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Fastener Modeling for Joining Parts Modeled by Shell and Solid Elements

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Abstract

The continued trend in finite element modeling of structures is toward the increased use of solid elements. For FE analysis of components containing two or more mechanically attached parts, it is often necessary to model each fastener to adequately represent the load transfer in the joint. It is desirable to be able to rapidly prepare model of each fastener to represent the actual joint behavior in a FEM containing solid elements, shell elements, or both.

The FEM representation of the fastener should capture the shear and bending stiffness of the fastener and the bearing stiffness at the fastener – joined part interaction. The stiffness of a fastener joint is a function not only of the fastener geometry and material, but also the properties of the joined structural members. A set of rigid elements should be used to ensure proper interaction of joined parts. The FEM fastener representation previously proposed meets this requirement quite well, and can be used to quickly prepare fastener representations when the structural members are modeled using shell elements.

The work presented in this paper extends the fastener FEM formulation previously developed to enable its use with solid elements. This paper describes a procedure to automate the creation of nodes, elements, MPCs, and constraints using MSC.Nastran to represent individual fasteners to develop mechanical connections between structural members modeled by shell elements, solid elements, or both. The procedures described in this work can be used with any number of joint members, and with a variety of element types.

1. Introduction.

With an increase of computer speed along with the amount of available memory, the trend for creation of more detailed models has arisen. It includes not only fine mesh modeling using shell elements but also increased use of solid elements due to extensive application of 3D CAD software packages and the desire of analysts to more realistically represent structural parts and their interaction, including fastener joints.

The distribution of loads between the components of a structural assembly depends not only on their dimensions and material properties but also on the stiffness of the fastener joints connecting the components. The accuracy of the finite element analysis is therefore significantly influenced by the representation of fastener joints in the model.

A procedure for modeling of fastener joints when the connected parts are represented by shell elements located at the plate mid-planes [1] was developed earlier. However, the extensive use of this procedure during these years by a number of companies has shown the necessity for additional capabilities, including:

- Modeling of fastener joints when all or some of the connected structural components are represented by solid elements;
- Ability to obtain tensile loads in fasteners directly from MSC.Nastran output.

These requirements are addressed in the presented paper. Other potential capabilities, i.e., the non-linear analysis of models with fastener joints, or the analysis of composite structures, will be addressed later.

The work presented in this paper extends the fastener FEM formulation to enable its use with solid elements. The paper describes a procedure for creation of a set of nodes, elements, MPCs, and constraints using MSC.Nastran to represent individual fastener joints. This fastener representation can then be used to model mechanical connections between structural members that are represented by shell elements, solid elements, or any combination of the two. The procedures described in this work can be used with any number of joint members, and can be used with a variety of element types, including quad, tri, tet, and hex elements. Higher order elements are also supported.

To enable the reading of tensile loads in fasteners directly from MSC.Nastran output, an alternative modeling procedure based on the linear gap techniques [2] was developed. However, this procedure does not consider the effect of the fastener pre-tension and fit. Also, the friction phenomenon in the joint is not considered here. These effects require non-linear analysis and therefore fall beyond the scope of this paper.

2. Fastener Modeling Approach.

The presented approach to modeling of a fastener joint is based on the definition of each deformation component contributing to joint flexibility, then modeling them using a corresponding finite element. The combination of these elements represents the complete behavior of a fastener joint. Some relative displacements in the fastener joint model are limited to ensure the compatibility of deformations.

2.1. Stiffness of Fastener Joint

In a fastener joint (Figure 1) the following stiffness components are considered [1]:

- Combined plate and fastener translational bearing stiffness;
- Combined plate and fastener rotational bearing stiffness;
- Fastener shank shear and bending stiffness.

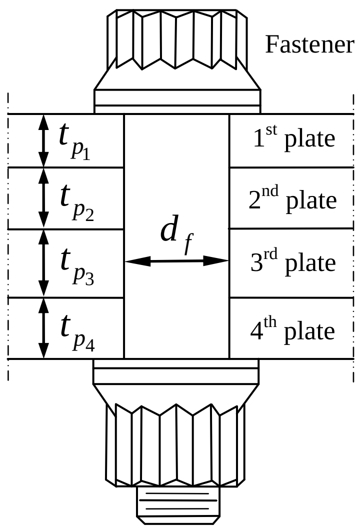


Figure 1. Fastener Joint.

The combined plate i and fastener translational bearing stiffness is

$$S_{bt_i} = \frac{t_{p_i}}{\dfrac{1}{E_{cp_i}} + \dfrac{1}{E_{cf}}}$$

where E_{cp_i} - compression modulus of plate i material;

E_{cf} - compression modulus of fastener material;

t_{p_i} - thickness of plate i.

The combined plate i and fastener rotational bearing stiffness is

$$S_{bt_i} = \frac{1}{12} \cdot \frac{t_{p_i}^3}{\frac{1}{E_{cp_i}} + \frac{1}{E_{cf}}}$$

The bearing stiffness is modeled by elastic elements. A more detailed definition of bearing stiffness is given in [1]. The shear and bending stiffness of a fastener are represented by a beam element.

If a plate is composed of a laminated composite material, a reasonable estimate of the bearing translational and rotational stiffness can be obtained by using an average of the apparent in-plane stiffnesses for E_{cp_i}. The apparent in-plane stiffnesses for a given composite laminate can be determined using classical lamination theory [3,4].

2.2. Representation of a Fastener Joint

Modeling of a fastener joint is described here in MSC.Nastran terms.

Idealization of a plate-fastener system includes the following:

- Elastic bearing stiffness of a plate and fastener at the contact surface;
- Bending and shear stiffness of a fastener shank;
- Compatibility of displacements of a fastener and connected plates in the joint.

The presented method creates a plate-fastener system that is illustrated in examples shown in Figures 2 – 7:

a. Model of a fastener joint connecting three plates modeled by shell elements (Figure 2).
b. Model of a fastener joint connecting three plates modeled by single ply of solid elements (Figure 3).
c. Model of a fastener joint connecting three plates modeled by two plies of solid elements (Figure 4). Modeling of fastener joints connecting plates represented by high order solid elements is similar to modeling shown in Figure 4.
d. Model of a fastener joint connecting three plates modeled as follows (Figure 5):
    - Plate 1 – solid elements;
    - Plate 2 – shell elements;
    - Plate 3 – solid elements.
e. Model of a fastener joint connecting three plates modeled as follows (Figure 6):
    - Plate 1 – shell elements;
    - Plate 2 – solid elements;
    - Plate 3 – solid elements.
f. Model of a fastener joint connecting three plates modeled as follows (Figure 7):
    - Plate 1 – solid elements;
    - Plate 2 – solid elements;
    - Plate 3 – shell elements.

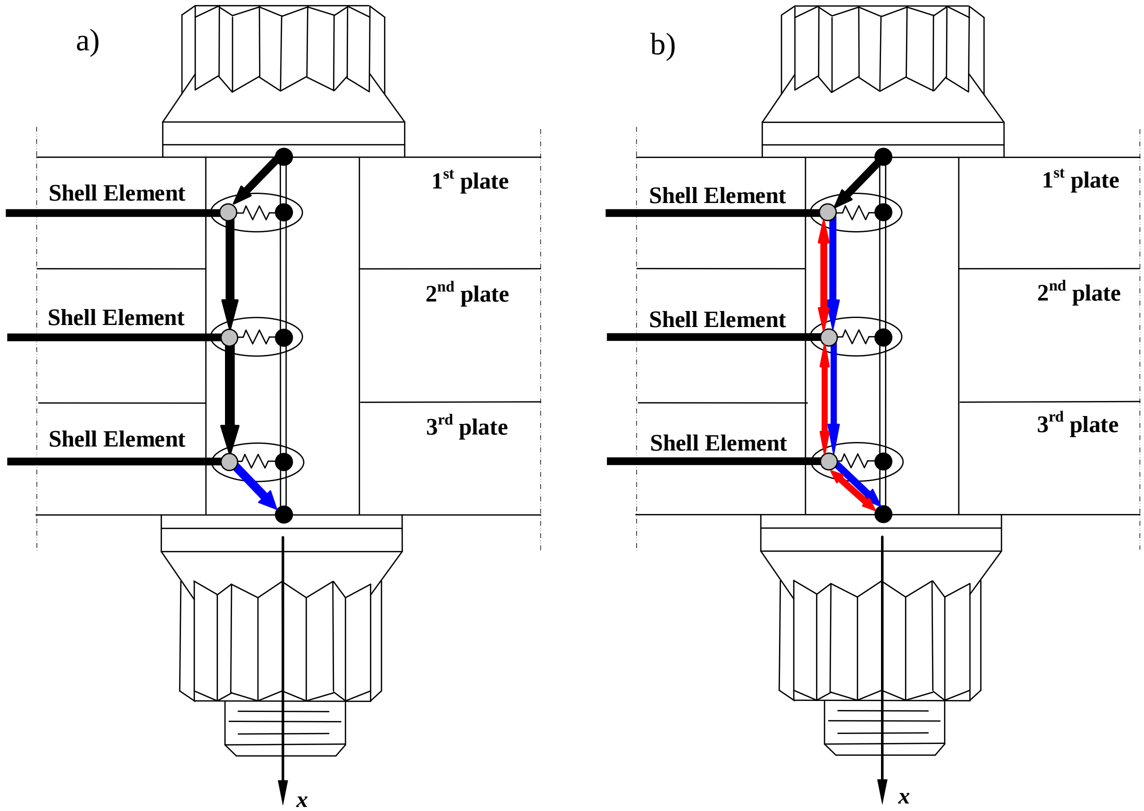


Figure 2. Model of a Fastener Joint Connecting Three Plates Modeled by Shell Elements:

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

A description of each of the components of the fastener joint models shown in Figures 2 – 7 is given in Table 1.

The method requires the creation of two additional sets of nodes:

- Nodes at the plate mid-planes for plates represented by solid elements (gray nodes in Figures 3 – 7). For plates represented by shell elements, additional nodes are not required because the elements are already located at the plate mid-plane.
- Nodes for the fastener shank modeling (black nodes in Figures 2 – 7). This set includes nodes coincident with corresponding nodes at plate mid-planes and nodes located on the intersection of the fastener axis and the outer surfaces of the first and last connected plates.

For correct definition of a fastener shear plane and its axial direction, a coordinate system with one of its axes parallel to the fastener axis must be defined in the bulk data. This coordinate system must be used as the analysis coordinate system for both the existing nodes (white solid element nodes and gray shell element nodes in Figures 2 – 7) and newly created nodes (gray mid-plane nodes of plates modeled by solid elements and black nodes of a fastener shank in Figures 2 - 7).

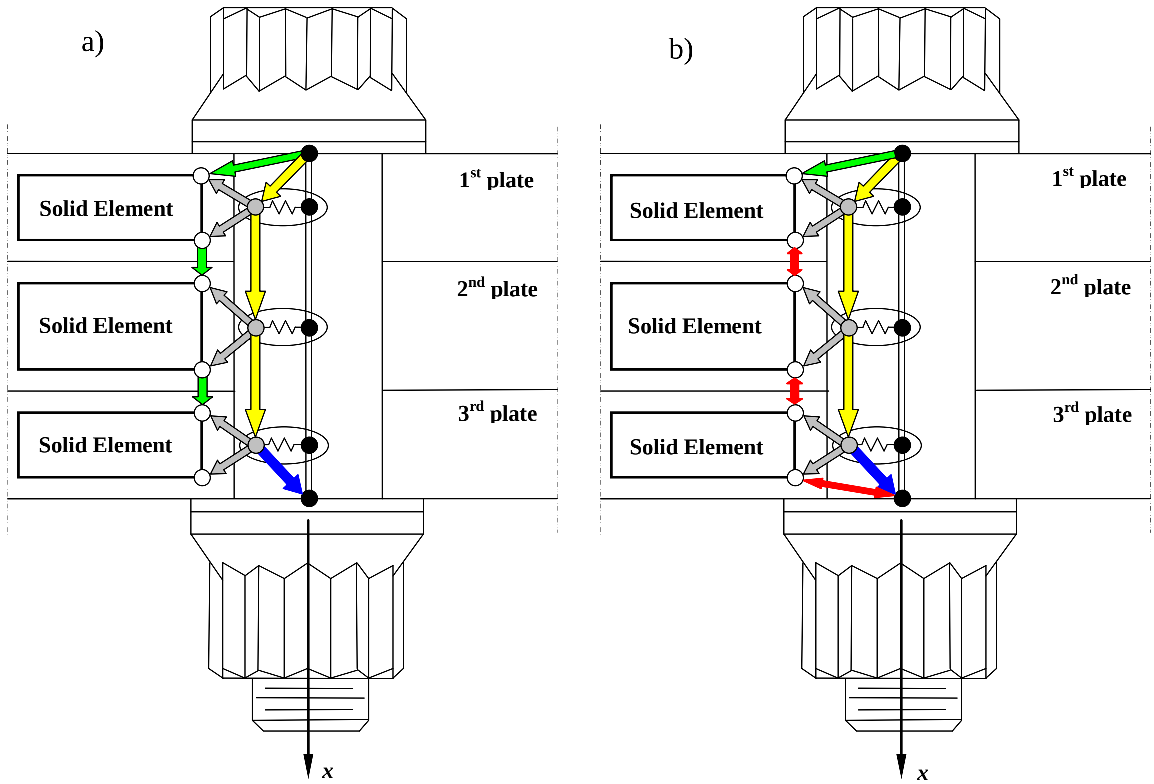


Figure 3. Model of a Fastener Joint Connecting Three Plates Modeled by Solid Elements:

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

2.3. Fastener Shank Modeling

The fastener shank is modeled by CBAR or CBEAM elements [5] with corresponding PBAR or PBEAM card for properties definition. For the CBAR or CBEAM elements connectivity, a separate set of nodes (black nodes in Figures 2 – 7) is created. This set also includes nodes located on the intersection of the fastener axis and the outer surfaces of the first and last connected plates.

All CBAR or CBEAM elements representing the same fastener shank reference the same PBAR or PBEAM card [5] with the same cross-sectional area, moments of inertia and torsional constant:

$$A = \frac{\pi d_f^2}{4} \qquad I_1 = I_2 = \frac{\pi d_f^4}{64} \qquad J = \frac{\pi d_f^4}{32}$$

where d_f - fastener shank diameter.

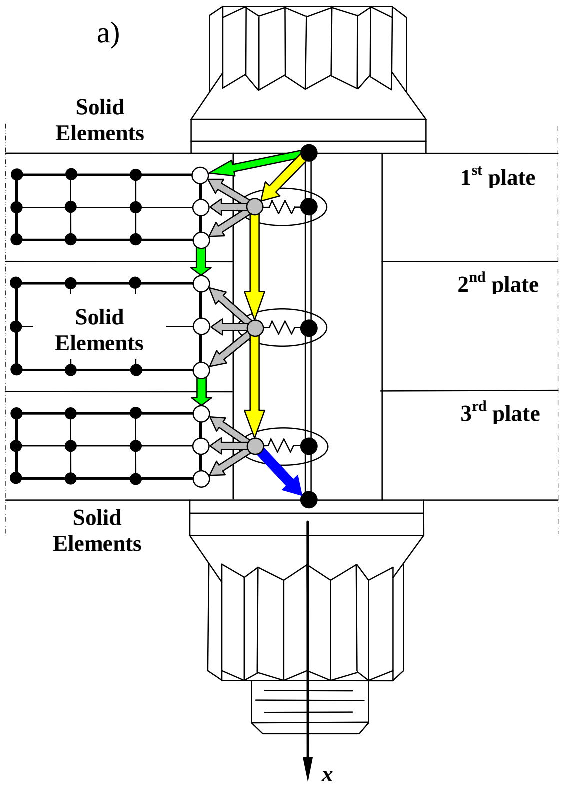


Figure 4. Model of a Fastener Joint Connecting Three Plates Modeled by Two Plies of Solid Elements:

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

2.4. Modeling of Interaction Between Fastener Shank and Joined Plates

The interaction between a fastener and plates results in bearing deformation of all components of the joint on their surfaces of contact. The combined bearing stiffness of a fastener and connected plates is defined in Section 2.1. The bearing stiffness is presented as a translational stiffness in the direction of axes normal to the fastener axis which define the fastener shear plane, and rotational stiffness about the same axes.

For the modeling of the bearing stiffness, both additional sets of grid points mentioned above are used. Each pair of coincident grid points created by a plate mid-plane node for a solid element or shell element node (gray node in Figures 2 – 7) and the corresponding fastener shank node (black node in Figures 2 – 7) is connected by a CBUSH element [5] or combination of CELAS2 elements with equal translational stiffness along the axes normal to the fastener axis and equal rotational stiffness about the same axes. The connectivity card CBUSH must be accompanied by a PBUSH card defining the element stiffness. When the plate is modeled by shell elements, the load from the CBUSH element is transferred directly to the shell elements. In the case of the plate modeled by solid elements, load from the plate mid-plane node is transferred to the solid element nodes by a rigid element RBE2.

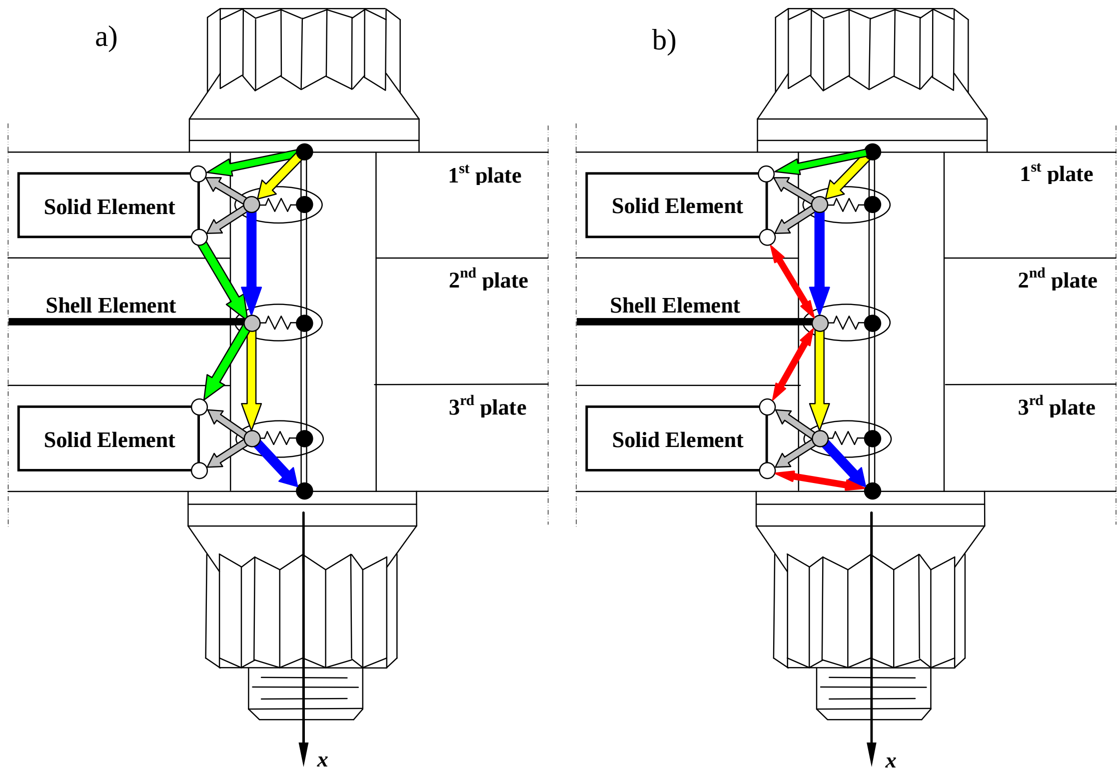


Figure 5. Model of a Fastener Joint Connecting Three Plates Modeled as Follows:

- Plate 1 – Solid Elements;
- Plate 2 – Shell Elements;
- Plate 3 – Solid Elements.

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

2.5. Compatibility of Displacements in the Joint

As mentioned above, two modeling procedures are considered here for representation of fastener joints:

1. Modeling using rigid elements only. This approach is recommended when tensile loads in fasteners can be neglected and shear loads on fasteners are the main goal of analysis. In this case load in the direction transverse to the joined plates is transferred through plate contact and the fastener shank is not loaded.
2. Modeling using rigid elements and linear gap techniques. This approach should be applied when the tensile loads in the fasteners are significant and are one of main goals of analysis. However the excessive use of linear gaps can slow model convergence.

The fastener joint model was designed under the following assumptions:

- No interference of plates under the load;
- The plate mid-planes stay parallel to each other under load;
- Planes under the fastener heads stay parallel to the plate mid-planes under load.

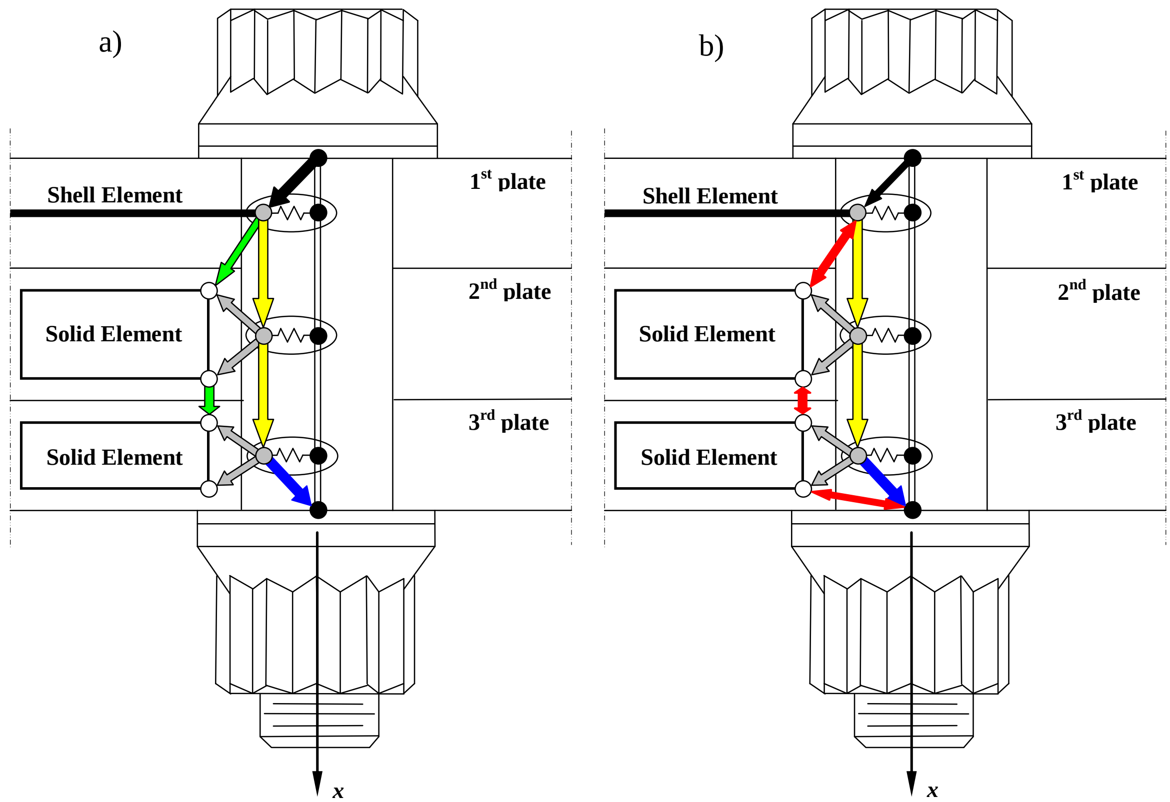


Figure 6. Model of a Fastener Joint Connecting Three Plates Modeled as Follows:

- Plate 1 – Shell Elements;
- Plate 2 – Solid Elements;
- Plate 3 – Solid Elements.

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

These goals are reached by using two sets of RBAR elements and the linear gap techniques.

When the first modeling approach (rigid elements only) is used the first set of RBAR elements (black and green arrows in Figures 2 – 7) satisfies the first assumption. These RBAR elements prevent the movement of plates relative to each other along the fastener axis. The first RBAR element in this set also prevents the fastener movement as a rigid body along its axis. In this case not only is the interference of plates prevented but a gap development in the joint is banned as well.

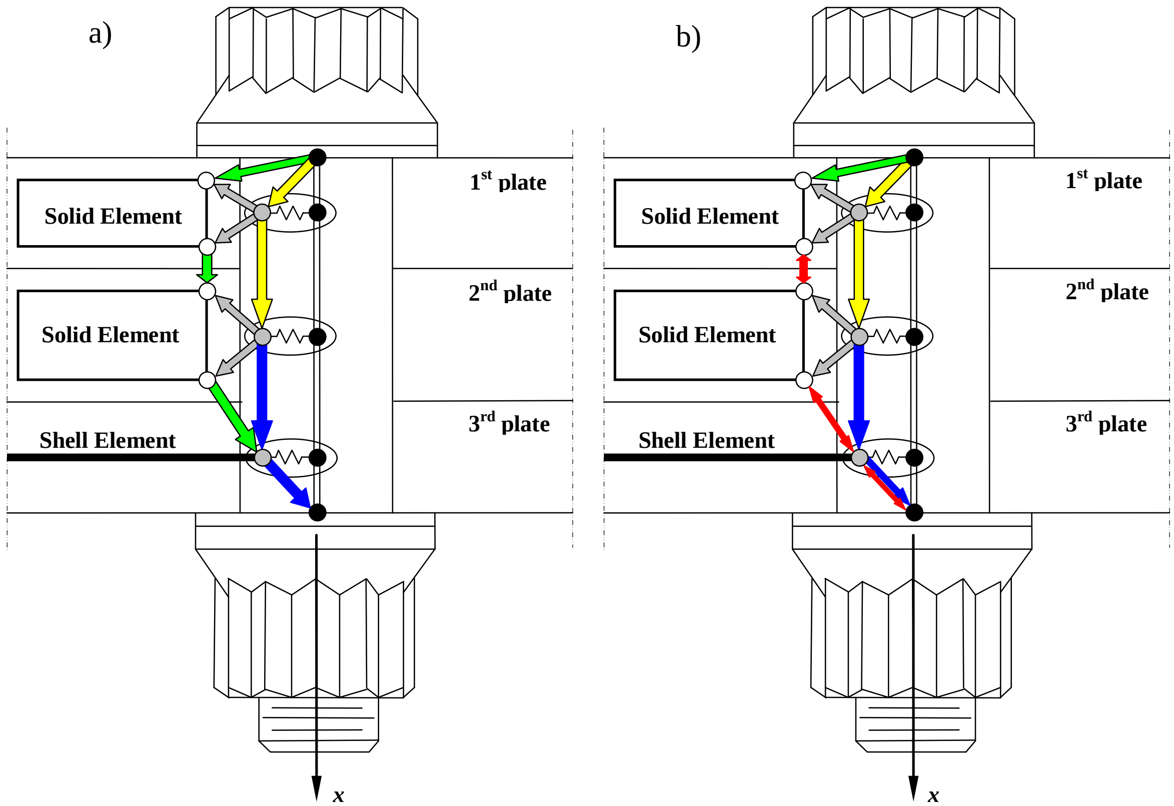


Figure 7. Model of a Fastener Joint Connecting Three Plates Modeled as Follows:

- Plate 1 – Solid Elements;
- Plate 2 – Solid Elements;
- Plate 3 – Shell Elements.

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

When the alternative modeling approach (rigid elements and linear gaps) is used, the degree of freedom of RBAR elements in the fastener axis direction is replaced by linear gaps (red arrows in Figures 2 – 7). The exception is the RBAR element between the upper fastener head and the first plate because it prevents free body movement of the fastener shank. Under this approach, gaps between plates are allowed but interference of plates is banned.

The second set of RBAR elements (blue and yellow arrows in Figures 2 – 7) satisfies the last two assumptions. It forces the plate mid-planes and planes under the fastener heads to remain parallel to each other under load.

Two sets of RBAR elements are required when the joined plates are modeled by solid elements because solid elements do not have rotational stiffness at their nodes.

Table 1. Components of Fastener Joint Models

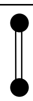
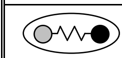
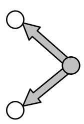
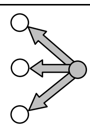
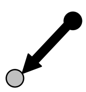
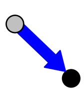
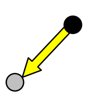
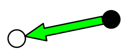
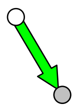
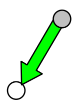
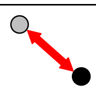
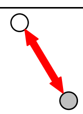
Component		Component Description	DOF's for Rigid Elements and Linear Gaps for Fastener Axis Directions		
			1	**2**	**3**
	GRID	Fastener shank node (node of fastener shank under the upper head must be constrained against rotation about fastener axis)			
	GRID	Node at plate mid-plane			
	GRID	Node of solid element involved in the fastener joint modeling			
	GRID	Node of solid element not involved in the fastener joint modeling			
	CBAR	Element for fastener shank modeling			
	CBUSH	Element connecting plate mid-plane node with coincident node of the fastener shank	2 3 5 6	1 3 4 6	1 2 4 5
 	RBE2	Rigid element connecting plate mid-plane node with nodes of solid element representing plate	2 3	1 3	1 2
	RBAR	Rigid element connecting node of the fastener shank under the upper head (independent node) with the node of shell element representing the first plate (dependent node)	1 5 6	2 4 6	3 4 5
	RBAR	Rigid element connecting nodes of shell elements representing two adjacent plates	1 5 6	2 4 6	3 4 5
	RBAR	Rigid element connecting mid-plane nodes of two adjacent plates	5 6	4 6	4 5
	RBAR	Rigid element connecting mid-plane node of the last plate (independent node) with the node of the fastener shank under the lower head (dependent node)	5 6	4 6	4 5
	RBAR	Rigid element connecting node of the fastener shank under the upper head (independent node) with mid-plane node of the first plate represented by solid elements (dependent node)	1 4 5 6	2 4 5 6	3 4 5 6
	RBAR	Rigid element connecting mid-plane nodes of two adjacent plates	1 4 5 6	2 4 5 6	3 4 5 6

Table 1 (continued). Components of Fastener Joint Models

Component		**Component Description**	**DOF's for Rigid Elements and Linear Gaps for Fastener Axis Directions**		
			1	**2**	**3**
	RBAR	Rigid element connecting node of the fastener shank under the upper head (independent node) with the coincident node of solid element representing the first plate (dependent node)	1	2	3
	RBAR	RBAR element connecting two coincident nodes of solid elements representing two adjacent plates	1	2	3
	RBAR	RBAR element connecting the corner node of solid element (independent node) with mid-plane node of adjacent plate modeled by shell element (dependent node)	1	2	3
	RBAR	RBAR element connecting mid-plane node of plate modeled by shell elements (independent node) with the corner node of adjacent plate modeled by solid elements (dependent node)	1	2	3
	Linear Gap	Technique connecting mid-plane nodes of two adjacent plates modeled by shell elements	1	2	3
	Linear Gap	Technique connecting mid-plane node of the last plate modeled by shell elements with the node of the fastener shank under the lower head	1	2	3
	Linear Gap	Technique connecting two coincident nodes of solid elements representing two adjacent plates	1	2	3
	Linear Gap	Technique connecting node of solid element representing the last plate with the coincident node of the fastener shank under the lower head	1	2	3
	Linear Gap	Technique connecting the corner node of plate modeled by solid elements with mid-plane node of adjacent plate modeled by shell elements	1	2	3

If the degrees of freedom of the second set of RBAR elements (blue and yellow arrows) were assigned to the first set of RBAR's (black and green arrows) the last two conditions would not be satisfied because of the absence of rotational stiffness at the solid element nodes. If the degrees of freedom of the first set of RBAR elements (black and green arrows) were assigned to the second set of RBAR elements (blue and yellow arrows) gap or interference development between plate surfaces cannot be prevented. So, when plates are modeled by solid elements the two sets of RBAR elements described above is an absolute necessity for correct formulation of the fastener joint behavior under load.

However, when plates are modeled by shell elements, all required degrees of freedom can be assigned to one set of rigid elements (Figure 2).

3. Modeling System.

A block approach to fastener joint modeling is presented in this section. A model of a fastener joint can be divided into three main parts (Figures 2 – 7):

- Interaction of the upper fastener head and fastener shank with the first plate;
- Interaction of two adjacent plates with each other and with the fastener shank;
- Interaction of the lower fastener head and fastener shank with the last plate.

Each of these model parts can be represented by a few related blocks. Using these blocks a model of a fastener joint connecting any number of joined plates represented by shell or solid elements can be created.

3.1. Interaction of Fastener with the First Plate

Interaction of a fastener and the first plate is presented by two blocks (Figure 8) for two possible modeling conditions:

- The first plate is modeled by shell elements;
- The first plate is modeled by solid elements.

These blocks are the same for both modeling approaches: modeling using rigid elements only and using rigid elements and linear gaps. Rigid elements in these blocks prevent relative rotation of the plate and the fastener head about the axes in the fastener shear plane and relative displacement along the fastener shank. The fastener shank node under the upper head is constrained against rotation about the fastener axis to prevent shank free body rotation.

3.2. Interaction of Two Adjacent Plates and Fastener Shank

Interaction of a fastener shank with two adjacent plates is presented by eight blocks (Figures 9 – 12) for the following modeling conditions:

- Both adjacent plates are modeled by shell elements (Figure 9);
- Both adjacent plates are modeled by solid elements (Figure 10);
- One plate is modeled by shell elements and the adjacent plate is modeled by solid elements (Figure 11);
- One plate is modeled by solid elements and the adjacent plate is modeled by shell elements (Figure 12).

For each of these modeling conditions two separate blocks were developed based on two modeling approaches: modeling using rigid elements only and using rigid elements and linear gaps. Rigid elements keep plate mid-planes parallel to each other, i.e. they prevent relative rotation of the plates about the axes in the fastener shear plane. Also, rigid elements and linear gaps prevent the interference between plates.

3.3. *Interaction of Fastener with the Last Plate*

Interaction of a fastener and the last plate is presented by four blocks (Figures 13 and 14) for two possible modeling conditions:

- The last plate is modeled by shell elements;
- The last plate is modeled by solid elements.

Here also for each of these modeling conditions two separate blocks were developed based on the two modeling approaches described above. Rigid elements in these blocks prevent relative rotation of the plate and the fastener head about axes in the fastener shear plane. The linear gap techniques transfer load from the plate to the fastener head.

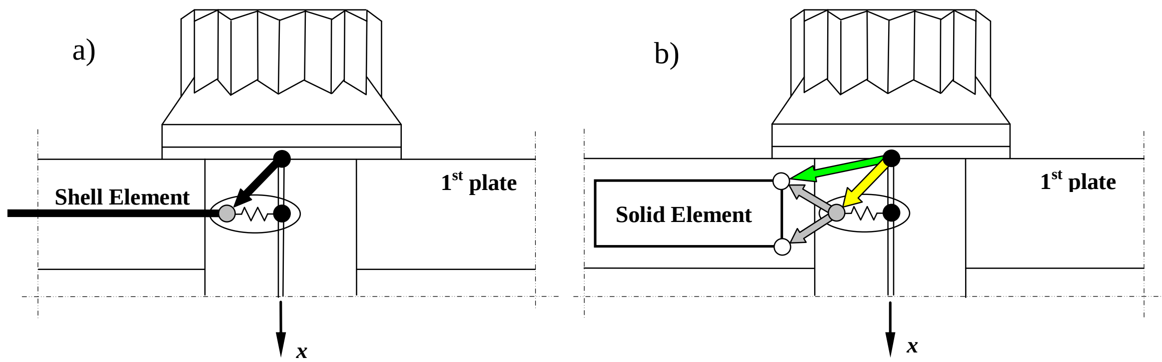


Figure 8. Interaction of Fastener and the First Plate:
a. The First Plate is Modeled by Shell Elements;
b. The First Plate is Modeled by Solid Elements.

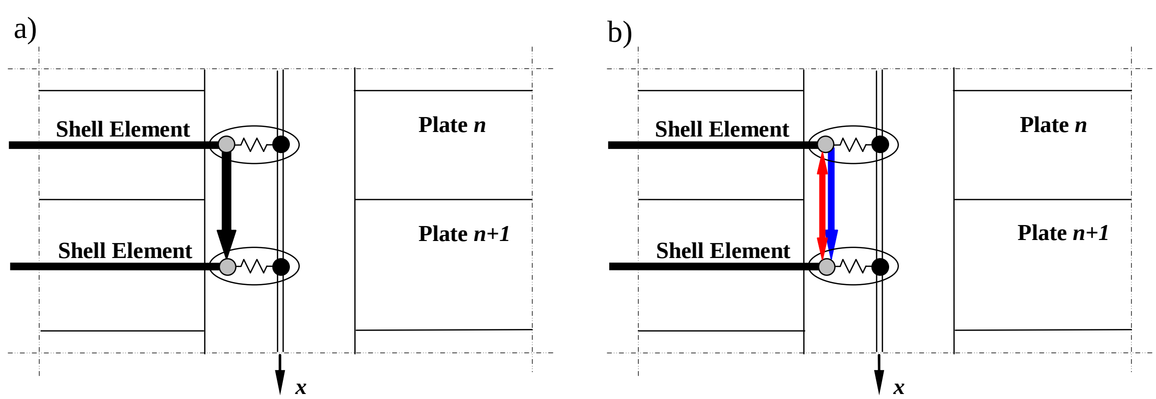


Figure 9. Interaction of a Fastener Shank with Two Adjacent Plates Modeled by Shell Elements:
a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

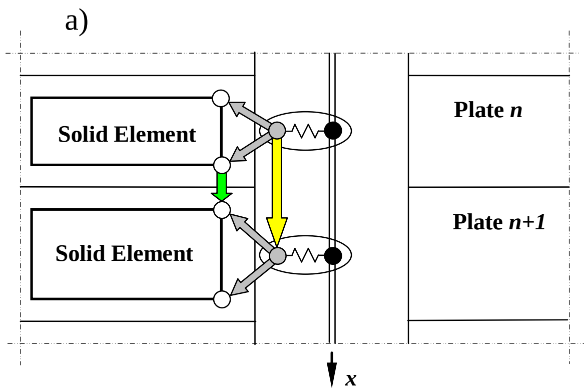


Figure 10. Interaction of a Fastener Shank with Two Adjacent Plates Modeled by Solid Elements:

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

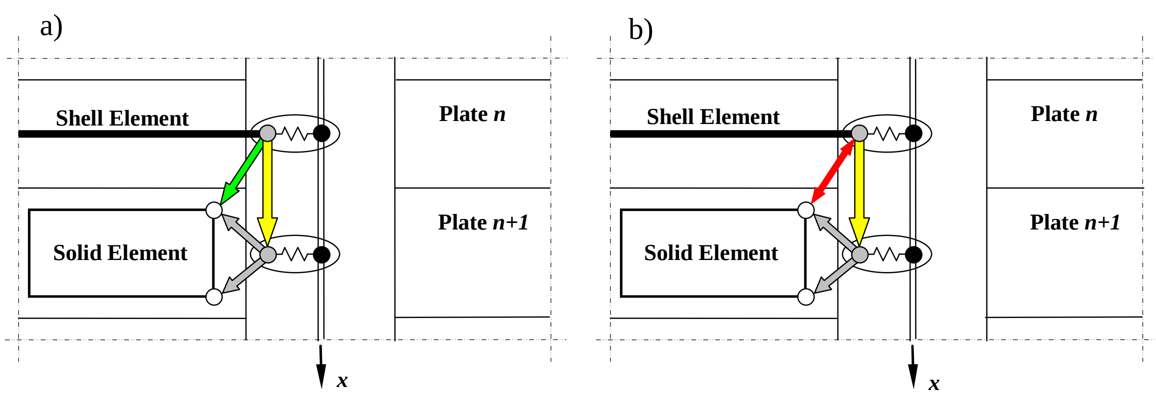


Figure 11. Interaction of a Fastener Shank with a Plate Modeled by Shell Elements and Adjacent Plate Modeled by Solid Elements:

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

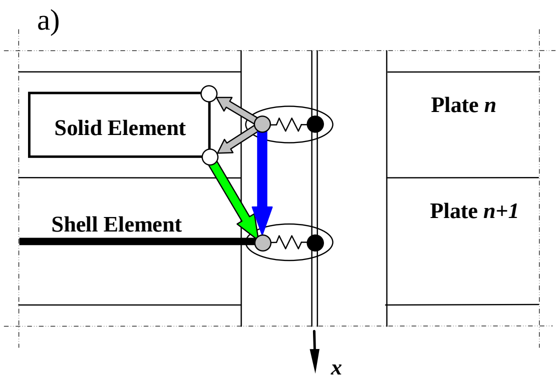


Figure 12. Interaction of a Fastener Shank with a Plate Modeled by Solid Elements and Adjacent Plate Modeled by Shell Elements:

a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

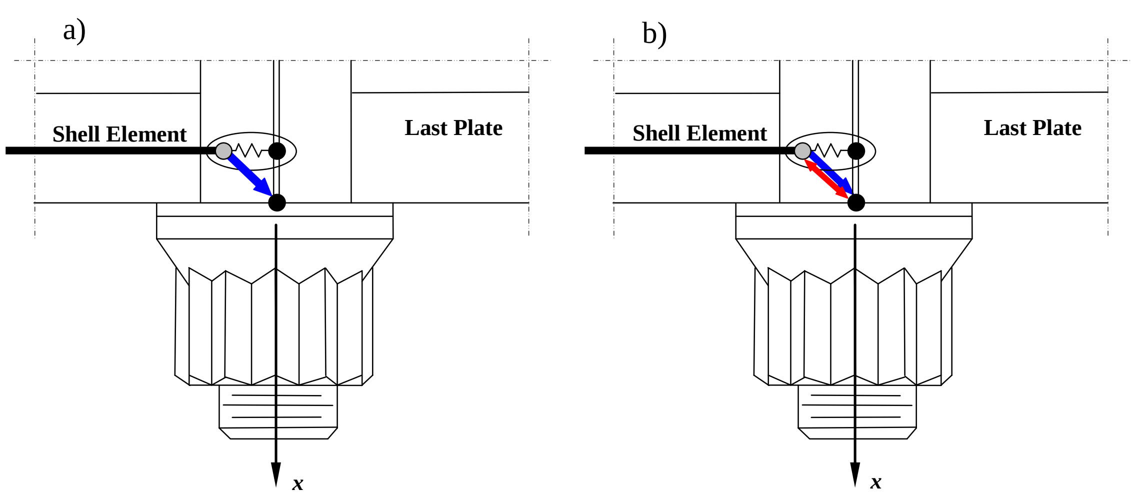


Figure 13. Interaction of Fastener and the Last Plate Modeled by Shell Elements:

c. Model with Rigid Elements Only.
d. Model with Rigid Elements and Linear Gaps.

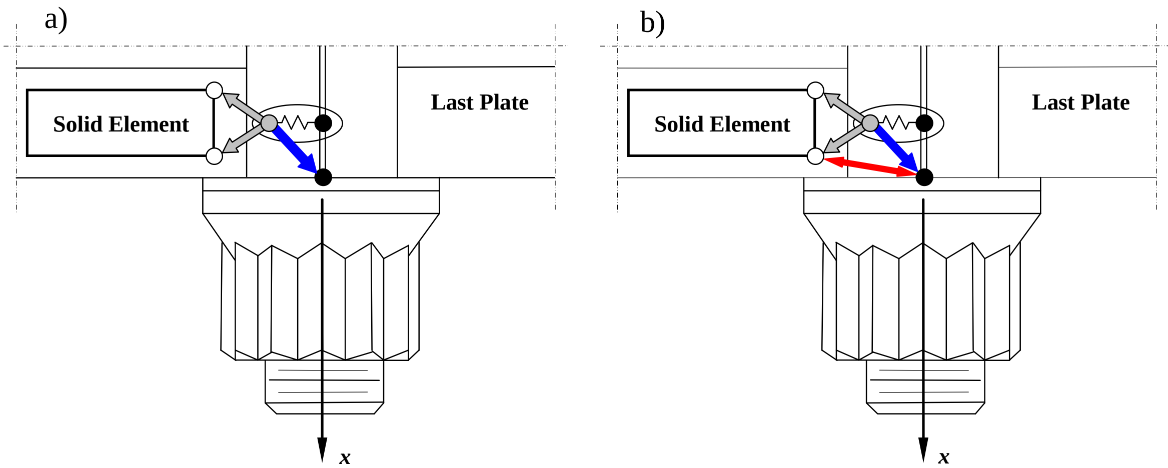


Figure 14. Interaction of Fastener and the Last Plate Modeled by Solid Elements:
a. Model with Rigid Elements Only.
b. Model with Rigid Elements and Linear Gaps.

4. Modeling Examples.

The following examples of fastener joint modeling are presented in this paper:

1. Symmetric double shear joint. Plates are modeled using shell elements (Figures 15 – 17). For the plate interaction the “Rigid Elements Only” modeling approach is used.
2. Symmetric double shear joint. Plates are modeled using solid elements (Figures 18 – 20). The inner plate is modeled by three plies of solid element, and the outer plates are represented by a single ply of solid elements. For the plate interaction the “Rigid Elements Only” modeling approach is used.
3. Symmetric double shear joint. The inner plate is modeled by shell elements (Figures 21 – 23), and the outer plates are represented by a single ply of solid elements. For the plate interaction the “Rigid Elements Only” modeling approach is used.
4. Attachment of a tension clip to a plate. The tension clip is modeled by solid elements and the plate is represented by shell elements (Figures 24 and 25). For the model parts interaction the “Rigid Elements and Linear Gaps” approach is used.

In the first three examples, load is transferred in the fastener joints by shear in fasteners. Axial loads in the fasteners are negligible. Therefore for modeling of joined plate interaction the “Rigid Elements Only” approach was used. In the fourth example, load is transferred by tension in fasteners. In this case interaction of the model parts is represented using the “Rigid Elements and Linear Gaps” approach.

In the first three examples, under the load, the joined plates slide along each other due to combined plates and fastener translational bearing deformation and the fastener bending and shear deformation. The fastener deformation causes a change of angle between the

fastener and the plate or, in other words, their relative rotation. This relative rotation results in non-uniform distribution of bearing stress through the plate thickness. The resultant load transferred through the contact area between the fastener and plate consists of a force in the plate mid-plane and out-of-plane moment. In the structure, the moment is reacted by loads on the plate contact surfaces and does not cause local bending of the plates, i.e. fastener does not guide the plates. The proposed modeling technique takes this phenomenon into account ensuring the plates mid-planes stay parallel to each other under load.

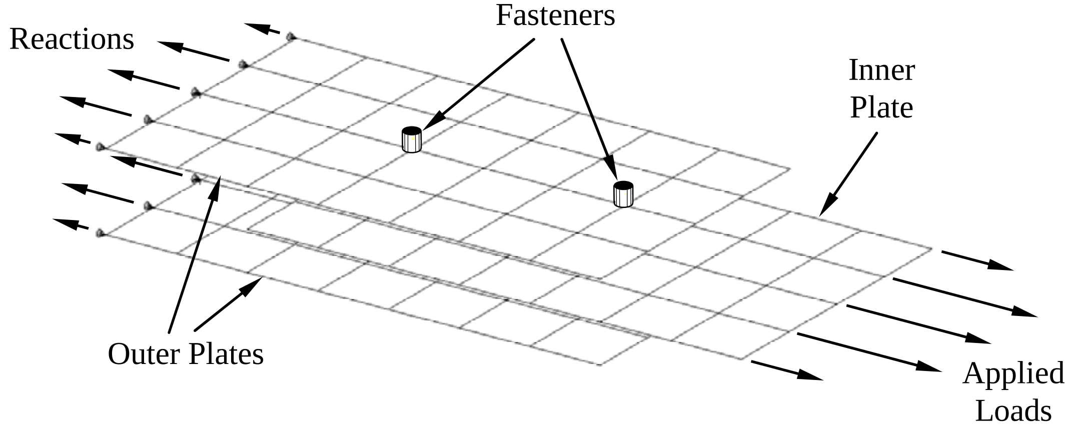


Figure 15. Example 1 – Symmetric Double Shear Joint with Plates Modeled by Shell Elements.

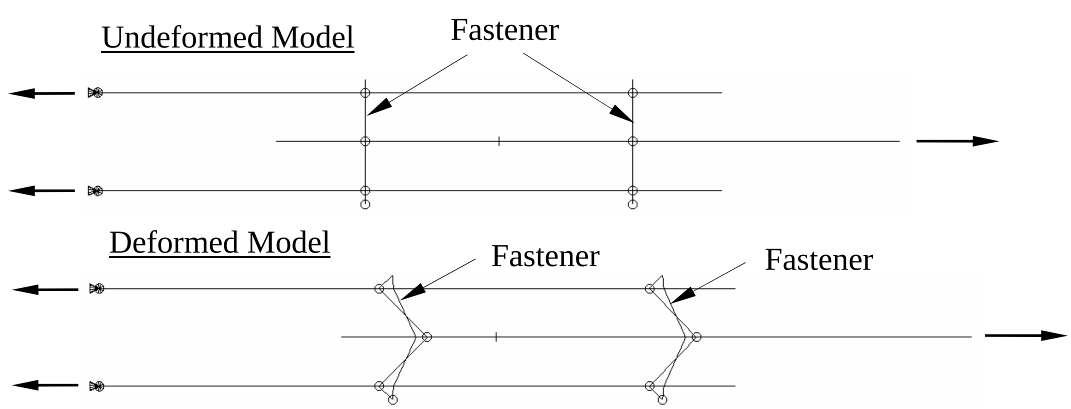


Figure 16. Example 1. Model Before and After Deformation.

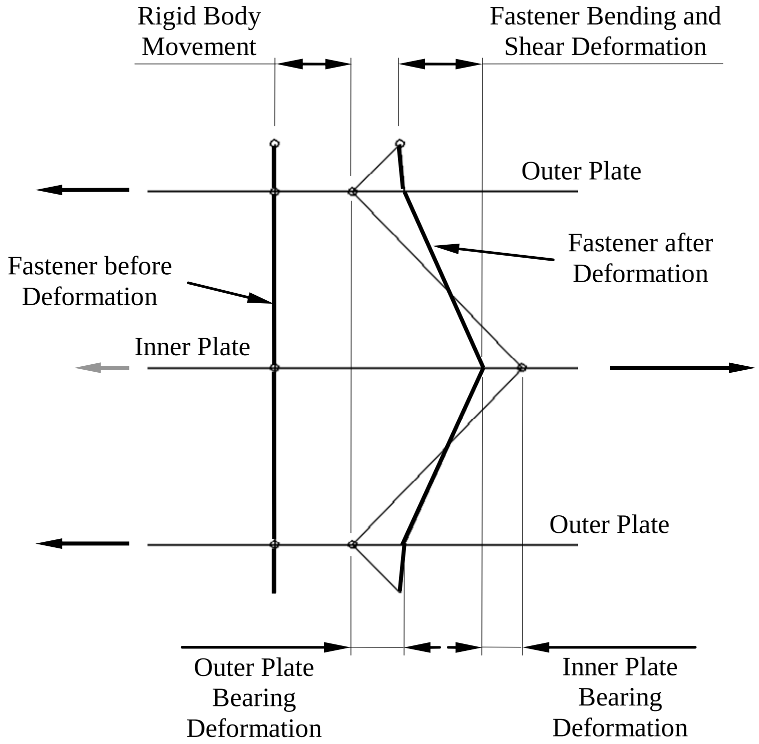


Figure 17. Example 1. Fastener Joint Deformation.

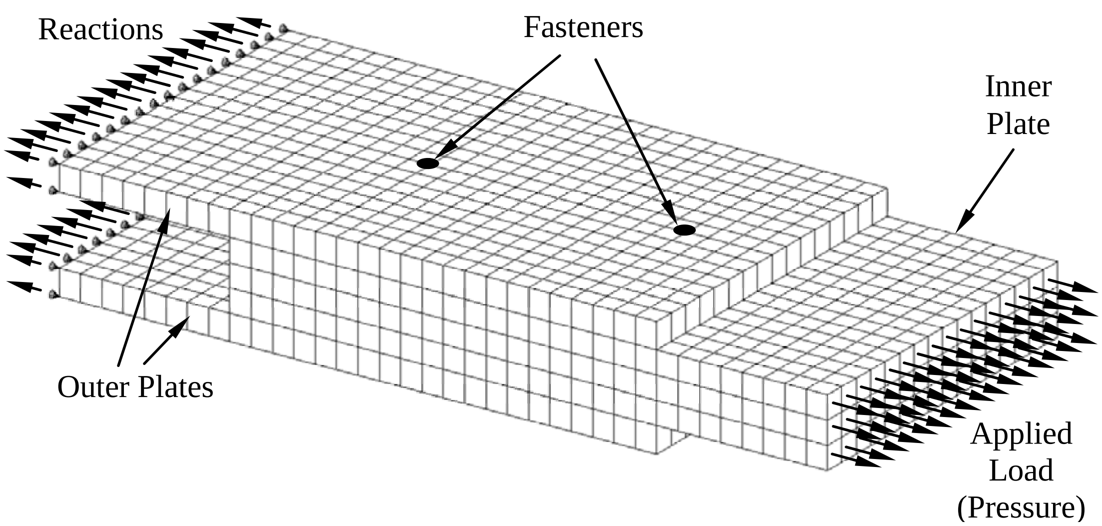


Figure 18. Example 2 – Symmetric Double Shear Joint with Plates Modeled by Solid Elements.

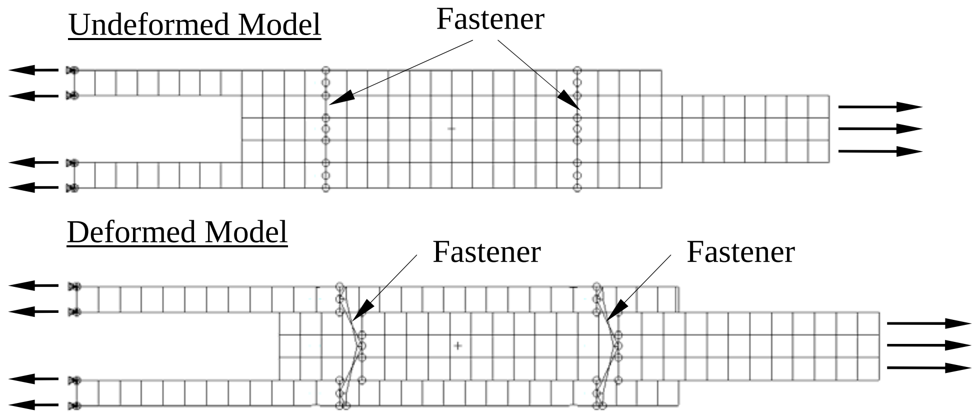


Figure 19. Example 2. Model Before and After Deformation.

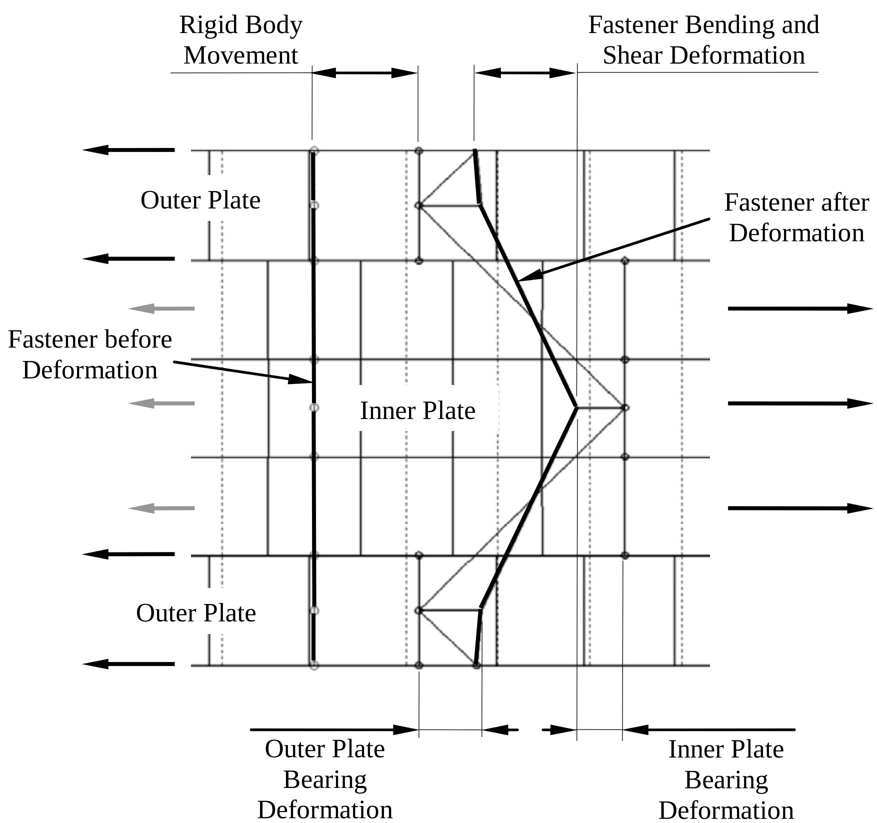


Figure 20. Example 2. Fastener Joint Deformation.

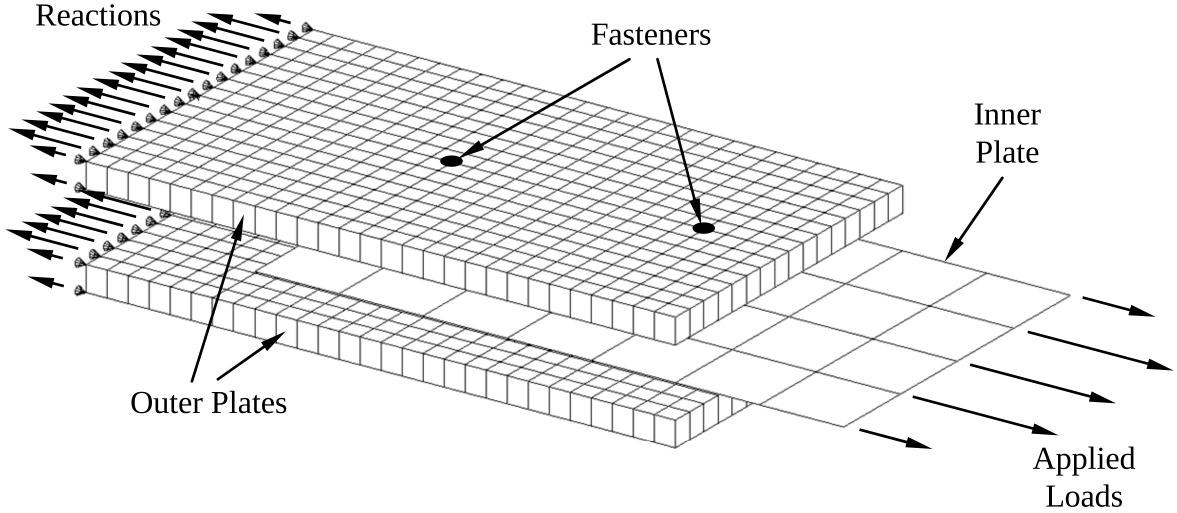


Figure 21. Example 3 – Symmetric Double Shear Joint with Outer Plates Modeled by Solid Elements and Inner Plate Modeled by Shell Elements.

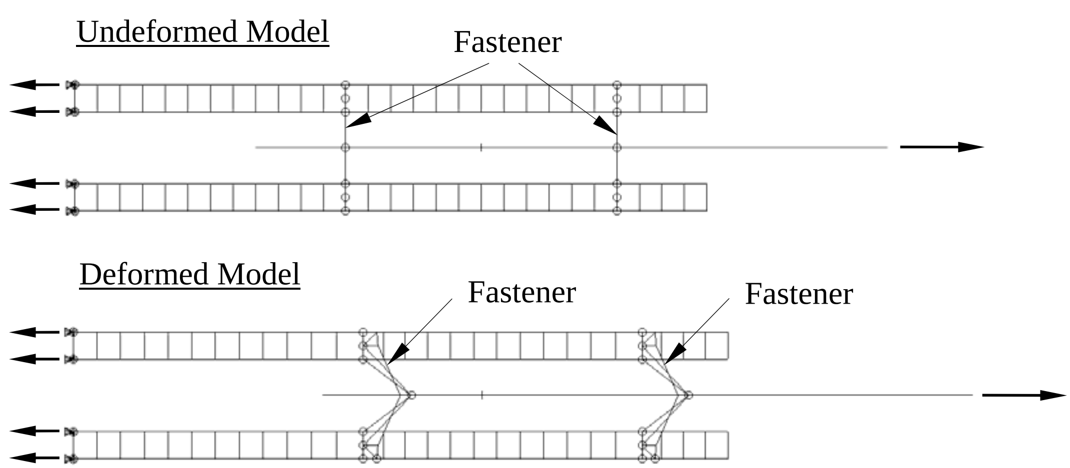


Figure 22. Example 3. Model Before and After Deformation.

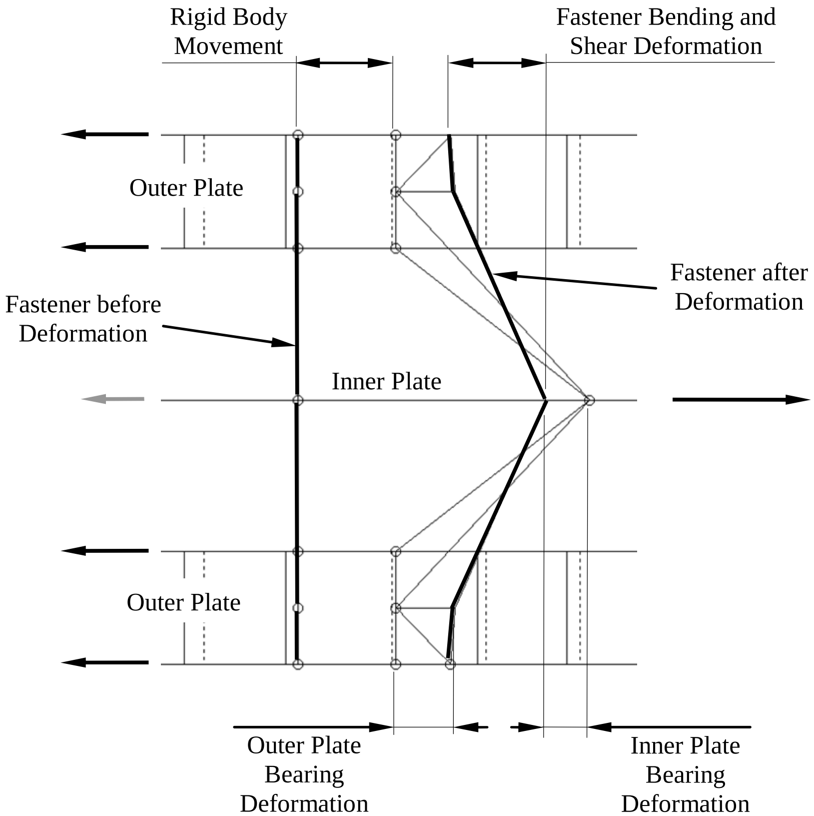


Figure 23. Example 3. Fastener Joint Deformation.

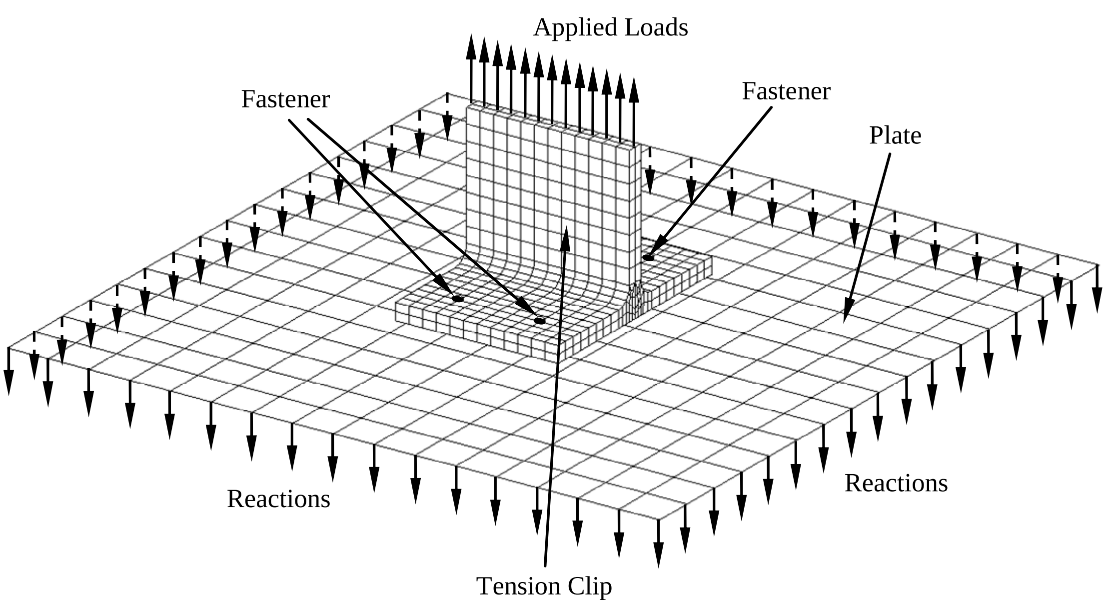


Figure 24. Example 4 – Attachment of Tension Clip Modeled by Solid Elements to Plate Modeled by Shell Elements.

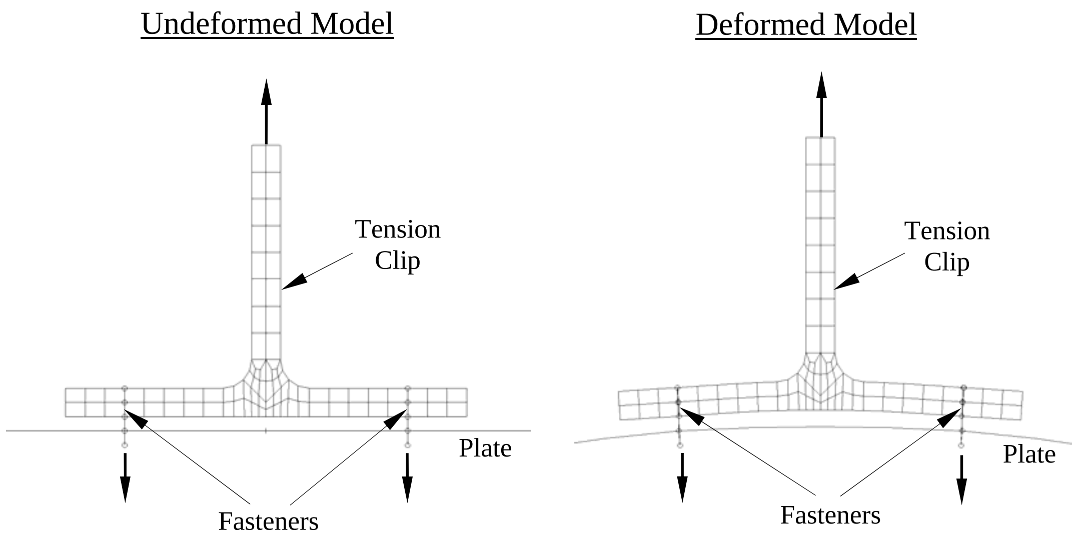


Figure 25. Example 4. Model Before and After Deformation.

5. Patran Utility.

To automate the creation of a fastener joint model, the Patran utility was developed. The input form for the utility is shown in Figure 26. This form has following section where the data necessary for modeling of a fastener joint is defined:

- Element and node ID control.

  The starting ID of the new nodes and elements can be selected, as it is usually done in majority of input forms.

- Definition of the group, to which all fastener joint entities will be added.

- Fastener parameters definition:
  - Fastener shank diameter.
  - Grip length.
  - Fastener material – This button opens a subform for a material selection for the fastener.
  - Modeling of joined plates contact – rigid elements or linear gaps.
  - Definition of symmetry condition [1]:
    - 1.0 - for fasteners not located on the model symmetry planes,
    - 0.5 - for fasteners belonging to one plane of symmetry,
    - 0.25 - for fasteners located on the intersection of symmetry planes.

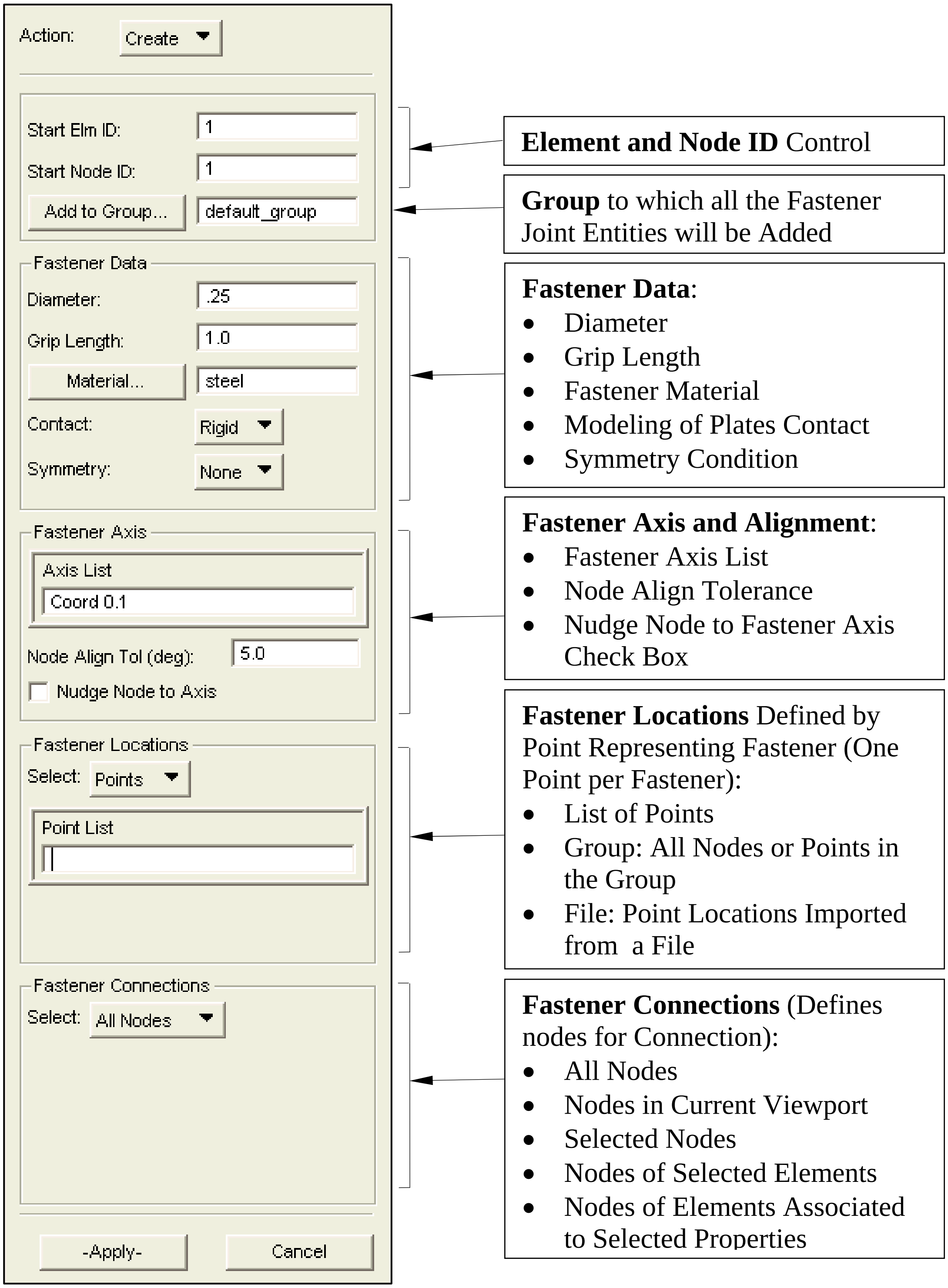


Figure 26. Patran Utility Input Form.

- Fastener axis definition and nodes alignment:
    - Axis list – Defines existing coordinate system ID and coordinate axis parallel to the fastener axis,
    - Nodes align tolerance – Nodes within this tolerance will be considered as possible part of the fastener joint,
    - Nudge node to fastener axis check box – If the box is checked the selected nodes that do not locate on the fastener axis will be moved (projected) to the axis.
- Fastener locations – Defined by point representing the fastener (one point per fastener). Points can be specified as:
    - Point list – This includes geometric points, nodes, *xyz* locations, etc.,
    - Group – All points or nodes in the group will be considered as fastener locations,
    - File - Point locations will be imported from a file.
- Fastener connection – Defines the nodes that will be considered for connection by fastener joint. Nodes can be specified as:
    - All nodes - All nodes in the database will by considered,
    - Current viewport - All nodes in the current viewport will be considered,
    - Nodes - Only selected nodes will be considered,
    - Elements - Nodes associated to selected elements will be considered,
    - Properties - Nodes associated to elements associated to selected property sets.

6. Conclusion.

The modeling techniques described above for connected parts represented by shell and solid elements reflects the entire fastener joint behavior including bending, shear, and bearing flexibility and compatibility of displacements in the joint. The modeling approach is presented in terms of MSC.Nastran using CBAR, CBUSH, RBAR, and RBE2 elements and the linear gap techniques; however, it can be applied to another finite element code with similar elements.

Acknowledgement

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