Turnout Frogs Evaluation Under Heavy Haul Railway Traffic

S. L. Issomura, S. M. Pessanha, C. V. C. Rocha, L. A. S. Lopes, L. A. C. M. Aragão Filho

***Abstract*— The increase in railway cargo transportation demand has been promoting proportional investment and upgrowth in Brazilian tracks, in order to match train size, speed, axle load with superstructure capacity. While this does not occur at required speed, permanent way experiences load growth and assets lifetime reduction. Turnout is one of critical assets in a railroad, on which high levels of acceleration and vertical and lateral forces occur, causing excessive wear, particularly under heavy axle load traffic. Over time, new designs were developed to meet load and required service life. This article presents a technical evaluation of low impact explosion hardened frog and movable point frog in relation to rail bonded manganese frog, under 27.5 tons axle load railway traffic.**

***Index Term*— force, frog, impact, railway, turnout**

I. INTRODUCTION

HISTORICALLY, Brazilian railroads have iron ore and coal as major cargo in railroad transportation index. These cargos accounted for about seventy-five percent of total amount transported from early years of privatization at the end of 90´s and had their production increased by 89% in 15 years. Such transportation demand has to be absorbed by using higher capacity wagons, increasing the number of wagons per train, increasing speed, reducing interval between trains or combining two or more factors, while major initiatives, such as new constructions, track expansions, renewals and other initiatives do not happen.

Also, loads on permanent way are increasingly severe and have contributed to decrease railways components lifetime. According to Sadeghi and Akbari (2006), it is due to intense wheel-rail interaction, which determines vehicles and track components replacement maintenance and replacement.

The most critical points in permanent way that suffer severe forces and maintenance occurs where there is a track discontinuity, which support dynamic interaction between rail and wheels, with high levels of impact, acceleration, lateral and vertical forces. Turnout contains the main critical points where impacts are frequent and track discontinuity is inherent to its performance: to guide the train from one track to another.

The change of direction of a train in a turnout occurs by moving the switches, identified in FIG. 1.

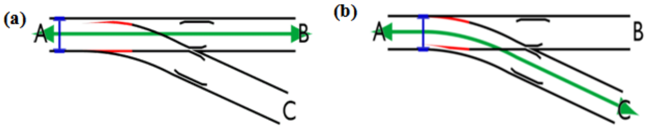


Fig. 1. Train passage over a turnout: (a) switches movement (in red) to allow train passage to A-B main direction and (b) switches movement to allow train passage to diverging direction (A-C). Source: Wikipédia (2014)

As soon as a train crosses the switches, regardless of direction, this train is required to go through the intersection point of both lines, called "frog", identified in FIG. 2 (a). From this point of view, it is possible to identify several discontinuities in the roadway, being more evident those existing at frog region. FIG. 2 (b) depicts schematically the passage of wheels over the frog region. When a wheel passes from wing to frog point, for example, this wheel is briefly in the air without support. After, the wheels are back in touch with a support point where the impact occurs.

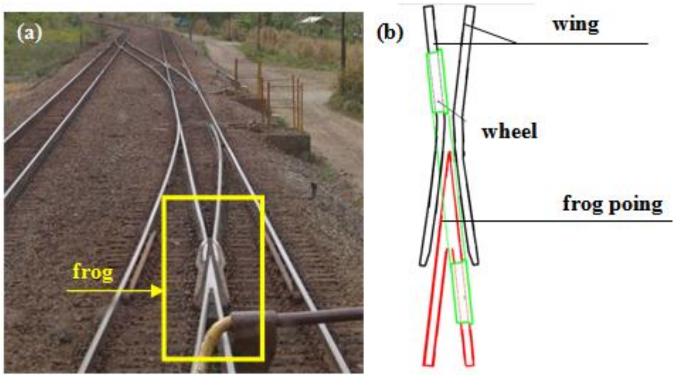


Fig. 2. (a) Train passage over a turnout from locomotive cabin point of view and (b) schematic view of a wheel passage over frog region
Sources: (a) authoress (2008) e (b) adapted from Muller et al (2013)

Since frog is a component exposed to more abrupt wheel impact forces, it needs more attention when it comes to life assessment materials exposed to high axle load train traffic. Rail bonded manganese frogs, or conventional frogs, under heavy haul railway traffic, exhibit degradation signs early, as depicted in the figures below: Fig. 3 (a) shows severe damage by impact and apparent surface defects, and FIG. 3 (b), the

---

S. L. Issomura is a master degree student at Military Institute of Engineering, Rio de Janeiro, RJ, Brazil (e-mail: simonelie00@yahoo.com.br)
S. M. Pessanha is a master degree student at Military Institute of Engineering, Rio de Janeiro, RJ, Brazil (e-mail:swellenmendonca@gmail.com)
C. V. C Rocha is a master degree student at Military Institute of Engineering, Rio de Janeiro, RJ, Brazil (e-mail:cvrengenharia.com.br)
L. A. S. Lopes is a professor at Military Institute of Engineering, Rio de Janeiro, RJ, Brazil (e-mail: laslopes@ime.eb.br)
L. A. C. M. Aragão Filho is a professor at Military Institute of Engineering, Rio de Janeiro, RJ, Brazil (e-mail: moniz@ime.eb.br)

step between carbon steel and manganese steel rail at frog heel.

Fig. 3. Frog defects (a) severe superficial frog defect; (b) step between manganese and carbon steel in a frog heel.

II. DIFFERENT TYPES OF FROGS IN THIS STUDY

A. Conventional Frog (Rail bonded manganese frog)

Fig. 4 (a) shows in more detail the frog conventionally used in railways (fixed point frog with manganese core screwed). Its structure has a manganese steel core, as shown in Fig. 4 (b), screwed to machined bent rails, as depicted by Fig. 4 (c).

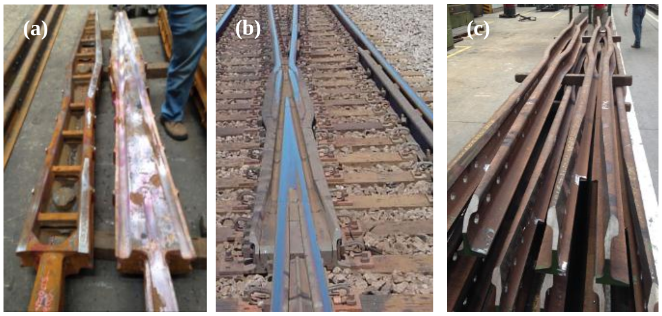


Fig. 4 (a) Conventional frog; (b) manganese frog core; (c) machined bent rails
Sources: (a) Koehler (2013); (b) e (c) authoress (2015)

According to Peters (2005), the unique manganese properties such as high hardness, high ductility, high hardening capacity in service and it excellent wear resistance made this material quickly accepted and applied in heavy industries. Frank (1986) adds that the unusual properties of this steel, give it as well as wear resistance, an ability to deal with severe impact, making it suitable for use in railways.

Currently AREMA (2008) recommends that austenitic manganese steel is produced according to the latest revision of ASTM 128, Specification for Steel Manganese Austenitic Cast, Grade A, except for the chemical requirements that must be modified as Table I:

TABLE. I
AREMA REQUESTS FOR RAILWAY FROGS

Element	Percent (%)	
	Minimum	Maximum
Carbon	1.00	1.30
Manganese	12.00	-
Silicon	-	1.00
Phosphor	-	0.07

Source: AREMA (2008)

B. Explosion Hardened Frog With Low Impact Heel

The unique manganese steel ability to harden under impact is its major advantage. However, according Baten *et al* (1986) due to its low flow resistance, plastic deformation may occur in isolated areas as a result of impact, before suitable hardening occurs by wheels passage.

To minimize metal flow, it would be necessary to ensure the required hardness before installation by prior hardening, slowing plastic deformation and increasing material lifetime.

An explosive in sheet form was developed in 1956, allowing better handling and flexibility to adapt it to any shape, which becomes adaptable to use for increase frog hardness. Hardness depth may vary depending on the number of bursts applied, 3 is the maximum number of explosions indicated. In addition to this amount, it is likely to surface fatigue and microcracks formation; if applied more than 3 bursts, the process would be more expensive and without reasonable performance increase, as laboratory tests and field described by Baten *et al* (1986). Explosion hardening gives a layer with high hardness at 10 to 12 mm layer, compared to other untreated areas.

In addition, this project includes a slope in frog heel and a gradual transition between carbon steel rails and manganese steel, avoiding premature heel fractures, smoothing passage of the wheels and thereby reducing defects and flaws.

For comparative purposes, Fig 5 (a) shows the conventional frog heel, where transition occurs more abruptly, at an approximate 45 degree angle.

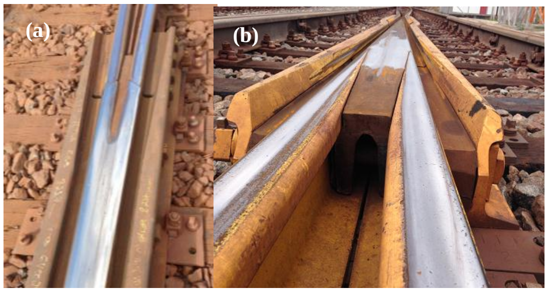


Fig. 5. (a) Conventional frog heel; (b) Low impact heel.

C. Movable Point Frog

Movable point frog, presents a design were the frog point has freedom to move to both straight or diverging directions, like turnout switches, making a continuous bearing surface, as shown in Fig 6. Frog point movement is performed by an additional switch machine and must be controlled according to commands sent remotely by Operational Center Control.

Fig. 6. Movable point frog.

BNSF (2011) recommends this type of frog when annual tonnage is less than 100 million gross tons in diverging direction. The additional infrastructure system to move the frog point, increase initial cost, limiting its application to lines with high traffic. Economic analysis calculated by Shu *et al* (2013) suggests that railways which transport from 60MGT / year can use this solution.

III. INFLUENCE FACTORS

When train-track system dynamic behavior is considered, Stone *et al* (2001) points out that track geometry, track components conditions and grid offset formed by rails, turnouts, fastenings, plates, ballast and sleepers, associated to train characteristics such as load, speed, wagons structural stiffness, wheel conditions etc., are factors that add complexity to understand the behavior of materials under train traffic, but have great influence in track components maintenance.

In order to understand the phenomenon and the main factors that influence conventional frog's lifetime, the following items are presented.

A. *Load Effect*

The vehicle load influences directly on vertical force, being more evident during traffic over frog region. According to Stone *et al* (2001), the load impact can be severe, reaching 200% of axle load, when under wheels with calluses or elliptical wheels effects. However, Wiest *et al* (2008) present contact forces between wheel and frog reaching values of two or four times wheel static load, reaching five times in practice, depending on rail surface and rolling stock conditions.

B. *Train Speed*

Herian and Aniołek (2011) measured vertical forces, acting simultaneously on two wheels over a turnout, at speeds between 20 km / h and 80 km / h. Vertical forces increase as higher is the speed and the mass of rail vehicle, while horizontal force does not seem to be influenced by speed. Thus, the results obtained from numerical simulations confirm the presence of high vertical load values acting on turnout components, in particular at frog.

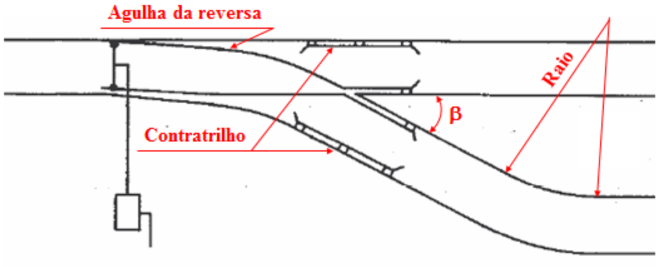
C. *Geometry*

The geometry related to a frog is quite a complex subject, due to interfaces that it makes with several areas, such rolling stock, switch machine and also construction design and maintenance tolerances. So this item it will be restricted the factors that influence frog lifetime: its design and maintenance tolerances.

1) Load Effect

According to Diaz-de-Villegas and Bugarín (1995), a vehicle on track generates lateral force when travelling through a curve. This force determines wheel and rail lifetime and also can be observed when the vehicle takes diverging direction in a turnout. Usually, this route is devoid of transition curve, causing an abrupt direction change. Continuing the route, a little before reaching frog point, wheelsets are led by a guard rail in order to run in proper position during passage through the frog.

Thus, the larger the frog opening, shown in Fig 7 as "β", the greater is the discharge of kinetic energy over switch and guard rail in diverging rout. This fact is further compounded when one considers the absence of proper elevation in this route, causing additional transverse accelerations.



Agulha reversa = diverging directon switch
Contratrilho = guardrail
Raio = radius

Fig. 7. Frog geometry. Source: adapted from Brina (1988)

Muller *et al* (2013) cited an experiment conducted in Sweden in a #15 turnout with 760m radius, on May 2006. In this occasion, wheel-rail lateral and vertical contact forces were measured with strain gages fixed in wheelset. The sampling frequency of contact force measurements was 9.6 kHz, and measured force signals are processed by low pass filter with a cutoff frequency of 1 kHz. The measurements were done in 25 axle tons wagons passing through the turnout main and diverging directions, at facing and trailing routes, at speeds of 10, 40, 60 80 and 100 km / h.

For all routes and traffic directions, there is an increase in maximum contact force, related to speed increase. However the increase of impact force was considered higher for diverging direction, when compared to main direction, due to the route curvature. Straight ahead, the contact force is increased by about 15% when speed is increased from 10km / h to 80km / h; in diverging direction case, the increase was about 40%.

Thus, as frog number represent a curve to be held without transition in the diverging direction, higher efforts occurs when compared to the loads shown in main direction. These loads become greater as the curve is steepest, i.e., the bigger is the frog number.

2) Maintenance Tolerances

Simple maintenance practices like setting safety tolerances also avoid unnecessary shocks and help in turnout maintenance. According to Vieira *et al* (2013), safety maintenance tolerances are geometric dimensions that ensure operational commitment to safety among rolling stock and permanent way systems, allowing free passage of wheel sets over the turnout. It should take into consideration the gauges of both systems, considering maximum and minimum values, according to ABNT NBR 15810/2010.

D. *Surface Interferences*

Permanent way and wheel components lifetime is closely linked to smoothness of train passage. For this reason, the main interference factors will be addressed in this section.

When wheels pass over a conventional frog region there is a bearing surface discontinuity between wing and frog point. Vertical force becomes more evident due to lack of support of wheels when passing through this region because disturbances are produced in the pathway, leading to high dynamic loads. To minimize the effects of these disorders, conventional frog design includes a ramp at the frog point.

After the ramp end, when the point level is equal to the wing, there is a region exposed to higher impacts, due to the concentration of dynamic and cyclic loads in a small area. According to Dahlberg (2006), considering the dynamic effect, this transition often induces a considerable vertical load impact in both wheel and frog.

It is understood so that wheels shock against the frog, after the discontinuity between its wing and point generates considerable disruption, raising vertical force to considerable values.

1) *Frog Damage*

According Herian and Aniolek (2011), wear formation on frog region is a result of temporary dynamic load acting on a small bearing surface at this location. This leads to an intensive wear and consequent material flow as a result of wheels shock, and also to rapid material destruction.

Wiest *et al* (2008) present an elastic-plastic finite-dimensional elements model between wheel and frog. In this work, several simulations were carried. When wheels pass over the wing and the ramp, they collide against the frog point and cause material plasticization. Damage is produced only if there is plastic deformation, since this is often followed by loss of material cohesion, as illustrated in FIG. 4.10 (a). Herian and Aniolek (2011) explain that this is due to high contact force, often reaching values which numerically exceed its yield and tensile strength. Thus, subsurface cracks are formed and propagated, leading to material failure.

Pletz *et al* (2012) point out that wheels contact pressure and microslip caused from the change in angular speed are important variables for frog surface damage. Microslip in combination with high contact forces can lead to wear and surface defects resulting from contact fatigue.

Beside defects formation and frog wear, impact load increases over specific operating conditions, such as frog point height reduction in relation to the wings. This variation, which can be several millimeters, plus the speed at this point can lead to higher accelerations over one hundred times gravity force (DAHLBERG, 2006).

Thus, it sets up a vicious circle where wheel shock against frog point increases damage in this region, and this damage, in turn, lead to increased impact loading.

2) *Transition between different materials*

According to Dahlberg (2006), there is yet another source of interference on bearing surface in conventional frog heel region. As previously mentioned, conventional frog is formed by core manganese, screwed to carbon steel rails. In frog heel there is a junction point between manganese and carbon steel, illustrated by Fig 8. Due to joint geometry, core manganese steel stiffness and mass, there is a sudden change in the bearing surface, inducing transient and high frequency vibrations, both on track and on rolling stock, contributing to make impact force significant.

In Fig 8 (b) it can be noted a light step in the transition region, between manganese steel and carbon steel.

Fig. 8. (a) Turnout overview, highlighting the heel; (b) transition between manganese and carbon steel

The transition between different materials, the difference between materials stiffness and hardness may generate steps over time, leading to high forces levels.

3) *Grinding Practices*

According to AREMA (2003), grinding is a maintenance practice that increases rail lifetime and contributes to track structure stiffness maintenance.

In case of corrective maintenance, it removes bearing surface imperfections, rectifying existing surface defects. In Fig. 9 (a) it is possible to identify flaw formation on frog wings, and in Fig. 9 (b) the treatment of such defects by manual grinding.

Preventive grinding, by contrast, may act by preventing the appearance of surface defects in order to guide wheels with greater smoothness. In both cases, correct profile by grinding should be studied and applied regularly.

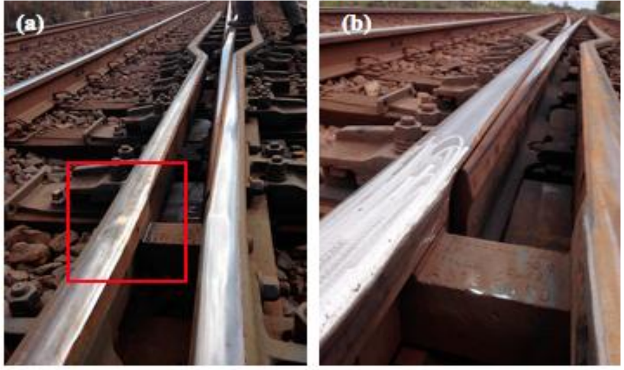


Fig. 9. (a) Superficial defect on movable point frog wing; (b) Manual grinding performed to correct superficial defect

Wan *et al* (2013) experimentally examined dynamic interaction between vehicles and frog through an instrumented frog. It can be seen that before grinding, results are considerably different from those obtained after grinding. Accelerations distributions along frog area, before and after grinding, were measured, and it was possible to identify that frog area is most likely to fatigue damage. Acceleration concentration at high amplitudes can be determined at distances between 0.50 and 0.60 m from the frog point, before grinding. Smaller acceleration values and small fatigued area are distributed over a larger area between 0.40 and 0.60 m from frog point, after grinding.

Thus, grinding practice can assist to reduce and better distribute forces along the treated surface, and also to remove surface defects by smoothing the train passage.

E. *Track Stiffness*

The track structure stiffness can influence shock magnitude and wear increase. According Puzavac (2012), the most common definition used for track stiffness is the ratio between vertical load and road deflection at any given moment. However, the most current definition also includes superstructure inelastic and non-linear behavior and its elements, as well as the difference between stiffness under static and dynamic loadings.

To determine track stiffness is necessary to determine the stiffness of each component of railway infrastructure. Berggren (2009) proposes a model in which, each component is connected via a linear elastic spring to different stiffnesses. However, most of components can introduce non-linear behavior, and vary with temperature, loading material, rolling stock conditions etc., which in turn also may vary along the track. Furthermore, trains passage cause high vibration levels, which may increase over time due to its components degradation.

When a train passes over a turnout, wheels are subjected to higher levels of vibration, reaching values of up to twice the level found in tangent track, according to Muller et al (2013).

Dahlberg (2010) explains that this occurs because of irregularities in frog region: sudden changes in vertical and lateral alignments cause variations in wheel-rail interaction forces, inducing high frequency vibrations. These vibrations influence, in turn, to increase rail deflection and its components deterioration, especially ballast permanent deformation, leading to irregular deflections on the railway.

In turn, superstructure also suffers from stiffness variation effects: track components degradation rate tend to increase, due to track geometry deterioration, to rail and sleepers fatigue and/or to uneven wheel-rail contact.

F. *Wheel Conditions*

Another important influencing factor is wheels: worn wheels with arbitrary shapes, passing over different contact positions change plastic deformation behavior considerably, and may cause high magnitude of forces which, besides causing more wear and fatigue in components, increase the risk of derailment, requiring operation at reduced speed. Turnouts are designed to result in a smooth transition of new wheels on the discontinuities. However, if a worn wheel passes over a frog, wheel transition is not so soft and then an impact is produced at frog point and wings. Similar features can be observed for new wheels passing over a worn frog, or when the two contact parts show abrasion. The change in the running surface between frog point and wing results in impact (WIEST et al, 2008). Leong (2007) studies in Australian heavy haul railways operating 106 tons cars in narrow gauge, showed the speed influence in track impact forces.

Simulations were performed with DTRACK software, considering the following parameters:

- Speed from 20 km / h to 120 km / h (higher speeds were considered unlikely to heavy haul railways), with 20km / h increments;
- Wheel defects:
  - ○ 5 mm chord and 0.0068mm depth;
  - ○ 25 mm chord and 0.1708mm depth;
  - ○ 50 mm chord and 0.6836mm depth;
- Constant suspension.

This experiment shows that for empty wagons, small wheels defects, with chords equal to 5 mm, impact forces do not significantly respond to changes in speed. For medium and large defects, with 25 mm and 50 mm chords respectively, impact forces still suffer slight drop at speeds greater than 60 km / h.

For loaded wagons, the opposite is observed in full wagons: impact force increases significantly due to increased speed for wheels with medium and large defects, 25 mm and 50 mm chords, respectively. Thus, Tunna (1998) *apud* Leong (2007) concludes that the increase in speed does not necessarily lead to increased impact force, but speed associated with increased load and larger defects can lead to impact values higher than 500 kN.

Thus, from the items discussed above, it was possible to have an overview about the main factors that contribute to frog degradation. Those are enumerated as relevant:

- Frog type (conventional, movable point frog, explosion hardened frog with low impact heel etc.);
- Frog geometry;
- Frog condition;
- Ballast condition;
- Sleeper type;
- Fastening type;
- Traffic direction over the frog (main or diverging);
- Load ;
- Train speed;
- Train composition;
- Wheels conditions.

IV. EXPERIMENTAL ANALYSIS

Due to the large number of variables that can influence impact force measurement *in loco*, parameters were set to be analyzed, to ensure fair comparison between frog types analyzed.

TABLE II
PARAMETERS FOR IN LOCO MEASUREMENT

Parameter	Description
Frog type	Conventional frog Explosion hardened frog, with low impact heel Movable point frog
Frog geometry	#20
Frog condition	New frogs, with less than 9 months on track
Permanent way condition	Good conditions/ New/ Renewed
Traffic direction	Main
Train speed	~ 60km/h
Train composition	GDE iron ore wagon, 27.5 axle ton
Wheel condition	Normal conditions, with new and worn wheels

The equipment was calibrated in laboratory by applying static load and comparing results with measured values. However, since it was not possible to perform field calibration, for reference, vertical forces on rails, where there is no wheels impact, were researched. There were taken in account some influence factors presented in Chapter 3 as axle load and speed, similar to those adopted in Table 2.

Leong (2007) showed the value of 87.57 kN under 25 axle ton railway at 83.1km / h, measured in Lara test site by Institute of Railway Technologies, Australia. Dahlberg (2010) found values close to 100 kN on measurements in 22 axle ton wagons traveling at 70 km / h. Also, Herian and Aniolek (2011) found values close to 93 kN, in 26.5 axle ton wagons at 60km / h.

For comparative purposes, reference values were investigated for impact force in frogs, whereas speed and axle loads, geometry alligator are similar to those indicated in Table 2.

Davis *et al* (2003) conducted measurements on site in a number 20 geometry conventional frog, installed in FAST, United States, subject to 39 axle tons load. Measurements were performed until the accumulated gross tonnage resulted 230. From these, at 60 km / h speed were found values about 250 kN. Herian and Aniolek (2011) presented 170 kN in a number 18 geometry frog, exposed to an axle load of 26.5 tons at 60 km / h. Wan et al (201-) conducted measurements in frogs with more aggressive geometry, number 15, but exposed to a lower axle load (19 tons), at 72 km / h and obtained values close to 230 kN.

Micron Optics sm130 fiber glass strain gages were bonded in rails web, forming 45º angle to the neutral line, facing sleeper side, as shown in Fig.10. In this arrangement, strain gages will measure specific deformations corresponding to pure shear stress, from which it is possible to calculate shear in this section. Enlight software, version 1.7.2., was used to analyze the data.

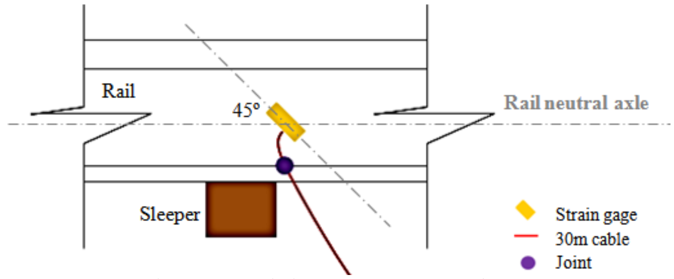


Fig. 10. Lateral view – measurement scheme.

Data processing results provides information on strain values over time, as represented by Fig.11. This graph was schematically enlarged to identify wheels passage over the analyzed section: each of sudden deformation variation in y-axis represents the passage of a wheel.

Furthermore, it is possible to identify two successive peaks representing wheelset passage and the difference between peaks represented by Wheels 2 and 3 identifies the wagon body passing over the monitored section.

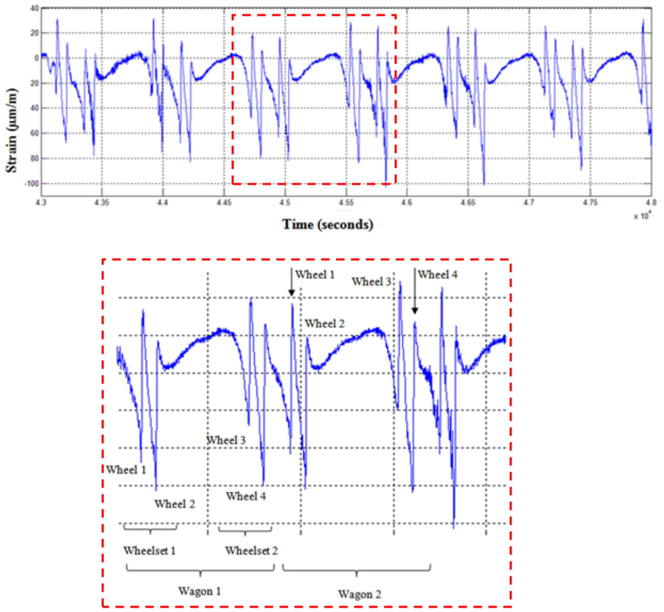


Fig. 11. Impact force measurement in a rail during train passage - very wheel passage over the monitored section generate a peak in the graphic, each pair of wheels represents a wheelset and two wheelsets compose a wagon in a impact force measurement graphic.

After data process, to calculate the maximum impact force measured in the monitored section, the following data are needed:

- Maximum measured strain (ε) - m / m;
- Moment of Inertia on X axis (I) - mm4;
- Center of gravity width section (b) - mm;
- Elasticity modulus (E) - MPa;

In conventional and low impact frogs it is necessary to perform homogenization, as these are composed by outside rails in carbon steel and manganese steel core.

$$E=E_1/E_2 \tag{1}$$

Where:

E_1 = Manganese steel elasticity module

E_2 = Carbon steel elasticity module

- Area static moment (Q) - mm³.

From Eq.2 it is possible to calculate shear force (V) - N:

$$V=(I.b.E.\varepsilon)/\ (Q.(1+\nu)) \tag{2}$$

Where:

ν = Poisson coefficient

The shear force is statically equivalent to the force applied across the bar. Thus the inferred shear value can be admitted equivalent to "impact force" on the rail or turnout section.

The inferred force values, considering the average values among peaks observed in field measurements, according to different frog types, were collected in two days, in seven events: three loaded trains were monitored as they passed through a conventional frog; two loaded trains were observed as they passed over the explosion hardened frog with low impact heel and other two trains were monitored during its passage over a movable point frog, as Table III presents.

TAB. III
MEASUREMENT RESULTS

Frog Type	**Measurement**	**Impact forces - average values (kN)**		
		Point	**Heel**	**Rail**
Conventional Frog	Date: 06/10/15 Time: 14:47:44	223.28	928.70	72.51
	Date: 06/10/15 Time: 15:19:56			
	Date: 07/10/15 Time: 09:38:24			
Explosion hardened frog with low impact heel	Date: 07/10/15 Time: 12:20:47	287.56	320.54	
	Date: 07/10/15 Time: 13:02:58			
Movable point frog	Date: 06/10/15 Time: 10:04:03	120.86	N/A	
	Date: 06/10/15 Time: 11:59:47			

These events were monitored by the author, according to the procedure described above, attaching strain gages to every measurement point, and analyzing data with Enlight software. Calculations after this point were made considering the geometry of those different sections monitored, and also every material elasticity module.

Taking into account the various parameters influencing the comparative analysis of the values obtained with literature values given in section IV, it is concluded that the measurements are within the expected values.

In this initial analysis, it was possible to conclude that low impact heel frog is subjected to loads 3 times lower, approximately, if compared to conventional frog. Movable point frog presented impact values of approximately 4 times lower when compared to conventional frog, having impact force close to the values measured on a rail, in which impact does not occur.

V. CONCLUSION

According to the results presented, there are many factors in a railway that can influence track components lifetime. Although maintenance practices such as grinding, ballast tamping, track geometry correction to keep safety tolerances etc are important to prevent higher impact forces, new developments in frog design can minimize effectively impact forces, providing longer lifetime for turnout and its components.

Also, it is recommended that next studies continue monitoring different types of frogs along its life in service, measuring wear and comparing it to impact forces. Researches about frog structural analysis, comparing scenarios in which variables like ballast, sleeper, wagon types and wheel conditions are related to impact forces in turnouts are highly recommendable.

REFERENCES

[1] American Railway Engineering and Maintenance of Way Association (AREMA). "Practical guide to railway engineering". 2nd Edition - AREMA. United States. 2003.

[2] American Railway Engineering and Maintenance of Way Association (AREMA). 2008 "Portfolio of trackwork plans AREMA". Compiled by Committee 5 – Track. Companion Volume to AREMA manual for Railway Engineering. United States. 2008.

[3] D.R. Baten, C.L. Goodman, J.W, Winger. "Manufacturing, reclamation, and explosive depth hardening of rail-bound and self-guarded manganese frog on the chessie system." Transportation Research Record 1071. 1986.

[4] E. Berggren. "Railway Track Stiffness - Dynamic Measurements and Evaluation for Efficient Maintenance." ISSN 1651-7660. ISBN 978-91-7415-293-7. Estocolmo, 2009.

[5] H.L.Brina. "Estradas de Ferro. " Volume 1 - Via Permanente". 2ª Edição. ISBN: 85-216-0011-9. Editora UFMG. Belo Horizonte, Brazil. 1998.

[6] Burlington Northern Santa Fe (BNSF) Railway. "Engineering instructions – Cap 9 Turnouts, OTM, and railroad crossings." 2011.

[7] T. Dahlberg. "Railway Track Stiffness Variations – Consequences and Countermeasures". February, 2010.

[8] J.M.G. Díaz-De-Villegas; M.R. Bugarín. "Desvíos ferroviários." Ingeniería Cántabra S. A. Madrid, Espanha. 1995.

[9] S. L. Guo, D.Y.Sun, F.C. Zhang. X.Y.Feng, L.H.Qian. "Damage of a Hadfield steel crossing due to wheel rolling impact passages." Wear 305 (2013) 267-273. China. 2013.

[10] Hardface Technologyes. [Online] Avaiable: http://www.hardface.com.au/.

[11] J. Herian. K. Aniołek. "Modeling of structure and properties of pearlitic steel and abrasive wear of the turnout frog in the cyclic loading conditions." Journal of achievements in materials and manufacturing engineering. Katowice, Polônia. November, 2011.

[12] R. Koehler. "Manual técnico de via permanente – Capítulo 3 - Aparelho de mudança de via." Departamento de Engenharia e Desenvolvimento Logístico – VALE. Belo Horizonte, Brazil. 2013.

[13] J. Leong. "Development of a limit state design methodology for a railway track." November, 2007.

[14] R. Muller, B. Nelain, J. Nielsen, S. Said, W. Rücker, E. Bongini. "Description of the vibration generation mechanism of turnouts and the development of cost effective mitigation measures." February, 2013.

[15] M. Pletz, W. Daves, H.Ossberger. "A wheelset/ crossing model regarding impact, sliding and deformation - Explicit finite element approach". Wear 294–295 (2012) 446–456. Áustria. 2012.

[16] L. Puzavac, Z. Popović, L. Lazarević. "Influence of track stiffness on track behavior under vertical load." Promet – Traffic & Transportation, Vol. 24, No. 5, 405-412. Sérvia. October, 2012.

[17] J. Sadeghi, B. Akbari. "Field investigation on effects of railway track geometric parameters on rail wear." Journal of Zhejiang University. 2006 7(11): 1846-1855p. Iran, Tehran. July, 2006.

[18] X. Shu, D. Davis, M. Akhtar. "Next generation foundations for special trackwork – Phase I." Federal Railroad Administration. U. S. Department of Transportation. February, 2013.

[19] R.A. Smith. "Railways: Structural Integrity, Past, Present, and Future." Volume 1; (ISBN: 0-08-044157-2); pp. 49–60. Comprehensive Structural Integrity. Elsevier. 2003.

[20] D. Stone, C. Lonsdale, S. Kalay. "Effect of wheel impact loading on shattered rims" in *Proceedings of the 13th International Wheelset Congress*. Italy. 2001.

[21] L. Xin, V.L.Markine, I.L. Shevtsov. "Dynamic interaction between the wheel and crossing nose." Proceedings of the Fourteenth International Conference on Civil, Structural and Environmental Engineering Computing. Paper 22. Civil-Comp Press. Holanda. 2013.

[22] C.Wan, V.L. Markine, I.Y Shevtsov, R.P.B.J. Dollevoet. "Improvement of Train-Track Interaction on Turnouts by Optimizing the Shape of Crossing Nose." Delft University of Technology. Holanda. 2013.

[23] M. Wiest, W. Daves, F.D. Fischer, H. Ossberger. "Deformation and damage of a crossing nose due to wheel passage." Journal Science Direct – Wear 265 (2008) 1431-1438p. Austria Leoben and Zeltweg. May, 2008.

[24] Wikipedia. [Online] Avaiable: http://en.wikipedia.org/wiki/Railroad_switch. Accessed 22/11/2014 at 17:50h.

Simone Lie Issomura was born in São Paulo city, Brazil, in 1981. She received the B.S. degree in civil engineering from State University of Campinas (UNICAMP), Campinas, São Paulo, Brazil, in 2004; quality and value engineering specialization degree from São Paulo University (USP), São Paulo, São Paulo, Brazil, in 2007; railway engineering specialization degree from Minas Gerais Pontifical Catholic University (PUC Minas), Belo Horizonte, Minas Gerais, Brazil, in 2008 and MBA degree from Getúlio Vargas Foundation (FGV), São Paulo, São Paulo, Brazil, in 2009. She is currently working pursuing the M.S. degree in transportation engineering at Military Institute of Engineering (IME), Rio de Janeiro, Rio de Janeiro, Brazil.

From 2005 to 2007 she has worked as Civil Engineer at São Paulo Subway Company and since 2008 she is working as Permanent Way Engineer at a Brazilian mining company in Vitoria, Espírito Santo, Brazil.

Cynthia Vargas Cuchava Rocha, was born in Itajaí city, Brazil in 1991. Graduated in Civil Engineering from the University of Vale do Itajaí - Santa Catarina state, Brazil (2013) and Master in Transportation Engineering from IME (2016). She has experience in civil construction through development and execution of projects (architectural, sanitary, electrical, structural) works monitoring of Compliance Projects Monitoring the disciplines: sociology and urban planning, architecture, design I and II, and transport engineering area has experience in urban mobility for freight transport.

Swellen Mendonça Pessanha was born in Campos dos Goytacazes city, RJ, Brazil, in 1989. Graduated in Architecture and Urbanism from Federal Fluminense Institute (IFF) in 2012. Currently, she is pursuing the M.S. degree in Transportation Engineering at Military Institute of Engineering (IME), Rio de Janeiro, Rio de Janeiro, Brazil.

She has experience in Architecture, Urban Planning, Construction Technologies and Transportation Engineering, mainly in demand´s behavior, Transferred Demand, Passenger Trains systems and Stated and Revealed Preference Survey.

Luiz Antônio Silveira Lopes was born in São Leopoldo, Rio Grande do Sul, Brazil. He graduated in fortification and construction engineering at Military Institute of Engineering (IME), Rio de Janeiro, Brazil, in 1982; he received the master degree in transportation engineering from (IME), Brazil, in 1987; Ph.D. degree in transportation engineering from Rio de Janeiro Federal University (UFRJ), Rio de Janeiro, Brazil, in 1995 and PostDoc from New Castle University, England, in 2013.

He has been working as a Professor at IME since 2002. His research interests include transportation engineering, specially railway and highway project, transportation system optimization, logistics and transportation geographic information system.

Luiz Augusto Cavalcante Moniz de Aragão Filho was born in Rio de Janeiro, Rio de Janeiro, Brazil. He graduated in fortification and construction engineering at Military Institute of Engineering (IME), Rio de Janeiro, Brazil, in 1995; he received the master and Ph.D. degrees in civil engineering from Rio de Janeiro Federal University (UFRJ), Rio de Janeiro, Brazil in 2000 and 2008, respectively.

He has been working as a Professor at IME since 2000. His research interests include: structural identification, modal analysis, structures dynamics, innovation and environment management.