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Geometric Analysis of Gutter Bracket Using Different NX Siemens Solver for Linear and Nonlinear Investigation

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Abstract

This study explores the geometric and material behaviors of a gutter bracket under linear and nonlinear conditions using Finite Element Analysis (FEA) with Siemens NX solvers SOL101, SOL106, and SOL401. Polyvinyl Chloride (PVC) was selected for its favorable mechanical properties and corrosion resistance. The study investigates deformation, stress, and displacement of the bracket under a 100 N load, comparing the accuracy of linear and nonlinear analyses. Results indicate that while linear analysis provides a simplified model, nonlinear analysis captures material nonlinearity, geometric rigidity changes, and cyclic loading effects, offering more realistic insights. The findings emphasize the importance of nonlinear solvers in predicting structural behavior under significant deformations, ensuring design reliability and performance optimization in engineering applications.

Keywords: Finite element, Linear analysis, Nonlinear analysis, Sectors.

1 | Introduction

In sectors like auto manufacturing, civil infrastructure, and aircraft, Finite Element Analysis (FEA) has grown into a significant instrument in the design concept. FEA is a mathematical approach for solving inters issues including structural, fluid mechanics, temperature, and so on. FEA accelerates the design and creation of products by minimising the number of various tests, which reduces prototyping and testing costs [1].

FEA outcomes differ according to the material's attributes, the FEA design, the FEA way of solving, and the assumptions used in the analyzation. If the FEA model does not accurately match the actual challenge, or the

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outcomes are incorrectly analysed, manufacturers or industries will face a huge risk because product backlogs will occur [2]. The linearity hypothesis is used to predict most engineering issues; yet many issues faced by creative professionals are nonlinear [3].

In the scenario involving tiny deformations, the hypothesis of a linear relationship involving strain and deformation is satisfactory; but, in the case of high rotation and deformation, a nonlinear hypothesis is necessary to produce valid findings since the linear hypothesis does not remain valid [4]. A building's approach is termed nonlinear when its mechanical components, induced force, framework rigidity, and interface connections change because of displacement [5].

Material nonlinearity can cause structural nonlinearity because the material's stress-strain distribution is nonlinear and fails to respect Hook's law. Nonlinearity may also result from substantial changes in rigidity qualities or force owing to the displacement behaviour of elasticity; once the difficulty includes considerable displacement, this kind is described as geometric non – linearity [6]. The goal of this study is to use FEA on a guttering bracket adopting NX12 Advanced Simulation tool, to analyse geometric linear and nonlinearity incorporating solvers SOL101 and SOL401 to illustrate the comparison of the two solvers.

2 | Theory

Majority of engineering issues involving solid body displacement are classified as static analysis issues. Fixed analysis is utilized to calculate deformation, reaction force, stresses, and strains in structural construction to constant load. There are two types of static analysis: linear and nonlinear analysis.

2.1 | Linear and Non-Linear Analysis

Linear analytic is used in FEA whenever an applied load constraints (force, heat, etc.) have a linear relationship to the control system (displacement, temperature, etc.) [7]. Hooke's law has been followed by this sort of study (stress is directly proportional to the strain) as expressed in equation 1. In fact, a material would be subject to these circumstances till it hits elastic limit [8].

$$\text{Stress}(\sigma) = \text{Modulus of elasticity}(\text{E}) \times \text{Strain}(\varepsilon). \quad (1)$$

If a reaction force conditions (force, heat, and so on) have a non-linear relationship with the response (displacement, temperature, and so on) received from a system known as Non-linear Analysis. The stiffness matrix in nonlinear analysis changes throughout the study. The shape, material, and contacts employed might all contribute to the non-linearity [9]. Nonlinearity is classified into three categories because of this: nonlinearity in geometry, nonlinearity of materials, and nonlinearity in contact. The load-displacement relationship is one of the key distinctions separating linear and nonlinear analysis.

Fig. 1 illustrates the rigidity factor K link when F=Ku. When K is maintained constant in the linear analysis, a simple connection can be formed based on the imposed loads on the part and the system's reaction. K is not stable in nonlinear analysis, implying that a nonlinear analysis is required to resolve it. The reason is that, unlike a linear solver, which presume the stress-strain curve is constant, a nonlinear solver generates fresh approach by focusing on the evolving curve, requiring numerous computation steps to solve the issue [10].

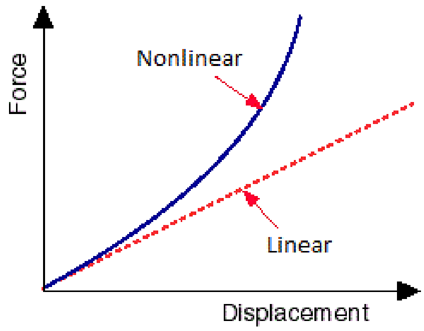


Fig. 1. The relation of load displacement of linear and nonlinear analysis [11].

Another distinction in linear and nonlinear is how the stress-strain connection is treated. Since linear analysis implies that the material with its component will always satisfy Hooks' rule, linear solvers are inappropriately utilised when substantial displacement are predicted. Nonlinear solvers account for yield points as well as the fact that the connection across stress will no longer be proportionate. Additionally, Xue [12] state that as a component deforms, the connection between stress shifts between linear to nonlinear, which occurs whenever the part is not consistently elastic.

The linear analysis does not account for load cycles; for example, if a load is introduced to a part, then withdrawn and re-added, the linear solution does not account for the consequences. A nonlinear response would consider the impacts on the material and structure of the component throughout a succession of cyclic loads and update the result in each increase to obtain an accurate analysis [7]. As a result, the conditions must be examined to complete the proper analysis [13]. Additionally, linear analysis may and should be used while the impacts of the part or component are entirely reversible, that is, after which the load has been eliminated the part will revert to its original condition. In such cases, a nonlinear analysis should be used since it analyses the component both before and after loading.

Linear solutions, as previously indicated, do not require numerous repetitions, and may solve the issue in a single step by applying the full load to the portion. Nonlinear analysis, on the other hand, uses numerous iterations to collect data from the external load and load path for the stiffness matrix. In nonlinear analysis, the load is applied incrementally, part by part, to ensure that each load increase is complete [11]. The ability to follow a load route leads in more realistic results that easily converge. To solve a nonlinear equation, many approaches such as the new method are applied.

3 | Types of Nonlinear Analysis

The types of nonlinear analysis include the geometric nonlinearity, material nonlinearity and boundary or contact nonlinearity.

3.1 | Geometric Nonlinearity

Once a structure undergoes greater displacement, the stiffness matrix changes, resulting in geometric nonlinearity [14].

3.2 | Material Nonlinearity

Material nonlinearity is defined by a set of characteristics that influence the material's qualities. It is determined by factors like as displacement, heat, pressure, strain, and rate of deformation. The above variables will either obey the laws of elasticity or the laws of plasticity. For example, if temperature has an influence on the material, thermo-elasticity or thermo-plasticity should be evaluated to account for both mechanical and thermal qualities [15].

3.3 | Boundary Nonlinearity

Contact nonlinearity is defined as the change in interactions caused by the force applied during the study [16].

4 | Newton Raphson Technique

The Newton-Raphson approach is one of the iterative techniques for determining the equilibrium state among the impact force and the structure's resistance value. The approach analyses the material's tangential rigidity at every successive iteration and accumulates towards the total analytical scheme in a few steps; however, the rigidity must be changed at every successive iteration, which leads to a high [16] computing cost for every repetition [17].

5 | Methodology

5.1 | Guttering Bracket Modelling

The model was design with the help of siemens NX12 software as shown in *Fig. 2*, with the dimension's length = 126 mm, height = 88 mm, and width 40 mm.

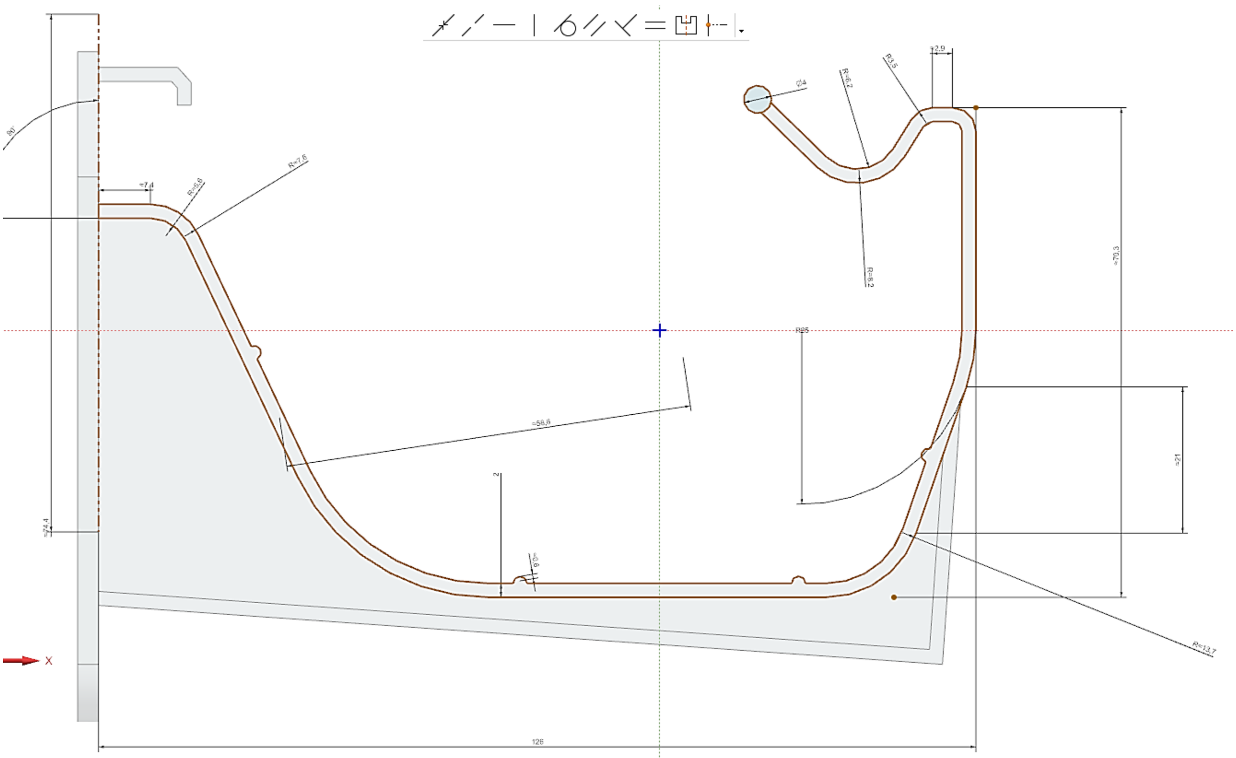


Fig. 2. Image of Gutter bracket modelling.

5.2 | Methods

Advanced simulations may be performed using a variety of Computer-Aided Engineering (CAE) tools, with Siemens NX being the one employed in this research to do a theoretical study on a clip component. Most program has three steps for doing these modelling: pre-processing, processing, and post-processing. *Fig. 2* shows a chart of these stages. Below are the procedures followed to create the simulation. For the processing to begin, the solution category is thus determined. It is critical when considering the results of the study [18], [19]. In the instance of the guttering clip simulation, three solutions were created: one with a linear solver "SOL 101," and the other a nonlinear solver "SOL 106," and SOL 401 (see *Fig. 3*).

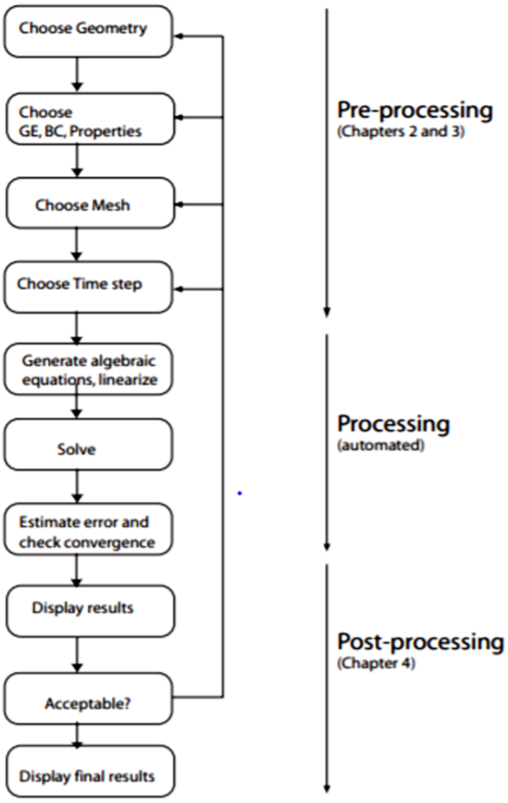
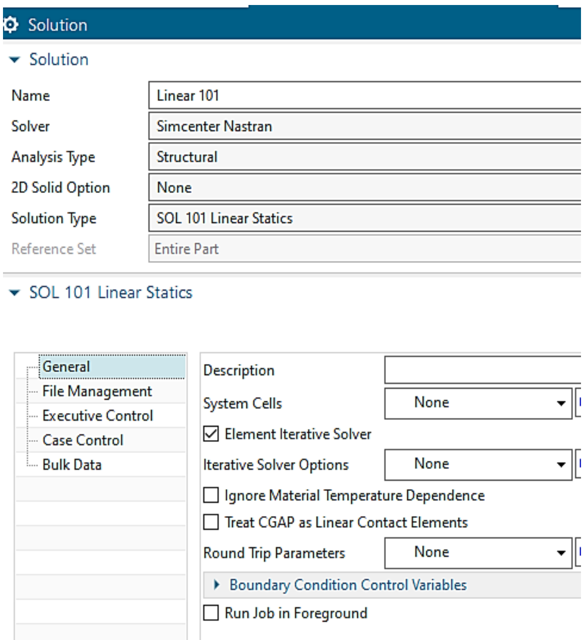
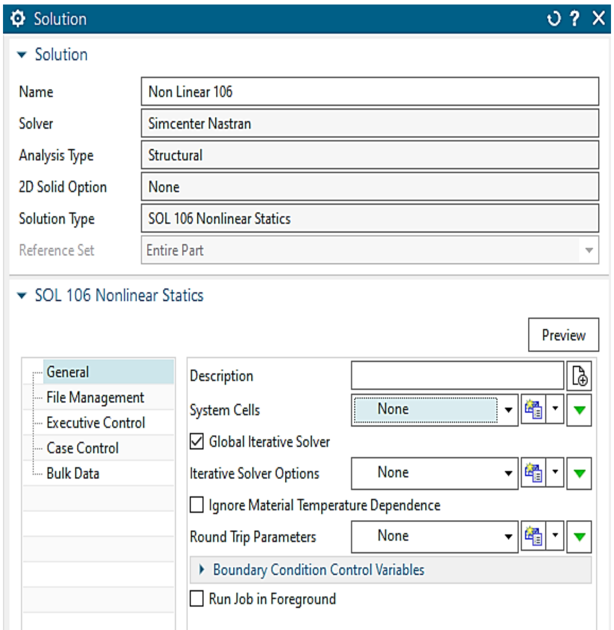


Fig. 3. FEA model to simulation flow chat [20].

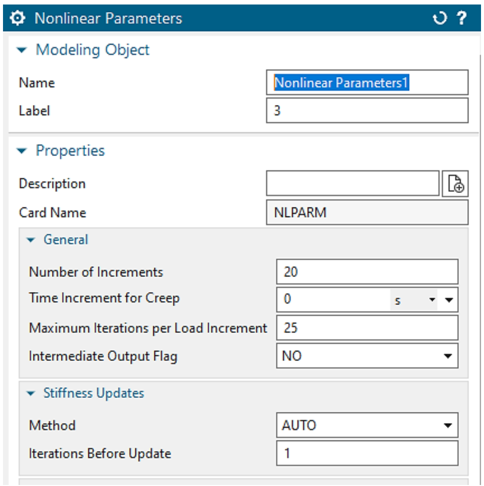
Prior to processing occurs, the solution type can be changed, along with the way the solution will optimize the parameters by modifying the Case Controls. The Case Controls for the 106 and 401 nonlinear solvers is modified the number of increments to 20 and stiffness to 1, as seen in *Fig. 4*.



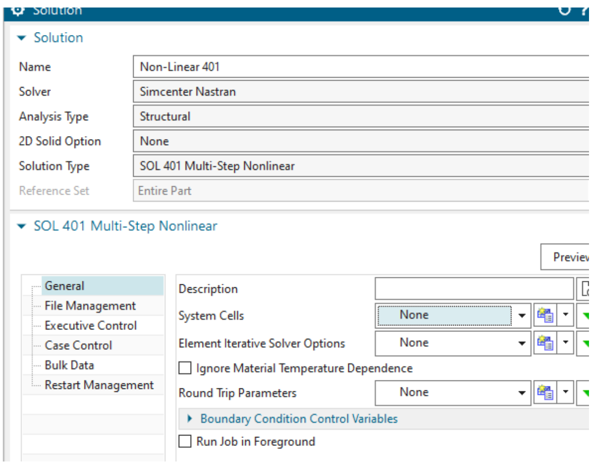
a.



b.



c.



d.

Fig. 4. Linear and non-linear model analysis of the guttering clip; a. SOL 101 Linear Solver, b. Non- Linear Solver 106, c. Case control 106, d. Non-Linear solver 401.

5.3 | Material

Material is a vital part during the pre- processing stages, which can lead to failure if there is no material selected or wrongly selected in the solution. The material used for the course of this analysis and model is the Polyvinyl Chloride (PVC), this is because of it been suitable for it purpose than metals in the guttering application and it is resistance to corrosion. The material property is pale in mass as it has a well-defined strength to its weight when compared to metal, with less cost. Young's modulus, yield strength, and stress data are all considered by the programme. This helps the programme deliver a precise result Williamson and Williamson. Some of the properties of the PVC such as young modulus, yield strength, and Poisson's ratio were 3000 Mpa, 37.259 Mpa and 0.4 respectively as show in *Fig. 5*, while the strain- stress data point boundaries were also inputted which can be seen in *Fig. 6*.

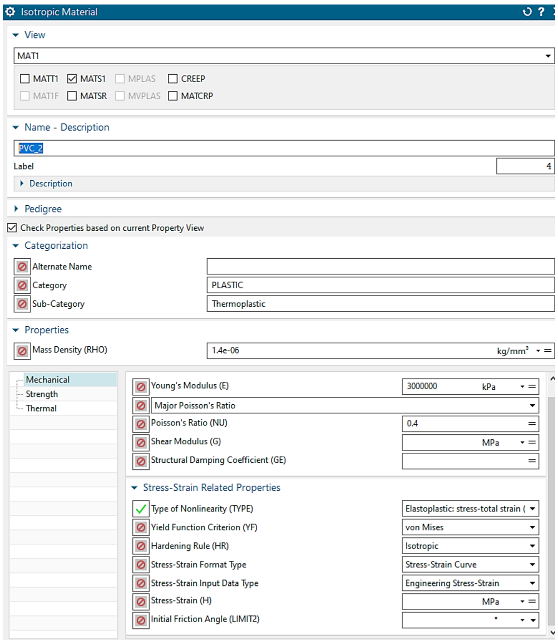
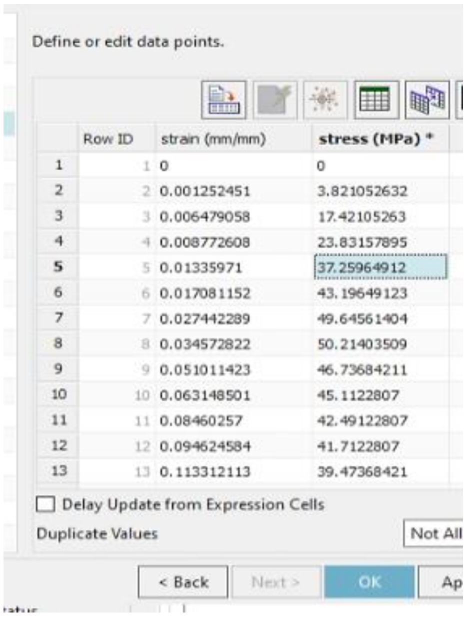


Fig. 5. Properties of PVC.



Define or edit data points.

	Row ID	strain (mm/mm)	stress (MPa) *
1	1	0	0
2	2	0.001252451	3.821052632
3	3	0.006479058	17.42105263
4	4	0.008772608	23.83157895
5	5	0.01335971	37.25964912
6	6	0.017081152	43.19649123
7	7	0.027442289	49.64561404
8	8	0.034572822	50.21403509
9	9	0.051011423	46.73684211
10	10	0.063148501	45.1122807
11	11	0.08460257	42.49122807
12	12	0.094624584	41.7122807
13	13	0.113312113	39.47368421

Delay Update from Expression Cells
Duplicate Values Not All
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Fig. 6. Strain- stress boundaries.

5.4 | Geometry

The geometry of the component is concerned with its meshing. Consider the element types that will be used for this part. A 3D tetrahedral mesh under a CTETRA (10) element is utilized. With Automatic Mesh control selected to pick a suitable mesh unit of 5.93 mm as can be seen *Fig. 7*. Although a smaller element produces a more precise result which will increase the computation time.

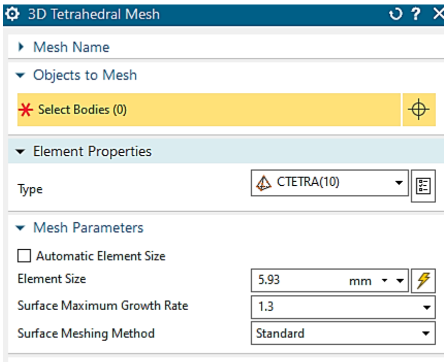

Fig. 7. 3-D Meshing with element size 5.93 mm.

5.5 | Loads and Fixed Constraints

Another aspect of pre-processing is the application of loads and constraints. A load of 100 N is marked on the faces of the guttering clip elements, and the solver converts these to a nodal loading [21]. As indicated in *Fig. 8*, the clip component will be secured with the other end restricted on the rear and a force exerted upon its upper side at the free end.

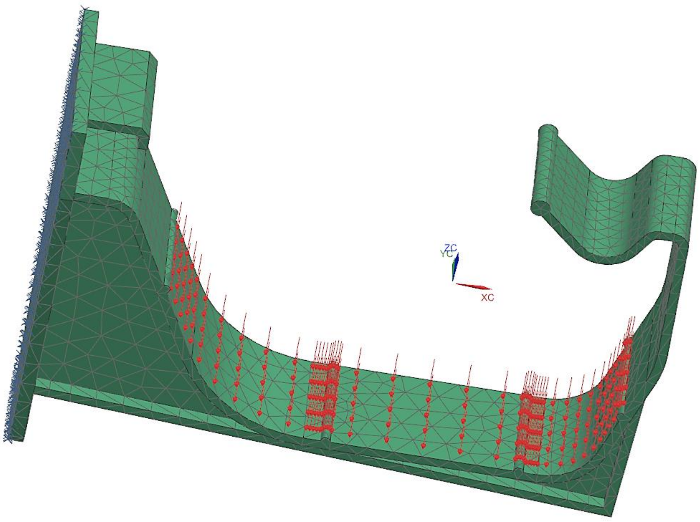

Fig. 8. Loads and constraints.

5.6 | Processing Stage

The computational part in which the problem is computed, and it may occur only after the pre-processing is already completed. The SOL 101 (linear) and SOL 106 (nonlinear) solvers used in this framework the data input via multiple methods and massive matrix to generate a numerical result that the viewer can comprehend. Before the evaluation was conducted, a second subcase named "removing loads" was added to the SOL 106 solution, which would reveal outcomes after the force is withdrawn from the portion.

5.7 | Post Processing Stage

This stage shows the processed outcomes from the modal analysis for good understanding and interpretation with practical applications.

This study investigated the FEA of a guttering bracket to compare the linearity and nonlinearity of the model. The SOL 101 (Linear), SOL 106, and SOL 401 (nonlinear) were used to analyse the guttering bracket. The load used for both analysis is 100 N. The displacement and Von mises stress of the SOL 101 is 5.206 mm and 21.26 Mpa, respectively.

Also, the displacement and Von mises of the SOL 106 is 5.234 mm and 24.83 Mpa respectively while the SOL 401 displacement and Von mises is 5.205 mm and 21.36 Mpa respectively, this can be seen in Figure 8. The difference between the nonlinear analysis SOL 106 AND SOL 401, 106 is static and not depending on any variable while SOL 401 is in respect to time. The yield point during the analysis is 37.2 Mpa.

This yield point is considered low for the material, though when comparing the different stress acted at the yield point, solvers SOL 101, SOL 106 and SOL 401 shows the stress acted upon at the yield as8.86 Mpa, 8.28 Mpa and 7.12 Mpa,respectively. Again, the SOL 106 showed that when load is removed from the material, the displacement occurred meaning that the material returned to its initial state and still within its elastic region (see *Fig. 9*).

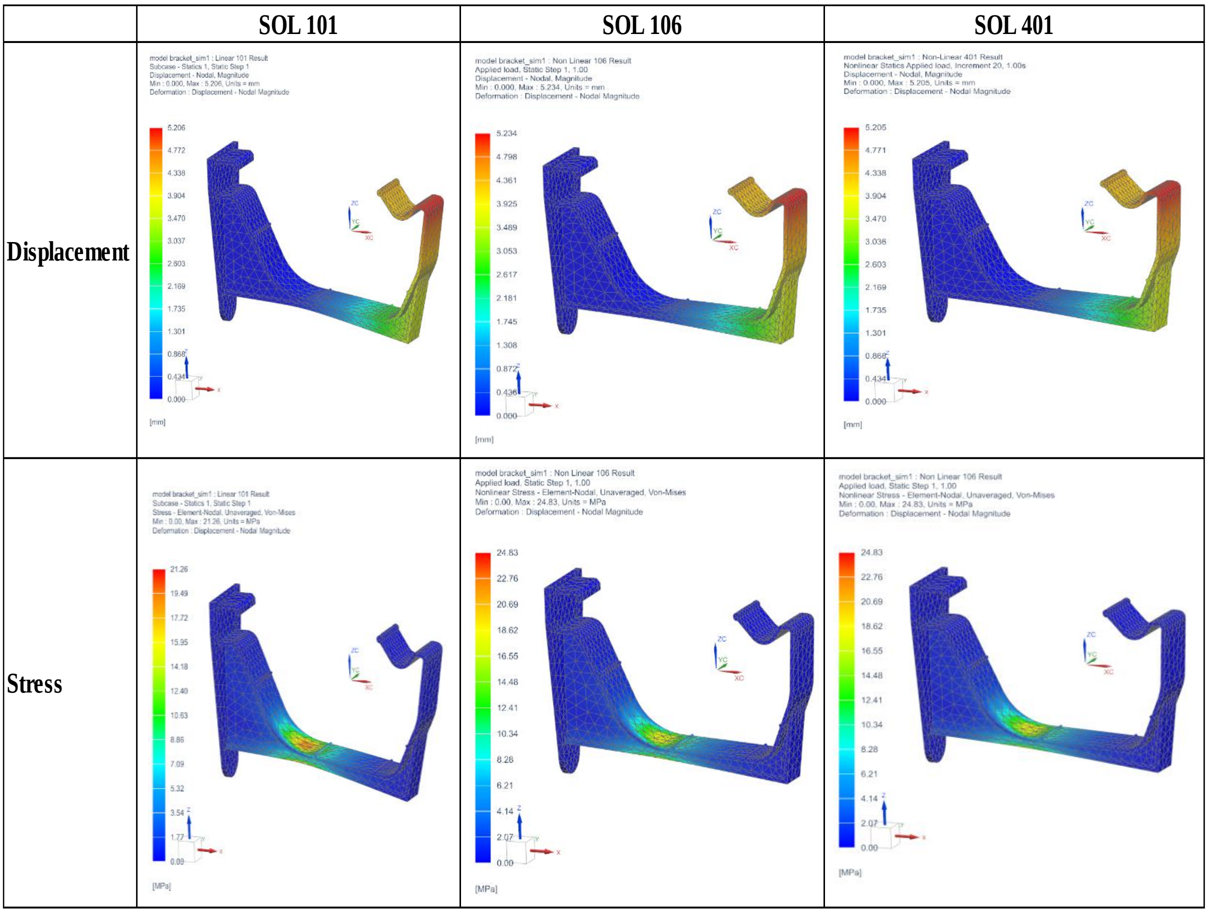

Fig. 9. Comparison of the SOL 101,106 and 401 with the displacement and Von Mises stress.

6 | Conclusion

This study implemented the SOL 101, SOL 106,and SOL 401 for the Linear and Non-Linear analysis of the guttering bracket. The simulated results indicate that both solver is competent in evaluating the linear and nonlinear behaviour of the model. The SOL 101 is used to describe the linear behaviour while SOL 106 and 401 were used for nonlinear. It was found that a displacement of 5mm was achieved with a load of 100 N. For this analysis, the nonlinear was presumed more accurate because the stiffness and geometry of the material was considered. Hence, PVC has varying mechanical properties, so it is important to conduct proper research for which properties to serve the purpose.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

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