14.39   COMBIN39 — Nonlinear Spring
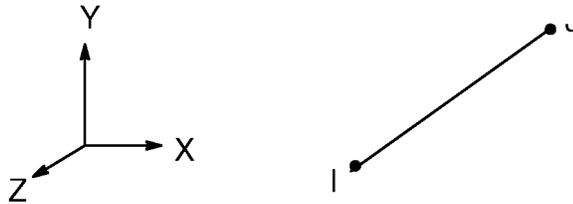
Matrix or Vector	Option	Shape* Functions	Integration Points
Stiffness Matrix	Longitudinal	Equation (12.2.2–1)	None
	Torsional	Equation (12.2.2–4)	None
Stress Stiffening Matrix	Longitudinal	Equations (12.2.1–2) and (12.2.1–3)	None

*   There are no shape functions used if the element is input as a one DOF per node basis (KEYOPT(4) = 0) as the nodes are coincident.

14.39.1   Input

The user explicitly defines the force–deflection curve for COMBIN39 by the input of discrete points of force versus deflection. Up to 20 points on the curve may be defined, and are entered as real constants. This input is illustrated in Figure 14.39–1. The input curve must pass through the origin and must lie within the unshaded regions, if KEYOPT(1) = 1.
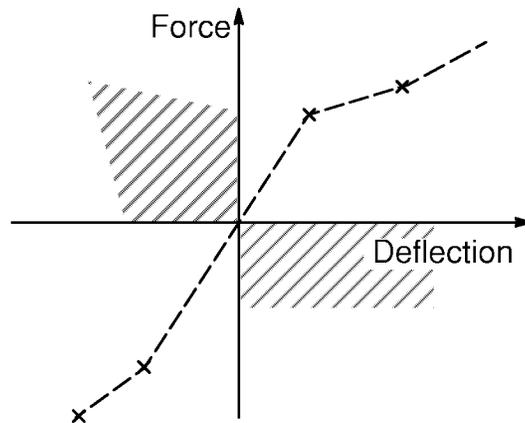
Figure 14.39–1 Input Force–Deflection Curve

The input deflections must be given in ascending order, with the minimum change of deflection of:

$$u_{i+1} - u_i > \Delta u_{min} \qquad (14.39-1)$$

where: u_{i+1} = input quantity D2, D3, ... D20 on **R** or **RMORE** commands, whichever applies

u_i = input quantity D1, D2, ... D19 on **R** or **RMORE** commands, whichever applies

Δu_{min} = $\dfrac{u_{max} - u_{min}}{10^7}$

u_{max} = most positive input deflection

u_{min} = most negative input deflection

14.39.2   Element Stiffness Matrix and Load Vector

During the stiffness pass of a given iteration, COMBIN39 will use the results of the previous iteration to determine which segment of the input force–deflection curve is active. The stiffness matrix and load vector of the element are then:

$$[K_c] = K^{tg} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \qquad (14.39-2)$$

$$\{F_e^{nr}\} = F_1 \begin{Bmatrix} 1 \\ -1 \end{Bmatrix} \qquad (14.39-3)$$

where: K^{tg} = slope of active segment from previous iteration (output quantity SLOPE)

$$F_1 \quad = \quad \text{force in element from previous iteration (output quantity FORCE)}$$

If KEYOPT(4) > 0, equations (14.39–2) and (14.39–3) are expanded to 2 or 3 dimensions.

During the stress pass, the deflections of the current equilibrium iteration will be examined to see whether a different segment of the force–deflection curve should be used in the next equilibrium iteration.
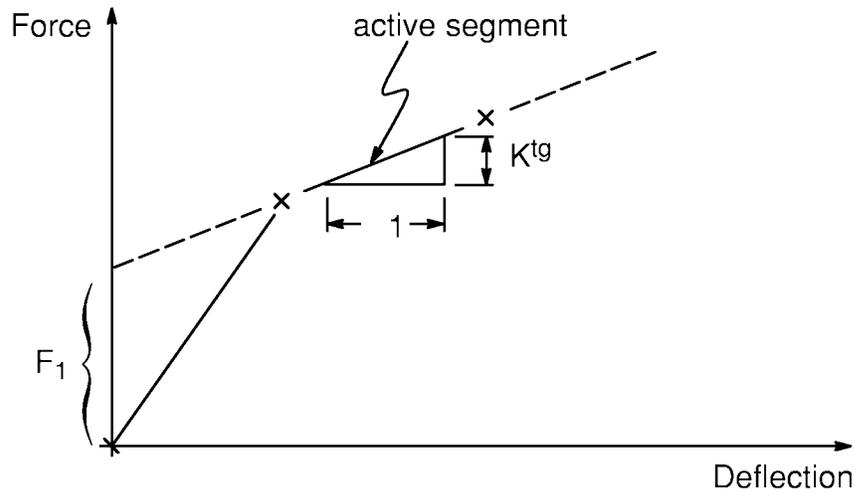

Figure 14.39–2 COMBIN39 – Stiffness Computation

14.39.3   Choices for Element Behavior

If KEYOPT(2) = 0 and if no force–deflection points are input for deflection less than zero, the points in the first quadrant are reflected through the origin (Figure 14.39–3).
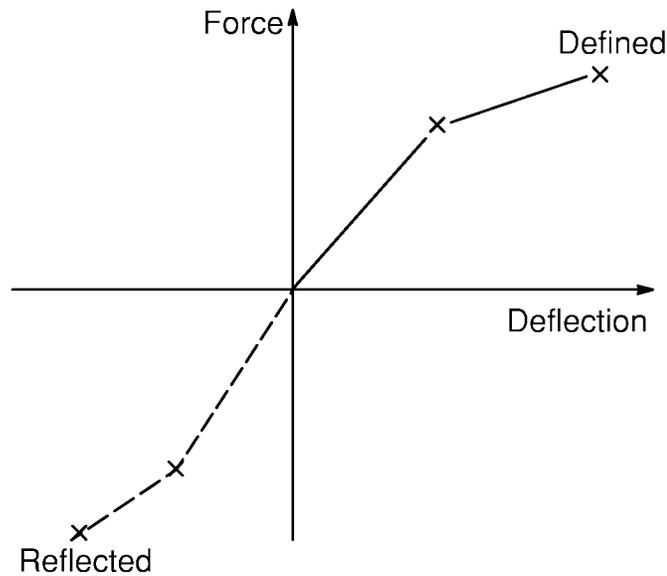
Figure 14.39–3 Input Force–Deflection Curve Reflected Through Origin

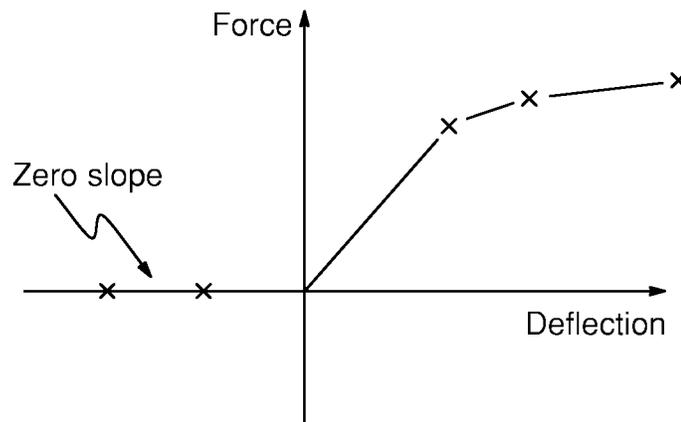If KEYOPT(2) = 1, there will be no stiffness for the deflection less than zero (Figure 14.39–4).

Figure 14.39–4 Force–Deflection Curve with KEYOPT(2) = 1

If KEYOPT(1) = 0, COMBIN39 is conservative. This means that regardless of the number of loading reversals, the element will remain on the originally defined force–deflection curve, and no energy loss will occur in the element. This also means that the solution is not path–dependent. If, however, KEYOPT(1) = 1, the element is nonconservative. With this option, energy losses can occur in the element, so that the solution is path–dependent. The resulting behavior is illustrated in Figure 14.39–5.
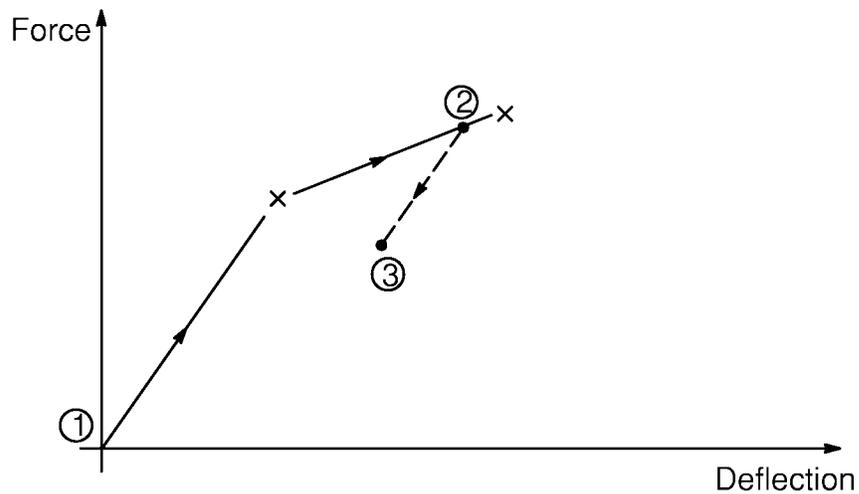
Figure 14.39–5 Nonconservative Unloading (KEYOPT(1) = 1)

When a load reversal occurs, the element will follow a new force–deflection line passing through the point of reversal and with slope equal to the slope of the original curve on that side of the origin (0+ or 0–). If the reversal does not continue past the force = 0 line, reloading will follow the straight line back to the original curve (Figure 14.39–6).
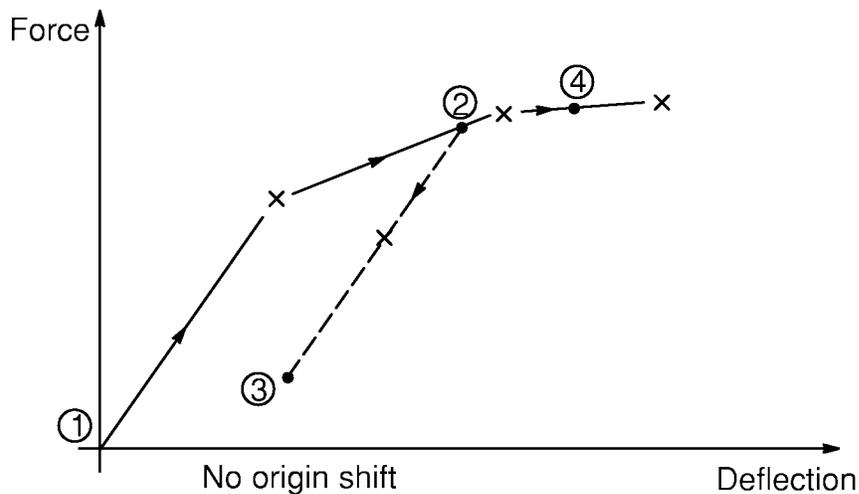

Figure 14.39–6 No Origin Shift on Reversed Loading (KEYOPT(1) = 1)

If the reversal continues past the force = 0 line, a type of origin shift occurs, and reloading will follow a curve that has been shifted a distance u_{orig} (output quantity UORIG) (Figure 14.39–7).
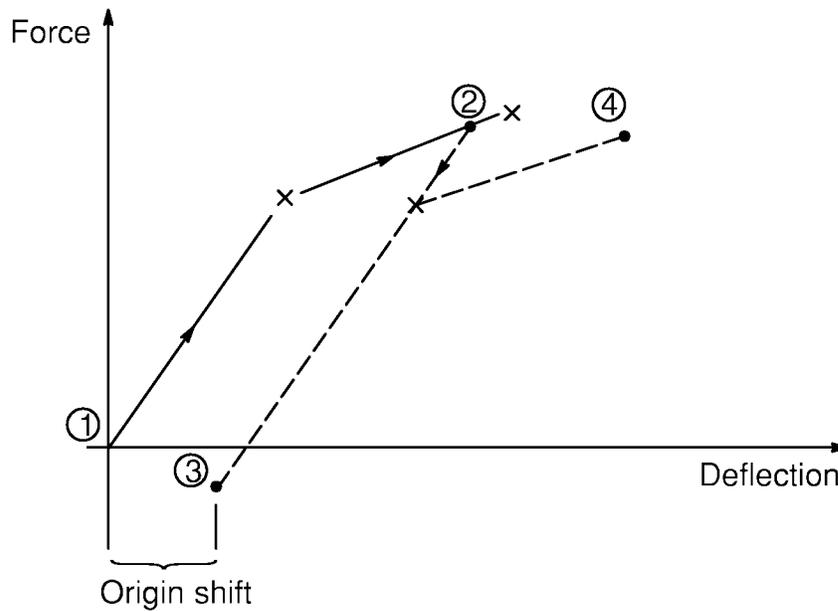
Figure 14.39–7 Origin Shift on Reversed Loading (KEYOPT(1) = 1)

A special option (KEYOPT(2) = 2) is included to model crushing behavior. With this option, the element will follow the defined tensile curve if it has never been loaded in compression. Otherwise, it will follow a reflection through the origin of the defined compressive curve (Figure 14.39–8).
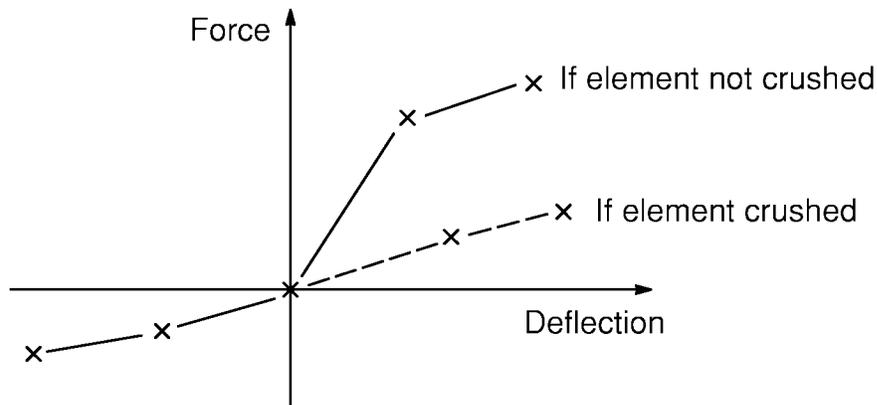

Figure 14.39–8 Crush Option (KEYOPT(2) = 2)