
Question 1:

- (a) FEA can be used to make the design process more efficient, including reducing the number of physical prototypes used in the testing phase. Instead of building physical prototypes, virtual prototypes can be created and analysed. This can significantly reduce the time and the expense of building prototypes. FEA can be used to assess the performance of a prototype with incurring the cost associated with creating a manufacturable CAD model. For the purpose of FEA and testing, it may be possible to ~~simplify~~ simplify the model by removing features such as bosses and fillets. If these will not affect the results of the FEA, the features will only hinder the run time for the calculations. Furthermore, using FEA can help to improve relations with customers as the cost and performance of the component can be realised much sooner in the design process. This can help assure the customer that the component they receive will be of high quality and fit for purpose. In addition to this, some complex components may require very specific tooling or equipment for manufacturing. In this instance, both time and investment has been saved by allowing analysis to be completed using virtual prototypes rather than physical ones. Finally, using FEA to reduce the number of prototypes is achievable

Question 1 (a) continued...

because small iterations can be made to the existing model. This can include changes not only the physical features of the component, but also through small iterations to the calculations including mesh size, element quality and through optimisation techniques such as topology and shape optimisation.

Question 1

- (b) Depending on the industry for which the component is being developed, it may still be necessary for physical prototypes to be made. This is to allow for components to be physically tested. Often safety is a major requirement for components used within the automotive industry, for example therefore may require certification and sign off as proof of achieving particular ISO or British standards. Such testing may include simple measuring devices like a DTI gauge or strain gauges. Other methods of testing may include using load cells or accelerometers.

Question 1

- (c) Correlation is needed between test and FEA to ~~proof~~ prove the accuracy of your results. FEA is an approximation therefore you must check that any assumptions that have been made have not had any detrimental impacts on your results. FEA calculations are a result of the data inputted by

Question 1 (c) continued...

the user therefore the output can only be as accurate as the input data meaning geometry, material properties, boundary conditions and loading of the component must be accurate.

Confidence may be achieved through the FE model using a variety of checks on element size and element mesh for example. The engineer completing the analysis should use some experience on similar problems modelled previously. Subjective checks can also be done to identify areas where there are large jumps in output measured. Here the mesh can be redefined in local areas and reassessed. Alternatively, quantitative checks can be done to check the error norm. There are two main types of refining meshes known as h -adaptive or p -adaptive. Plotting the output and element size, analysing results and repeating until convergence is reached should give confidence in the FEA model. Generally, there will be accepted difference of 5-10% in results of strain energy and maximum stress values.

Question 2

- (a) The pre-processing stage can be considered as the first five steps of the SIMPLE acronym. Firstly, the geometry needs to be split down into finite elements, to create elements and nodes. This is so that mathematical assumptions can be made from one node to the next. As long as these distances are small enough, close approximations can be obtained. During this step, the user will need to consider element type, element order and density.
- Interpret - in order to obtain a result, FEA will always be a trade off between the accuracy of the results and the run time. As a result, the part needs to be idealised during this step. This means small details that add complexity should be removed. Here it is important to control the version of CAD data, ie, parts for FEA and parts for manufacture.
- Material - Once the part has been simplified and meshed, material information should be added. You need to consider if the material is linear or non-linear as this will determine the solver used. Ensuring this information is accurate between physical and virtual is key for accurate results. Also consider material tolerance.
- Physical - The information required at this stage will depend on what type of elements have been used. For 1D elements, area, second moment of area and orientation will be needed whereas for 2D elements then the thickness of the elements has to be

Question 2 (a) continued...

considered. 3D elements are more complex and time consuming because this information is defined by the geometry. The final stage of the pre-processing is loading.

Loading - Once the above information has been added, the final requirements for processing is the loading and boundary conditions. Here it is important that the part is fully constrained so that accurate predictions/calculations can be made relating to the loading the part will be subjected to. Without fully constraining the part, the degrees of freedom for each node will not be accurate.

Question 2

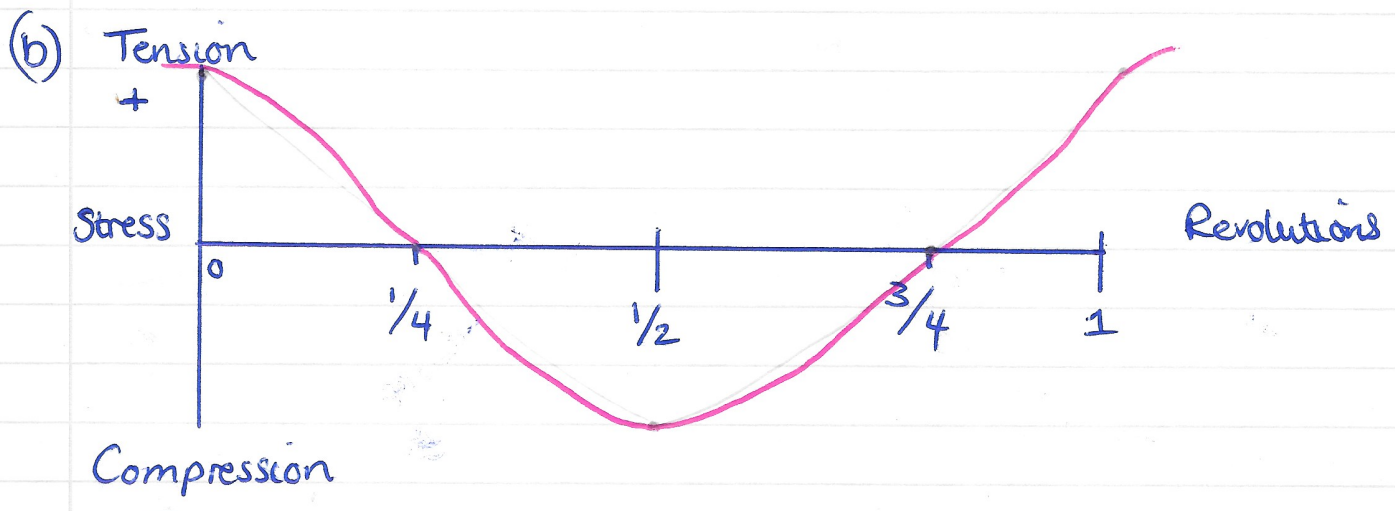
- (b) Processing describes the computer software actually carrying out the calculations of matrix algebra. FEA is all about calculating a stiffness matrix for the structure being considered. Sets of simultaneous equations can only be obtained and solved once all of the information is obtained during the pre-processing stage. Hence it is clear that the information needs to be accurate at this stage to obtain reliable results. These calculations would have previously been done manually although as computing power improves, we are able to exploit this to process more complex problem. ~~At~~ Although, it should always be remembered that there is a trade off between run time and accuracy of results. Also, the method is an approximation.

Question 2

- (c) During the post-processing stage, the final step of the SIMPLE acronym has to be completed - Evaluate. In this stage, the analyst will need to evaluate the results returned. Questions like what previous steps have influenced the ~~results~~ results should be considered. FEA is an approximate result so engineering judgement should be ~~to~~ used. If something does not look correct, it probably isn't. You should carry out both subjective and quantitative checks. If consequences of inaccurate results are substantial, you need to ensure repeated tests reach a convergence in your results. Physical testing may also be needed for safety or quality approval / sign off. Checks should be carried out for element type (1D, 2D or 3D), element size, and mesh. These include element size, element quality, element duplicates, element free edges and element normals. These are various aspects of element quality to consider including skewness, aspect ratio, warpage, Jacobian and element length. Again more complex checks may be required for 3D elements like tetra collapse and volumetric skew.

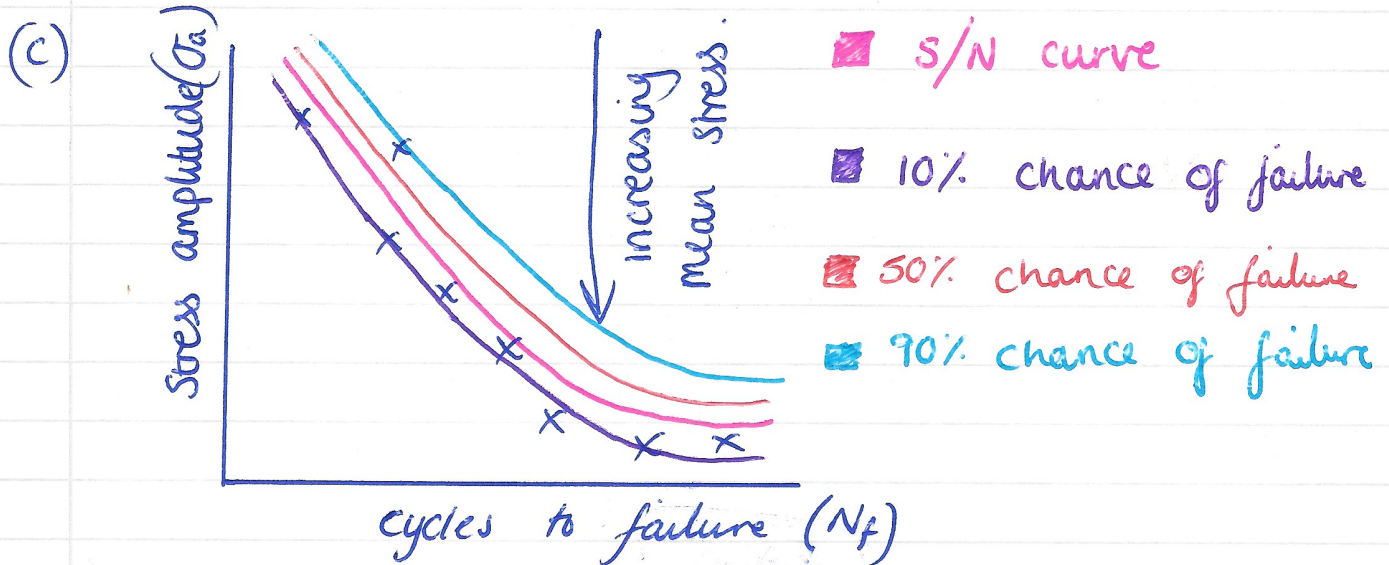
Question 4

- (a) Wohler machines are typically used to carry out fatigue tests. Specimens are tested under conditions of rotating - bending and with a zero mean stress. This puts the top surface into tension and the bottom surface into compression. Commonly fatigue failure occurs due to cyclic stressing taking place. Crack is initiated from points of high stress concentration and propagates under cycling loading, until critical size causing fast fracture.



The loading would look similar to the graph above where even every half a revolution the specimen revolves, the loading stress is changing from tension to compression.

Question 4 continued...



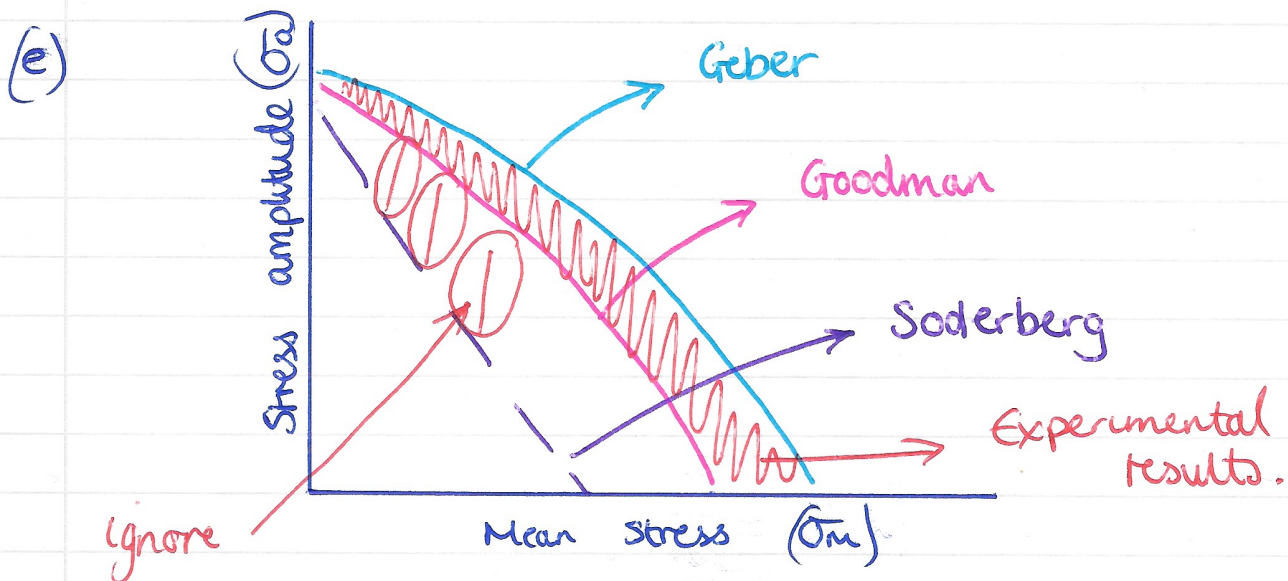
By carrying out the test in part (a) one plot can be made on the graph. This test would need to be repeated using several different stress amplitudes. Once these are plotted, a line of best fit can be added to determine the relationship between the stress amplitude and the number of cycles. Depending on whether the material is ferrous or non-ferrous, the fatigue limit or endurance limit can be realised.

The fatigue life of a component can differ differ widely even with seemingly identical specimen.

P/S/N curves are used to display the probability of failure after several tests have been conducted at the same stress.

Question 4 continued...

- (d) Please see diagram on part (c). As mean stress of a specimen is increased, the fatigue life is decreased. If a component is tested with a higher mean stress, in order to see a similar fatigue life to a component with a lower mean stress, then the stress amplitude must be reduced. In other words, the relationship between mean stress and fatigue life is inversely proportional



Goodman $\sigma_a = \sigma_N \left[1 - \left(\frac{\sigma_m}{\sigma_{TS}} \right) \right]$

Geber $\sigma_a = \sigma_N \left[1 - \left(\frac{\sigma_m}{\sigma_{TS}} \right)^2 \right]$

Soderberg $\sigma_a = \sigma_N \left[1 - \left(\frac{\sigma_m}{\sigma_y} \right) \right]$

Lois Harris (1907505)

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Question 4 (e) Continued...

These are the theories of Goodman, Geber and Soderburg. Geber's theory is most ~~appe~~ optimistic whereas Soderburg is most conservative. As a result Soderburg's theory provides a margin of safety. In reality, experimental results generally fall between the region of Goodman and Geber. The major difference with Soderberg's theory, rather than the other two is that the yield strength of the material is considered rather than the tensile strength of the material. With ~~Good~~ Goodman's equation otherwise identical, it is no surprise that ~~Soder~~ Soderburg is more conservative.