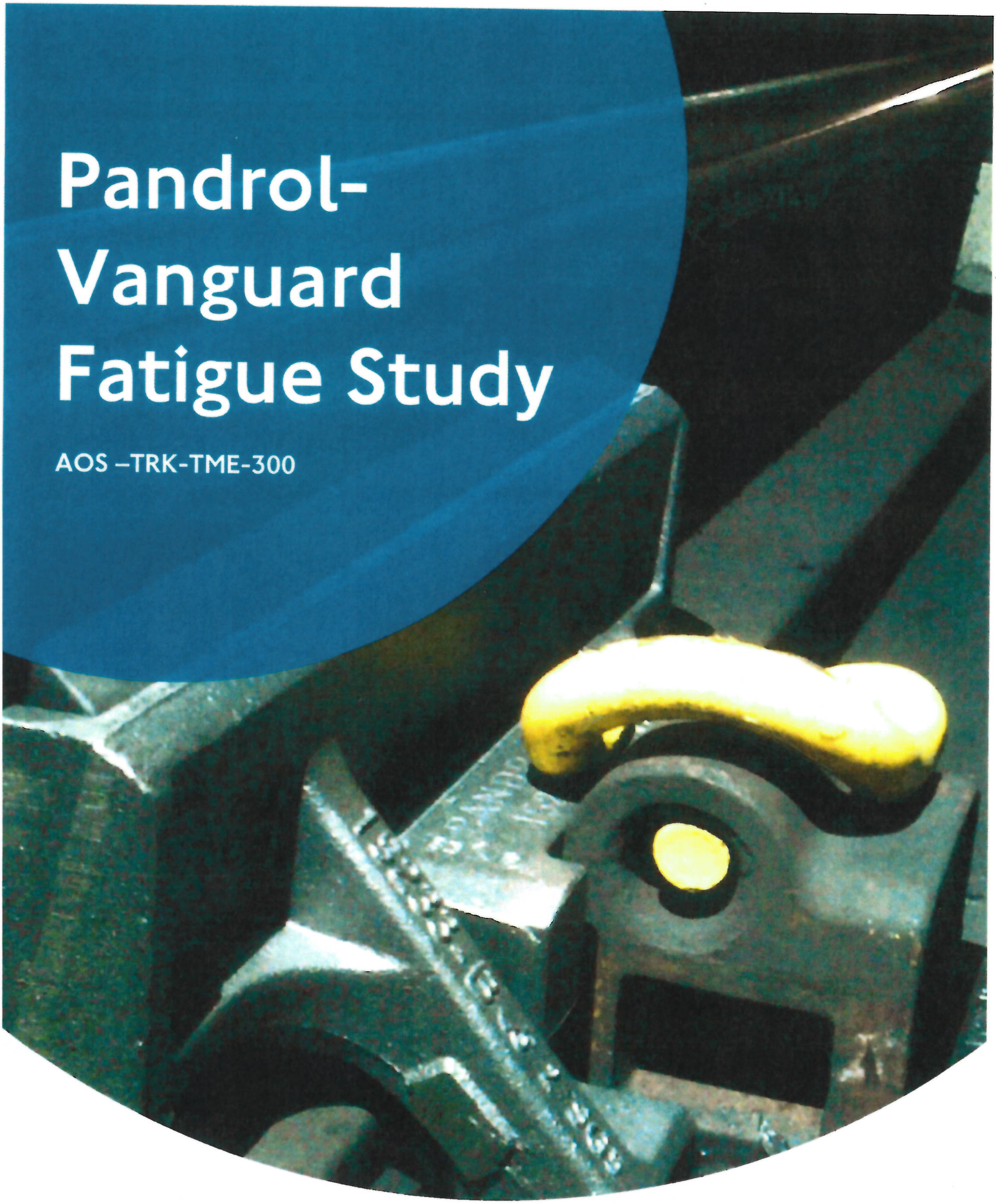
Pandrol-Vanguard Fatigue Study

AOS –TRK-TME-300



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Pandrol-Vanguard Fatigue Study

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Executive Summary

The aim of this report was to investigate the failure modes of the Pandrol Vanguard (PV) rail fasting system, used on London Underground. Specifically, reviewing the possibility of the shoulder component failing, a bespoke design for London Underground. This is due to the lateral force transmitted through the rail (as a result of train movements), which create high levels of cyclic & fatigue loading.

The highest lateral force applied to the rail was calculated using VAMPIRE software. This investigation simulated a train moving through a curve at high speed and yielded a maximum lateral force of 30kN. This value was subsequently used to set up the loading conditions required for a Finite Element Analysis (FEA) study.

The FEA set-up replicated the fixed support of the component embedded within the concrete NTF415 sleepers and applied the lateral force on the rail side of the part. This assumed no vertical load to replicate the worst case scenario.

The results of the simulation identified the region of highest stress to be 201MPa, below the 500MPa yield strength of the specified material. This was also 10% lower than the unnotched fatigue limit for this material (224MPa). Therefore, it can be concluded that the LU shoulder component should not fail through fatigue loads induced by train movements over the running rails. It can be determined that there is no additional risk of fatigue of the sleeper system due to installing PV.

1 Introduction

The PV rail fastening system has been successfully installed as a noise mitigation measure in a number of sites on the London Underground network. PV is a unique method of rail fastening that uses rubber wedges to support the web of the rail. These wedges give the rail a very low stiffness and change the natural frequency of the rail. This natural frequency of approximately 20-25Hz provides a high level of vibrational attenuation and reduces ground borne noise.

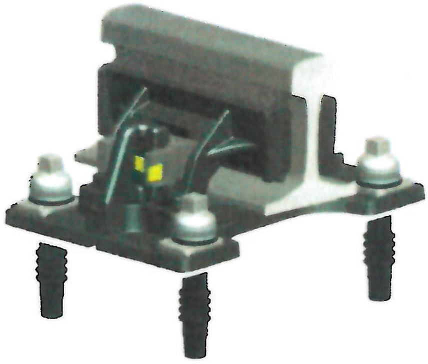

Figure 1: CAD model of the standard PV design. (6)

The system employed on the LU network differs from the standard PV design as it was required to be retrofitted to existing track structures. Specifically, it is the Pandrol 'shoulders' that are embedded within the concrete NTF415 sleeper that differ from the original PV shoulder design currently installed on other rail networks. NTF415 sleepers are fully concrete with the exception of the wire strands that lie perpendicular to the length of the rail, rebar situated within the shoulder component and rebar that interconnect multiple sleepers. Figure 2, taken from London Underground Drawing DWG-TRK-S001-0400415 (1), shows the exact position of the LU shoulder within the sleeper.

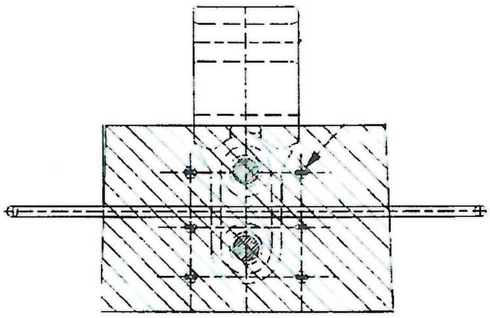

Figure 2: Sectional view of the NTF415 sleeper displaying the position of the LU shoulder (1).

The modified Pandrol Vanguard design allowed for the system to be installed without having to replace the existing sleeper arrangements. Subsequently, the different shoulder design requires verification for the initial and cyclic loading perceived during normal traffic operation, ensuring the maximum stresses are below the yield stress and endurance limit.

2 Design

2.1 PV Design

Figure 3 displays the variation in design between the original PV system and the retrofit LU design. The LU shoulder, as denoted by the arrow in the left hand image, is the component that will be investigated in this report.

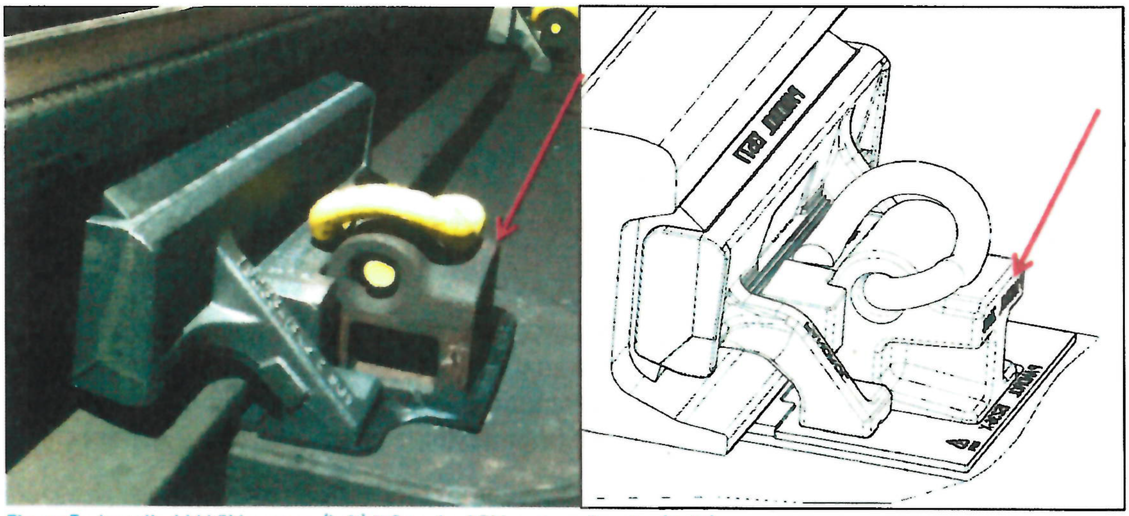

Figure 3 : Installed LU PV system (left) & Standard PV system drawing (right).

2.2 LU Shoulder

London Underground Drawing T400238 illustrates this part, which was used to create a 3D model within Solidworks, as shown in Figure 4 (2).

This drawing also defines the material as Iron EN –GJS 500-7, which the yield strength is defined as 500 MPa and the unnotched fatigue limit is approximately 224 MPa (3) (4).

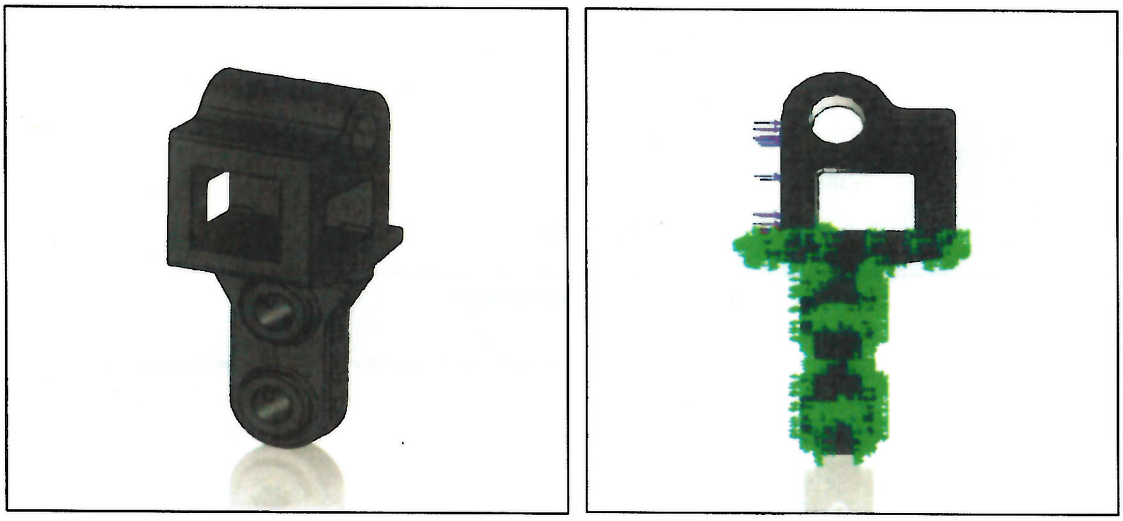

Figure 4 : LU shoulder Solidworks 3D model (left) & the loading conditions the model will be simulated under for FEA (right).

The right hand image in Figure 4 illustrates the FEA set-up where the green icons shows the fixed region, which aims to simulate the shoulder being embedded in the sleeper.

The lateral force is shown by the purple arrows. This is assumed to be transmitted through the rail side of the component. The vertical direction forces generated from the e-clip are neglected within this analysis, focusing on the lateral forces independently.

In reality, the vertical and lateral forces would act concurrently, however the effect would reduce the higher stresses seen in this simulation. This would likely be through the vertical stress opposing the bending moment from the lateral force, reducing the overall stress within the shoulder component.

3 Lateral Force on the Rail

In order to calculate the lateral force on the rail, it was necessary to set up a simulation using the VAMPIRE vehicle dynamics software.

The software was set up to simulate a 96TS train travelling through a 300m curve; this geometry was chosen based on the current PV site in the network that featured the tightest radii curve being 300m on the Jubilee line. The simulation assumed a maximum speed of the stock to be 100km/hr. The track file that was used simulated the train repeatedly moving through the 300m curve at a variety of different cant deficiencies.

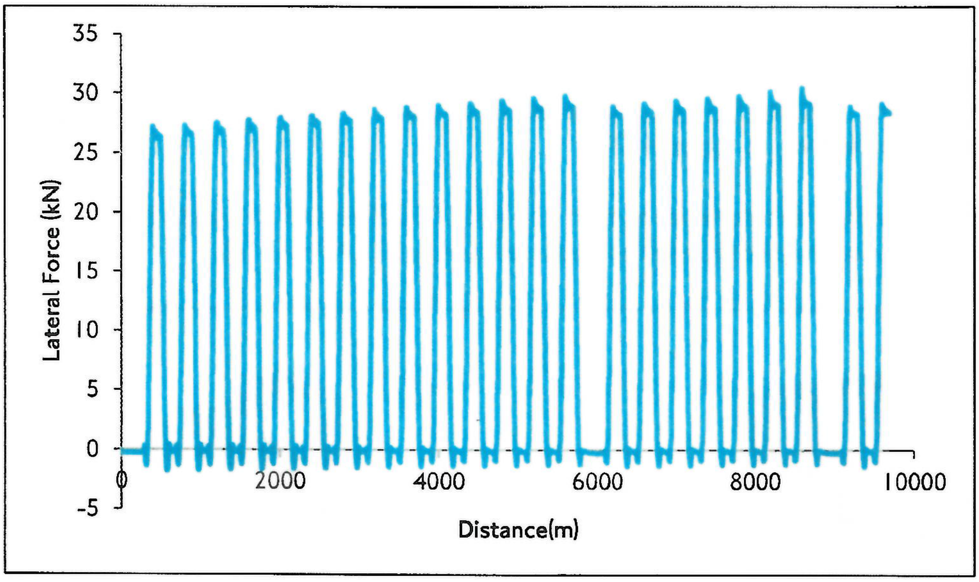

Figure 5: VAMPIRE output for lateral force against simulation meterage.

Figure 5 graphically displays the lateral force output as the train moves through the simulation. The results of the simulation yielded the maximum lateral force on the rail to be 30400N. This value was then used in FEA to calculate the regions of high stress in the component.

4 Finite Element Analysis

4.1 Stress Distribution

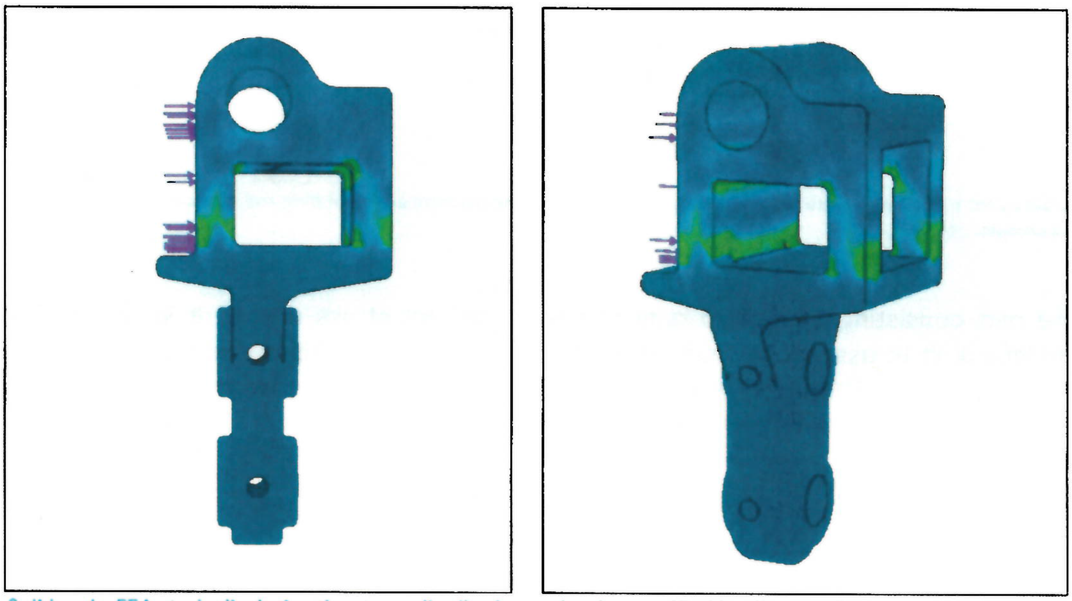

Figure 6: Solidworks FEA study displaying the stress distribution under the specified loading conditions.

When the shoulder is loaded, the component acts as a cantilever beam with a uniformly distributed load applied across its length (in this case created by lateral rail force). The regions of highest stress calculated in the FEA, shown in green in Figure 6, are situated at nearest the fixed end of the component.

4.2 Fatigue Analysis

As specified in the FEA, the region of highest stress in the component was identified as 201MPa. This is 40% of the yield strength of the material hence would not cause an issue through normal loading.

As previously mentioned this load also needs to be verified as a cycling load to confirm the fatigue characteristics of the part and its predicted life. The fatigue limit of a given material is defined as the maximum stress at which a material will withstand an unlimited number of cycles without failure (5). Data for the fatigue limit of a material is found experimentally through mechanical testing of sample coupons. Figure 7 shows a standard setup for a Wohler fatigue test that can incorporate both bending and torsional loads. Coupon tests for materials are carried out with both notched and unnotched samples. A notched sample has a far lower fatigue limit due to the geometric discontinuities increasing local stress concentration that can lead to crack initiation.

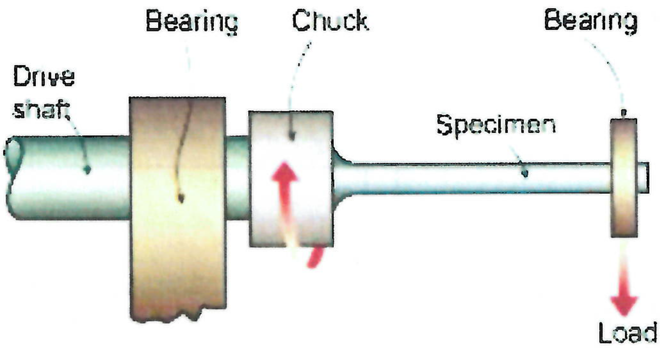

Figure 7: The setup for a Wohler fatigue test that can be calibrated to incorporate both bending and torsional loads for an unnotched sample.

Due to the part consisting of filleted radii and no significant stress raisers, it is likely the most accurate fatigue limit to use will be from an unnotched sample. For this material this is 224MPa, as mentioned in section 2. Therefore the perceived stress is 10% lower than the fatigue limit which suggests this part can operate for 'unlimited' cycles.

5 Discussion

Based on the overall highest stress that the simulations demonstrate earlier in this report, it can be determined that the shoulder component used as part of the PV fasting system on the LU network will not fail as a result of fatigue. However, there are some notable areas within this study that could affect the accuracy of this assessment, these are discussed below.

Firstly, the loading conditions used in the FEA study taken directly from VAMPIRE simulate the tightest radius PV site at the highest speed value that the stock could achieve. In reality it is predicted that only a negligible percentage of the PV sites will ever experience the loading conditions described in this study. It is likely that the speed values used will be an overestimate of the true values that occur on the running line due to the effect of signalling. Subsequently, it can be concluded that the maximum lateral force used in the FEA study is likely to be greater than the fastening system would experience in regular use.

As aforementioned in section 2, the model differs from the actual loading conditions by excluding the e-clip from the model. This can be considered the largest inaccuracy in the value quoted as the highest stress amplitude in this study. However, as also discussed in section 2, the clip is reduce the highest stress found in the shoulder. Therefore, although this exclusion may affect the accuracy of the final value, it is likely that the results have yielded a conservative estimate for the region of highest stress.

Fatigue limits of materials are found experimentally; for this reason can be difficult to obtain and can also vary from source to source. The data used in this study is taken from a manufacturer for different types of cast iron and specifically, the referenced value used is for an unnotched sample. In order to determine which fatigue limit would be appropriate, the geometric arrangement of the LU shoulder was assessed and it was concluded that there was not sufficient stress raisers present in the design to compare to the notched value. It is however, likely that the true fatigue limit of the component would differ from the quoted value in section 2, though to identify this value, fatigue testing would need to be completed on a number of samples.

6 Conclusion

Overall, it can be concluded that due to the highest stress being identified as 201MPa, which is 10% lower than the fatigue limit, this component would not fail within normal operation from fatigue. Following this assessment, it can be determined that there is no additional risk of fatigue of the LU PV system due to this specific component.

7 References

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