 35t has been stipulated as maintenance alarm in the WILD which has to be checked during scheduled inspections only for any defect. These rail stress calculation does not take into account the increase in dynamic augment due to wheel deformations. The RDSO report no C-100 indicates that a wheel flat of dimension of 18x25x3 mm in ICF coach produced a dynamic augment (DA) as high as 257% at speed of 96 kmph against the normal DA of 57.4%. Therefore, it can be inferred that even of flat of size 10-15 mm or little deformation in wheel, which is very likely for a large number of wheels, will produce an instantaneous wheel load of such order that rail stress crosses its permissible limit in 60 kg rail.

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

11.2 Sleepers:

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

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

11.3 Rubber pads:

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

11.4 Other Track Components:

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

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

CONCLUSION

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

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

The way side monitoring, timely maintenance and replacement of both aged rolling stock and fixed infrastructure are also pre-requisites to keep the forces low and long term economical sustainability of heavy axle load operations along with semi-high speed passenger operations.