



Can FEA re- place physical testing?

RESEARCH INFORMED

LIT = 17.4/30

KNOWLEDGE &
UNDERSTANDING = 16.2/30

PRACTICAL APPLICATION
& DEPLOYMENT 16.5/30

SKILLS FOR
PROF. PRACTICE = 6/10

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1 INTRODUCTION

This research paper is an investigation into the study of Finite element analysis and the importance of FEA compared to physical testing. To show the importance of FEA and physical testing it will be applied to a case study to show what impact that will have on the component design and the manufacturing process. The first section that will be discussed is why FEA is carried out alongside physical testing which will depend on the types of companies and the type of component specification. The next section that will be discussed will be how FEA can be correlated to physical testing and what factors need to be accounted for. The final section will be concluding whether FEA could ever replace physical testing and what would the implications be if it did.

2 WHY COMPANIES TYPICALLY CARRYOUT FEA ANALYSIS ALONGSIDE PHYSICAL TESTING

2.1 PRINCIPLES OF FEA

FEA analysis reduces costs because the software is able to create a mesh of the component designed in CAD, the mesh splits the component down into small nodes, the smaller the mesh the more accurate the FEA will be to an extent. (Dutt, 2015) The mesh can be produced within minutes ready for force to act on the component. The force can be applied to any face in the X, Y and Z direction with any amount of force. This can all be done in minutes whereas in real life the component would need to be machined, a test rig would need to be designed with correct forces being applied. This therefore means that FEA testing can produce results accurately (depending on the mesh size and boundary conditions) in a much smaller time scale which increases productivity and means components can be designed to a higher quality. (Anon., n.d.)

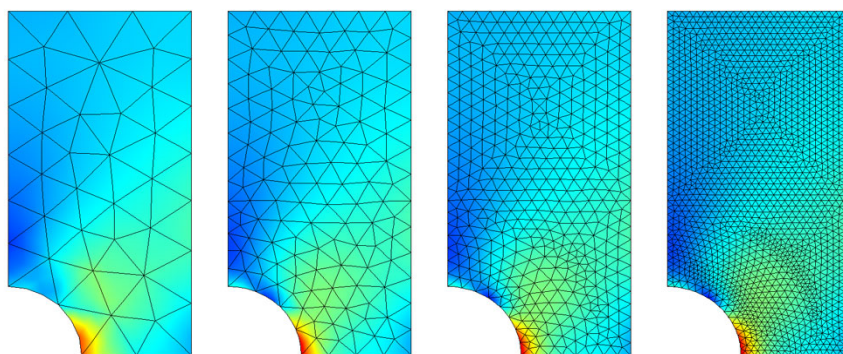


Figure 2-1 Comparison in mesh sizes of triangular elements

2.2 MESH SIZE

Figure 2-1 shows the comparisons in mesh size, you can see from the smallest mesh that the von mises stress is more defined increasing accuracy but can be more time consuming, however decreasing the element size can be more time consuming with results decreasing in accuracy.

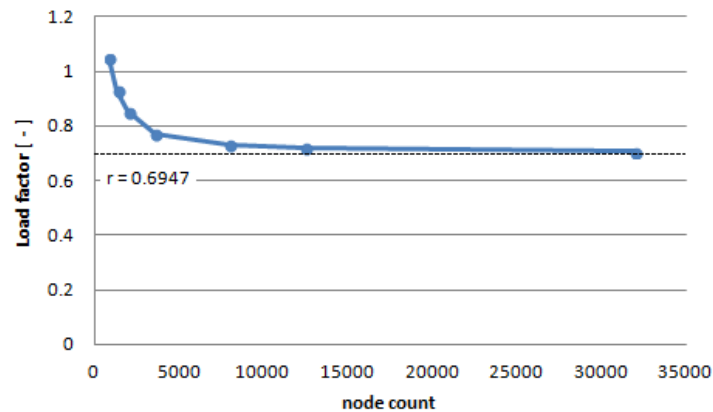


Figure 2-2 Graph showing element sizes vs accuracy

The “correct mesh size guide” on enterfea.com states that “usually smaller mesh means more accurate results, but the computing time gets significant as well”, (Anon., n.d.) this can be seen in the graph in figure 2-2 which shows that the results start to “flatline” the smaller the mesh size (Dutt, 2015). This is because the accuracy can only increase so much that that computing time increases.

2.3 EFFECT ON THE DESIGN PROCESS

Design process without simulation



Design process with simulation

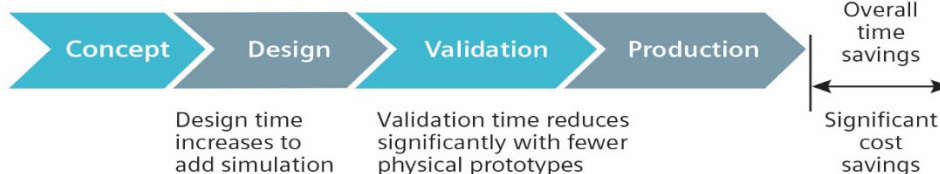


Figure 2-3 Comparison in physical vs simulation effect on the design process

Figure 2-3 shows how using no FEA increases the validation step which would also increase costs of materials for updated components. However if the FEA model was not set up correctly this could also increase the validation step as the FEA is not correlating to real life, this could be because the mesh is too coarse or the boundary conditions haven't been set right, but this would all depend on the deformation of the FEA model. (Carigliano, 2018) (Belhe, 2014)

Figure 2-4 shows the swingarm component under heavy loading in physical testing. A too coarse mesh would over predict the strength of the component which means that during physical testing the component could break or not be up to the required static safety factor whereas a too fine mesh could take too long to produce results which would also increase the duration of the manufacturing process. (Yucheng Liu, 2013) Therefore the mesh size is all depend on the scenario, if a design needs to be produced in a 2 hour window then a coarser mesh will be used or a finer mesh in the area of heavy loading as this can give accurate results without excessive computing time. (Javidinejad, 2012)

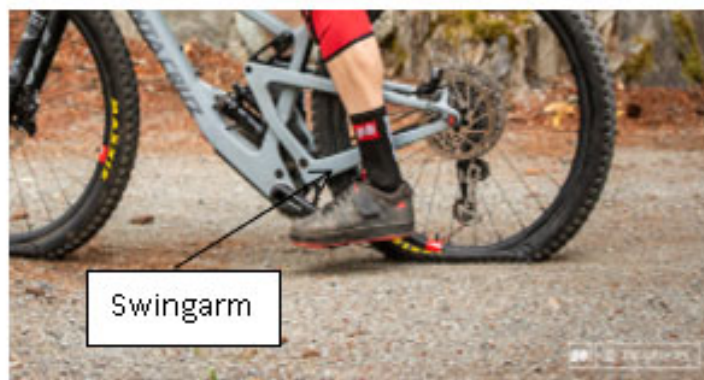


Figure 2-4 Physical test of a mountain bike frame to be compared to FEA simulation

2.4 EFFECT ON DIFFERENT MESH SIZES OF A MOUNTAIN BIKE FRAME

In the “analysis of a mountain bike frame by F.E.M” Rajeev gupta states that that there was difference between “0%-42.6% in results from mesh size” this shows how much varying the mesh size can affect the results which shows that before upgrading the component design the FEA needs to correlate with the physical testing. (Gupta, 2016) However Rajeev’s investigation was into a full mountain bike frame which is a larger component which means that the mesh size will have a larger effect on the results as there are more elements compared to a swingarm which is less material. This could get more complicated with racing car roll cages as there is more material and more variation in how each bar deforms which means the mesh will have a greater effect on the accuracy of the results. (C.D, 2012)

2.5 CASE STUDY

Selecting the correct material will also be important because the FEA model could cause deformation differently depending on the material, some materials deform more linear than others, this will be another area of how accurate the results are going to be..



Figure 2-5 Comparison of deformation of a shipping package of FEA vs real life

In Matthew R. Feldman's paper titled *"comparison of analytical and physical testing results for the DPP-2 shipping package"* which states that *"FEA has been shown to be an extremely useful tool during the development process for both design development and test orientation determination"*. This shows that when the mesh size is set correctly that you can get accurate results to real life if there was just a von mises stress benchmark target.

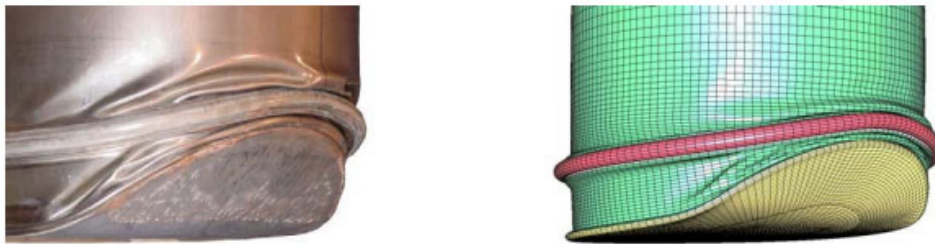


Figure 2-6 deformation of shipping package physical vs real life

However because the component is shipping package it just needs to meet a set value so that the component doesn't deform excessively. This means that there can be a lot more FEA as there can be less physical testing because it doesn't need to meet a performance requirement like a mountain bike frame with stiffness subjected to rider requirements. Figure 2-6 also show that the mesh is square instead of triangular which increases accuracy but also does increase the amount of nodes which increases the solve time, this should mean that the results between physical to real life should be very accurate. This mentioned in the article which states, *"The point of impact was deformed 5.7 in. during testing, while FEA predicted a deformation of 5.6 in"* and that the *"analysis and the testing indicates that FEA is correctly simulating the mechanics of the plastic strain that leads to the deformations"* because of the increased nodes in the mesh. (R.Feldman, 2004)

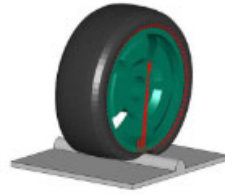


Figure 2-7 CAD model of wheel rim test in CAE simulation

In Justin Cunningham's article on "virtual vs physical testing" it states that "while it is clear manufactures still demand physical test data, much of the design and development work of engines, chassis, suspension virtually, with physical tests only used for checking assumptions". This shows that FEA leads the component design compared to physical testing as it reduces costs and is less time consuming. The example, Justin referred to was a motorsport rim for a GT3 car seen in figure 2-7, as a large component that would need a mould to produce updated designs FEA can reduce costs as long as the FEA correlates to real life as stated in Virtual vs physical testing article. (Cunningham, n.d.)

3 HOW A PHYSICAL TEST MAY BE CORRELATED TO AN FEA MODEL

3.1 VARIABLES IN FEA AFFECTING THE TEST ACCURACY

3.1.1 Modelling the component

How accurately has the component been measured? If the CAD model is out of scale then even if the mesh is fine there will be differences in how the material deforms under load meaning the CAD model needs to be accurate, for example the CAD model of the mountain bike frame will need to be hollow just like real life. (Anon., n.d.)

3.1.2 Boundary conditions

How accurately is the component fixed compared to how it would be in reality, will it require other components to replicate the fixed points, for example a mountain bike frame swingarm will need load bearing faces against the frame instead of just fixing the end face to replicate what would happen in the physical test. (Anon., n.d.)

3.1.3 Material and mass property values

Have the correct mass property values been selected so the material deforms in the same way as reality other wise this will reduce the accuracy as well as the correct material been selected otherwise this will affect the linearity of the component deformation. The mass will affect the force acting on the component as theoretically a heavier mass is stronger which means that inaccurate forces could be selected which wouldn't correlate to real life. (Harris, 2016)

3.2 TESTING EXPERIMENT CORRELATION BETWEEN FEA AND REAL LIFE

The extent of the physical testing could be important for the component design as some of the testing could be wasted which could delay the manufacturing process and increase the costs of the design process. For example if the physical testing was just to correlate to the FEA, just the swingarm fixed at 2 points and a load being applied to the top face to make sure the displacement is within 2% of the FEA model this wouldn't take too long to compare to the FEA is acting the same in reality. (Belhe, 2014) This wouldn't be as time consuming as full testing the component like in figure 3-1 with a complete bike going off a 1 metre platform to see how the swingarm performs in real life application, this will be time consuming and no guarantee that data from it will improve the component design, however the forces acting on it could affect the loading force in the FEA simulation.

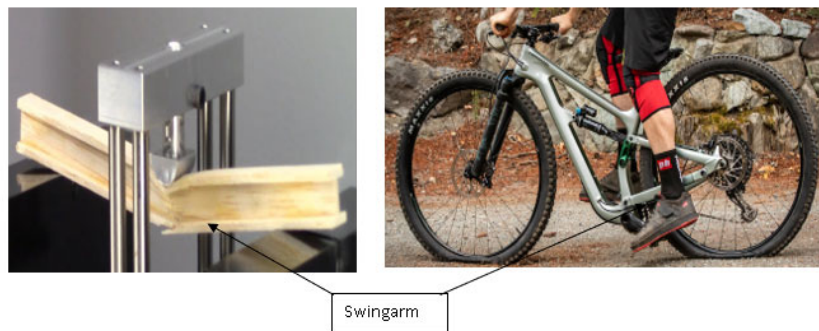


Figure 3-1 Basic vs real life application physical testing

For the FEA analysis if you just selected 500 N acting downwards on the x – direction, how accurate will the results be, why select 500 N and how could that correlate to real life? This is why you need the physical testing to select what loads and boundary conditions will most likely to compare against real life. For example, the physical test to analyse the swingarm and frame design would be a 1 metre drop to flat with a rider onboard going at 20 Km/h. (Sani, 2016) This would be severe enough impact to replicate the greatest force acting on the mountain bike. This physical test can also be replicated in FEA but the selecting the boundary conditions and setting up the CAE model could be more difficult meaning it could be easier to cause a correlation error between the two, there could also be too many variables that could not be simulated in the CAE such as rider force acting on the bike as this varies a lot in reality. (Gupta, 2016) Therefore for the FEA to replicate this test would be to get a rough value of the force acting on the swingarm instead of deformation.

In Leisha A. Peterson and Kelly j. londrys paper on *“finite-element structural analysis: a new tool for bicycle frame design the strain energy design method”* the loading conditions vary on the situation, there are 6 in total. Static start up, horizontal impact, vertical impact, front wheel braking, rear wheel braking and steady state pedalling. (J. Londry, n.d.) This shows that mountain bike frames are subject to such different forces acting in different directions that the FEA needs to replicate them, this can be more time consuming because of all the different scenarios with the boundary conditions needing to be set right. (Anon., n.d.)

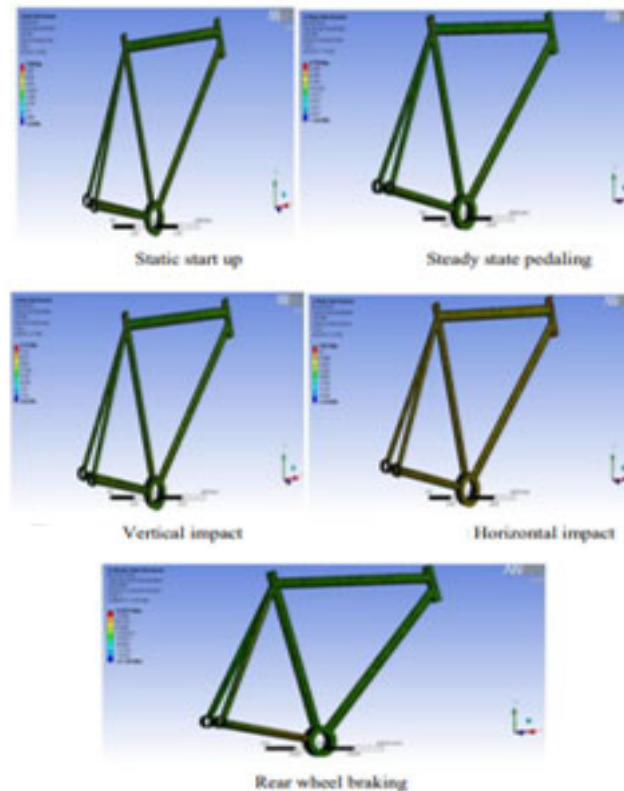


Figure 3-2 5 different scenarios of FEA testing of a mountain bike frame

Therefore the FEA conducted for their experiments was designed to directly correspond to physical testing with real life scenarios, this can be more time consuming with the increased physical testing but will also make the FEA more accurate and using FEA to speed up the physical testing by replicating real life scenarios. (J.Londry, n.d.) This means that in the FEA study a logically thought process will be needed to think about every step.

4 IF YOU THINK THAT FEA ANALYSIS CAN (OR SHOULD) EVER REPLACE PHYSICAL TESTING

4.1 SIMPLE

Split the geometry, using a too fine mesh to a coarse mesh can decrease the accuracy then will need to be validated by physical testing, therefore if the correct mesh size was used to get within 2% of real life then FEA could replace the physical testing but could lead to correlation errors. (Anon., n.d.)

Interpret the geometry- referring mainly to the fixed points or focusing on heavy loading, if these areas a selected wrong in the FEA study and there was no physical testing this means that you're not using FEA to replicate the same test has been conducted which means the accuracy of the FEA will be decreased, therefore to use FEA to replace real life you need to use FEA as if it were the physical testing with the same thought process. (Dutt, 2015) (Pointer, 2002)

Material information – in order for FEA to be accurate the material selection will need to be the same as different materials deform linearly and non-linearly. Therefore the physical testing will still need to be in place in order determine how the material deforms so the when running an FEA solve the material deforms in the same way, so the results are accurate. (Hughes,

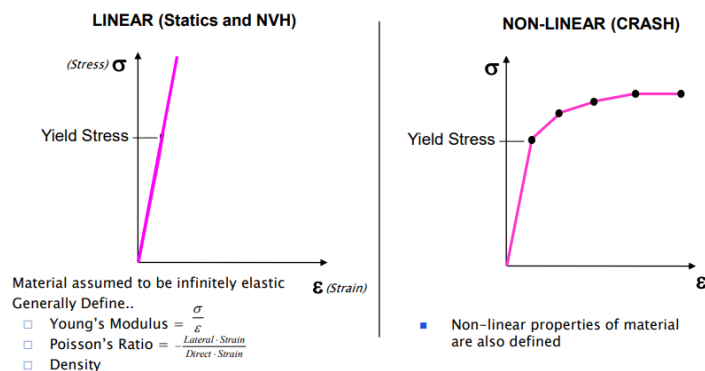


Figure 4-1 Graph showing the difference in linear to nonlinear deformation

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Physical property – If FEA were to replace physical testing the CAD model would need to be extremely accurate (± 5 mm for a swingarm) so that the component would deform the same as in real life, however you would still need to physically produce the component to measure accurately which means that there is still reliance on physical testing. However if you want to get a rough result then you may not need physical testing as you could use a less accurate geometry. (Bathe, 2016)

Loading – For the FEA to be effective and replace physical testing you would need to treat the FEA study as a physical test. For example just applying 500 N in the x direction, what would that prove? How could that be related to real life? Therefore you need to think about the FEA

study as a real test but even then, you could validate the mesh, is it in the correct range by comparing with a physical test.

Results – If you only evaluated the FEA results you could get a good understanding of different mesh size affects and how the component deforms but you may not have that correlation to real life to validate the FEA study without physical testing. (Cunningham, n.d.) (Carigliano, 2018)

4.2 IMPORTANCE OF FEA IN RELATION TO PHYSICAL TESTING

FEA is very useful tool which can increase the manufacturing and testing process but shouldn't replace physical testing because there is not better testing than physical testing itself because of the limitations of FEA. It will always be important to compare against the two but the ratio of FEA to physical testing will all be down the product specification and how engineered the design will be. For example, the mountain bike swingarm from the case study will always be an area of high loading and likely to break, as well the load force will vary with weight and riding style which means there still need to be physical testing in order to select the boundary conditions and what force needs to be subjected to. As well the component stiffness can affect the handling of the bike with stiffer reducing grip and this can be subject to rider preference. (Sani, 2016) This means there will still need to a lot of physical testing in order decide what the benchmark von mises stress will be.

However if the set force was already know, for example a rolled steel joist for a house would be subjected to very high loads in one direction there can be less physical testing and more FEA because the benchmark of the von mises stress will always be set at the value with force acting in one direction. (Dutt, 2015) (Anon., n.d.) Therefore you will just need physical testing alongside the FEA study to correlate that the FEA is accurate and not as much physical testing needs to be carried out before.

The accuracy of the FEA could also affect the physical testing because if the FEA doesn't correlate with real life then component could be designed incorrectly and not meet the requirements, therefore there still needs to be the correlation to real life. Some of the problems that could occur is if FEA replaced physical testing is that assumptions are made in the FEA model that need to backed up from physical testing, this means that by removing the physical testing some of the assumptions cannot be validated which can cause correlation errors which increases the validation step of the manufacturing process. (Belhe, 2014) (Harris, 2016)

5 CONCLUSION

Overall FEA can further the development of components by reducing costs by purchasing less material as there will be less prototypes being made, there is also a reduction in costs of use of test rig or real life testing application which will all decrease the validation step of the manufacturing process. It also less time consuming because of the time that can be saved by the reduced physical testing that would need to be carried out to achieve the same progress that can be made in the FEA model. However the FEA would need to break down to ensure that there are no correlation errors as mentioned in the S.I.M.P.L.E steps as these can lead to correlation errors instead of updating the component design. The importance of FEA compared to physical testing would also depend on the importance of the component and the amount of load it is subject to. For example cables supporting a suspension bridge will need a lot of FEA to increase the strength of the component but will also need the physical testing to validate the FEA, this would also require a fine mesh as the result need to be very accurate as it's an important component. Whereas a component that is subject to low level loading can have a coarse mesh and the results don't need to be very accurate as there is low level load on the component and less likely to fail, but the setup of the FEA model (simple) will affect how important FEA will be compared to physical testing.

STATING THAT FEA TAKES 'MINUTES' SHOWS A LACK OF UNDERSTANDING OF WHAT IS REQUIRED TO GET CORRELATION.

WHILST YOU HAVE PRESENTED THE CASESTUDY WELL & OBVIOUSLY ABSORBED WHAT WE HAVE DISCUSSED IN CLASS, MORE DETAILS WOULD HAVE ADDED TO YOUR REPORT

6 REFERENCES

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