

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	RICHARDSON	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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:	<i>Assignments will not be accepted without a signature here</i>	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	19.5
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	19.2
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
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	6.3

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)		63	%
	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

Title of the Coursework

Can FEA replace physical testing?

Name and P Number

Danny Richardson

P151196

Module Name and Code

Advanced Stress Analysis & FEA

M6X00420

Date

25/02/20

Lecturer's Name

Kelvin Lake

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WHERE IS THIS FIGURE REFERRED TO IN THE TEXT?

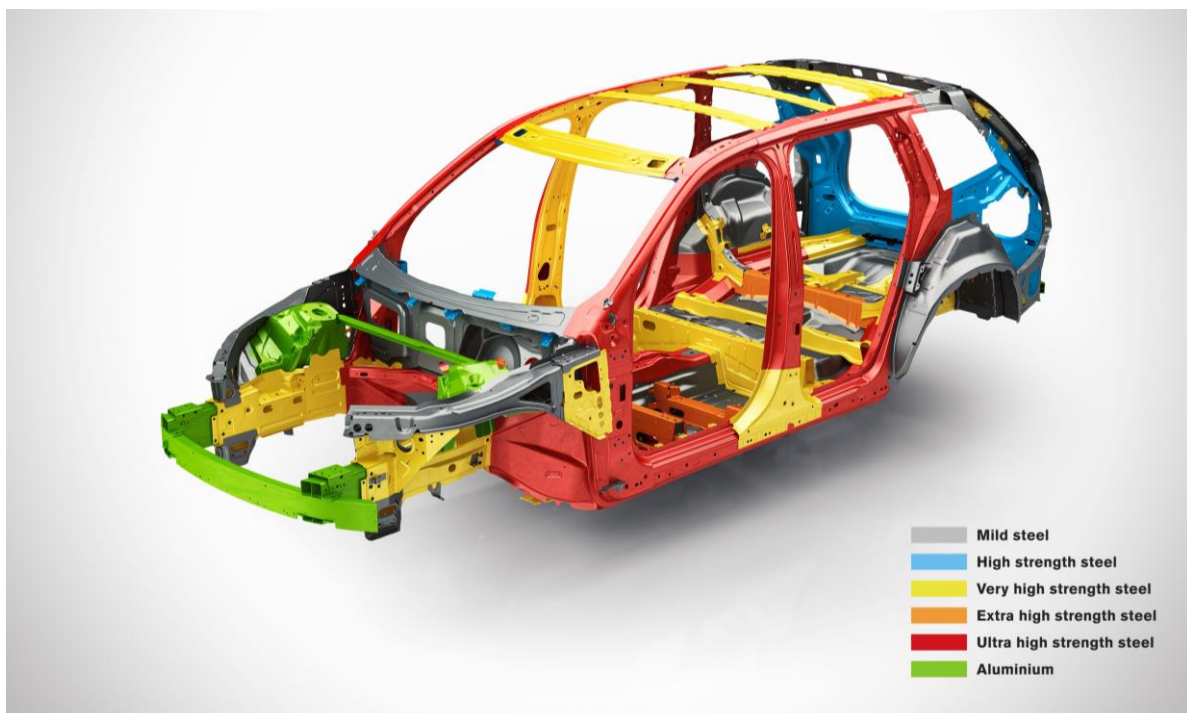


Figure 1 Material type strength across Volvo's XC-90 chassis (Volvo, 2014).

1. Introduction.

With seemingly so many pro's and a lack of con's, it is thought that FEA could potentially replace physical testing all together. Given that Finite Element Analysis software has pioneered the whole of engineering as an industry, enabling many to complete highly complex stress and strain analysis, within short periods of time and a somewhat little cost in comparison to real-world testing. The simulations conducted within an "FEA" computational package are forever progressing, but this progress owes itself to our ability to conduct tests and measure the forces, pressures and strains of these many parts & products. Such as vehicle chassis strength, engine block torsional stiffness, interior trim component interactions, suspension compliance & deformation, the list goes on. But being able to take those results and correlate the measured data to that of the predicted, in order to understand any inaccuracies occurring is the key to our success.

With many years of this correlative testing now informing the FEA packages of today, a company's ability to save money in their product's design and development has been greatly improved. This is because there is less of a requirement for physical prototypes and testing, a reduction in planning and development time allowing for potentially increased revenue, along with designs being enhanced and more complex that perhaps could not be physically tested. All whilst being immediately available across the world because it is of an electronic form (MANOR, 2020).

This research paper has been written and informed by two primary case studies, "Accurate FEA Predictions for Roof Crush Performance of Automotive Structures" conducted by Naga A. Narayana. And "FEA Based Durability Evaluation of HD Tipper Chassis and Cab Through Correlated Transient and Fatigue Analysis" conducted by Sanjay Tiwari & Ashutosh Dubey.

Objectives –

- Outline why many companies are still choosing to use their FEA simulations alongside physical testing.
- Describe how to correlate physical test data to the CAE simulation predictions.
- Discuss how FEA software could eventually remove the need for physical testing all together and perhaps why it shouldn't.

2. Why use FEA alongside physical testing?

THE AMOUNT OF PROCESSING IS STILL THE SAME?
COMPUTERS ARE JUST CHEAPER!

With finite element analysis, the capabilities of today's software's are very advanced and the requirement for extremely powerful computers is no longer the case. So having the ability to conduct studies on stress, buckling, fatigue, vibration of heat transfer before even producing a physical part is a massive technological leap for many engineers (CALIBER DESIGN, 2020).

For example, be able to model something as complex and important as a vehicle's roof crush performance could both save or sink an engineering company. Because the safety element of today's road vehicles is an important factor in sales, if the company were to only use FEA to develop their chassis structure for it to then fail or act vastly different in the real world, this could ruin a company given the potentially huge amount of money that has in essence been wasted, along with their reputation being ruined. So, avoiding the possibility of collapsing a company, the best approach for this would be to develop the simulation modelling alongside the physical tests.

Using the following case study, conducted by Naga A. Narayana, "Accurate FEA Predictions for Roof Crush Performance of Automotive Structures" as an example, the paper shows the sheer amount of complex considerations like the windshield structural integrity, the joints between types of materials (welds, hinges, rivets, etc.), adhesive strength, body/chassis stiffness, etc. However, even with a phenomenon such as roof crush performance, a developed and accurate model within a solitary FEA package or integrated CAD package is possible but shown to only be because it was developed alongside real testing.

The reason for this is because of the uncertainty within any computational programme and the underlying fundamental principle of using partial difference equations [PDE's] to solve the mathematical problems, of which will only ever be an estimation. The FEA software will most likely be capable of using various types or multiple types of "solvers" and these are tasked with calculating the equations within the simulation. It could be done in a linear or non-linear process, using solver types such as sparse or iterative, like in Autodesk's package. More often than not the type of solver is left of automatic where the software will figure out the most effective way in which to calculate the given problem, usually based on the number of elements within the model (AUTODESK, 2017).

Another area of concern that could cause drastically wrong results is the mesh type used for the study. The mesh is responsible for creating the potentially millions of elements that will be used to create the individually calculated elements and formulated to develop the results of deformation, stress/strain or potential failure. The type of mesh used will affect the results drastically because of the required interpolation between them using the nodal points, these are the known values (SimWiki, 2020). They're often located on the boundaries of the element and depending on the approximation method used, incorrectly sized elements could lead to poorly estimated values across these elements and therefore could cause completely inaccurate results.

An example of the effect of mesh density can be seen from results of a study on a thin walled beam, undergoing static, modal and impact analysis, conducted by Yucheng Liu and Gary Glass. Their study showed that depending on the type of analysis, the mesh density could have catastrophic errors in results, primarily the accuracy of maximum impact force and displacement.

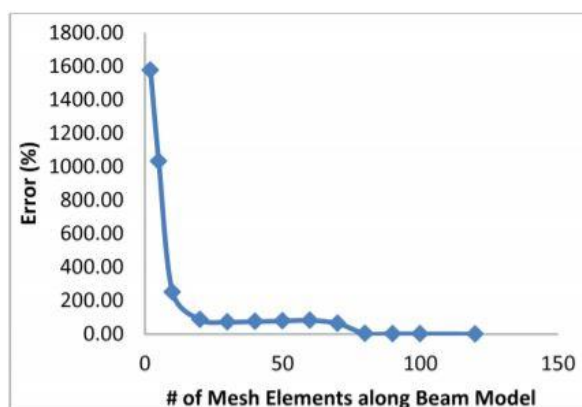


Figure 3 Element size Vs Accuracy for maximum impact force (Liu & Glass, 2013).

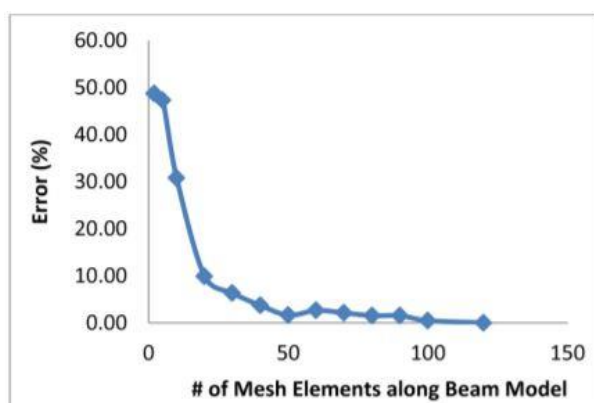


Figure 2 Element size Vs Accuracy for maximum displacement (Liu & Glass, 2013).

Given the obviously drastic inaccuracy potentially caused by incorrect meshing on something as important as the maximum impact force, arguably the most important factor for modelling roof crush performance, it's clear why engineers would want to correlate their FEA models and results simultaneously with real-world physical testing and the measured data. Although it can be expensive, and the time taken to recreate the correct model may be more than planned, the repercussions of not developing an FEA model alongside real-world test data for roof crush performance does not bear thinking about.

GOOD EXAMPLE

3. Correlating physical testing to FE models.

When considering the results from a study conducted within an FEA simulation, it's important to understand how to correlate these with that of the tested. Primary pointers are understanding the model constraints and ensuring that these would've been representative of those defining the real structure, i.e. the weld points, point loads, degrees of freedom, etc. These constraints are fundamental and can have a large impact on the predictions shown within FEA, hence why conducting parametric studies upon the constraints within the model are so important and can help the researcher to develop a more accurate & time efficient study. Parametric studies can also highlight the constraints and model content that perhaps may not be needed because they show no significant change. This is shown by the following figures from Naga A. Narayana, in that the studies on adhesive and contact properties and how they effect the modelled prediction to that of the tested data.

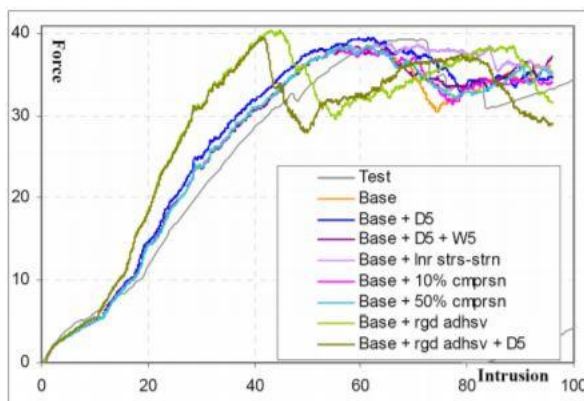


Figure 5 The parametric study of adhesive properties constraining the windshield. (Narayana, 2011).

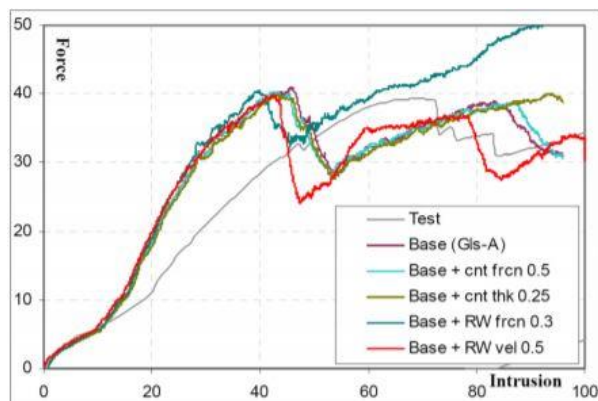


Figure 4 The parametric study of contact parameters of the vehicle's windshield. Contact friction, thickness and rigid wall friction and velocity (Narayana, 2011).

Model content is also of great importance for correctly correlating the FEA model to the real test data, especially with roof crush performance because one issue is that “strength is a property of materials, not of structure” (TASA Group, 2020). So, within a model of this type it's extremely important that the materials are defined, with they're correct measured and known yield points associated. This can be done with conducting individual part stress/strain tests in real life and then replicating the test virtually with an FEA simulation to ensure they behave the same, giving confidence within the modelling. [Appendix A]

Also, understanding the influence each individual part has because of its material properties is key to being able to reduce the computational time required for the simulation. Naga A. produced a study on the influence that external parts alike door glass, sunroof

glass and doors would have on the crush structure performance. It was found that by having removed the door glass or sunroof assembly would negatively influence the results. But removing the doors opposite test side showed no real impact, therefore a reduction in computational time could be found because the model size could be reduced.

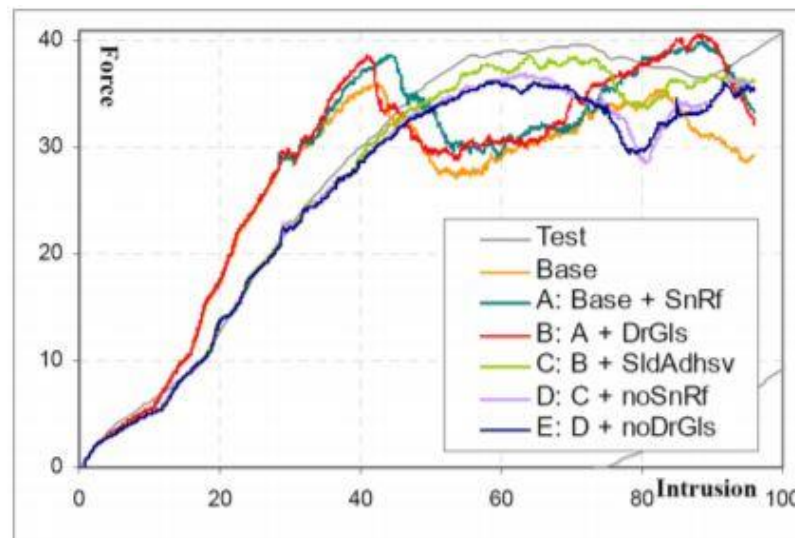


Figure 6 Parametric study of model content sensitivity (Narayana, 2011).

When conducting the test's and retrieving data, it's key that the type of measurement is understood, the measuring equipment is calibrated correctly, and any conversions required are correctly calculated. Regarding the type of measurement, it's important to know the target of results i.e. stress, strain, acceleration, etc. The stress/strain results are usually found via some form of strain gauge placed on a member or suspension component and as the external force changes, as does the internal resistance of the sensor. This change is then converted into an electrical current that can be measured (OMEGA, 2020).

Alternatively, the vertical accelerations can be measured across areas of interest of a part or body and then converted into displacement signals. This was the approach of another study conducted on "FEA Based Durability Evaluation of HD Tipper Chassis and Cab Through Correlated Transient and Fatigue Analysis", by Sanjay Tiwari and Ashutosh Dubey. Their measured displacement excitations were then used in a transient study of the truck chassis, with the stress/strain measured in the same areas of interest virtually. The predicted values are then compared against the measured for trends, magnitude and frequency, to ensure that the model is correctly constrained, shown in the following.

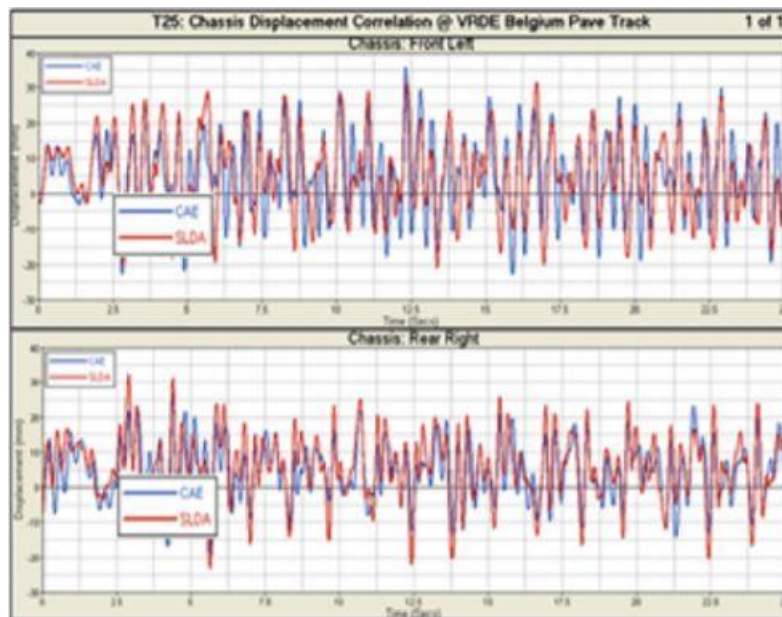


Figure 7 HD Tipper chassis correlation of their chosen front left and right measured displacement and the predicted FEA values (Tiwari & Dubey, 2011).

Finally, when correlating FEA simulations to real test results it's is key that the errors within all aspects of the project are taken into consideration. From those that could and most likely will happen when testing, be it measuring equipment, computational or human error. Modelling and constraint errors, although given the software's of today these issues will most likely be found and highlighted, or automatic corrected. Lastly, any correlation between real-world tests and FEA simulations is almost inherently subjective to the designer/manufacturer, and the acceptable percentage of errors should be clearly defined and characterised at the start of the project development stage.

Once all factors have been considered and there is historical recorded data for the specific material and tests, the level of error percentage could be used to inform if only the FEA simulation is required, having the potential to reduce the number of physical tests and prototypes to be used, all in the name of saving money.

These same FEA simulations can also then be used for predicting the points of failure, issues in manufacture, possible weight saving, product safety, etc. within slightly modified new generation products (Belhe, 2016). Which for an engineering company would again help massively to reduce the time required to bring out a new product, naturally then increasing their income revenue and decreasing production costs.

4. FEA analysis to take over physical testing?

It's of no doubt that the progression seen within the world of engineering owes a certain level of gratitude to finite element analysis simulations. With the software's becoming more readily available for many, the computational requirements being lowered and their accuracy of predictions forever increasing, it sparks thought for what the future of our industry holds. Given how we have the ability to produce virtual simulations of product performance, deformation and fatigue life within relatively short periods of time, that can easily be transferred or sent globally to other companies & teams, it seems only logical to for this to be the future of product design.

Because of the seemingly endless number of positives to come from doing so, and not only on the principle of saving time and money. But also, the way in which products are designed from their safety aspect, to the aesthetic appearance, all within a completely virtual environment where prototypes can be created within CAD instead of physical material. Not only can FEA be used to correlate and produce topology or safety reports, but it allows the possibility to inform future simulations and creates the base for producing many test conditions and settings that would either cost too much or couldn't be done within real-world testing. For example, Tiwari & Dubey highlight within their conclusion that their durability test could be made entirely virtual, dependent on entirely simulated inputs and tested on "digitised" roads, to conduct further fatigue investigations.

Therefore, the authors response to the proposed question of "Should FEA replace physical testing?" is no. Because regardless of the many wonderful features and capabilities of finite element analysis software, it is still only ever a prediction based on our perception of the problem.

And as shown within any real-world complex problem, the initial simulations and predictions aren't within an acceptable level of tolerance. The FEA models will always inherently have errors obviously, and these can be accepted, but only when the data produced becomes correlated to measured test data. Elsewise it remains somewhat of a mystery as to whether the simulation can be trusted and given our industries, and all others for that matter, dependence upon reputation and reputability of safety & reliability, there could or at least shouldn't ever be a completely virtual replacement of physical testing.

From the perspective of could it ever replace physical testing, perhaps in some aspects of product development it could. If said product wasn't exclusively for safety or seen as a structurally load bearing. If this is the case then from looking at many studies conducted across the board, it would certainly be possible for FEA simulations to replace physical

testing or at least for the most part until a finalised prototype is required. However, it should be noted that these simulations will again only be a derivative of historically informed modelling that had to be correlated to physical test data.

Final consideration would be the definite improbability of material and manufacture defects. These could arguably be said to have already been considered, given that they've always been an issue and they're certainly no secret, so they could potentially be accounted for in some manner. But with the progression of material development and manufacture procedures/protocols, the constraint boundaries of materials will be consistently changing and will require some form of testing in order to characterise the properties and provide a form of calibration for finite element analysis.

5. Conclusion.

To summarise this research report, the main reason for any finite element analysis involvement within a product design stage is to fundamentally save time and money, while simultaneously aiding ease of transferability within a company or external manufacturer because of its virtual electronic form, that can be sent instantaneously anywhere in the world. One reason for using FEA alongside physical testing would be to try and reduce the number of physical tests actually required. By correlating perhaps older generation products within the chosen software so that manipulation and predications of model changes can be done within short periods of time throughout the design phase with confidence of accuracy, until finalised designs demand physical prototypes. This correlation can be done in various ways depending on the level of accuracy required by specification and the target results, i.e. stress/strain, force, displacement etc. using multiple parametric studies. These studies would need to consider important aspects alike, mesh density, solver type and model content and their effect on the results, which can be achieved by analysing the accuracy of the tests against measured data. Parametric studies can also be used to inform decisions on how the simulations can be made "computationally efficient".

Finally, it's the opinion of the author that physical shouldn't ever be replaced by completely virtual FEA simulations, because of the simple fact the results are only ever as good as the model. And if the model, along with its constraints are poorly defined or unknown, the results will be effectively useless, until compared to measured data. As for whether it could, there is undeniable potential shown in multiple studies that a large portion of the product development stage could be moved to a fully virtual environment, but not all.

6. References

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<https://www.media.volvocars.com/global/en-gb/media/photos/148215/volvo-xc90-body-structure>

- SPELLING THE TITLE WRONG WAS NOT A GOOD START & SUGGESTS LITTLE CARE
- WHILST THE CONCLUSION OF A REPORT LIKE THIS WILL OBVIOUSLY CONTAIN YOUR OPINION, YOU SHOULD BACK UP YOUR OPINION FURTHER BY REFERRING MORE SPECIFICALLY TO OTHER SECTIONS WITHIN YOUR REPORT.

7. Appendices

- A. The material properties of the adhesive used within the study considered in this report.

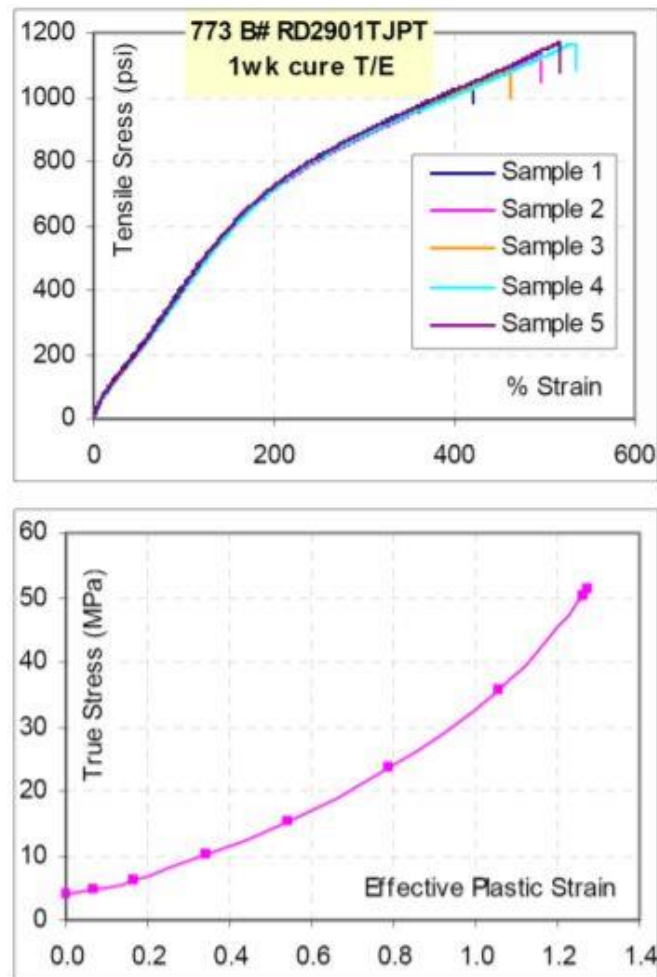


Figure 8 Adhesive material properties (Narayana, 2011).