A 4-node geometrically nonlinear degenerated shell element for **fabric** modeling

This work is aimed at creating FEM-like fast methods for calculating deformations (wrinkling/draping) for clothing worn by soldiers in Nuclear, Biological, and Chemical (NBC) warfare.

By:
Salam Rahmatalla

Virtual Soldier Research
The University of Iowa
http://www.engineering.uiowa.edu/~amalek/VSR
http://www.digital-humans.org

THE UNIVERSITY OF IOWA

Objectives

- Formulate a geometrical nonlinear thin shell element for fabric modeling.

- Test the model to simulate drape over complex arbitrary surfaces.

- Test the model to capture buckling and wrinkles.

- Extend the model to analyze fabrics with seams, stitches and multiple ply fabric assemblies.

- Extend the model to include contact with surfaces.

Degenerated shell element

Assumptions are:

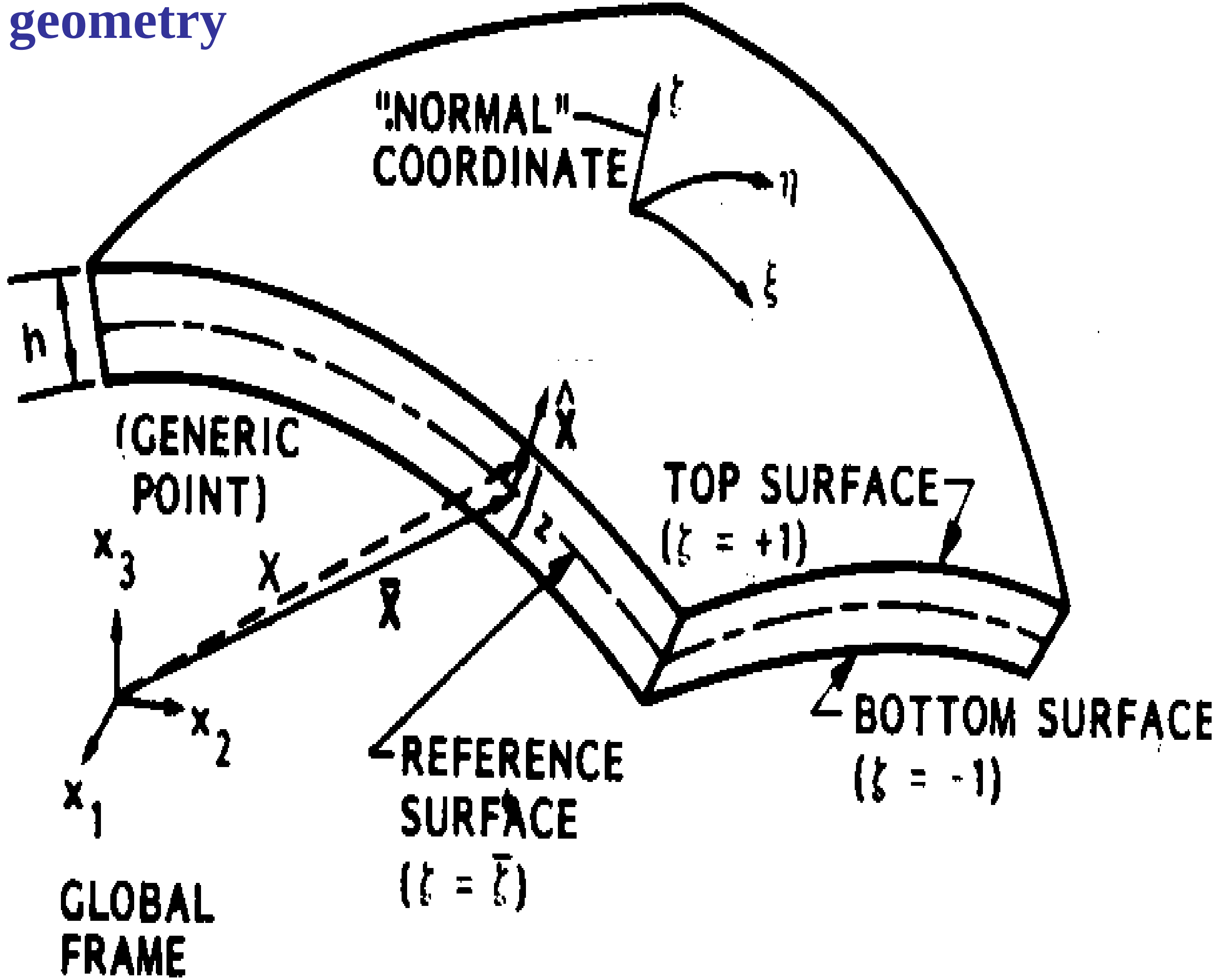
1. Fibers remain straight (modified Mindlin-Reissner assumption)

2. The stress normal to the midsurface vanishes (also called the plane stress condition)

Note: Selective reduced integration is used to avoid membrane and transverse shear locking.

THE UNIVERSITY OF IOWA

Shell geometry



Shell geometry

$$\boldsymbol{x}(x,h,z) = \bar{\boldsymbol{x}}(x,h) + \boldsymbol{X}(x,h,z)$$

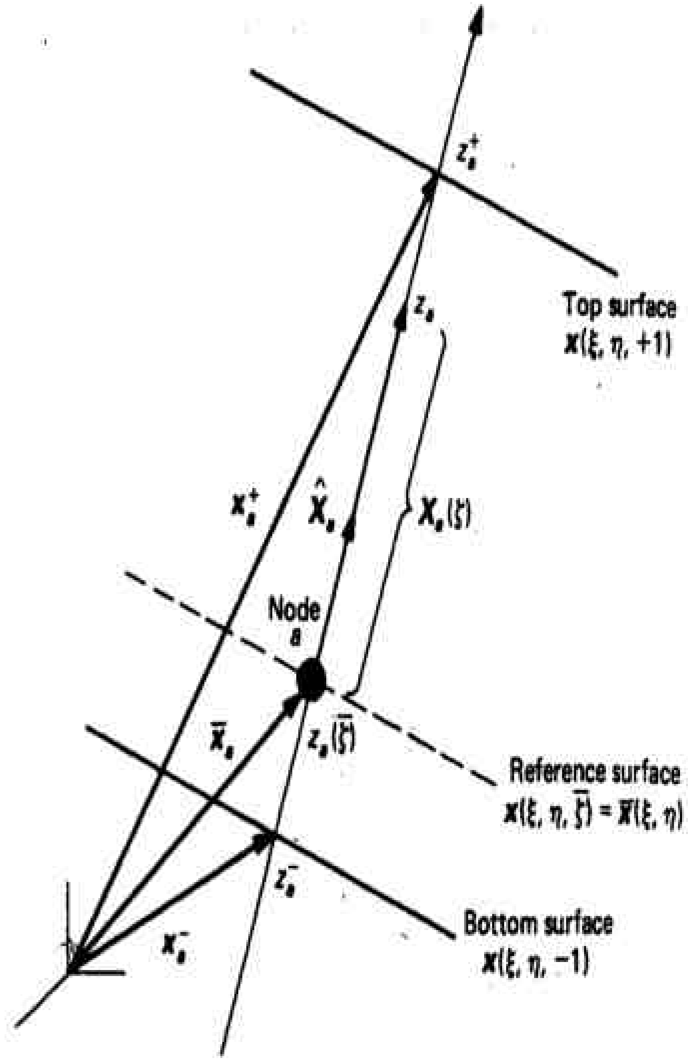
$$\bar{\boldsymbol{x}}(x,h) = \sum_{a=1}^{nen} N_a(x,h)\,\bar{\boldsymbol{x}}_a$$

$$\boldsymbol{X}(x,h,z) = \sum_{a=1}^{nen} N_a(x,h)\,\boldsymbol{X}_{\mathbf{a}}(z)$$

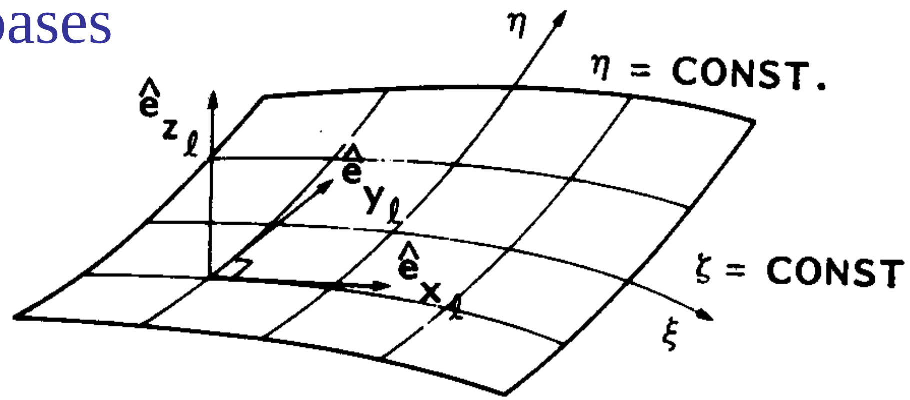
$$\boldsymbol{X}_{\mathbf{a}}(z) = z_a(z)\,\hat{\boldsymbol{X}}_a$$

$$z_a(z) = N_+(z)\,z_a^+ + N_-(z)\,z_a^-$$

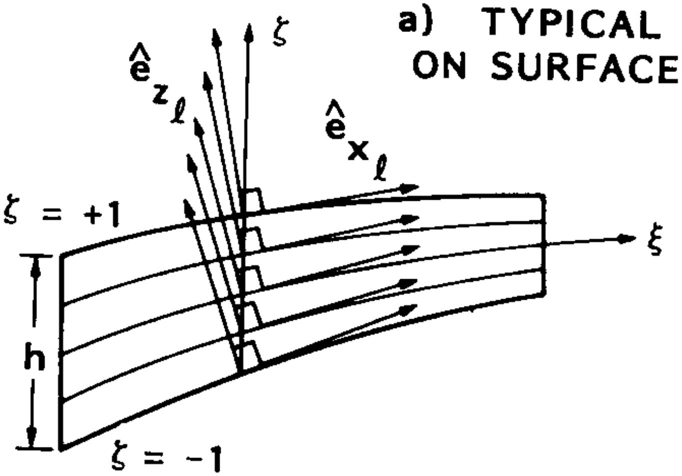
$$N_-(z) = \frac{1}{2}(1-z) \qquad N_+(z) = \frac{1}{2}(1+z)$$



Lamina and fiber bases

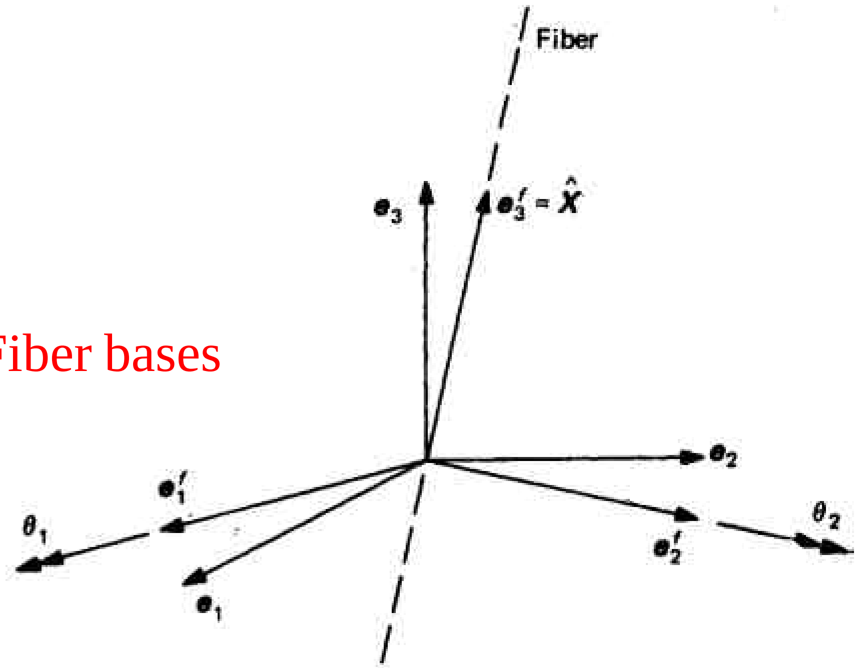


a) TYPICAL LAMINA BASIS ON SURFACE: ζ = CONST.



Lamina basis

Fiber bases



Shell kinematics

$$\mathbf{u}(x,h,z) = \sum_{a=1}^{nen} N_a(x,h)\mathbf{u}_a + \sum_{a=1}^{nen} N_a(x,h)\mathrm{z}_{\mathrm{a}}(\sin q_{a2}\mathbf{e}_{a1}^{f} - \sin q_{a1}\mathbf{e}_{a2}^{f})$$

$$u_{i,I}^{l} = \sum_{m=1}^{3} q_{im} \sum_{a=1}^{nen} \left\langle N_{a,I}u_{am} + (N_a z_a)_{,I}(\sin q_{a2}e_{am1}^{f} - \sin q_{a1}e_{am2}^{f}) \right\rangle$$

$$d\mathbf{E} = \begin{pmatrix} F_{i1}du_{i,1} \\ F_{i2}du_{i,2} \\ F_{i3}du_{i,3} \\ F_{i1}du_{i,2} + F_{i2}du_{i,1} \\ F_{i2}du_{i,3} + F_{i3}du_{i,2} \\ F_{i3}du_{i,1} + F_{i1}du_{i,3} \end{pmatrix} ; \qquad d\mathbf{E}_{(5\times1)} = \sum_{a=1}^{nen} \mathbf{B}_{(5\times5)}^{\mathbf{a}} \begin{pmatrix} d\bar{\mathbf{u}}_a \\ dq_{a1} \\ dq_{a2} \end{pmatrix}_{(5\times1)}$$

Hyperelastic material model

The particular strain energy function used here is that of Ciarlet, wherein the volumetric (U) and deviatoric $(\bar{W})$ strain energy functions are assumed to be decoupled and of the forms:

$$E(\mathbf{F}) = U(J) + \overline{W}(\mathbf{?})$$

$$U(J) = \frac{1}{2}K\left[\frac{1}{2}(J^2 - 1) - \ln(J)\right]$$

$$\overline{W} = \frac{1}{2}m[tr(\overline{\mathbf{?}}) - 3]$$

Stiffness, stress, and elasticity tensor expressions

From the strain energy function, we can find expressions for the stress tensor, elasticity tensor, and the stiffness matrix .

$$\mathbf{S} = \frac{k}{2}(J^2 - 1)\mathbf{C}^{-1} + mJ^{(-\frac{2}{3})}\mathbf{1} - \frac{1}{3}mJ^{(-\frac{2}{3})}tr(\mathbf{C})\mathbf{C}^{-1}$$

$$C_{IJKL} = \left\{KJ^2 + \frac{2}{9}mJ^{(-\frac{2}{3})}tr(C)\right\}C_{IJ}^{-1}C_{KL}^{-1} - \left\{K(J^2 - 1) - \frac{2}{3}mJ^{(-\frac{2}{3})}tr(C)\right\}C_{IK}^{-1}C_{JL}^{-1} - \frac{2}{3}mJ^{(-\frac{2}{3})}(C_{KL}^{-1}d_{IJ} + d_{KL}C_{IJ}^{-1})$$

$$\mathbf{K}_{IL}^{AB} = \int_{\Omega_S} B_{JI}^{A} C_{JK} B_{KL}^{B} d\Omega_S + \int_{\Omega_S} N_{,J}^{A} S_{IJ} N_{,K}^{B} d_{IL} d\Omega_S$$

THE UNIVERSITY OF IOWA

THE UNIVERSITY OF IOWA

References

Hughes, T.J.R, (2000), The Finite Element Method, Mineola, New York.

Zienkiewicz, O.C., and Taylor, R.L., (2000), The Finite Element Method, Volume 2: Solid Mechanics. Butterworth Heinemann, Oxford.

FENDAC software, C.C.Swan.

Contact Information:

Virtual Soldier Research program

The University of Iowa

Tel. 319-335-5722

Email: deborah-hampton@uiowa.edu

http://www.engineering.uiowa.edu/~amalek/VSR

http://www.digital-humans.org

VIRTUAL SOLDIER RESEARCH

THE UNIVERSITY OF IOWA