3) b) $$\frac{d^2y}{dt^2} = -g + \frac{k}{m}(l-y) - \frac{k}{m}\frac{l_0(l-y)}{\sqrt{x^2+(l-y)^2}}$$

$$\tau = \sqrt{\frac{l}{g}}\ ,\ L = l$$

substitute $t = \tau\bar{t}\ ,\ y = L\bar{y}\ ,\ x = L\bar{x}$

$$\frac{L\,d^2\bar{y}}{\tau^2\,d\bar{t}} = -g + \frac{k}{m}(l - L\bar{y}) - \frac{k}{m}\frac{l_0(l-L\bar{y})}{\sqrt{L^2\bar{x}^2+(l-L\bar{y})^2}}$$

$$g\frac{d^2\bar{y}}{d\bar{t}^2} = -g + \frac{k}{m}(l - l\bar{y}) - \frac{k}{m}\frac{l_0(l-l\bar{y})}{\sqrt{l^2\bar{x}^2+(l-l\bar{y})^2}}$$

divide both sides by g and factor l out:

$$\frac{d^2\bar{y}}{d\bar{t}^2} = -1 + \frac{kl(1-\bar{y})}{gm} - \frac{k\,l\,l_0\,(1-\bar{y})}{mg\sqrt{l^2\bar{x}^2+l^2(1-\bar{y})^2}}$$

$$\frac{d^2\bar{y}}{d\bar{t}^2} = -1 + \frac{1}{\sigma}(1-\bar{y}) - \frac{1}{\sigma}\frac{l_0(1-\bar{y})}{l\sqrt{\bar{x}^2+(1-\bar{y})^2}}$$

$l_0 = l(1-\sigma) \longrightarrow \frac{l_0}{l} = (1-\sigma)$, substitute for $\frac{l_0}{l}$ to get:

$$\boxed{\frac{d^2\bar{y}}{d\bar{t}^2} = -1 + \frac{1}{\sigma}(1-\bar{y}) - \frac{1}{\sigma}(1-\sigma)(1-\bar{y})\Big/\sqrt{\bar{x}^2+(1-\bar{y})^2}}$$

non-dimensional equation