For seawater, take ρ = 1.99 slug/ft^3, μ = 2.23E–5 slug/ft·s. With L_p = 150 ft and V_p = 15 knots = 25.3 ft/s, evaluate

$$Re_{proto} = \frac{\rho_p V_p L_p}{\mu_p} = \frac{1.99(25.3)(150)}{2.23E\text{–}5} \approx 3.39E8; \quad Fr_p = \frac{25.3}{[32.2(150)]^{1/2}} \approx 0.364$$

$$\text{For} \quad Fr \approx 0.364, \quad \text{interpolate to } C_{F,wave} \approx 0.0027$$

Thus we can immediately estimate $F_{wave} \approx 0.0027(1.99)(25.3)^2(150)^2 \approx \underline{77000}$ lbf. However, as mentioned in Fig. 5.8 of the text, Re_p is far outside the range of the friction force data, therefore we must *extrapolate* as best we can. A power-law curve-fit is

$$C_{F,friction} \approx \frac{0.0178}{Re^{0.144}}, \quad \text{hence } C_{F,proto} \approx \frac{0.0178}{(3.39E8)^{0.144}} \approx 0.00105$$

Thus $F_{friction} \approx 0.00105(1.99)(25.3)^2(150)^2 \approx \underline{30000}$ lbf. $\mathbf{F_{total} \approx 107000}$ **lbf**. *Ans.*

5.77 A dam spillway is to be tested by using Froude scaling with a one-thirtieth-scale model. The model flow has an average velocity of 0.6 m/s and a volume flow of 0.05 m^3/s. What will the velocity and flow of the prototype be? If the measured force on a certain part of the model is 1.5 N, what will the corresponding force on the prototype be?

Solution: Given $\alpha = L_m/L_p = 1/30$, Froude scaling requires that

$$V_p = \frac{V_m}{\sqrt{\alpha}} = \frac{0.6}{(1/30)^{1/2}} \approx \mathbf{3.3\ \frac{m}{s}}; \quad Q_p = \frac{Q_m}{\alpha^{5/2}} = \frac{0.05}{(1/30)^{5/2}} \approx \mathbf{246\ \frac{m^3}{s}} \quad \textit{Ans. (a)}$$

The force scales in similar manner, assuming that the density remains constant (water):

$$F_p = F_m\left(\frac{\rho_p}{\rho_m}\right)\left(\frac{V_p}{V_m}\right)^2\left(\frac{L_p}{L_m}\right)^2 = F_m(1)\left(\frac{1}{\sqrt{\alpha}}\right)^2\left(\frac{1}{\alpha}\right)^2 = (1.5)(30)^3 \approx \mathbf{40500\ N} \quad \textit{Ans. (b)}$$

5.78 A prototype spillway has a characteristic velocity of 3 m/s and a characteristic length of 10 m. A small model is constructed by using Froude scaling. What is the minimum scale ratio of the model which will ensure that its minimum Weber number is 100? Both flows use water at 20°C.

Solution: For water at 20°C, ρ = 998 kg/m^3 and Y = 0.073 N/m, for both model and prototype. Evaluate the Weber number of the prototype:

$$We_p = \frac{\rho_p V_p^2 L_p}{Y_p} = \frac{998(3.0)^2(10.0)}{0.073} \approx 1.23E6; \quad \text{for Froude scaling,}$$