Optimizing Rail System Stability: Investigating Wear Patterns in Adjustable Steel Washer Equipped Base Plate Designs

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Abstract: The rail fastening system is a critical component ensuring the secure attachment of rails, thereby playing a pivotal role in track safety and the prevention of derailments. Key constituents, including rail clamps, tensioning bolts, washers, elastomer pads, and base plates, collectively contribute to the system's efficacy. In the context of Malaysia, the base plate design has remained unchanged for more than a decade. Notably, the adjustable washer, crucial for absorbing train vibrations, encounters compatibility issues with the teeth configuration of the base plate. Consequently, excessive rotational force is necessitated during installation, resulting in initial deformation and wear. This adversely affects the performance of both the base plate and the rail fastening system. To address these challenges, this research undertakes a comprehensive investigation and analysis aimed at enhancing the performance and design of the base plate and its associated components. The outcomes reveal a redesigned base plate capable of reducing stress on the tooth structure by an impressive 69.4%.

Keywords: Rail fastening system; Baseplates; ANSYS; Simulation; Washer

1. Introduction

Rail transport involves the movement of goods and passengers on wheels along a fixed path, commonly referred to as rails or tracks (Nikitin & Strepetov, 2020; Ferdous et al., 2020). Unlike conventional vehicles on open flat roads, rail vehicles are guided and directed by the track they run on. The railway track consists of essential components such as steel rails, sleepers (or ties), and sometimes ballast or concrete flooring (Jayasuriya et al., 2019; Zulkifli et al., 2018). The part of the train that makes contact with the rails is a specially designed metal wheel capable of withstanding high heat and abrasion (Chiba et al., 2022; Seo et al., 2019). Trains typically comprise multiple cars, coupled together to form an extended train. The elongated structure of the train leads to cyclic loads on the steel rail, especially during turns and crossovers (Sobek et al., 2016; Patrascu et al., 2019).

The steel rail plays a crucial role in the railway system by not only guiding the trains but also preventing derailments. Thus, it must be securely anchored to the ground. A vital element in maintaining the safety and punctuality of the train is the rail fastening system, which includes components like rail clamps, tensioning bolts, washers, elastomer pads, and the base plate (Noor et al., 2020). The base plate, a key component, has maintained the same design and material in Malaysia for over a decade, lacking necessary improvements. An essential part ensuring the base plate effectively absorbs railway vibrations is the adjustable washer (Jönsson et al., 2016). However, the current design does not align with the tooth configuration of the base plate, compromising its intended function. Workers need to apply higher torque during installation, leading to initial deformation and wear on the adjustable washer. Investigations and analyses have been conducted to enhance the performance and design of the base plate and its components.

Base plates are utilized throughout the railway track, with various types serving distinct purposes depending on whether they are installed on straight paths, curves, or turnouts where trains switch tracks (Park et al., 2019). Before implementing an improved design of the adjustable washer, a detailed breakdown of the base plate is undertaken to understand the vital role each part plays in ensuring the rail fastening system functions seamlessly without causing accidents. Additionally, conditions faced by the base plate are thoroughly examined and investigated.

2. Methodology

This section is dedicated to the design and analysis of the adjustable washer for the base plate. The existing design of the adjustable washer has remained unchanged for approximately 10 years, and its current configuration does not seamlessly integrate with the base plate. This suggests potential errors in both the design and manufacturing processes. The current design features a sharper and smaller tooth contact surface, leading to challenges in maintenance. Workers must use additional tools to secure the washer while torquing down the bolt, requiring a larger torque to prevent the base plate from slipping during train passage. Over-tightening may occur, causing initial deformation that adversely affects the original geometry of both the washer and the base plate securing hole, ultimately impacting overall performance.

In Figure 1, the highlighted red square represents a critical area on the base plate, subjected to focus testing. Two such areas exist on each base plate diagonally, playing a pivotal role in anchoring the base plate to the sleepers or crossties of the railway track. Moreover, these areas prevent the base plate and rail from sliding during trains' traversal of curved paths.

Figure 1. Base plate

Given the inadequacies of the current design in fitting the base plate, a revised design primarily aims to optimize performance. The tooth of the adjustable washer is redesigned to enhance the surface contact with the base plate's tooth. This increased contact surface allows the washer to securely hold the base plate in place, ensuring optimal performance during damping work. The old tooth design, with minimal contact surface, struggles to maintain the base plate in position for extended periods. While the adjustable washer undergoes redesign, the tooth design of the base plate remains unchanged due to time and cost constraints in revising the manufacturing process. Drawings provided are used to redrawn designs in SOLIDWORKS CAD software. Surprisingly, the CAD simulations reveal a significant gap (loose fit) in the current washer design when fitted into the securing hole, conflicting with previous findings. The loose fit washer's simulations aim to understand its potential impact on performance. This research will provide a comparative study of the current and revised designs using ANSYS simulation software, focusing on stress and possible deformation. The mesh control of the simulation is shown in Table 1.

Table 1. Mesh Control of The Simulations

Object Name	*Body Sizing*	*Patch Conforming Method*	*Body Sizing 2*
State		Fully Defined	
Scope			
Scoping Method		Geometry Selection	
Geometry		1 Body	
Definition			
Suppressed		No	
Type	Element Size		Element Size
Element Size	3. mm		3. mm
Method		Tetrahedrons	
Algorithm		Patch Conforming	
Element Midside Nodes		Use Global Setting	
Advanced			
Defeature Size	Default		Default
Behavior	Soft		Soft

Before simulations commence, calculations establish boundary conditions. Assuming a maximum super-elevation of 150mm and a train speed of 50km/h on a curved track, the curve radius is determined by the equation 1:

$$C = 11.85 \times \frac{v^2}{R} \quad \text{.............................. (equation 1)}$$

where C is the cant/super-elevation (*mm*)
v is the velocity/speed of the train (*km/h*)
R is the curve radius of the track (*m*)

These values, predetermined and regulated, interrelate to balance forces and ensure passenger comfort and safety. The study reinforces the importance of simulating real-world curved track conditions to comprehensively assess adjustable washer performance. The stresses and deformations of both the new and old designs are meticulously studied and simulated, aiming to demonstrate the superior performance of the new adjustable washer in handling stresses and minimizing deformations. The newly designed adjustable washer, depicted in Figure 2 (left), is 3D printed as a model to showcase its capacity to secure the base plate, handle increased stresses, and improve overall tooth contact for enhanced performance. The existing design only marginally accommodates the base plate; hence, a revised design is primarily focused on seamless integration, with an additional emphasis on optimizing performance. The tooth of the adjustable washer undergoes a redesign aimed at augmenting the surface contact between the washer's tooth and the base plate's tooth. This enhancement, resulting in a larger contact surface, enables the adjustable washer to effectively secure the base plate in position. Consequently, when the base plate is engaged in damping work, it can fully rely on the rubber component, fulfilling its primary role.

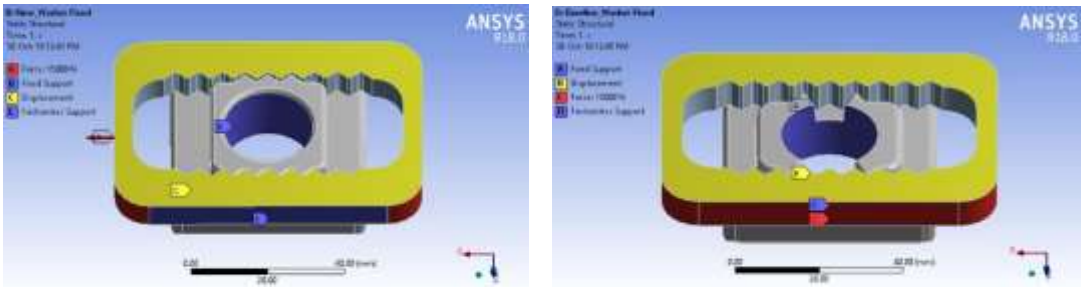
Figure 2. New (left) and old (right) design of adjustable washer.

Conversely, the outdated tooth design of the adjustable washer offers minimal contact surface with the securing hole's tooth on the base plate. This limitation prevents it from securely holding the base plate in place for extended periods compared to the revised tooth design. Optimal performance of the base plate is only achieved when securely positioned on the sleeper or concrete. Importantly, this project does not involve a revision of the tooth design of the base plate, as such an undertaking would demand extensive time and incur additional costs in revising the manufacturing process.

3. Result and Discussion

ANSYS is employed to simulate the subjects of this project, with materials selected accordingly: the adjustable washer is crafted from gray cast iron, and the base of the base plate is constructed from structural steel. The project encompasses two simulations: (1) simulating the new adjustable washer on the base plate and (2) simulating the old adjustable washer on the base plate. The chosen simulation type is static structural simulation, suitable for simulating static objects, as the washer and the base plate are assumed to be static. The movement of the base plate is deemed negligible due to its minimal motion when a train passes by. The contact regions between the base plate and the adjustable washer are set to "no separation" for both the flat face and the tooth contact region. This decision is rooted in the preload resulting from the pre-tensioning of the securing bolt during the base plate installation. However, in this simulation, preloading is excluded as it does not impact the horizontal movement under examination. The focus of these simulations is on the horizontal effect on the tooth of the base plate and washer. To ensure accurate results, the contact regions of the two bodies cannot separate throughout the simulation, mirroring the real-world scenario of the base plate and adjustable washer. Consequently, these regions are set to "no separation.".

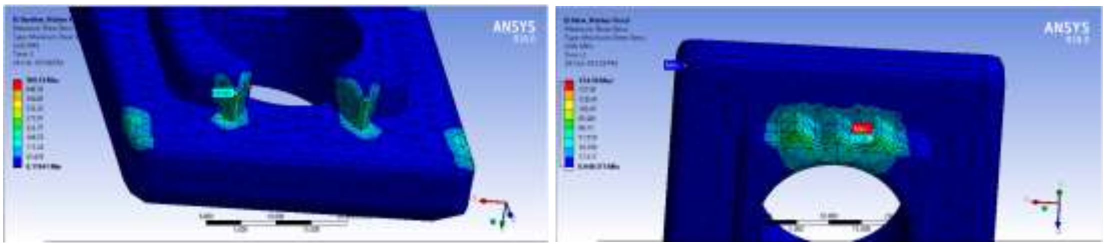
Furthermore, for both simulations, the meshing of the two bodies is appropriately configured to achieve more accurate results. The mesh method is set to tetrahedrons, with an element size of 3mm to ensure fine and even grains throughout both objects, contributing to optimal simulation results. Fixed support and other boundary conditions are set to mimic real-world situations, where the washer is secured by a bolt to the sleeper. Specifically, the center hole of the adjustable washer is set as a fixed support (labeled as B in Figure 4.3(a)) to prevent movement in all axes. Frictionless support (labeled as E) is implemented to prevent the base plate from buckling due to the exerted force. Displacement control is applied to the bottom faces (labeled as C) of the base plate to restrict movement to a single axis—the x-axis—corresponding to the direction of the force. In Figure 4.3, the red region labeled A is where the force is applied. The base plate experiences a force in the x-direction, determined by the earlier resolved force acting on the base plate (F = 15kN). This force application aligns with the simulation conducted on this specific part of the base plate. In an actual scenario, the entire base plate undergoes force exerted by the wheel of the bogie onto the rail. However, in simulation, only the relevant part of the base plate is necessary, given correct boundary conditions. The same boundary conditions are applied to the old washer design with the base plate, as depicted in Figure 3(b).



(a) (b)

Figure 3. Fixation and boundary conditions of the new washer with base plate for (a) new washer and (b) old washer

In Figure 4(a), the maximum stress on the tooth of the new washer is indicated in the red-colored region, measuring 154.59MPa—a 51.3% reduction in shear stress compared to the old washer in Figure 4(b), which measures 317.63MPa. The maximum shear stress on the tooth of the base plate for the new washer application is 154.59MPa (Figure 5(a)), while it is 500.14MPa for the old washer application (Figure 5(b)). The new washer design demonstrates a 69.1% reduction in shear stress on the base plate tooth.



(a) (b)

Figure 3. Shear stress simulation on the (a) new adjustable washer and (b) old adjustable washer

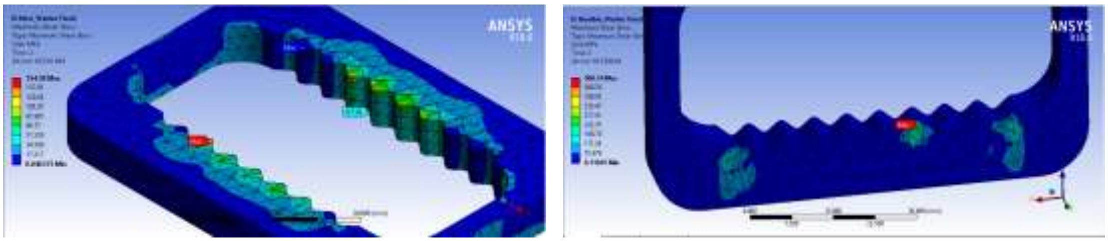
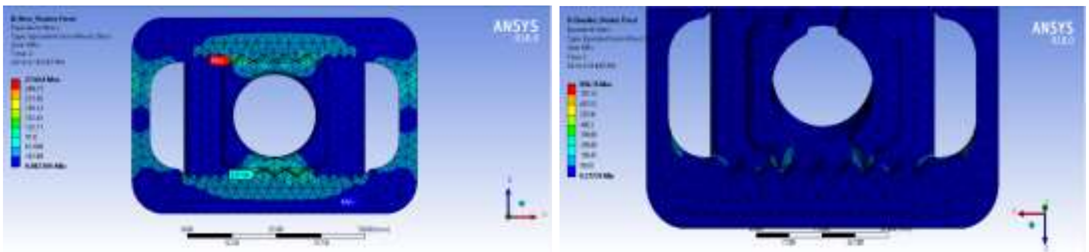


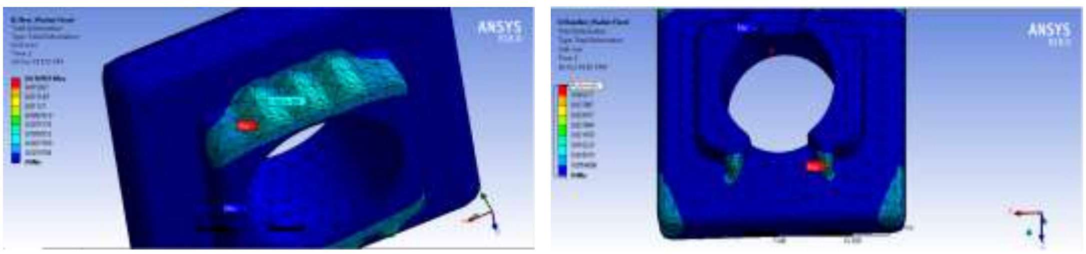
Figure 5. Shear stress simulation on the base plate on the (a) new washer and (b) old washer

The equivalent stress (Von-Mises Stress) is illustrated in Figure 6(a) for the new washer assembly and Figure 6(b) for the old washer assembly. The new washer design achieves a 51.8% reduction in stress on the tooth, decreasing from 569.85MPa with the old washer to 274.64MPa with the new washer. On the base plate tooth, the stress decreases by 69.4%, from 896.76MPa in the old washer application to 274.64MPa in the new washer application. The new washer design results in a 57.3% reduction in equivalent elastic strain, matching the reduction in the base plate. In Figure 7(a) and Figure 7(b), the deformation on the new and old washer is displayed, respectively. The new washer exhibits a maximum deformation on the tooth of 0.0169mm, while the old washer shows a maximum deformation on the tooth of 0.0179mm—a 5.6% reduction in deformation from the old to the new washer design.



(a) (b)

Figure 6. Equivalent stress simulation of the (a) new assembly (b) old assembly



(a) (b)

Figure 7. Deformation on the (a) new washer and (b) old washer

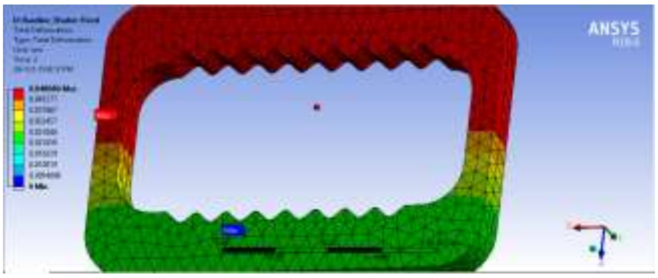


Figure 8. Deformation on the base plate for old washer

In an actual situation, the base plate would be less likely to deform in that region, so only the deformation on the tooth of the base plate will be considered. The deformation on the base plate for both new and old washer applications show minimal values, considered negligible. This once again confirms the earlier statement in this report that the adjustable washer is the part that will always be replaced during maintenance work (when workers disassemble the base plate, the old washer will be replaced with a new one). The reason for this is that the material of the adjustable washer is softer than that of the base plate. In Figure 8, the deformation occurs due to the washer tooth positioning-the washer tooth design is too small to contact the base plate tooth, consistent with the earlier statement. In the red region, the tooth of the washer did not reach out to the tooth of the base plate, causing the highest deformation in that region. The results confirm that increasing the contact surface effectively improves the strength of the adjustable washer in securing the base plate. According to the SOLIDWORKS CAD software, the new adjustable washer design has a total surface area of 7903.49mm^2, compared to the original washer design with a total surface area of 7425.32mm^2. Additionally, the tooth surface area of the new adjustable washer, which plays a crucial role in securing the base plate, is 299.92mm^2, compared to the original washer tooth design of 99.36mm^2. While the design changes in the adjustable washer slightly increase the manufacturing cost, the results prove that the larger contact surfaces contribute to improved performance.

4. Conclusions

This research has focused on investigating the sustainability of the adjustable washer in the base plate. The adjustable washer, which is recognised as the most susceptible part of the rail fastening system, presents difficulties in calculating its lifespan due to the need for regular replacement during maintenance. Hence, there is a need to improve the design of the washer not only to anticipate its longevity but also to optimise its total efficiency. The secondary objective of this research was to improve the design of the adjustable washer and its associated components within the base plate. This goal was successfully achieved by the end of the study. The primary improvement in the washer design entails a deliberate enhancement in optimising the surface interaction between the teeth of the washer and the tooth structure of the base plate. The revised adjustable washer is smoothly integrated into the fastening hole of the base plate by including extra teeth, expanding the surface area, and improving fitting. This guarantees a strong connection between the sleeper and viaduct, which has a considerable influence on the overall effectiveness and durability of the rail fastening system.

Significantly, this redesign leads to a noteworthy decrease of 69.4% in stress on the base plate tooth structure. The calculation of this % was achieved by conducting simulated tests using Finite Element Analysis (FEA) software, as part of the third aim to perform complete simulation tests for both the previous and updated designs of the adjustable washer. The simulations, conducted with ANSYS software, involved a comprehensive examination of stress, strain, deformation, and shear stress. The subsequent comparative investigation definitively demonstrates the higher performance of the new washer design in comparison to its predecessor. To summarize, the enhanced design of the adjustable washer has a significant impact on the overall performance and lifespan of the rail fastening system. The improved washer design reduces stress on the base plate tooth structure, resulting in increased longevity, safety, and efficiency of the rail infrastructure. This highlights the crucial significance of the research's findings.

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