

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	SORG	Student P number:	
Programme:	BEng Automotive and Manufacturing streams		
Module:	Advanced Stress Analysis & FEA	Module Level (4, 5, 6):	6
Module code:	M6X00420	Contribution to Overall Module Assessment (%):	50 %
Lecturer:	Kelvin Lake	Internal Verifier:	Rob Goodson
Assignment Title:	Can FEA replace physical testing?	Assignment No (x of x):	1 OF 1
Hand Out Date:	25/02/2020	Submission deadline:	29/03/2020

Referencing:	In the main body of your submission you must give credit to authors on whose research your work is based. Append to your submission a reference list that indicates the books, articles, etc. that you have read or quoted in order to complete this assignment (e.g. for books: surname of author and initials, year of publication, <u>title of book</u> , edition, publisher: place of publication).		
Disclosure:	I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people. All references have been duly cited.		
Student's Signature:	Assignments will not be accepted without a signature here	Date:	
Turnitin: Lecturer to tick to indicate if an electronic version of the assignment must be submitted to Turnitin. Note: the Turnitin version is the primary submission and acts as a receipt for the student. Penalties for late submission: Up to four weeks late, maximum mark of 40%. Over four weeks late, Refer. Only Year Tutors and the Programme Director may grant an extension.			YES
			NO

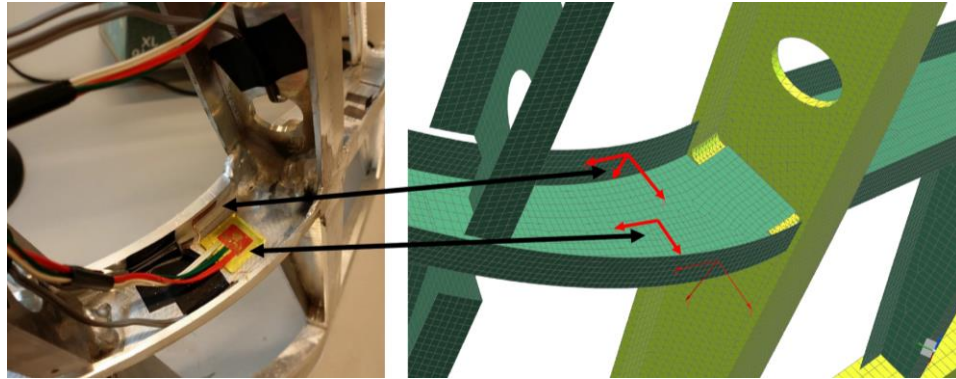
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- DO NOT put this form into Turnitin or it will match many similarities with other students' submissions.

TASK DESCRIPTION

This assignment explores FEA and the role that it plays in product development. It is expected that the student will research this topic (referencing any sources used, using Harvard or Vancouver).

GUIDANCE FOR STUDENTS IN THE COMPLETION OF TASKS



The above image shows a component undergoing physical testing and the corresponding FE model. Your task for this assignment is to discuss the following;

1. Why companies typically carryout FE analysis alongside physical testing.
2. How a physical test may be correlated to an FE model.
3. If you think that FE analysis can (or should) ever replace physical testing.

In order to do this, you should consider a case study and use this to discuss the above tasks.

This report should be 3000 words long and should be submitted via moodle

STRUCTURAL SECTION MARKING CRITERIA AND STUDENT FEEDBACK

This section details the assessment criteria. The *extent* to which these are demonstrated by you determines your mark. The marks available for each criterion are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Common Assessment Criteria Applied	Marks available	Marks awarded
1. Research-informed Literature Extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions.		
(Assessed in point 1)	30	16.5
2. Knowledge and Understanding of Subject Extent of knowledge and understanding of concepts and underlying principles associated with the discipline.		
(Assessed in point 2)	30	19.5
3. Analysis Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence		
(N/A)	0	
4. Practical Application and Deployment Deployment of methods, materials, tools and techniques; application of concepts; formulation of innovative and creative solutions to solve problems.		
(Assessed in point 3)	30	18.9
5. Skills for Professional Practice Attributes in professional practice: individual and collaborative working; deployment of appropriate media; presentation and organisation.		
(Assessed in report presentation and structure)	10	6.5

Assignment Mark Overall (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)	Late Submission Penalties (tick if appropriate)		61.4 %
	Up to one-week late		
	Over one week late		

COMMON ASSESSMENT AND MARKING CRITERIA

	OUTRIGHT FAIL	UNSATISFACTORY	SATISFACTORY	GOOD	VERY GOOD	EXCELLENT	EXCEPTIONAL
Assessment Criteria	0-29%	30-39%*	40-49%	50-59%	60-69%	70-79%	80-100%
1. Research-informed Literature Extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions	Little or no evidence of reading. Views and findings unsupported and non-authoritative. Referencing conventions largely ignored.	Poor evidence of reading and/or of reliance on inappropriate sources, and/or indiscriminate use of sources. Referencing conventions used inconsistently.	References to a limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently.	Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied.	Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.	A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied.	Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.
2. Knowledge and Understanding of Subject Extent of knowledge and understanding of concepts and underlying principles associated with the discipline.	Major gaps in knowledge and understanding of material at this level. Substantial inaccuracies.	Gaps in knowledge, with only superficial understanding. Some significant inaccuracies.	Evidence of basic knowledge and understanding of the relevant concepts and underlying principles.	Knowledge is accurate with a good understanding of the field of study.	Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.	Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.	Highly detailed knowledge and understanding of the main theories/concepts, and a critical awareness of the ambiguities and limitations of knowledge.
3. Analysis Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence	Unsubstantiated generalisations, made without use of any credible evidence. Lack of logic, leading to unsupportable/missing conclusions. Lack of any attempt to analyse, synthesise or evaluate.	Some evidence of analytical intellectual skills, but for the most part descriptive. Ideas/findings sometimes illogical and contradictory. Generalised statements made with scant evidence. Conclusions lack relevance.	Evidence of some logical, analytical thinking and some attempts to synthesise, albeit with some weaknesses. Some evidence to support findings/ views, but evidence not consistently interpreted. Some relevant conclusions and recommendations, where relevant	Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use evidence to support the argument. Valid conclusions and recommendations, where relevant	Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity & significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions / recommendations.	Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations.	Exceptional work; judiciously selected and evaluated evidence. Very high quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Highly persuasive conclusions
4. Practical Application and Deployment Effective deployment of appropriate methods, materials, tools and techniques; extent of skill demonstrated in the application of concepts to a variety of processes and/or contexts; formulation of innovative and creative solutions to solve problems.	Limited or no use of methods, materials, tools and/or techniques. Little or no appreciation of the context of the application.	Rudimentary application of methods, materials, tools and/or techniques but without consideration and competence. Flawed appreciation of the context of the application.	An adequate awareness and mostly appropriate application of well established methods, materials, tools and/or techniques. Basic appreciation of the context of the application.	A good and appropriate application of standard methods, materials, tools and/or techniques. Good appreciation of the context of the application, with some use of examples, where relevant.	A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.	An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, with extensive use of relevant examples. Application and deployment extend beyond established conventions. Innovation and creativity evident throughout.	Outstanding levels of application and deployment skills. Assimilation and development of cutting edge processes and techniques.
5. Skills for Professional Practice Demonstrates attributes expected in professional practice including: individual initiative and collaborative working; deployment of appropriate media to communicate (including written and oral); clarity and effectiveness in presentation and organisation.	Communication media is inappropriate or misapplied. Little or no evidence of autonomy in the completion of tasks. Work is poorly structured and/or largely incoherent.	Media is poorly designed and/or not suitable for the audience. Poor independent or collaborative initiative. Work lacks structure, organisation, and/or coherence	Can communicate in a suitable format but with some room for improvement. Can work as part of a team, but with limited involvement in group activities. Work lacks coherence in places and could be better structured.	Can communicate effectively in a suitable format, but may have minor errors. Can work effectively as part of a team, with clear contribution to group activities. Mostly coherent work and is in a suitable structure.	Can communicate well, confidently and consistently in a suitable format. Can work very well as part of a team, with very good contribution to group activities. Work is coherent and fluent and is well structured and organised.	Can communicate professionally and, confidently in a suitable format. Can work professionally within a team, showing leadership skills as appropriate, managing conflict and meeting obligations. Work is coherent, very fluent and is presented professionally.	Can communicate with an exceptionally high level of professionalism. Can work exceptionally well and professionally within a team, showing advanced leadership skills. Work is exceptionally coherent, very fluent and is presented professionally.

Student Self Evaluation Form

Student name:		Student P number:	
Programme:		Year of programme	
Assignment Title:			

This section repeats in brief the common assessment criteria detailed on previous pages. The *extent* to which these are demonstrated by you determines your mark. Using these criteria, tick the box that best indicates the level of achievement you feel you have achieved with regard to each of them.

Common Assessment Criteria Applied	Level of Achievement						
	REFER		3 rd	2:2	2:1	1 st	1 st
	OUTRIGHT FAIL	UNSATISFACTORY	SATISFACTORY	GOOD	VERY GOOD	EXCELLENT	EXCEPTIONAL
1. Research-informed Literature	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
2. Knowledge and Understanding of Subject	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
3. Analysis	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
4. Practical Application and Deployment	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
5. Skills for Professional Practice	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐

PLEASE COMMENT ON AREAS IN WHICH YOU FEEL THAT YOU HAVE PERFORMED WELL	PLEASE COMMENT ON AREAS YOU FEEL THAT YOU NEED TO DEVELOP

Student's Name		Date	
Student's Signature			

Can FEA Replace Physical Testing ?

Advanced Stress Analysis & FEA, (M6X00420)

University of Wales Trinity Saint David, School of Engineering
BEng Motorcycle Engineering

Jason Sorg
Student Number: 1700589

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Introduction

The concept of using finite element analysis to approximate solutions for partial differential equations is not a new idea, in fact the earliest recorded use for a very basic type of finite element analysis was when Alexander Hrennikoff divided the domain of a Civil framework problem into simpler parts (i.e. finite elements) to determine the associated stress concentrations within the framework (Hrennikoff, 1941). The concept of splitting the domain into smaller discrete elements would then be refined over the coming years but complex problems could still not be undertaken by solely using finite element analysis due to the vast amount of calculations needed. This of course was until the age of computing, which then allowed for more complex problems due to the ability to use them to perform difficult repetitive tasks that humans are incapable of solving in an accurate and timely manner. Although the advancements of the finite element analysis have given engineers a very capable and robust design tool, one of the inherent problems is being overconfident in the FEA results and not perform real-world testing to validate the FEA results. This report will explore if finite element analysis can replace physical testing or if the need for real-world validating will always be needed in order to produce accurate results.

Task 1

Historically, the process to successfully design a component without FE analysis would typically involve making prototypes and then completing a series of physical tests to determine if the solution successfully met the design criteria. Although this method has proven to be successful, it also generates a large amount of errors at the beginning of the design process due to the oversight of certain initial conditions such as materials choice, boundary constraints and component interactions to name a few. In addition, this process can be more time / resource consuming due to the fact that a change in the design means additional prototypes and thus more physical testing would need to be completed in order to guarantee a successfully designed component (Churazova, 2018). Finite element analysis was then introduced into the design process to try and eliminate these short comings. Some of the key benefits of using FE analysis are outlined in the following list below, (UK, 2019):

1. Increased accuracy – The designers must consider all boundary conditions and material choices before prototyping which creates for a more robust initial design due to the fact that key restrictions (i.e. stress concentrations, manufacturing constraints) won't be overlooked when compared to traditional design methods.
2. Critical design parameter insight – FEA programs are able to both model the external and internal design parameters of a component, which in turn gives the designer the biggest advantage over traditional methods because the entire structure can be analysed for critical failure points. The ability to determine the critical failure points with interacting components is also a key advantage.
3. Virtual prototyping – The ability to change critical design parameters and virtually test if the change has improved the overall design in a matter of hours instead of weeks due to the steps needed to create hard prototyping is very beneficial when trying to design a robust component in a set amount of time, thus creating a more efficient process.
4. Increased productivity – The ability to save precious time for each design process within a company setting is very advantageous due to the fact that the saved time can lead to a more productive work force, which can then lead to an increase in overall revenue.
5. Domain constraints – FEA allows designers to think creatively about solutions due to the amount of time saved over traditional methods, which is especially important when complex problems arise. The ability to virtual test a wide range of solutions allows for an end design that has been validated throughout the design process and thus producing a robust component.

6. Multiple applications – The ability to solve numerous analysis types, (i.e. Linear or non-linear, static, or dynamic and comparative or absolute (Design, 2017)). This is very important because this allows designers to critically think about the real-world scenario and being able to appropriately design for such implications.

The above advantages of using FE analysis clearly demonstrates the reason why it has been implemented in modern day component design, but this solution does not come without inherent problems as well. The biggest downside associated with FE analysis is being overconfident in the end results and the following list outline's some of the reasons why designers can be overconfident with bad results:

1. Initial boundary conditions – If the initial setup of the FE analysis is not carefully chosen at the beginning of the design process it can cause hidden issues within the design in the future. Which is why material interactions and boundary constraints must be critically determined at the start of the design process.
2. Program Usability – The current software programs available to engineers have been refined over the last decade and the tools available now are very user friendly. Although this is usually advantageous to engineers, it can also become a big problem due to the amount of background processing the program is making without the designer's oversight. This lack of input can become especially dangerous if the designer is not aware of the fundamental principles that the software is built upon and instead relies on the software's best judgement.
3. Bad Assumptions – The current software packages are also able to determine mesh size, mesh strategy, element type and boundary constraints to name a few, without the designer's input. These assumptions made by the software can cause critical underlying problems that the designer is unaware of and thus the results generated cannot be used with any confidence.
4. Results – Let's say that the designer has successfully designed a component and was able to mitigate any assumptions the software has made and has also effectively mimicked the real world situation for the component. The final problem with FE analysis is the way the results are displayed to the user. Typically the results are shown with the von-Mises stress analysis, when in fact another type of stress (i.e. shear stresses) could demonstrate much different results and thus the importance of critically analysing the different result strategies that the program is able to output is very important.

Task 2



Typically a designer will use an FE model to predict certain structural / behavioural results in order to determine if the current model will meet the design criteria. The results generated from the model would then be compared to physical testing of the component to ensure the accuracy of the model is within tolerance. This will also validate the design in a real-world application and thus demonstrating that the component has successfully / unsuccessfully met all the design criteria. This way of correlating physical testing to an FE model is usually carried out for one-off or very limited design changes as this method can be time consuming due to the specific design criteria or particular component applications.

Another way of utilizing physical testing to assist in the validation of an FE model is to determine the discrepancies between the FE model and the physical testing. Once the discrepancies have been determined, the designer can then begin to alter the FE model to account for these differences and thus producing a more robust FE model. Although this process can be time consuming because the number of iterations that must be completed to produce an accurate model can be very high in some cases. This can be due to many reasons, for example, the complexity of the component, component interactions, dynamic real world situations and unknown variables such as environmental changes can play a big part in determining the correlation of physical testing to an FE model. Although this iterative process can be very time consuming, the benefits of successfully minimizing the error between the FE model's predictions and physical testing results will yield a greater confidence in the FE models future predictive capabilities (Engineering, 2019). This enhanced predictive capability can be very beneficial to a designer when trying to design similar components in the future because the new models will have to undergo less physical testing to achieve a similar amount of confidence due to the already established error percentage.

In order to highlight how physical testing is correlated to developing accurate and robust FE models the case study published by Carl Gregefors was used (Gregefors, 2016). The report demonstrates the relationship between FE models and physical testing by using a hypoid gear set (figure 1) as the main component in question. The reason why this case study was chosen to demonstrate how physical testing can be linked to FE models is due to the component complexity and precise manufacturing tolerances. These complexities and tolerances



Figure 1: Hypoid Gear Set (NICE, 2018)

found in this case study overemphasize the smallest errors found between the FE model and physical testing and thus perfectly demonstrate how physical testing may be correlated to an FE model study. The critical design feature of a hypoid gear set is the contact between the pinon (small gear) and ring gear (larger gear). This contact must remain uniform and consistent regardless of the external torque values applied to the gears and this is why determining the contact discrepancies in the FE model and physical testing are important for validation / future designs. The contact pattern results achieved from the case study FE model and physical testing can be seen below in figure 2, which shown a torque value of 100Nm for the top row, 500Nm of torque for the middle row and 1250Nm for the bottom row.

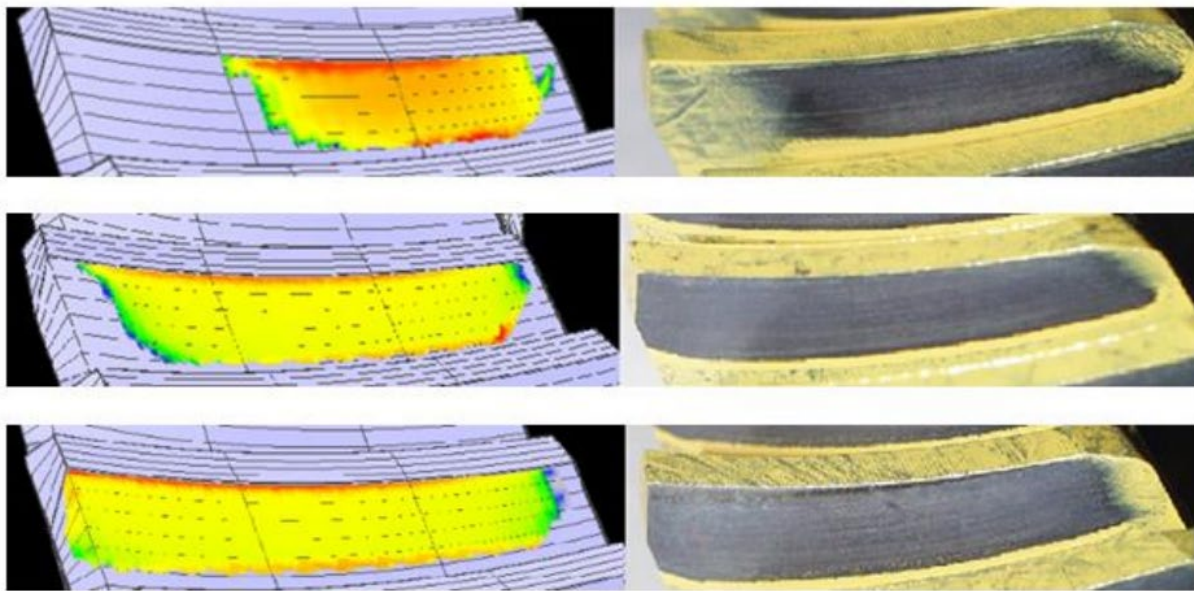


Figure 2: Contact Pattern Comparison, FE Model Left, Physical Testing Right (Gregefors, 2016)

The results reveal that at lower torque values such as 100Nm the contact pattern varies by 15-20%, while the 500Nm applied torque only results in a 5 -10% discrepancies and the larger torque value of 1250Nm is within 2% (Gregefors, 2016). The importance of being able to determine the differences between physical testing and FE models in a manner like this can be a very powerful tool because it will allow the designer to have greater confidence when creating future designs of a similar nature. The significance of being able to determine the relationship between FE models and physical testing is clearly a very important step in the design phase due to the ability to validate / create greater predictive capabilities for the FE model.

Task 3



The report so far has highlighted that the relationship between FE models and physical testing can be a very important phase when designing or redesigning components, but can FE models ever replace physical testing entirely? The above case study will be used to help answer this important question. When designing a hypoid gear set there are multiple failure modes, but the most important failure mode to design for is the edge contact between the two gears. This edge contact is the most critical design element due to the large strain values applied to such a small surface area. The two figures below show the edge contact patterns of a hypoid gear set.

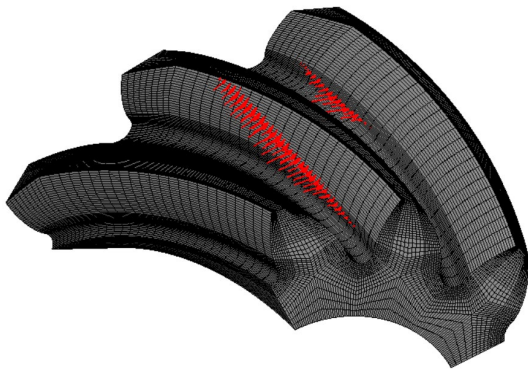


Figure 3: Ring Gear Edge Contact Pattern

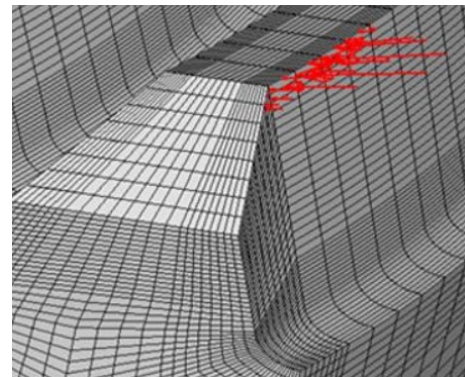


Figure 4: Ring Gear Closeup Edge Contact

The case study outcomes from exerting 500 Nm of torque from the pinion to the ring gear in the FE model and physical testing resulted in the following graph and table, figure 5 and 6.

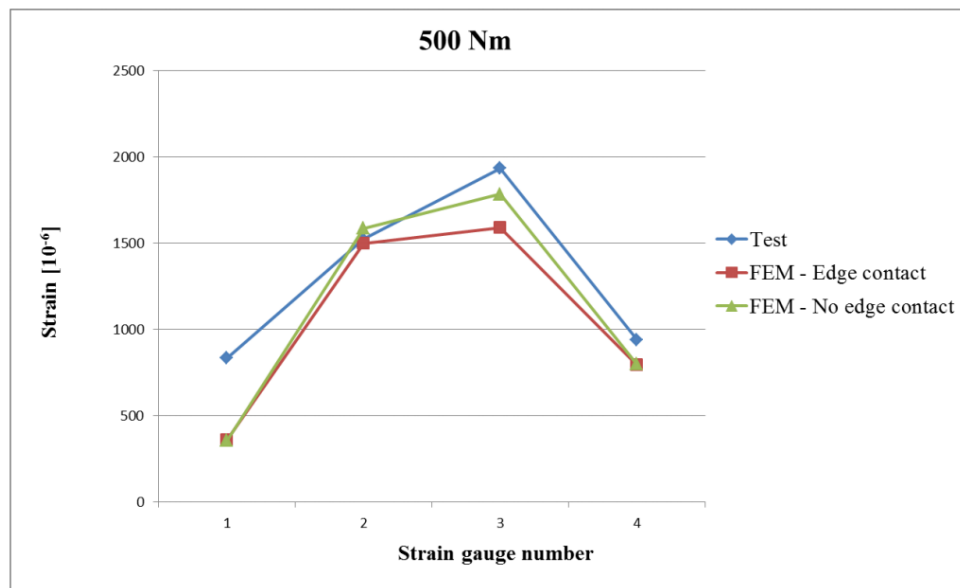


Figure 5: FE Model vs Physical Testing Contact Pattern Results

Strain gauge no.	Gauge 1	Gauge 2	Gauge 3	Gauge 4
Measured strain [10^{-6}]	835	1523	1936	942
Calculated strain [10^{-6}]	361	1499	1592	797
Strain difference [10^{-6}]	474	23,8	344	145
Relative error [%]	56,8	1,56	17,8	15,4
Stress difference [MPa]	98	49,3	71,1	30,1

Figure 6: Raw Data Edge Contact Results

The results demonstrate that the FE model is only accurately predicting the actual strain figures at one location and that the model is also under predicting the peak strain value by up to 17% (Gregefors, 2016). This study highlights the need for physical testing due to the fact that certain complex parameters such as edge contact patterns are very difficult to model correctly in an FEA package. It also demonstrates that with physical testing the FE model can be adjusted accordingly to provide better predictive capabilities. The problem with relying on FE models entirely is that the existing software programs are unable to accurately mimic real-world scenarios with 100% accuracy. This is due to the fact that certain input variables must be slightly modified in order for the program to run smoothly. An example of an input variable being slightly manipulated are the initial boundary conditions that are applied to the component. Typically components in real world situations never have a fixed boundary condition due to the fact that there is always some amount of contraction / movement between other components or with environmental influences. But in order to properly run an FE model the component must be completely fixed in one direction and thus the assumptions the FE model is making will slightly change the results compared to the real world scenario. Now of course this small discrepancy might not play a huge role in the end results for certain components but in other cases this may be the difference between a successful design or a failed design. Not to mention that the initial boundary condition is only one of the assumptions the FE model is making. If you begin to compound the potential small errors caused by multiple variable assumptions that the FE model is making it becomes a much larger issue when trying to validate a design. Which is why I believe that the need for correlation between physical testing and FE models will always play a vital role in component design, especially when the consequences of a failed design will equate to catastrophic failure like the case study example in this report. Even if catastrophic failure is not a governing parameter, I believe that some sort of physical testing must be used to accurately verify the newly designed component to ensure a successful design.

Conclusion

The results generated from this report highlight the important role that FE analysis currently has when designing components and systems. It has also demonstrated how FE models are correlated to physical testing to validate / enhance the future predictive capabilities of the model and thus providing a more powerful tool for engineers to rely upon. More importantly, this report has established that FE analysis should never entirely replace physical testing for high risk components (i.e. where the risk of failure is catastrophic). This is due to the assumptions and unknown variables that current FEA software implements. In conclusion this report has verified that when an engineer / designer is creating a component without any previous data physical testing is a must to ensure a robust and accurate FE model, and even when previous data is available, some sort of physical testing should be implemented to verify a successfully designed component.



REASONABLE REPORT, ALTHOUGH TASK 1 IS FAIRLY DESCRIPTIVE WITH NOT ENOUGH RESEARCH TO SUPPORT YOUR COMMENTS,

References

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