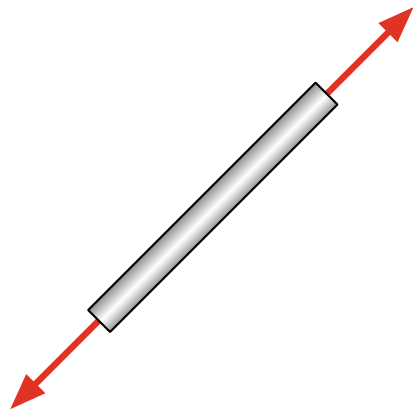


# Structural Analysis with the Direct Stiffness Method

*Modeling Structural Systems as Springs*



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## 1 Truss Direct Stiffness Method

The *Direct Stiffness Method* is a *Finite Element Method* of analysis that models structural elements as springs. We will begin with deriving the axial stiffness of a structural element. [Felippa, 2000]

### 1.1 Axial Stiffness

Members in a truss are modelled as springs with only axial deformation. The axial force in the spring is modelled by Hooke's law:

$$F = ku \quad (1)$$

where  $F$  is the axial force,  $k$  is the axial stiffness, and  $u$  is the axial deformation. To define the axial stiffness we will look at a member of constant cross-sectional area with only elastic deformation. The stress in such a member is defined by the stress-strain relationship:

$$\sigma = E\varepsilon \quad (2)$$

where  $\sigma$  is the stress,  $E$  is the modulus of elasticity, and  $\varepsilon$  is the strain. Multiplying both sides of the equation by the cross-sectional area,  $A$ , will convert the stress into a force.

$$\sigma A = E\varepsilon A \quad (3)$$

$$F = E\varepsilon A \quad (4)$$

The engineering definition of strain will be used here. Strain is defined as:

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{u}{L} \quad (5)$$

where  $L$  is the original length of the member and  $\Delta L$  is the change in length of the member. Then substituting in the definition of engineering strain into the previous equation:

$$F = EA \frac{u}{L} \quad (6)$$

Therefore the axial stiffness from the equation is  $\frac{AE}{L}$  for any structural member. The axial force of a structural element can be rewritten as:

$$F = \frac{AE}{L}u \quad (7)$$

### 1.2 Local Element Stiffness

Each element in a structural system will have its own local element stiffness equations. The goal of this section will be to develop the local element stiffness equations for a member in matrix form. Taking the nodal equilibrium from figure 1 becomes:

$$-F = ku_{1x'}$$

$$-F = ku_{2x'}$$

Next we will put these equations in matrix form in terms of the local coordinate system. The equation will take the form:

$$\mathbf{F} = \mathbf{k}\mathbf{u} \quad (8)$$

Figure 1: Local Member FBDs

$$\begin{bmatrix} -F \\ 0 \\ F \\ 0 \end{bmatrix} = \frac{AE}{L} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} u_{1x'} \\ u_{1y'} \\ u_{2x'} \\ u_{2y'} \end{Bmatrix} \quad (9)$$

Next, we must take the local element stiffness matrix and derive the global element stiffness matrix.

### 1.3 Global Element Stiffness

### 1.4 Global Structural Stiffness

## References

[Felippa, 2000] Felippa, C. A. (2000). A historical outline of matrix structural analysis: A play in three acts.