Overview of Contact in Abaqus

1. Contact Mechanics

In general contact is the study of deformable bodies that touch each other at least one point in the space. A 3D object may contact on a (or a series of) shared point(s) or surface(s). Contact mechanics, developed based on the continuum mechanics and mechanics of materials, is a theory to describe pressure and adhesion (normal) and friction (tangential) stresses that arise during shared point/surface contact between deformable bodies.

Depending on the geometry and material properties of each deformable body, contact can be an extremely non-linear event. Analytical contact mechanics dates back to 1882 with the original work by Hertz which is mainly dealing with contact problem between elastic bodies. In many engineering applications, contact between elastic bodies is not a sufficient approach to deal with contact. In general, contacting pairs very often undergo non-linear plastic and permanent deformations (like in the metal forming), and thus contact problems are mostly solved numerically (computational approach).

Computational modeling of contact is a very challenging topic and many research works are still being performed in this field. Proper modeling of contact problems requires significant knowledge/experience from the modeler. Fortunately, Abaqus comes with a selection of the state-of-the-art computational algorithms to deal with contact problems that require minimum user input. In the sequel, only a very brief introduction to contact modeling in Abaqus is provided and readers are strongly encouraged to inquire Abaqus documentation for further understanding.
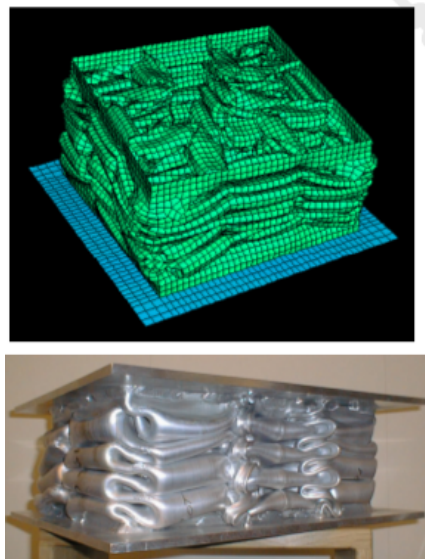

Fig 1- Application of contact mechanics in modeling crushing of aluminum extrusion (Courtesy of Alcan Mass Transportation Systems, Zurich)

2. Types of Contact

In Abaqus/Standard contact is defined by:
- General Contact: with a single interaction definition, contact is enforced over many or all regions of a model
- Contact Pairs: only contact between two surfaces can be described

- Contact elements

Each approach in the modeling of contact has its on advantages and limitations. General contact is a more versatile method to deal with contact since contact between disconnected regions of the bodies can be described with a single interaction. Contact pair requires more careful definition of contacting surfaces and has many restrictions on the types of surfaces involved.
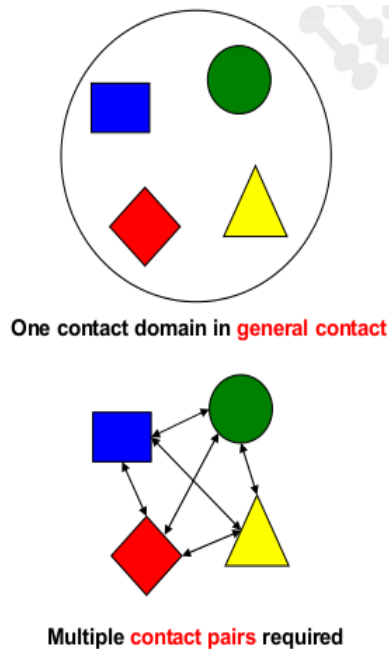

Fig 2- General contact and contact pairs in Abaqus.

3. Surface-based Contact Definition

Despite contact definition type, a contact problem in Abaqus requires
- definition of bodies that may potentially be in contact
- definition of surfaces that interact during contact (contact interactions)
- definition of the properties of surfaces in contact with each other
- additional contact properties including mechanical properties (friction) and thermal properties (contact conduction coefficient)
- an algorithm to control contact interaction during the simulation

In many applications, user can use default Abaqus settings for each item listed above to minimize convergence problems.

3.1. Surfaces

Contact surfaces can be defined at the beginning or during a restart analysis. Abaqus/Standard uses these types of surfaces for contact:
- Element-based deformable and rigid surfaces
- Node-based deformable and rigid surfaces
- Analytical rigid surfaces

3.1.1 Selection of Master and Slave Surfaces

In Abaqus, user must define a master and a slave surface for each contact pair. In general, what differentiates master and slave surface from each other are following:
- Nodes on slave surface can not penetrate the master surface
- Analytical rigid surfaces and rigid element-based surfaces must always be master surface
- A node-based surface can act only as a slave surface and always uses node-to-surface contact
- Both surfaces in a contact pair cannot be rigid surfaces with the exception of deformable surfaces defined as rigid
- Generally, if a smaller surface contacts a larger surface, it is best to choose the smaller surface as the slave surface
- Master surfaces should be smooth
- The slave surface should be more finely meshed
- For same mesh density, slave surface should be selected such that it has lower stiffness
- If the two surfaces are on structures with comparable stiffness, master surface should be selected as the surface with the coarser mesh
- The stiffness of the structure and not just the material should be considered when choosing the master and slave surface. For example, a thin sheet of metal may be less stiff than a larger block of rubber even though the steel has a larger modulus than the rubber material
- If the stiffness and mesh density are the same on both surfaces, the preferred choice is not always obvious

Despite above the deformable surfaces should be meshed fine enough to interact with any surface feature on the rigid surfaces. In a general contact domain the master and slave roles are assigned to surfaces automatically, although it is possible to override these default assignments.
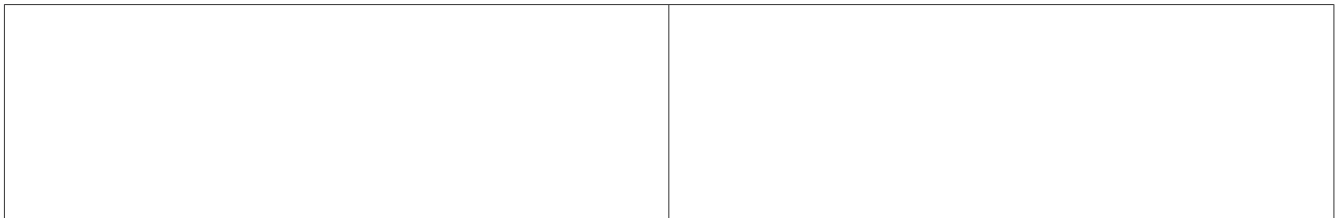

Fig 3- Definition of master and slave surfaces (left),

3.2. Contact Interactions
For contact pairs and general contact, contact interactions can be pairs of surfaces and/or at least a self-contacting surface. Using general contact approach, it is possible to define a single self-contacting surface for all bodies involved in contact which allow an easy and powerful method to define contact. In contact interaction definition, user should notice that:
- At least one surface in an interaction must be a non-node-based surface
- At least one surface in an interaction must be a non-analytical rigid surface

3.3. Surface Properties
Allows for defining non-default surface properties such as thickness and offset for particular surfaces in a contact model. In general contact method this feature can not be assigned to analytical rigid surfaces and it generally controls:
- Geometric corrections for regions of a surface: By default, contact calculations are based on

unsmoothed, faceted representations of the finite element surfaces in a general contact domain. An optional contact smoothing technique simulates a more realistic representation of curved surfaces in the contact calculations, resulting in improved contact stress and pressure accuracy.

- Surface thickness: can be used to change the contact thickness used for regions of a surface based on structural elements or to add a contact thickness for regions of a surface based on solid elements
- Offset: can be used to specify surface offsets for regions of a surface based on shell, membrane, rigid, and surface elements

3.4. Contact Properties

Contact properties for contacting surface(s) are analogous to element property in used in Abaqus. By default, the surfaces interact only in normal direction to resist penetration, however depending on the choice of contact algorithm the method of solution (Standard/Explicit) these properties are also available:

- Contact pressure-overclosure: described with more details in the next section
- Contact damping: to describe relative motion between the interacting surfaces
- Friction: to define relationship between normal and shear forces transmitted over contacting surfaces.
- User-defined constitutive model for surface interactions
- Spot welds boding two surfaces together
- Other: thermal, thermal-electrical and pore-fluid surface interactions

3.4.1 Contact Pressure-Overclosure

Following contact pressure-overclosure relationships can be used to define the contact model in Abaqus:

- The "hard" contact relationship minimizes the penetration of the slave surface into the master surface at the constraint locations and does not allow the transfer of tensile stress across the interface

- A "softened" contact relationship in which the contact pressure is a linear function of the clearance between the surfaces

- A "softened" contact relationship in which the contact pressure is an exponential function of the clearance between the surfaces (in Abaqus/Explicit this relationship is available only for the contact pair algorithm)

- A "softened" contact relationship in which a tabular pressure-overclosure curve is constructed by progressively scaling the default penalty stiffness (available only for general contact in Abaqus/Explicit)

- A "softened" contact relationship in which the contact pressure is a piecewise linear (tabular) function of the clearance between the surfaces

- A relationship in which there is no separation of the surfaces once they contact

3.5. Contact Formulation

Abaqus/Standard provides several contact formulations. Each contact formulation is automatically selected (or may be altered by user) based on

- Choice of contact discretization: node-to-surface contact discritization and surface-to-surface contact discretization
- Tracking approach: have considerable impact on how contact surfaces interact and selected to be:
  - Finite sliding: most general case
  - Small sliding: despite the state of deformation assumes little sliding between contact pairs is assumed
- Assignment of master and slave roles to contact surfaces.

General contact algorithm in Abaqus/Standard uses finite-sliding, surface-to-surface contact formulation by default.

3.5.1 Contact Discretization

Abaqus/Standard uses conditional constraints to enforce contact between interacting surfaces. The location and conditions of these constraints may vary based on the type of contact discretization. In traditional node-to-surface discretization each slave node interacts with a point of projection on the master surface on the opposite side of the contact interface (a single slave node interacts with a group of master nodes) with following characteristics:

- Slave nodes are constrained not to penetrate master surface
- Nodes of master surface can, in principle, penetrate into the slave surface.
- Contact direction is selected based on the normal of master surface
- only information needed for a slave surface node are i) its location, and ii) surface area associated to it. Thus, the slave surface can be defined as a group of nodes—a node-based surface.
- Node-to-surface discretization is available even if a node-based surface is not used in a contact pair definition

In surface-to-surface contact discretization the shape of both master and slave surfaces are considered, therefore it provides more accurate results than node-to-surface discretization. In surface-to-surface discretization:

- contact conditions are enforced in an average sense over regions nearby slave nodes rather than only at individual slave nodes.
- the averaging regions are approximately centered on slave nodes, so each contact constraint will predominantly consider one slave node but will also consider adjacent slave nodes.
- some penetration may be observed at individual nodes; however, large, undetected penetrations of master nodes into the slave surface do not occur
- the contact direction is based on an average normal of the slave surface in the region surrounding a slave node
- is not applicable if a node-based surface is used in the contact pair definition
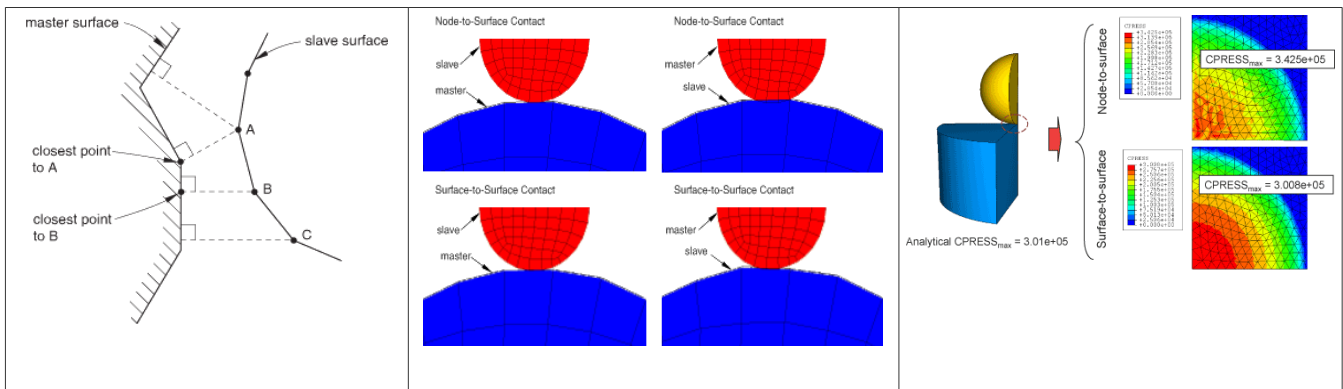
Fig 4- Node-to-surface contact discretization (left), Comparison of contact enforcement for different master-slave assignments with node-to-surface and surface-to-surface contact discretizations (middle), and Comparison of contact pressure accuracy for node-to-surface and surface-to-surface contact discretizations (right)

3.5.2 Contact Tracking

Finite sliding is the most general tracking approach. This method allows for arbitrary separation, sliding, and rotation of the contacting surfaces. In this method, the connectivity of the currently active contact constraints changes upon relative motion of the contacting surfaces. Small sliding method uses a linearized approximation of the master surface per constraint and therefore allows for little relative sliding of the surfaces. The groups of nodes involved with individual contact constraints are fixed throughout the analysis for small-sliding contact, although the active/inactive status of these constraints typically can change during the analysis. This approach should be considered when the approximations are reasonable, due to computational savings and added robustness.

4. Selection Chart

The choice of contact discretization and tracking approach may have considerable impact on an analysis. Table 1 provided general guidelines on the selection of appropriate formulation during contact modeling.

Table 1- Comparison of contact formulation characteristics.

Characteristic	Contact formulation			
	Node-to-surface		Surface-to-surface	
	Finite-sliding	Small-sliding	Finite-sliding	Small-sliding
Account for shell thickness by default	No	Yes	Yes	Yes
Allow self-contact	Yes	No	Yes	No
Allow double-sided surfaces	Slave surface only	Slave surface only	Yes	Yes
Surface smoothing by default	Some smoothing of master surface	Yes for anchor points; each constraint uses flat approximation of master surface	No	No for anchor points; each constraint uses flat approximation of master surface
Default constraint enforcement method	Augmented Lagrange method for 3D self-contact; otherwise, direct method	Direct method	Penalty method	Direct method
Ensure moment equilibrium for offset reference surfaces with friction	No	No	Yes	Yes

5. References
1- Abaqus 6.13 Documentation