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Appendix

Gauss Quadrature Integral Approximation

In the application of finite element method, the singular element shape function generally must be evaluated in term of integral equations. The ρ-quadratic form of shape function often makes the integral difficult to solve analytically. However, the integrals over triangular element can also be proceed by employing the Gaussian or Gauss-Legendre quadrature numerical integration. But the integration must be held in term of reference element coordinate system, thus the arbitrary shape triangular element must be transformed into reference element.

The geometrical transformation of real element (expressed in x and y coordinates) to the reference element (expressed in ξ and η) can be seen on Figure 1. The relation of those element is denoted as

$$x(\xi,\eta) = \sum_{n=1}^{3} N_n x_n = N_1(\xi,\eta)\cdot x_1 + N_2(\xi,\eta)\cdot x_2 + N_3(\xi,\eta)\cdot x_3 \qquad (1)$$

$$y(\xi,\eta) = \sum_{n=1}^{3} N_n y_n = N_1(\xi,\eta)\cdot y_1 + N_2(\xi,\eta)\cdot y_2 + N_3(\xi,\eta)\cdot y_3 \qquad (2)$$

where $N_n(\xi,\eta)$ is a geometrical function that must satisfy the condition of equal to unity on the node n and vanished on the other nodes.

The integration of real element area, then, can be evaluated using the gaussian

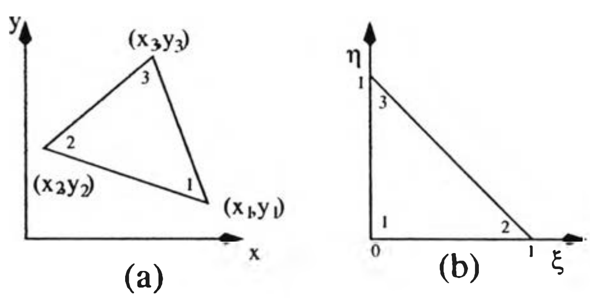

Figure 1: Geometrical transformation of triangular area

approximation.

$$\iint_e \phi(x,y)dxdy = \int_0^1\int_0^{1-\xi} \phi(\xi,\eta)\cdot|J|d\eta d\xi \tag{3}$$

$$\int_0^1\int_0^{1-\xi} f(\xi,\eta)d\eta d\xi = \sum_{i=1}^{n} w_i \cdot f(\eta_i,\xi_i) \tag{4}$$

where the points ξ_i are the point at which the function is evaluated and the coefficient w_i are called weights. Therefore, the integral can be expressed as

$$\iint_e \phi(x,y)dxdy = |J|\sum_{i=1}^{n} w_i \cdot f(\eta_i,\xi_i) \tag{5}$$

in which $|J|$ is the determinant of the Jacobian matrix.

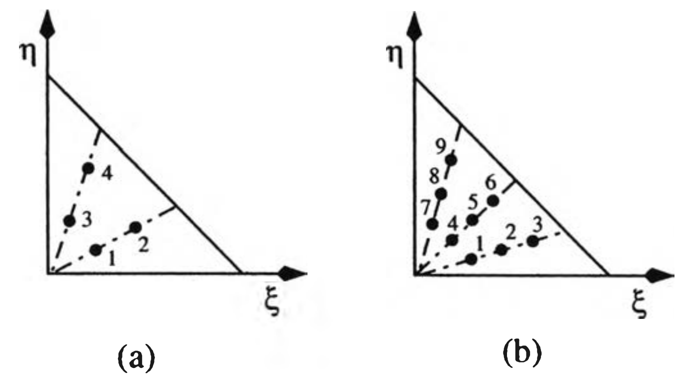

Figure 2: The sample point of gaussian integral approximation for $n = 3$ (a) and $n = 9$ (b).

Table 1: Sample point of Gauss quadrature integral approximation with 4 points

i	ξ_i	η_i	w_i
1	0.2800199155	0.0750311102	0.0909793091
2	0.6663902460	0.1785587283	0.1590206909
3	0.0750311102	0.0909793091	0.0909793091
4	0.1785587283	0.6663902460	0.1590206909

Table 2: Sample point of Gauss quadrature integral approximation with 9 points

i	ξ_i	η_i	w_i
1	0.188409406	0.023931132	0.019396383
2	0.523979068	0.066554068	0.063678085
3	0.808694386	0.102717655	0.055814420
4	0.106170269	0.106170269	0.031034213
5	0.295266568	0.295266568	0.101884936
6	0.455706020	0.455706020	0.089303073
7	0.023931132	0.188409406	0.019396383
8	0.066554068	0.523979068	0.063678085
9	0.102717655	0.808694386	0.055814420

Biography

Iswandi was born in Kulon Progo, Central Java, Indonesia, on April 15, 1976. He received his bachelor degree in electrical engineering from Gadjah Mada University, Yogyakarta, Indonesia, in November 2000. Since 2002 he joined the faculty of Gadjah Mada University. His research topic interests include antenna, waveguide and numerical technique. In June 2003, he received a scholarship from the AUN/SEED-Net to continue his study at Graduate School of Engineering, Faculty of Engineering, Chulalongkorn University.