MATERIAL MODELS IN FSI

Chapter 5

Material Models in FSI

Incompressible inviscid flow

*MAT_ELASTIC_FLUID

- Density
- Bulk modulus

Incompressible viscous laminar flow

*MAT_NULL

- Density
- Viscosity
- Include an EOS

*EOS_GRUNEISEN
*EOS_LINEAR_POLYNOMIAL

MAT_ELASTIC_FLUID and MAT_NULL only consider the normal (pressure) stresses

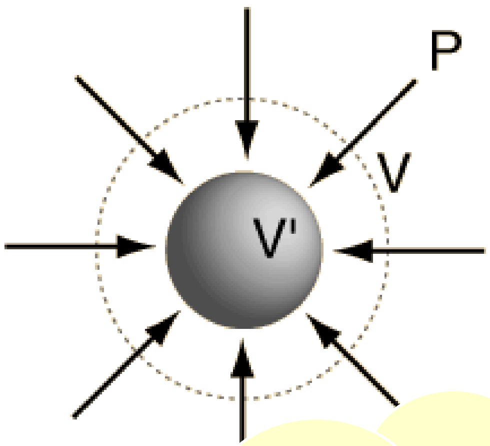
$$\underbrace{\overbrace{\sigma_{ij} = \sigma_{ii}^{e}}}_{} + \sigma_{ij}^{e} + \sigma_{ij}^{p}$$

$$\sigma_{ij} = \underbrace{\sigma_{ii}^{e}}_{\text{Dilational (normal)}} + \underbrace{\sigma_{ij}^{e} + \sigma_{ij}^{p}}_{\text{Deviatoric (shear)}}, \quad \text{Elastic: } \sigma_{ii}^{e} + \sigma_{ij}^{e}, \quad \text{Plastic: } \sigma_{ij}^{p}$$

These materials allow equations of state to be considered without computing deviatoric stresses.

Bulk modulus (modulus of compressibility)

The bulk elastic properties of a material determine how much it will compress under a given amount of external pressure. The ratio of the pressure to the fractional change in volume is called the bulk modulus of the material.



$$B = \frac{P}{-\Delta V / V}$$

Bulk modulus values:

Steel	B = 160e+09 N/m^2
Aluminum	B = 71.3e+09 N/m^2
Water	B = 2.2e+09 N/m^2

For an elastic solid

$$B = \frac{E}{3(1-2\upsilon)}$$

*MAT_ELASTIC

$$\sigma_d = 2.G.\varepsilon'$$

E: Young Modulus
ν: Poisson ratio
P_c : Pressure Cutoff
G: Shear Modulus
K: Bulk Modulus

$$P = -K\frac{1}{3}tr(\varepsilon)$$

$$\varepsilon' = \varepsilon - \frac{1}{3}tr(\varepsilon)Id$$

$$G = \frac{E}{2(1+\nu)} \qquad K = \frac{E}{3(1-2\nu)}$$

*MAT_NULL

This material model is used to model gasses and liquids. The deviatoric stresses are purely viscous. The viscosity is constant. This material model needs an equation of state for the pressure evaluation.

$$\sigma_d = 2\mu\dot{\varepsilon}'$$

$$\sigma = -P.Id + \sigma_d$$

$$P = F(E, \rho)$$

μ: Dynamic viscosity
Pc: Pressure Cutoff

The shear Stress σ_d is Proportional to the Shear Strain Rate , not to the Shear Strain
The Coefficient of Proportionality is the Viscosity μ.

*MAT_NULL

- The Deformation for Solids is due to Displacement Gradient or Strain ε.
- The Deformation for Fluid is Due to Velocity Gradient or Strain Rate $\dot{\varepsilon}$.
- In Solid Mechanics Displacements are the Dependent Variables.
- In Fluid Mechanics Velocities are the Dependent Variables.
- A Fluid unlike the Solid Cannot Sustain Finite Deformation Under the Action of Constant Shear Stress.
- When a Shear Stress is Applied to a Fluid, The Fluid Will Deform Continuously so Long as The Shear Stress is Applied.
- The Viscosity is a Measure of the Resistance of the Fluid to flow.

*MAT_NULL

RO Mass density
PC Pressure cutoff (≤ 0.0).
MU Dynamic viscosity coefficient.
TEROD Relative volume., for erosion in tension. Typically, use values greater than unity. If zero, erosion in tension is inactive.
CEROD Relative volume, or erosion in compression. Typically, use values less than unity. If zero, erosion in compression is inactive.
YM Young's modulus (used for null beams and shells only)
PR Poisson's ratio (used for null beams and shells only)

Note: the cutoff pressure is the dilatation pressure limits. Small negative values compared to the atmosphere is good approximation.

*MAT_ELASTIC_FLUID

K Bulk Modulus
μ_d Viscosity Coefficient between 0.1 and 0.5
Pc Pressure Cutoff
Δx Characteristic element length
c Speed of Sound
ρ Density of he fluid

The ELASTIC_FLUID Material is used for incompressible inviscid Fluid. The Viscosity stress is a numerical dissipation.

$$\sigma_d = [\mu_d . \Delta x . c . \rho] \dot{\varepsilon}'$$

$$\dot{P} = -K . \frac{1}{3} tr(\dot{\varepsilon})$$

*MAT_HIGH_EXPLOSIVE_BURN

RO	Mass density.
D	Detonation velocity.
P_{CJ}	Chapman-Jouget pressure.
BETA	Beta burn flag, BETA (see comments below):
	EQ.0.0: beta + programmed burn,
	EQ.1.0: beta burn only,
	EQ.2.0: programmed burn only.
K	Bulk modulus (BETA=2.0 only).
G	Shear modulus (BETA=2.0 only).
SIGY	σ_y,yield stress (BETA=2.0 only).

*MAT_HIGH_EXPLOSIVE_BURN

Detonation Velocity is *V*

Beta=1 Beta Burn only

The Detonation will be caused by Volumetric Compression only.

$$F_1 = \frac{\rho V^2}{P_{cj}}(1. - \frac{v}{v_0})$$

Beta=2 Programmed burned

The Detonation is controlled by the Detonation time for each element. The burn fraction is

$$F_2 = (t - t_b)V\frac{2}{3.dx}$$

The burn function is a function of time which is referred to as programmed burn.

*MAT_HIGH_EXPLOSIVE_BURN

dx : Characteristic length of the element.

t_b :burn time of the element

t : time

If programmed burn is used, the explosive model will behave as an elastic plastic material, and therefore the explosive material can compress without causing detonation.

The Burn Fraction

Beta=0 → Beta burn + Programmed burned.

The Burn Fraction is

$$F = \max(F_1, F_2)$$

The Pressure in a High Explosive material is scaled by the Burn Fraction

$$P = F * P_{eos}(\rho, E)$$

*MAT_ACOUSTIC

Density ρ
Sound Speed C
Damping factor
Atmospheric Pressure P_{atm}

X-Coordinate of Free Surface
Y-Coordinate of Free Surface
Z-Coordinate of Free Surface
X-Normal to Free Surface
Y-Normal to Free Surface
Z-Norma; to Free Surface

Φ Potential Velocity

$$\phi = -grad.V$$

*MAT_ACOUSTIC

$$\frac{\partial^2 \phi}{\partial t^2} = c^2 . \Delta \phi$$

$$P_{ac} = \rho \frac{\partial \phi}{\partial t}$$

$$P_{hydro} = \rho g z$$

$$P = P_{ac} + P_{hydro} + P_{atms}$$