5. RESULTS

5.1 Introduction

This section shall try to expose the results obtained after carrying out all the simulations with all the models and their different variations. In order to make it more understandable there shall be an exposition of the most important figures and all the contents in a written manner and the other figures can be consulted in the **Appendix** at the end of the work.

The explanations and brief descriptions of each model and its results shall be divided in three basic sub-sections, referring to the Plastic points, the Strain field and the Stress field created. If it is necessary, the explanation can mention some cross sections which are documented as well in the **Appendix** situated at the end of the work.

5.2 Models

As it was done in the simulations, the models have been separated in two different groups, the three- and the five-layer model. It is necessary to recall that the main topic of this work is the study of the five-layer model in order to see the mechanical interaction between closely neighboured beds with different mechanical properties and parameters.

Anyway, simulations of a three-layer model (without any fracture) have been done in order to have a first approximation of how the software could work and which kind of results it could be expected of it. It will also be very important to understand how finite element software works in order to understand the way of the results.

Immediately the results shall be shown, divided in some sub-sections, depending of the type of simulation.

5.2.1 Three-layer model

5.2.1.1 Base case (model 3.a.1 and model 3.a.2)

In this section it will be shown all the results, since it has to be taken into account that this case will be taken like a reference in order to compare it with all the other simulations of the three-layer model. First of all, it has to be recalled that two models with two different prescribed total displacements (15 cm and 15 mm) have been run, as it is shown in **Table 4** in the previous section. These two models have allowed us to see the first zones of the model which can be in tension within the model, as well as the most strained and stressed zones. In this way, it is possible to establish the first zones where it is more likely to develop a fracture. It is also important to remind that since now these models with prescribed displacements of 15 mm and 15 cm will be respectively called as **model 3.a.1** and **model 3.a.2** when it will be necessary to refer to them, as it is shown in the **Table 4**.

Plastic points

The Plastic points are the stress points in a plastic state, displayed in a plot of the undeformed geometry. The plastic stress points are indicated by small symbols, and they mean the plastic zones within the model and, therefore, those zones where the tension stress value is higher than the tension cut-off value; moreover, it can be more possible that a fracture develops in. In **Figure 9** it is shown the plot with the plastic points reached in the model with a prescribed displacement of 15 mm.

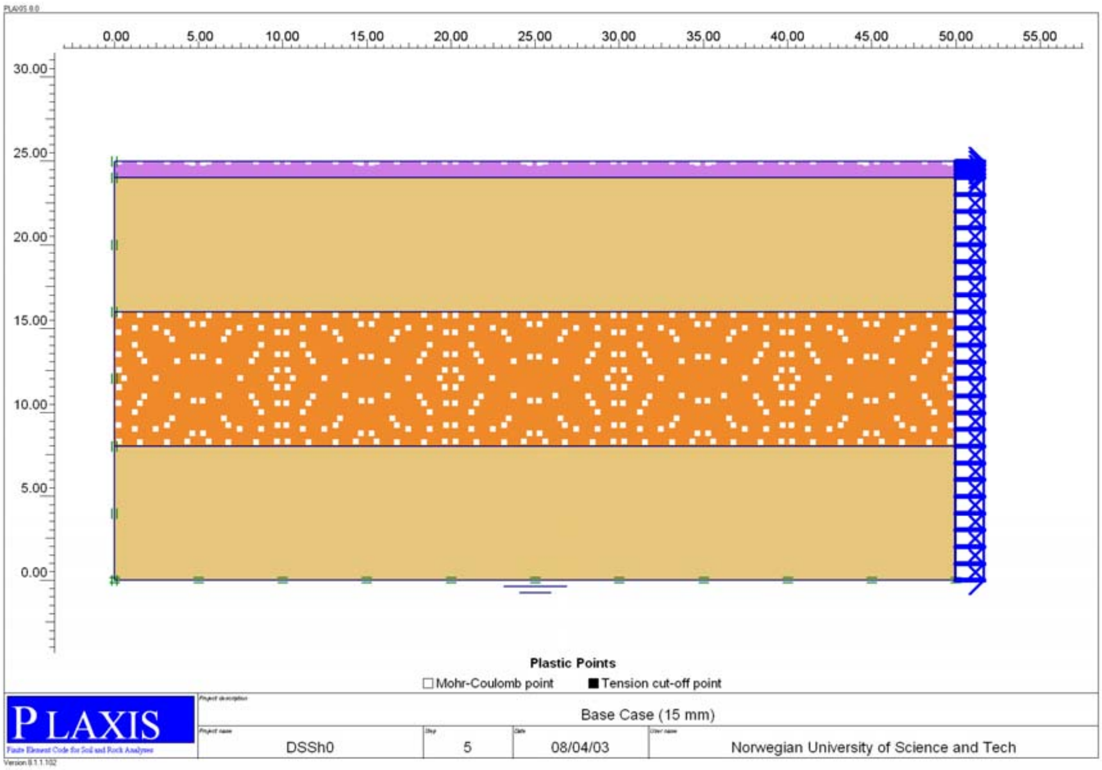

Figure 9. Plastic points in the three-layer model with a displacement of 15 mm (**model 3.a.1**).

It is necessary to make note of that the geometric distribution pattern of the figure is an artefact due to grid geometry.

In **Figure 10** it is possible to observe the plastic points with a prescribed displacement of 15 cm. Obviously, a different behaviour is observed in the two figures, depending on the displacement applied. In Figure 10 all the body is in tension, both the competent and the incompetent layers. In Figure 9, only the heavy and the competent layer have plastic points. The explanation of these different phenomena is based on the application of the displacements and the mechanical properties of the different layers. In the case of the displacements, if a higher displacement is applied, a high stress field is created. Concerning the mechanical properties, it is important to recall that the competent layer is stiffer than the others, and the heavy layer has the same mechanical properties of the incompetent layers, but it has a higher specific weight, which can be the reason why the heavy layer is showing the plastic points in the plot.

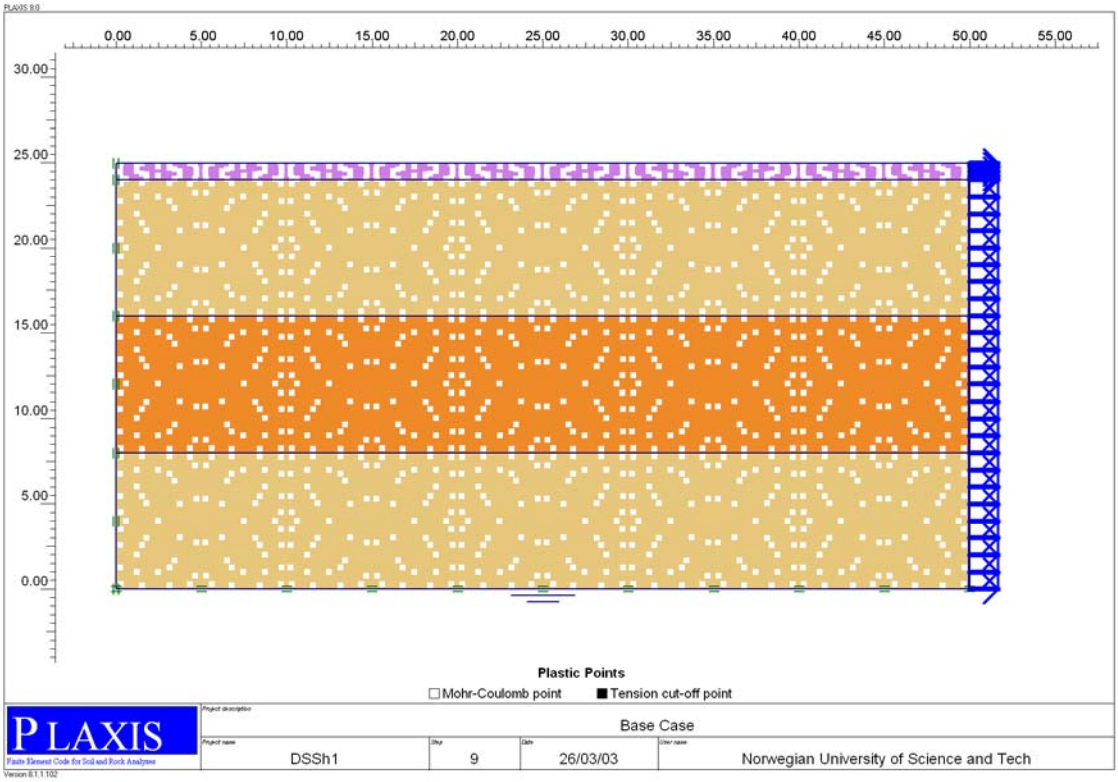

Figure 10. Plastic points in the three-layer model with a displacement of 15 cm (**model 3.a.2**). Note: plastic points (tension cut-off points) are the white squared points in the model; note that there is an error in the colour coding in the software for all the models.

Strains

In this section it shall be shown the strain fields created due to the applied displacements. It has been selected only the Cartesian horizontal strains (individual total strain component ε_{xx}). The strains distribution can determine the zones within the body where it is more possible that a fracture develops in. It is also important to recall that negative values correspond to contraction (compressive stresses and forces).

In order to predict some possible behaviour in the near future by means of the plots, it is important to observe the scales of the plots, since it may be that the plot is completely full of different colours (meaning some different behaviours) but the range of the scale is small. Depending also on the distribution of the colours it shall be possible or not to describe those behaviours.

In the first figure (**Figure 11**) it is shown the plot with the horizontal strains in the model with a prescribed displacement of 15 mm (**model 3.a.1**). In **Figure 12** it is possible to observe the horizontal strains with a prescribed displacement of 15 cm (**model 3.a.2**). It has to be mentioned that the “wave” phenomenon observed in these figures does not show any important effect or behaviour to take into account. The explanation is because of the scale used by the software in order to show the differences in strains, but it is important to specify the small range of variation of values, so, at last, it means a very small variation. It is also necessary to notice the values at top as likely artefacts, due probably to a boundary effects. Finally, it has been checked that the numerical results were as expected.

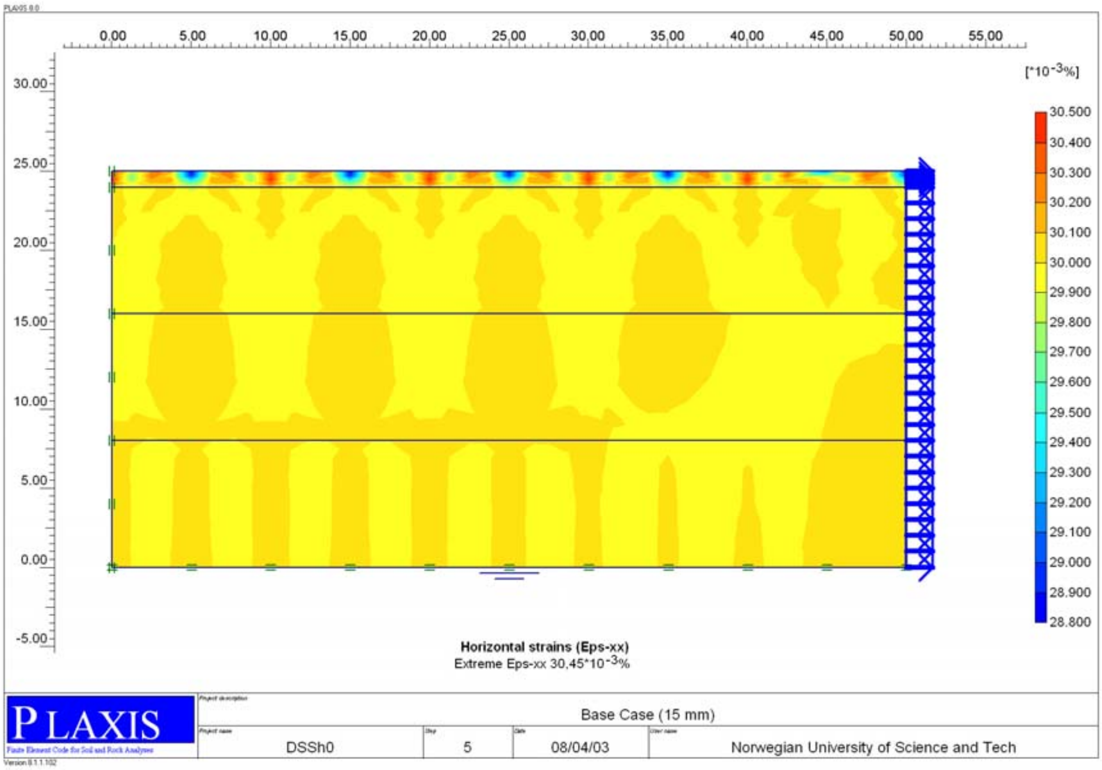

Figure 11. Horizontal strains in the three-layer model with a displacement of 15 mm (**model 3.a.1**).

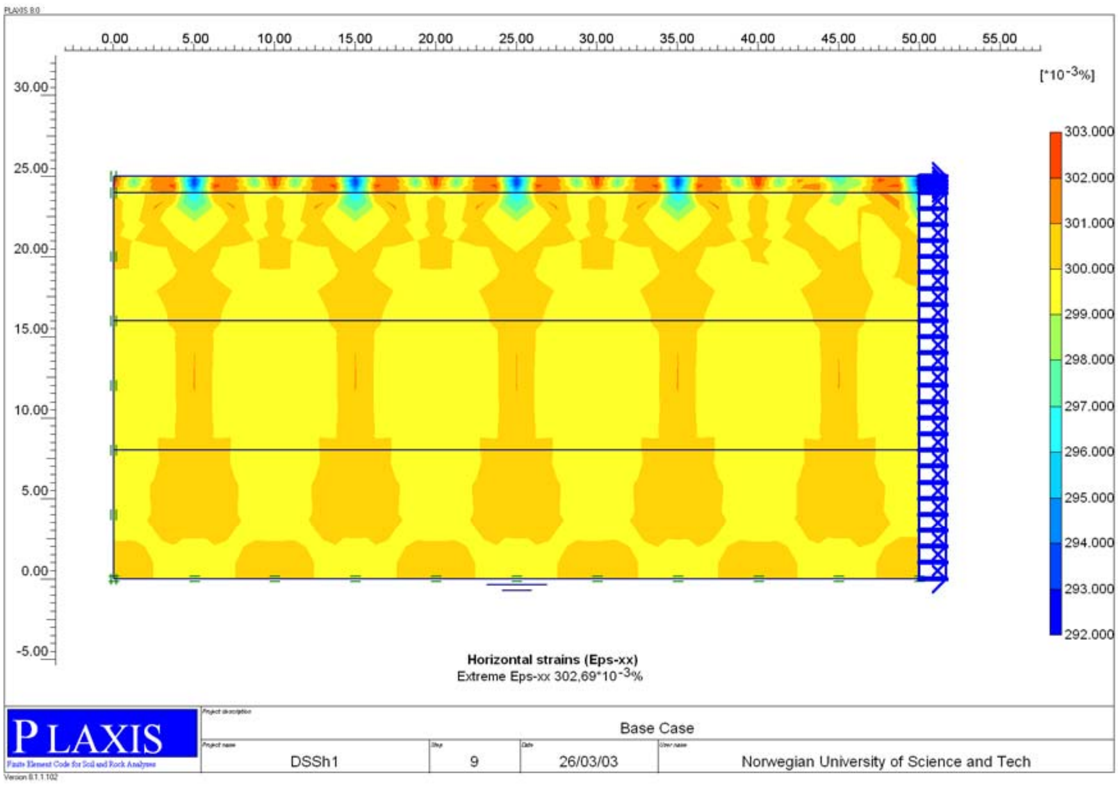

Figure 12. Horizontal strains in the three-layer model with a displacement of 15 cm (**model 3.a.2**).

Stresses

In this section it shall be shown the stress fields created due to the applied displacements. Only the horizontal effective stresses shall be shown, since the aim of this section is to observe the differences created in the horizontal direction. The effective stresses are the stresses in the geometry model at the end of the current calculation step, displayed in a plot of the geometry. Concretely, it has been selected the Cartesian horizontal effective stresses (individual effective stress component, σ'_{xx}). The stress distribution can determine the zones within the body where it is more possible that a fracture develops in. It is also important to recall that positive values correspond to tensional stress.

In order to predict some possible behaviour in the near future by means of the plots, it is also important here (as in the previous section) to observe the scales of the plots, since it may be that the plot is completely full of different colours (meaning some different values of stress) but the range of that values is small. Depending also on the distribution of the colours it shall be possible or not to describe the behaviours. Also it is possible that sometimes we will find a high distribution of stresses, but these stresses will be low, in the sense that they will not be enough to cause any perturbation in the body or any development or growth of a fracture.

In the first figure (**Figure 13**) it is shown the plot with the horizontal effective stresses in the model with a prescribed displacement of 15 mm. In **Figure 14** it is possible to observe the horizontal effective stresses with a prescribed displacement of 15 cm. It has to be observed that the anomalies in spacing means nothing since the variation in the range of values are certainly small.

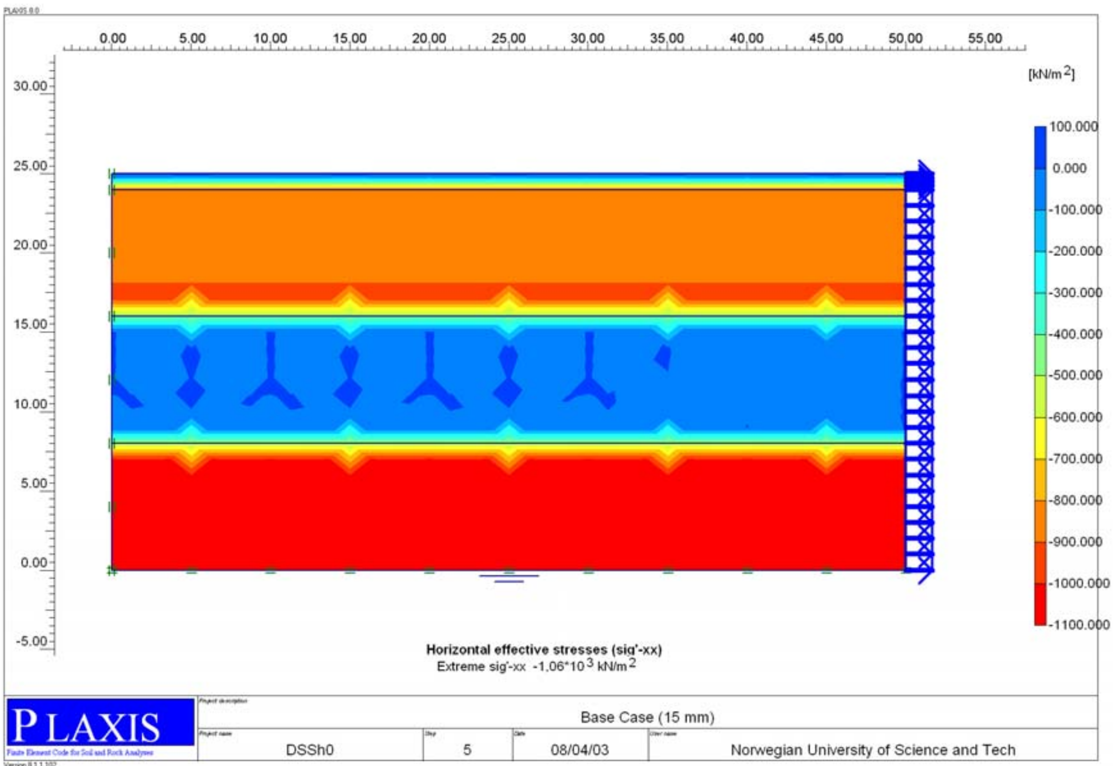

Figure 13. Horizontal effective stresses in the three-layer model with a displacement of 15 mm. Note that only the middle and the upper most layer are tensional; the rest are compressional.

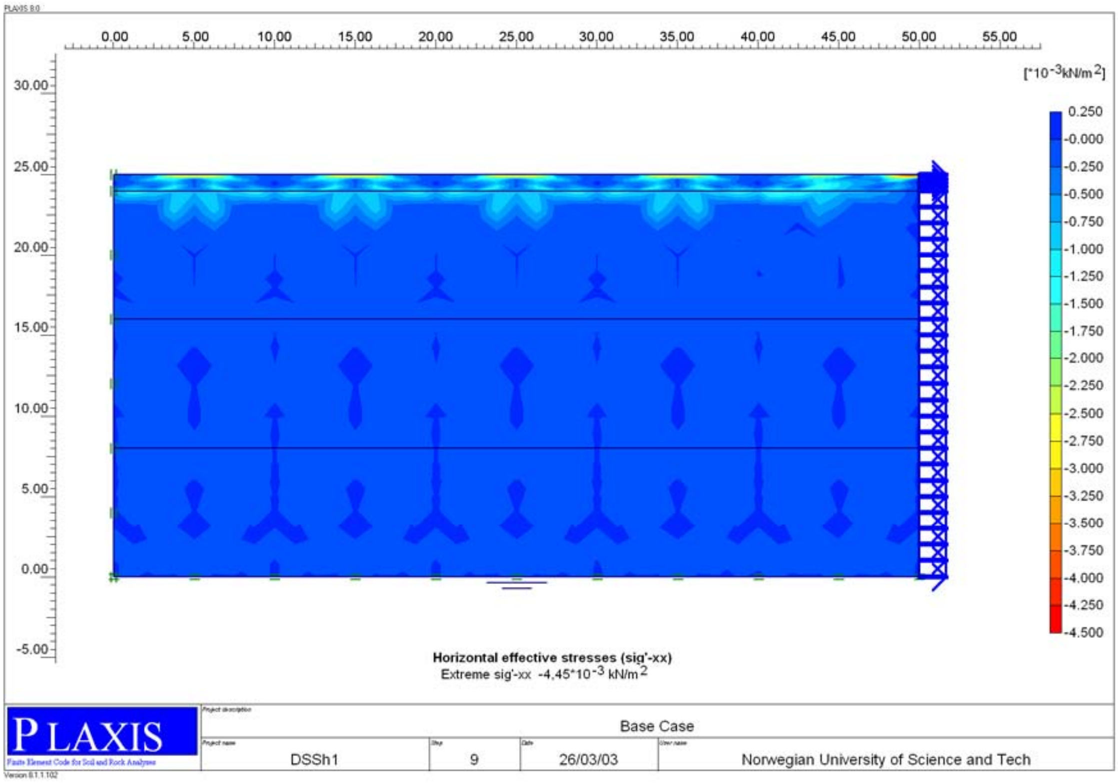

Figure 14. Horizontal effective stresses in the three-layer model with a displacement of 15 cm. Note that all the layers are tensional, i.e. the original compressive stress has been completely released.

5.2.1.2 Variations of H_h, H_{su} and H_{sb}

Some variations concerning the thickness of the different layers have been simulated in this section. It has to be reminded that the value of the prescribed displacement was 15 cm in all the simulations done in this section, and three different thicknesses of H_h have been simulated (4 m, 8 m and 12 m). As it has been explained in the previous sections, it has only been changed the height of the competent layer, but keeping the same height for all the body; it means that at the same time that the variation of the competent layer was applied, the thickness of the surrounding incompetent layers was also being changed.

Since now, the next models with the variations in thickness of the competent layer (4 m, 8 m and 12 m) will be respectively called as **model 3.b.1**, **model 3.b.2** and **model 3.b.3** when it will be necessary to refer to them, as it is shown in the **Table 4**, in order to make it easier and faster the understanding and the description.

Plastic points

As it can be observed in the **Appendix**, the plots of the Plastic points for the three models show that all the body (in the three cases) is in tension. Anyway, checking the different phases of the calculations, it is possible to observe that the middle competent layer is the first one in showing plastic points in the plot, in the three different cases (4 m, 8 m and 12 m) of the simulations.

Strains

Not so many differences can be found in the plots of the horizontal Cartesian strains in the simulations of the thickness of the layers in the three-layer model. As it can be observed in the **Appendix**, some patterns of systematic variations can be seen. Anyway, as it has been commented before, it is important to check the scales in order to see the real differences.

Figure 15 shows that the extreme horizontal strain in the middle competent layer increases with the increasing thickness of the layer. However, it must be noted that the variation is very low.

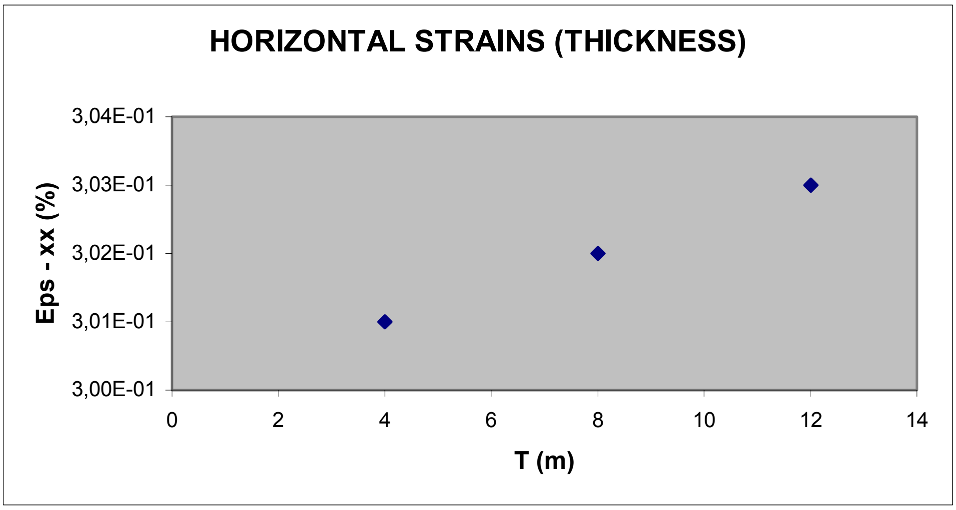

Figure 15. Increasing extreme horizontal Cartesian strain with the increasing thickness of the middle competent layer.

Stresses

In the same way as in the Strain's section, here the plots of the Cartesian horizontal effective stress are showing low differences between them. Some patterns are observed in all the plots referring to zones where it is possible that a fracture develops, and also the extreme values change in a low order in each one of the simulations. These zones and this possible development shall be dealt in the Discussion.

Next figure (**Figure 16**) shows that the extreme Cartesian horizontal effective stress in the middle competent layer decreases with the increasing thickness of the layer, but it must be noted that the variation is very low.

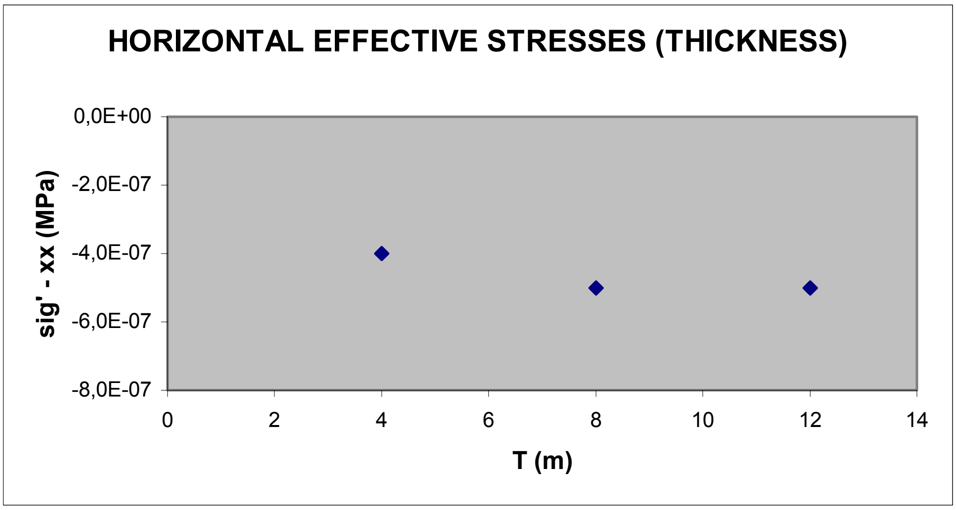

Figure 16. Decreasing extreme Cartesian horizontal effective stress with the increasing thickness of the middle competent layer.

5.2.1.3 Variations of the mechanical properties in the competent layer

Some variations concerning the mechanical parameters in the competent layer have been simulated in this section. It has to be reminded that the value of the prescribed displacement was 15 cm in all the simulations done in this section, and it has been simulated three different variations of parameters: the Young modulus (E), cohesion (c) and the friction angle (φ).

As it can be observed in the **Appendix**, the plots concerning the variations of the cohesion and the friction angle did not show any variation with respect to the plots obtained in the Base Case, and because of that only the variations of the Young modulus shall be commented in this section.

However, it has to be recalled that since now, and as it is shown in the **Table 4**, the next models with the variations in the mechanical parameters of the competent layer will be called as **model 3.c.1**, **model 3.c.2** and **model 3.c.3** when it will be necessary to refer to them in order to make it easier and faster the understanding and the description.

Plastic points

As in the previous sections the plots concerning the Plastic points for the three models show that all the body (in the three cases) is in tension, as it can be observed in the **Appendix**. Also in this case, if the different phases of the calculations are checked, it is possible to observe that the middle competent layer is the first one in showing plastic points in the plot, in the three different cases for the three different values of the Young modulus in the simulations.

As it has been commented before, neither cohesion nor friction angle have any effect in this case.

Strains

Observing the different plots in this section concerning the strains, it is possible to see some differences in the behaviour of the body, as it was expected. The plots can be inspected in the **Appendix**. In **Figure 17**, it is possible to observe the extreme horizontal Cartesian strain in the middle competent layer with the increasing value of the Young modulus of that layer. Once more it is necessary to recall that if all values are still within uncertainty limits of software, plot is useless (this observation is valid for the similar late figures).

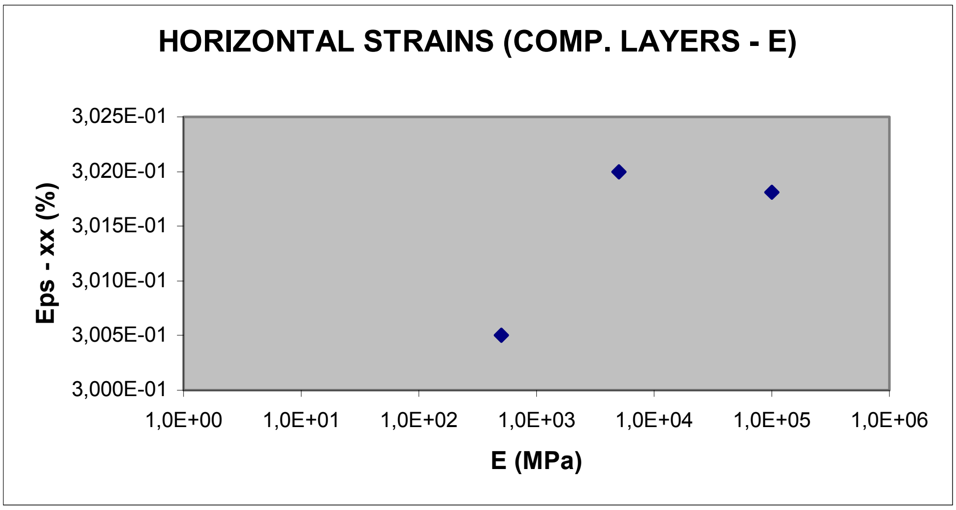

Figure 17. Extreme Cartesian horizontal strain with the increasing value of the Young modulus in the middle competent layer.

Stresses

Some patterns and variations are shown in the plots of the extreme Cartesian horizontal effective stress when the Young modulus is varied, as it can be checked in the **Appendix**. These variations are resumed in the next plot (**Figure 18**).

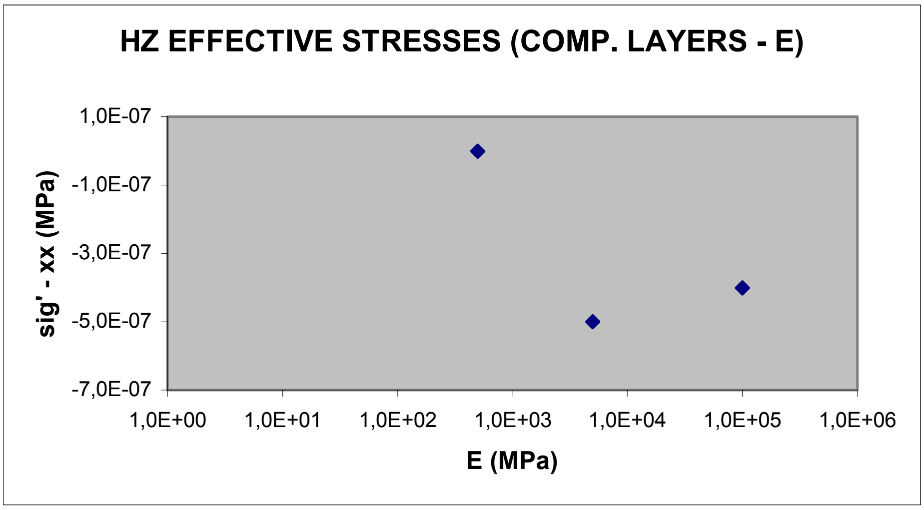

Figure 18. Extreme Cartesian horizontal effective stress with the increasing value of the Young modulus in the middle competent layer.

5.2.1.4 Variations of the mechanical properties in the incompetent layers (model 3.d.1, model 3.d.2 and model 3.d.3)

Some variations concerning the mechanical parameters in the incompetent layers have been simulated in this section. It has to be reminded that the value of the prescribed displacement was 15 cm in all the simulations done in this section, and it has been simulated three different variations of parameters: the Young modulus (E), cohesion (c) and the friction angle (φ).

As it can be observed in the **Appendix**, the plots concerning the variations of the cohesion and the friction angle did not show any variation respecting to the plots obtained in the Base Case, and because of that only the variations of the Young modulus shall be commented in this section.

Plastic points

As in the previous sections the plots concerning the Plastic points for the three models show that all the body is in tension, excepting for the lower value of the Young modulus which has been applied, as it can be observed in the **Appendix**. Also in this case, if the different phases of the calculations are checked, it is possible to observe that the middle competent layer is the first one in showing plastic points in the plot, in the three different cases for the three different values of the Young modulus in the simulations.

As it has been commented before, neither cohesion nor friction angle have any effect in this case.

Strains

Plots of extreme horizontal Cartesian strains for these cases show some geometric patterns in terms of future possible fracture spacing. These patterns have quite different peaks of strain and also they are moving within different ranges of scale. This question shall be discussed in the last chapter of the paper.

Anyway, **Figure 19** is showing the extreme horizontal Cartesian strain in the middle competent layer with the increasing value of the Young modulus. Figures always shall be referred to the middle competent layer since it is the layer where it is more probable that a fracture or a set of fractures occur within it.

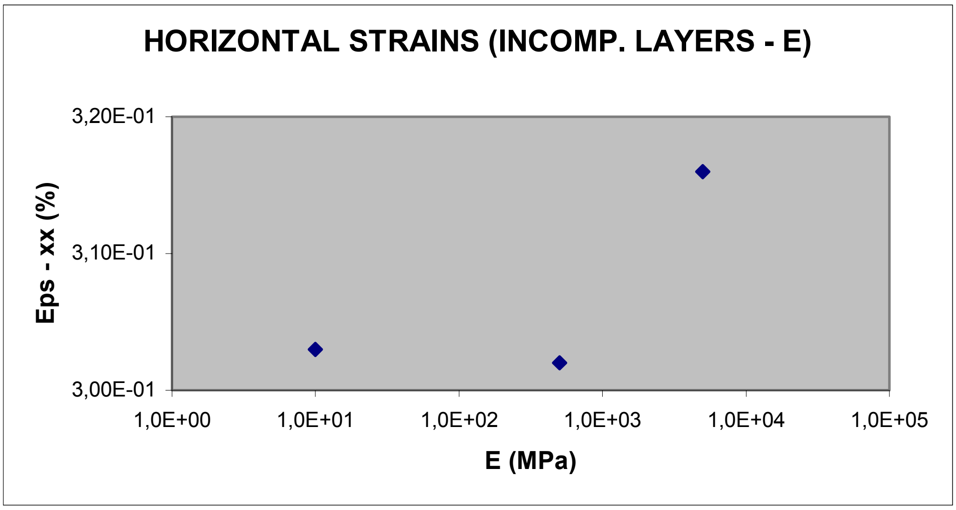

Figure 19. Extreme Cartesian horizontal strain with the increasing value of the Young modulus in the middle competent layer.

Stresses

Some patterns and variations are shown in the plots of the extreme Cartesian horizontal effective stress when the Young modulus is varied, as it can be checked in the **Appendix**. These variations are resumed in the next plot (**Figure 20**). The stress values have been taken also from the middle competent layer depending on the increasing Young modulus in the incompetent layers.

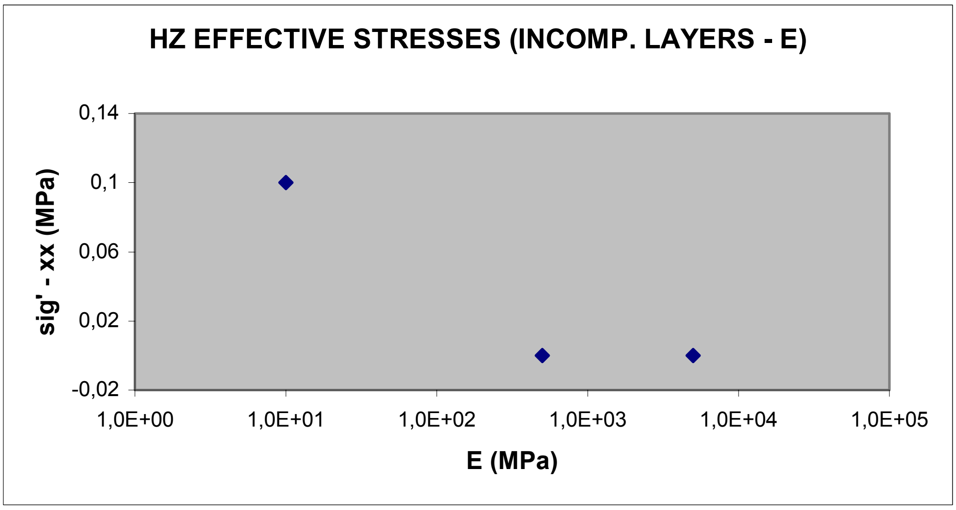

Figure 20. Extreme Cartesian horizontal effective stress with the increasing value of the Young modulus in the middle competent layer.

5.2.2 Five-layer model

5.2.2.1 Base case

In this section it will be shown all the results, since it has to be taken into account that this case will be taken like a reference in order to compare it with all the other simulations of the five-layer model. First of all, it has to be recalled that two models with two different prescribed displacements (15 mm and 15 cm) have been run, as it is shown in the **Table 4** in the previous section (**model 5.a.1** and **model 5.a.2** respectively). These two models have allowed us to see the first zones of the model which can be in tension within the model, as well as the most strained and stressed zones. In this way, it is possible to establish the first zones where it is more likely to become a fracture in the future.

Plastic points

In the first figure (**Figure 21**) it is shown the plot with the plastic points reached in the model with a prescribed displacement of 15 mm. In this case the plot offers, more or less, nothing interesting to see.

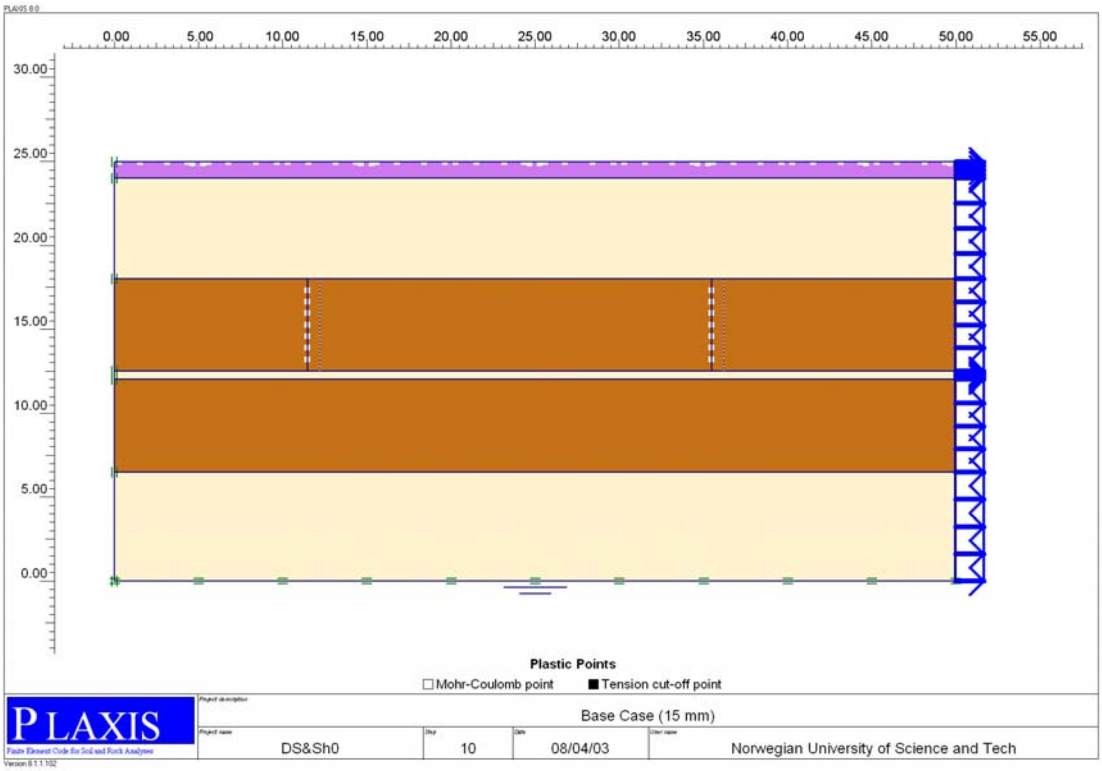

Figure 21. Plastic points in the five-layer model with a displacement of 15 mm (**model 5.a.1**). Note: plastic points (tension cut-off points) are the white squared points in the model; note that there is an error in the colour coding in the software for all the models.

In **Figure 22** it is possible to observe the plastic points with a prescribed displacement of 15 cm. Obviously, a different behaviour (in terms of development of the Plastic Points) is observed in the two figures, depending on the displacement applied, as in the Base Case for the three-layer model.

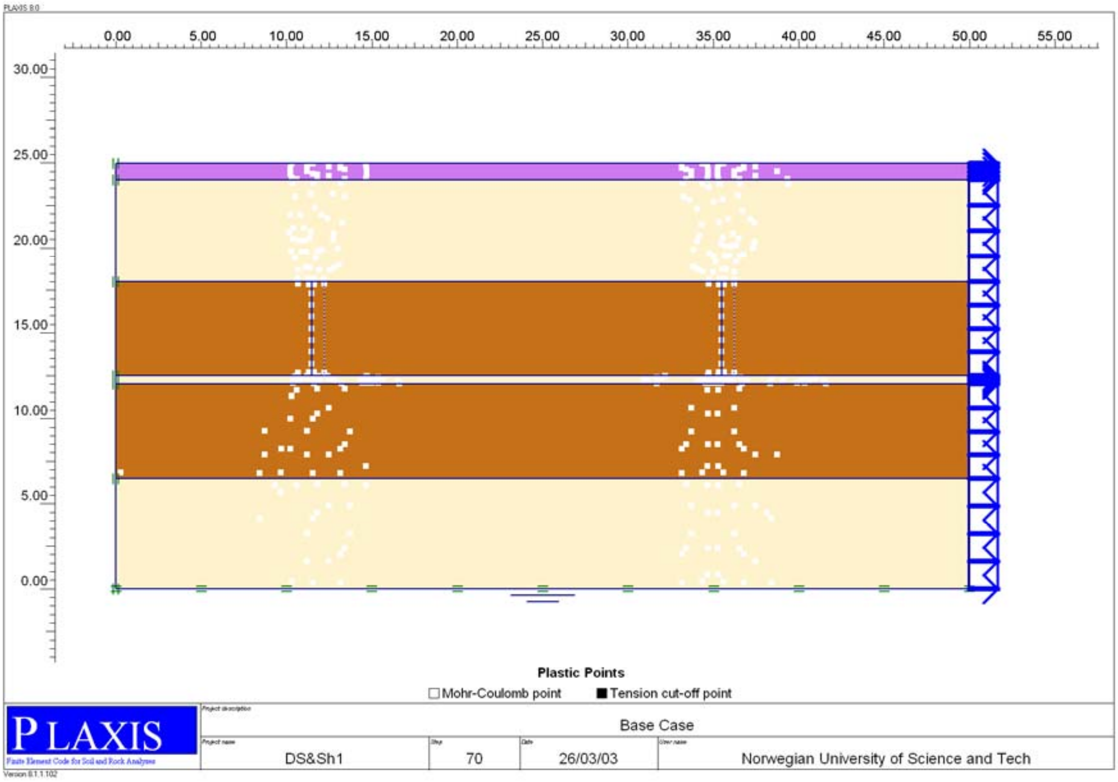

Figure 22. Plastic points in the five-layer model with a displacement of 15 cm (**model 5.a.2**).

Strains

In this section it shall be shown the strain fields created due to the applied displacements. It has been selected only the Cartesian horizontal strains (individual total strain component, ε_{xx}), as in the three-layer model.

In **Figure 23** it is shown the **model 5.a.1** with the horizontal strains in the model with a prescribed displacement of 15 mm. In **Figure 24** it is possible to observe the horizontal strains with a prescribed displacement of 15 cm (**model 5.a.2**).

It is very interesting to observe the extensional strain concentrations at tips of joints. This fact has some features; it seems to be that the joints develop a wider zone of high strain, with high values (see scale), reaching farther any from tip at high displacement. Moreover, in the incompetent layers the extension is further than the competent ones. Comparing with the three-layer model, it is easy to see the clear difference (in terms of development of the strain fields created) between the two models, probably because of the introduced fractures in the five-layer model.

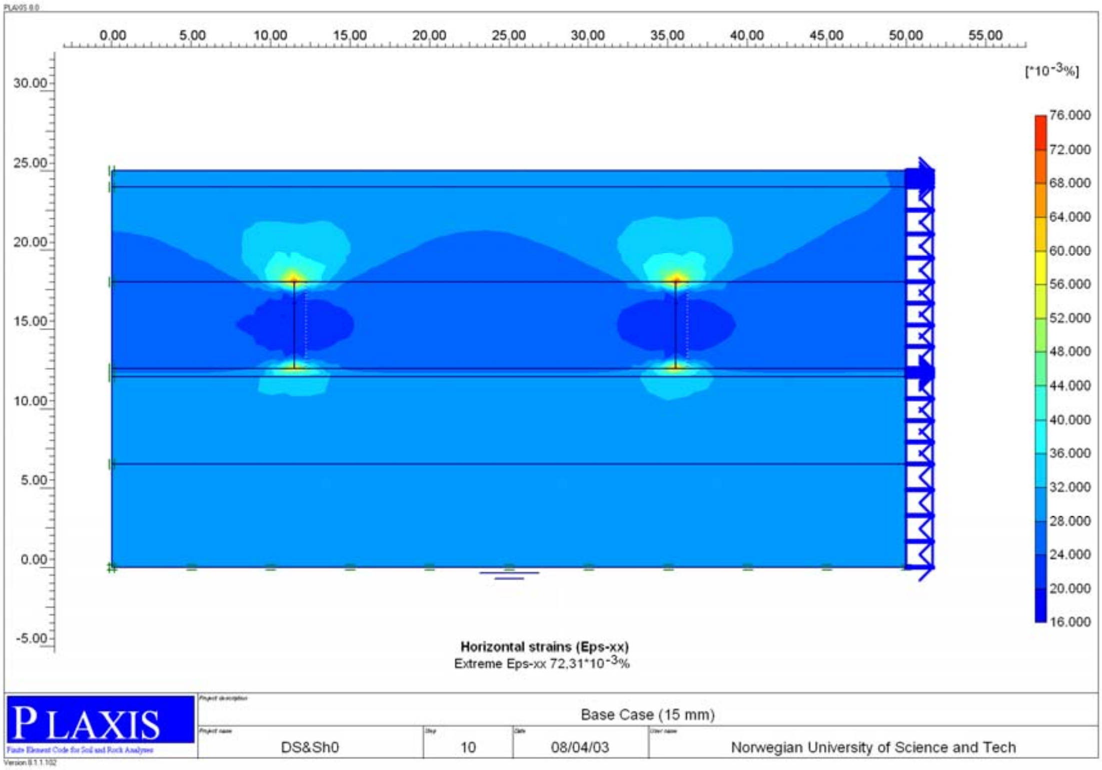

Figure 23. Horizontal strains in the five-layer model with a displacement of 15 mm (**model 5.a.1**).

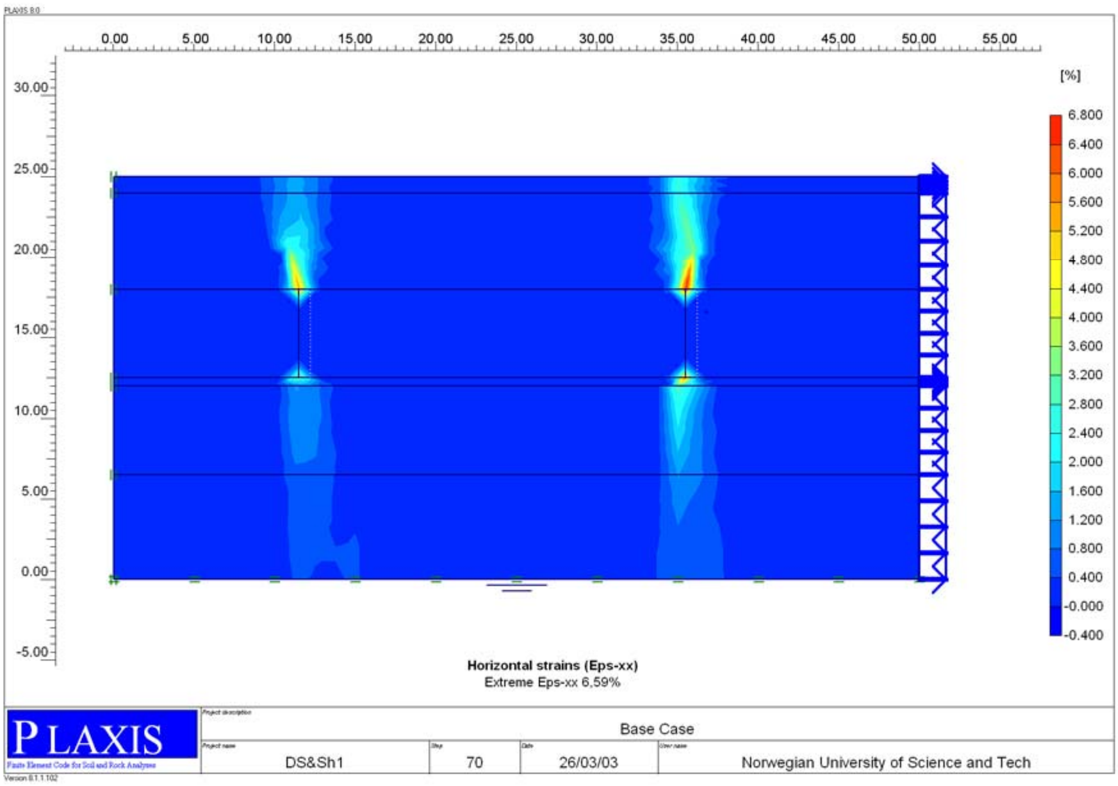

Figure 24. Horizontal strains in the five-layer model with a displacement of 15 cm (**model 5.a.2**).

Stresses

In this section, as in the Base Case in the three-layer model, it shall be shown the stress fields created due to the applied displacements. It has been selected only the horizontal effective stresses. Concretely, it has been selected the Cartesian horizontal effective stresses (individual effective stress component, σ'_{xx}).

In **Figure 25** it is shown the plot with the horizontal Cartesian effective stresses in the model with a prescribed displacement of 15 mm (**model 5.a.1**), and in **Figure 26** it is possible to observe the horizontal effective stresses with a prescribed displacement of 15 cm (**model 5.a.2**).

In order to predict some possible behaviour by means of the plots, it is also important here (as in the three-layer model) to observe the scales of the plots, since it may be that the plot is completely full of different colours (meaning some different values of stress) but the range of that values is small. Depending also on the distribution of the colours it shall be possible or not to describe the behaviours. Also it is possible that sometimes we will find a high distribution of stresses, but these stresses will be low, in the sense that they will not be enough to cause any perturbation in the body or any development or growth of a fracture, as in the case of the next two figures.

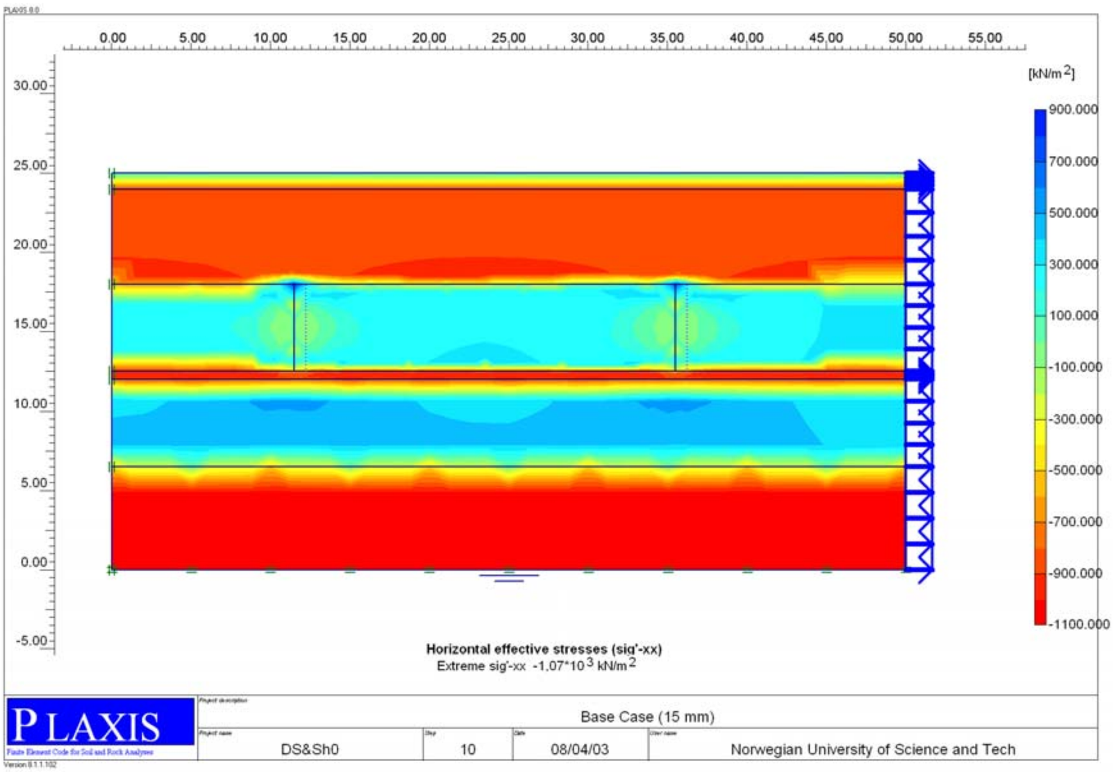

Figure 25. Horizontal effective stresses in the five-layer model with a displacement of 15 mm (**model 5.a.1**). Note: due to an unknown reason, in the output files, the software has changed (inverted) the range of colours of the plot scale in this figure and in the next one, and it has not been possible to change it.

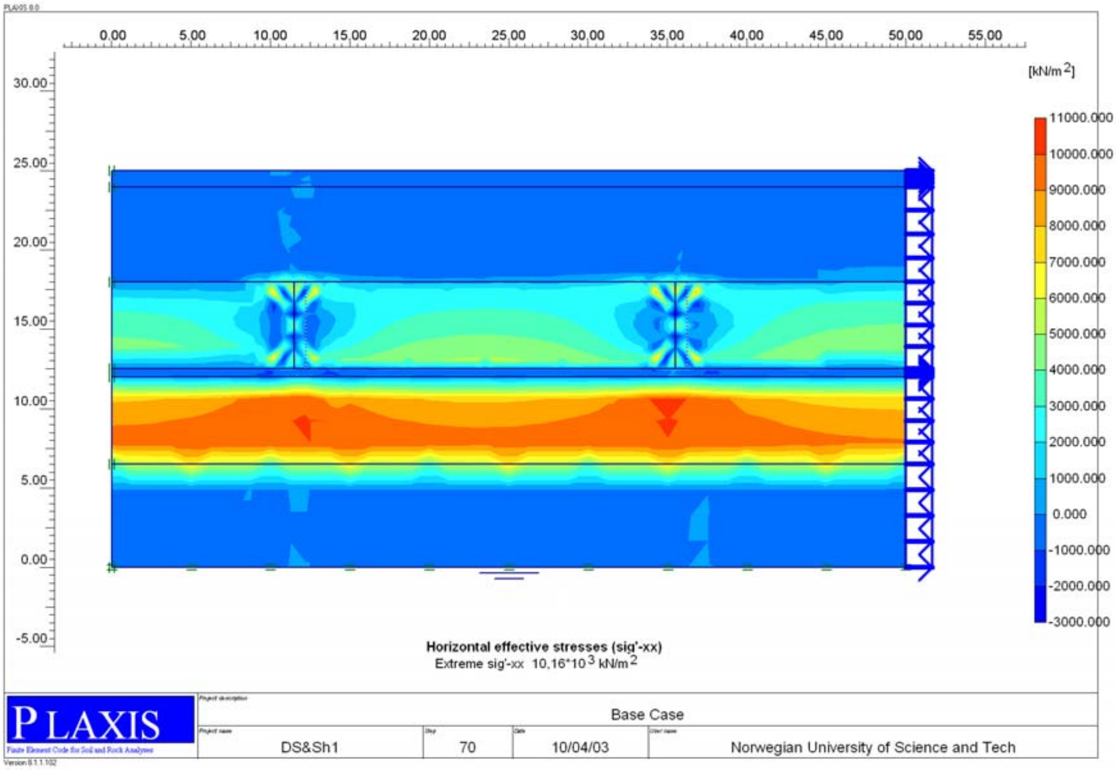

Figure 26. Horizontal effective stresses in the five-layer model with a displacement of 15 cm (**model 5.a.2**). Note: as in the previous figure and due to an unknown reason, in the output files, the software has changed (inverted) the range of colours of the plot scale in this figure and in the previous one, and it has not been possible to change it.

5.2.2.2 Variations of H_{sm} (model 5.b.1, model 5.b.2 and model 5.b.3)

Some variations concerning the thickness of the middle incompetent layer of the model have been simulated in this section. It has to be reminded that the value of the prescribed displacement was 15 cm in all the simulations done in this section, and it has been simulated three different kinds of thicknesses (0.5 m, 1.5 m and 2.5 m). These values correspond to the H_{sm} (middle incompetent layer). As it has been explained in the previous sections, it has only been changed the height of the middle incompetent layer, but keeping the same height for the competent layers; it means that at the same time that the variation of the middle incompetent layer was applied, the thickness of the top and the lower incompetent layers was also being changed.

Plastic points

The plots of the Plastic points for the three models show that, in the three cases, there is a clear tendency in the situation of these plastic points in the body, as it can be checked in the **Appendix**. Anyway, observing the different phases of the calculations, it is possible to observe that fractures in the top competent layer are the first ones in showing plastic points in the output plot, in the three different cases (0.5 m, 1.5 m and 2.5 m) of the simulations. Furthermore, it seems to be that the propagation (it means the extent zone where the tension cut-off values are met) of a fracture or a set of fractures towards the lower competent layer is decreasing with the increasing thickness of the middle incompetent layer.

Strains

Figure 27 is showing that the extreme horizontal strain in the top of the lower competent layer decreases with the increasing thickness of the middle incompetent layer. However, it must be noted that the variation is very low. The maximum strain in the lower layer is adjacent to the fracture in the upper layer. Moreover it is possible to see a fracturing effect on the lower layer.

As it can be observed in the **Appendix**, neither the ranges of values of the stress in the scale are changing in a great manner.

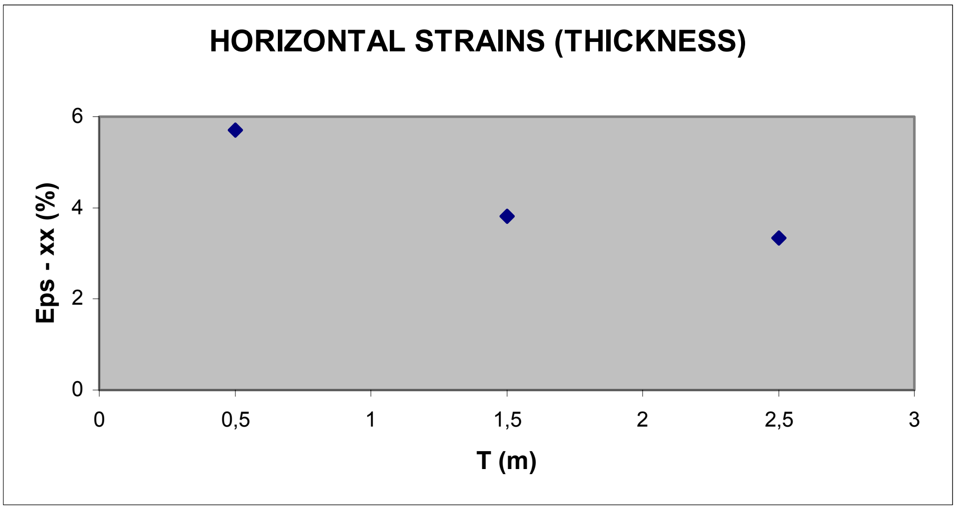

Figure 27. Decreasing extreme horizontal Cartesian strain in the top of the lower competent layer with the increasing thickness of the middle incompetent layer.

Stresses

In the same way as in the previous section, here the plots of the Cartesian horizontal effective stress are showing low differences between them. Some patterns are observed in all the plots near the zones where the fractures have been situated, but also the extreme values change in a low order in each one of the simulations.

Figure 28 shows that the extreme Cartesian horizontal effective stress in the top of the lower competent layer decreases with the increasing thickness of the middle incompetent layer, but it must be noted that this variation is quite low. These extreme values correspond exactly with the progression (to the lower competent layer) of the fractures.

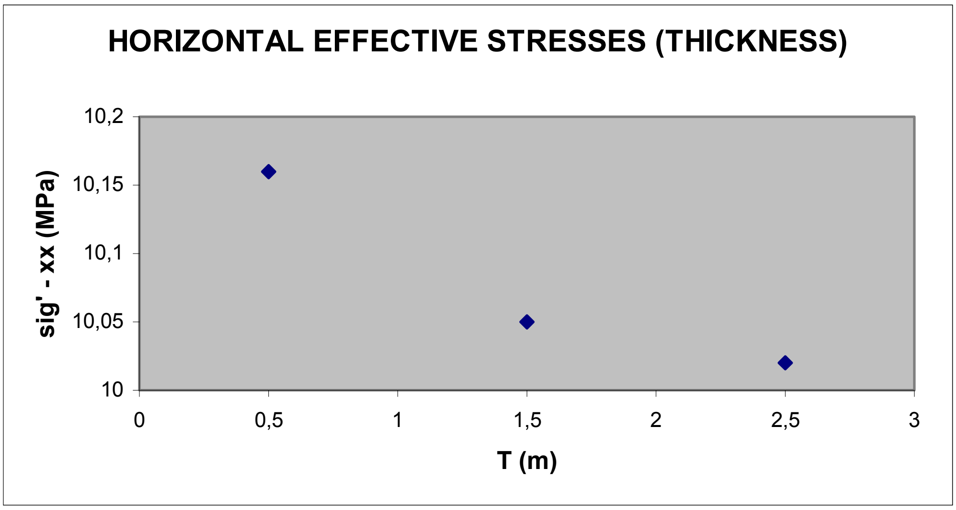

Figure 28. Decreasing extreme Cartesian horizontal effective stress in the top of the lower competent layer with the increasing thickness of the middle incompetent layer.

5.2.2.3 Variations of the mechanical properties in the incompetent layers (model 5.c.1, model 5.c.2 and model 5.c.3)

Some variations concerning the mechanical parameters in the incompetent layers have been simulated in this section. It has to be reminded that the value of the prescribed displacement was 15 cm in all the simulations, and it has been simulated three different variations of parameters: the Young modulus (E), cohesion (c) and the friction angle (φ).

As it can be observed in the **Appendix**, the plots concerning the variations of the cohesion and the friction angle did not show any variation respecting to the plots obtained in the Base Case, and because of that only the variations of the Young modulus shall be commented in this section.

Plastic points

The plots of the Plastic points for the three models show that, in the three cases, there is once more a clear tendency in the situation of these plastic points in the body, as it can be checked in the **Appendix**.

Observing the different phases of the calculations, it is possible to observe that fractures in the top competent layer are the first ones in showing plastic points in the plot, in the three different cases for the three different values of the Young modulus in the simulations. Furthermore, it seems to be that the propagation towards the lower competent layer is decreasing with the increasing Young modulus of the incompetent layers.

Strains

Plots of extreme horizontal Cartesian strains for these cases show some geometric patterns in terms of future possible fracture spacing. These patterns have quite different peaks of strain but they are moving more or less within the same ranges of scale. This question shall be discussed in the last chapter of the paper.

Figure 29 is showing the increasing trend of the extreme horizontal Cartesian strain in the top of the lower competent layer with the increasing value of the Young modulus of the incompetent layer. Figures always shall be referred to the lower competent layer since it is the layer where it is more probable that a fracture or a set of fractures develop within it.

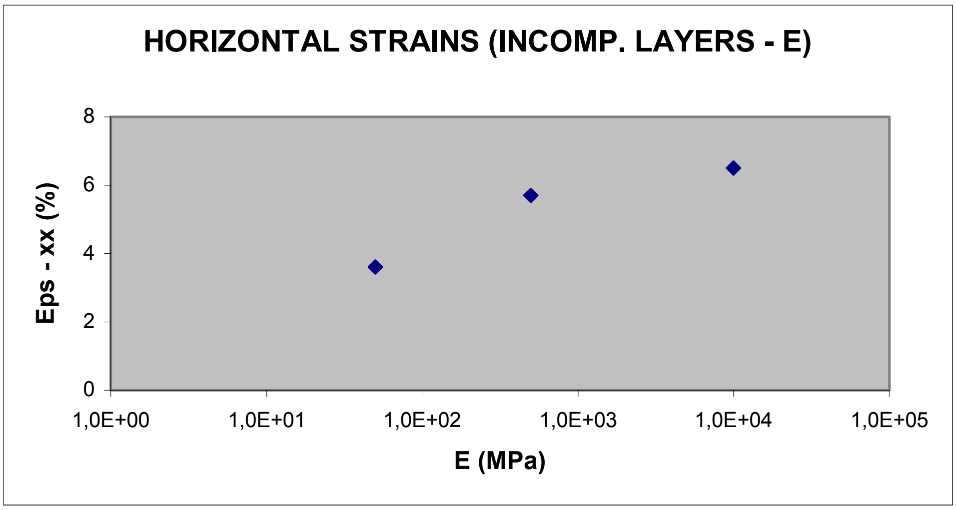

Figure 29. Increasing extreme Cartesian horizontal strain in the top of the lower competent layer with the increasing value of the Young modulus in the incompetent layers.

Stresses

Some patterns and variations of the low differences between the layers are shown in the plots of the extreme Cartesian horizontal effective stress when the Young modulus is varied in the incompetent layers, as it can be checked in the **Appendix**. Some patterns are observed in all the plots near the zones where the fractures have been situated, but also the extreme values change in a low order in each one of the simulations.

These variations are resumed in **Figure 30**. The extreme Cartesian horizontal effective stress in the top of the lower competent layer increases with the increasing value of the Young modulus in the incompetent layer. These extreme values correspond exactly with the progression (to the lower competent layer) of the fractures.

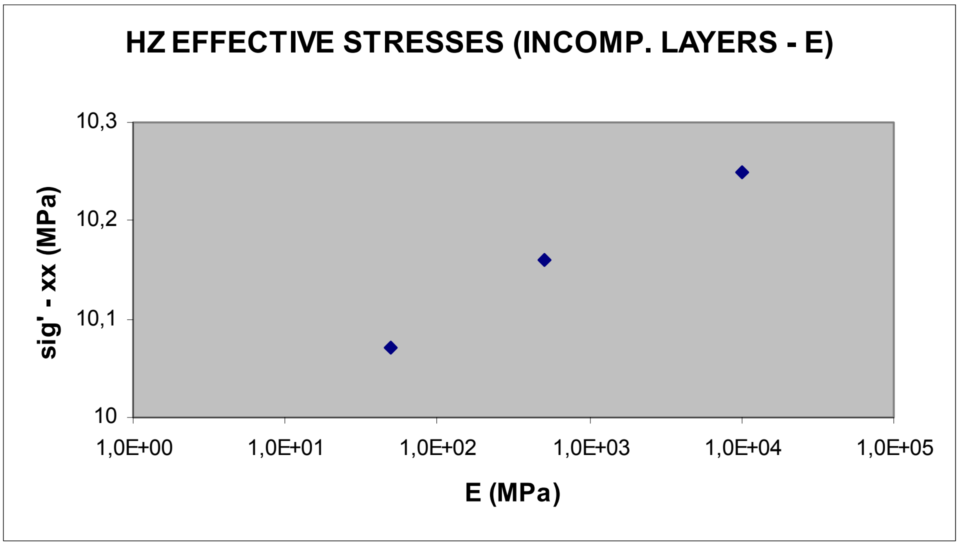

Figure 30. Increasing extreme Cartesian horizontal effective stress in the top of the lower competent layer with the increasing value of the Young modulus in the incompetent layers.

5.2.2.4 Variations of the mechanical properties in the competent layers (model 5.d.1, model 5.d.2 and model 5.d.3)

Some variations concerning the mechanical parameters in the competent layers have been simulated in this section. It has to be reminded that the value of the prescribed displacement was 15 cm in all the simulations done in this section, and it has been simulated three different variations of parameters: the Young modulus (E), cohesion (c) and the friction angle (φ).

As it can be observed in the **Appendix**, the plots concerning the variations of the cohesion and the friction angle did not show any variation respecting to the plots obtained in the Base Case, and because of that only the variations of the Young modulus shall be commented in this section.

Plastic points

As in the previous sections the plots concerning the Plastic points for the three models show that there is a clear tendency of the situation of these plastic points (it means around the fractures), as it can be observed in the **Appendix**. Also in this case, if the different phases of the calculations are checked, it is possible to observe that fractures in the top competent layer are the first ones in showing plastic points in the plot, in the three different cases for the three different values of the Young modulus in the simulations. Moreover, it seems to be that the propagation towards the lower competent layer is decreasing with the decreasing Young modulus of the competent layers.

Strains

Observing the different plots in this section concerning the strains, it is possible to see some differences in the behaviour of the body, as it was expected. The plots can be revised in the **Appendix**, but anyway here it is showed the **Figure 31**, where it is possible to observe the high increasing extreme horizontal Cartesian strain in the middle competent layer (in comparison with the average) with the increasing value of the Young modulus.

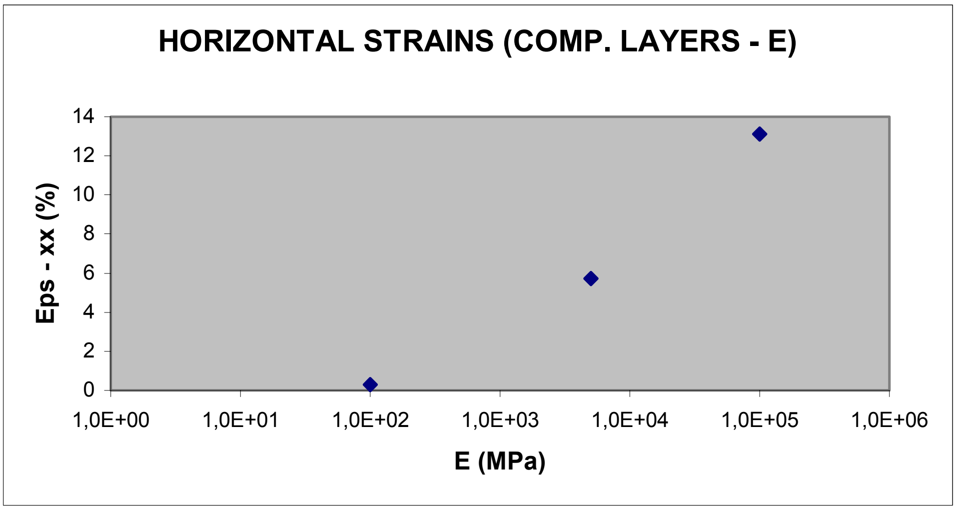

Figure 31. Increasing extreme Cartesian horizontal strain in the top of the lower competent layer with the increasing value of the Young modulus in the competent layers.

Stresses

Some patterns and variations are shown in the plots of the extreme Cartesian horizontal effective stress when the Young modulus is varied, as it can be checked in the **Appendix**. These variations are resumed in the next plot (**Figure 32**).

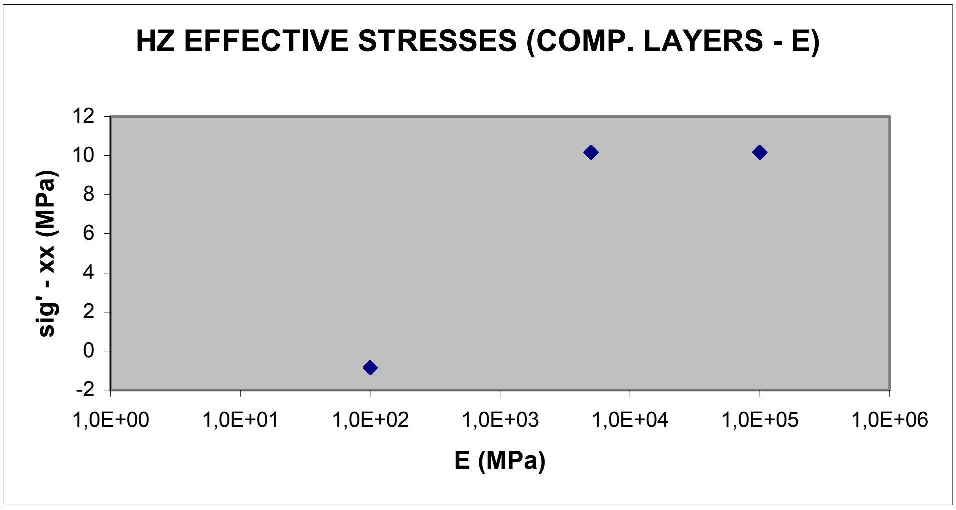

Figure 32. Extreme Cartesian horizontal effective stress in the top of the lower competent layer with the increasing value of the Young modulus in the competent layers.

5.2.2.5 Variations of fracture spacing in the top competent layer (model 5.e.1, model 5.e.2, model 5.e.3, and model 5.e.4)

In this section it will be shown all the results concerning to the introduction of some fractures in the model. First of all, it has to be recalled that all the simulations in this section have been carried out with a prescribed displacements of 15 cm. Depending on the number of the fractures introduced in the model, and since now, the models will be called as it is referred in the **Table 4**, when it will be necessary to refer to them, in order to make it easier and faster the understanding and the description.

Plastic points

The Plastic points actually follow the same trend of propagation showed in the previous sections, as it can be shown in the **Appendix**.

Strains

Observing the different plots in this section concerning the strains, it is possible to see some differences in the behaviour of the body, as it was expected, depending on the number of fractures. The plots can be revised in the **Appendix**, but anyway here it is showed the **Figure 33**, where it is possible to observe the decreasing extreme horizontal Cartesian strain in the top of the lower competent layer with the increasing number of fractures introduced in the top competent layer.

Note that, of course, the fracture spacing of the top competent layer shall decrease with an increasing number of fractures introduced.

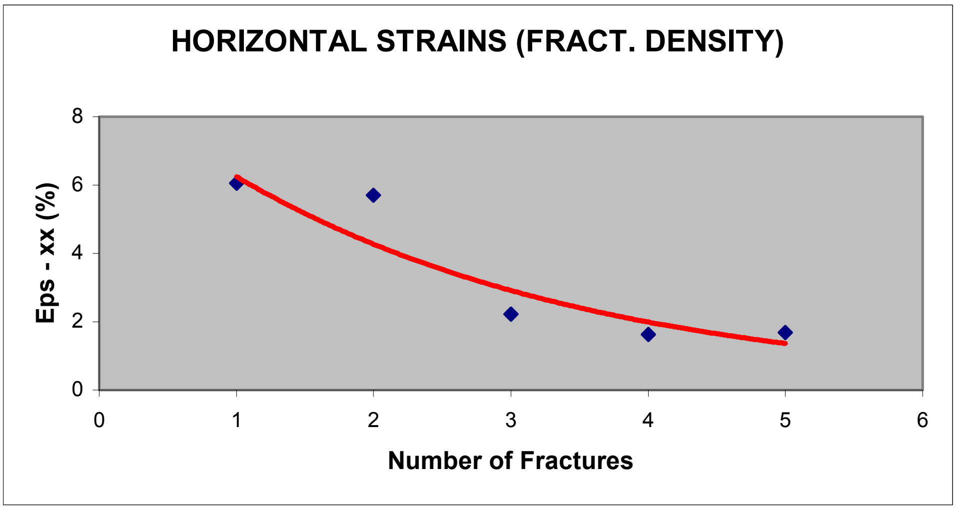

Figure 33. Decreasing trend (plotted with a smooth red line) of the extreme Cartesian horizontal strain, in the top of the lower competent layer, with the increasing number of fractures in the top competent layer.

Stresses

Plots of the Cartesian horizontal effective stress are actually showing some differences between the different plots. Some patterns are observed in all the plots near the zones where the fractures have been situated, but also the extreme values change in a quite low order in each one of the simulations.

Next figure (**Figure 34**) shows that the extreme Cartesian horizontal effective stress in the top of the lower competent has an increasing tendency with the increasing number of fractures introduced in the top competent layer, but it must be noted that this variation is quite low. These extreme values correspond exactly with the progression (to the lower competent layer) of the fractures.

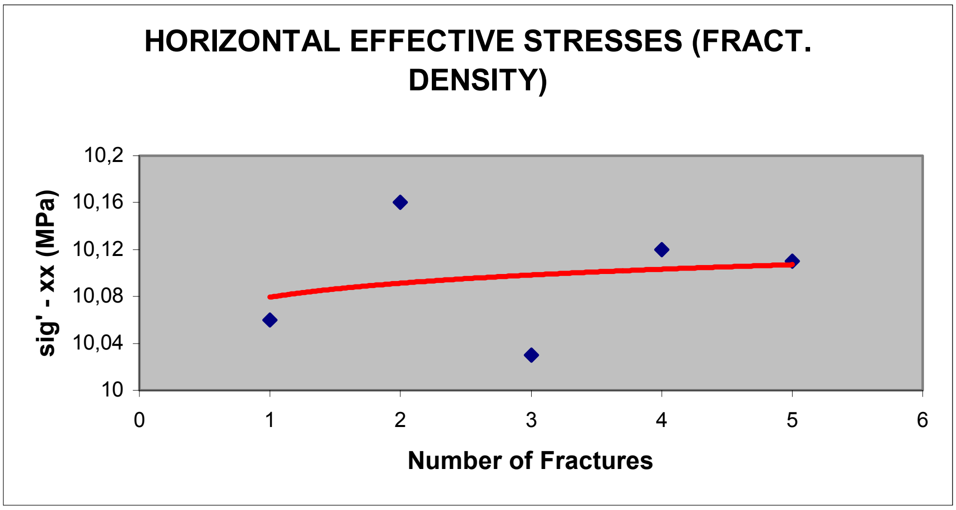

Figure 34. Increasing trend (plotted with a smooth red line) of the extreme Cartesian horizontal effective stress, in the top of the lower competent layer, with the increasing number of fractures in the top competent layer.