① Let the cm of the boat be a distance x from the shore. Then for the system of dog + boat:

$$x_{cm} = \frac{(4.5)(6.1\,m) + (18.2\,kg)(x)}{4.5\,kg + 18.2\,kg}$$

If the dog walks a distance d toward the shore, the cm of the boat moves a distance $2.4 - d$ away from the shore. But the cm of the system must remain in the same place:

$$\frac{(4.5\,kg)(6.1\,m) + (18.2\,kg)(x)}{4.5\,kg + 18.2\,kg} = \frac{(4.5\,kg)(6.1 - d) + (18.2\,kg)(x + 2.4 - d)}{4.5\,kg + 18.2\,kg}$$

$$\Rightarrow d = 1.9\,m$$

$\Rightarrow$ The dog is now $6.1\,m - 1.9\,m = 4.2\,m$ from shore.

② (a) Using the CM equation $(F - Mg)d_1 = \frac{1}{2} M v_{cm}^2$

After she breaks contact with the floor we can use the true conservation of energy equation: $\frac{1}{2} M v_{cm}^2 = Mg d_2$

$$(F - Mg)d_1 = Mg\, d_2$$

$$F = Mg(1 + d_2/d_1) = (55.0\,kg)(9.8\,\tfrac{N}{kg})\left(1 + \frac{0.3\,m}{0.5\,m}\right) = 860\,N$$

(b) $v_{cm} = \sqrt{2 g d_2} = \sqrt{2(9.8)(0.3\,m)} = 2.4\,m/s$

③ (a) $-F_{ext} S_{cm} = -\frac{1}{2} M v_{cm}^2$

$$F_{ext} = \frac{\frac{1}{2} M v_{cm}^2}{S_{cm}} = \frac{\frac{1}{2}(110\,kg)(3.0\,m/s)^2}{0.30\,m} = 1650\,N$$

(b) $0 = \Delta K_{cm} + \Delta E_{int}$ $\qquad \Delta K_{cm} = -\frac{1}{2} M v_{cm}^2 = -495\,J$

$\Rightarrow \Delta E_{int} = +495\,J$

④ (a) $-F_{ext} s_{cm} = -\frac{1}{2} M v_{cm}^2$

$$F_{ext} = \frac{\frac{1}{2} M v_{cm}^2}{s_{cm}} = \frac{\frac{1}{2}(2340\,kg)(3.5\,m/s)^2}{0.64\,m} = 22{,}400\,N$$

(b) $W_{ext} = \Delta K + \Delta E_{int}$

Work done on car by abutment $= -F \cdot d = -(22{,}400\,N)(0.083\,m)$
$= -1860\,J$

$$\Delta E_{int} = W_{ext} - \Delta K = -1860\,J - (-14330\,J) = +12{,}500\,J$$