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STUDY ON THE RAILWAY TURNOUT CROSSING PERFORMANCE DURING A TRAIN WHEEL-SET PASSAGE

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الملخص العربى :

تحاويل السكك الحديدية هامة لأنها تقدم مرونة لنظام التشغيل، وبقدر أهميتها بقدر حساسيتها، حيث أن أي إضطراب فى التحويلة يؤثر على إنتظام التشغيل، من وجهة نظر نظام المسار، نظرا للتأثير الكبير الواقع على التحاويل فإنه من الممكن حدوث تلف كبير فى مكونات التحويلة، العديد من العوامل قد تحكم هذا التأثير مثل سرعة مسير القطارات، إتجاه المسير، الأحمال، العوامل الهندسية المتعلقة بالتصميم الهندسى للعجلة وأجزاء التحاويل، نظام التثبيت، فلنكات التحاويل، وتثبيت السكة على طبقة خرسانية أو بازلتية، إلخ.

فى هذه الورقة البحثية تم تنفيذ دراسات للتحقيق فى أداء تقاطع التحويلة, أولا : - تم تحليل سلوك تقاطع تحويلة بإستخدام نموذج ثلاثى الأبعاد بطريقة العناصر المحددة تم تطويره بإستخدام بيئة عمل أباكوس لمنطقة تقاطع تحويلة 1 : 8 مع الأخذ فى الإعتبار جميع عناصر نظام السكة مثل التقاطع، الفلنكات، والبازلت، وبخلاف النماذج الرقمية الموجودة حاليا فإن تأثير العجلة الخارجية تم أخذه فى الإعتبار من خلال نمذجة محور ذو عجلتين للقطار يمر بمنطقة تقاطع تحويلة بدون عمل أي إفتراضات للظروف الإبتدائية للعجلة الداخلية، بإستخدام هذا فإن سلوك العجلة يمكن أخذه فى الإعتبار ويمنحنا إجابات متعلقة بأداء التقاطع، ونتيجة لذلك فإن إستجابات الإجهادات تم الحصول عليها، ثم مراجعة/مناقشة تلك النتائج

الكلمات المفتاحية : التحليل الديناميكى للسكك الحديدية, أداء التحاويل, تقاطعات التحاويل, نموذج العناصر المحددة، التأثير المتبادل بين العجلة والسكة

Abstract

Railway turnouts are so important because they provide flexibility for the system traffic, as important as these turnouts are, as they are sensitive, because of any turnout disturbance affects the regularity of operation. In terms of track discipline, due to the high impact acting on the turnouts, Major damages can be happened to the turnout components, a lot of factors that may control this impact, such as the running speed of the trains, moving directions, loads, geometric factors related to the train wheels and the turnouts components geometric design, Fastening system, turnout sleepers, and bedding of track on a concrete layer or a ballast layer etc.

In this paper studies are performed to investigate the performance of the turnout crossing, First, the behavior is analyzed using a 3D finite elements model developed using ABAQUS environment for a 1:8 turnout crossing zone considering the whole track system such as frog, sleepers, and ballast, Unlike the existing numerical models the outer rail effect has been considered by modeling a wheel-set without making assumptions of the initial condition of the train wheel, by using this the behavior of the wheel can be considered and give us great answers regarding to the crossing performance. As a result, the stresses responses in crossing have been obtained, then reviewing/discussing the results.

Keywords—Railway dynamic analysis, Turnout performance, Turnout crossing, Finite elements modeling, Wheel-rail interaction

INTRODUCTION

Turnouts are the heart of recent Railway operation because of the flexibility to traffic given by them, by enabling routing trains onto tracks, the turnouts helped us to increase the capacity of railway by not making the track occupied by a single train for a single direction. There are a lot of types of turnouts to fit the various operation requirements. The common turnouts consist of a switch, closure rails, sleepers, crossing, fasters, etc. In the switch zone (Figure 1-a), the switch blades can move laterally into one of two directions to orient trains traffic towards a straight or a diverging route.

Figure (1-a). a switch panel

Figure (1-b). a crossing panel

The crossing is also known as frog or V-rail is the intersection point of two rails, this can be assembled by cutting and bent pieces of rail or can be a cast frog, the crossing zone rails consists of crossing nose and two wing rails in addition to stock rails and checkrails that make a lateral constraint on passing wheelsets. Unlike the regular track the rail profile is not constant along the crossing (Figure 1-b), In the crossing zone, The crossing nose which is a key component in the turnout that provides moving of train wheels on intersecting tracks, because of this hard mission it is subjected to major impacts. the crossing profile is gradually growing from its tip to a normal rail, In the facing direction the train first passes the wing rail before passing the crossing nose unlike the trailing direction the train first passes the crossing nose before passing the wing rail. The common turnout crossing zone system typically include: - crossing may fastened directly with the sleepers or indirectly using elastic fasteners which provides more flexibility to the system in addition to rails, sleepers, and check rail bedding on a ballast or a concrete layer.

the small cross-section area makes a challenge for the crossing to bear these major impacts. due to the geometrical discontinuity of rail in the crossing zone, major impact acting on the crossing nose. The major impact and non-constant crossing profile result in damage to the crossing which affects the health of the crossing by the time.

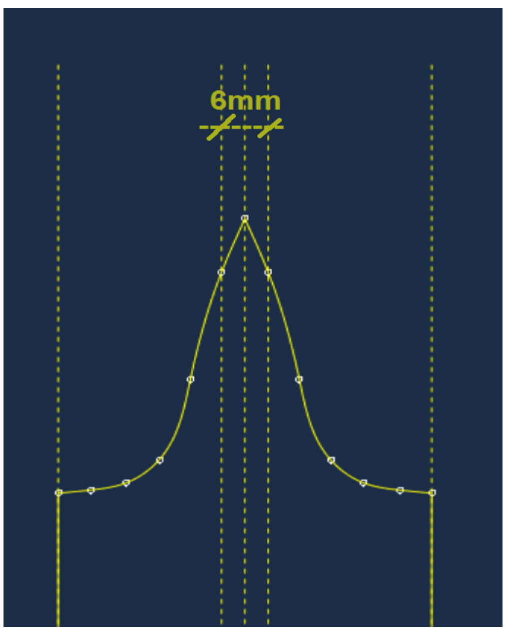


Figure (2-a)

The crossing nose cross-section at 48 mm of the crossing theoretical point (TP)

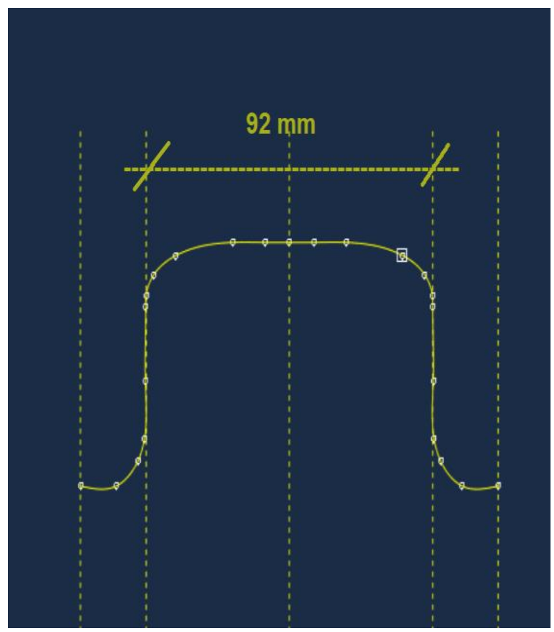


Figure (2-b)

The crossing nose cross-section at 1300 mm of the crossing TP

Figure 2. the cross-section of the crossing nose at different positions

A lot of parameters control the Turnouts design speed. Generally, for running on the divergent track, the smaller the turnout angle, the higher the running speed, for common recently turnouts the running speed on divergent direction varies from 25 km/h to130 km/h, based on the required speed the turnout with a particular angle is chosen.

In normal conditions, there is no significant effect on the crossing sleepers comparing to the crossing itself, however poor fixation of the crossing with the sleepers and lack of ballast or not well tamped sleepers may have a major impact on both of them, so that our study will focus on the crossing nose which has highest impacts at this system.

Comparing the maintenance cost of the switches and crossings with other track parts leading us to figure out that the high cost of switches and crossings (S&C) maintenance [1]. The rail profile discontinuity in crossing (in facing and trailing moves) causes major impact loads. rolling contact fatigue (RCF), Wear, plastic deformation. This high-cost indicators lead us to study their reasons and find solutions to reduce it.

To assess the turnout condition, regular measurements, and structural health monitoring are done in railway networks, such as geometry inspection of the turnouts [2]. Based on the measurements, it is observed that the repaired or renewed crossings during wheel passage often suffer from a large dynamic acceleration [3]. This led us to get a better understanding of the wheel– track interaction especially in the crossing zones, as well as finding out how to improve the crossing performance and increasing its service-time

In order to study the performance of track at crossing zone for presenting solutions to maintainers, we must understand first the behavior of crossing during wheel-set passage based on the numerical model obtained outputs which refers to the most critical locations at rail crossing. The method proposed her is developing a Numerical model which enables us to analyze the track performance in different configurations, the numerical model presented in this paper have been developed based on a turnout with crossing angle of 1:8. This method can be applied to other turnouts with different specs.

Literature Review: -

A lot of related researches have been performed to investigate the turnout crossings performance as follows: -

A. M. Wiest, E. Kassa, 2008, implemented a comparison between two linear-elastic material behavior wheel-rail contacts models (Hertz and the non-Hertzian method) using the computer software CONTACT, and investigated this with the ABAQUS, this study concluded that the calculated contact pressure using Hertz and CONTACT correlate with ABAQUS finite element method as long as the material is elastic with no plasticization [4].

B. Pletz. M, Daves. W, Ossberger. H, 2012, developed a finite elements model for a wheel passing a crossing, and a representation for a bogie, supports of crossing, and wheel-set using masses, springs, Dampers, and friction-generating elements, in this study the loading of crossing nose is estimated for different (axle load, train speed and direction, [5].

C. C. Wan, V.L. Markine, I.Y. Shevtsov, 2013, Developed a 2-D finite elements model for studying the interaction between train and railway turnout, in addition to a multi body system (MBS) model, and concluded that the 2D model is able to simulate train and turnout interaction instead of computing resources consuming simulations [6]
D. B.A. Palsson, 2015, has developed Methods for Optimization of railway turnouts and investigate how can we reduce the rail profile degradation by geometry optimization, a method for crossing geometry optimization has been introduced, and also optimization of crossing cross-section for minimum contact pressure [7].
E. L. Xin, V.L. Markine, 2017, Developed a 3D FEM to investigate the effect of different rail pads, travelling directions, friction coefficient of the turnout crossing, this behavior analysis accounts plasticity of rails, based on this model a fatigue analysis has been done through a parametric study to understand the relation between different track parameters and the service life of the crossing [8].
F. Wiedorn. J, Daves. W, Ossberger. U, Ossberger. H, Pletz. M, 2018, developed an explicit finite elements model to calculate the cyclic loading of a wheel on a crossing nose, and applying this model on a different manganese crossing materials [9].
G. Wei, Zilong, Núñez, Alfredo, Liu, Xiubo, 2020, have introduced a method for Evaluating the wheels and turnout crossings degradation by composing finite elements model of wheel rail interaction, and multi-criteria analysis in terms of yield behavior, then conducted a case study on 1:9 turnout under specific traffic condition [10].

Numerical Modeling

A numerical model of a turnout crossing zone developed to study the behavior of the crossing performance during the wheel-set passage. The model shown in (Figure 3) illustrates a piece of 1:8 turnout crossing. This turnout is a curved with a radius of 150 m. During this simulation, the inner wheel will travel from the wing rail to the crossing nose.

Unlike the existing models with only one wheel running over a crossing, wherein to study the effect of the outer rail assumptions for initial locations for the wheel-set will be done, in this model a wheel-set has been modeled to consider the wheel-set lateral movement with no need for these assumptions.

The crossing zone components modeled here are stock rail, wing rail, and crossing nose directly fastened on wooden sleepers with a spacing of 600 mm bed on a ballast layer with a thickness of 350 mm. All the components are modelled here using solid elements to enable us to investigate the stresses.

All parts modeled with element size 100 mm, due to computing resources limitations a fine mesh with elements size 20 mm is used in contact regions, this simulation is composed of 2 steps, step 1 for stabilizing the track/wheel-set system in 0.1 sec, step 2 starts after stabilization for running the wheel-set along 2.5 m of crossing in 0.1125 sec, hence the whole step times for the model is 0.1325 sec.

The penalty-based contact has been used because it takes into account the linear/non-linear material properties, geometry and deformations of contacted bodies [11]

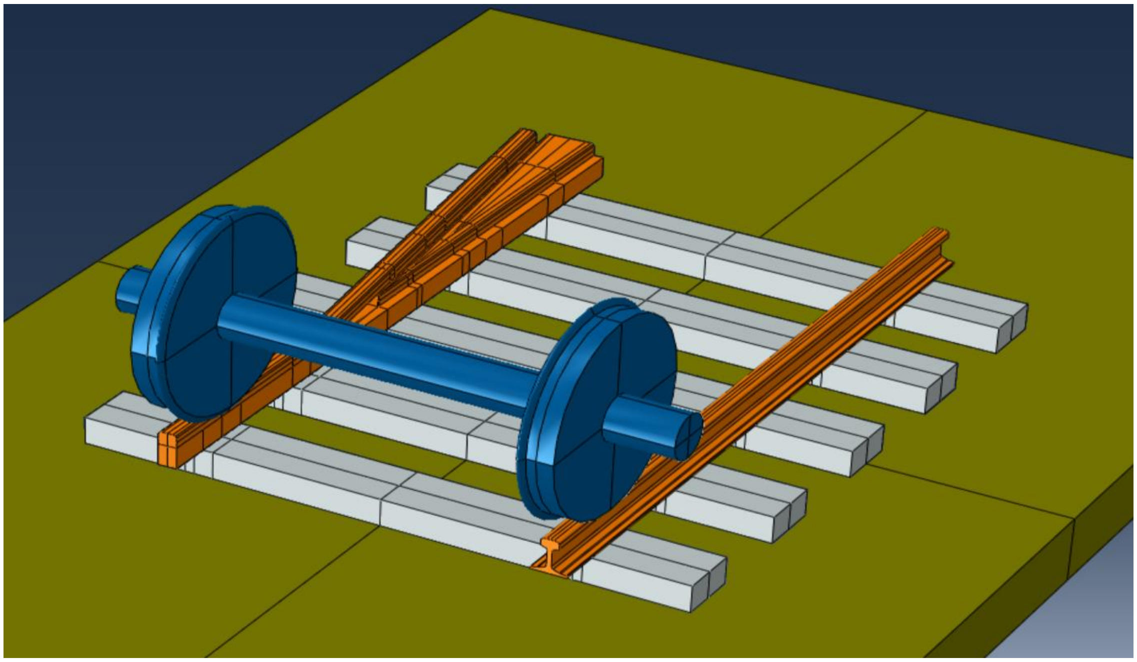


Figure 3- Finite Elements Model

The key properties of the Model

The material properties, and wheel-set passing configurations used in this numerical model are mentioned in Table 1.

Table 1. The key properties of the model

Part	Parameter	Unit	Value
Crossing [12]	Young's Modulus	Mpa	1.9E+5
	Poisson's ratio		0.3
	Density	Kg/m^3	7800
Rail [11]	Young's Modulus	Mpa	2E+5
	Poisson's ratio		0.3
	Density	Kg/m^3	7850
Wooden Sleeper [13]	Young's Modulus	Mpa	1.382E+4
	Poisson's ratio		0.3
	Density	Kg/m^3	690
Ballast [11]	Young's Modulus	Mpa	134
	Poisson's ratio		0.2
	Density	Kg/m^3	1800
Wheel-set [12]	Young's Modulus	Mpa	2.1E+5
	Poisson's ratio		0.3
	Density	7800	Kg/m^3
	Axle Load	Kn	150
	Velocity	80 km/hr.	
	Moving Directions	Facing	

Model Validation: -

For validating the model, the obtained values of the vertical acceleration of crossing nose during a wheel-set passage along 2.5 m at crossing facing direction in 0.1125 second (Figure 4) have been compared with the values in [11] and show a good correlation.

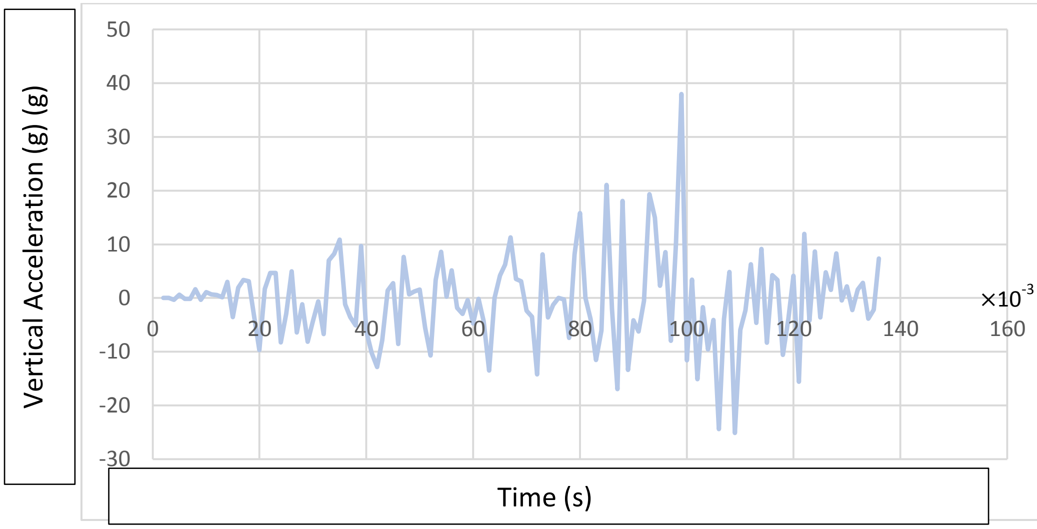


Figure 4. Vertical Acceleration Diagram

RESULTS AND DISCUSSION

This model capabilities enables us to obtain the dynamic Reponses of the track components, a few main responses can be used to assess the crossing performance, this research focuses on the main causes of rolling contact fatigue and/or wear like the von mises stresses, shear and pressure.

4.1 General Overview of the key crossing responses: -

To study how the turnout crossing performs during the wheel-set passage, Von- Mises stresses values are obtained, before and at the crossing nose, the location of (TP) considered as a reference point with location = 0, (Figure 5) illustrates VM-stresses at 1000 mm from each side of (TP) along the crossing: -

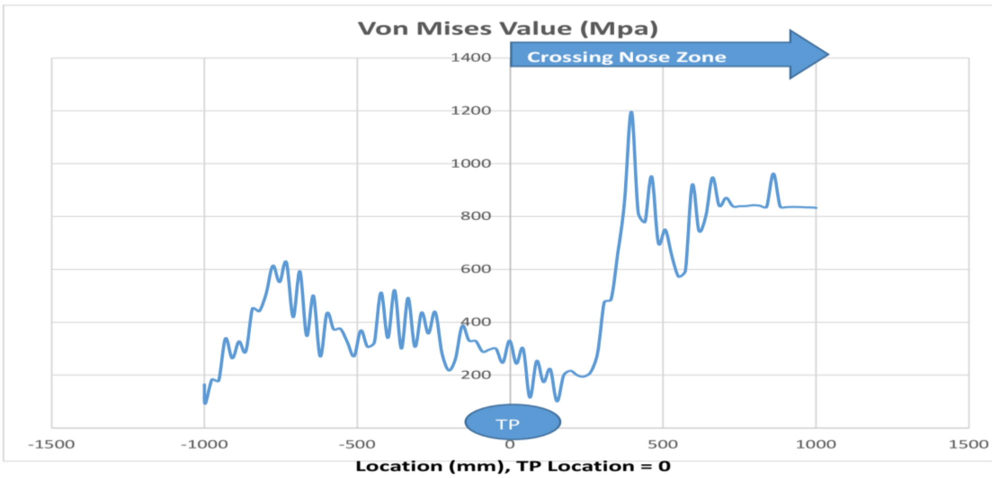
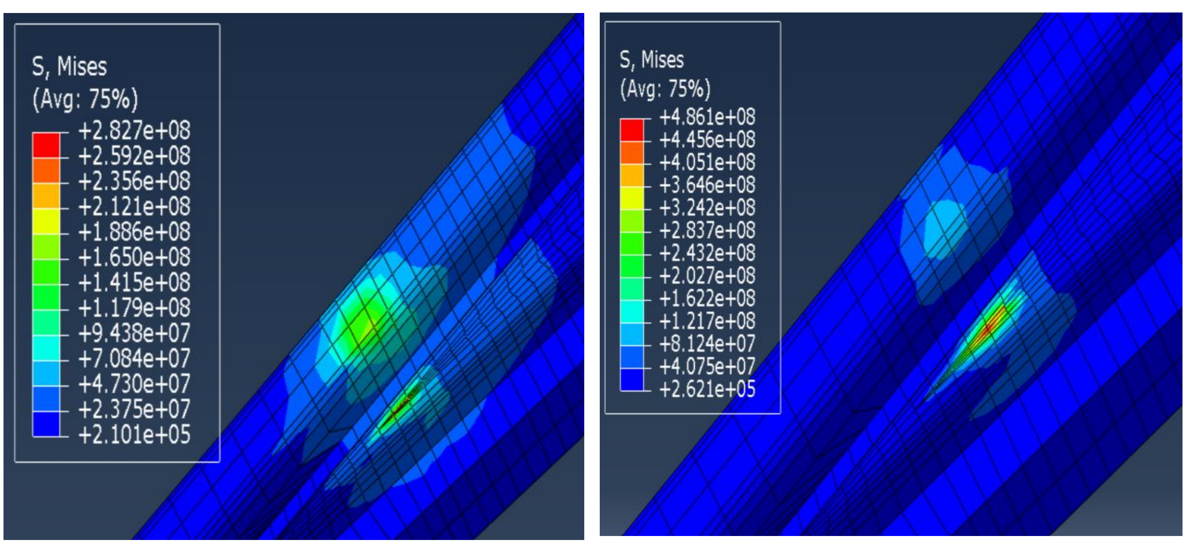


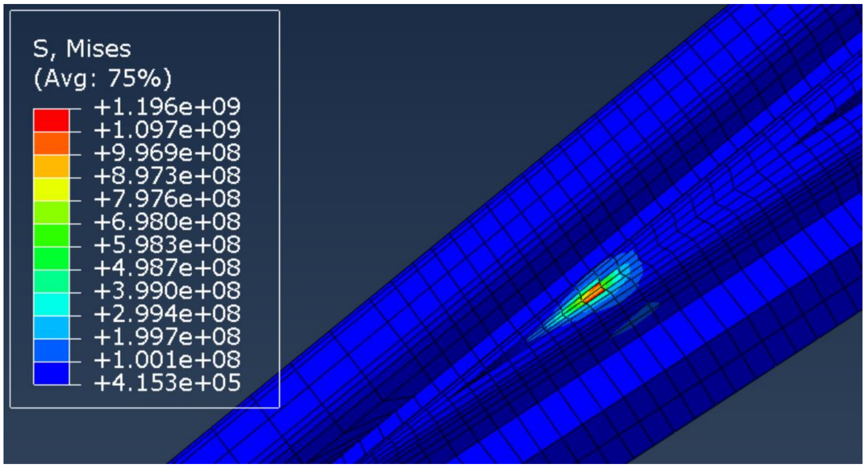
Figure 5. Von Mises stresses distribution along 2000 m of the crossing surface

4.2 Transition zone

At the transition zone the wheel leaves a rail to catch another rail, in case of running in facing direction inner wheel will travel from the wing rail to the crossing, Once the wheel catches the nose correctly it can safely pass to another track. this model helps us to investigate one of the most critical train running scenarios, (Figure 6) shows the transition zone from the wing rail to the crossing, we can observe that the stresses are increased at this stage. However, the highest stresses occur after the end position of the transition at below referred Point no.3 at 396 mm of TP (impact position). It leads us to understand that the transition and after transition zones are facing a large plastic deformation and damage [8]



a- Point no.1. at 280 mm of the TP **b- Point no.2. at 338 mm of the TP**

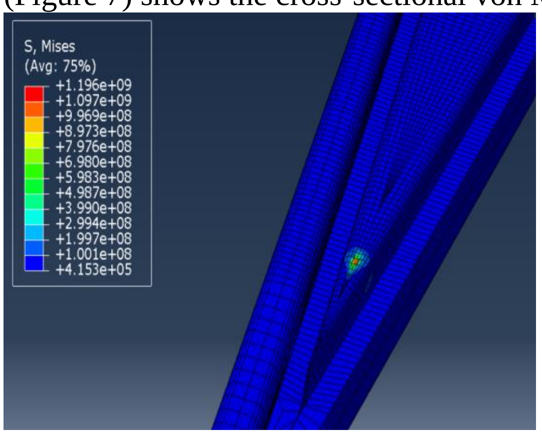


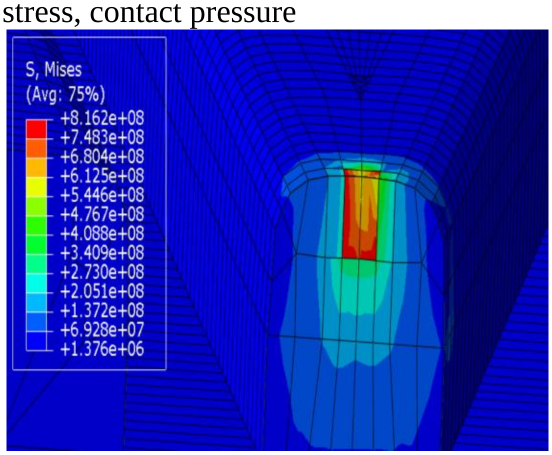
c- Point no.3. at 396 mm of the TP

Figure 6. Von Mises stresses along the transition zone, (a) Beginning of transition zone, (b) end of transition, (c) highest Von Mises stress

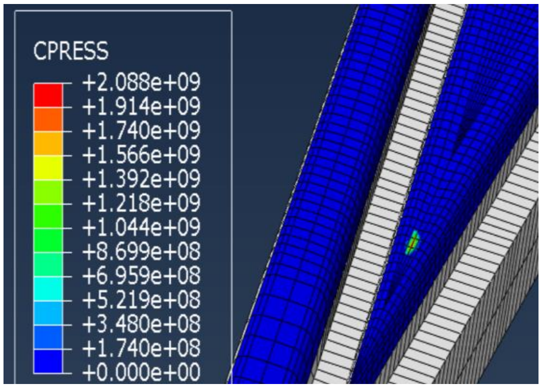
4.3 Stresses in the crossing

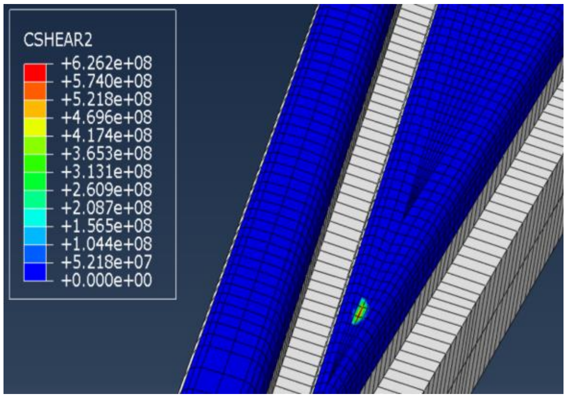
The position (Point no.3. at 396 mm of the TP) has the maximum von Mises stress value. (Figure 7) shows the cross-sectional von Mises stress, contact pressure





a **b**





c **d**

Figure 7. Stresses at the highest impact location, (a) Von Mises stress, (b) Von Mises Stress distribution, (c) Contact Pressure stress (d) Contact shear stress

CONCLUSIONS

A 3-D finite elements model for a wheel-set traveling on a 1:8 turnout crossing zone has been developed using ABAQUS to investigate the impact and stresses at rail crossing during a wheel-set passage, to rich this simulation experience the locations and values of some stress types have been mentioned such as Von Mises stresses, Contact pressure, and Shear stresses which refer to a rolling contact fatigue and/or wear at crossing, this model is generic, its capabilities do not stop at analyzing the rail crossing, but all the common turnout with different configurations and turnouts track components which have been modeled (figure 4), while a single wheel-set passing the turnouts crossing zone we could capture the rail frog performance at the most critical scenario of train rolling on the track, based on the results extracted from this model the service life-time of rail crossing analysis can be studied at further studies.

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