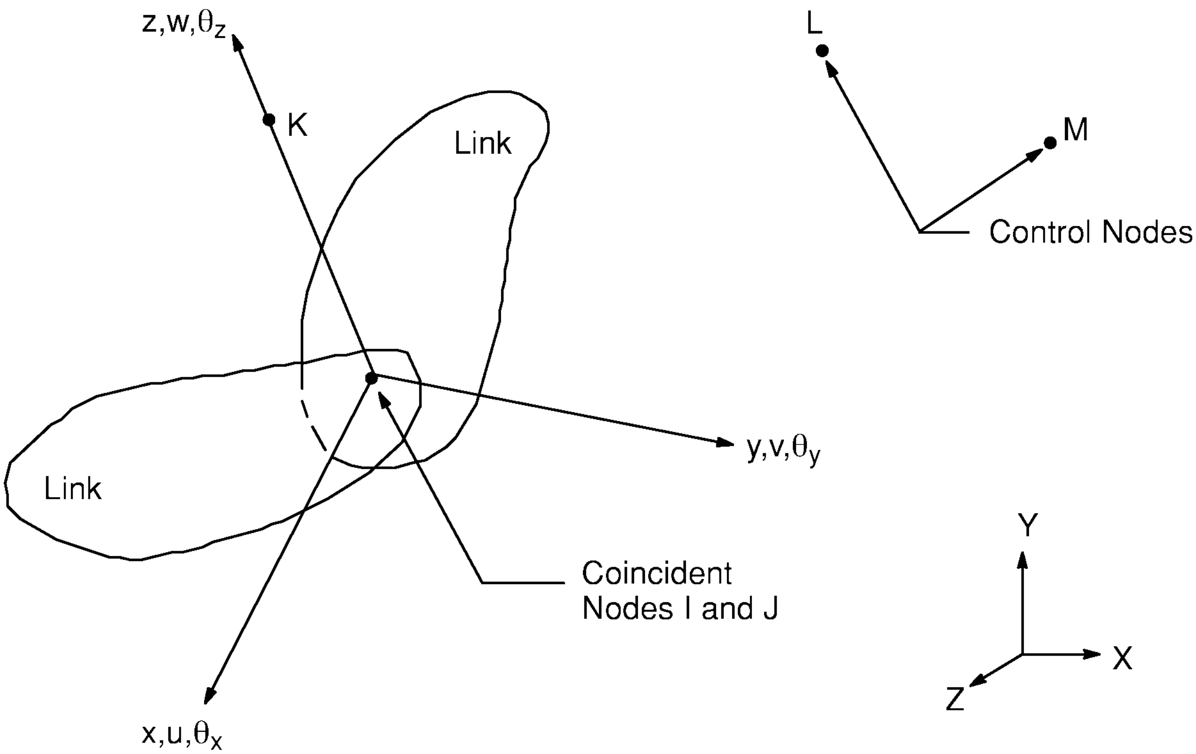
14.7 COMBIN7 — Revolute Joint



Matrix or Vector	Shape Functions	Integration Points
Stiffness Matrix	None (nodes should be coincident)	None
Mass Matrix	None (lumped mass formulation)	None
Damping Matrix	None	None
Load Vector	None	None

14.7.1 Element Description

COMBIN7 is a 5–node, 3–D structural element that is intended to represent a pin (or revolute) joint. The pin element connects two links of a kinematic assemblage. Nodes I and J are active and physically represent the pin joint. Node K defines the initial (first iteration) orientation of the moving joint coordinate system (x, y, z), while nodes L and M are control nodes that introduce a certain level of feedback to the behavior of the element.

In kinematic terms, a pin joint has only one primary DOF, which is a rotation (θ_z) about the pin axis (z). The joint element has six DOFs per node (I and J) : three translations (u, v, w) and three rotations (θ_x, θ_y, θ_z) referenced to element coordinates (x, y, z). Two of the DOFs (θ_z for nodes I and J) represent the pin rotation. The remaining 10 DOFs have a relatively high stiffness (see below). Among other options available are rotational limits, feedback control, friction, and viscous damping.

Flexible behavior for the constrained DOF is defined by the following input quantities:

K_1 = spring stiffness for translation in the element x–y plane (input as K1 on **R** command)

K_2 = spring stiffness for translation in the element z direction (input as K2 on **R** command)

K_3 = spring stiffness for rotation about the element x and y axes (input as K3 on **R** command)

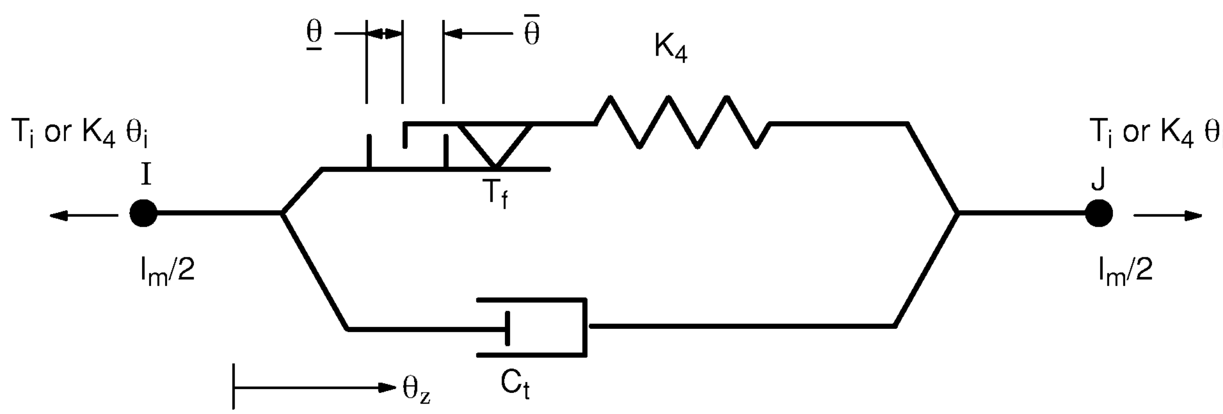


Figure 14.7–23 Joint Element Dynamic Behavior About the Revolute Axis

The dynamics of the primary DOF (θ_z) of the pin is shown in Figure 14.7–23. Input quantities are:

K_4 = rotational spring stiffness about the pin axis when the element is “locked” (input as K4 on **R** command)

T_f = friction limit torque (input as TF on **R** command)

C_t = rotational viscous friction (input as CT on **R** command)

T_i = imposed element torque (input as TLOAD on **RMORE** command)

$\underline{\theta}$ = reverse rotation limit (input as STOPL on **RMORE** command)

$\overline{\theta}$ = forward rotation limit (input as STOPU on **RMORE** command)

θ_i = imposed (or interference) rotation (input as ROT on **RMORE** command)

I_m = joint mass (input as MASS on **RMORE** command)

A simple pin can be modeled by merely setting $K_4 = 0$, along with $K_i > 0$ (i = 1 to 3). Alternately, when $K_4 > 0$, a simple pin is formed with zero friction ($T_f = 0$). The total differential rotation of the pin is given by:

$$\theta_t = \theta_{zJ} - \theta_{zI} \tag{14.7–1}$$

When friction is present ($T_f > 0$), this may be divided into two parts, namely:

$$\theta_t = \theta_f + \theta_K \tag{14.7–2}$$

where:
θ_f = the amount of rotation associated with friction
θ_K = the rotation associated with the spring (i.e., spring torque /K_4)

One extreme condition occurs when $T_f = 0$, and it follows that $\theta_K = 0$ and $\theta_t = \theta_f$. On the other hand, when a high level of friction is specified to the extent that the spring torque never exceeds T_f, then it follows that $\theta_f = 0$ and $\theta_t = \theta_K$. When a negative friction torque is specified ($T_f < 0$), the pin axis is "locked" (or stuck) with revolute stiffness K_4. The pin also becomes locked when a stop is engaged, that is when:

$$\theta_f \geq \overline{\theta} \text{ (forward stop engaged)} \tag{14.7–3}$$

$$\theta_f \leq -\underline{\theta} \text{ (reverse stop engaged)} \tag{14.7–4}$$

Stopping action is removed when $\underline{\theta} = \overline{\theta} = 0$.

Internal self–equilibrating element torques are imposed about the pin axis if either T_i or θ_i are specified. If T_i is specified, the internal torques applied to the active nodes are:

$$T_J = -T_I = T_i \tag{14.7–5}$$

If a local rotation θ_i is input, it is recommended that one should set $T_f < 0$, $K_4 > 0$, and $T_i = 0$. Internal loads then become

$$T_J = -T_I = K_4\theta_i \tag{14.7–6}$$

Element Matrices

For this element, nonlinear behavior arises when sliding friction is present, stops are specified, control features are active, or large rotations are represented.

As mentioned above, there are two active nodes and six DOFs per node. Thus, the size of the element mass, damping, and stiffness matrices is 12 x 12, with a 12 x 1 load vector.

The stiffness matrix is given by:

$$[K] = \begin{bmatrix} K_1 & 0 & 0 & 0 & 0 & 0 & -K_1 & 0 & 0 & 0 & 0 & 0 \\ & K_1 & 0 & 0 & 0 & 0 & 0 & -K_1 & 0 & 0 & 0 & 0 \\ & & K_2 & 0 & 0 & 0 & 0 & 0 & -K_2 & 0 & 0 & 0 \\ & & & K_3 & 0 & 0 & 0 & 0 & 0 & -K_3 & 0 & 0 \\ & & & & K_3 & 0 & 0 & 0 & 0 & 0 & -K_3 & 0 \\ & & & & & K_p & 0 & 0 & 0 & 0 & 0 & -K_p \\ & & & & & & K_1 & 0 & 0 & 0 & 0 & 0 \\ & & \text{Symmetry} & & & & & K_1 & 0 & 0 & 0 & 0 \\ & & & & & & & & K_2 & 0 & 0 & 0 \\ & & & & & & & & & K_3 & 0 & 0 \\ & & & & & & & & & & K_3 & 0 \\ & & & & & & & & & & & K_p \end{bmatrix} \quad (14.7\text{–}7)$$

where:

$$K_p = \begin{cases} K_4, & \begin{cases} \text{if } \theta_f \geq \overline{\theta} \text{ or } \theta_f \leq -\underline{\theta} \text{ and both } \overline{\theta} \text{ and } \underline{\theta} \neq 0 \text{ (stop engaged);} \\ \text{or } T_f < 0 \text{ (locked);} \\ \text{or } K_4\theta_K < T_f \text{ (not sliding)} \end{cases} \\ 0, & \text{if } -\underline{\theta} < \theta_f < \overline{\theta} \text{ and } K_4\theta_K \geq T_f \geq 0 \text{ (sliding)} \end{cases}$$

The mass matrix is lumped and given by:

$$[M] = \frac{1}{2}\begin{bmatrix} M & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & M & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & M & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & I_m & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & I_m & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & & I_m & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & & & M & 0 & 0 & 0 & 0 & 0 \\ & & \text{Symmetry} & & & & & M & 0 & 0 & 0 & 0 \\ & & & & & & & & M & 0 & 0 & 0 \\ & & & & & & & & & I_m & 0 & 0 \\ & & & & & & & & & & I_m & 0 \\ & & & & & & & & & & & I_m \end{bmatrix} \quad (14.7\text{–}8)$$

where: M = total mass (input as MASS on **RMORE** command)

I_m = total mass moment of inertia (input as IMASS on **RMORE** command)

The damping matrix, derived from rotational viscous damping about the pin axis, is given as:

$$[C] = C_t \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & & 1 & 0 & 0 & 0 & 0 & 0 & -1 \\ & & & & & & 0 & 0 & 0 & 0 & 0 & 0 \\ & & \text{Symmetry} & & & & & 0 & 0 & 0 & 0 & 0 \\ & & & & & & & & 0 & 0 & 0 & 0 \\ & & & & & & & & & 0 & 0 & 0 \\ & & & & & & & & & & 0 & 0 \\ & & & & & & & & & & & 1 \end{bmatrix} \quad (14.7\text{–}9)$$

The applied load vector for COMBIN7 is given by:

$$\{F\} = \lfloor 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; -(T_i + K_4\theta_i) \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; (T_i + K_4\theta_i) \rfloor^T \quad (14.7\text{–}10)$$

Modification of Real Constants

Four real constants (C_1, C_2, C_3, C_4) are used to modify other real constants for a dynamic analysis (**ANTYPE**,TRAN with **TRNOPT**,FULL). The modification is performed only if either $C_1 \neq 0$ or $C_3 \neq 0$ and takes the form:

$$R' = R + M \quad (14.7\text{–}11)$$

where:
- R' = modified real constant value
- R = original real constant value
- $M = \begin{cases} C_1 \, |C_v|^{C2} + C_3|C_v|^{C4} & \text{if KEYOPT(9)} = 0 \\ f_1\left(C_1, C_2, C_3, C_4, C_v\right) & \text{if KEYOPT(9)} = 1 \end{cases}$
- C_1, C_2, C_3, C_4 = input as C1, C2, C3 and C4 on **RMORE** command
- C_v = control value (defined below)
- f_1 = function defined by subroutine USERRC

By means of KEYOPT(7), the quantity R is as follows:

$$R = \begin{cases} K_1 & \text{if KEYOPT(7) = 0 to 1} \\ K_2 & \text{if KEYOPT(7) = 2} \\ K_3 & \text{if KEYOPT(7) = 3} \\ \vdots & \\ ROT & \text{if KEYOPT(7) = 13} \end{cases} \tag{14.7–12}$$

Negative values for R′ are set equal to zero for quantities T_f (KEYOPT(7)=6), $\underline{\theta}$ (KEYOPT(7)=11), and $\overline{\theta}$ (KEYOPT(7)=12).

The calculation for C_v depends on control nodes L and M, as well as KEYOPT(1), KEYOPT(3), and KEYOPT(4). The general formulation is given by:

$$C_v = \begin{cases} \Delta u, & \text{if KEYOPT(1) = 1 or 0} \\ \dfrac{d(\Delta u)}{dt}, & \text{if KEYOPT(1) = 2} \\ \dfrac{d^2(\Delta u)}{dt^2}, & \text{if KEYOPT(1) = 3} \\ \displaystyle\int_o^t \Delta u \; dt, & \text{if KEYOPT(1) = 1 or 0} \\ t, & \text{if KEYOPT(1) = 1 or 0} \end{cases} \tag{14.7–13}$$

in which t is time and Δu is determined from

$$\Delta u = \begin{cases} u_L - u_M, & \text{if KEYOPT(3)} = 0, 1 \\ v_L - v_M, & \text{if KEYOPT(3)} = 2 \\ w_L - w_M, & \text{if KEYOPT(3)} = 3 \\ \theta_{xL} - \theta_{xM}, & \text{if KEYOPT(3)} = 4 \\ \theta_{yL} - \theta_{yM}, & \text{if KEYOPT(3)} = 5 \\ \theta_{zL} - \theta_{zM}, & \text{if KEYOPT(3)} = 6 \end{cases} \tag{14.7–14}$$

If KEYOPT(4) = 0, then the DOFs above are in nodal coordinates. The DOFs are in the moving element coordinates if KEYOPT(4) = 1.