Wave Current Interaction

Core Components and Initialization

The `WaveCurrentInteraction` class, implemented in C#, models the interaction between waves and currents in an estuarine environment using linear wave theory and simplified wave-enhanced friction. The class is initialized with the following parameters:

- Wave height: H_w (m)
- Wave direction: θ_w (degrees, aligned with wind)
- Wave period: T_w (s)
- Water depth: h (m)
- Gravitational acceleration: $g = 9.81\,\mathrm{m/s^2}$

The constructor sets these parameters, and the `UpdateParameters` method allows dynamic updates during simulation.

Functioning Logic

The class provides two primary methods to account for wave-current interactions:

1. `ComputeStokesDrift`: Calculates Stokes drift velocities (u_s, v_s) based on linear wave theory, representing the net mass transport induced by waves.
2. `ComputeWaveEnhancedFriction`: Computes a wave-enhanced bottom friction coefficient using a simplified Grant-Madsen approach, accounting for increased turbulence due to wave orbital velocities.

Stokes Drift Computation

The `ComputeStokesDrift` method calculates Stokes drift velocities using linear wave theory for shallow water:

- **Wave characteristics**:
  - Approximate wavelength: $\lambda = \sqrt{gh}T_w$
  - Wave number: $k = 2\pi/\lambda$
  - Angular frequency: $\omega = 2\pi/T_w$
  - Wave amplitude: $a = H_w/2$
- **Stokes drift magnitude**: Near the surface ($z \approx 0$):

$$u_s = \frac{a^2 \omega k \cosh(2kz)}{2\sinh^2(kh)} \approx \frac{a^2 \omega k}{2\sinh^2(kh)} \tag{1}$$

- **Directional components**:

$$u_s = u_{s,\text{mag}} \cos(\theta_w \pi/180) \tag{2}$$
$$v_s = u_{s,\text{mag}} \sin(\theta_w \pi/180) \tag{3}$$

If $H_w \leq 0$ or $T_w \leq 0$, the method returns $(u_s, v_s) = (0, 0)$. NaN or Infinity values are clamped to zero to ensure numerical stability.

Wave-Enhanced Friction

The `ComputeWaveEnhancedFriction` method calculates an enhanced bottom friction coefficient:

- **Wave orbital velocity** at the bottom:

$$u_b = \frac{a\omega}{\sinh(kh)} \tag{4}$$

  where $a = H_w/2$, $\omega = 2\pi/T_w$, $k = 2\pi/\sqrt{gh}T_w$.

- **Enhanced friction coefficient**:

$$C_d = C_{d0}(1 + \beta|u_b|) \tag{5}$$

  where C_{d0} is the base friction coefficient, and $\beta = 0.2$ is an empirical factor.

- **Constraints**: The result is clamped between C_{d0} and 0.01 to prevent numerical instability.

If $H_w \leq 0$ or $T_w \leq 0$, the base friction coefficient is returned unchanged.

Physical and Mathematical Models

The `WaveCurrentInteraction` class employs the following models:

- **Stokes Drift**:

$$\lambda = \sqrt{gh}T_w \tag{6}$$
$$k = \frac{2\pi}{\lambda}, \quad \omega = \frac{2\pi}{T_w}, \quad a = \frac{H_w}{2} \tag{7}$$
$$u_{s,\text{mag}} = \frac{a^2 \omega k}{2\sinh^2(kh)} \cosh(2k \cdot 0) \tag{8}$$
$$u_s = u_{s,\text{mag}} \cos\left(\theta_w \frac{\pi}{180}\right), \quad v_s = u_{s,\text{mag}} \sin\left(\theta_w \frac{\pi}{180}\right) \tag{9}$$

- **Wave-Enhanced Friction**:

$$u_b = \frac{a\omega}{\sinh(kh)} \tag{10}$$
$$C_d = C_{d0}(1 + 0.2|u_b|), \quad C_d \in [C_{d0}, 0.01] \tag{11}$$

These models capture wave-induced transport and turbulence effects, integrating with estuarine circulation models to enhance realism in velocity and friction calculations.