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सत्यमेव जयते

भारत सरकार - रेल मंत्रालय
अनुसंधान अभिकल्प और मानक संगठन
लखनऊ - 226 011
Government of India - Ministry of Railways
Research Designs & Standards Organisation
Lucknow - 226 011

No.CT/DG/Research Dt:16-10-2006

The Chief Track Engineer:

1. Central Railway, CST, Mumbai – 400 001.
2. Eastern Railway, Fairlie Place, Calcutta – 700 001.
3. East Central Railway, Hajipur – 844 101.
4. East Coast Railway, Chandrasekharpur, Bhubaneshwar – 751 016.
5. Northern Railway, Baroda House, New Delhi – 110 001.
6. North Central Railway, Allahabad - 211 001.
7. N.E.Railway, Gorakhpur - 273 001.
8. N.F.Railway, Maligaon, Guwahati – 781 011.
9. North Western Railway, Jaipur – 302 001.
10. Southern Railway, Park Town, Chennai – 600 003.
11. S.C.Railway, Rail Nilayam, Secunderabad – 500 371.
12. S.E.Railway, Garden Reach, Calcutta – 700 043.
13. South East Central Railway, Bilaspur 495 004
14. South Western Railway, Hubali– 580 023.
15. Western Railway, Churchgate, Mumbai – 400 020
16. West Central Railway, Jabalpur – 482 001.

Sub: Rail stress calculation methodology.

Ref: (i) Item no.1074 (SNo.9) of 76th TSC on Track Stress Calculation.

(ii) Item no.1078 (SNo.9) of 76th TSC on review of rail stress calculation methodology.

(iii) Railway Board's orders on recommendations of 76th TSC vide letter no.2005/CE-II/TSC/2 dt:13-9-2006.

The issue was discussed vide item no.957 in 73rd TSC, Item no.1031/25 in 74th TSC and Item No.1057/12 in 75th TSC. Following the discussions on the item in 75th TSC held at Mumbai in December, 2004, TSC had recommended that the sectional

properties of rails at different wear percentage of rails should be issued by RDSO early. These recommendations were approved by Railway Board.

Pursuant to these recommendations and Railway Board's order thereon, RDSO had worked out the sectional properties of 52Kg and 60Kg rails at different percentages of wear and circulated the same to Zonal Railways vide RDSO's letter of even no.dt:20-10-2005. Certain errors in the sectional properties worked out have been noticed and accordingly revised sectional properties are enclosed herewith as Annexure-1.

Further, Railway Board have approved adoption of the values of track modulus for PRC sleepers recommended by TSC after discussion on Item no.1078. The subject of track stress calculation was also discussed in 76th TSC vide Item No.1074 (S.No.9). Railway Board have desired that the rail stress calculation methodology should be circulated by RDSO to Zonal Railways.

In view of above, the methodology for computation of track stresses comprising of explanatory notes regarding computation of stresses in various components of track (Annexure 2), "Stress" software for calculation of stresses (copy being sent by e-mail) and sample calculation of rail stresses (Annexure 3) is being sent herewith for your information and necessary action.

(Anirudh Jain)
Executive Director/Track
For Director General/Track

DA: As above

Copy for information to:

1 Executive Director CE (P), Railway Board, Rail Bhawan, New Delhi-110 001.
2 Director, IRICEN, Pune.

Rail section		Rail Wear (%) of area	Moment of Inertia about xx-axis	Section modulus of worn Rail		Polar moment of inertia	Factor *		Lateral section modulus for head	Lateral section modulus for foot	Distance between centre of twist and point of action of lateral force
				compression	Tension						
	Area cm^2		I'xx (cm^4)	$Z_c$worn (cm^3)	$Z_t$worn (cm^3)	Ip (cm^4)	EI_1h_1r/CZ_1	EI_1h_1r/CZ_2	Z_3(cm^3)	Z_4 (cm^3)	h_f(cm)
52 kg	66.15	10	1792.14	202.13	266.15	2090.84	0.0270	0.0259	146.80	43.86	10.28
	66.15	9	1823.43	207.64	267.43	2128.56	0.0285	0.0257	138.65	44.81	10.34
	66.15	8	1855.84	213.37	268.87	2167.40	0.0297	0.0256	132.16	45.75	10.41
	66.15	7	1889.40	219.34	270.45	2207.39	0.0308	0.0255	126.91	46.69	10.48
	66.15	6	1924.12	225.55	272.18	2248.54	0.0318	0.0254	122.61	47.64	10.55
60 kg	76.86	10	2501.54	248.98	349.72	2918.17	0.0193	0.0213	218.00	55.55	11.43
	76.86	9	2549.68	256.26	351.66	2975.93	0.0211	0.0212	198.32	56.83	11.49
	76.86	8	2599.35	263.81	353.80	3035.23	0.0227	0.0211	183.83	58.12	11.55
	76.86	7	2650.59	271.65	356.13	3096.10	0.0241	0.0211	172.80	59.40	11.61
	76.86	6	2703.41	279.79	358.65	3158.55	0.0253	0.0210	164.19	60.68	11.67

* E= Young's Modulus of Elasticity

I_1=Moment of inertia for head

I_2=Moment of inertia for foot

h_1=Distance of centroid of head postion from centre of twist

h_2=Distance of centroid of foot postion from centre of twist

r =Factor

Z_1=section modulus for head

Z_2=section modulus for foot

C=Torsional Rigidity

Rail section	Area cm^2	Wear (%)	H.width(mm)	Radius (mm)	Loss of area A1 (cm^2)	Beff (mm)	Depth of wear (mm)	Iw (cm^4)	Ixx (cm^4)	Yt (cm)	AwX^2 (cm^4)	I'xx (cm^4)	% Reduction in Ixx(cm^4)	Stipulated load (t)	Proposed values	
															60t	65t
75R	47.37	4.2	61.91	11	1.98954	50.91	3.907955	0.02532	1055.56	6.629	41.39124	973.1852	7.8039	65 (90UTS)	55.31766	59.92747
	47.37	4	61.91	11	1.8948	50.91	3.721862	0.021873	1055.56	6.629	41.51105	976.883	7.45358		55.52785	60.15517
	47.37	3	61.91	11	1.4211	50.91	2.791397	0.009228	1055.56	6.629	42.1127	995.7044	5.670506	60(72UTS)	56.5977	61.31417
	47.37	2	61.91	11	0.9474	50.91	1.860931	0.002734	1055.56	6.629	42.71869	1015.086	3.834402		57.69936	62.50764
	47.37	1	61.91	11	0.4737	50.91	0.930466	0.000342	1055.56	6.629	43.329	1035.035	1.944493		58.8333	63.73608
90R	56.95	5	68.68	12.7	2.8475	55.98	5.086638	0.061397	1600	7.493	52.39832	1450.734	9.3291		77.07026	
	56.95	4	68.68	12.7	2.278	55.98	4.06931	0.031435	1600	7.493	53.13731	1478.922	7.56739	85(90UTS)	78.56772	
	56.95	3	68.68	12.7	1.7085	55.98	3.051983	0.013262	1600	7.493	53.88148	1507.93	5.754361		80.10879	
	56.95	2	68.68	12.7	1.139	55.98	2.034655	0.003929	1600	7.493	54.63083	1537.772	3.889278		81.69411	
	56.95	1	68.68	12.7	0.5695	55.98	1.017328	0.000491	1600	7.493	55.38535	1568.458	1.971403		83.32431	

EXPLANATORY NOTES TO CALCULATION OF TRACK STRESSES

1. Track stresses are worked out on the basis of elastic theory which is based on the assumption that the several components of track are one complete unit and the rails are continuously supported on sleepers which are considered to be elastic. The ballast and formation are also considered elastic.

2. Track Modulus:

   For calculation of track stresses, the following track moduli values recommended by 53rd and 76th Track Standards Committee vide item no.716 and Item No.1078 respectively and approved by Railway Board are to be followed:

Gauge	Sleeper Type	Sleeper Density	Initial Load	Initial Track Modulus	Elastic Track Modulus
BG	Other than PRC	All	4t	75Kg/cm/cm	300 Kg/cm/cm
	PRC	1540	4t	125/kg/cm/cm	425/kg/cm/cm
	PRC	1660	4t	135/kg/cm/cm	540/kg/cm/cm
MG	All	All	3t	50 Kg/cm/cm	250 Kg/cm/cm

3. Rail section properties:

   For working out rail stresses, the properties like moment of inertia and section modulus of rails are being assumed 10% lesser than the properties for new rails. The wear is assumed to be 5%.

4 Speed/impact factor:

   For BG vehicles, the graphs plotted in RDSO's report C-100 are being followed for different vehicles. In case of M.G. vehicles, similar graphs plotted in Report C-92 are being used. These graph are enclosed here with for ready reference. Where the measured values of dynamic augment are not available , the dynamic augment values for similar vehicles are to be adopted.

5 The Bending Stresses in rails:

   These are calculated using double modulus method based on the method given in Technical Paper 323. The maximum lateral flange force per axle is as per Prud' Homme Limit. In case actual measured figures are available for the stock under consideration, the same are being assumed in calculating stresses. An eccentricity of 15mm for vertical load is adopted for calculations.

Following permissible values for rail stresses are being adopted at present for rails with minimum UTS of 72Kg/mm^2 and 90Kg/mm^2 .

i) Bending longitudinal rail stresses due to vertical wheel load including eccentricity effect- 23.5Kg/mm^2.

ii) Combined bending longitudinal rail stresses including the effect of lateral flange forces:

For 72 UTS rail:

1	For jointed track	30 Kg/mm^2
2	For track with short-welded panels	24.25 Kg/mm^2
3	For long-welded rail panels	19.25 Kg/mm^2

For 90 UTS rail:

1	For jointed track	36.0 Kg/mm^2
2	For track with short-welded panels	30.25 Kg/mm^2
3	For long-welded rail panels	25.25 Kg/mm^2

6. Fishplate Stresses:

For calculating fishplate stresses, the bending moment is to be worked out adopting the dynamic wheel load, by double modulus method, using the bending moment formula given in the Track stresses Research Report by M/s Gelson & Blackwood (given below). The stresses developed are to be worked out by dividing the B.M. by minimum section modulus value for the pair of fishplates. The dynamic stress range, for fatigue consideration should be taken as 1.33 times the calculated fishplate bending stress and should not exceed 25 Kg/mm^2. The maximum stress in fishplates is calculated by adding the stress due to initial bolt tension, to the value of fishplate bending stress. This value is taken as 10Kg/mm^2. The maximum stress in fish plates should not exceed 30 Kg/mm^2 .

The formula for calculating bending moment is as below:

$$Mo = \frac{Ip}{\beta^2 L I} \left\{ W - 2\beta Mo - \frac{(W-\beta Mo)\ P\alpha \sum}{2\beta^3 EI + P\alpha \sum} \right\}$$

Where Mo = B.M. in the pair of fish plates.

$\beta = 4\sqrt{\frac{U}{4EI}}$ to be worked out for Ui and Ue separately

U	=	Track modulus kg/cm/cm
L	=	Effective length of fishplate cm
α	=	Influence factor from the master diagram (for distance of joint sleeper centre from rail end)
$\sum$	=	Additional bearing area ratio
P	=	U x S, 'S' being intermediate sleeper spacing in cm

2W	=	Dynamic wheel load in kgs
Ip	=	M.I. of pair of fishplates (cm^4)
I	=	M.I. of rail (cm^4)
E	=	Young's modulus of rail steel (Kg/cm^2)

7. <u>Bolt Hole Stresses:</u>

The principal stresses at fish bolt holes are calculated by the formula given below. A stress concentration factor of 3 is applied.

$$\text{Thus } p = 3 \left\{ \frac{f1 + f2}{2} \pm \sqrt{\left(\frac{f1-f2}{2}\right)^2 + q^2} \right\}$$

Where f1 = Direct stress in rail web due to bolt tension of 3 tonnes
f2 = Stress in rail web due to vertical bending moment caused by dynamic load
q = Shear stress due to shear force in rail

The stress range is worked out with maximum and minimum values of principal stresses obtained with above formula. This range should not exceed $27 Kg/mm^2$.

Notes: For calculation of bolt hole stresses a tables showing the factors for different rail sections has been enclosed.

8. <u>Formation Pressure:</u>

For working out maximum intensity of pressure on formation following formula as per Technical Paper No.245, is used using elastic track modulus value only;

$$Pmax = \frac{2PS}{\pi DL} \sqrt[4]{\frac{U}{64\,EI}}$$

Pmax	=	Maximum formation pressure in Kg/cm^2
P	=	Dynamic wheel load in kgs.
S	=	Sleeper spacing in cm
D	=	Depth of ballast in cm.
L	=	Effective length of sleeper per rail seat in cm 76 cm for BG, 63cm for MG.
U	=	Track Modulus kg/cm/cm
E	=	Modulus of elasticity of rail steel in kg/cm^2.
I	=	M.I. of rail in cm^4.

The permissible limits of formation pressure are as below:-

1. For locomotives 3.5 kg/cm^2

2. For other stock namely
   Wagons, coaches only 3.0 kg/cm^2

8. <u>Rail wheel contact shear stress:</u>

The contact shear stress developed at a depth of 5-7mm below top table in the head of the rail is calculated by the following formula:

$$T_{max} = 4.13 \sqrt{\frac{Q}{R}}$$

Tmax = Contact shear stress in Kg/mm^2

Q = wheel pressure in kg (static wheel load + 1 tonne to account for constant on-loading on the curves)

R = wheel radius in mm (Worn wheel radius)

The permissible value for this stress is taken as 30% of UTS of rail steel, i.e. 21.6 kg/mm^2 for 72UTS rails. If these stresses are exceeded shear fatigue failures leading to kidney shaped fatigue cracks in rail head may develop.

9. <u>Joint Loading:</u>

Due to the effect of unsuspended masses and speeds the joints are subjected to severe over-loads given by the formula:

$$F = F_o + 0.1188\, V \sqrt{W}$$

Where
- F = Dynamic overload at joint in tonnes
- Fo = Static wheel load including sprung and unsprung masses in tones
- V = Velocity in km/h
- W = Unsprung mass per wheel in tonnes.

The following permissible values are being adopted:

B.G.-	Locomotives	…..	27 tonnes
	EMU stock	…..	23 tonnes
	Wagons & coaches	…..	19 tonnes
M.G-	Locomotives	…..	17 tonnes
	EMU stock	…..	14 tonnes

Wagons & coaches ….. 11 tonnes

CALCULATIONS FOR RAIL STRESSES DUE TO BOXN WAGON AT 75KMPH ON 52KG, M+7(1540nos/km), 250MM TRACK (WITH DOUBLE TRACK MODULUS METHOD)

Initial track modulus (μ_i) = 125Kg/cm/cm
(for first 4 tonnes live wheel load)

Elastic track modulus (μ_e) = 425 Kg/cm/cm
(for rest of live wheel load)

Assumed that I & Z of 5 % worn rail are reduced by 10 %

Ixx (worn) = 1942. 2cm4
Zc (worn) = 241.65 cm 3
Zt (worn) = 256.95cm 3

X_1 = The distance from the load to the point of contra flexure of the rail in cm.

$$= 42.33 * \sqrt[4]{\frac{Ixx\ (worn)}{\mu}}$$

X_{1i} for initial load of 4t $= 42.33 * \sqrt[4]{\frac{1442.2}{125}}$

= 84.04 cm

X_{1e} for rest of the load $= 42.33 * \sqrt[4]{\frac{1442.2}{425}}$

= 61.89 cm

Impact factor at 75Km/h = 53 % taken from graph plotted in RDSO report no. C-100.

Axle Load = 21.82 tonnes

Wheel Load = 10.91 tonnes

Dynamic wheel load = 10.91 * 1.53 = 16.69t

B.M Co-efficient from master diagram

With X_{li} = 84.04cm	With X_{1e} = 61.89cm
For 200cm (-) .19	for 200.0cm (-) .10
For 452.4cm (-) 0	for 452.4cm 0
For 652.4 cm 0	for 652.4 cm 0

Effects of adjacent wheels

4 * (-).19 = - .76t

For initial load of 4 tonnes

12.69 * (-) .10 = -1.2692t
for elastic loading
(balance of dynamic wheel load)

Rail stresses due to vertical bending

T_{lv} considering initial load of 4 tonnes.

	1	2	3	4
	200.0	452.4	200.0	
Effect of Wheel no.1	4	-.76	-	-
Effect of Wheel no.2	-.76	4	-	-
Effect of Wheel no.3	-	-.	4	-.76
Effect of Wheel no.4	-	-	-.76	4
Virtual wheel load	3.24	3.24	3.24	3.24

Effect of leading wheel to be taken if the distance between adjacent axle is more than 6 times X_{li}

In the present case 6 * X_{li} = 6 * 84.04 = 504.24 cm
No wheel except wheel nos. 1 and 4 is having effect of leading axle

Adding 10 % for the effect of leading wheel

$T_{l\,v}$ = 3.24 + .324 = 3.564 tonnes.

T_{lv} considering remaining load.

	1	2	3	4
	200.0	452.4	200.0	
Effect of Wheel no.1	12.69	-1.269	-	-
Effect of Wheel no.2	-1.269	12.6.9	-	-
Effect of Wheel no.3	-	-	12.69	-1.269
Effect of Wheel no.4	-	-	-1.269	12.69
Virtual wheel load	11.421	11.421	11.421	11.421

6 * X_{1e} = 6 * 61.89 = 371.34 cm

Hence, wheel 2 & 3 will also have leading wheel effect

T_{lv} for wheel nos. 1 & 4 = 11.421+1.1421= 12.5631 tonnes

T_{lv} for wheel nos. 2 & 3 = 11.421+1.1421= 12.5631 tonnes

For max. Value of T_{lv}, ,the T_{lvs} due to initial and elastic loading will be added.

T_{lv} due to initial loading	3.564	3.24	3.564	3.24
T_{lv} due to elastic loading	12.5631	12.5631	12.5631	12.5631
Total T_{lv}	16.1271	15.8031	15.8031	16.1271

Max. T_{lv} = 16.1271 tonnes.

B.M. in rail = .318 * 84.04 * 3.564 + .318 * 61.89 * 12.5631

= 95.246 + 247.254
= 342.50 t.cm

Stress in head (comp) = $\frac{342.5}{241.65}$ = 1.417 t /cm^2
= 14.17 Kg/mm^2

Stress in foot (tensile) = $\frac{342.5}{256.95}$ = 1.332 t /cm^2
= 13.32 Kg/mm^2

b) Stresses due to eccentricity of vertical load

Eccentricity (e) = 1.5cm (assumed)
Torque = 2Mt = T_{Lv} * e

Mt = $\frac{16.1271 * 1.5}{2}$ = 12.095325 t.cm

Note: $\frac{E*I_1* h_1*r}{C*Z_1}$ = .0351
$\frac{E*I_1* h_1*r}{C*Z_2}$ = .0247

(i) Stress in head = $\frac{Mt* E*I_1* h_1*r}{C*Z_1}$

= 12.095325 * .0351 = .427 t/cm^2
= 4.27 Kg/mm^2

ii) Stress in foot = $\frac{Mt* E*I_1* h_1*r}{C*Z_2}$

$= \quad 12.095325 * 0.2470 = ..298\ t/cm^2$
$= \quad 2.98\ Kg/mm^2$

c) Stress due to twisting by flange force

Maxm. Flange force/axle $= .85\ (1 + \frac{21.82}{3})$
$= 7.032t$
flange force / wheel $= 3.516\ t$

$2\ Mt = 3.516 * h_f$

$Mt = \frac{3.516 * 10.958}{2} = 19.264164\ t.cm$

(i) Stress in head $= \frac{Mt * E * I_1 * h_1 * r}{C * Z_1}$
$= .676\ t/cm^2 = 6.76 kg/mm^2$

(ii) Stress in foot $= \frac{Mt * E * I_1 * h_1 * r}{C * Z_2}$
$= .485\ t/cm^2 = 4.85\ kg/mm^2$

d) Stresses due to lateral deflection under flange force

Flange force / wheel $= 3.516\ t$

Sleeper spring $= 68\ cm$

BM $= \frac{3.516 * 68}{4} = 59.772.cm$

Lateral Modulus $Z_3 = \frac{59.772}{108.253} = .552 = 5.52\ Kg/mm^2$

Lateral Modulus $Z_4 = \frac{59.7725}{53.324} = 11.20\ Kg/mm^2$

Combined stresses:

(a + c + d-b) for head =

$14.17 + 6.76 + 5.52 - 4.27 = 22.18 Kg/mm^2$

(a + b +d –c) for foot $= 13.33 + 2.98 + 11.20 - 4.85 = 22.66\ Kg/mm^2$