

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	HOPKINS	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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
			✓
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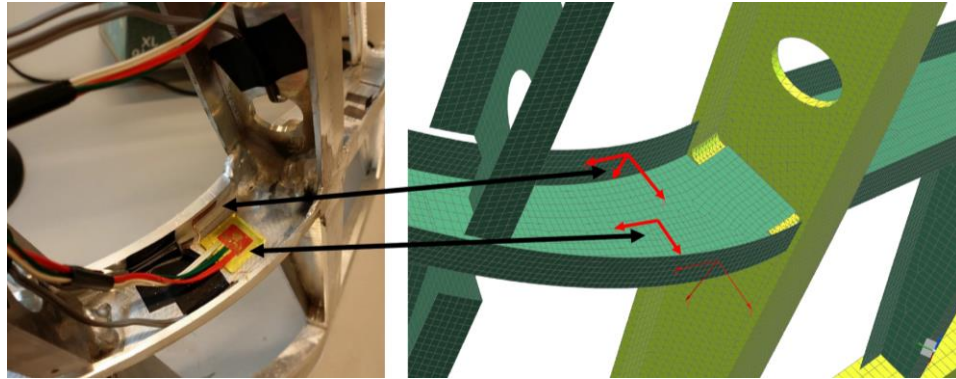
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	17.4
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	18
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	19.2
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)		61.1 %
	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			

University of Wales Trinity Saint David

School of Engineering

Can FEA replace physical testing?

Christopher Hopkins

149588

24/04/2020

Advanced Stress Analysis & FEA M6X00420

Kelvin Lake

Contents

1	Introduction	1
1.1	Aims	1
3	Carrying Out both FEA and physical testing.....	2
4	How Physical testing may be correlated to an FE model.....	5
5	Can and should FEA replace physical testing.	9
6	Conclusion	11
7	References	12
Figure 3.1	(Bechtel, et al., 2009) Results	2
Figure 3.2	(Chajes, et al., 2010) Results	3
Figure 4.1	(Yucheng, 2013) Results.....	5
Figure 4.2	V&V plan (Abbey, 2015).....	6
Figure 4.3	(Rawson, 1994) Results	7
Figure 4.4	(Rawson, 1994) Results 2	7
Figure 5.1	TML.....	10

1 Introduction

This report will undertake an investigation into the role that finite element analysis (FEA) plays during production and development when applied to destructive and non-destructive testing within the industry. The report will examine 3 areas of study, the first being the use of finite element analysis coupled with real world physical testing and why companies typically carry out both when finite element analysis should remove the need for physical testing. Following this, a study will be carried out into the impact physical testing may have on a finite element model and the connection between the two forms of testing. Finally, an enquiry into the possibility of replacing physical testing completely in support of finite element analysis discussing the possibility and if so the practicality of the matter. Finally, the information gathered within the 3 sections will be correlated and concluded upon with justification based upon the research gathered.

1.1 Aims

- Using a case study investigate why companies tend to carry out both finite element analysis and physical testing during the design stage of a product determining the usefulness of this concept
- Investigate the relationship between physical testing and finite element analysis in hopes of determining how finite element analysis is affected by physical testing
- Discuss whether finite element analysis could be used to completely replace physical testing by exploring the pros and cons of this with the aim of making an educated judgement on the viability of removing physical testing.

3 Carrying Out both FEA and physical testing

Typically, when designing a product, a company will use both finite element analysis alongside physical testing. However, this means companies are spending time and resources on two different testing methods leaving the question why?

According to (Bechtel, et al., 2009) although advancements in FEA have allowed for more accurate system-level analyses, allowing for a more efficient design process some knowledge surrounding simulated solutions is still too sparse to make it perfectly accurate. (Bechtel, et al., 2009) used both destructive testing and FEA to determine the ultimate capacity of skewed steel I-Girder bridges. When performing physical testing 2 of the 4 bridge girders exceeded yield with the application of 12 -13 scaled trucks with the ultimate capacity of the bridge being 22 scaled trucks. However, 3 FEA models were created 2 of which failed as they incorporated a static analysis, whereas the final model used an Explicit central difference operator was successful and predicted the load of 21 scaled trucks would achieve the ultimate capacity. This means that the FEA model was within 1 truck load of the physical test results showing high accuracy between the two methods. However, figure 3.1 shows the comparison of load to deflection between the 2 tests. Although at lower loads girders 2-3 show practically identical deflection the FEA model is not 100% accurate throughout the higher loads.

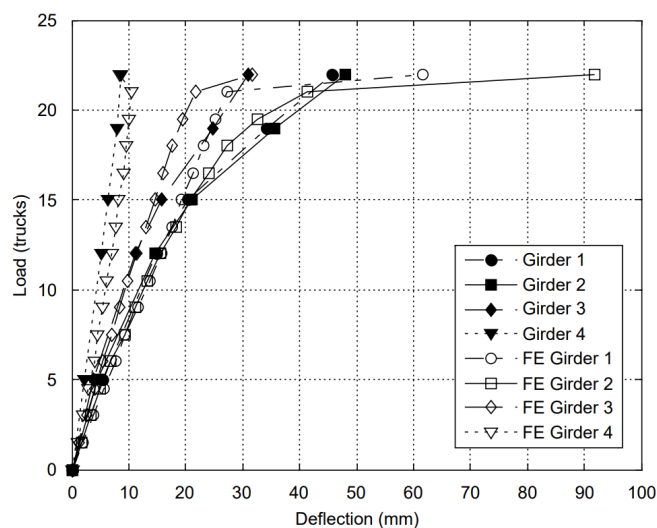


FIGURE 4 Load versus deflection for specimen and FEA model girders.

Figure 3.1 (Bechtel, et al., 2009) Results

The accuracy concerns of standalone FEA modelling are further backed up by a similar study also carried out on I-Girders by (Chajes, et al., 2010) where FEA predicts higher strain at almost every load increment.

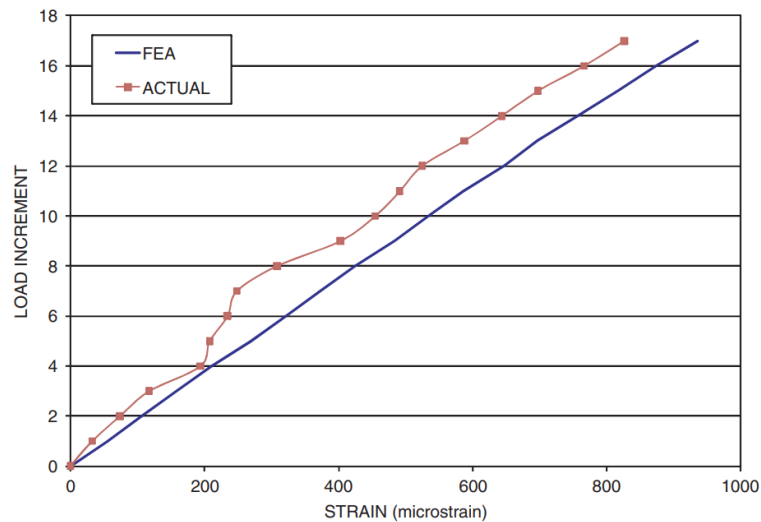


FIGURE 7 Comparison of finite element analysis and actual bottom flange strains at Site G2-A.

Figure 3.2 (Chajes, et al., 2010) Results

These studies demonstrate one reason companies use both FEA and physical testing as although FEA was close to the real world values there was a slight difference even if the simulation predicted a lower ultimate capacity in this instance, if the product wasn't physically tested and the FEA model suggested a bridge that could support a load that it couldn't it would cause major implications on the manufacturers. This suggests that companies are likely to use FEA models to achieve close values and then when happy with a design verifying the FEA model with physical testing resulting in fewer prototypes but verified and validated results. Finally, these studies are both backed up by (Design World Staff, 2007) who state that the method used by FEA is an approximation as the analysis is produced on a model rather than the structure itself meaning that for full trust within the results tests must be carried out on both the model and real structure. This does however allow for a reduced number of studies to be carried out on the real structure reducing the overall cost.

Additionally, (Penner, 2020) finds that linear FEA solvers have severe limitations in the case of stress concentrations like gussets or keyways. This is due to the large stress over a very small area causing the material to yield and no longer behave linearly. This can lead to parts failing unexpectedly when produced and resulted in the company running stress concentration tests alongside FEA to determine acceptable stress concentrations. Linear solvers, however, use drastically lower computer resources and time making them the only viable option at times. Both the above points are backed up by (Pre Technologies, 2020) claiming that linear solvers lead to significant computational and cost savings as the stiffness matrix is presumed to be unchanged throughout the simulation. However, when a ductile material has a load exerted upon it that surpasses the materials yield point more complex

and expensive FEA is required which further supports the use of more accessible software with the addition of physical testing for verification.

Finally, According to (Kurowski, 2002), although FEA software is becoming easier to use it is not a simple programme that just anyone can use and therefore there is an aspect of possible human error defining objects. Poorly defined FEA objects are a wasted effort as they will not produce accurate results. This suggests that the use of physical testing is required to verify the results of FEA. However, also advise about human error with a focus on human error during manufacturing which could skew the results of FEA testing due to unforeseen tolerances. Without the use of physical testing in addition to FEA in this case produced ships could fail in the real world that would be deemed functional within FEA.



4 How Physical testing may be correlated to an FE model

Once a model structure has been formed the only way to verify the results accuracy is through physical testing of the actual structure and comparing the results to those of the FE model. This is because the FE model is only an approximation of the real structure and the simulation is not being ran on the real structure.

“All models are wrong, but some are useful “ (Box & Draper, 1987, p. 424)

With that being said, for the model to be useful the validity of the calculations must be proven through physical testing. This means that if the FE results do not match nor follow a strong correlation to the physical results then something within the FE model is incorrect. This may be down to a few things, such as the initial material parameters being set wrong/insufficient meshing which is demonstrated in (Yucheng, 2013) ran a range of simulations on a metal plate with the independent variable being the mesh density.

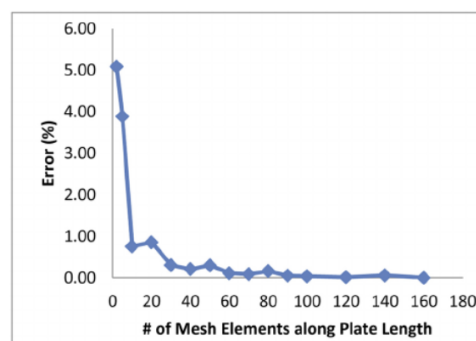


Figure 2. Element size vs accuracy for maximum von Mises stress

Figure 4.1 (Yucheng, 2013) Results

As seen in figure 4.1 the trend appeared to show that the higher the density the lower the error % with a few outliers towards the higher end. The study also showed the increase in computing time suggesting that using physical testing to gauge an appropriate mesh value that would provide accurate enough results without drastically increased run time. This could be done by investigating the error % and selecting an acceptable error % which could remove hours from the simulation for 0.1% of an error.

(Abbey, 2015) suggests that FEA and physical testing are correlated together through verification and validation. Verification is the checks carried out on the FE model to ensure that the model itself is working, the maths used within the simulation is correct and providing an accurate analysis. Validation is making sure that not only does it work but that it does what it is supposed to do, gets the physics correct and is checking the model against the

physical test. From this it can be assumed that verification consists of typical checking process periodically as the model develops whereas validation is the process of comparing the model against available test data.

“Verification: The process of determining that a computational model accurately represents the underlying mathematical model and its solution.”
(ASME, 2006)

“Validation: The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.” (ASME, 2006)

Figure 4.2 demonstrates a combined verification and validation plan.

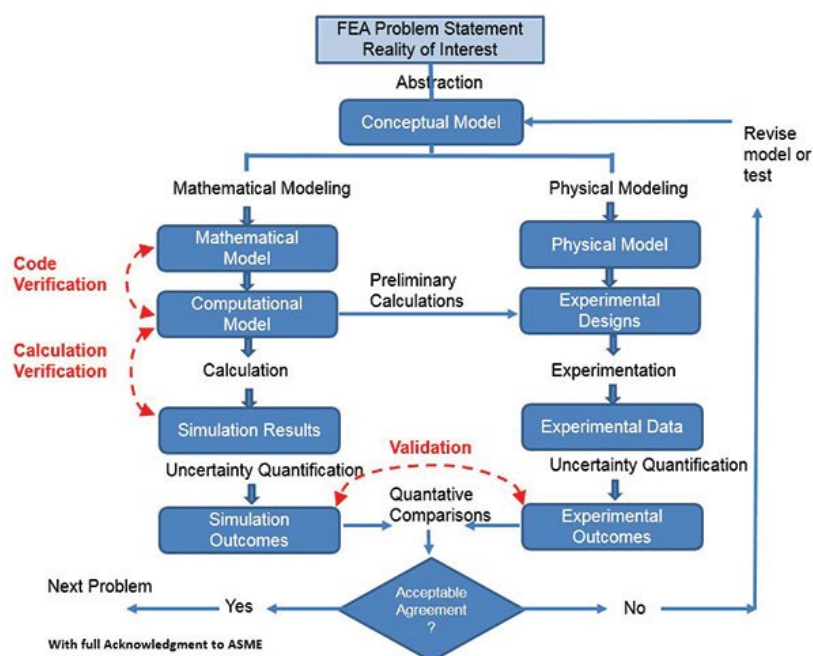


Figure 4.2 V&V plan (Abbey, 2015)

Comparing test and analysis based on metrics means that that single comparison such as ultimate failure in destructive testing is supplemented by numerous incremental metrics. This allows for a greater validation between physical testing and the FE model.

(Rawson, 1994) who conducted a study comparing FEA with actual physical test data of a thermoplastic bumper that would replace steel bumpers within the automotive industry. The results from the study show that the model was verified as shown in figure 4.3 by the FEA model following a similar trend to the physical test. However, the model isn't validated as closely and could do with extra refinement so that the model closer fits the real-world data and therefore making the FEA results more reliable for future tests.

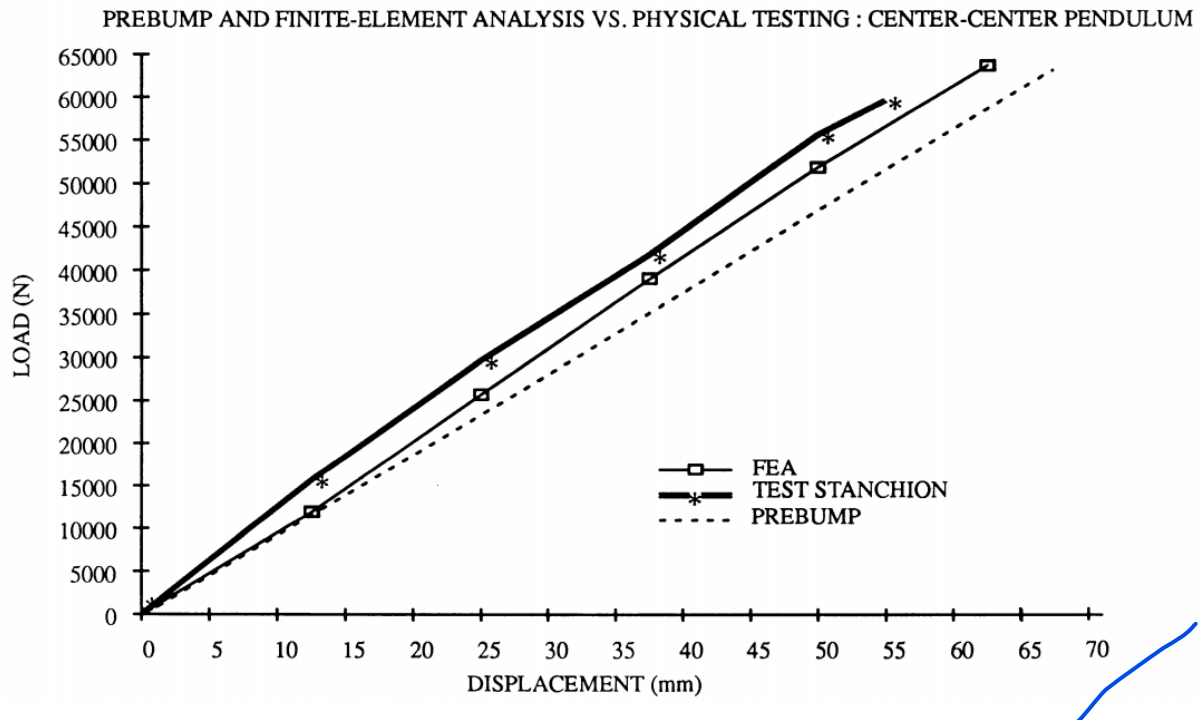


Figure 4.3 (Rawson, 1994) Results

Further tests also show similar trends where the model fits the general trend however doesn't perfectly match the results of the physical testing as shown in figure 4.4

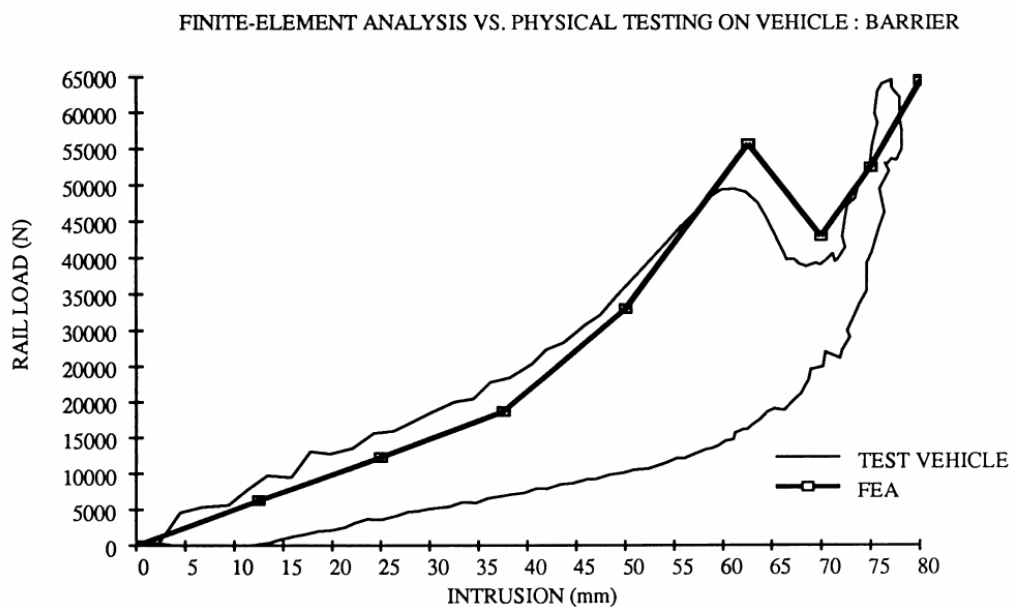
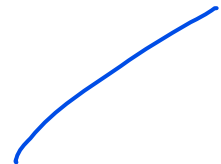


Figure 14: Comparison of Finite-Element Analysis to Physical Testing on a Test Vehicle for a Barrier Impact

Figure 4.4 (Rawson, 1994) Results 2

A study carried out by (Cheng, et al., 2001) where a reverse engineered FE model of a 1997 Honda Accord is refined to improve the computational performance of the model, and validate the crash response with crash data of actual vehicles. Various issues with this were noted by the researchers such as missing parts that weren't located in major load transmission paths, connection problems such as correct welding modelling and with over 200 parts assigning the correct material properties proved difficult. The model was then compared to physical data numerous times and refined each time until the FE model was a closer representation to the physical test data. The study concluded with a successful model that was validated as a suitable for use as a crash partner for other vehicles. Tests found that the model was computationally stable, reliable and repeatable. This means that without real manufacturers models accurate FE models can still be created through verification and validation means, retesting the FE model with refined parameters section by section allowed for an accurate representation of a physical model suggesting the influence from physical testing on FE models can help to obtain realistic FE models.



5 Can and should FEA replace physical testing.

FEA has become a very important product testing tool for manufacturers. Due to this it has become a very integral part within the design process for engineers. It has significantly assisted manufacturers in the reduction of product development time as well as the associated costs. As a tool capable of predicting flaws within designs as well as performing ultimate capacity simulations with a good amount of accuracy, provided initial conditions are set up correctly. However, the question remains whether finite element analysis could replace physical testing now or in the future?

According to (Vyas, 2015) computer simulations provide results based on mathematical equations that are solved to define the physical system. As such, the results of the simulation are based upon the user's inputs and therefore meaningful results are at the experience and expertise of the user itself. This creates arguments for both sides as valid inputs would allow for physical testing to be removed however, the risk of human error supports maintaining the relationship between physical testing and FEA.

Additionally, although there have been many phenomena that can be defined accurately through equations that can be applied to data to validate results, changes in design or parameters being input can produce different results that would need to be further validated. Furthermore, if the results obtained fail the study would need to be repeated in a physical nature. This would suggest that FEA wouldn't be capable of replacing physical testing completely as there are too many uncertainties when creating new designs that could react differently to current designs making physical testing of some sort paramount when refining models and to improve their accuracy. This is backed up by (Thornton, 2011) & (Parnell, cited by Wong, 2010) who states that FEA does not remove the need for prototypes just reduces the amount needed and without physical testing to validate the FEA the results are not credible. Additionally, according to (Schmitz, 2016) concluded that the use of simulation does not replace the need for verification and validation. Although it does allow for testing with greater efficiency reducing results time from months down to mere hours. (Vyas, 2015) does however suggest that models that have been developed using several experimental validations may be able to eliminate physical tests completely.

Moreover, (Vyas, 2015) states that as new materials are being developed and tested to replace conventional ones such as carbon fibre, it is difficult to predict behaviour for them if there is no prior testing been conducted on this material suggesting that physical testing will always be required as technology and ideas develop.

(Parnell, cited by Wong, 2010) states that simulation by itself is not enough. However, the amount of physical testing required depends on the value of the product even more so in products that involve life and safety. This suggests that physical tests can be very important and irreplaceable for any product designed to protect an individual as a simulation is never 100% accurate.

Finally, (Vyas, 2015) believes that although currently physical tests are a necessity with the development into 2 areas there might be a possibility of removing physical testing all together. This would require development of systematic maturity model. In 2013 a platform was established to evaluate simulation tools for composites. The purpose of the hub was to certify simulation tools. Tools are assessed using the Tool Maturity Level which is split into the 5 levels displayed in figure 5.1.

Tool Level TML	Tool Maturity Description
1	Analytical process is exploratory in nature. Fidelity of predictions is largely unproved. Provides some physical insight but cannot reduce development testing.
2	Proven capability for comparative assessment, ranking or trending. Experimental validation is still necessary. Can drive development of assessment plan and test matrix.
3	Material or process can be developed or assessed with significantly reduced testing. Expectation that development iterations will be reduced or eliminated. Accuracy and uncertainty effects must be quantified. Range of applicability well defined.
4	Material or process performance and impact on system or application are understood. Accuracy and uncertainty effects must be verified. Additional data may be required when applied to new materials or processes, or to extend range of application.
5	All material and process performance and system interaction effects are understood within defined range of application. Analytical process can be used to predict mean performance without testing.

Figure 5.1 TML

At level 5 the model is considered to be mature enough to carry out stimulations without V&V Vyas believes that further development into this model would bring us closer to removing physical tests. The second area Vyas believes exascale computing or increasing computational power more specifically from peta to exa allowing for more sophisticated calculations. However, this would require huge expenditures but is a necessity for computational science to be fully predictive for real world systems. This suggests that although there is no way to replace physical testing currently there is a possibility that this could only be for a limited amount of time if developments allow for it.



6 Conclusion

To conclude, companies tend to use both FEA and physical tests for numerous reasons most tying into each other. The first being accuracy of the model, it is possible to receive results that do not represent the real-world model and even if the results do, they will never be perfect as the simulations is on a model not the real product. Accuracy can also be affected by human input errors which would lead to incorrect simulation. Inaccurate simulation could be dangerous if left untested physically holding companies accountable for any injuries caused by not testing thoroughly enough. Finally, some FE software's only offer linear solvers meaning material properties are kept the same. This would mean that although simulations can be carried out if the material is to go into yield it won't be modelled. For this reason, it is common for a company to run simulations on a design and then verify it on a prototype.

The main correlation between physical testing and FE models is verification and validation. A lonely FE model may be verified correctly acting in an expected way however without validation from physical testing to refine and improve the accuracy of the simulation the model is practically useless therefore the FE model and physical testing are used together throughout the process to provide an accurate representation of the real world within the simulation with as little money spent.

Finally, FEA cannot currently replace physical testing completely. The use of FE models has drastically reduced the number of physical tests that are required because using a verified and validated model removes the need for most physical tests used along the design process but not the need for a final test to validate the results throughout. This is most important with products that involve life or safety. There could, however, be a possible scope to make physical tests obsolete in future by hardware developments allowing for more complex simulations and development of models that are sophisticated enough to not need further V+V (TML)

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