ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

GRADUATE PROGRAM IN RAILWAY ENGINEERING

Fatigue Durability Analysis for Welded Bogie Frame of AALRT

BY: Ruhama Minwuyelet

A Thesis submitted to the School of Mechanical and Industrial Engineering in partial fulfillment of the requirements for the Degree of Masters of Science in Mechanical Engineering

(Railway stream)

ADVISOR: Dr. Daniel Tilahun

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ABSTRACT

This research paper presents the fatigue durability analysis for the welded bogie frame of AALRT. The purpose of this research is to observe the fatigue life of the welded bogie frame and to protect it from failure. In the analysis of the research a three-dimensional finite element model of the bogie frame has been used to investigate the effect of the applied loading force at the frame surface area and observing the effects on the welded joints. The specimen S/N-curve is locally modified by different influence parameters as stress-gradient to take into account notch effects, mean-stress influence which is quantified by means of a Haigh-diagram, surface roughness and treatments, temperature, technological size, etc. This paper discusses some applications of the outstanding fatigue simulation program FEMFAT supporting the assessment of the applied loads and welding seams.

On the bases of the model analysis the following results have been achieved. Output results without Sensitivity Factor: – maximum and minimum log10 damage values are 30 and -7.09 respectively, maximum and minimum log10 endurance safety factors are 1 and -5.11 respectively, maximum and minimum fatigue limits are 282 N/mm^2 and 255 N/mm^2 respectively, and fatigue life is 2e^6. Output results with small weld seam sensitivity Factor: – maximum and minimum log10 damage values are 30 and -20 respectively, maximum and minimum log10 endurance safety factors are 1 and -5.11 respectively, maximum and minimum fatigue limits are 282 N/mm^2 and 0 N/mm^2 respectively, and fatigue life is 2e^6. Hence it is possible to conclude that the maximum damage result, which is 30 in number is much exaggerated result, it is because the weld quality that I have taken is poor. Whereas the fatigue limit at each analytical outputs has been proved to be the recommended value. The endurance safety factor is below the anticipated value. There for a special attention should be given to the welded joints. Based on sensitivity seam thickness results, it is possible to conclude that welded connections are almost nearer to failure because they are highly exposed to residual stress. The study is significant and applicable because it introduces new knowledge on fatigue life analysis of welded bogie frame in the minds of the beneficiaries of the study particularly to those who are working in Railway Corporation.

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NOMENCLATURE

UIC	International union of railways
Nt	Fatigue life of a detail
Ni	Fatigue Crack Initiation
Np	Fatigue Crack Propagation
AALRT	Addis Ababa light rail transit
σ_a	Applied Stress
σ_{mean}	Mean stress
R	Ratio of minimum to maximum stress
Se	Endurance Limit
M_V	The mass of car in running order;
P1, P2	the mass of passengers at exceptional loads and normal service load cases respectively
C	The wheel loads of the relevant bogie expressed as a%
m_1	Effective car body mass
m^+	the bogie mass
n_b	Number of bogies

CHAPTER ONE: INTRODUCTION

1.1. Background

It must be clearly understood that the major difference between a railway vehicle and other types of wheeled transport vehicles is the guidance provided by the track. The surface of the rails not only supports the wheels, but also guides them in a lateral direction. The rails and the switches change the rolling direction of wheels and thus determine the travelling direction of the railway vehicle. In this paper, an automation of fatigue durability analysis for the weld bogie frame of railway vehicles will be realized. After the analysis the result will indicate the way of improving life time of bogie frame of the train for AALRT. A bogie frame of railway vehicles plays an important role in sustaining the static load from the dead weight of a car body. Quasi-static loads occur periodically during curving and braking operations, and cyclic dynamic loads are caused by an irregular rail surface and relative movement of the attached equipment. Since the majority of the bogie frame is a welded structure which is very susceptible to the fatigue failure under such loads, a fatigue durability analysis to ensure the sufficient fatigue strength of its weldments is a relevant issue. [1]

The bogie of railway vehicle is the primary structures, which support the weight of car body and passengers, and under the repeated external loading between rail and wheel. Therefore, in order to have enough strength and stiffness against the external loading, bogie frame were made of solid steel or welded structures based on metal materials such as SM490A. The weight of the bogie makes up approximately 37% of the whole vehicle weight. [2]

The wheelsets and the bogies are the components of the rail vehicles that experience the hardest conditions. In particular the bogie frame, due to the dynamic loads induced from the operating condition (train speed, quality of track, and so on), may show initiation of fatigue cracks and eventually fatigue failure. Stresses on bogie frames will be developed as a results of loads, displacement constrains and acceleration effects. [3]

1.1.1 Types of bogie frames of AALRT

1. Motor bogie frame

One of the major components of bogie is the frame. The frame adopts welded structure, incorporating steel plates and cast steel parts. It is mainly consisted of side sill, cross beam and end sill. The frame is designed and calculated in compliance with UIC615-4, EN13749 and VDV152 European railway standards. It is welded and examined according to EN 15085 European railway standard. After welding, frame will be subjected to tempering to eliminate residual stress due to welding. [4]

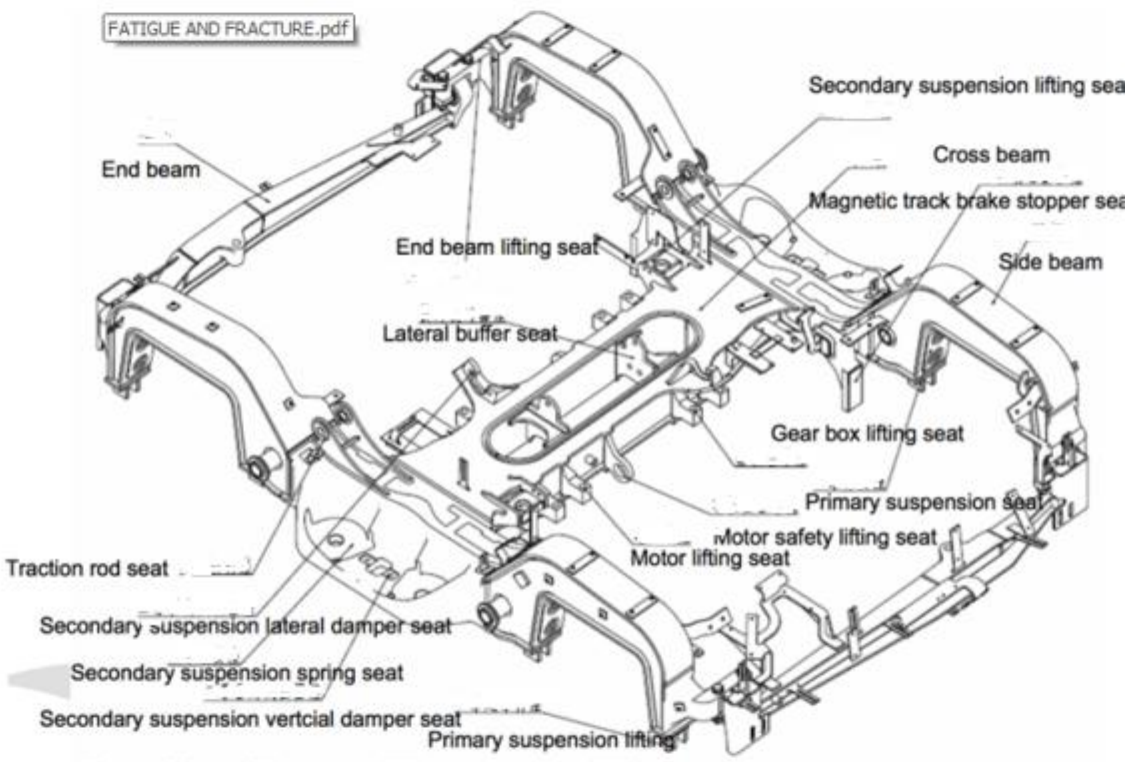


Fig 1.1 motor bogie frame [4]

2. Trailer bogie frame

The frame is H shaped welded structure, and is welded of casting and square boxes. Designed, calculated, welded and examined criterions are same as motor bogie frame. Bogie frames are always subjected to dynamic random loads and consequently fatigue phenomena.

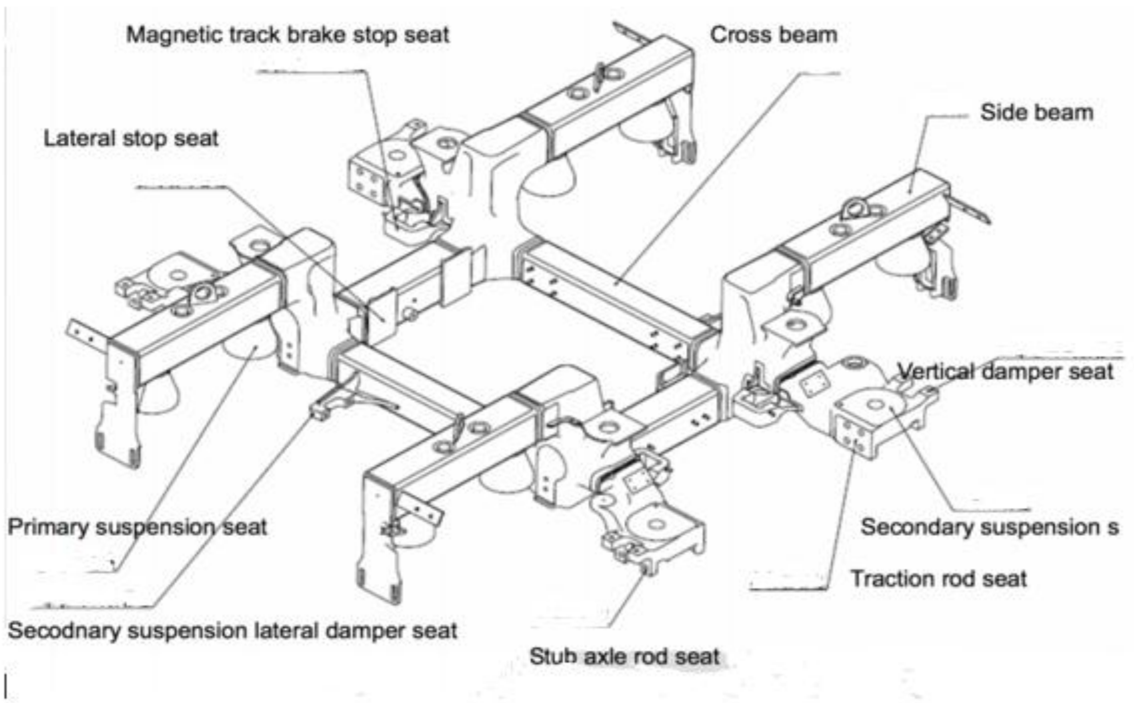


Fig 1.2 Trailer bogie frame [4]

1.1.2 Introduction to fatigue

It is a well-known fact that if the maximum load acting on a structure becomes higher than its material yield strength limit, a failure is assumed in the structure. However, in a structure that undergoes fluctuating loads, even if they are well below the material elastic limit, a failure can be expected after many loading cycles. The latter situation, which is a result of accumulated damages in the material, is known as fatigue failure. In other words, static loading of a ductile material which increases from zero to a maximum, will cause large deformations. In that case, failure of the structure occurs after a single load application with large plastic deformation, whereas, if the same material is repeatedly loaded to stresses well below the elastic limit, fatigue failure may happen after as little as a few hundred cycles or after, say, several million cycles of load application without any large plastic deformation. Fatigue is a progressive process that takes time to initiate and develop. Therefore, the process of fatigue is time-consuming and can only happen as an outcome of a repeated loading. In most cases the crack initiates in a confined small area that is either subjected to high local stresses or suffering from local defects in the material. On the contrary, in adjacent parts, where the stress state is insignificantly lower, no crack would initiate. Hence, fatigue is clearly a much localized process in which the crack originates in a location where several micro-cracks are available and grow together into one dominant crack. The mentioned process of crack formation after a coalescence of several micro-cracks is called the initiation phase of fatigue crack growth and is a result of plastic deformations in a small area in front of the crack tip. The presence of plastic deformations also implies that fatigue is an irreversible process which leaves permanent structural damages. Under normal working conditions, bogie frame has a life cycle of 30 years. Contrary to the above fact it is quit impossible to maintain normal working conditions due to many reasons all the time. Some of the reasons that could affect the normal working conditions might be:-

1. It is usually observed over loading experience are inevitable in Ethiopia.
2. Unskilled man power involved in the production and lack of modern welding mechanisms can affect the strength of the welded bogie frame.
3. Lack of regular and careful supervision on the bogie frame could be another reason that can affect the normal working conditions.

I. Fatigue and failure of structures

Fatigue failure has a brittle nature. This characteristic of fatigue makes it a potentially dangerous failure mode of structures. These failures happen at extremely high speed without prior large deformations. Moreover, Gurney estimates that 90% of the engineering component failures occur due to fatigue. [5]

Fatigue life of a detail, *Nt*, is often divided into two stages:

• Fatigue crack initiation, *Ni*

• Fatigue crack propagation, *Np*

The separation of these two stages is mainly practical because fatigue crack initiation can be affected by several parameters which the propagation phase is more or less independent. Recent microscopic investigations have shown that, fatigue crack nuclei form almost immediately after the fatigue loading has been applied, providing that the stress is above the fatigue limit.

II. Metal fatigue

Fatigue is a failure that occurs after cyclic loading, and it is a common cause of structural fracture. Fatigue damage is one of the most common faults in dynamically loaded structures. In principle, the entire development of fatigue damage can be described as follows: one or more cracks form in the structure, and the cracks grow until fatigue failure takes place.

III. Fatigue loading

Structures that are subjected to fatigue loading, experience fluctuated loads during their lifetime. Generally, the stress history of such structures varies constantly. However, the simplest stress history that can be assumed for a structure is a constant amplitude cyclic stress, as illustrated in Figure 1.3.

This type of loading is usually experienced by the specimens tested in the laboratories as it doesn't require advanced testing equipment's. A constant amplitude loaded structure, is subjected to a maximum stress (σmax) and a minimum stress (σmin). Thus, the stress range and the mean stress can be expressed as:

$$\Delta\sigma = \sigma max - \sigma min \quad \ldots\ldots\ldots\ldots\ldots (1.1)$$

$$\sigma mean = \frac{\sigma max + \sigma min}{2} \quad \ldots\ldots\ldots\ldots\ldots (1.2)$$

Stress amplitude (σa) is defined as half of the stress range, and hence it can be calculated as follows:

$$\sigma a = \frac{\sigma max - \sigma min}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.3)$$

Stress ratio, which implicitly represents the loading type, is defined as the ratio of the minimum to maximum stress:

$$R = \frac{\sigma min}{\sigma max} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.4)$$

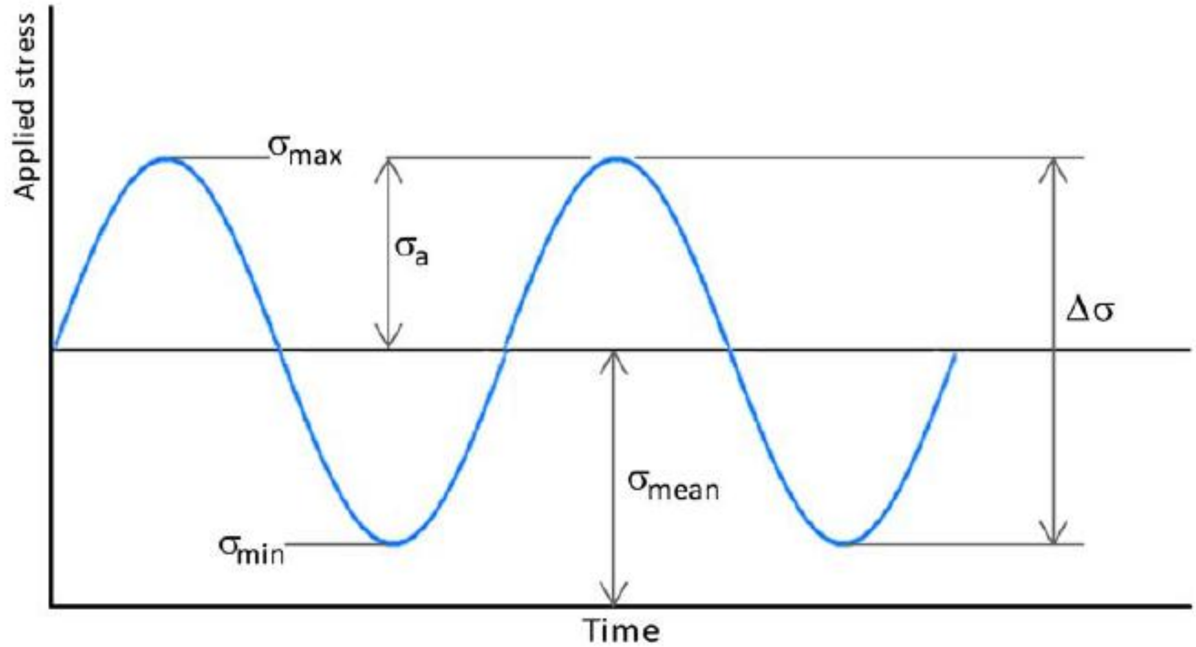


Fig 1.3 Constant amplitude loading [5]

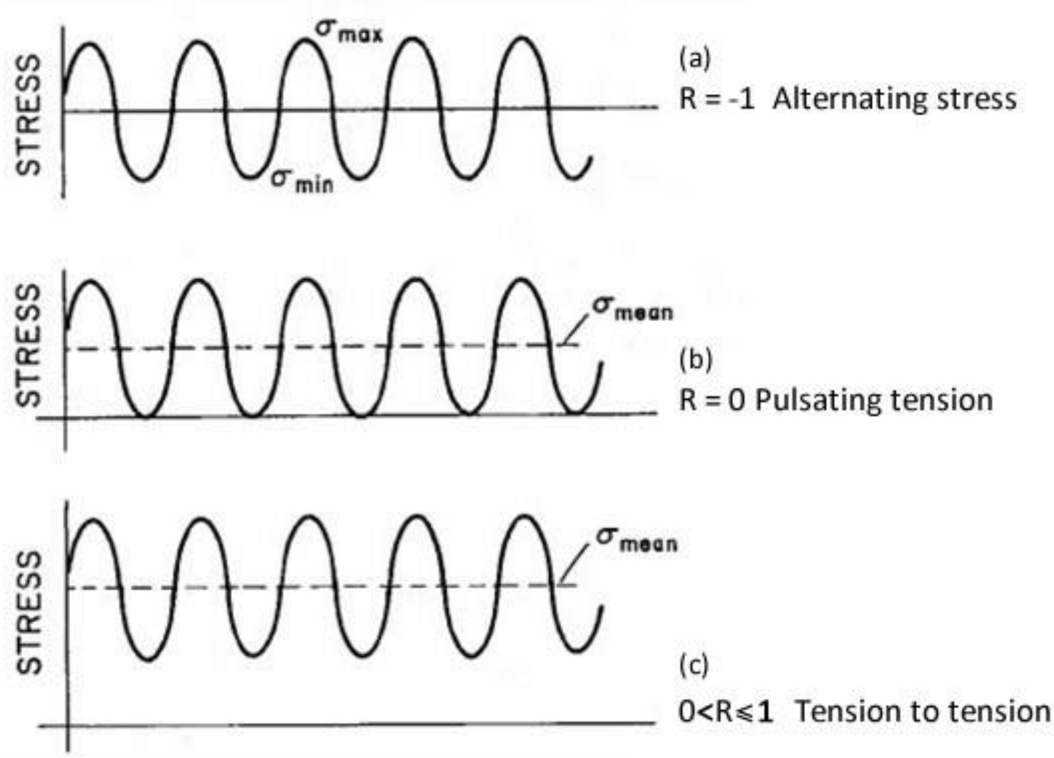


Fig 1.4 Different stress ratios for various loadings [5]

Therefore, as it is shown in Figure above, $R = -1$ is followed by reversing the stress state from a compressive stress to an equal tensile stress, while $0 \leq R \leq 1$ corresponds to any fluctuation of stress from a minimum tensile to a maximum tensile load. In general, the fatigue life of specimen depends mainly on the stress range ($\Delta\sigma$) so that a higher stress range would result in a lower fatigue life. Nevertheless, the constant amplitude loading is not a realistic loading pattern for real structures such as bridges, buildings or offshore platforms. The mentioned structures experience random sequence load histories through their life time. This loading pattern is called *variable amplitude loading* and cannot be represented by an analytical model. Figure 1.5 shows an example of a variable amplitude loading which maybe experienced by a structure. For such loadings, a stress histogram is usually used to simplify the problem. A stress histogram is a chart of separate blocks that defines the number of cycles that a constant stress range is repeated during the life time of the structure.

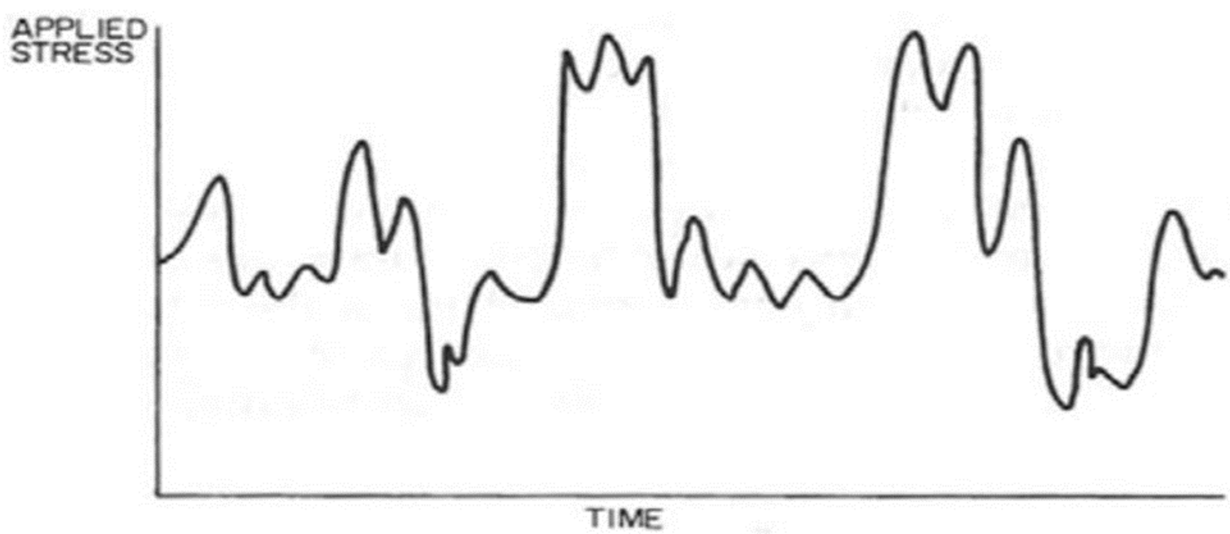
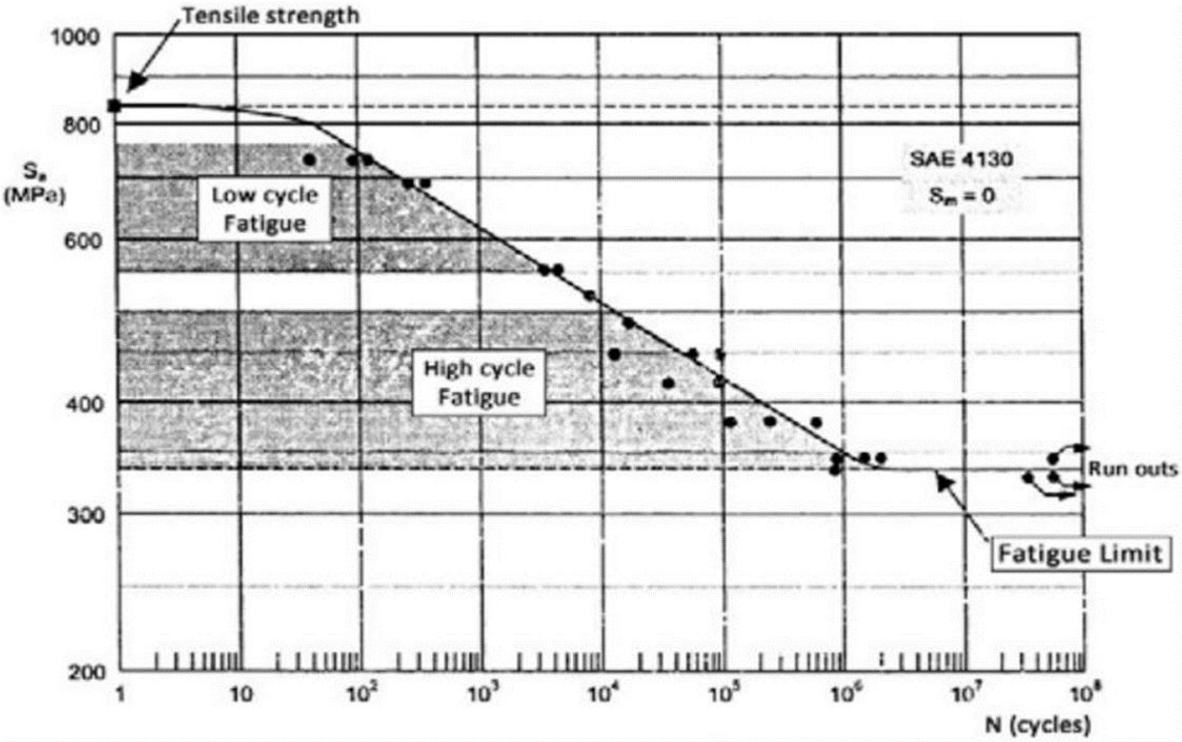


Fig 1.5 Variable Amplitude loading [5]

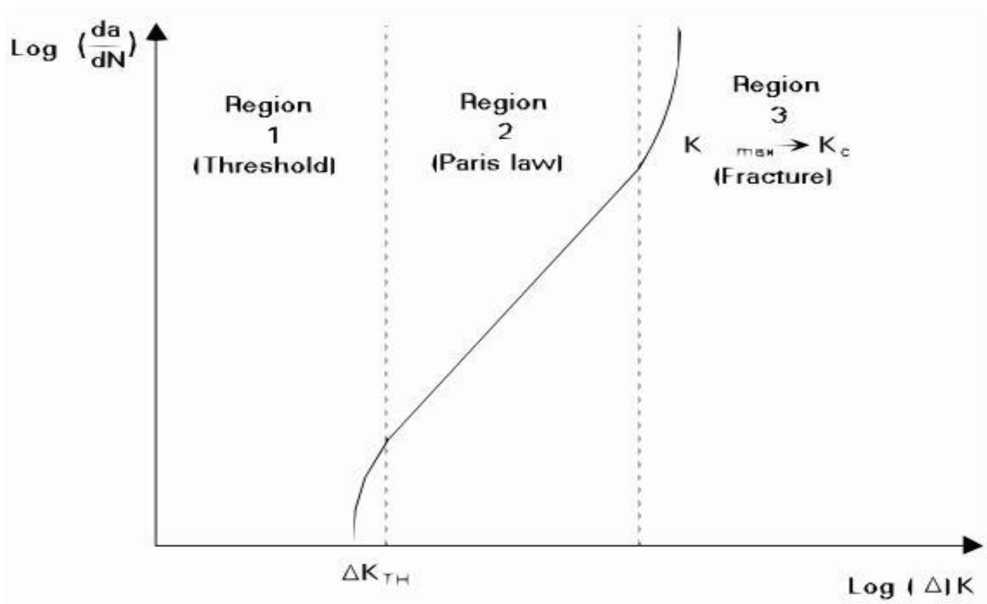
IV. S-N curves

The stress range has the most influence on the fatigue life of specimen. Accordingly, the most important outcome of fatigue tests is the fatigue life of the specimen in terms of number of cycles (*ni*) at different stress ranges. Common way to represent these results is the so called S-N curve, also known as Wohler diagram. Usually, plotting the test results of a specified specimen on along-log graph with the stress ranges on the vertical axis and the number of cycles to failure on the horizontal axis, would result a large scatter. However, in most cases, it is possible to get a regression line of the test data by running a statistical analysis of the results. The obtained line on the mentioned graph is called an S-N curve for a specified specimen, see Figure 1.6a. Moreover, as it is depicted in Figure1.6b, by rotating the S-N curve 90 ◦ clockwise, it becomes analogous to the fatigue crack propagation curves. Therefore, the top left corner of S-N curve is there in which the applied stress range is so high that plastic deformations occur momentarily.

This region is known as *low cycle fatigue* where the fatigue failure usually happens very fast. On the other hand, the bottom right corner represents the region in which the stress is so low that the specimen can be loaded for an infinite number of cycles without any fatigue damage. This stress range is called *fatigue limit*. Similar to the “Paris law” region in a crack propagation graph which follows a straight-line on a log-log scale, the region between low cycle fatigue and fatigue limit can be expressed by a linear equation as follows:

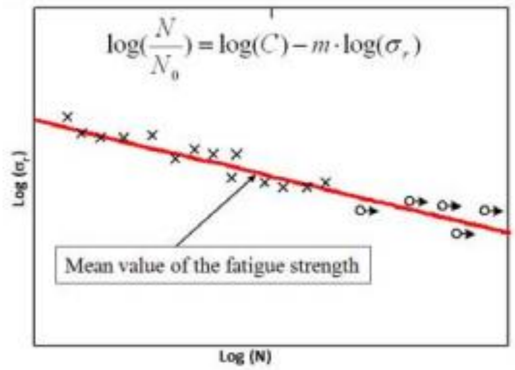


(a) Typical S-N curve [5]

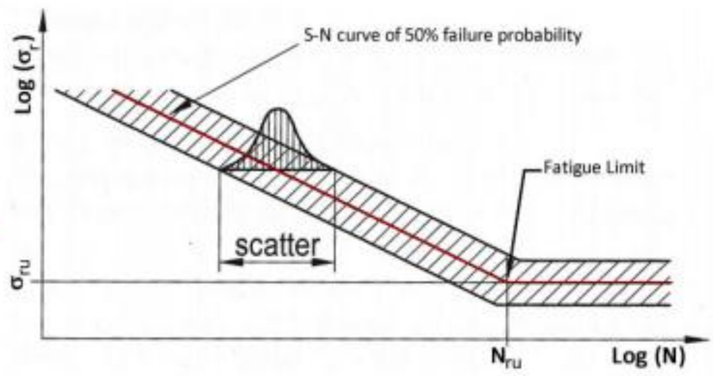


(b) Different distinguishable regions for a typical fatigue crack propagation behavior [5]

Fig 1.6 Analogy of S-N curves and fatigue crack propagation regions [5]



S-N curve fitted on test results



(b) Mean S-N curve and the scatter band

Fig 1.7 Fatigue S-N curves [5]

$log\,\frac{N}{NO} = \log(C) - mlog(\sigma r)$…………………………………….. (1.5)

taking out the logs results:

$\mathrm{N} = \; No.\left(\frac{c}{\sigma r}\right)^{m}$ ……………………………………………………….. (1.6)

Where *N* represents the fatigue life, σr is the stress range and *C* and *N*0 are fatigue strength constants. m is a material constant and for typical steel welded joints is around 3.Figure 1.4(a) demonstrates a typical S-N curve fitted to the test results. As it is mentioned in the figure, this line is the mean value of the fatigue test data. However, for the design purposes, an acceptable safety margin should be provided.

This requirement can be satisfied as follows:

- A sufficient number of tests should be carried out at each stress range to ensure the validity of statistical evaluation of the results.
- The design S-N curve should be driven by considering the standard deviation of the test results.

1.1.3 Fatigue of welded structures

Welding is of great interest of engineers, since it offers great flexibility to design details and components that couldn't be made by any other means. This special feature of welding has made it one of the most common ways of production of large structures such as bridges, offshore platforms and crane girders. However, various issues are related to welding as a production technique. Welding induces stress concentration points as a result of in homogeneities. Several defects are also attributed to the welding. These known problems as well as other effects of welding, has made it an important subject that an extensive number of literature, codes and standards have been created for. Tests that have been conducted on both welded and not welded details have shown that there is a significant drop in terms of fatigue life for welded details. [5]

Although the fatigue strength of a hole notched plate is lower than a plain plate, yet a plate with welded longitudinal gusset attachment exhibits an almost 8 times lower fatigue strength. In the following section, the reasons for such poor fatigue behavior of welded details will be discussed in more details.

I. Weld shape effects

By welding a plate, in homogeneities are also being introduced. These in homogeneities might cause an abrupt change in the stress distribution. As a result, a weld profile can be a potential site of high stress concentrations. Generally, the stress concentration caused by a stress raiser depends on the orientation of the stress raiser in relation to the direction of the applied load. The maximum stress concentration is expected when the plane of the stress raiser becomes perpendicular to the direction of the tensile stresses. Conversely, as the stress raiser plane becomes parallel to the applied tensile load direction, the stress concentration factor approaches zero. Hence, if a plate is loaded transverse to the weld, the stress concentration happens at the intersection of plate surface and weld metal, i.e., weld toe. The stress concentration would be lower if the transition between plate and weld is smoother On the other hand, stress raisers also exist for a continuous weld that is loaded parallel to the weld direction. In this case, surface irregularities such as, ripples or weld stop-start positions are the most likely places for stress concentration and consequently cracks to occur. Nevertheless, these points are less severe than those of transversely loaded details and a higher fatigue strength is expectable in this case.

II. Weld defects

The stress concentration factor for a transversely loaded fillet weld is about the same as the edge of a hole. The welded attachment has a significantly lower fatigue strength compared to the detail with the hole. This contrast arises from the fact that weld defects can be present at a weld profile. Despite the numerous attempts that have been made to reduce the amount of weld defects, it is inevitable to prevent them. Improper design, inaccessibility of welding location and lack of skilled welders are some of the reasons that can lead to weld defects. Automated welding process has been developed to specifically eliminate the human errors. Overlaps and lack of penetration and fusion are among the defects that correspond to pre-existing cracks. This implies that, the crack initiation stage for welded details occupies only a very small portion of the total fatigue life. Therefore, the number of cycles to initiate a crack in a welded joint is remarkably reduced. For an as-rolled plate and a plate with fillet welded attachment. Lack of penetration can cause severe stress concentration in weld roots under repeated loading. As a result, cracks may start to propagate from the root of the weld rather than the weld toe. Due to the fact that the root cracks can be invisible for a long time and consequently develop over a considerable area, they are often regarded as the most serious fatigue cracks. Porosities and Slag inclusions can also be serious defects for the fatigue crack initiation .Furthermore, undercuts may also be a severe stress concentration point since they introduce a sharp change in the stress distribution at the weld toe. The excessive weld material can also introduce stress concentration at the weld toe even if an undercut is not present. Additionally, the welding process is capable of leaving small scale crack-like discontinuities at the weld toe. This destructive feature of welding makes the weld toe condition even more severe. Microscopic pictures have shown the existence of these discontinuities, also known as *intrusions,* at the weld toe. The existence of intrusions exempts the material from taking more number of load cycles for the crack initiation. These findings clearly confirm that the fatigue life of a welded detail is only consisted of the crack propagation phase. Crack initiation in a material is a surface phenomenon, whereas, crack propagation depends only on the bulk properties of the material. In other words, by increasing the strength of a material, more number of cycles is required for a crack to initiate, whereas, the crack propagation rate in the material is not influenced. Hence, the fact that fatigue life of welded details is only consisted of propagation phase also implies that, very little or no benefit in fatigue strength of welded details would be accomplished by increasing the strength of the material. By increasing the ultimate limit strength of steel in a plain plate, the fatigue strength improves correspondingly while, it has very little effect on the welded detail.

III. Residual stresses

Welding of a material is often associated with stresses that are locked into the welded detail. These stresses form during the cooling period of the deposited molten weld metal. When the weld is cooling down to the room temperature, it shrinks. The shrinking procedure does not occur freely since the weld is restrained by the adjacent colder parent material. The implication of the contraction between the weld metal and the parent plates is that residual stresses would be introduced in both the longitudinal and transverse direction. These stresses are both tensile and compressive which are balanced in order to maintain equilibrium at the section. The actual residual stresses can be measured using a variety of methods, both destructive and nondestructive. Besides, parametric studies and tests have also shown that the magnitude of residual stresses depends on several factors such as tensile strength, joint type and size, and also run size and sequence. However, in the absence of test results, the magnitude of residual stresses is often taken as the maximum tensile yield strength. The presence of such high tensile residual stresses implies that, on the one hand, fatigue failures can happen under nominally compressive loading conditions, and on the other hand, the fatigue strength of the detail depends only on the stress range irrespective of the applied stress ratio. Therefore, it can be seen that tensile residual stresses can be very harmful so that a fatigue crack could initiate under a compressive applied load. However, these cracks will grow only in the tensile residual stresses region. As the cracks propagate, they cause the stresses to redistribute and some of the tensile residual stresses may relieve as a consequence. As soon as reaching the compressive residual stress zone, the cracks stop propagating further. [5]

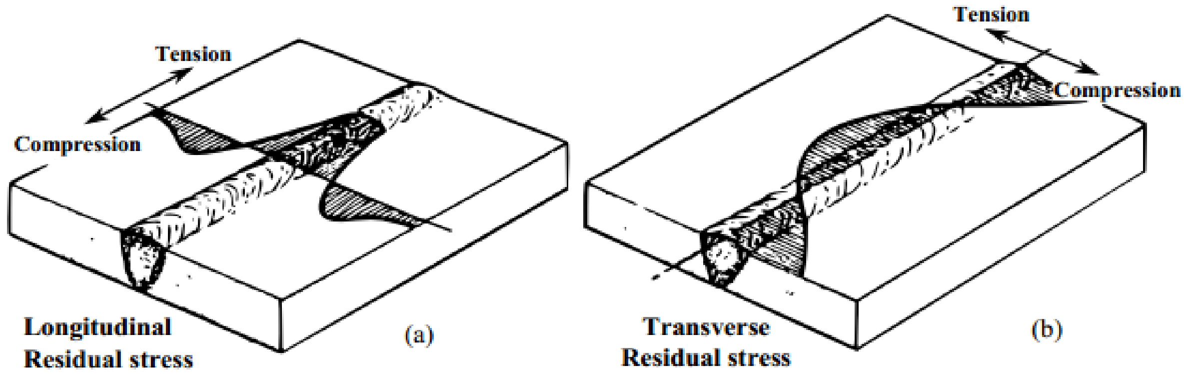


Fig 1.8 Residual stress distribution as a result of welding [5]

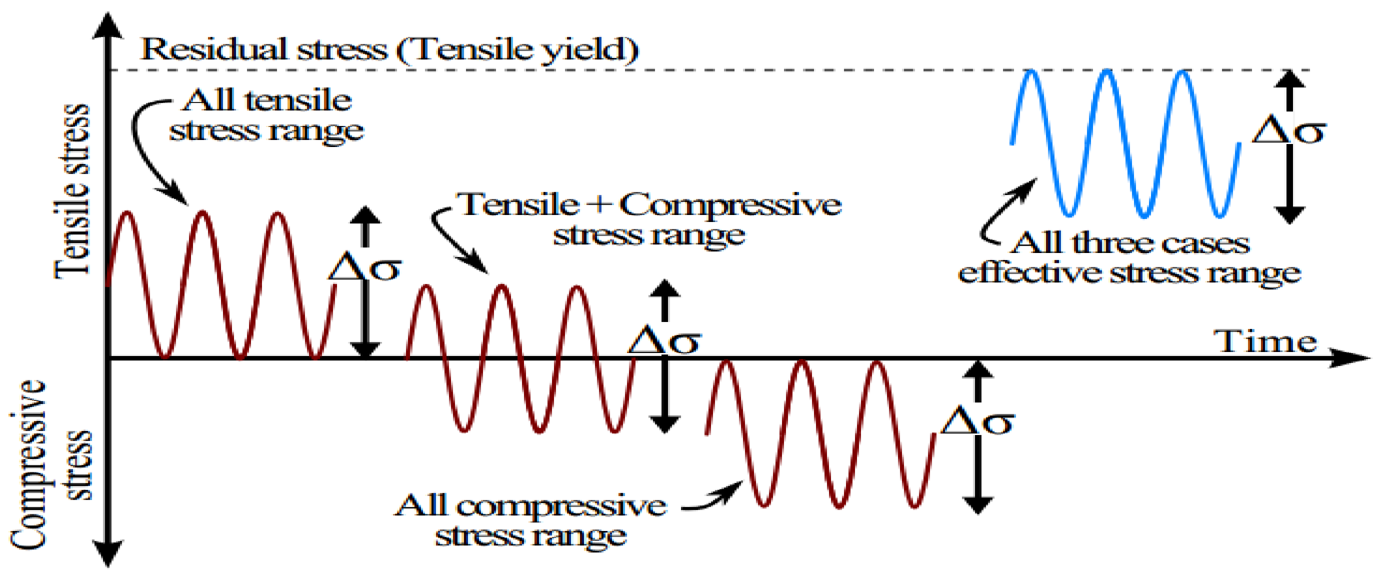


Fig 1.9 Effect of Residual stress on the stress range [5]

The stress concentration at the weld toe is in general the critical area, but for some structures stress concentrations at the weld root can be more severe than that of the weld toe. Both of the cases may lead to a fatigue crack and ultimately failure of the structure. There are several methods for assessing fatigue strength and service life of welded structures using local approaches. These approaches are based on structural stresses, notch stress and fracture mechanics, and they all have different applicability the nominal stress approach is performed by comparing well tested specimens with the detail in question. Each test specimen is associated to a SN-curve according to direction of loading, weld geometry and the technological properties of the weld. The hot spot stress method is a local approach for fatigue assessment of the weld toe, performed by a finite element analysis (FEA). The most recent approach for fatigue assessments in welded structures is the effective notch stress method, which also is a method performed using FEA. This approach can be used to assess fatigue at the weld root as well as the weld toe. Producing a smoother transition between plate and weld toe will give a lower stress concentration. This is however difficult to achieve by welding under normal conditions. There are however weld improvement methods that can be applied post welding. Including amongst others:

- Peening methods: Introducing plastic deformation at the weld by impacting the weld with a specially intended tool. Reduces residual stresses that arise during welding.
- Post-weld heat treatment: Heating the weld and maintaining a high temperature over time, followed by slowly cooling down the weld. Reduces residual stresses in the weld.
- Grinding of the weld toe by burr or disc grinding, and weld toe re-melting techniques: Improves the weld toe geometry such that stress concentrations at the toe are reduced.

Although all these methods have demonstrated improved fatigue strength for the weld toe, they are uncertain as they rely on quality of workmanship, environment and other factors. They are therefore not considered in general design of welds, but rather used as a way of improving welds that are under dimensioned, or for weld repairs. The weld toe is in general the most likely site for fatigue cracking, but for partially penetrated welded joints under transverse loading, stress concentration will also occur at the root of the weld. The stress concentration at the root depends on joint geometry and extent of weld penetration, and can be more severe than that of the weld toe. A fatigue crack may then propagate from the root across the weld throat, which is difficult to detect by non-destructive testing. Seeing that a root defect is harder to detect than a toe defect recommends the use of a design such that weld toe failure is more likely than a root failure.

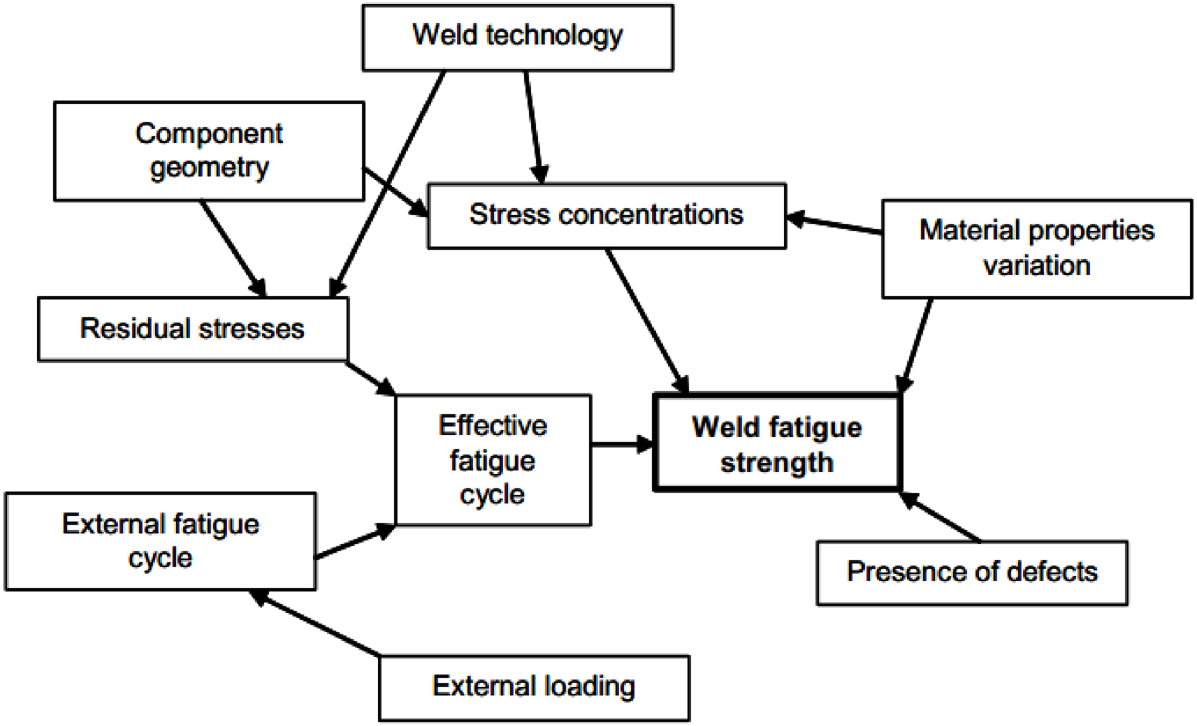


Fig.1. 10 Factors affecting welded structures fatigue strength [5]

1.2 Statement of the problem

Rail transport is of great importance for the functioning of the economic system of each country. The efficiency of rail transport indirectly affects the efficiency and functioning of the entire economic system of a country. Many countries are usually being confronted by such a type of problem. Thus economic impact is always the major concern for the Government and the society. Bogies are major parts in the configuration of railway vehicles that directly interact with the rail and track irregularities as a result studding the fatigue durability of bogie frames is imperative. While in motion bogies tolerate severe dynamic loadings. Fatigue in bogie axles, center bowls and frames is unavoidable. As a consequence of fatigue, safety in travel will be put in a dangerous situation and the cost of maintaining the train will increase. There is also the need to improve safety aspects of the trip.

1.3 Objective

1.3.1 General objective

The main objective of this research is, analyzing fatigue durability of the welded bogie frame of AALRT.

1.3.2 Specific objective

The specific objectives of this research are:

1. To study the durability at welded joints of welded bogie frame of AALRT.
2. To carry out Fatigue durability modeling for Welded Bogie Frame by ANSYS and FEMFAT software's.
3. Analyzing factor of safety, Damage value, equivalent stress, deformation, stress gradient, fatigue limit, and fatigue life for the static model of bogie frame with ANSYS work bench and FEMFAT software's.
4. To facilitate the way of improving fatigue Durability by suggesting different ideas on the basis of the results of the study.

1.4 Scope and Limitations of the Research

1.4.1 Scope

The present work focuses on fatigue durability analysis for welded bogie frame of AALRT. It predicts and compares fatigue life, safety factor and damage results for welded structures by analyzing sensitivity factors in different welding parameters using FEMFAT (Finite Element Fatigue) software and taking into consideration tempering and surface treatment influence factors. The FEMFAT MAX module is used to analyze components subjected to multi-axial loadings and it allows a superposition of multiple stress states.

1.4.2 Limitations

The limitations that the researcher has encountered are

1. Lack of the required fatigue testing equipment, hence no experimental testing on obtained analytical outcomes was evaluated and compared to numerical results.
2. As the technology on railway engineering is a new one there are no sufficient written documentary sources.

1.5 Outline of the Thesis

This thesis contains five chapters that address the research enquires. The content of each chapter is briefly outlined as follows: Chapter one briefs general information about the research conducted. Initially, the background of the research is discussed and presented. Following the back ground of the research, statement of the problem, general and specific objectives, scope and the limitations of this research are described. Finally, the thesis structure is presented by summarizing all of the chapters. Chapter two presents an overview of the related literatures. Chapter three describes the methodological part of this work, addressing all necessary steps when performing static structural fatigue analysis with the finite element software's ANSYS and FEMFAT respectively. Chapter four treats all the results of the research and their discussions. Chapter five contains conclusions, recommendations and future works of the study for further investigations.

CHAPTER TWO: LITERATURE REVIEW

2.1. Review of related literatures

Few researches have been recently conducted to evaluate and improve fatigue life of the bogie frames. Park has estimated fatigue life of some types of bogie frames using FEM. He has also optimized the bogie weight based on the genetic algorithm. A web-based automation of fatigue durability analysis for a welded bogie frame of railway vehicle has been investigated under the multi-agent based engineering framework using JADE software by Bang. The macro program of I-DEAS, the APDL of ANSYS, and an in-house fatigue code are utilized for the parametric geometry modeling and automatic generation of finite element models, the static stress analysis, the fatigue durability analysis, respectively. A multi-agent based engineering framework is implemented on the JADE to integrate the overall process. All engineering programs are integrated by a XML based wrapper. The web based automation of fatigue durability analysis for welded bogie frame of railway vehicles is realized with several kinds of system integration techniques. Sub tasks for the fatigue durability analysis such as the parametric geometry modeling, the automatic generation of finite element models, the static stress analysis, and the fatigue durability analysis is automated with the macro program of I-DEAS, the APDL of ANSYS, and the BFAP. The multi-agent based framework is used to manage the overall process. Developed automation techniques show the significant decrease in man-hours in order to achieve the fatigue durability analysis. Compared with a conventional manual process of fatigue durability analysis, this brought a time reduction about up to 80%. They have got different damage values in deferent positions the damage value at position 3 is much higher 0.28~0.47 and 0.13~0.30 in the case of the Bogie Nominal and Bogie Hot Spot project, respectively. With increasing the MCen, the damage value increases slightly and then decreases significantly after holding with constant value. As two transom support brackets approach each side frame of bogie, resistance to the twist behavior of bogie frame may be increased. Finally they concluded that they are trying to develop the more decentralized engineering framework which has intelligent capabilities such as a dynamic distributed resource allocation, load-balance, fault tolerance, and conflict resolution and to apply it to the optimal design considering mutually interactive physical phenomena in the future. [6]

Fatigue strength evaluation for the bogie frame of a Korean tilting train was carried out by J.-S. Kim and N. P. Kim using an experiment based on UIC615-4 standard. They showed that the bogie frame of the tilting train is exposed to more severe loadings compared with the conventional one because of the tilting of the car-body and the high-speed curve negotiation. An automation technique was proposed by Han et al. in order to do fatigue durability analysis for welded bogie frames according to the LJIC-code proposed by using the Model-Center, which enables several tools used in fatigue durability analysis to be integrated. A new method to predict fatigue lifetime based on the combination of frequency domain and time domain calculations, which allow lifetime prediction with reduced computational effort is given by Dietz et al. The benefits of the new approach are demonstrated by application to the bogie of a freight locomotive. J. S. Kim has assessed fatigue strength of the bogie frame for the Korean tilting train. For evaluation of the loading conditions, multi-body dynamic analyses have been carried out and strength analysis has been performed by FE analyses. [7]

Fatigue assessment of bogie frames with FEMFAT is conducted by Johann Habenbacher, Sebastian Walch, Matthias Brücker and Alois Starlinger. They have conducted their research by using Validation program EN 13749 and have carried out the Analysis by FKM-Guideline and IIW-Recommendations they have conduct static and fatigue laboratory tests finally they have executed Track tests using FKM-Guideline and IIW-Recommendations. The analysis have been taken by modeling Shell elements for weld seams Using THK-groups for thickness correction. About 64 single load cases for FE simulation, 100 load cases for superposition which represent normal service operating conditions and the loads are derived from standards, simulations, tests or previous experience. About 25 different types of weld seams are considered of post weld improvements.in the laboratory tests 0 - 28 Cylinder for fatigue tests and 10 Million Load cycles are applied. In the laboratory test 100 stain gauges channels are compared with analytical results. Track tests – EN 13749 is carried out and Fatigue strength is evaluated by Rainflow-counting and Miner rule methods. finally they summarized the paper as follows from Fatigue assessment for rolling stock with FEMFAT, FEMFAT handles complex FE-models, allows for in-house databases, Treatment of data from measurements using FEMFAT scratch files is possible and it was a Cooperative research on multiaxial loading conditions. Based on the summary they concluded that they have achieved Successful concepts and all bogie frames passed laboratory tests. [8]

They have conducted a research which is similar to mine. The necessity of conducting a research on this topic will be imperative as long as there will be many short comings when we adapt this technology to our own environment and technological practices. The local welding activities' will have lots of drawbacks because of unskilled manpower and the welding equipment's are not modernized. There are different kinds of rail truck conditions that might produce deferent load cases on the bogie frame, hence it is essential to carry out this research. It has been observed that overloading is a common phenomenon in Ethiopia, because of this issue studying fatigue durability analysis for welded bogie frame is an escapable fact.

in Chalmers University of Technology, Göteborg, Sweden Institute of Theoretical and Applied Mechanics (ITAM) a new research have been studied which is entitled as "fatigue testing and analysis of an orthotropic bridge welded detail using structural hot spot stress method" In this study, application of the method on a joint available in the orthotropic bridge decks was investigated. Fatigue tests were carried out on full-scale specimens. In the analytical part, various finite element models were made. Different modelling techniques to incorporate the weld itself into shell element models were also investigated and compared to the results from the experiments and to those obtained from solid element models. The application of structural hot spot stress for fatigue life assessment of a fillet-welded orthotropic bridge detail was carried out by means of full-scale tests and finite element analysis. Three shell element models were considered with the weld modelled in a different way in each of them. The accuracy of these shell element models was assessed by comparing the calculated structural hot spot stress values to the experimental values and to the results from the FE-model with solid element. The agreement between the results from the shell element models and solid element model was not good. It seems that the difference in the SHSS values in shell element models and solid element models is more significant when a geometric feature (such as a cope hole or a notch) exists in the hot spot region. Therefore, it is suggested that solid element models being used for these types of details. Modelling of the weld with solid elements in a shell element model can also be considered but it is a troublesome modelling task. Finally, the testing and analysis results (from solid element model) were put into relevant fatigue strength S-N curve recommended by the

Euro code, to compare the fatigue life as predicted by the code to the fatigue life in the tests. This comparison was also done for the relevant S -N curve for the nominal stress method. The structural hot spot method was found to be more accurate in predicting the fatigue life of the studied detail. [9]

The research which is carried out by Farshid Zamiri of the Chalmers University of Technology and the technics used in the paper have supportive ideas for my research. Therefore it has taken my attention to review this literature. On the basis of the literatures that I have reviewed it is possible to acknowledge that the bogie frame is the main and the largest component of the bogie that needs a further investigations.

CHAPTER THREE: ANALYTICAL METHODS AND CONDITIONS

The research method for the analysis of fatigue durability for bogie frame has considered the complexity and dynamics associated with the problem that has been dealt in this research, FEM is considered to be an appropriate method for modeling the system structure.

3.1The bogie frame material

The AALRT bogie frame is designed and calculated in compliance with UIC615-4, EN13749and VDV152 European railway standards. This European Standards cover a wide variety of different bogie types, According to EN 13749 STD the AALRT Bogie will be categorized to bogie category B-IV which is bogies for light rail vehicles and trams. [10]

Frame: steel UNI EN 10025 S355J2G3C

- According to the thickness of the frame, yield strength will be 335Mpa.
- Axle box: EN-AC-AI-Si-7Mg0.6

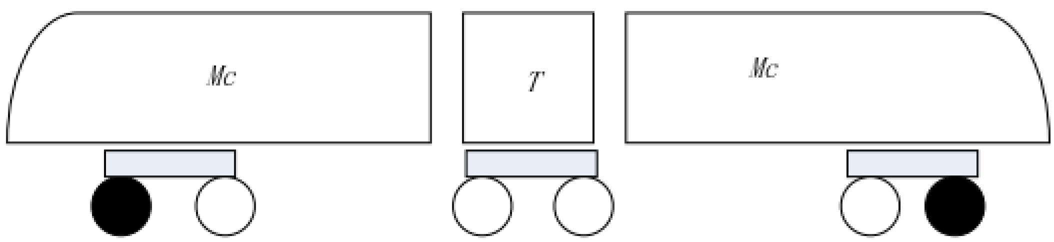


Fig.3.1 LRT train [4]

3.2 Dimension

Table 3.1 Main Technical Parameters of the bogie. [4]

Item	Motor bogie	Trailer bogie
Type	CW12	CW13
Maximum operating speed	70km/h	
Maximum test speed	80km/h	
Rail Gauge	1,435mm	
Car body mass (actual)	44,000kg	
distance between the back of the wheel flange	1380^{0}_{-2}mm	1377.7^{+2}_{-1}mm
Wheel base	1900mm	1800mm
Axle load	10.5t	11.5t
Wheel diameter (new/worn)	660mm/580mm	
Bogie weight	≤6t	≤4t

Table 3.2 Main Technical Parameters of the motor bogie frame. [4]

item	Bogie frame
Roll coefficient	$\alpha = 0.1$
Bounce coefficient	$\beta = 0.2$
Mass of bogie frame (actual)	900kg
Mass of bogie (actual)	5631kg

3.3 Methods

This research is specifically conducted on Addis Ababa light rail transit vehicle, by observing the effect of fatigue exhibited on the welded bogie frame, and detail analysis work and it will be carried out in order to verify its effect.

- **Modeling: -** the system will be modeled using FEM with appropriate software such as CATIA, ANSYS and FEMFAT software's.
- **Parameterization**: - the system will be simulated by feeding some known parameters. Analytical Study and Calculation for Fatigue Durability at Welded Joints of Bogie Frame will be conducted and Research work will be done to improve it.
- **Fatigue calculation according with EN 13749 for bogie structures**

  General methodology

  As regards the calculation process, the structural analysis is divided in two phases:

  − structural analysis of the bogie frame by FEM calculations;

  − structural analysis of the attachments components-bogie frame by FEM calculations.

  For the two verifications above the calculation process for the acceptance procedure requires the following activities:

  − determination of the forces that occur in the interfaces of the structure

  − combination of these forces in load cases representing operation conditions

  − analysis of the stress values caused by the application of every load cases

  − assessment of the calculated stress values comparing them to the acceptable stress limits.

  Bogie frame calculation

  During bogie lifetime several external forces act in the normal service loads on the bogie frame. These forces are coming from the wheel-rail contact points and from the interfaces with the car body and are generated from:

  − double sprung masses, including payload;

  − track irregularities;

  − lateral accelerations caused by curve riding;

  − longitudinal accelerations caused by traction and braking;

The forces to apply for fatigue calculation are:-

- vertical forces coming from sprung masses
- transversal forces coming from each axle
- longitudinal forces
- track twist

Frame attachments calculation

- inertial forces due to the masses attached to the bogie frame;
- inertial forces due to the masses attached to the axle box (unsprang masses);
- loads resulting from damper
- loads resulting from braking;
- loads resulting from traction motor;
- load applied on anti-roll system;

The fatigue calculation shall be carried out separately for every support. Two load cases for each calculation have to be performed. Concerning Fatigue Strength analysis techniques the main approaches are the following:

- "Nominal stress" method
- "Hot spot stress" method
- "Effective Notch Stress" method

- **Nominal stress method: -** The nominal stress approach is the simplest and the most common applied method for estimating the fatigue life of steel structures. The FEM model can be constructed both by employing solid ("brick") elements or "shell" elements. In both cases, it is important to have a correct simulation of effective welded joint stiffness, as compared to base metal sheet stiffness, as this can affect stress distribution within the different regions of the joint. For fillet welds, this makes it preferable to schematically represent the weld transverse geometry and, in the case of shell models, to insert specific elements having a conventional representative thickness. Of special concern is the mesh size in the weld zone. The nominal stress can usefully be calculated by extracting the forces and moments transmitted through a weld length of the order of the transverse size and calculating, by simple beam theory relationships, the stresses produced on the corresponding resistant section.

- **"Hot spot" stress method: -** The hot spot stress approach has been developed to enable evaluating the fatigue strength of welded structures in cases where the nominal stress is hard to estimate because of geometric and/or loading complexities. This approach has been used for the fatigue design of pressure vessels and welded tubular connections The HSS requires an estimate of the linear component of the stress filed at the weld toe. This stress component is best achievable by "shell" element models, which automatically filter the non-linear component.
- **"Effective Notch Stress" method: -** The fatigue strength of welded joints is heavily depended on their notch properties giving higher stress concentrations which leads to lower fatigue life. The notch stress in welded joints is the total local stress caused by both the component geometry and the local stress raiser, i.e. the weld itself. The FEM model for ENS evaluation is most frequently based on sub structuring techniques. The effective notch stress approach is mainly based on the computed highest elastic stress at the critical points, i.e. crack initiation points.
- Since the bogie frame has welded tubular connections conducting the analysis by hot stress method is imperative.

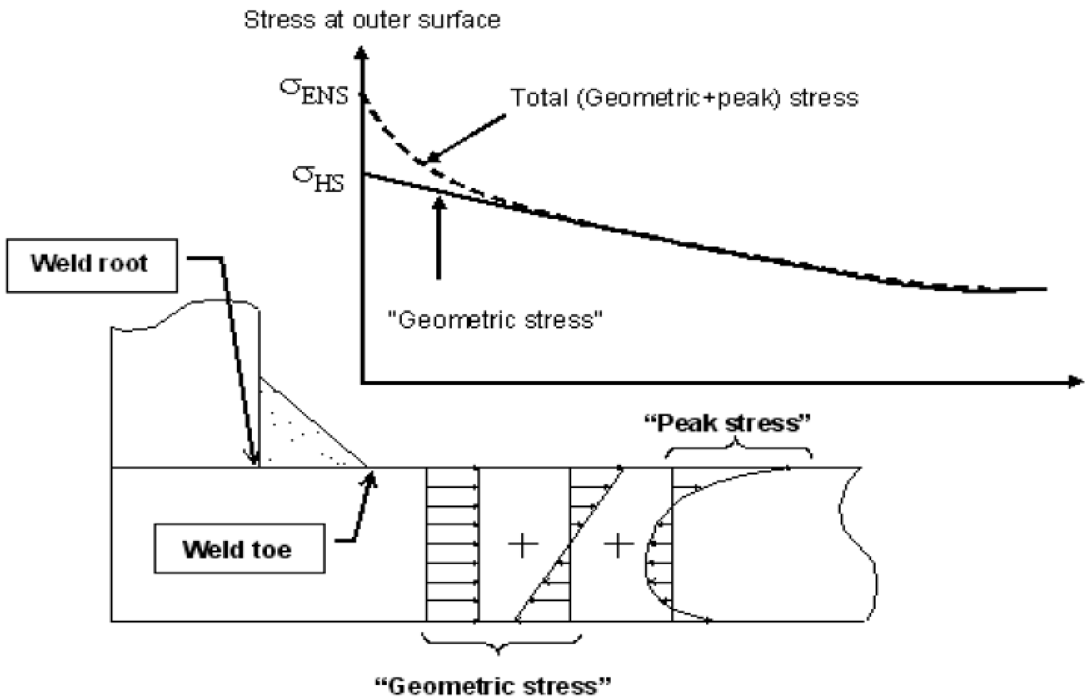


Fig. 3.2 Stress contributions with "Hot Spot" and "Effective Notch" Stress Indication [5]

Relevant factors for Fatigue Strength analysis

- stress concentrations;
- material mechanical properties variation between different weld joint zones;
- residual stresses;
- fatigue cycle mean stress;
- presence of defects (cracks)

Stress concentrations in welded structures are mainly due to the following two mechanisms:

- weld joint geometry
- material properties variation within the joint

3.4 Condition

3.4.1 Load cases of the bogie frame [10]

For exceptional loads the effective car body mass m_1 including passengers, corresponding to a particular bogie is

$$m_1 = \frac{(M_v+P_1)C}{100} - nbm^+ \quad (3.1)$$

$$P_1 = \text{mass of passengers} = \text{numberof passengers} * \text{average weight} \quad (3.2)$$

$$P_1 = 317 * 60\text{Kg} = 19{,}020\text{Kg}$$

$$m_1 = \frac{(44{,}000\text{Kg} + 19{,}020\text{Kg})95}{100} - \big((2 * 5{,}631) + 3{,}803\big)\text{Kg}$$

$$m_1=44{,}804\text{Kg}$$

For normal service loads the effective car body mass m_1 including passengers, corresponding to a particular bogie is

$$m_1 = \frac{(M_v+P_2)C}{100} - nbm^+ \quad (3.3)$$

$$P_2 = \text{mass of passengers} = \text{numberof passengers} * \text{average weight} \quad (3.4)$$

$$P_2 = 254 * 60\text{Kg} = 15{,}240\text{Kg}$$

$$m_1 = \frac{(44{,}000\text{Kg} + 15{,}240\text{Kg})95}{100} - \big((2 * 5{,}631) + 3{,}803\big)\text{Kg}$$

$$m_1 = 41{,}213\text{Kg}$$

Where

Mv is the mass of car in running order;

P_1, P_2 is the mass of passengers;

C are the wheel loads of the relevant bogie expressed as a %;

m^+ is the bogie mass;

n_b Number of bogies.

3.4.2 General expressions for the basic load cases [10]

Exceptional loads

Car body loads:-

Longitudinal forces (applied at the center of gravity):

$$F_{xc} = m_1 * a_{xc} \quad (3.5)$$

$$F_{xc} = 44804Kg * 0m/s^2$$

$$F_{xc} = 0N$$

Transverse forces (applied at the center of gravity):

$$F_{yc} = m_1 * (a_{yc}+a_{ycc}) \quad (3.6)$$

$$F_{yc} = 44804Kg * (3m/s^2 + 2m/s^2)$$

$$F_{yc} = 268{,}824N$$

Vertical forces (applied at the center of gravity):

$$F_{zc} = m_1 * (g+a_{zc}) \quad (3.7)$$

$$F_{zc} = 44804Kg * (9.81m/s^2 + 6m/s^2)$$

$$F_{zc} = 708{,}352N$$

$$F_{z1c} = F_{z2c} = \frac{F_{zc}}{2} = \frac{708{,}352N}{2} = 354{,}176N \quad (3.8)$$

Bogie frame loads

Longitudinal forces (applied at the center of gravity):

$$F_{xb} = m_2 * a_{xb} \quad (3.9)$$

$$F_{xb} = 5631Kg * 0m/s^2$$

$$F_{xb} = 0N$$

Where:-

m_2 = bogie weight which is 5631K.g for Mc and 3803K.g for Tp bogies of AALRT

Transverse forces (applied at the center of gravity):

$$F_{yb} = m_2 * (a_{yb}+a_{ycb}) \quad (3.10)$$

$$F_{yb} = 5631Kg * (5m/s^2 + 2m/s^2)$$

Fyb=39,417N

Vertical forces (applied at the center of gravity):

$$F_{zb} = m_2 * (g+a_{zb}) \quad (3.11)$$

$$F_{zb} = 5631Kg * (9.81m/s^2 + 12m/s^2)$$

$$F_{zb} = 122{,}812N$$

Normal service loads

Car body loads

Longitudinal forces (applied at the center of gravity):

$$F_{xc} = m_1 * a_{xc} \quad (3.12)$$

$$F_{xc} = 41213Kg * 0m/s^2$$

$$F_{xc} = 0N$$

Transverse forces (applied at the center of gravity):

$$F_{yc} = m_1 * (a_{yc}+a_{ycc}) \quad (3.13)$$

$$F_{yc} = 41213Kg * (9m/s^2 + 0m/s^2)$$

$$F_{yc} = 370{,}917N$$

Vertical forces (applied at the center of gravity):

$$F_{zc} = m_1 * (g+a_{zc}) \quad (3.14)$$

$$F_{zc} = 41213Kg * (9.81m/s^2 + 2m/s^2)$$

$$F_{zc} = 486{,}726N$$

$$F_{z1c} = F_{z2c} = \frac{F_{zc}}{2} = \frac{486{,}726N}{2} = 243{,}363N \quad (3.15)$$

Bogie frame loads

Longitudinal forces (applied at the center of gravity):

$$F_{xb} = m_2 * a_{xb} \quad (3.16)$$

$$F_{xb} = 5631Kg * 0m/s^2$$

$$F_{xb} = 0N$$

Transverse forces (applied at the center of gravity):

$$F_{yb} = m_2 * (a_{yb} + a_{ycb}) \quad (3.17)$$

$$F_{yb} = 5631Kg * (5m/s^2 + 1m/s^2)$$

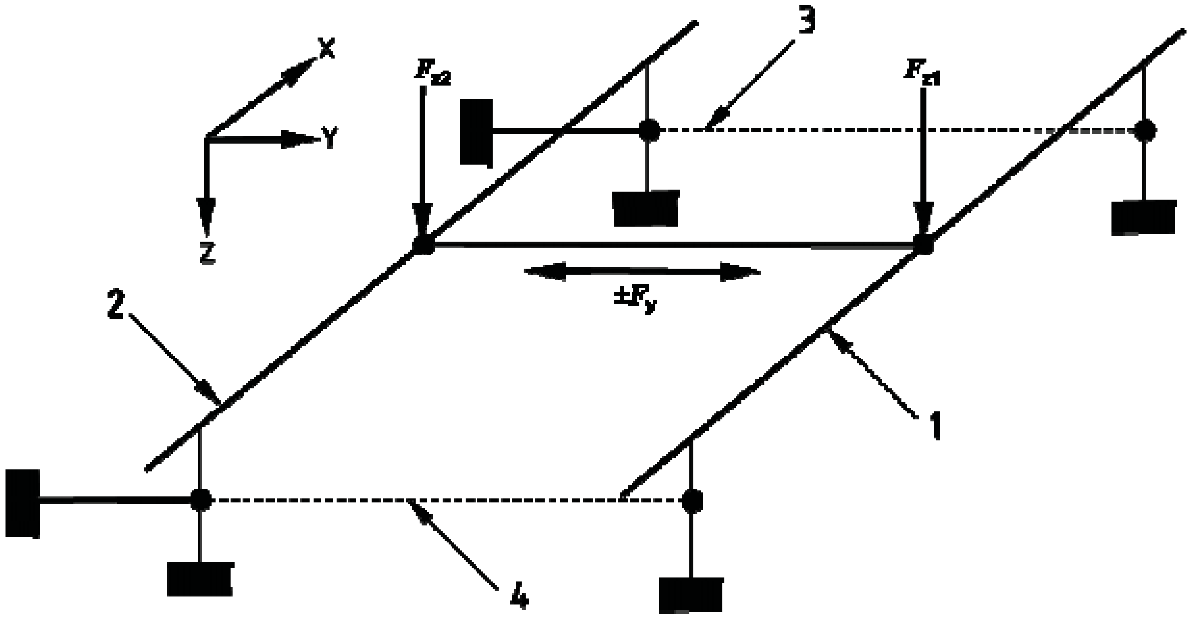
$$F_{yb} = 33{,}786N$$

Vertical forces (applied at the center of gravity):

$$F_{zb} = m_2 * (g + a_{zb}) \quad (3.18)$$

$$F_{zb} = 5631Kg * (9.81m/s^2 + 8m/s^2)$$

$$F_{zb} = 100{,}288N$$



Key:-

1. Side Beam 1
2. Side Beam 2
3. Axle 1
4. Axle 2

Fig 3.3 Side frame bogie loading arrangement [10]

Table 3.3 symbols of Accelerations which are used in load cases. [10]

Acceleration (m/s^2)	**Symbol**	
	Vehicle body	Bogie (primary spring)
Vertical	a_{zc}	a_{zb}
Transverse (dynamic)	a_{yc}	a_{yb}
Centrifugal (quasi-static)	a_{ycc}	a_{ycb}
Longitudinal	a_{xc}	a_{xb}

Table 3. 4symbols of Masses which are used in load cases. [10]

Mass (kg)	**Symbol**
Vehicle in running order	M_V
Vehicle body	m_1
Bogie mass without any secondary spring masses (if present)	m^+
Bogie primary spring mass	m_2
Exceptional payload	P_1
Normal service payload	P_2

Table 3.5 symbols of forces which are used in load cases. [10]

Force (N)	Position	Symbol		
		Static	Quasi-Static	Dynamic
Vertical	Load applied to bogie	F_z		
	Force on sideframe 1 or sidebearer 1	F_{z1}	F_{z1qs}	F_{z1d}
	Force on sideframe 2 or sidebearer 2	F_{z2}	F_{z2qs}	F_{z2d}
	Force on centre pivot	F_{zp}	F_{zpqs}	F_{zpd}
	Force at (vehicle body) c of g	F_{zc}		
Transverse	Load applied to bogie	F_y		
	Force on axle 1	F_{y1}	F_{y1qs}	F_{y1d}
	Force on axle 2	F_{y2}	F_{y2qs}	F_{y2d}
	Force at (vehicle body) c of g	F_{yc}		
	Force due to wind	F_{w1}		
Longitudinal	Force at each wheel	F_{x1}		
	Force at (vehicle body) c of g	F_{xc}		
	Force at (vehicle bogie) c of g	F_x		

Table 3.6 Acceleration values for exceptional loads. [10]

Load case	Vehicle body masses					Bogie masses			
	a_{zc} (m/s^2)	a_{yc} (m/s^2)	a_{ycc} (m/s^2)	a_{xc} (m/s^2)	q (N/m^2)	a_{zb} (m/s^2)	a_{yb} (m/s^2)	a_{ycb} (m/s^2)	a_{xb} (m/s^2)
Switches	3,2	2,2	—	Emergency braking rate	600 [a]	30	16	—	Emergency braking rate
Running through Curves	1,6	1,3	2,0	Emergency braking rate	600 [a]	12	6,5	2	Emergency braking rate

[a] Wind speed of 105 km/h.

Table 3.7 Acceleration values for normal service loads. [10]

Load case	Vehicle body masses					Bogie masses			
	a_{zc} (m/s^2)	a_{yc} (m/s^2)	a_{ycc} (m/s^2)	a_{xc} (m/s^2)	q (N/m^2)	a_{zb} (m/s^2)	a_{yb} (m/s^2)	a_{ycb} (m/s^2)	a_{xb} (m/s^2)
Switches	2,4	1,6	—	—	200 [a]	25	12	—	—
Straight track	1,2	0,9	—	Service braking rate	—	8,5	4,5	—	Service braking rate
Running through curves	1,2	0,9	1,0	Service braking rate	—	8,5	4,5	1,0	Service braking rate

[a] Wind speed of 60 km/h.

3.5 Finite element method modeling of the bogie frame

For the finite element analysis the researcher have selected the motor bogie frame type between the two kinds of AALRT bogie frames.

3.5.1 Modeling using CATIA

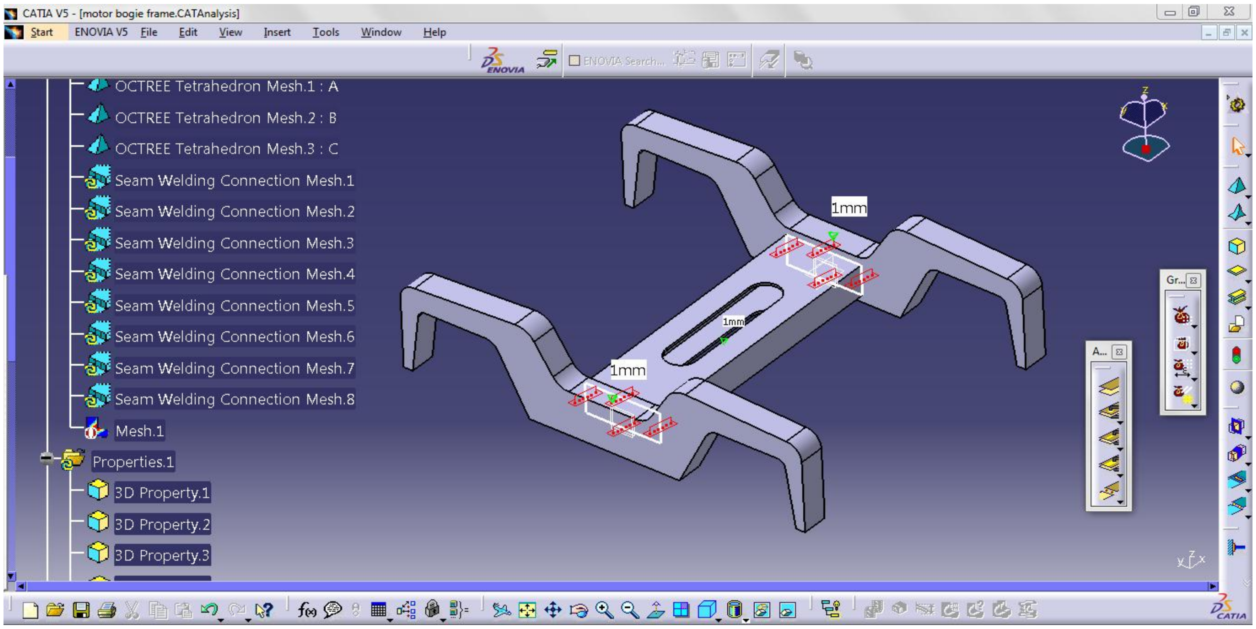


Fig 3.4 modeling of the bogie frame and connecting by seam welding using CATIA

3.5.2 Modeling the bogie frame using ANSYS

Geometry of bogie frame using ANSYS work bench for Exceptional loads

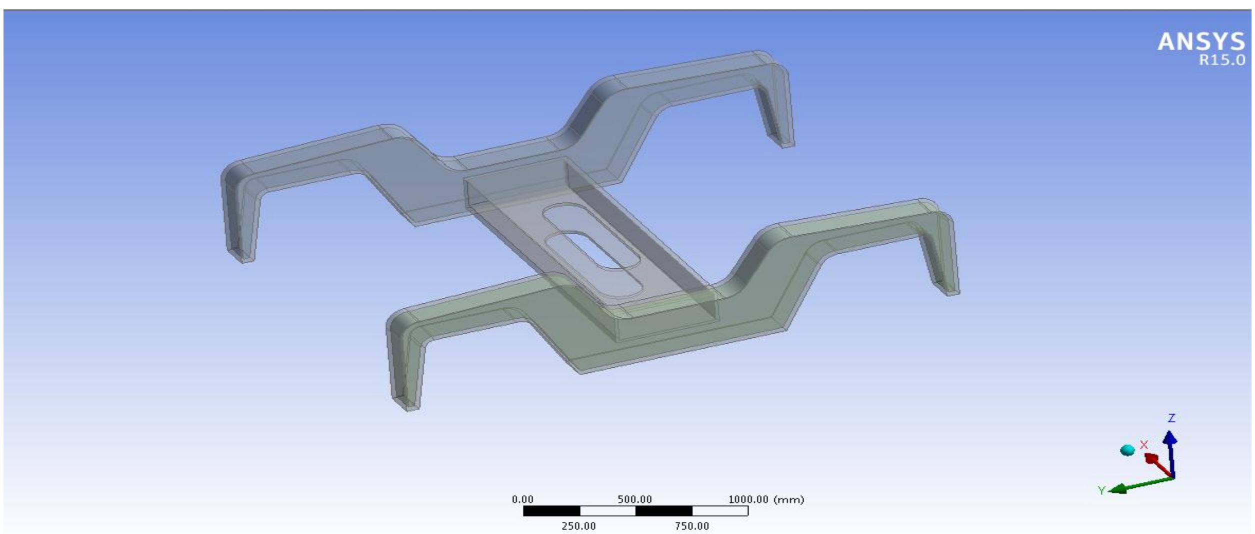


Fig. 3.5 Static structure analysis the Geometry of the bogie frame

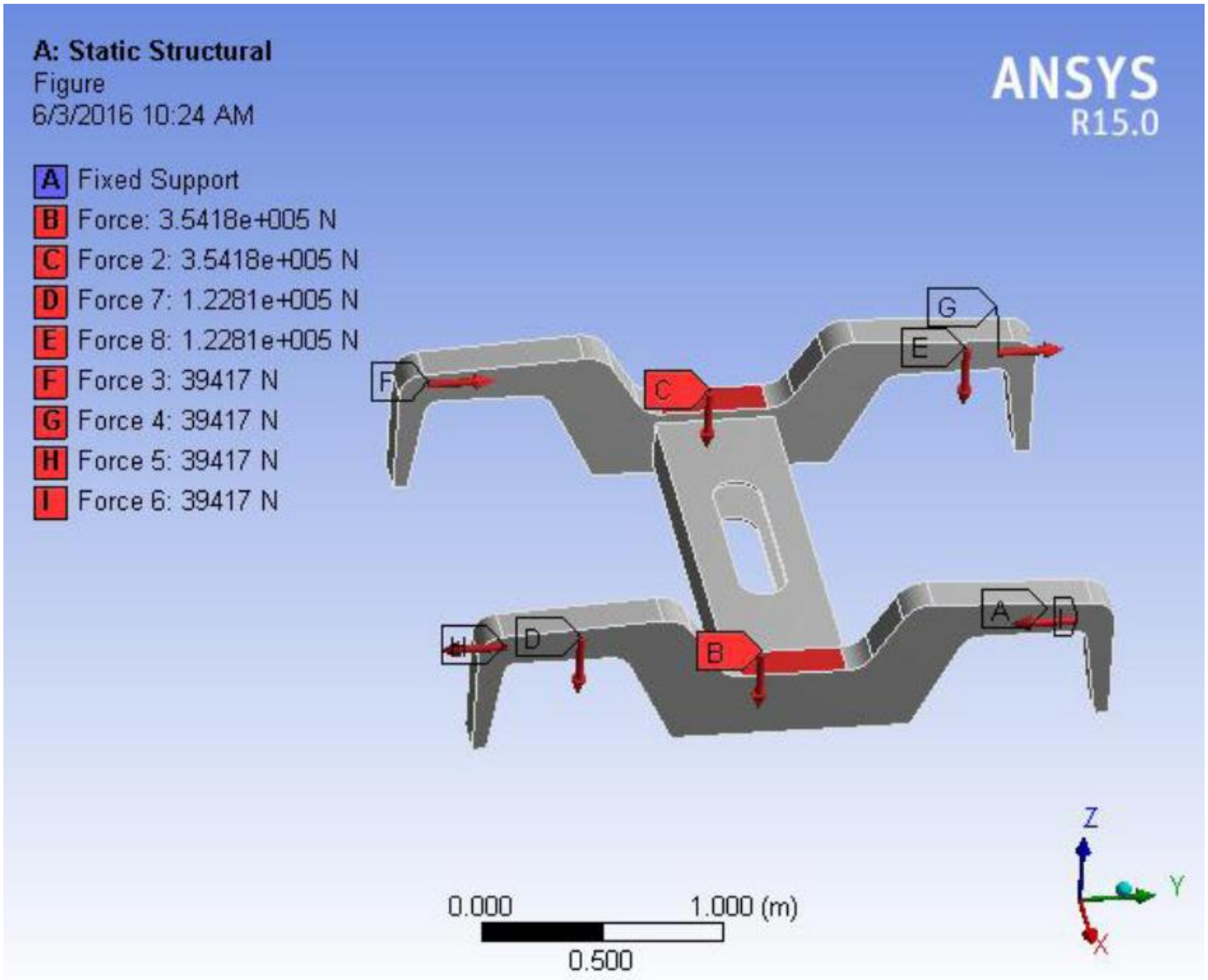


Fig. 3.6 the applied forces and fixed support on the frame

3.6 Fatigue Simulation Process using fatigue simulation program FEMFAT

A simulation tool for fatigue assessment is FEMFAT, developed by the Austrian company Magna Steyr. It is a well-established software used by various companies in the automotive and engineering industry. It carries out fatigue assessment based on the results of finite element analyses. The software consists of different modules. The FEMFAT MAX module is used for analyzing components subjected to multi-axial loadings and it allows a superposition of multiple stress states. All analyses within this Thesis were carried out with FEMFAT MAX version 5.0 and whenever it is written FEMFAT in this paper, it is referred to the software tool FEMFAT MAX. In the following section the simulation process for fatigue assessment of the bogie frame is outlined.

An FE-model is subjected to a number of load cases in linear finite element analyses. Each load case results into a stress plot, which is scaled by a load time signal. The stress states over time are superposed to a single stress state at each time step, which represent the stress state due to the total loading. Based on this stress state as a function of time the fatigue assessment is carried out. The final output result is the analysis report and the damage distribution plot. The fatigue simulation process is explained more detailed in the following by using a complete bogie frame model.

I. Geometry data

In the first step the geometry data, i.e. the FE-model, has to be imported into FEMFAT. Various input files types of different FE programs are supported. It is possible to evaluate 2D and 3D elements but in this Thesis the analyses are limited to 3D elements. The geometry data allows FEMFAT to compute the distances between nodes.

II. Stress data and load signals

FEMFAT evaluates stress data always at the nodes of the finite element. In this case the result file contains stress data at the elements, the data is averaged at the nodes. In the analysis of the complete bogie frame, the frame is subjected to 8 loads. In order to reduce the computational effort not only for the static FEA but also for the fatigue simulation, only the force load cases are taken into account.

III. Influence Factors

Fatigue behavior of materials can be influenced by several factors and FEMAT offers the possibility of taking most of them into account. One of these factors is the effect of surface finish. Smooth surfaces increase the resistance to fatigue, whereas a rough surface introduces small cracks at the surface, which facilitate the crack propagation and decrease the fatigue resistance. Furthermore, surface treatments like shot peening or nitriding of steel may also be considered. Two other important influence factors are the stress gradient and the mean stress effect. The stress gradients are obtained from the stress data and the finite element model, which is used to compute the distances between the nodes. High stress gradients usually appear at notches. A high stress peak is decreasing rapidly over the distance from the notch. The material is not sensitive to the peak stress, but rather to the average stress that acts over a small region. That means that the fatigue life would be shorter when the stress peak is used for fatigue analysis instead of an average stress value over a small region. Therefore, FEMFAT suggests that the influence of stress gradients should be activated to obtain more realistic results. Having deactivated the influence of mean stress, means that only stress amplitudes are considered in the fatigue life evaluation and mean stresses are neglected. The mean stress plays an important role when it comes to fatigue assessment and therefore needs to be considered. FEMFAT offers multiple ways for mean stress accounting, e.g. Goodman or by using constant life diagrams.

IV. Output data

The main output of the fatigue analysis is the resulting damage, *D*. It can be written into output files of the same format as output files of various FE programs. In case the stress analysis was carried out in ANSYS the FEMFAT results can be written in an output file of ANSYS type. The damage plot can then be visualized in a post processor. A detailed protocol file is also output by FEMFAT. It contains a summary of the fatigue analysis including material data, analysis parameters and damage results. Furthermore, it is possible to display the equivalent stress over time signal for the critical node or for any selected node, when it is defined in a detailed result group. The fatigue analysis is based on this equivalent stress history, on which the rainflow counting method is applied to The result of the rainflow counting method is available as an output and is used in this Thesis. It gives information not only about the number of cycles of each rainflow class but also about the partial damage of each rainflow class. FEMFAT offers various methods for computing an equivalent stress. The methods can be distinguished between methods based on the critical plane approach or general methods. Methods based on the critical plane approach require a high computational effort. The method *normal stress in the critical plane* for example is seeking for the plane of a stress state with highest normal stress. Based on this normal stress the fatigue assessment is carried out. The computational effort is high for these methods but on the other hand they deliver more accurate results than general methods. General methods compute an equivalent stress based on the stress state by using for example the von Mises stress. I have adapted some of the methods that have been employed by HARTWIG PÖRTNER in his Master's Thesis on Applied Mechanics because the methods are backing for my research analysis. [11]

FEMFAT WELD sensitivity analysis helps assessing the influence of variation in weld geometry parameters on fatigue results.

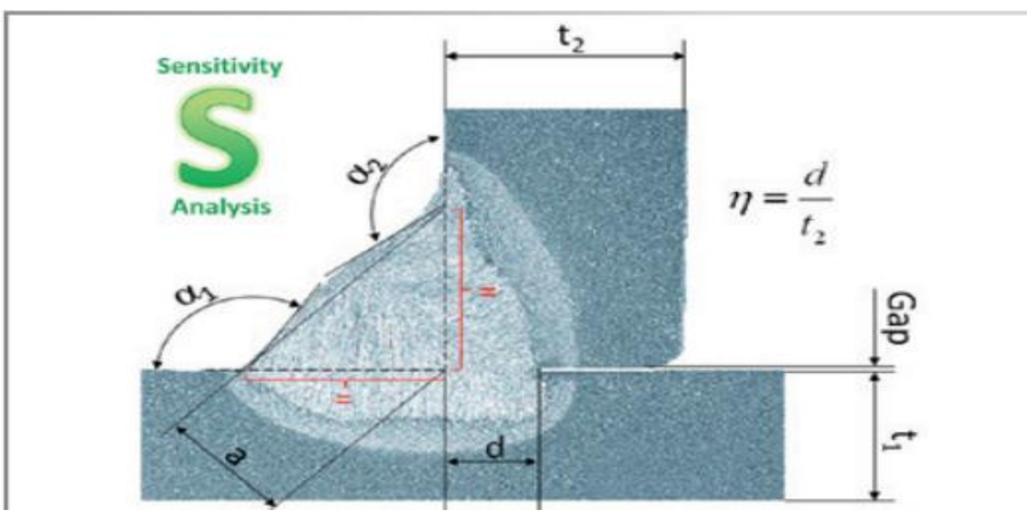


Fig 3.7 sensitivity analysis factors for a typical filet weld [12]

Weld parameters:-

- Degree of weld penetration- η
- Seam thickness-a
- Seam inclination angle-α
- Weld Gap

Joint Types for Sensitivity Analysis

There are different types of weld joints such as: - T-Joint 45 ^{0}, T-Joint 90 ^{0}, Y-Joint, Butt Joint and Overlap Joint. In my fatigue analysis of the bogie frame I have taken the welding type of T-Joint 90 ^{0}. The welding type is demonstrated in the following table. [12]

Table 3.8 Weld Qualities for welding Parameters of T-Joint 90 ^{0} [12]

	Good Quality	Standard Quality	Poor Quality
Weld Climb Angle α	110^0	100^0	90^0
Weld Thickness a	15 mm	10 mm	7 mm
Gap Dimension	0 mm	1.67 mm	5 mm
Degree of penetration η	100%	50%	0%

Among the lables that justify different qualities of welding paramaters I have choosen the poor quality in order to get the output results at the worest condition and to check the consquences of poor welding performance.

CHAPTER FOURE: RESULT AND DISCUSSION

4.1Result

4.1.1 ANSYS Results

Static analysis results for the bogie frame

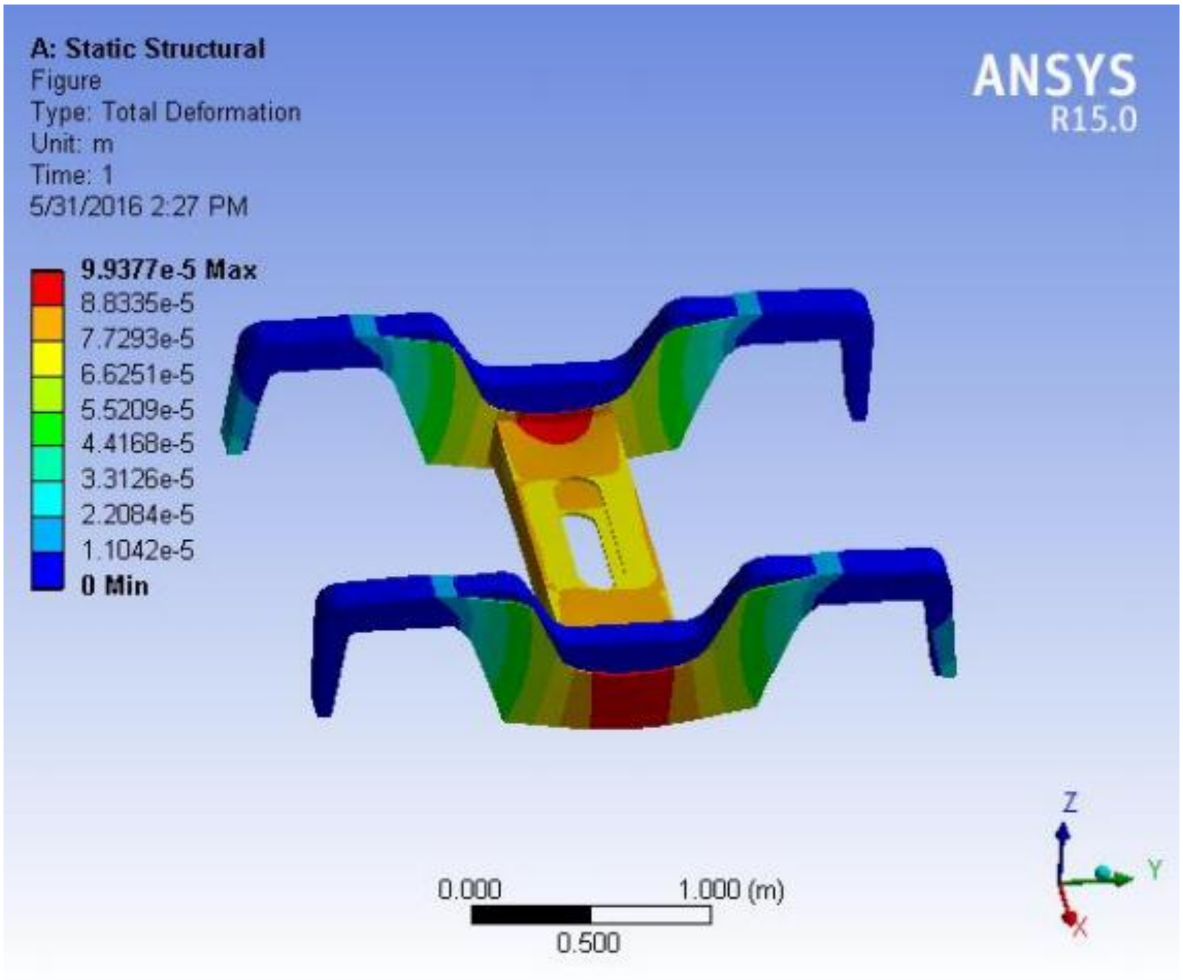


Fig. 4.1 Static structure analysis deformation results

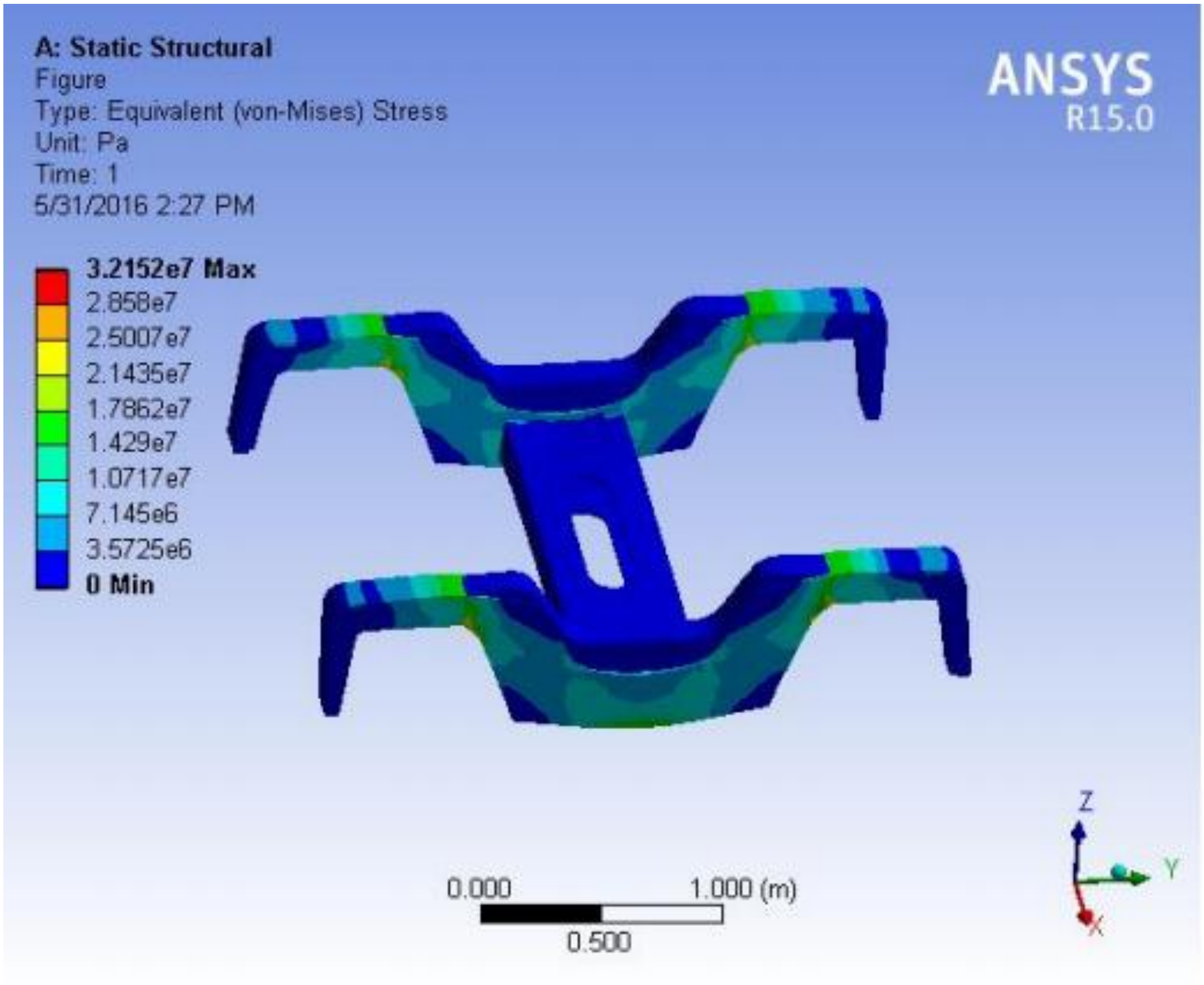


Fig. 4.2 Static structure analysis Equivalent (von-Mises) Stress results

4.1.2 FEMFAT results

I. FEMFAT WELD Pre-Processing

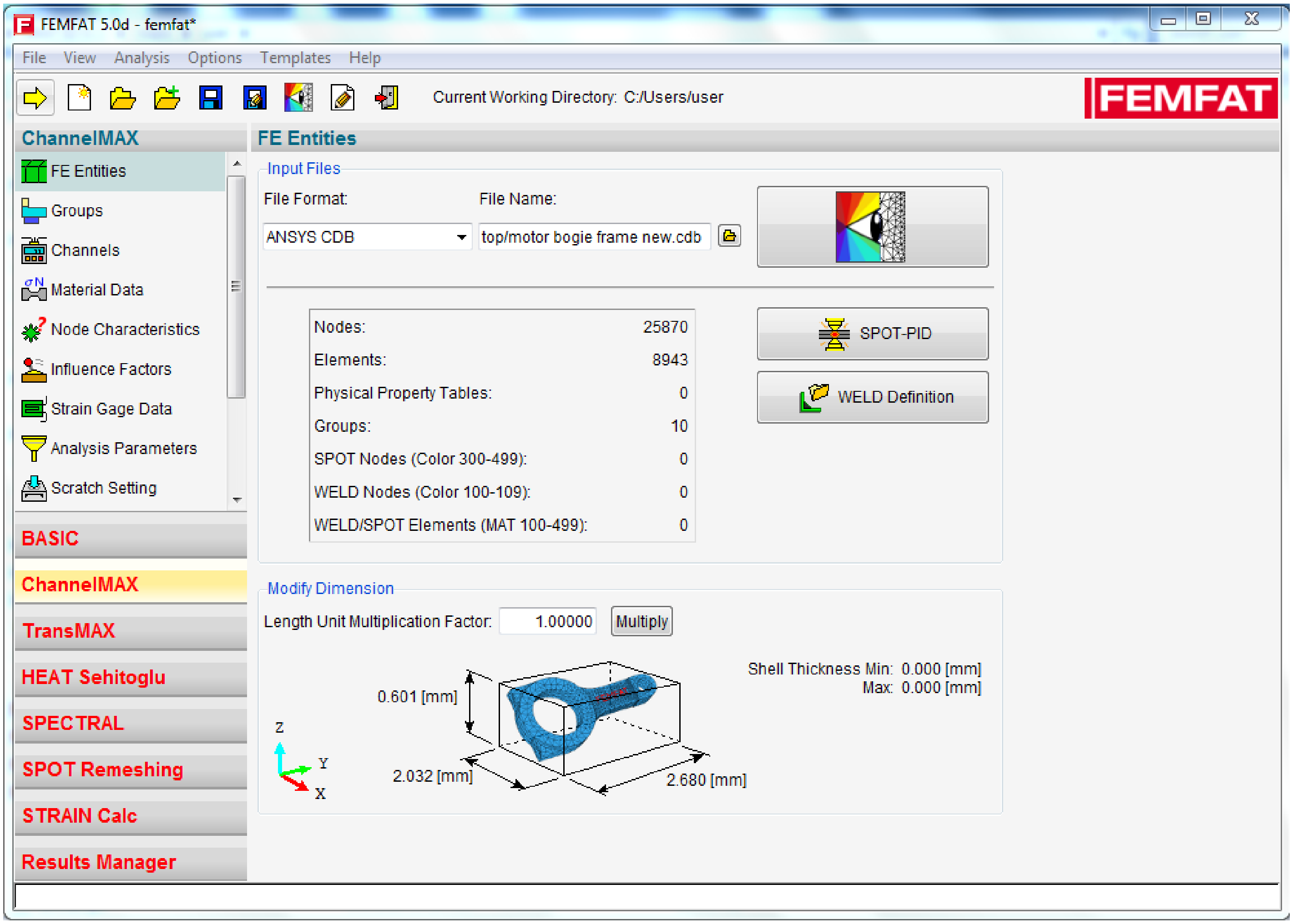


Fig. 4.3 Input files in FEMFAT

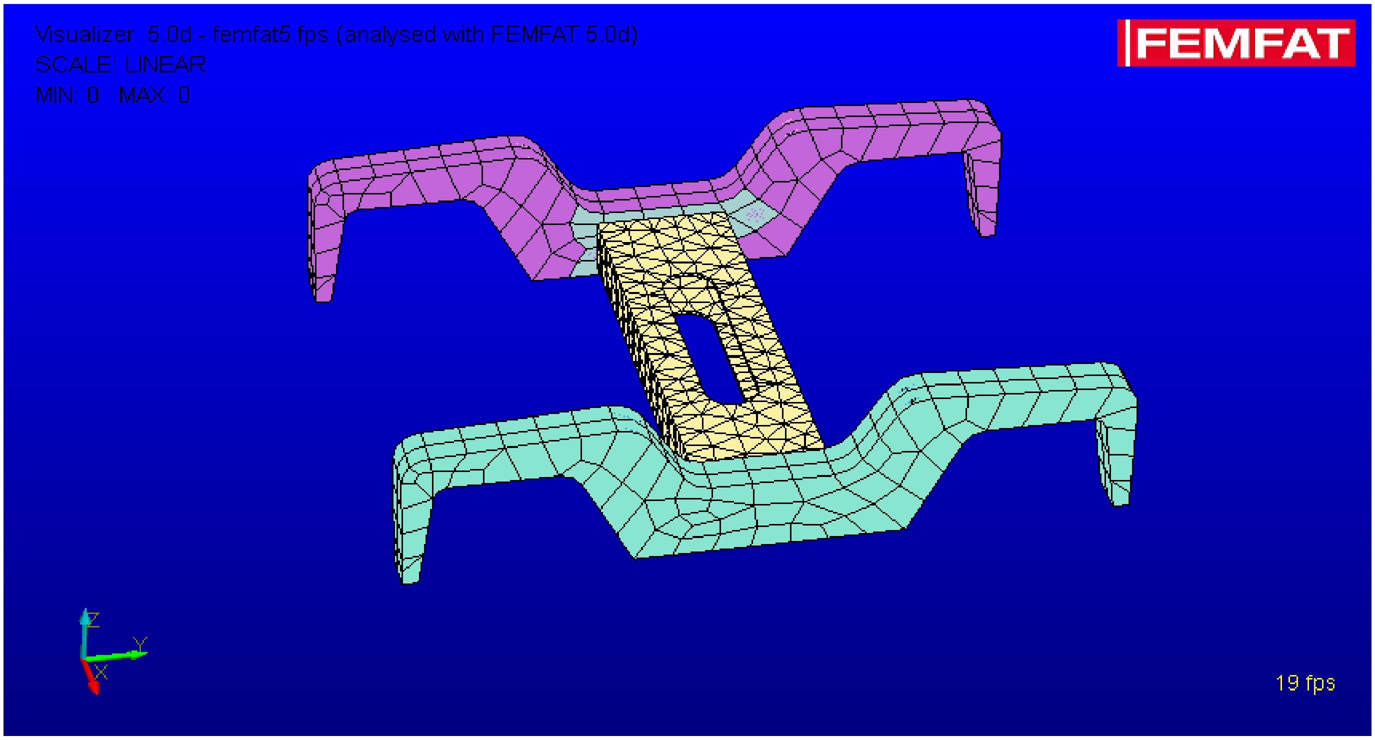


Fig. 4.4 Geometry of the frame in FEMFAT Visualizer

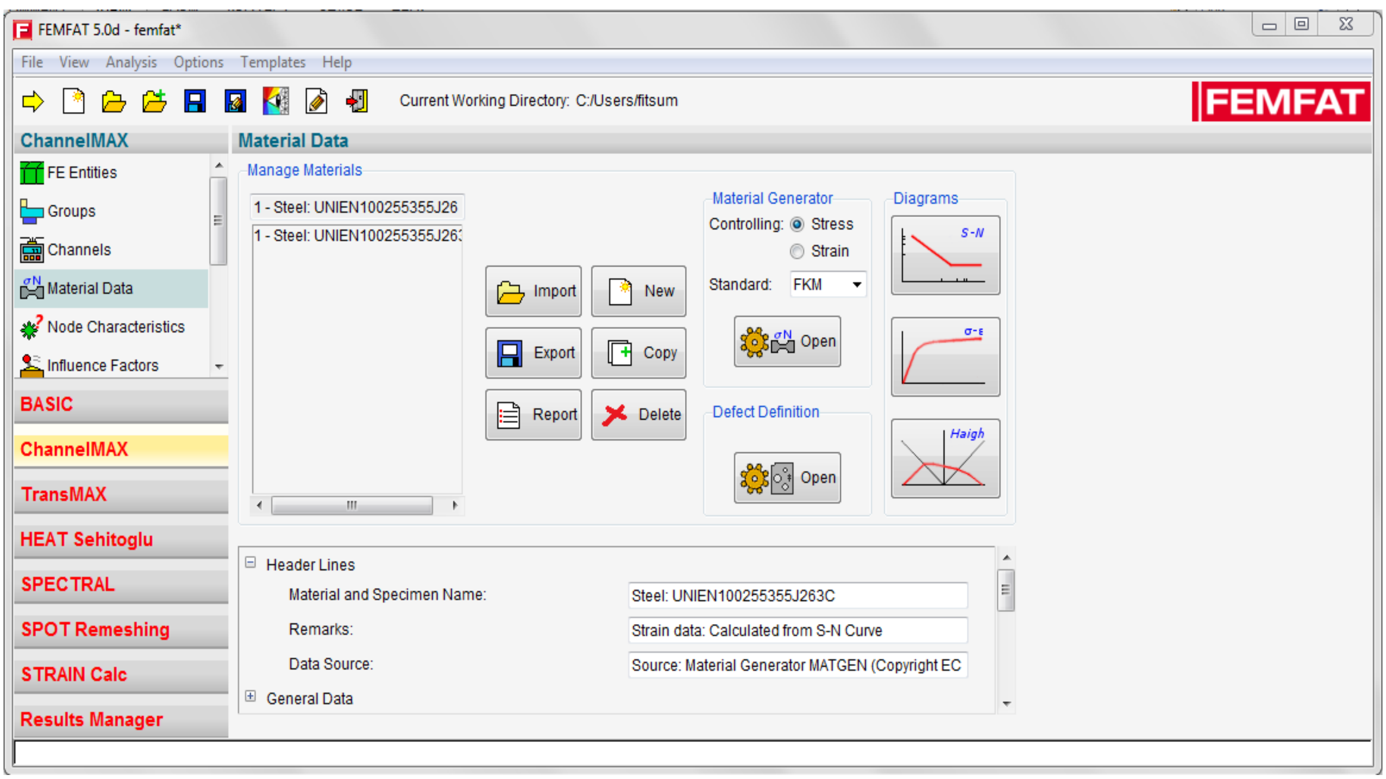


Fig. 4.5 imputing material data's in FEMFAT File

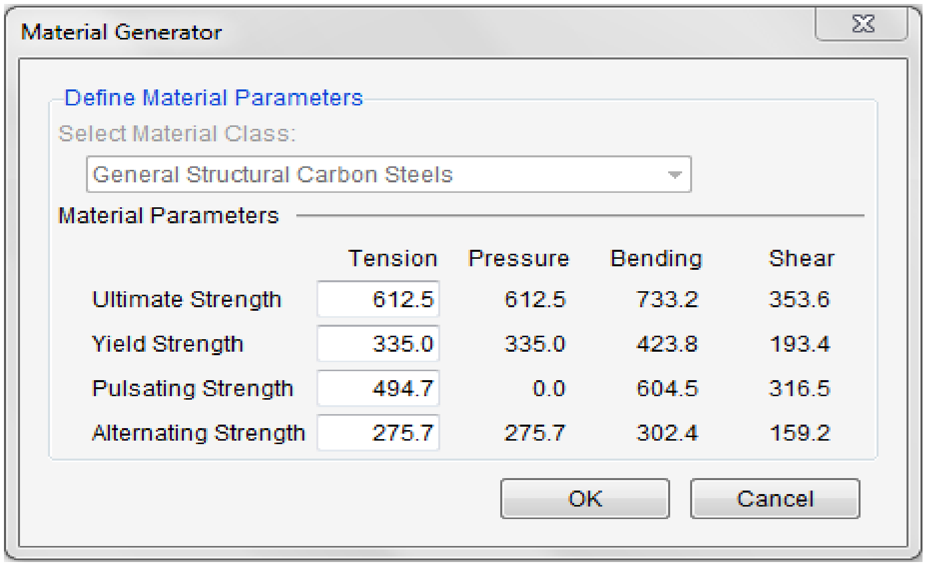


Fig. 4.6 Material parameters

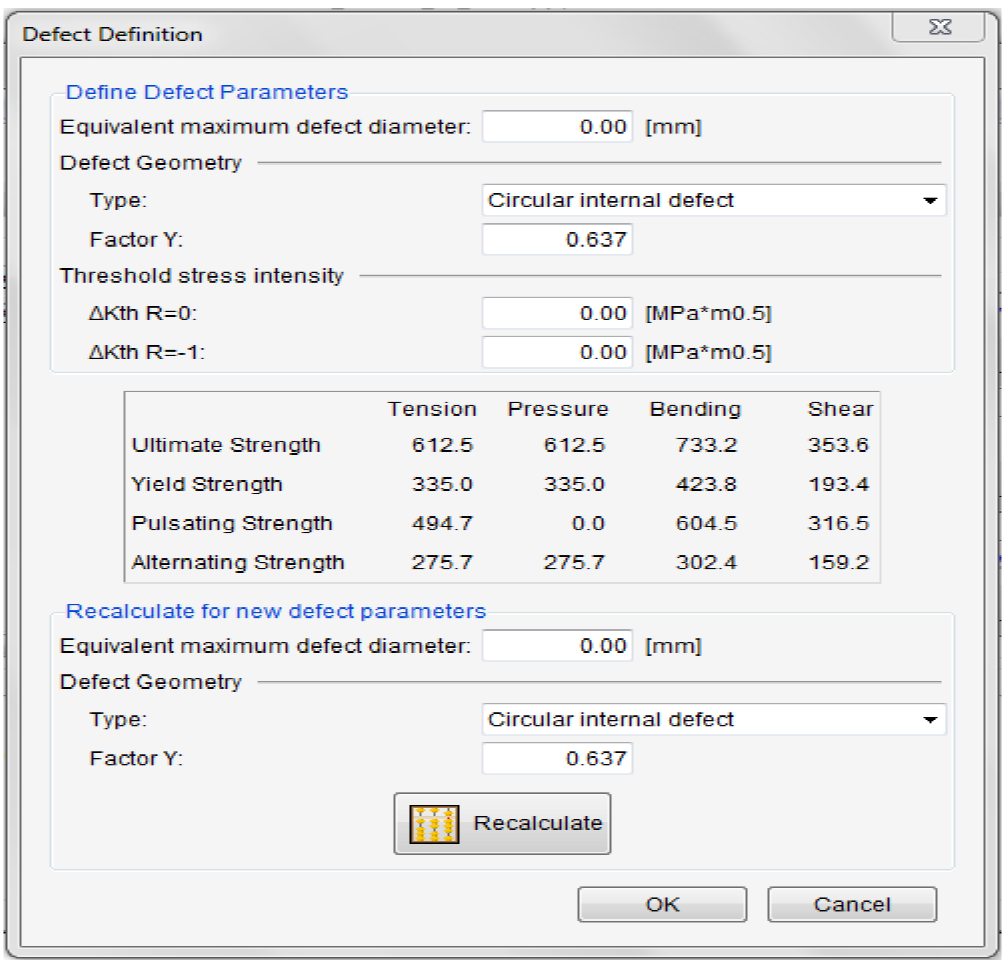


Fig. 4.7 Defect Definition

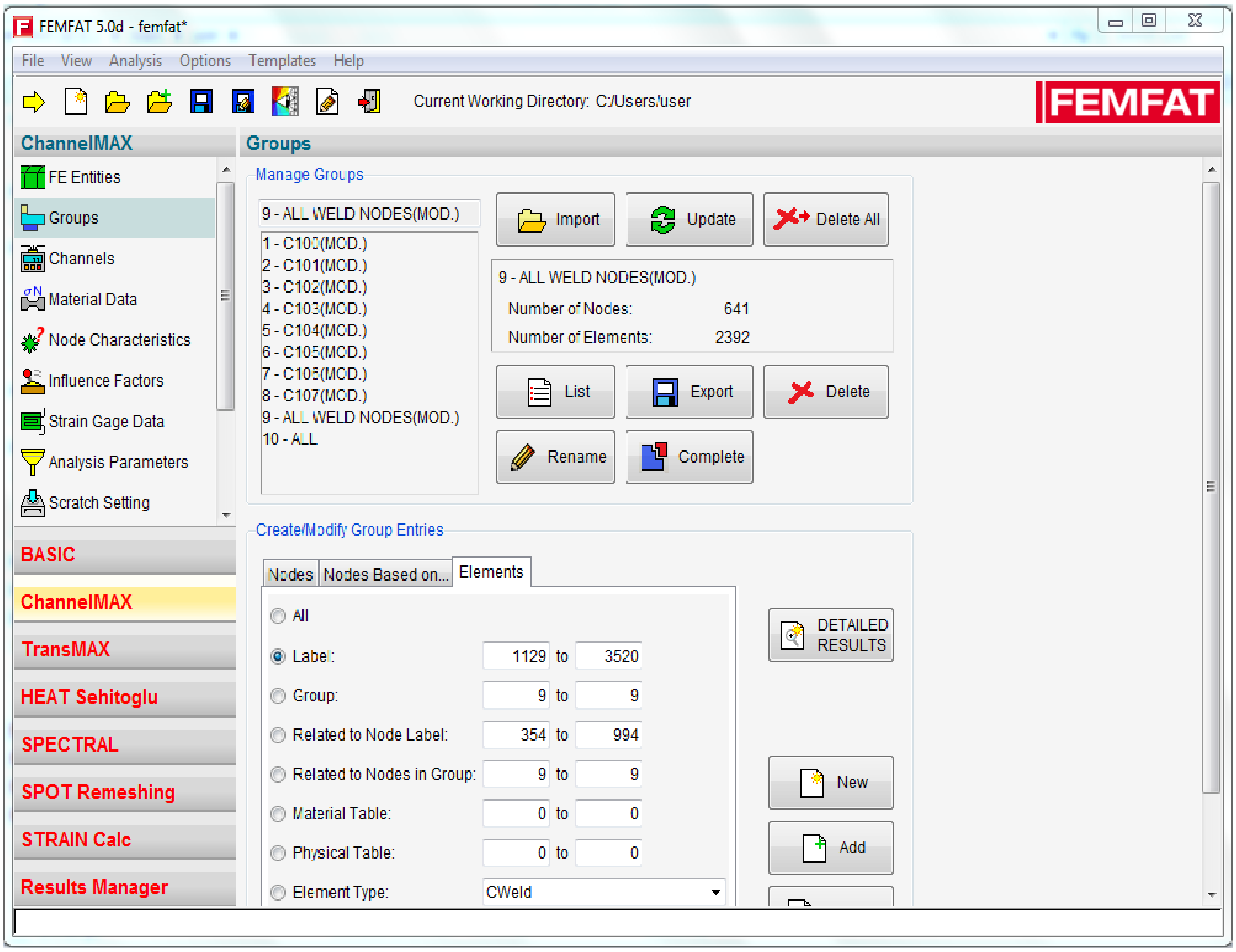


Fig. 4.8 imputing and managing group data's in FEMFAT channels

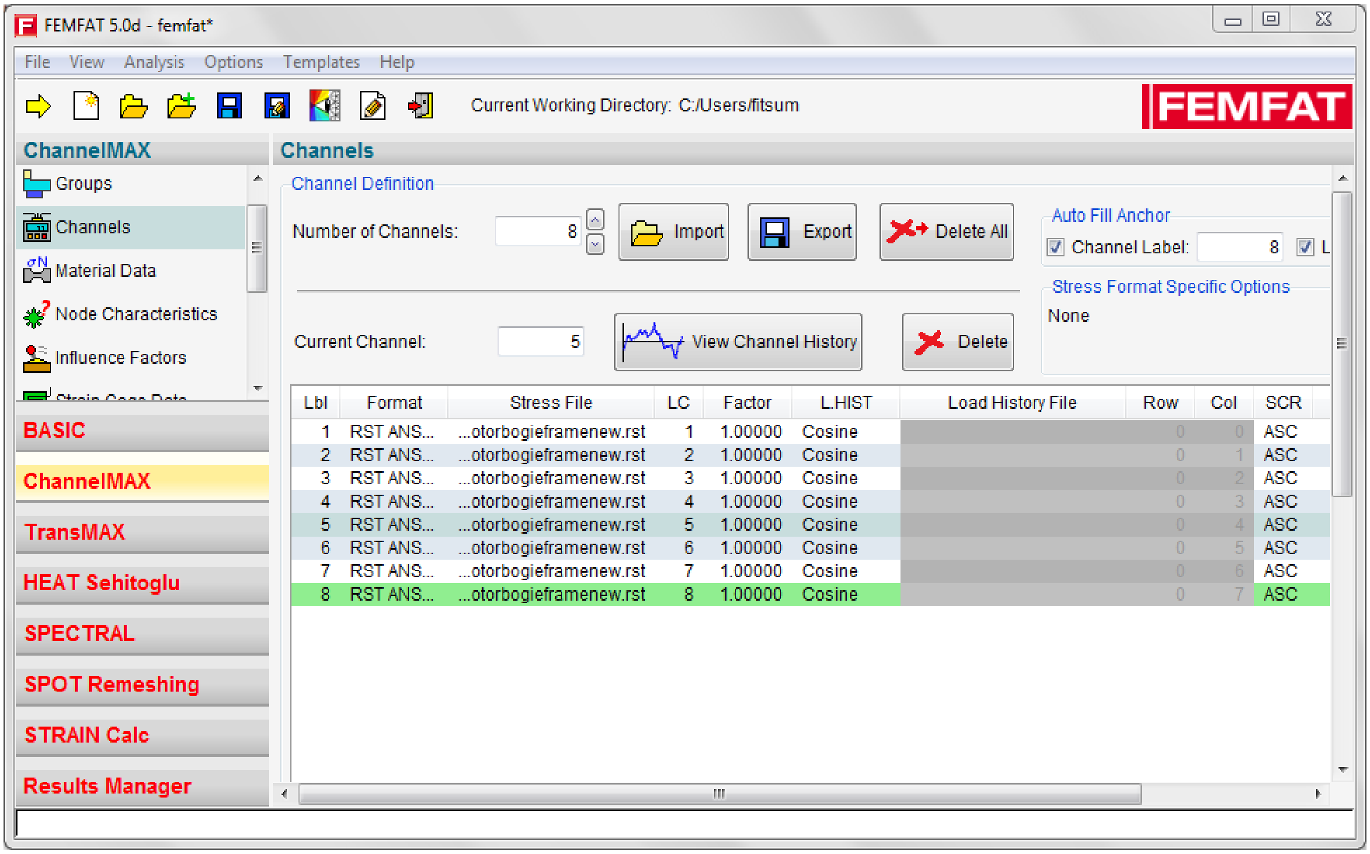


Fig. 4.9 imputing material stress data's in FEMFAT channels

The stress data`s are inserted in 8 load case channels with 100 samples in each load cases. The stress files are in the form of ANSYS rst format.

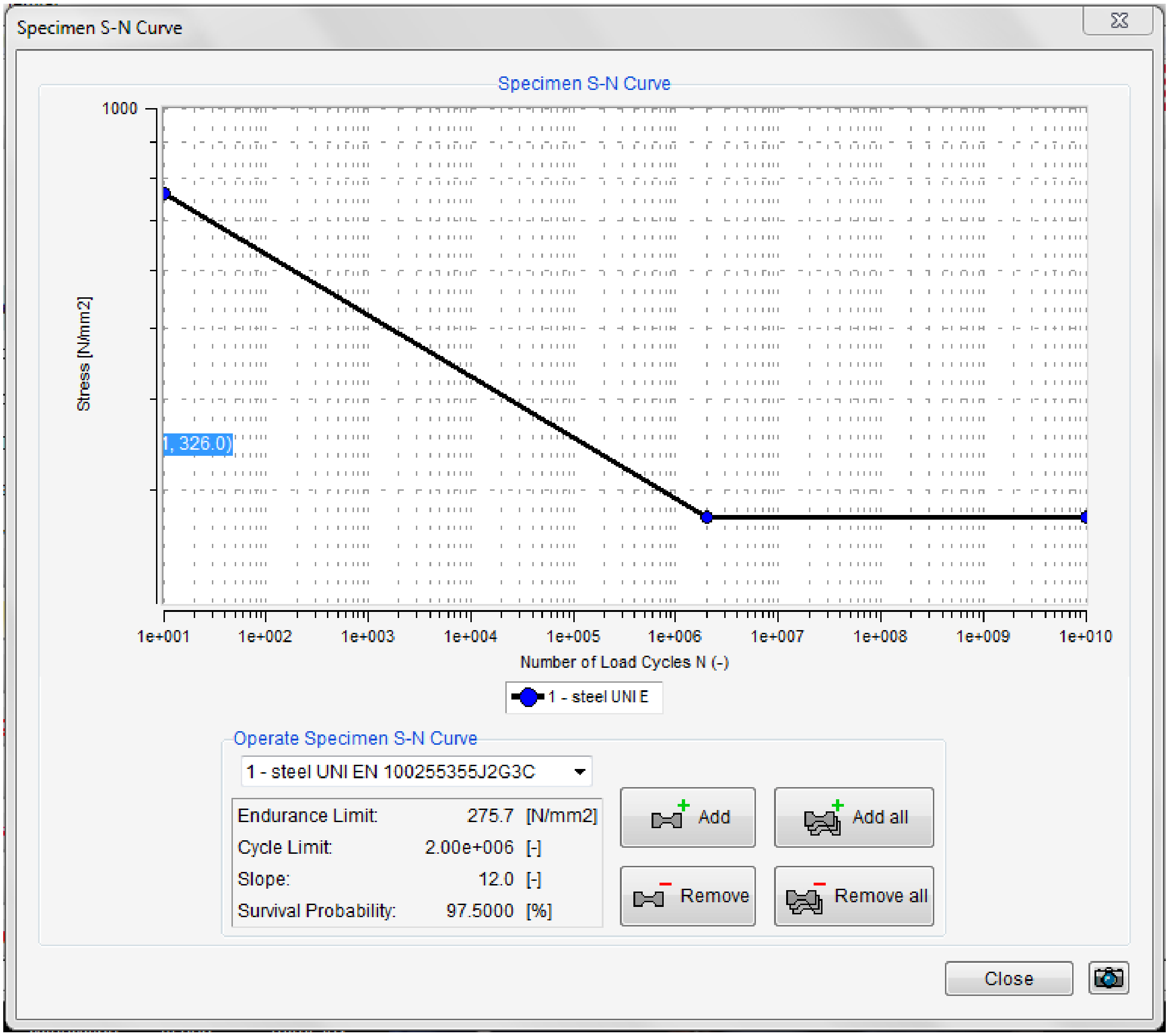


Fig. 4.10 Specimen S-N Curve

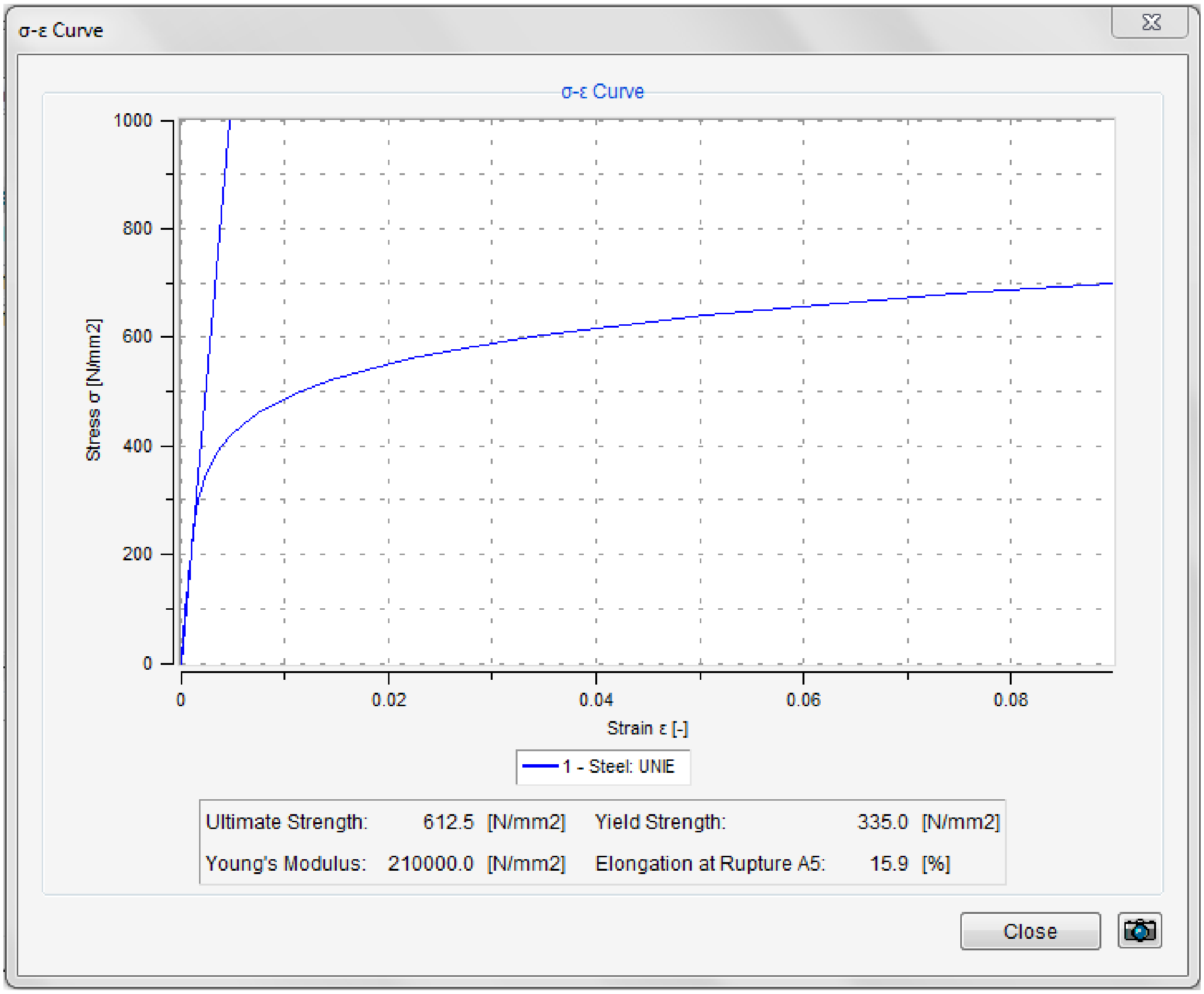


Fig. 4.11 specimen σ-ε Curve

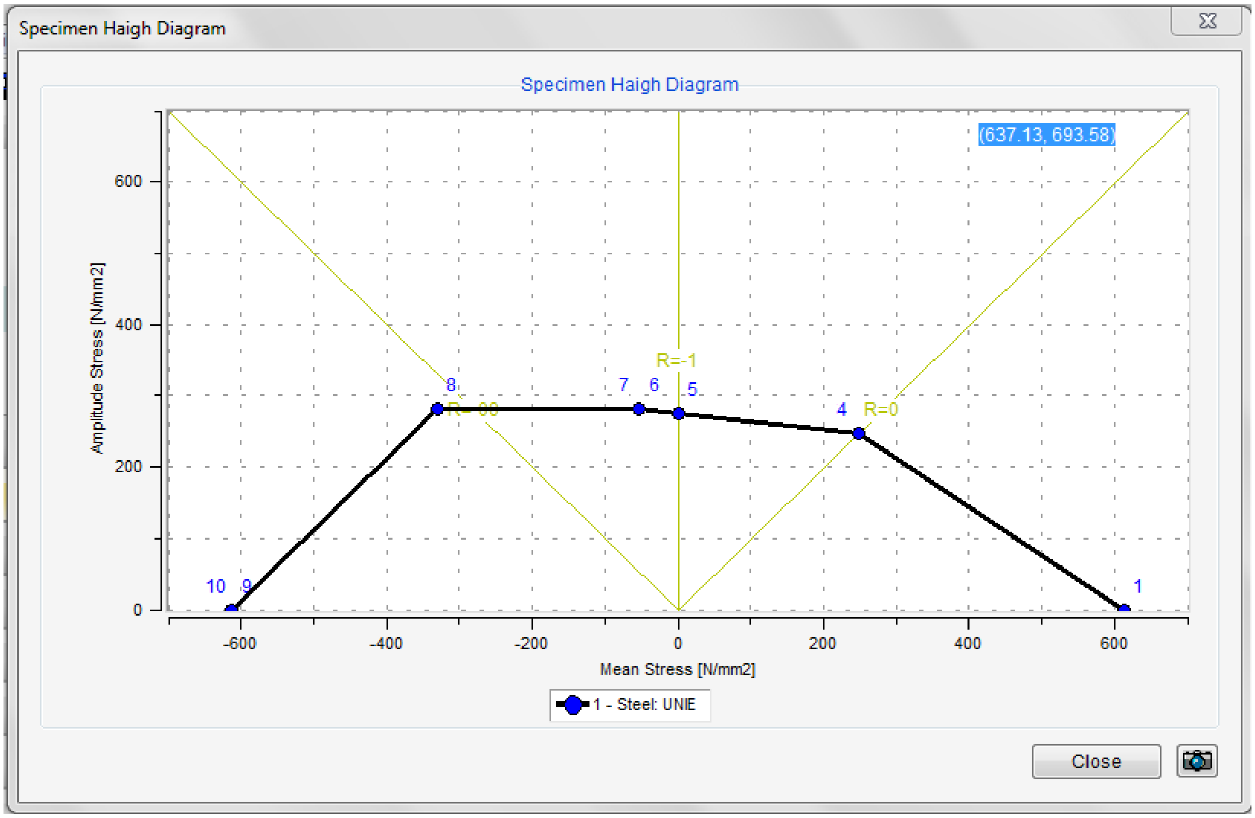


Fig. 4.12 Specimen Haigh Diagram

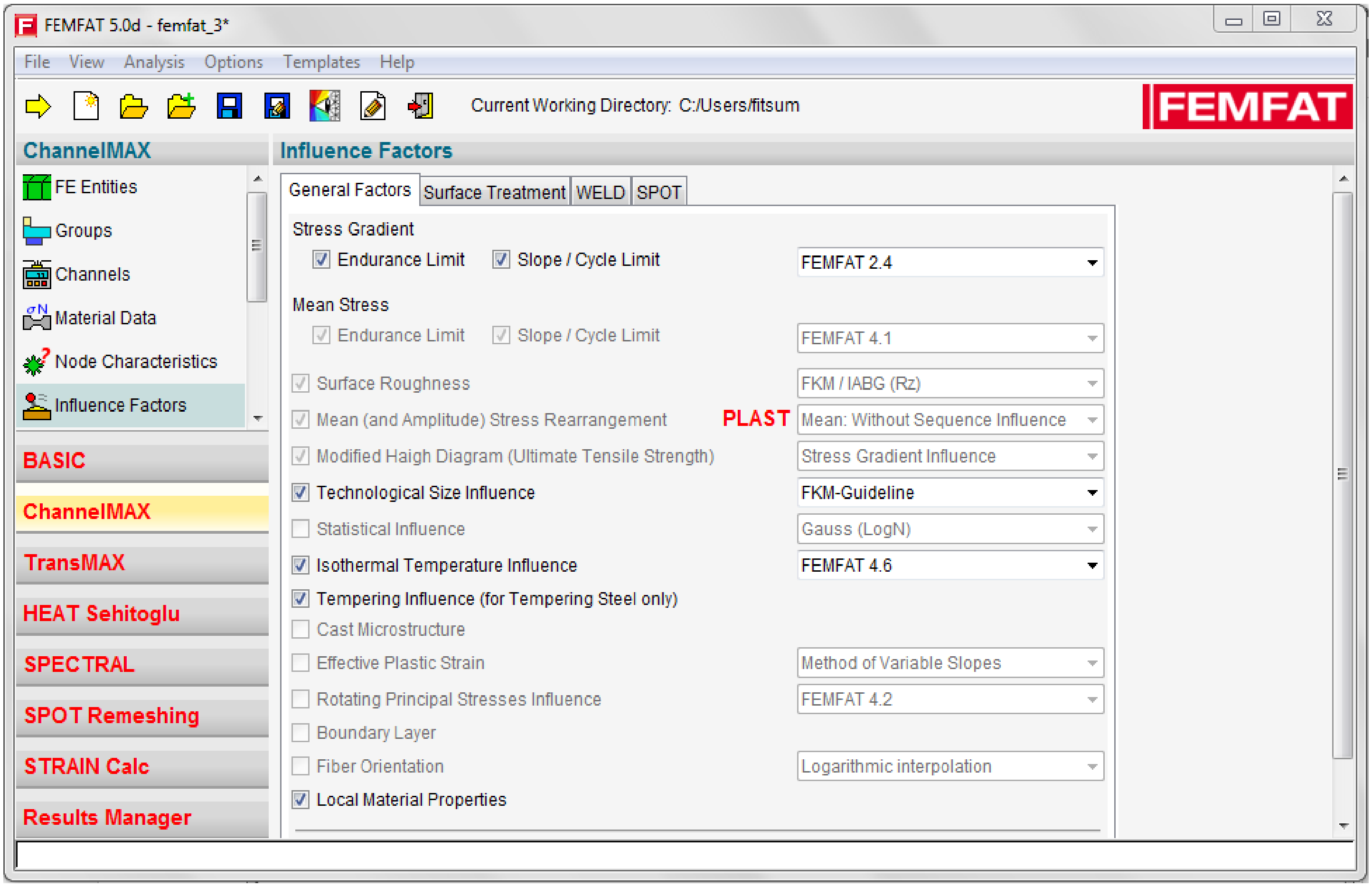


Fig 4.13 General Influence Factors

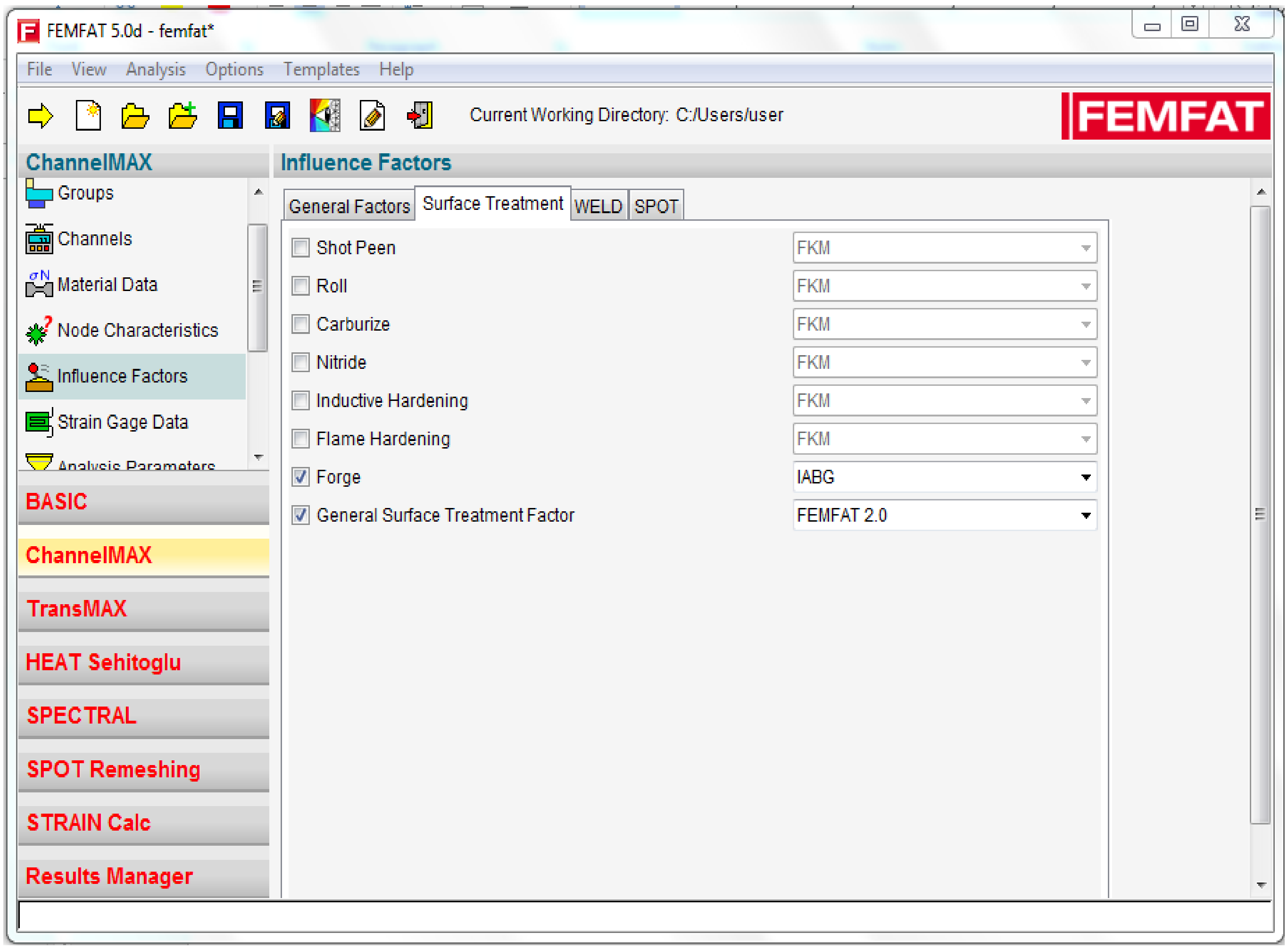


Fig. 4.14 Surface Treatment Influence Factors

The surface treatment`s which are available in Ethiopia are forging and heat treatment by tempering which are general surface treatment methods.

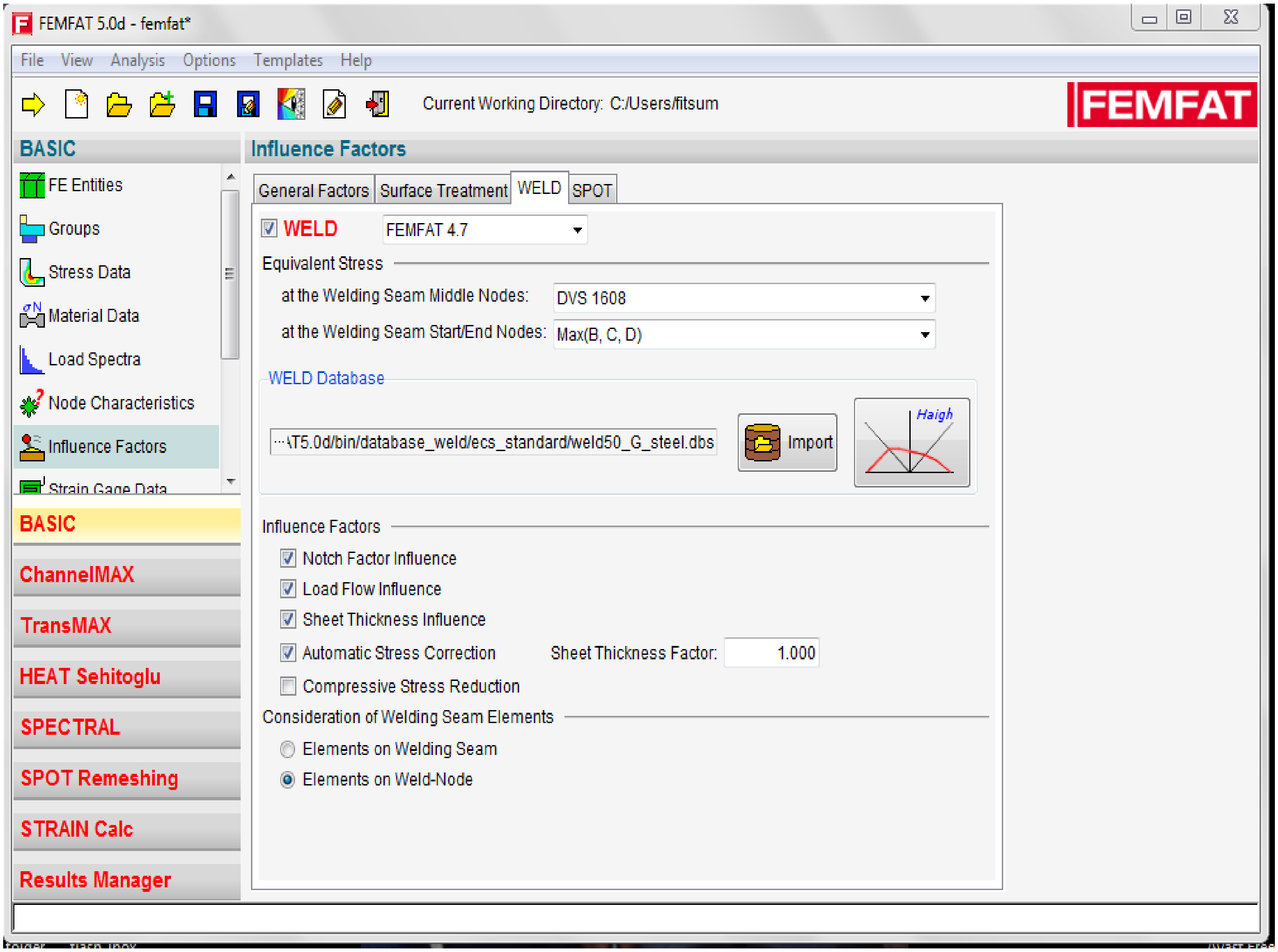


Fig. 4.15 Weld influence Factors

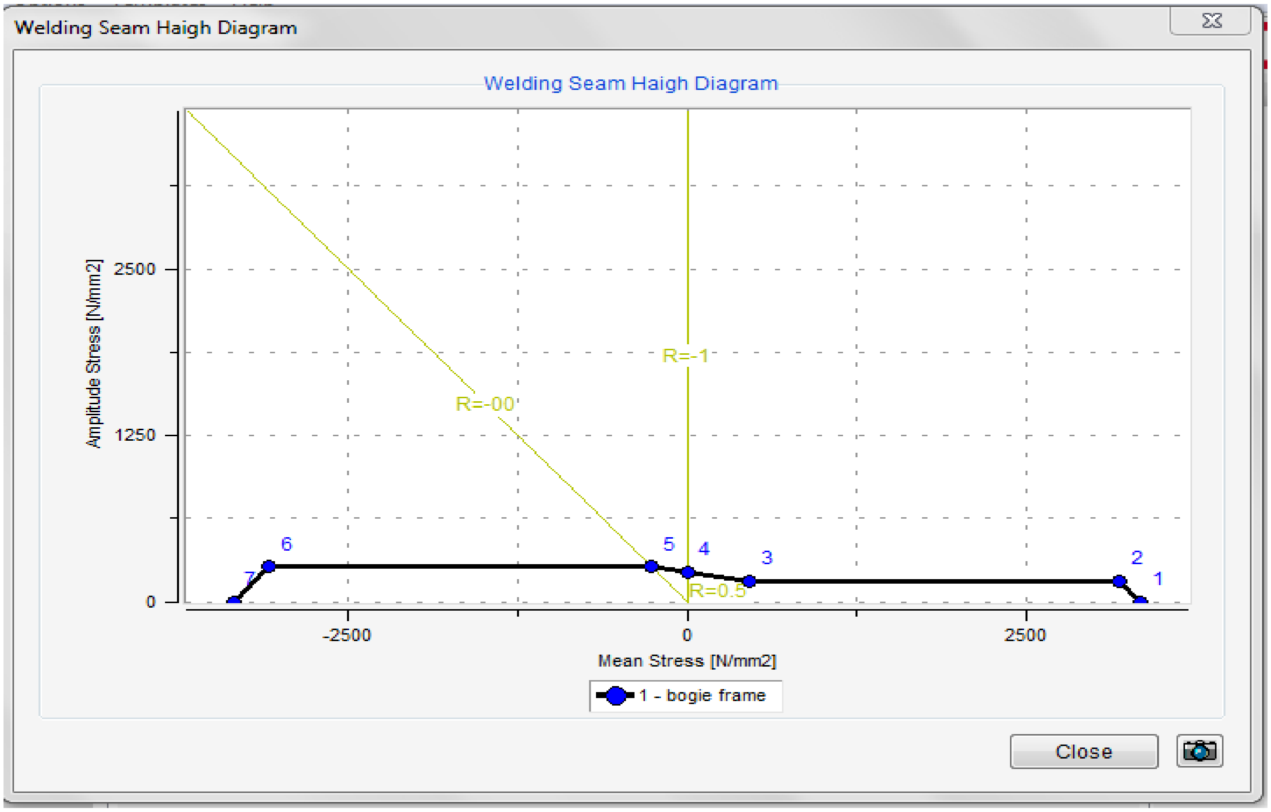


Fig. 4.16 Welding seam Haigh Diagram

II. FEMFAT WELD Post-Processing

1. Results with FEMFAT WELD Module Without Sensitivity Factor

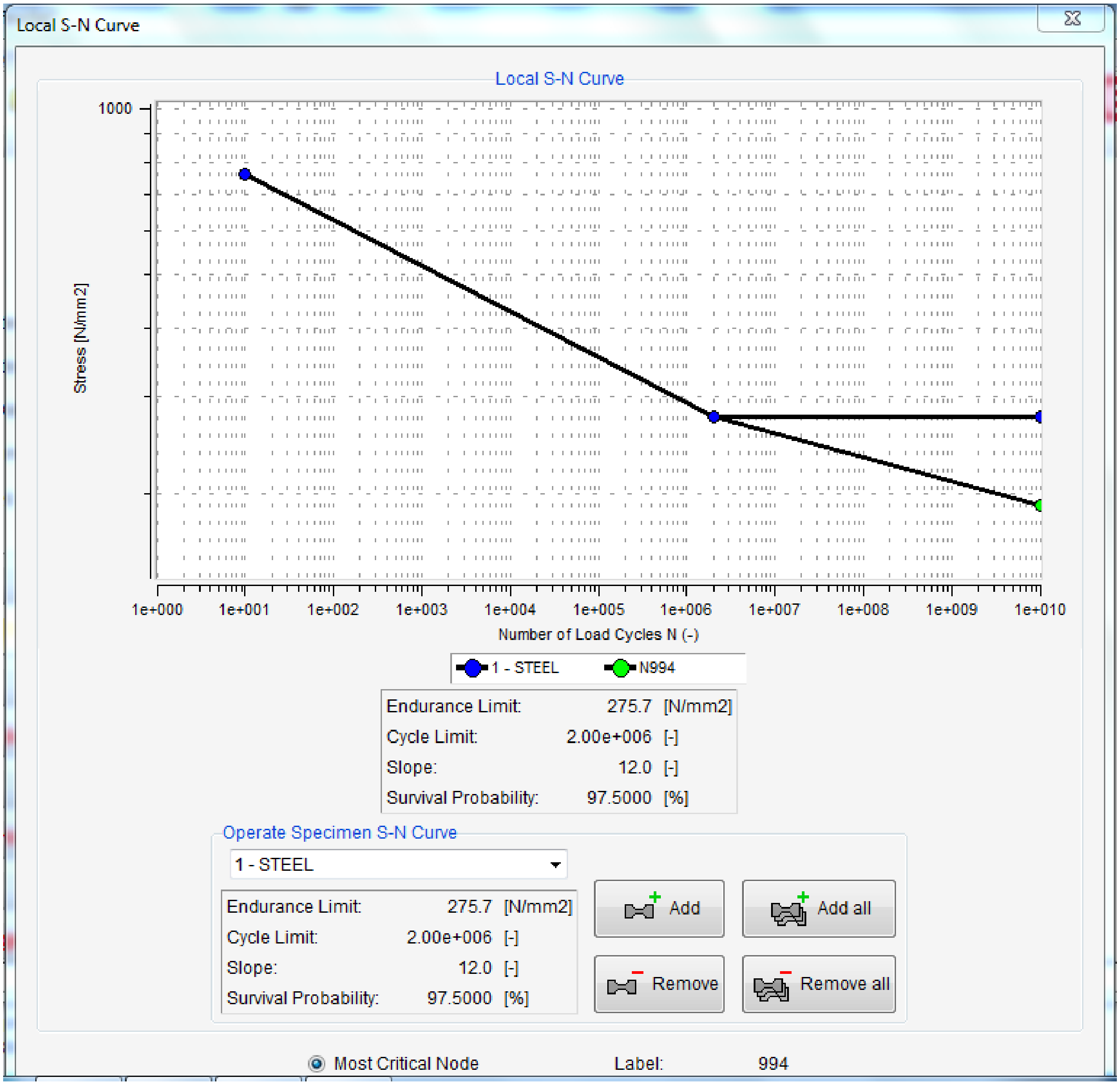


Fig 4.17 Local S-N curve Without Sensitivity Factor

The Local S-N graph includes the following 275.7 N/mm^2 Endurance limit, 2.0e6 fatigue life and 97.5% survival probability.

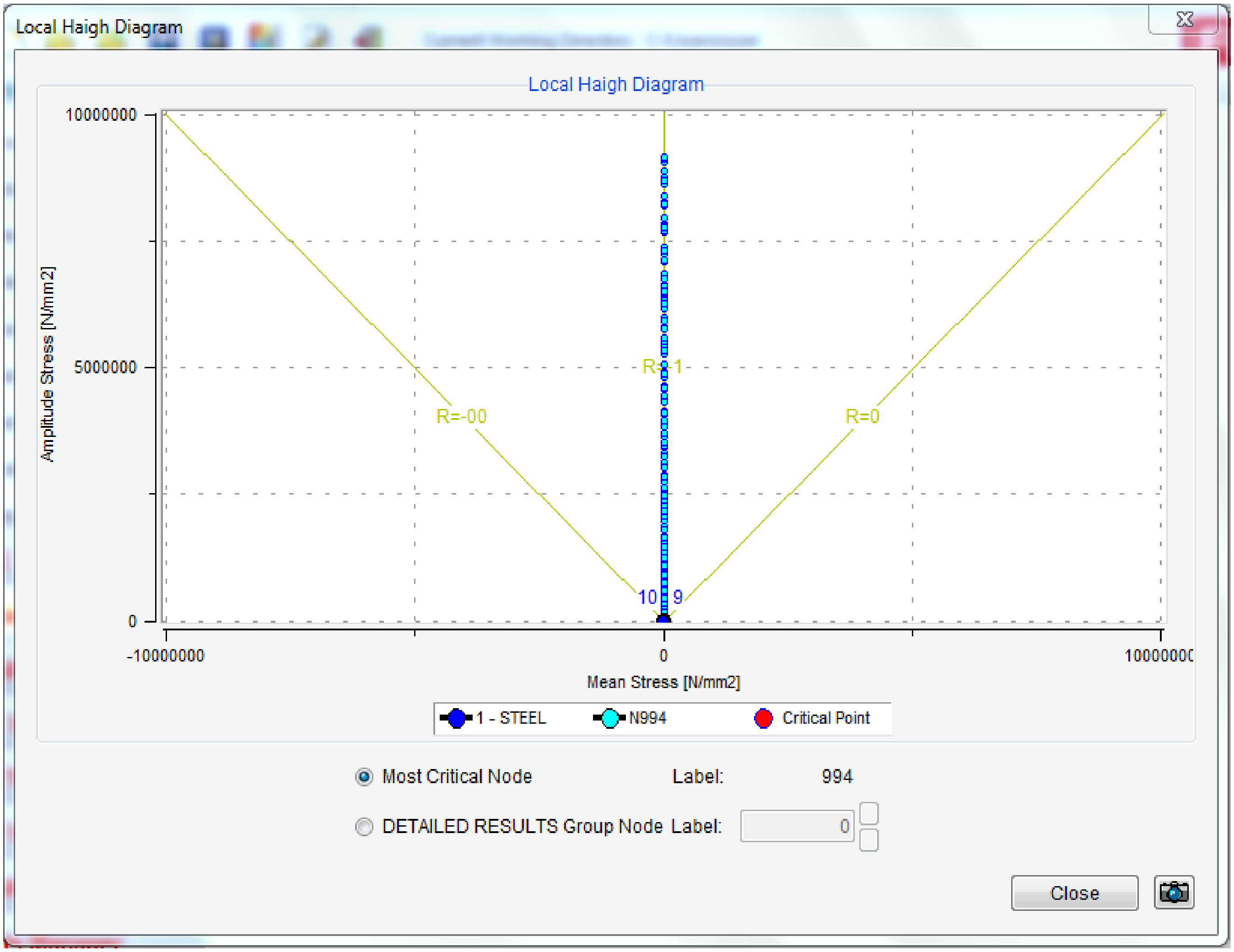


Fig 4.18 Local S-N curve Without Sensitivity Factor

This diagram shows the critical point of failure is at node 994 and the ratio of amplitude stress to mean stress (R) falls at R=-1. Which means the amplitude loading is constant.

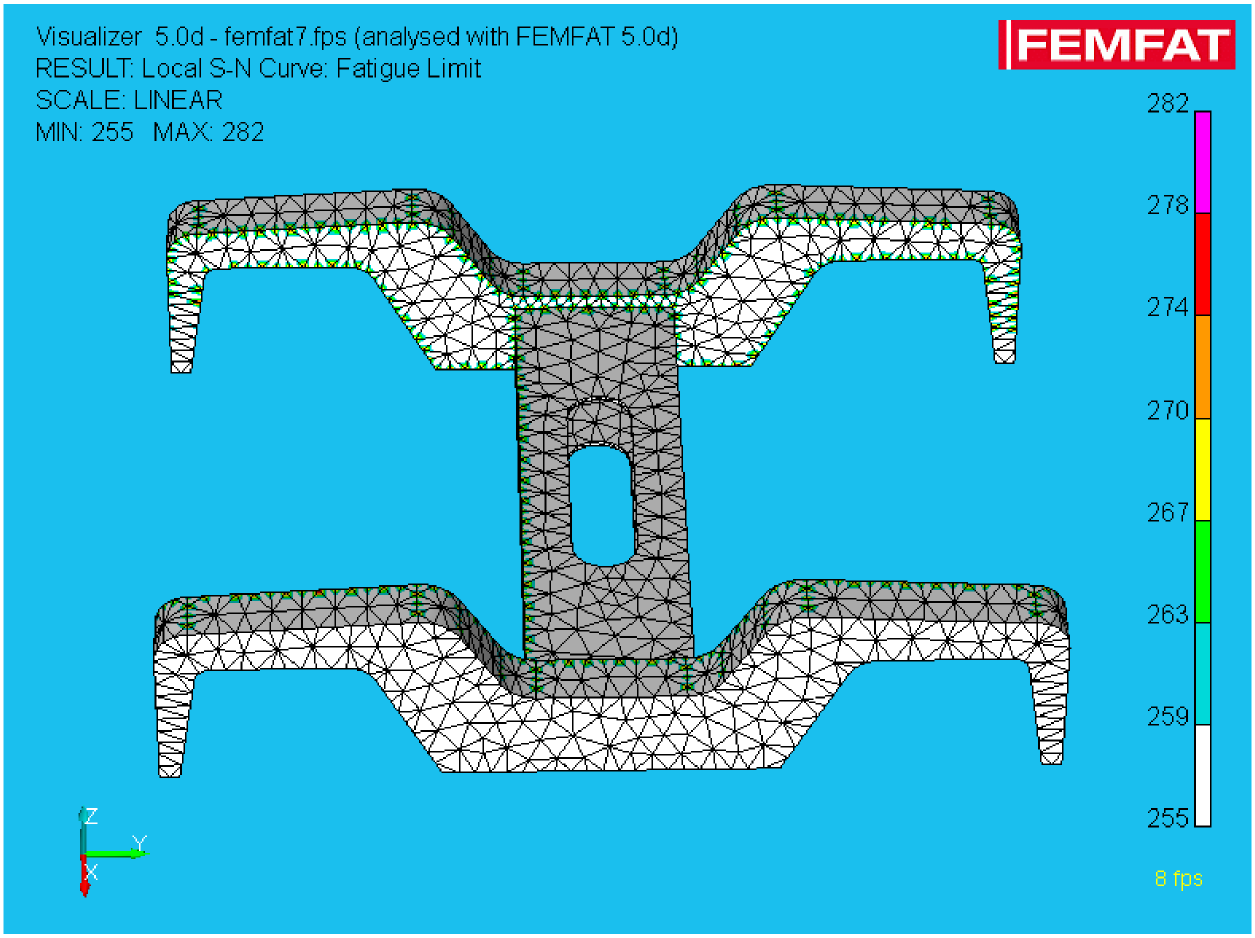


Fig 4.19 Fatigue Limit without any sensitivity factor

From the Local S-N curve the fatigue limit ranges from 282 to 255 N/mm2. The fatigue limit is expressed in terms of stress value, it is not more than the material yield strength that is 335 N/mm2 and hence we can say the material is safe in this range.

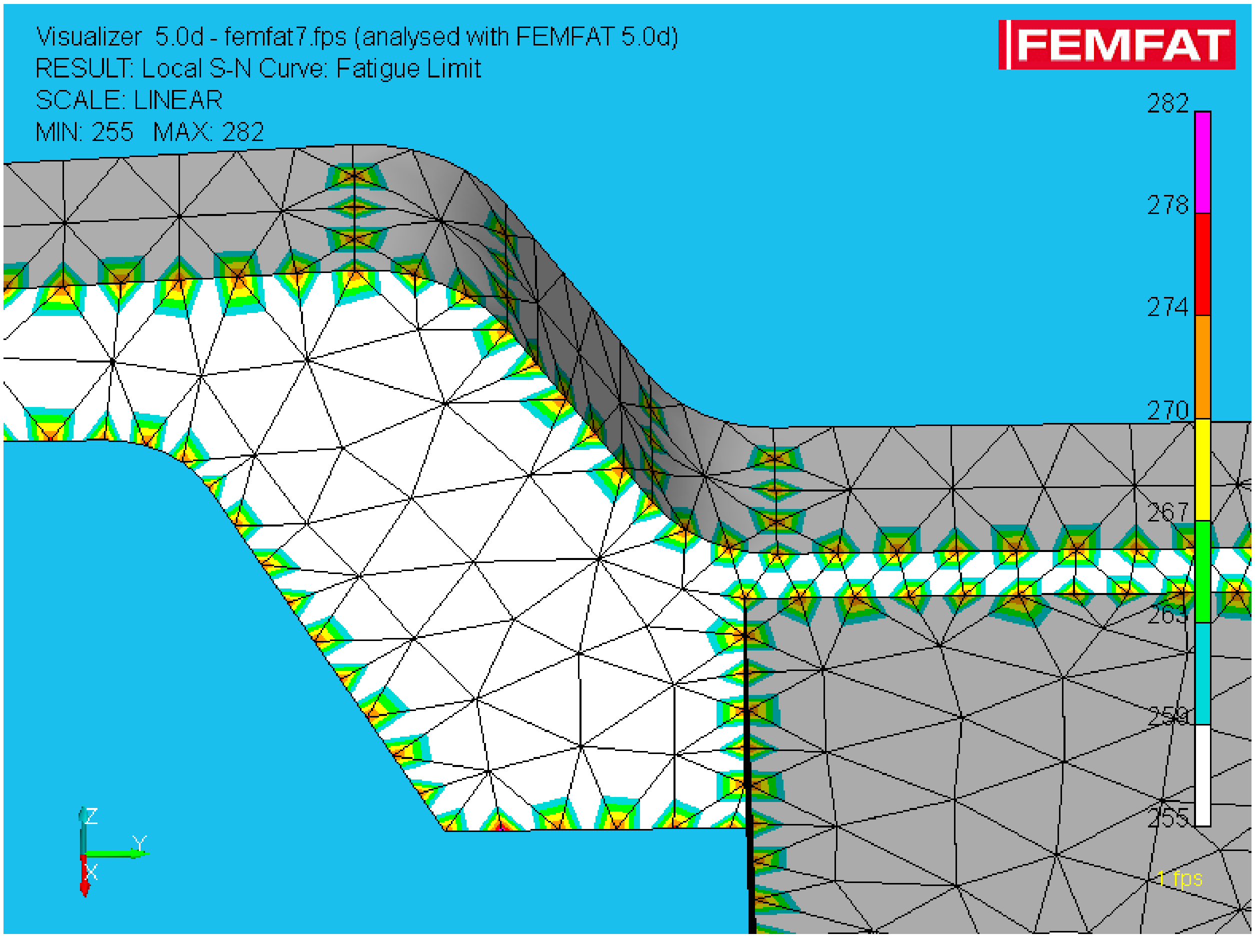


Fig 4.20 Fatigue Limit without any sensitivity factor by zooming

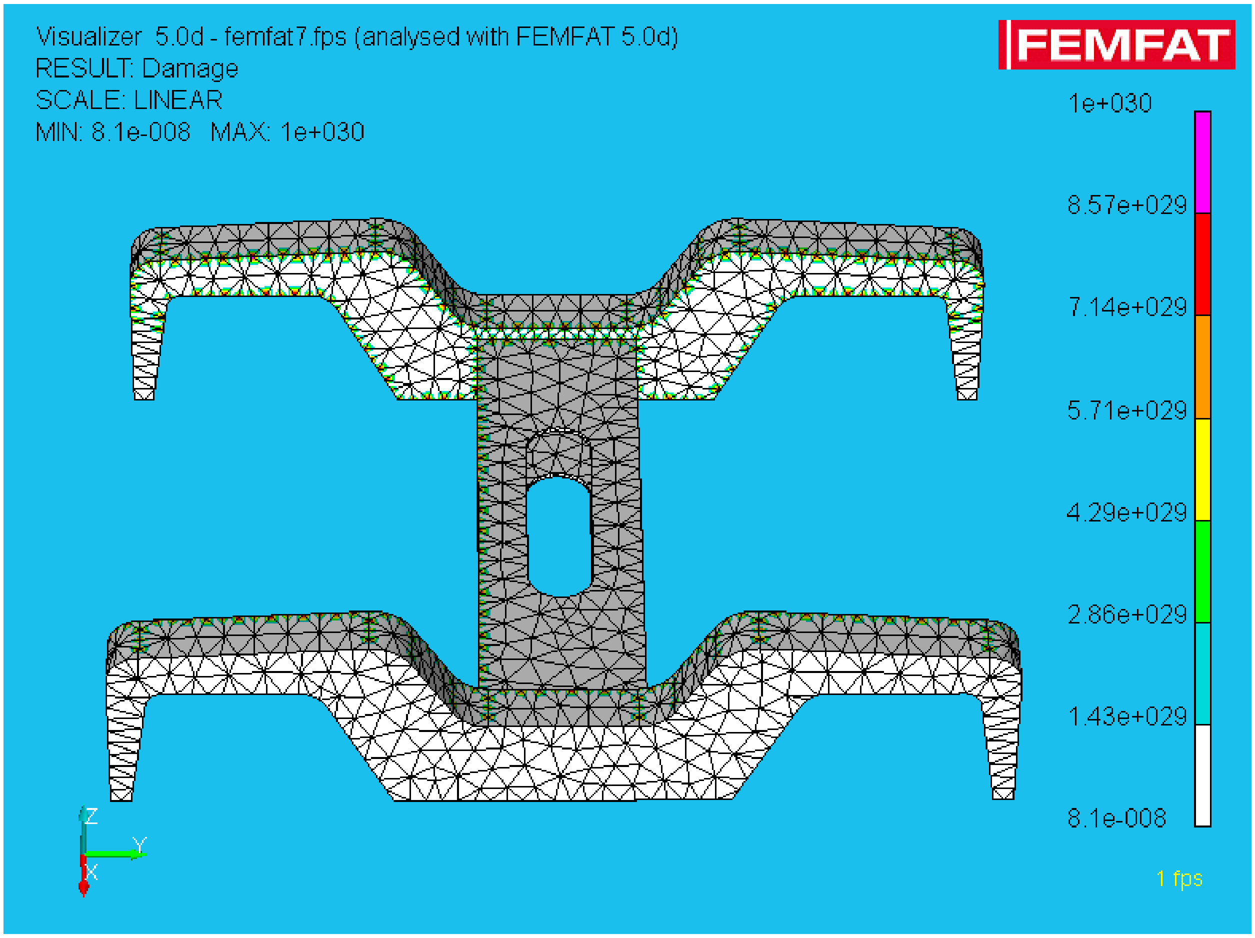


Fig 4.21 Damage value without any sensitivity factor

From the figure above which is damage value without any sensitivity factor, the Damage result ranges from 8.1e-8 to 1e+030 in log form. The damage value is maximum at the weld joints so that special attention should be given for the weld connections.

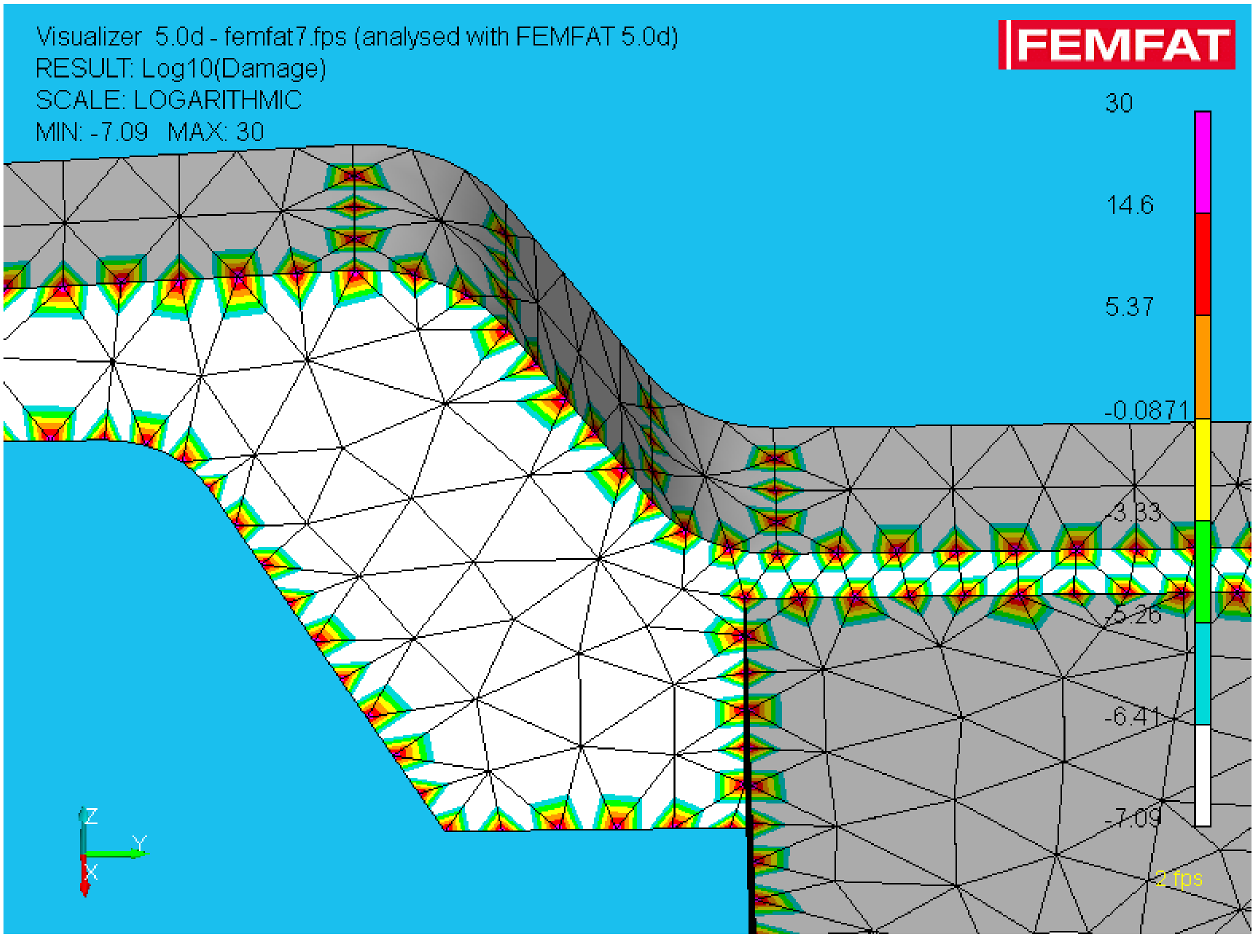


Fig 4.22 Log10Damage value without any sensitivity factor

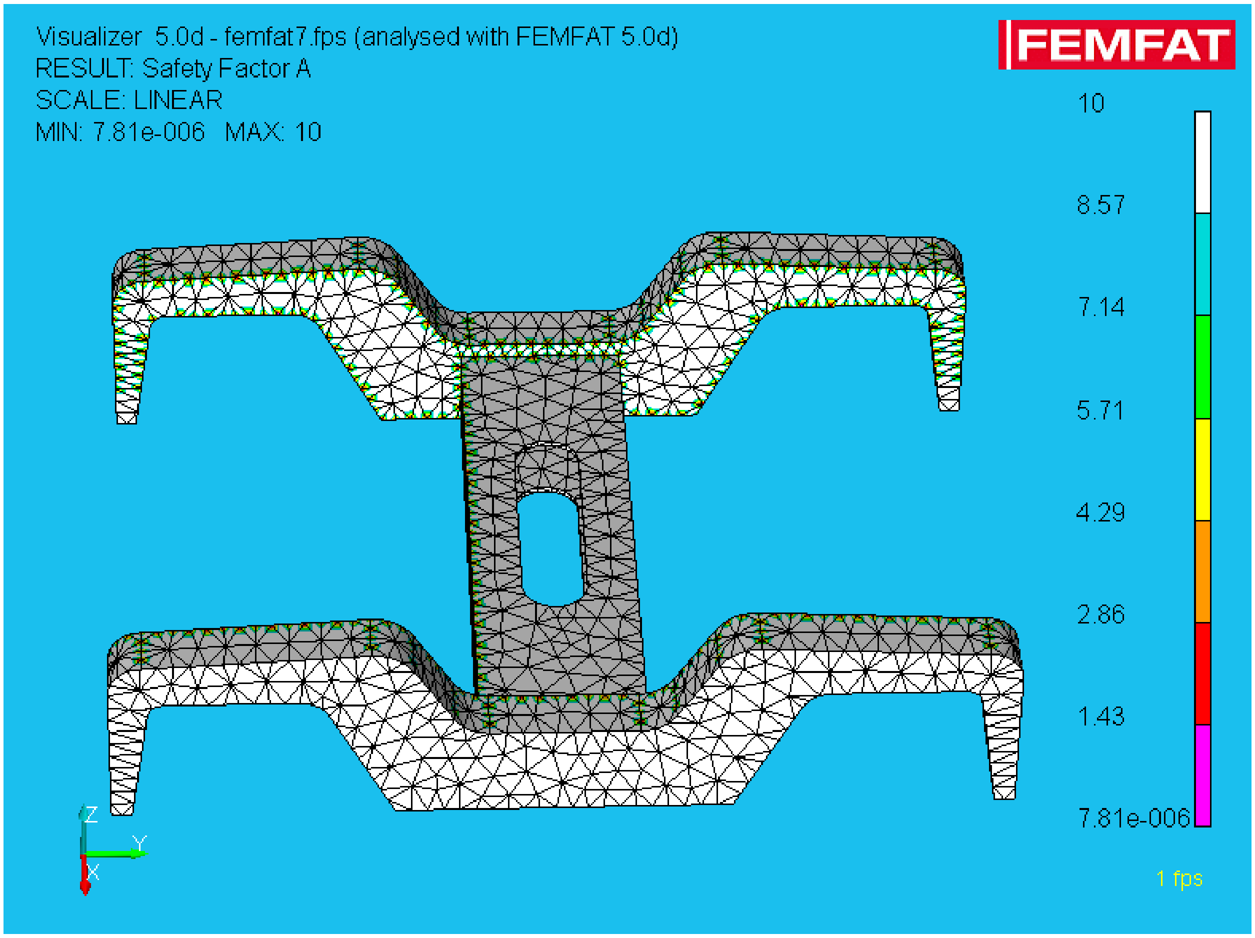


Fig 4.23 Endurance Safety Factor without any sensitivity factor

From the figure above the endurance safety factor for the welded bogie frame ranges from 7.81e-6 to 10.

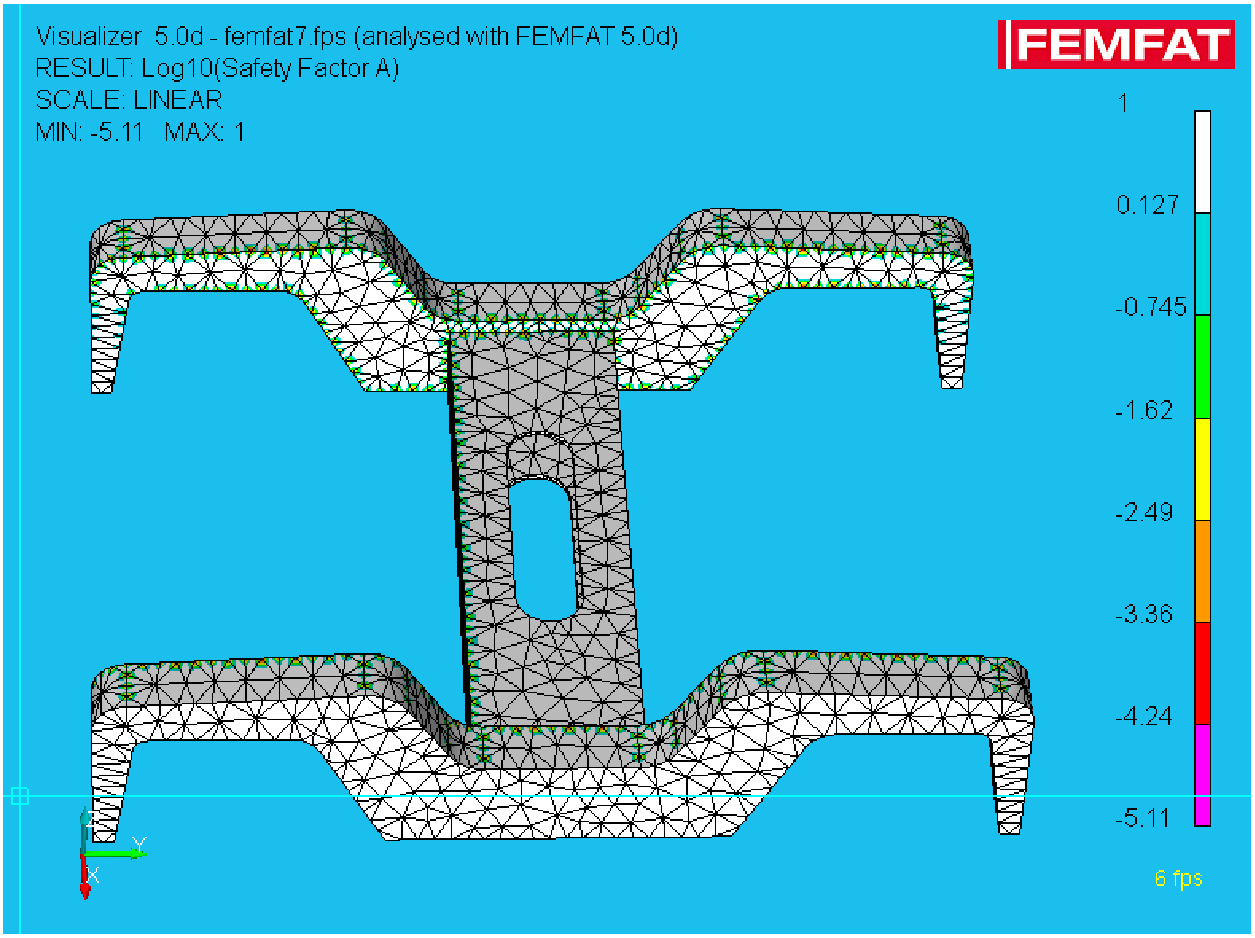


Fig 4.24 Log10 Endurance Safety Factor without any sensitivity factor

From the figure above the endurance safety factor for the welded bogie frame ranges from -5.11 to 1.the figure shows that the minimum safety factor occurs at the welded joints where as it is below 1 and needs special attention.

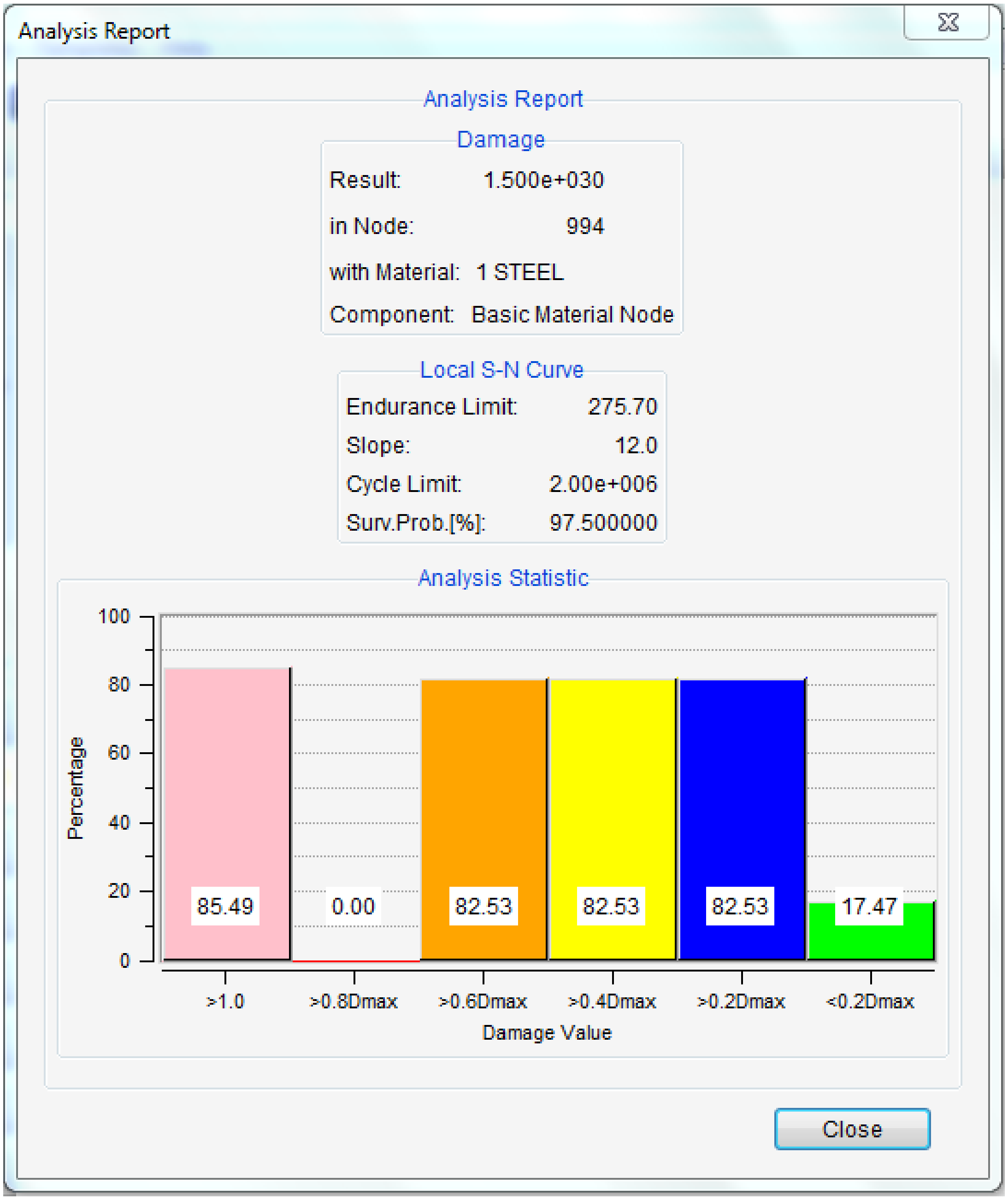


Fig 4. 25 Damage Analysis Report without any sensitivity factor

From the above damage analysis report the following results have been found 1.5e+30 maximum damage value at node 994 with 275.7N/mm2 Endurance limit, 2e6 fatigue life and 97.5% survival probability.

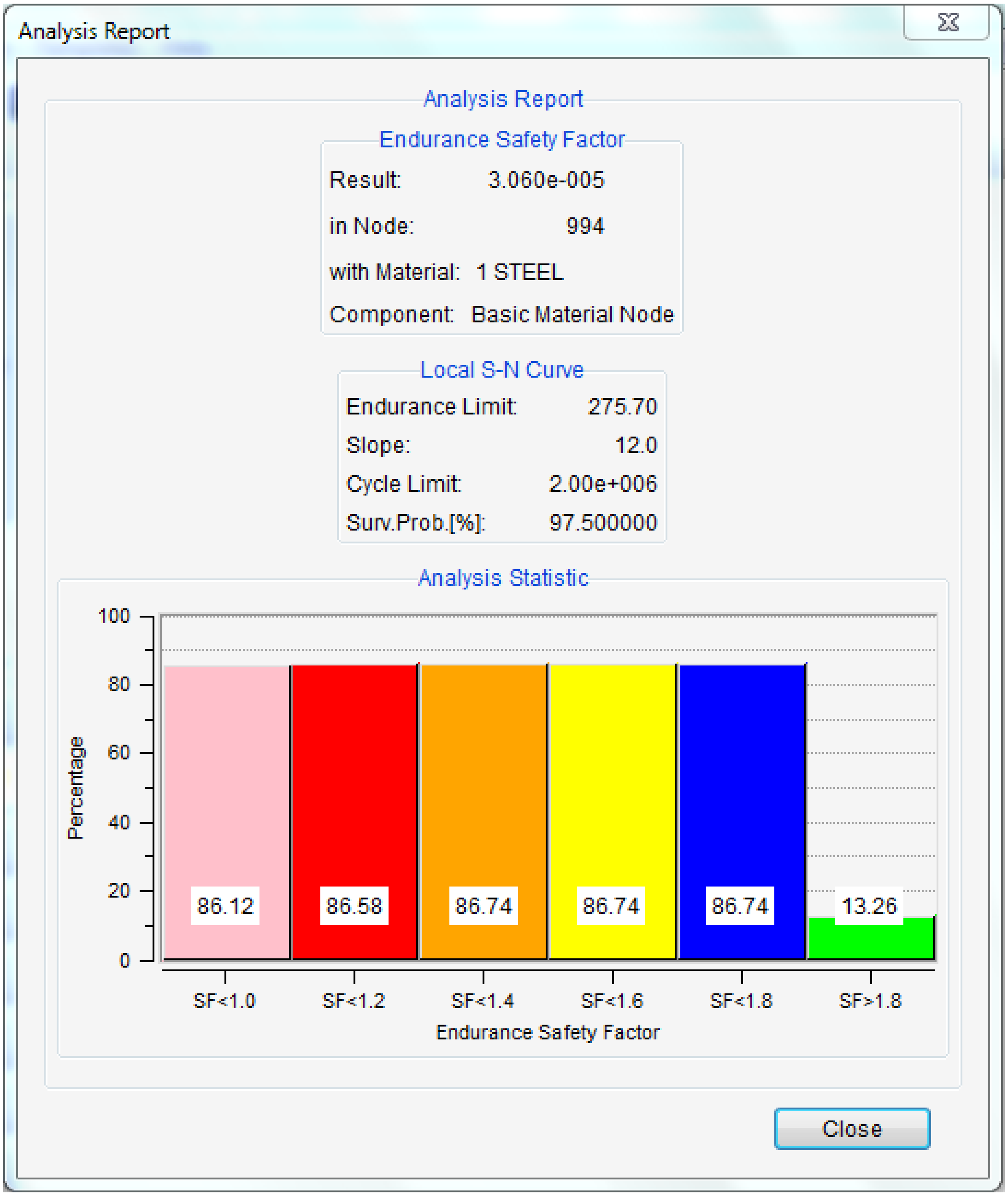


Fig 4.26 Endurance Safety Factor Analysis Report without any sensitivity factor

From the above endurance safety factor analysis report the following results have been found 3.06e-5 min endurance safety factor at node 994 with 275.7 N/mm2 Endurance limit, 2.0e6 fatigue life and 97.5% survival probability.

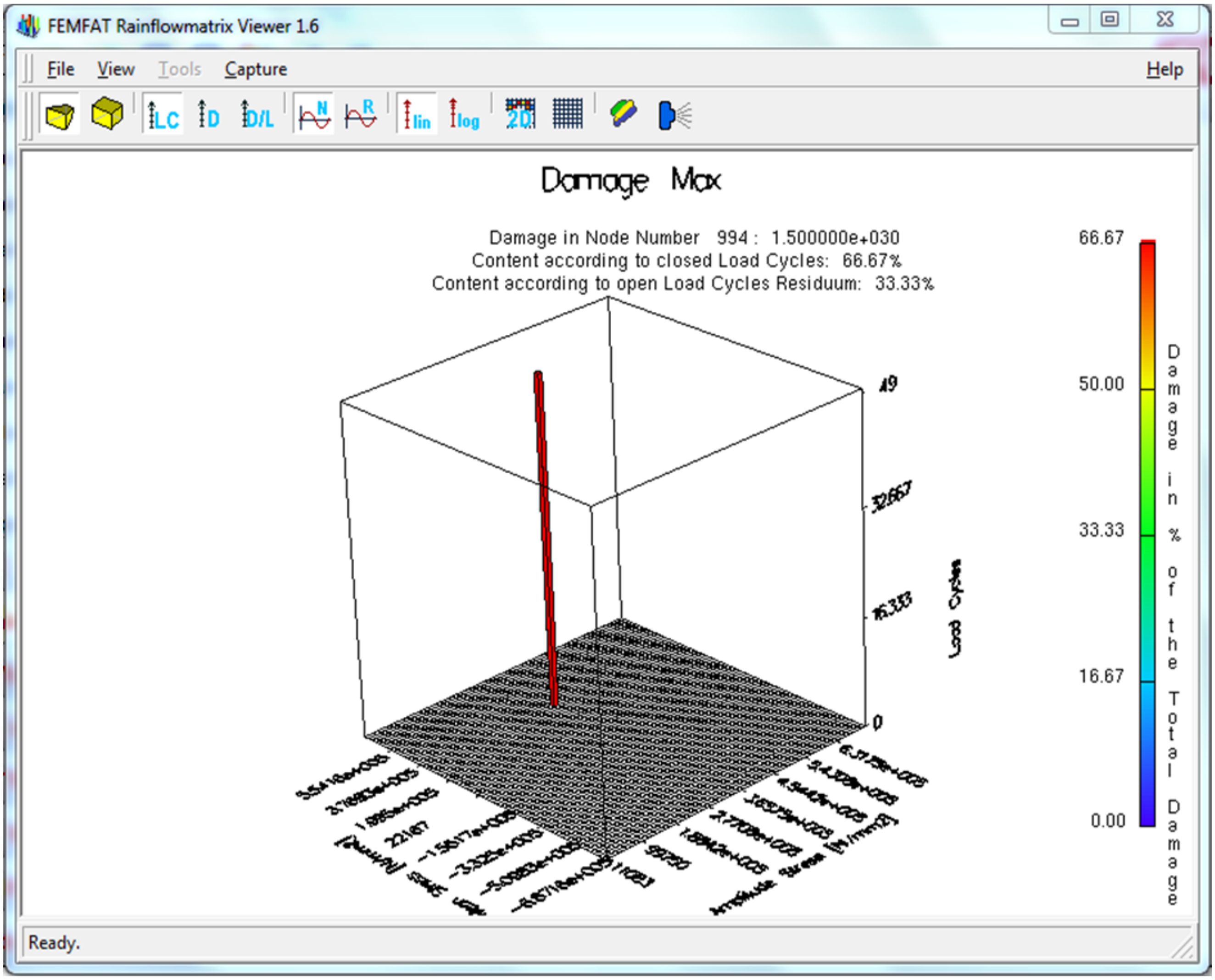


Fig 4.27 Rain Flow Matrix without any sensitivity factor

The header of the rainflow matrix gives information how much damage is caused by closed load cycles and how much damage is caused by residual stress. In this case 33.33% of the total damage is caused by residual stress and 66.67% is caused by closed load cycles.

2. Results with FEMFAT WELD Module sensitivity seam thickness

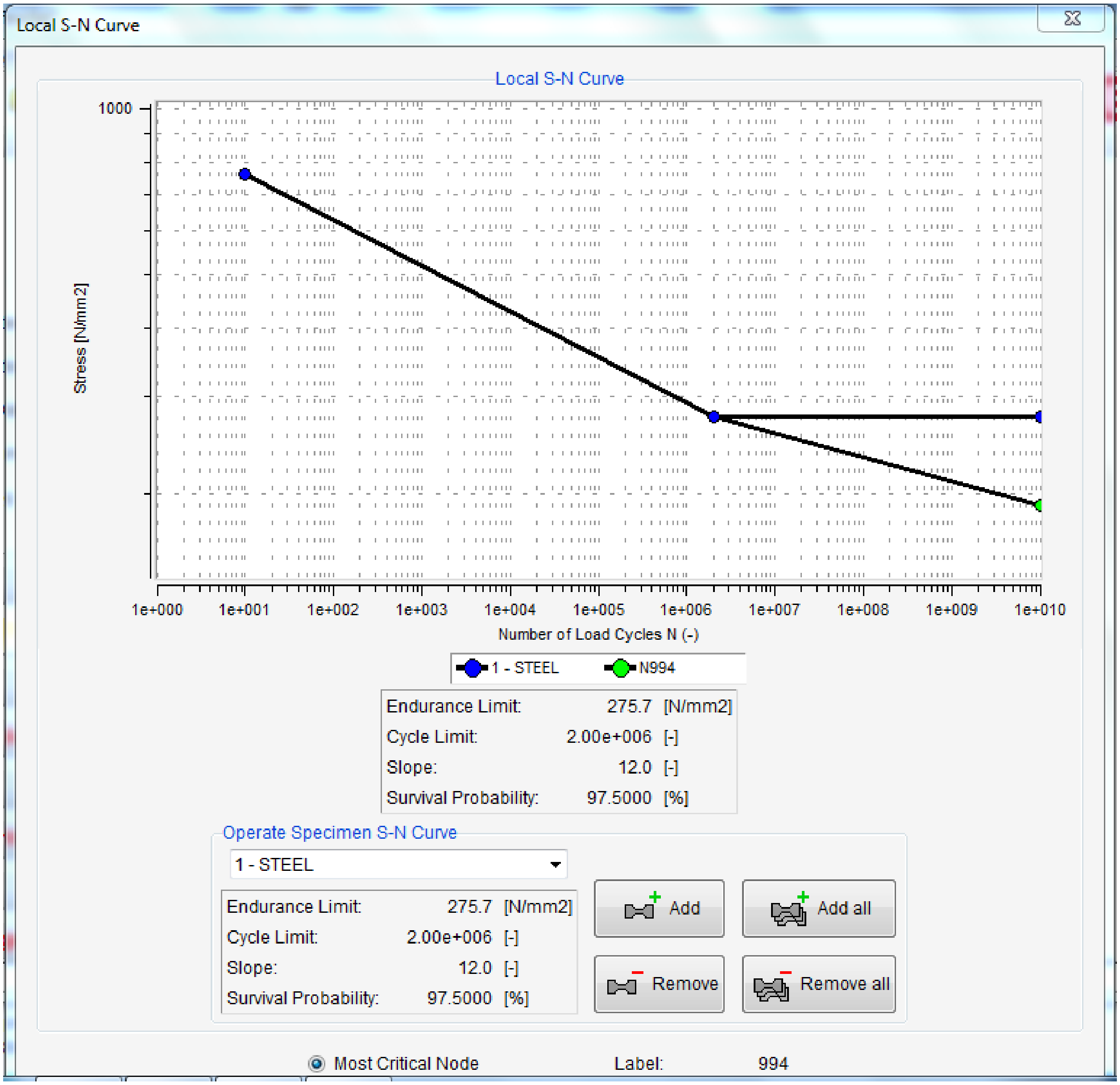


Fig 4.28 Local S-N curve at small seam thickness sensitivity

The Local S-N graph for small seam thickness sensitivity includes the following 275.7 N/mm2 Endurance limit, 2.0e6 fatigue life and 97.5% survival probability.

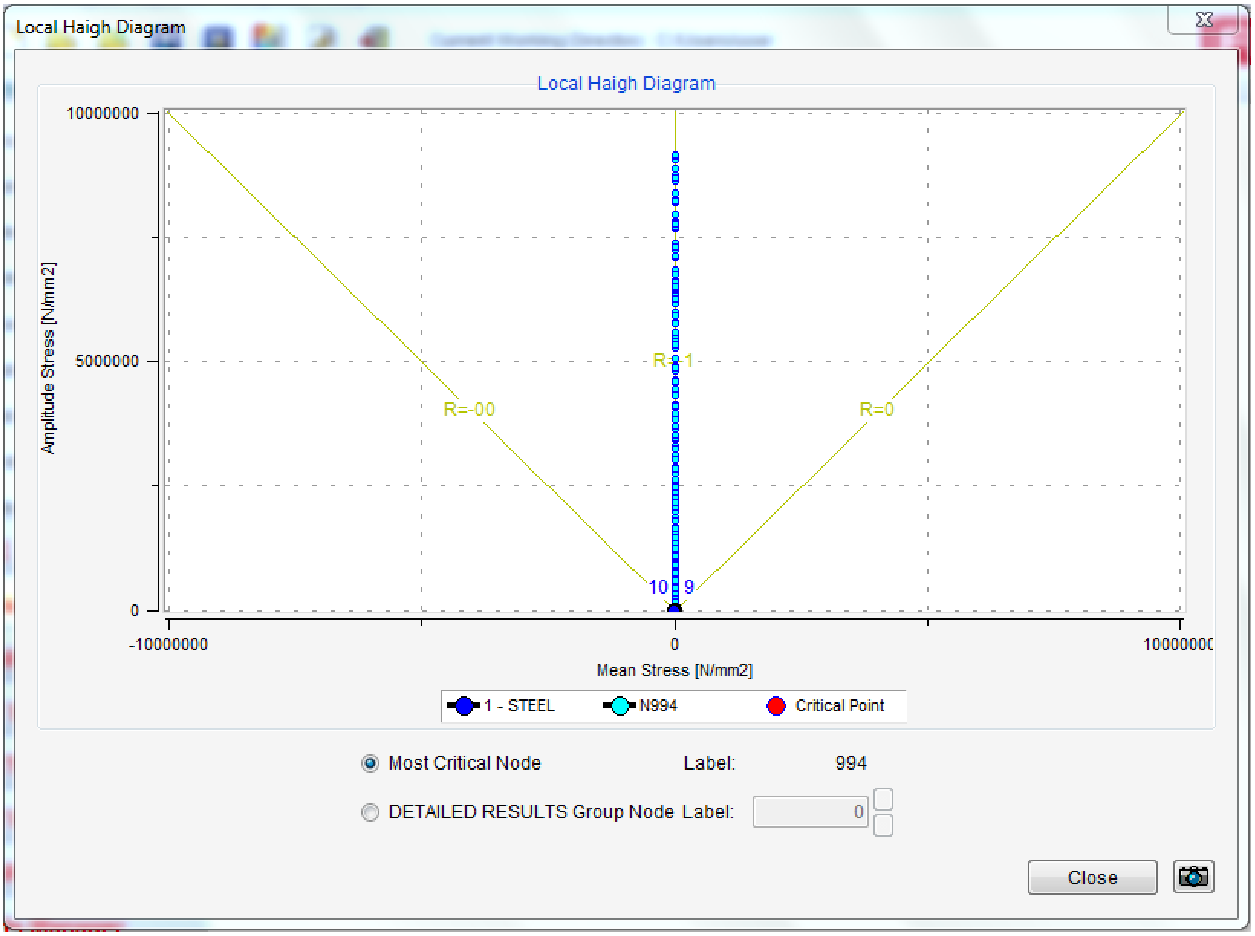


Fig 4.29 Local Haigh Diagram at small seam thickness sensitivity

This diagram shows the critical point of failure is at node 994 and the ratio of amplitude stress to mean stress (R) falls at R=-1. Which means the amplitude loading is constant.

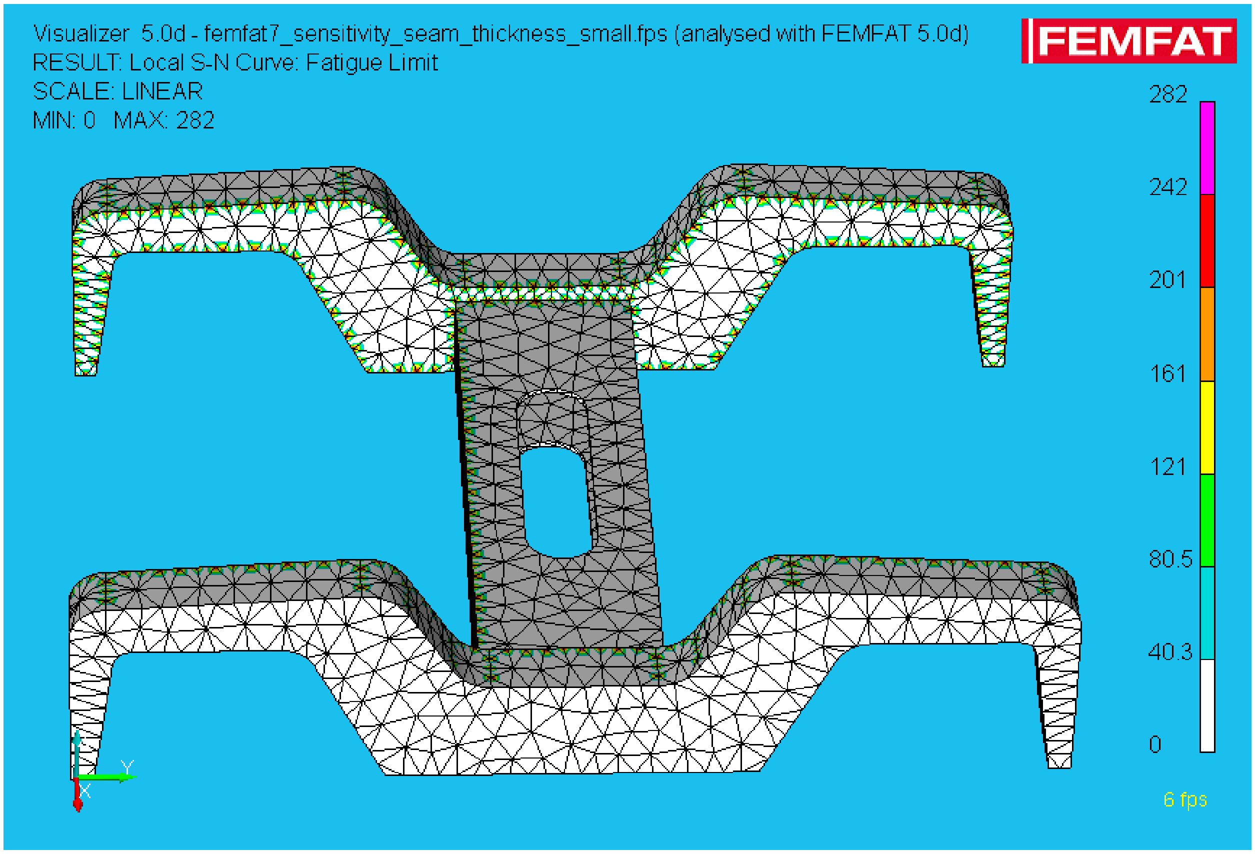


Fig. 4.30 Fatigue limit at small seam thickness sensitivity

From the Local S-N curve for small seam thickness sensitivity the fatigue limit ranges from 282 to 0 N/mm2. The fatigue limit is expressed in terms of stress value, it is not more than the material yield strength that is 335 N/mm2 and hence we can say the bogie frame is safe in this range.

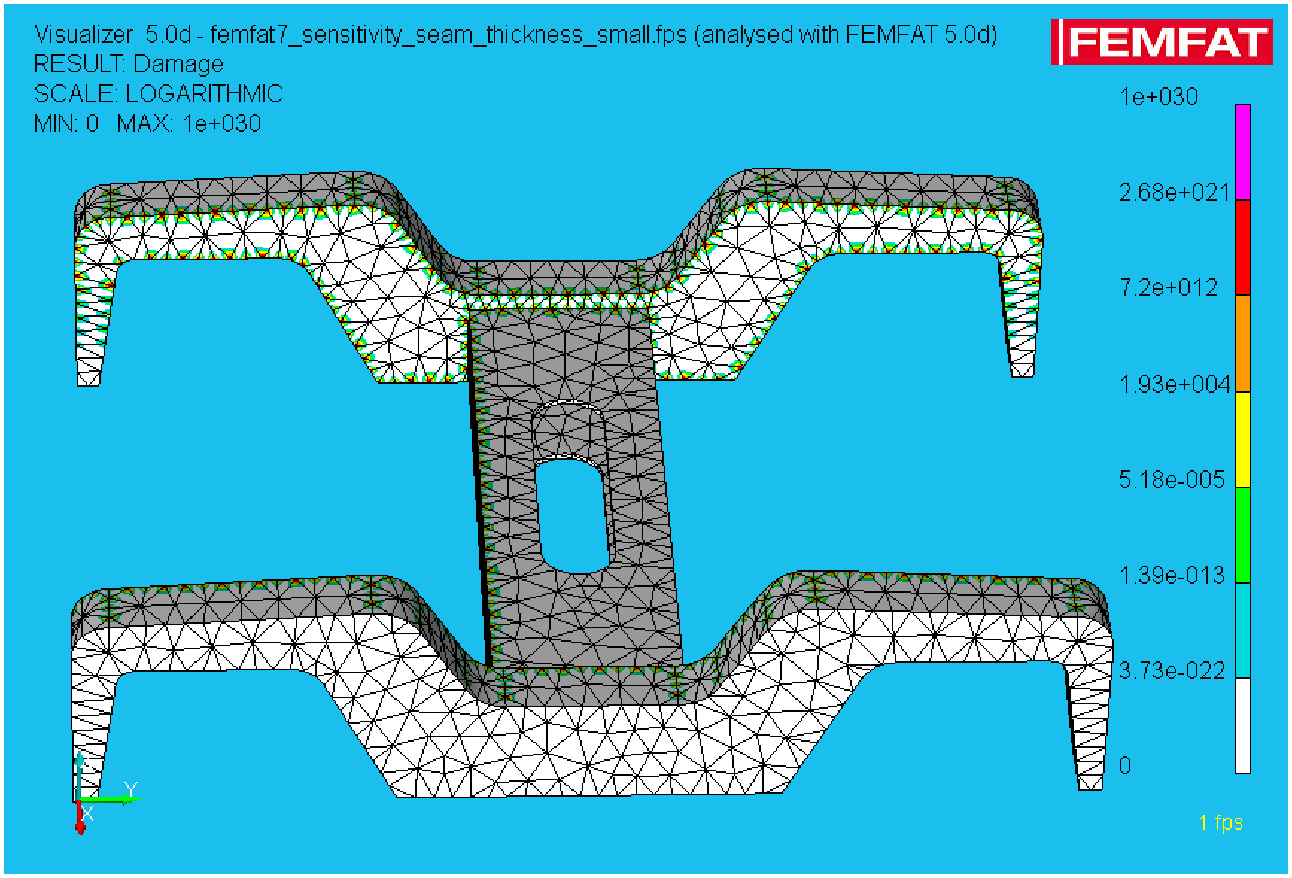


Fig. 4.31 Damage value at small seam thickness sensitivity

From the figure above which is sensitivity for small seam thickness, the Damage result ranges from 0 to 1e+030 in log form. The damage value is maximum at the weld joints so that special attention should be given for the weld connections.

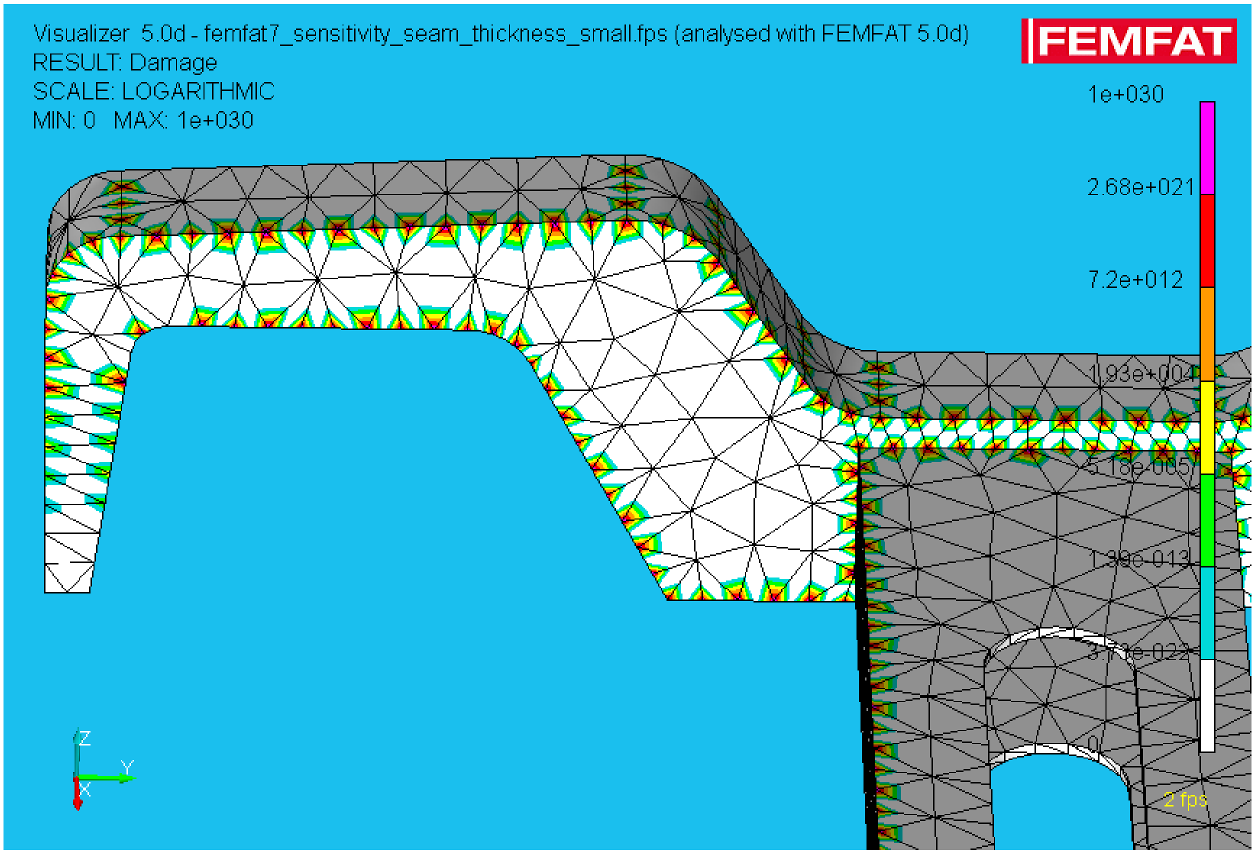


Fig. 4.32 Damage value at small seam thickness sensitivity by zooming

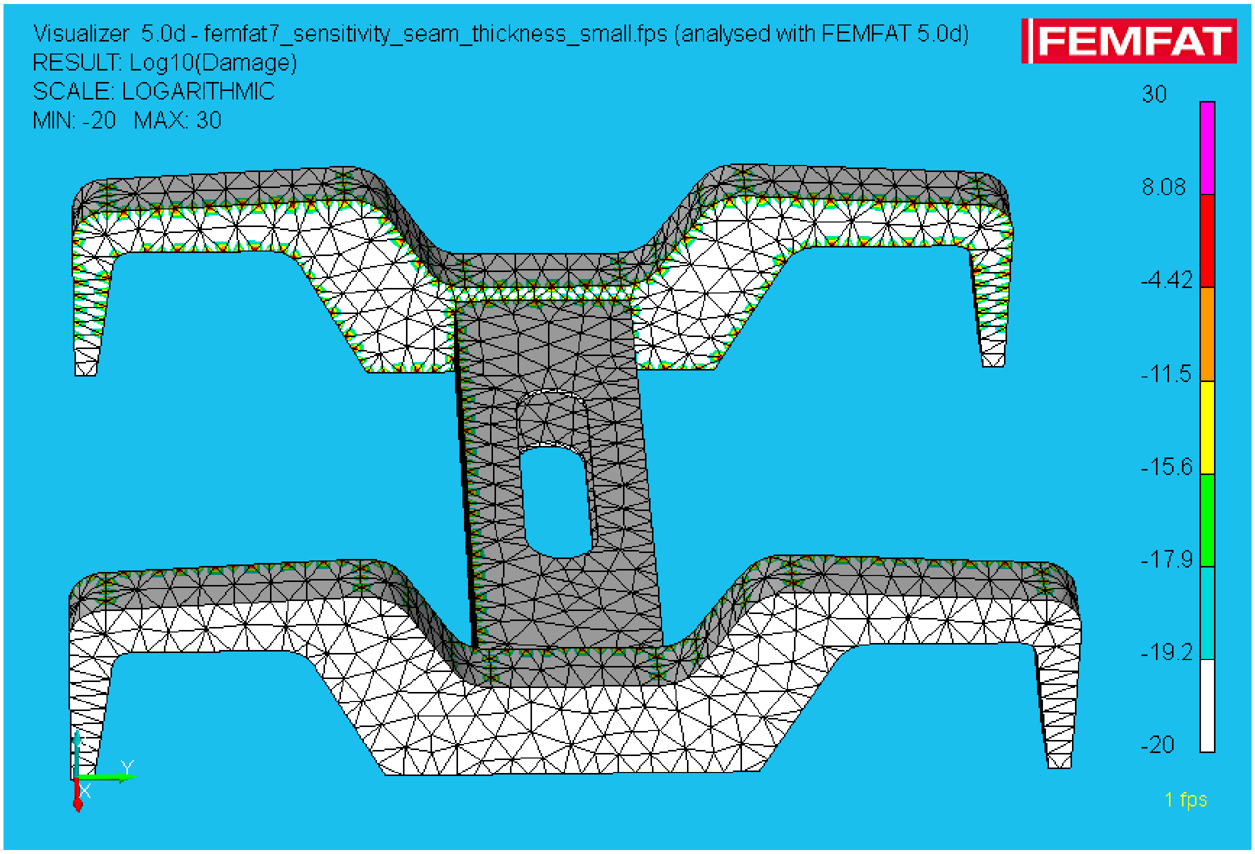


Fig. 4.33 Log10 Damage value at small seam thickness sensitivity

From the figure above which is sensitivity for small seam thickness, theLog10 Damage result ranges from -20 to 30. The damage value is maximum at the weld joints so that special attention should be given for the weld connections.

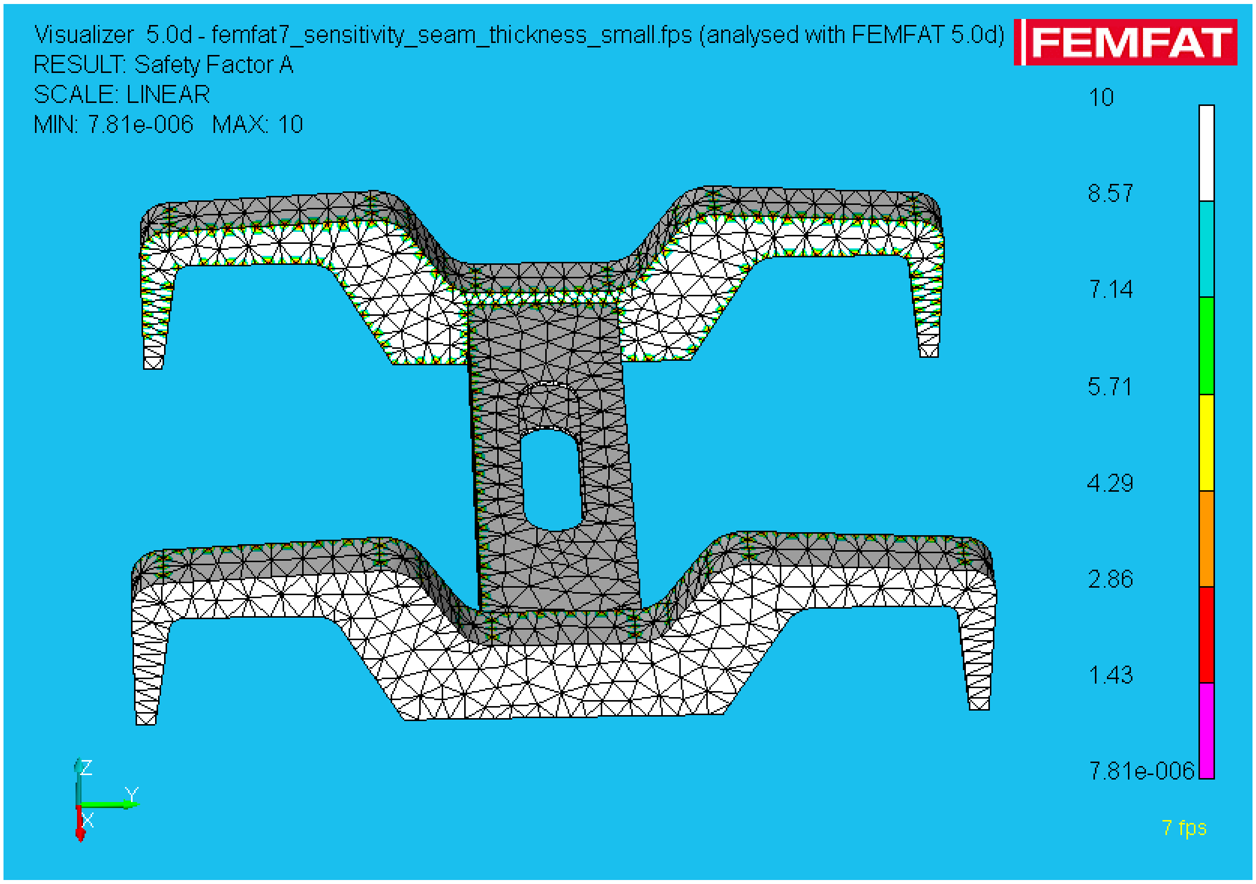


Fig. 4.34 Endurance safety factor at small seam thickness sensitivity

From the figure above which is Endurance safety factor at small seam thickness sensitivity, the endurance safety factor ranges from 7.81e-006 to 10. The minimum safety factor is below the safe limit so that it should be improved.

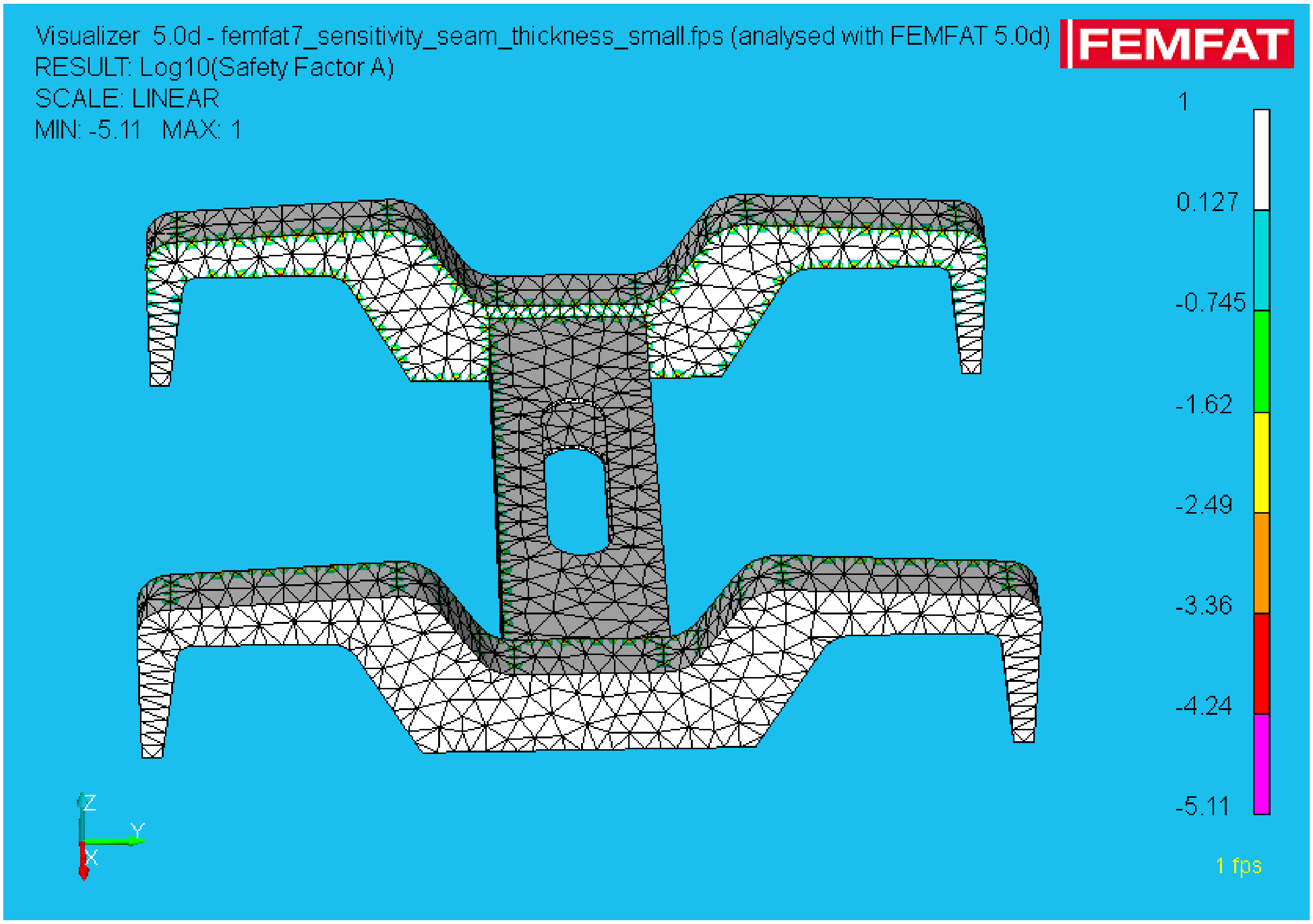


Fig. 4.35 Log10 Endurance safety factor at small seam thickness sensitivity

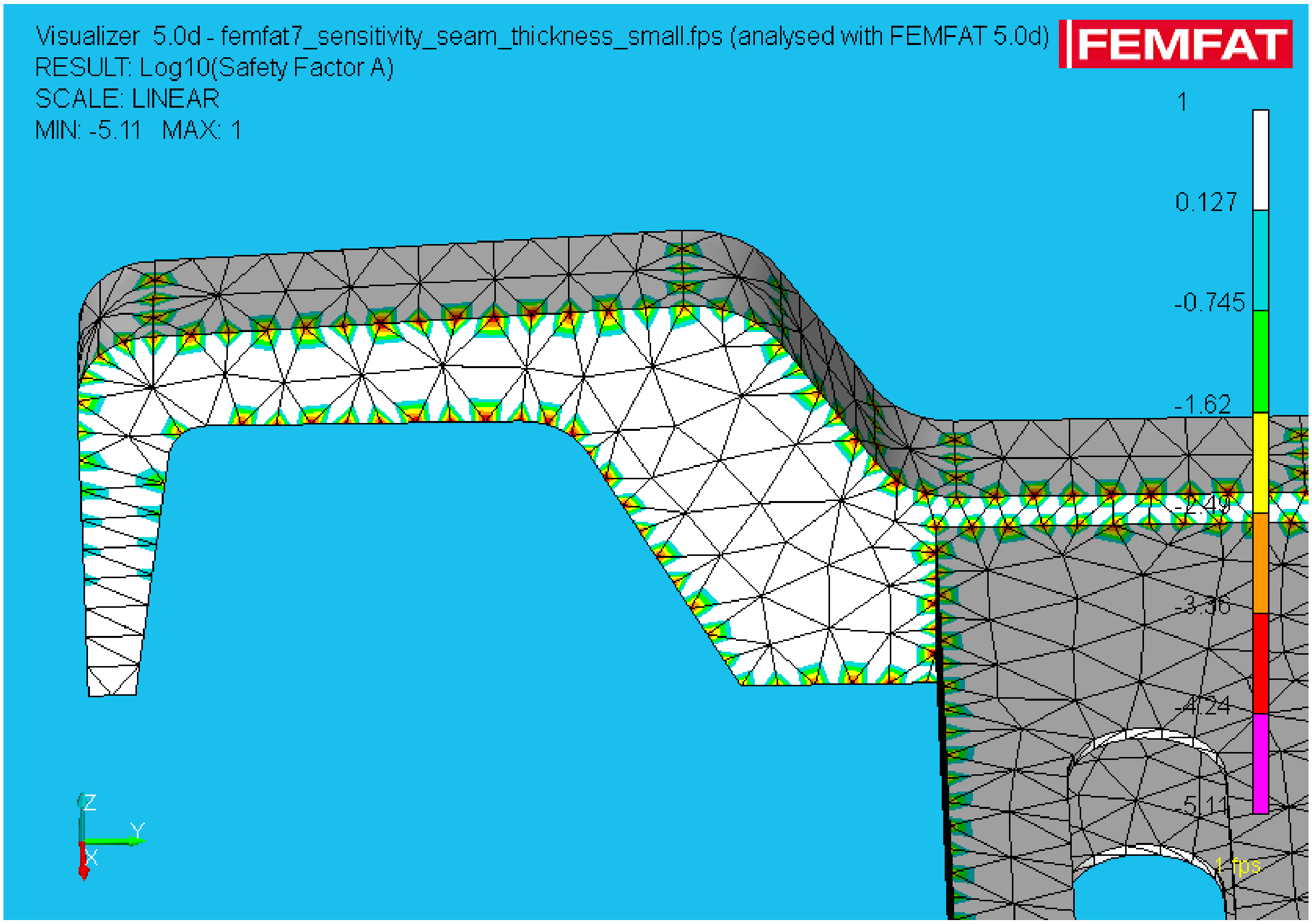


Fig. 4.36 Log10 Endurance safety factor at small seam thickness sensitivity by zooming

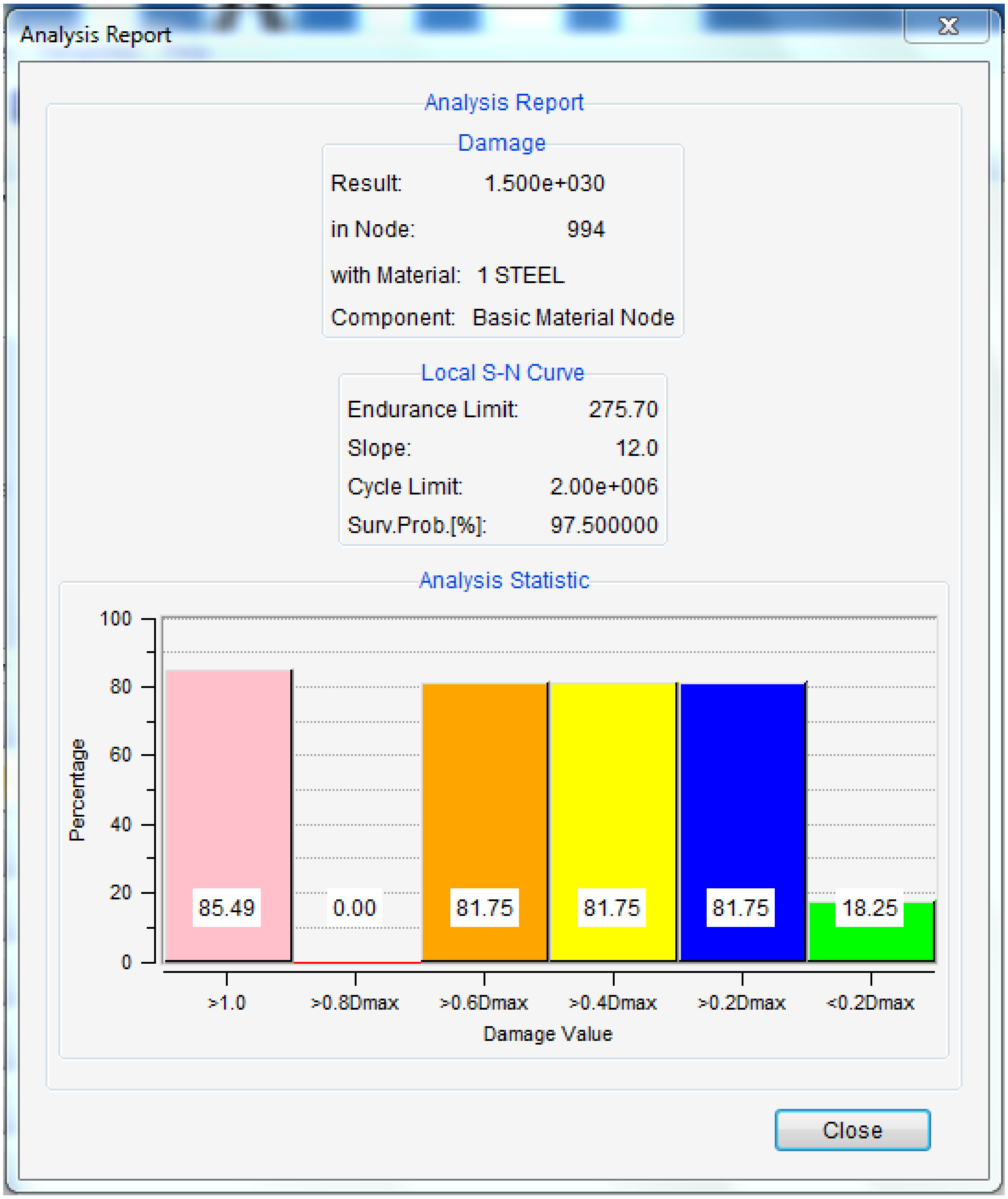


Fig. 4.37 damage analysis report at small seam thickness sensitivity

From the figure above which is sensitivity for small seam thickness the Damage analysis report has a result of 1.5e+30 maximum damage value at node 994 with 275.7N/mm2 Endurance limit, 2e6 fatigue life and 97.5% survival probability.

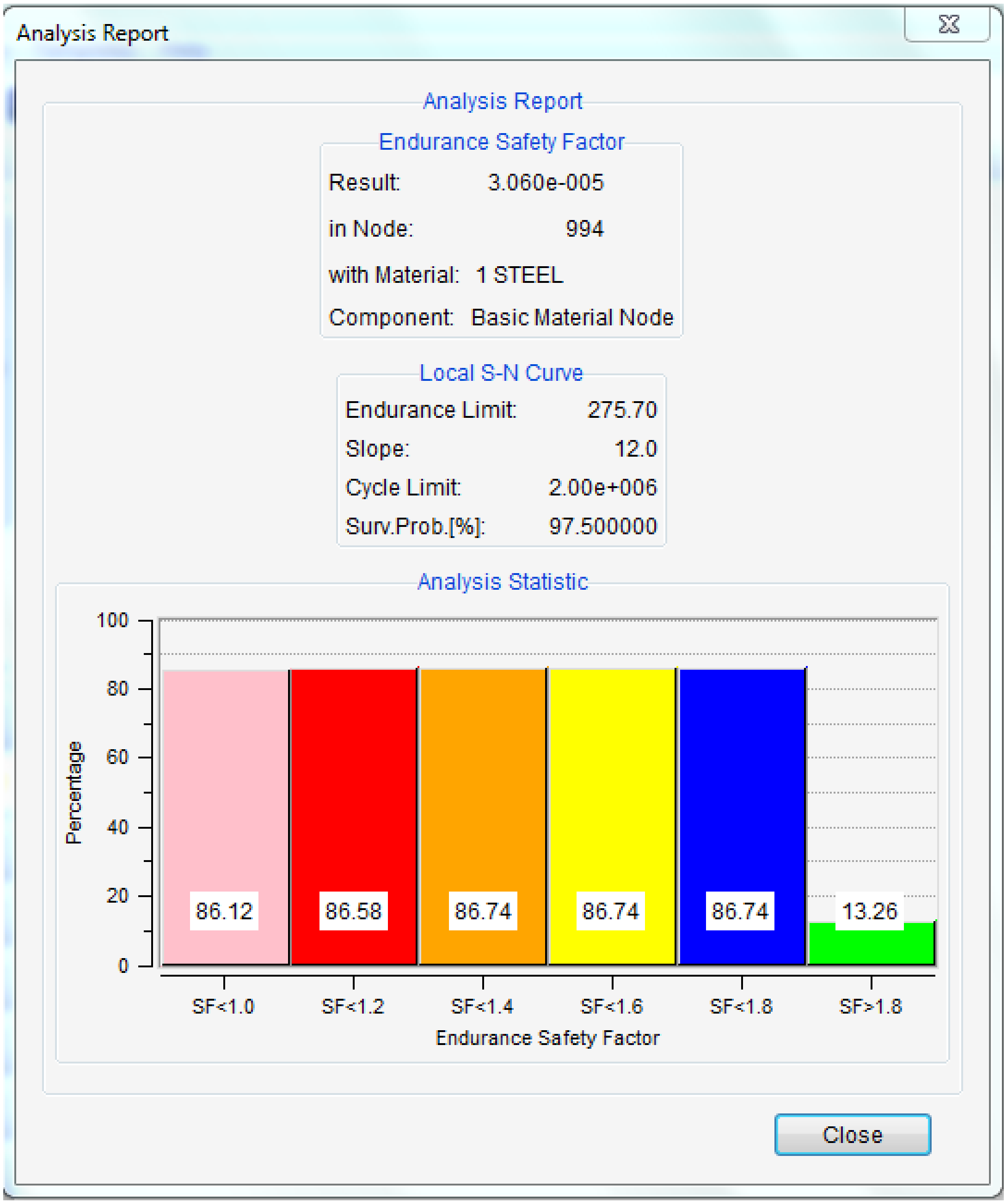


Fig. 4.38 endurance safety factor analysis report at small seam thickness sensitivity

From the figure above which is sensitivity for small seam thickness the endurance safety factor analysis report has a result of 3.06e-005 min endurance safety factor at node 994 with 275.7 N/mm2 Endurance limit, 2e6 fatigue life and 97.5% survival probability.

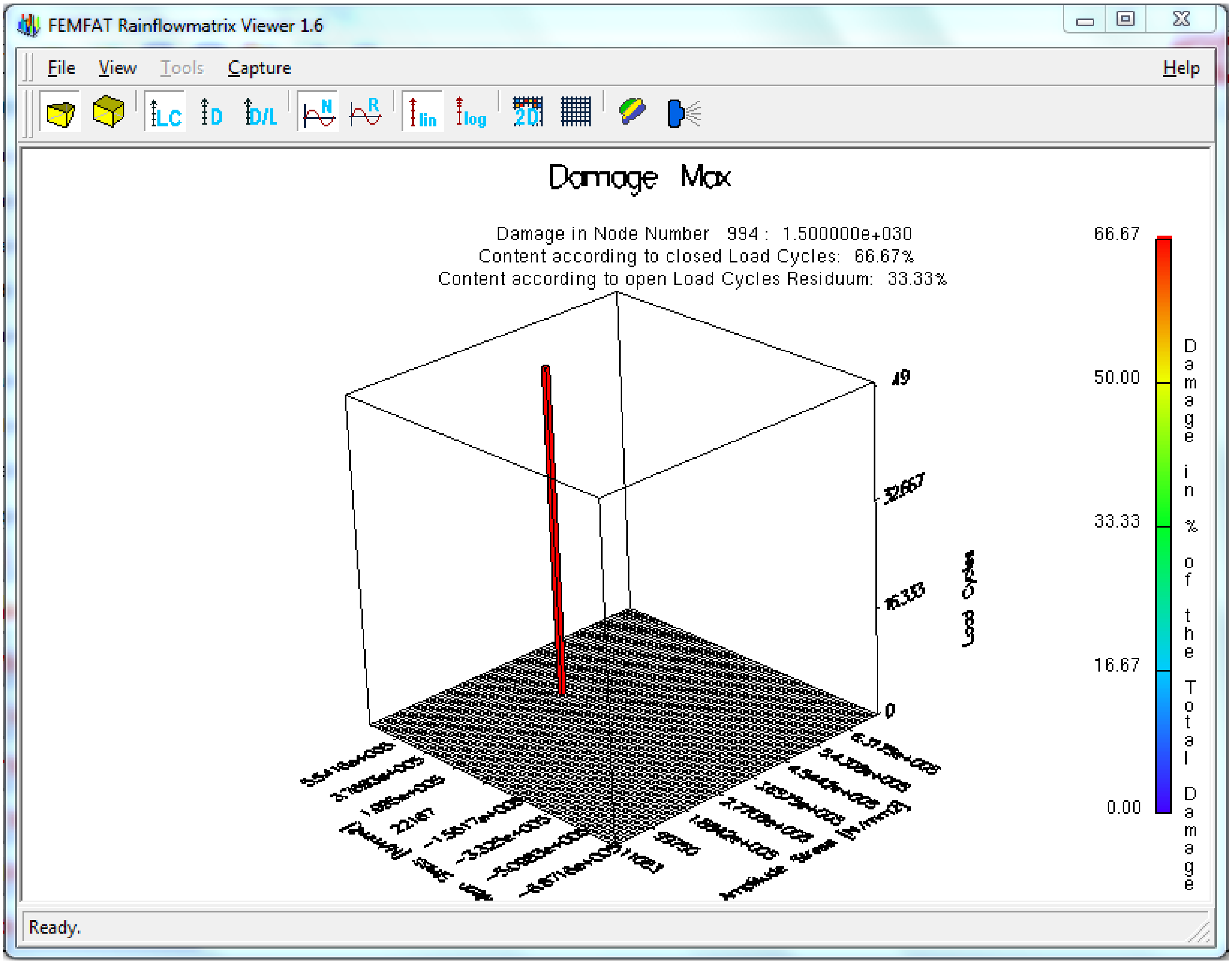


Fig. 4.39 Rain flow matrix at small seam thickness sensitivity

The header of the rainflow matrix gives information how much damage is caused by closed load cycles and how much damage is caused by residual stress. In this case 33.33% of the total damage is caused by residual stress and 66.67% is caused by closed load cycles.

4.2 Discussion

Arc-welded components have a considerably reduced ability to sustain dynamic loads; hence, numerical simulation of welded components is an important issue. To solve this problem, concepts for the automatic assessment of dynamically stressed welds have been developed and implemented in FEMFAT weld. Results will be damage/life or endurance safety factors. Detailed results are available in the report file discussed below, from the above FEMFAT visualizer post processing.

FEMFAT WELD helps to identify the critical weld seam from the series of weld seam joint in an assembly. All other influences on the local operating strength of the bogie frame like stress distribution, notch effects, size, mean stress, mean stress rearrangement due to residual stresses, temperature distribution, quenching and tempering conditions, surface influences like roughness, edge hardening by mechanical, chemical or thermal treatment, etc. have been taken into consideration along the way of my analysis.

This paper focuses on assessing the bogie frame fatigue life at its welded joints, by employing the sensitivity effect of different weld geometry parameters.: - seam thickness, inclination angle, penetration degree and weld gap but I have selected weld seam thickness parameter in my thesis because all weld parameters have similar output values. The output results that have been obtained during the analysis of the research shall be demonstrated in the following tables below.

4.2.1 Detailed FEMFAT WELD Results without Sensitivity Factor

Table 4.1 Output results without Sensitivity Factor

type	damage	Log10 damage	Fatigue limit	Endurance Safety factor	Log10 Endurance Safety factor	Fatigue Life	endurance limit at maximum damage node	endurance limit at minimum safety factor node
Max	1e30	30	282	10	1	2xe6	275.7	275.7
Min	8.1e-8	-7.09	255	7.81e-6	-5.11			

4.2.2 Detailed FEMFAT WELD results with weld sensitivity small seam thickness

Table 4.2 Output results with small seam thickness weld sensitivity

type	damage	Log10 damage	Fatigue limit	Endurance Safety factor	Log10 Endurance Safety factor	Fatigue Life	endurance limit at maximum damage node	endurance limit at minimum safety factor node
Max	1e30	30	282	10	1	2xe6	275.7	275.7
Min	0	-20	0	7.81e-6	-5.11			

Discussion of the results of the above tables:-

Output results without Sensitivity Factor in table 4.1 will be discussed below:-

The maximum damage result which is 30 in number is much exaggerated result comparing to that of the reviewed research papers; it is because the weld quality that I have taken is poor.

Whereas the fatigue limit at each analytical outputs has been proved to be the recommended value which is 282 N/mm^2. The endurance safety factor has a maximum value of 1 and a minimum value of -5.11. At the welded joint which is the critical point of the frame has a value of -5.11 safety factor which is below the anticipated value. There for the welded joints needs better treatment.

Output results with small weld sensitivity seam thickness Factor in table 4.2 will be discussed below:-

The maximum damage, fatigue limit and endurance safety factor values are similar to that of Output results without Sensitivity Factor, on the other hand the minimum damage and fatigue limit are deferent, which means they have got less value. This is because small seam thickness minimizes the welding quality and its safety.

CHAPTER FIVE: CONCLUSION, RECOMMENDATION AND FUTURE WORK

4.1 Conclusion

The purpose of this study is analyzing the fatigue durability of the welded bogie frame of AALRT. In the current simulation processes the FEMFAT software is used to evaluate the fatigue life of the component. The multi-axiality of the stress state needs to be taken into account for the case of failure in order to obtain reliable results. The researcher has conducted the analysis on welded bogie frame model and from the post processing of FEMFAT different results have been found such as S-N curve with endurance and cycle limits, fatigue limit, damage and safety factor in different weld geometry parameters . Those results show seam welded joints are highly sensitive area to failure and leads to a minimum component`s fatigue life. Hence it is essential to present different results as an output to predict accurate seam weld life.

On the bases of this discussion the researcher forwards the following conclusion. The maximum damage result which is 30 in number is much exaggerated result comparing to that of the reviewed research papers; it is because the weld quality that I have taken is poor. Whereas the fatigue limit at each analytical outputs has been proved to be the recommended value. The endurance safety factor has a maximum value of 1 and a minimum value -5.11 at the welded joint, which is below the anticipated value. There for a special attention should be given to the welded joints.

Based on sensitivity seam thickness results, it is possible to conclude that welded connections are almost nearer to failure because they are highly exposed to residual stress.

4.2 Recommendation

The research study shows an optimum endurance limit, maximum damage, minimum safety factor and an optimum fatigue life for the welded bogie frame. On the bases of the results the researcher recommends giving a special attention to the weld seam parameters such as seam thickness, inclination angle, penetration degree and weld gap and improving the parameters from the poor quality has a great value to ascertain the strength of the weld structure as it bears out a better fatigue life. Further more accurate and qualitative surface treatment should be practiced. Additionally the researcher suggests that there should be a skilled man power who can conduct the welding operation carefully in order to minimize the weld defects and increase fatigue life of the bogie frame.

4.3 Future work

The future plan of Ethiopian Railway Corporation is intended to produce the whole components of the train; so that manufacturing process needs to be qualified. While we are talking about safety issues concerning the bogie frame conducting a fatigue analysis will be imperative. The train body and it`s components have lots of welded structure so that conducting a research on fatigue durability of the welded bogie frame is very essential to prove the safety of the train for a long time.

For further research activities the researcher will suggest the following future works:-

- Conduct a practical fatigue test on the welded bogie frame by using fatigue testing machine in the laboratory and compare the results with the analytical one.
- Conduct the experiment by developing a material with a better fatigue strength and improved weld geometry parameters.
- Identify and improve the life of crack initiation and propagation.
- Conduct a fatigue analysis on different kinds of bogie frames including freight trains.
- While conducting the fatigue test avoid the residual stress by using deferent technics i.e. Surface treatment, tempering and etc.

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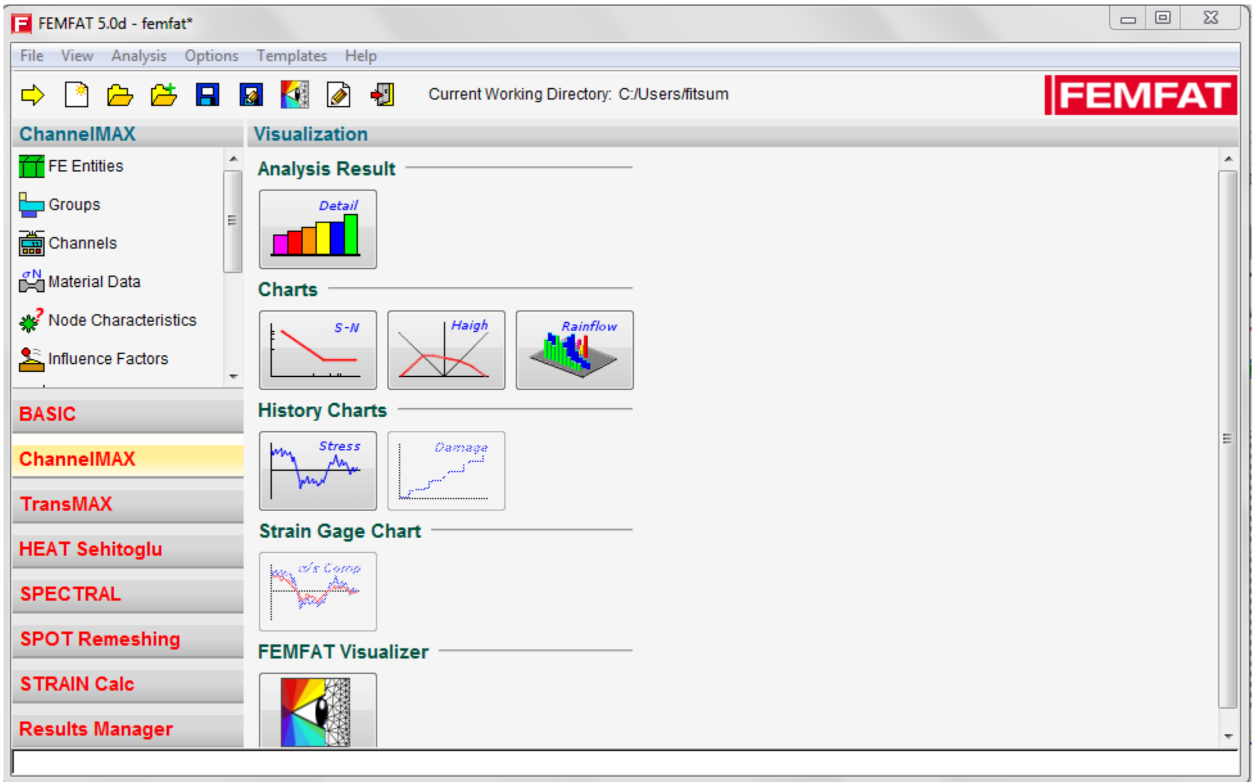
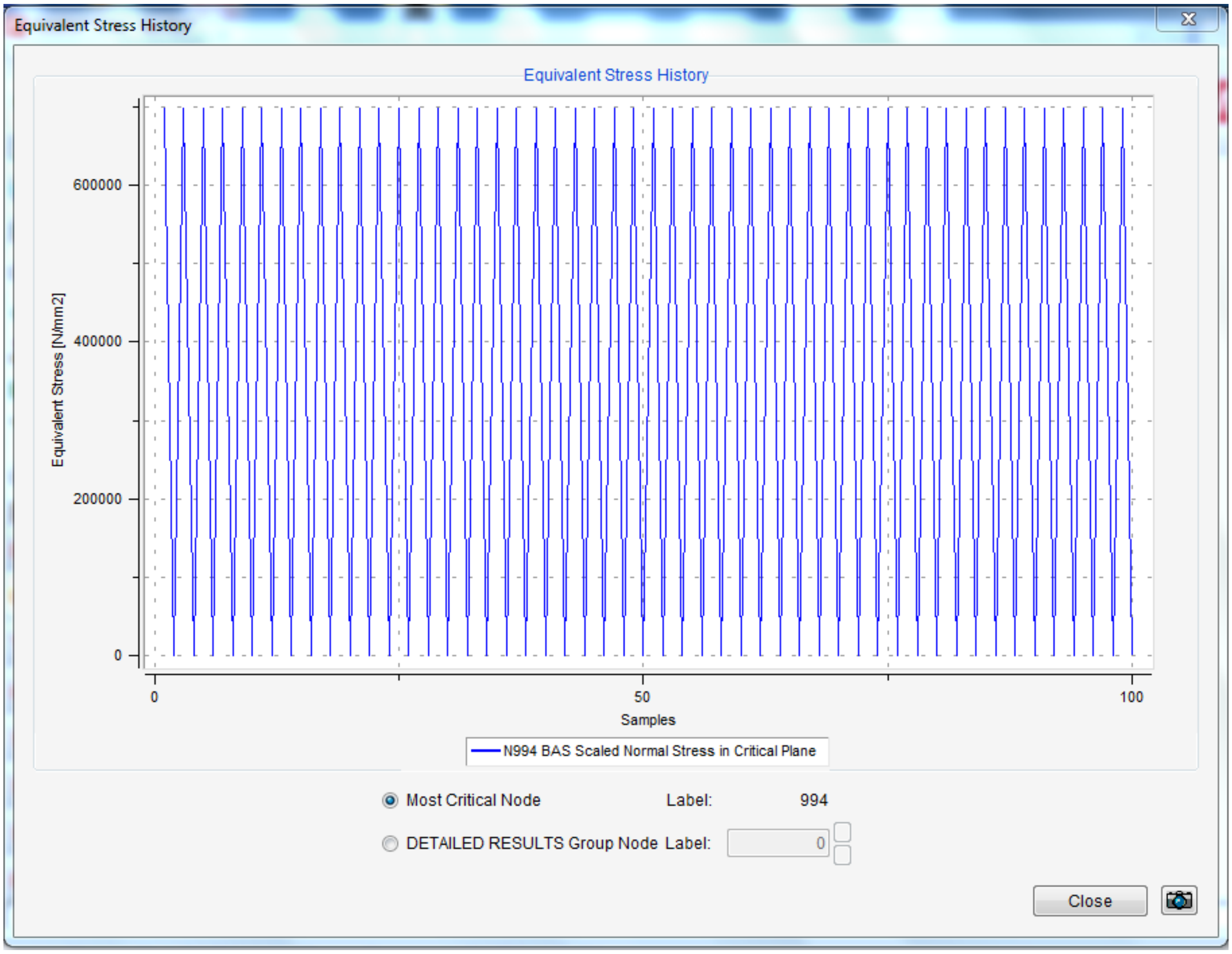
11. HARTWIG PÖRTNER Multi-axial Fatigue Models for Composite Lightweight Structures- Master's Thesis in Applied Mechanics CHALMERS UNIVERSITY OF TECHNOLOGY Göteborg, Sweden 2013 Master's Thesis 2013:79.
12. "FATIGUE ASSESSMENT WITH FEMFAT WELD INCLUDING SENSITIVITY ANALYSIS" 5th FEMFAT USERMEETING USA, Nov 8th 2012

Appendix

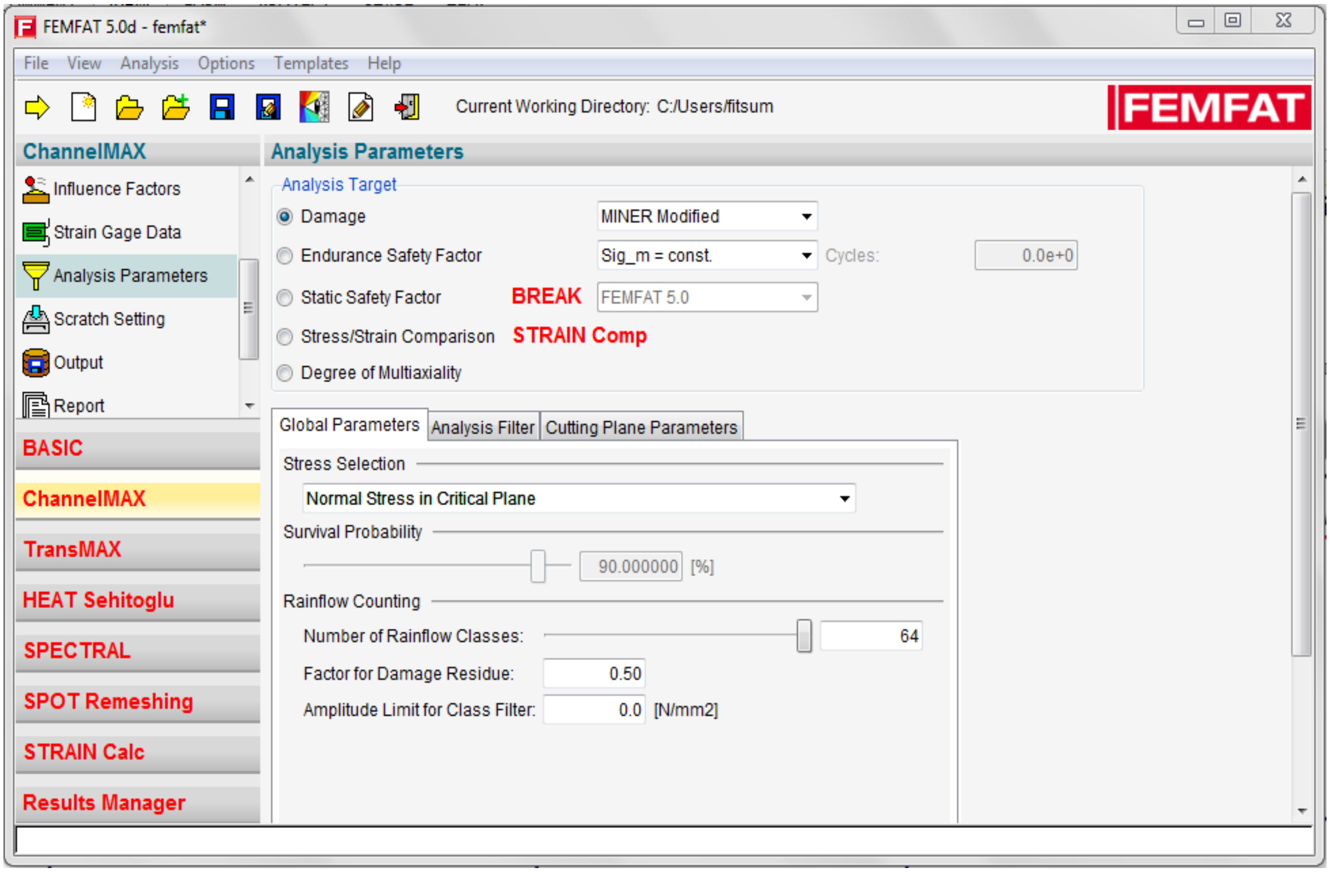
A1: Visualization of Analysis Results in FEMFAT



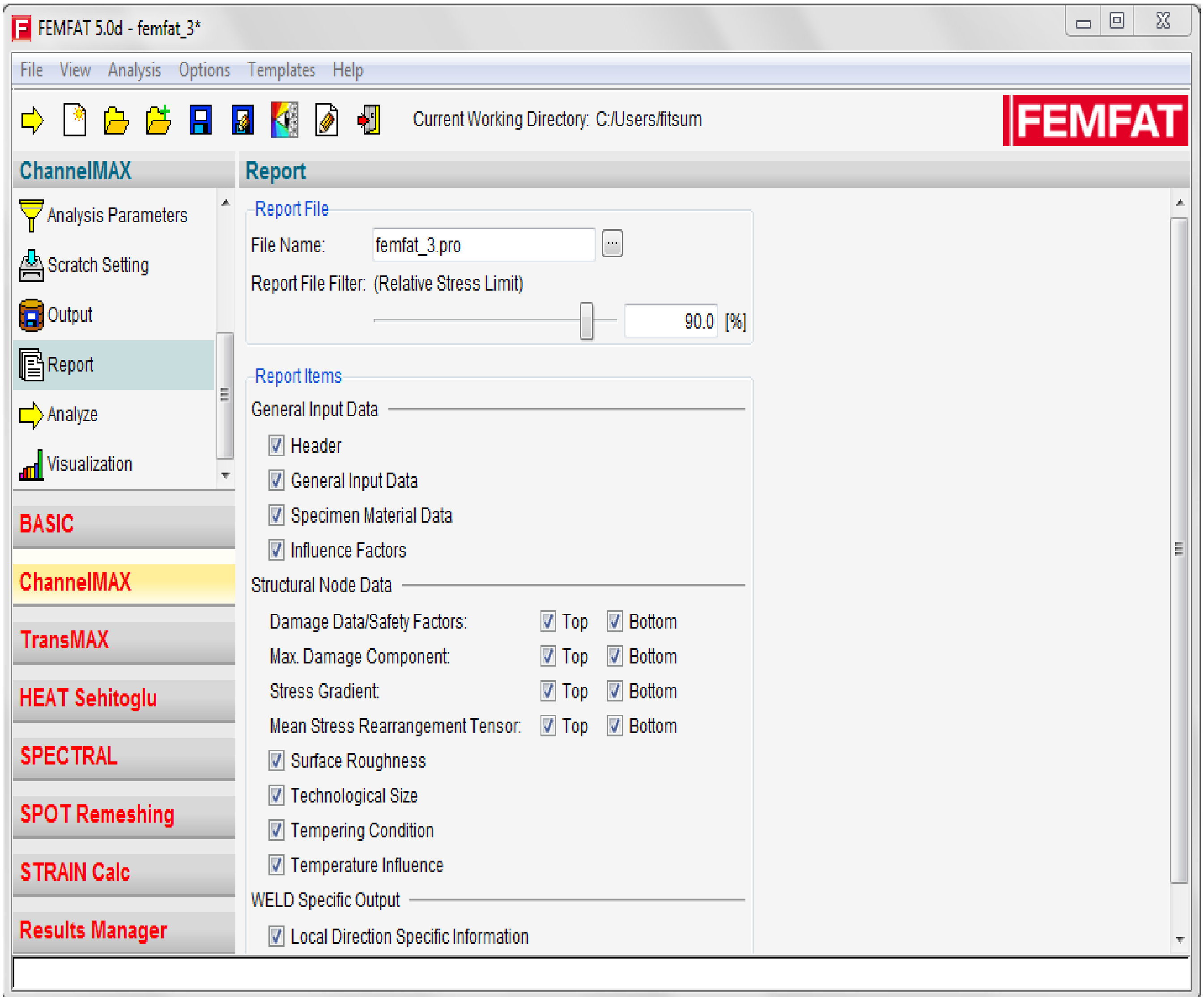
A2: Equivalent Stress History with weld seam thickness sensitivity factor in FEMFAT.



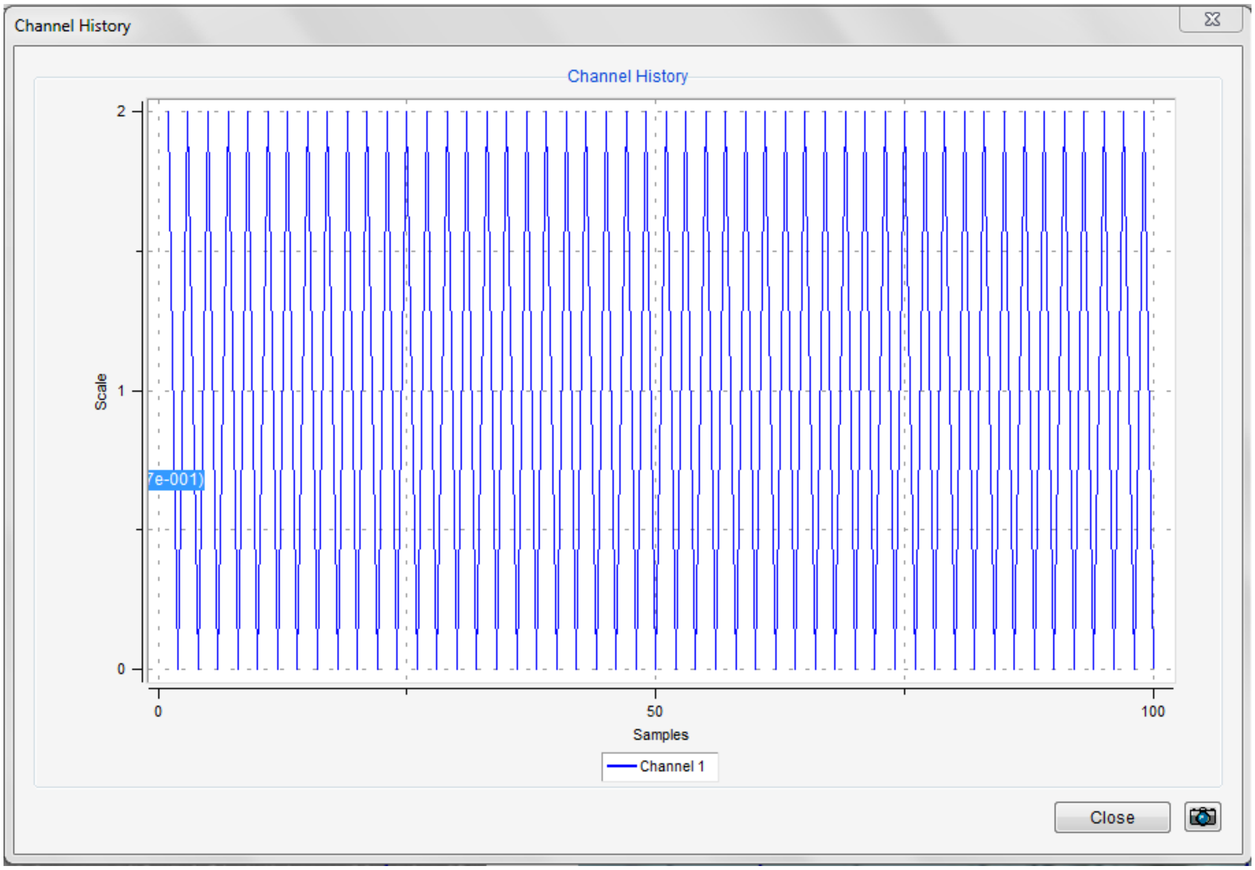
A3: Analysis parameters in FEMFAT



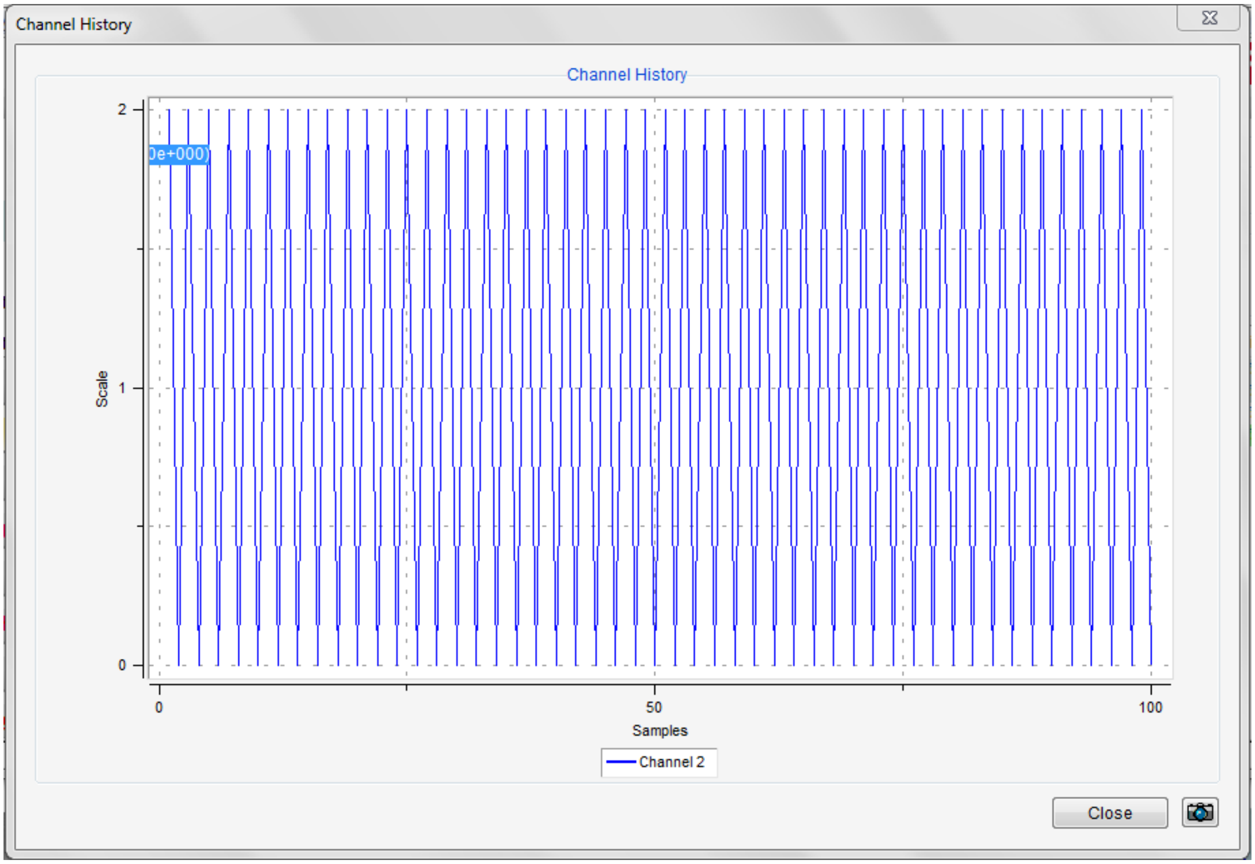
A4: Report files in FEMFAT



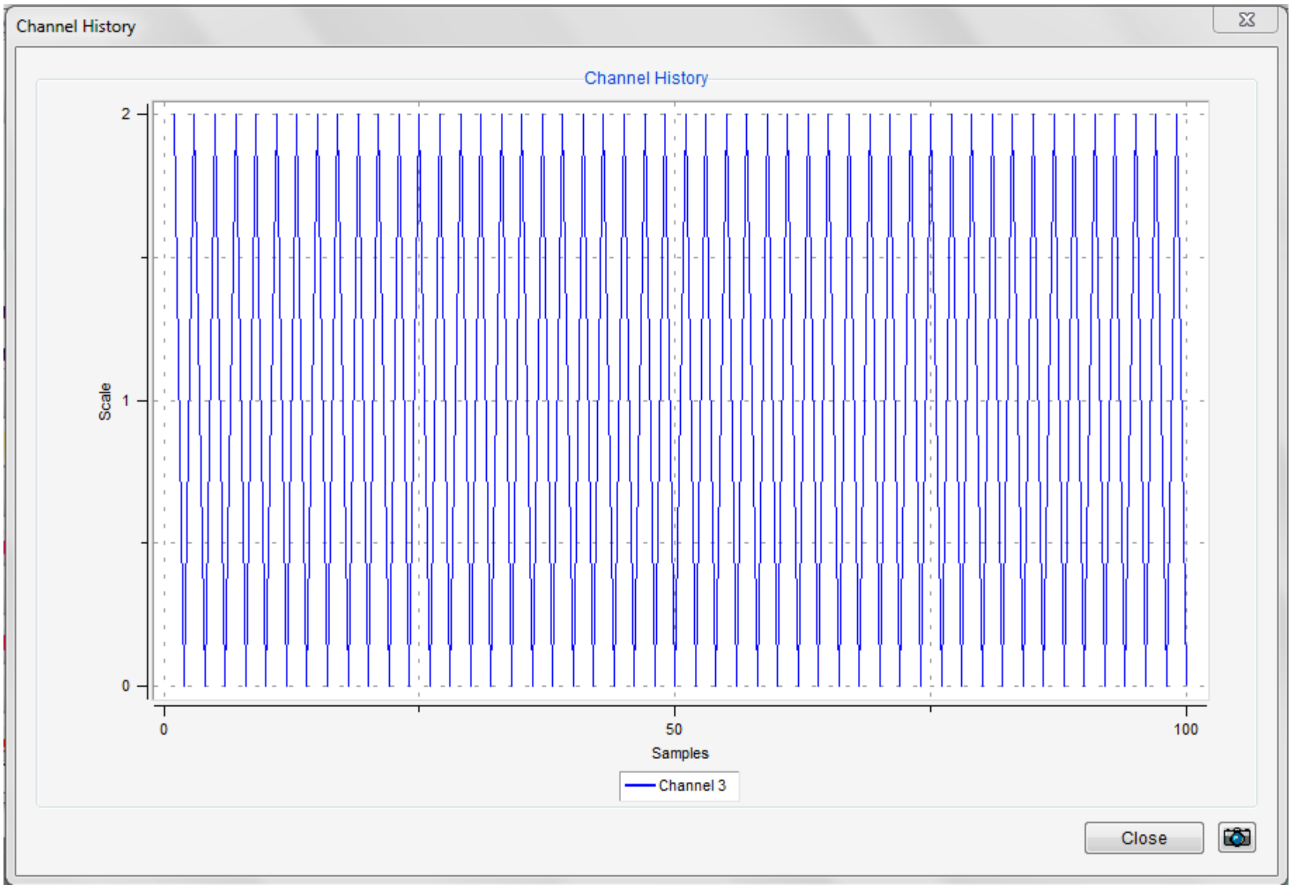
A5: Channel History samples in FEMFAT



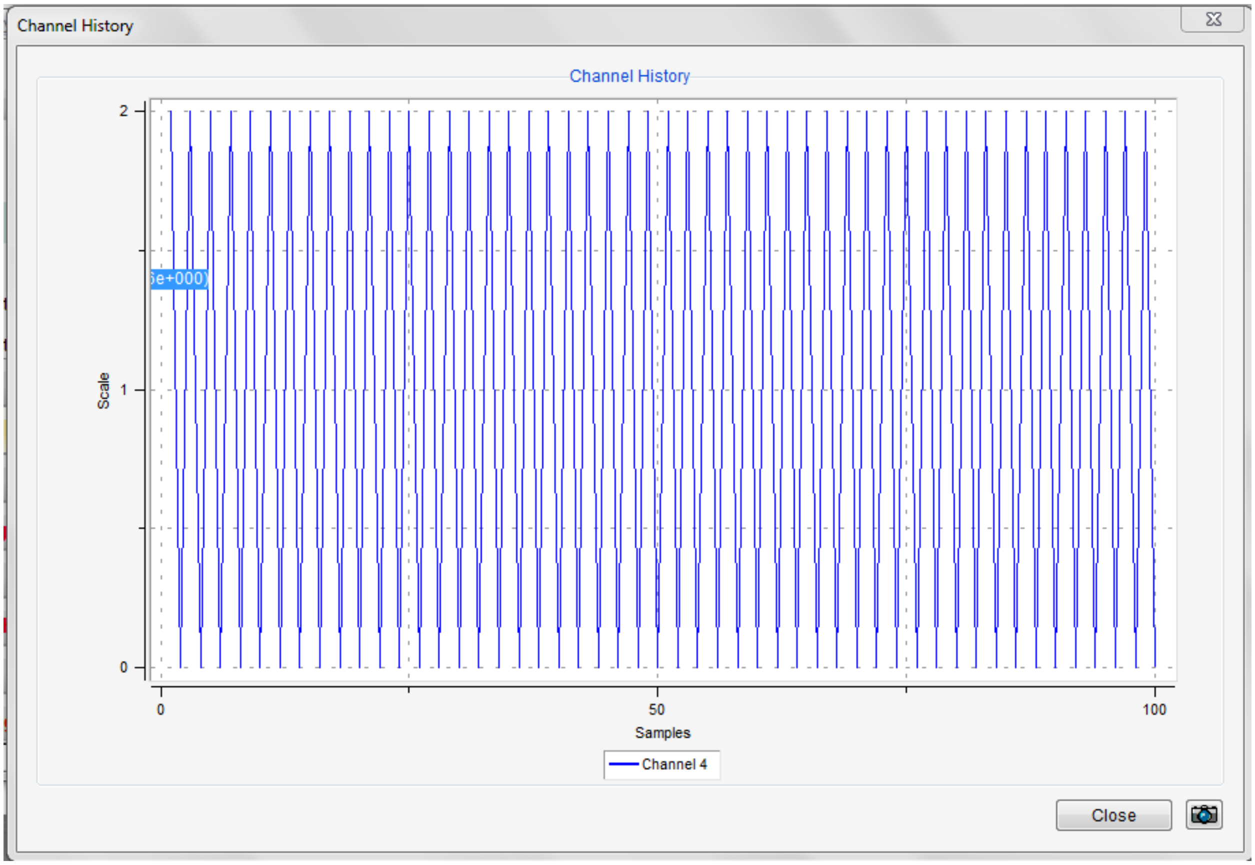
Channel 1


Channel History
Channel History
2
1
0
Scale
0e+000)
0
50
100
Samples
Channel 2
Close

Channel 2


Channel History
Channel History
2
1
0
Scale
0
50
100
Samples
Channel 3
Close

Channel 3


Channel History
Channel History
Scale
Samples
Channel 4
Close
0
1
2
0
50
100

Channel 4