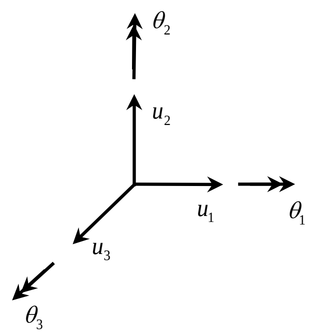
Section 1 Node and DOF

Nodes and elements determine the size and shape of the finite element model and are the starting point of all analyses. A model defined by nodes and elements is the same as physical phenomena expressed using numerical equations in matrix form. The variables that affect the matrix equation are displacement, rotation, pore pressure and other physical quantities, which are called degrees of freedom (DOF).

For example, a structural analysis problem is assigned 3 displacements and 3 rotational DOFs. These 6 DOFs are as follows.

Figure 2.1.1 Displacement and Rotation DOFs on the rectangular coordinate system



Each DOF is generally expressed using the following signs:

$\text{DOF } 1 = T_1 = u_1$, $\text{DOF } 2 = T_2 = u_2$, $\text{DOF } 3 = T_3 = u_3$

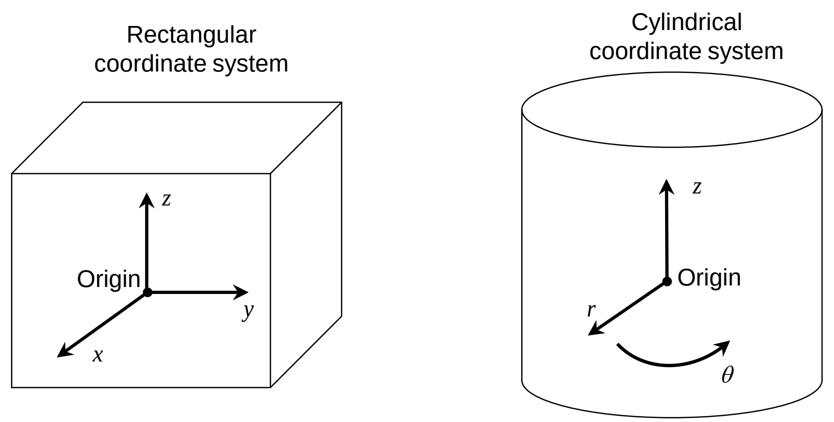
$\text{DOF } 4 = R_1 = \theta_1$, $\text{DOF } 5 = R_2 = \theta_2$, $\text{DOF } 6 = R_3 = \theta_3$

Each node has a coordinate system that describes the direction of motion. This is called the nodal displacement coordinate system. All DOFs mentioned above follow the coordinate system direction assigned to the nodes, and all nodes describe the direction of motion with reference to the global coordinate system. The pore pressure DOF does not have a direction and hence, it is unrelated to the nodal displacement coordinate system.

Section 2 Coordinate System

Various coordinate systems are needed to use the finite element method to appropriately model and correctly analyze the given problem. For example, a coordinate system is needed to define the nodal displacement direction outlined above and to set the direction for transversely isotropic materials. A particular coordinate system is also specified for result value extraction. The rectangular coordinate system and cylindrical coordinate system are both available on GTS NX.

Figure 2.2.1 Rectangular coordinate system and cylindrical coordinate system



For example, if the nodal motion direction is defined about a cylindrical coordinate system, the DOFs are as follows.

DOF 1 = translation in r -direction
DOF 2 = translation in θ -direction
DOF 3 = translation in z -direction
DOF 4 = rotation in r -direction
DOF 5 = rotation in θ -direction
DOF 6 = rotation in z -direction

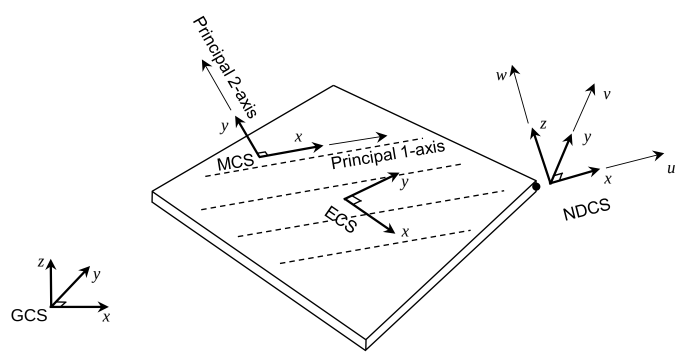
GTS NX uses the following coordinate systems for ground or structural modeling and analysis.

Table 2.2.1 Major coordinate systems on the GTS NX

Type of coordinate system	Explanation
GCS : global coordinate system	Coordinate system that expresses the entire model using the same standard. Rectangular coordinate system
NDCS : nodal displacement coordinate system	Coordinate system that describes the nodal motion direction. Rectangular/Cylindrical coordinate system
ECS : element coordinate system	Coordinate system determined by the position of the nodes that make up the element. Rectangular coordinate system
MCS : material coordinate system	Coordinate system that defines the direction of the material applied on the element. Rectangular/Cylindrical coordinate system
ERCS : element result coordinate system	Coordinate system that prints the element results. Rectangular/Cylindrical coordinate system
EFCS : element formulation coordinate system	Coordinate system used for finite element formulation. Same as GCS or element coordinate system

Here, the EFCS is used in the solver and, although it may not be directly related to the instructions for the GTS NX, it provides a better understanding of the materials of this manual. Also, the MCS and ERCS can affect the analysis and results. Detailed information on the ECS, MCS and ERCS are provided in Chapter 3.

Figure 2.2.2 Various coordinate systems on the GTS NX



Section 3 Finite Rotation Simulation

Geometric nonlinear analysis that includes finite rotation needs a variable for rotation. GTS NX uses the rotation vector as a DOF of a particular node to describe finite rotation. In other words, the result values for nodal DOF 4~6 on the geometric nonlinear analysis results are each components of the rotation vector. The rotation vector $\boldsymbol{\theta}$ has a size $\|\boldsymbol{\theta}\|$ and direction $\mathbf{e} = \boldsymbol{\theta} / \|\boldsymbol{\theta}\|$. Expressing this in physical terms, the rotation vector $\boldsymbol{\theta}$ rotates about the axis $\mathbf{e}$ by an angle $\|\boldsymbol{\theta}\|$ (radian) as shown in Figure 2.3.1

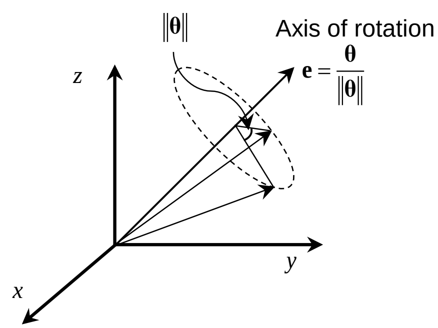


Figure 2.3.1 Direction and size of a rotation vector

Be aware that a compound rotation, which applies multiple rotation vectors continuously, does not consist of the sum of each vector for finite rotations. For example, if a rotation of $\Delta\boldsymbol{\theta}$ is continuously applied after $\boldsymbol{\theta}$, the final rotation value $\boldsymbol{\theta}^*$ has a property of $\boldsymbol{\theta}^* \neq \boldsymbol{\theta} + \Delta\boldsymbol{\theta}$. Also, because the commutative law does not apply, applying $\Delta\boldsymbol{\theta}$ and $\boldsymbol{\theta}$ in reversed order creates a different rotation value, as shown in figure 2.3.2. Various methods such as a rotation matrix can be used to calculate compound rotations, but the GTS NX uses the quaternion product. The quaternion q has the following relationship the rotation vector $\boldsymbol{\theta}$:

$$q = (q_0, \mathbf{q}) = (\cos(\|\boldsymbol{\theta}\| / 2), \sin(\|\boldsymbol{\theta}\| / 2)\mathbf{e}) \tag{2.3.1}$$

The product of two quaternions can be calculated using the following equation:

$$q^* = \Delta q \circ q = (\Delta q_0 q_0 - \Delta\mathbf{q} \cdot \mathbf{q},\ \Delta q_0 \mathbf{q} + q_0 \Delta\mathbf{q} + \Delta\mathbf{q} \times \mathbf{q}) \tag{2.3.2}$$

q^* : Quaternion corresponding to $\boldsymbol{\theta}^*$

Δq : Quaternion corresponding to $\Delta \boldsymbol{\theta}$

Figure 2.3.2 Example of compound rotations that do not satisfy the commutative law