



Esercizi

ONDE FLUIDI TERMODINAMICA

ESERCIZI a.a. 2023-2024

NUMERAZIONE E SOLUZIONI FANNO RIFERIMENTO AL
MATERIALE FORNITO DALLA PROFESSORESSA DE MORI.

ARGOMENTI ESERCITAZIONI

# 1 - 4	ONDE
# 5 - 8	FLUIDI
# 9 - 12	TERMODINAMICA

ESERCIZI CHE HO LASCIATO:

NELLE ESERCITAZIONI VECCHIE

ES 8 ESERCITAZIONE 7

NELLE ESERCITAZIONI NUOVE

ES. 8 ESERCITAZIONE 4

ES. 5, 6, ESERCITAZIONE 6
(SONO 4 ESERCIZI DI PROVE D'ESAME
SENZA SOLUZIONE)

ES. 2 ESERCITAZIONE 7 (PUNTO d)

ES. 8 ESERCITAZIONE 7

ES. 2 ESERCITAZIONE 8 (PUNTO b)

ES. 7 ESERCITAZIONE 8

ES 9 ESERCITAZIONE 8 (PUNTO c, d)

ES 1 ESERCITAZIONE 9 (PUNTO d DA
CONTROLLARE)

ES 2 ESERCITAZIONE 9 (DA CONTROLLARE)

ES 5 ESERCITAZIONE 9 (b, c, d)

ES 9.7c IN PIÙ (DA CONTROLLARE)

ES 2 ESERCITAZIONE 10 (NUMERI)

ES 3 ESERCITAZIONE 10 (DOMANDA IN FONDO)

ES 6 ESERCITAZIONE 10 (PUNTO b, d)

ES 2 ESERCITAZIONE 11 (PUNTO e)

ES 3 ESERCITAZIONE 11 (NON HO CAPITO IL TESTO)

ES 7 ESERCITAZIONE 11 (DA CONTROLLARE)

ES 1,3,5,6 ESERCITAZIONE 12
(SONO 4 ESERCIZI DI PROVE D'ESAME
SENZA SOLUZIONE)

ES 11.9C ESERCIZI IN PIÙ, DA CONTROLLARE

ES 10.8C ESERCIZI IN PIÙ, DA CONTROLLARE

ES ● ESERCITAZIONE ●

ESERCITAZIONE 1

1 OTTONE, $\Delta l_{\max} = 3 \text{ mm}$ con $F_H = 4 \text{ kN}$
AVENDO $E = 105 \text{ GPa}$; $\sigma_{\max} = 180 \text{ MPa}$

DETERMINA:

- $d_{\min}$
- $l_{\max}$ DELL'ASTA

$$\text{SO } \Delta l = l \frac{\sigma}{E} = \frac{F l}{E S}$$

DUNQUE

$$\Delta l_{\max} = l_{\max} \frac{\sigma_{\max}}{E} \Rightarrow l_{\max} = \frac{E \Delta l_{\max}}{\sigma_{\max}} = \boxed{1,75 \text{ m}}$$

$$\Delta l_{\max} = \frac{F_H l_{\max}}{E \pi r^2} \Rightarrow r^2 = \frac{F_H l_{\max}}{E \pi \Delta l_{\max}} \Rightarrow r_{\max} = \sqrt{\frac{F_H l_{\max}}{E \pi \Delta l_{\max}}} = 0,002659 \text{ m}$$
$$= \boxed{2,659 \text{ mm}}$$

$$[r] = \left(\frac{F}{\frac{F}{A}} \right)^{1/2} = (A)^{1/2} = \text{m}$$

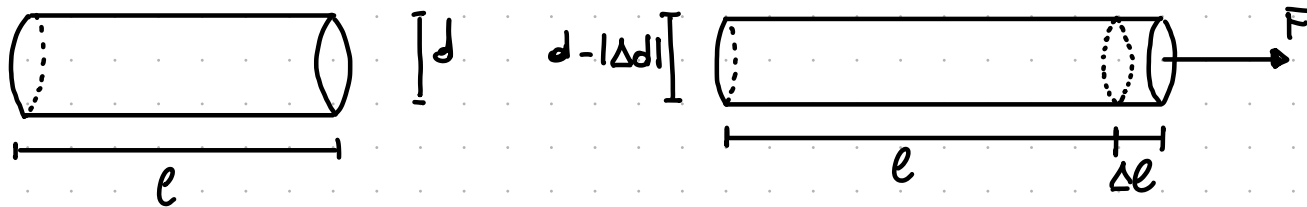
2 MATERIALE OMogeneo e isotropo

$$l = 300 \text{ mm} \quad d = 16 \text{ mm}$$

$$F = 12 \text{ kN} \quad \Delta l = 300 \text{ }\mu\text{m}$$

$$\Delta d = -2.4 \text{ }\mu\text{m}$$

DETERMINA: ν , $\sim$



$$\sigma = \frac{F}{A} \quad \epsilon = \frac{\Delta l}{l}$$

$$A = \pi \left(\frac{d}{2} \right)^2 = 2,01 \cdot 10^{-4} \text{ m}^2$$

QUINDI

$$\sigma = 59,701 \text{ MPa} \quad ; \quad \epsilon = 0,6 \cdot 10^{-3}$$

MODULO di YOUNG :

$$Y = \frac{\sigma}{\epsilon} = 99,502 \cdot 10^9 \frac{\text{N}}{\text{m}^2} = 99,502 \frac{\text{GN}}{\text{m}^2}$$

POISSON :

$$\frac{\Delta d}{d} = -\nu \frac{\Delta l}{l} \Rightarrow \nu = -\frac{l}{\Delta l} \frac{\Delta d}{d} = 0,4$$

3

$$d = 2,52 \text{ cm}$$

$$M = 873 \text{ kg}$$

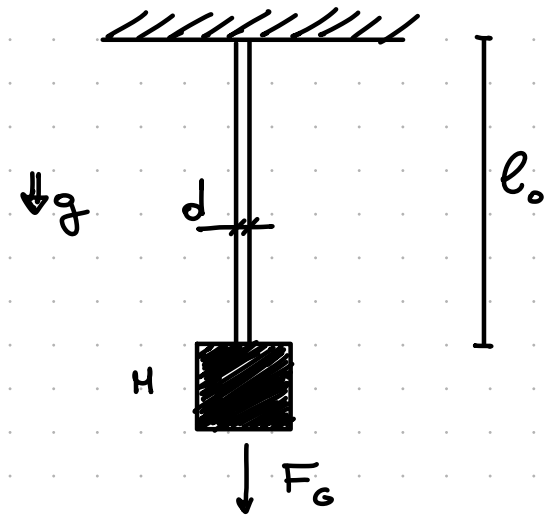
$$l_0 = 42,6 \text{ m}$$

$$\gamma = 200 \cdot 10^9 \text{ N/m}^2$$

$$\nu = 0,3$$

DETERMINA:

- Δl
- $\frac{\Delta d}{d}$



$$F_G = Mg = 8564,13 \text{ N}$$

POSSO CALCOLARE $\sigma = \frac{F_G}{A} = \frac{4F_G}{\pi d^2} = 17,170 \text{ MN/m}^2$

$$\gamma = \frac{\sigma}{\epsilon} = \frac{\sigma}{\Delta l} l_0 \Rightarrow \Delta l = \frac{\sigma l_0}{\gamma} = \boxed{0,00366 \text{ m}}$$

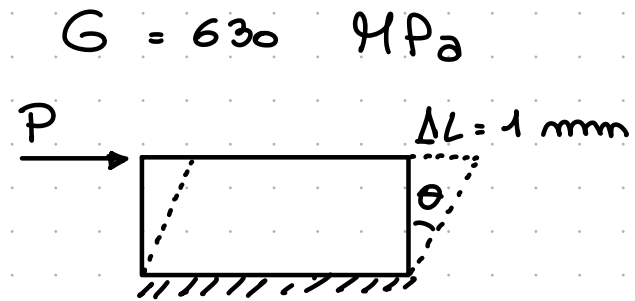
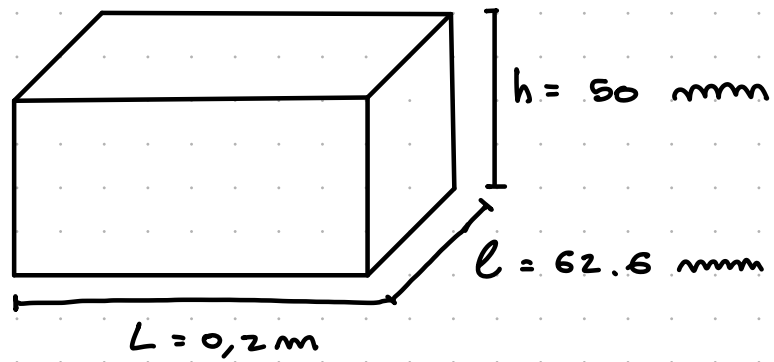
$$(\gamma = 2 \cdot 10^9 \frac{\text{N}}{\text{m}^2}) = 0,366 \text{ m}$$

PER LA LEGGE DI POISSON POSSO DIRE

$$\frac{\Delta r}{r} = \frac{\Delta r}{r} \frac{2}{2} = \frac{\Delta(2r)}{2r} = \frac{\Delta d}{d} \approx -\nu \frac{\Delta l}{l_0} \Rightarrow \boxed{\frac{\Delta d}{d} = -0,00026}$$

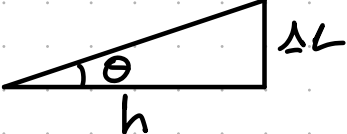
$$(\gamma = 2 \cdot 10^9 \frac{\text{N}}{\text{m}^2}) = -0,0026$$

4



DETERMINA : • P • θ

CONOSCO $\sigma = \frac{F}{A} = G\theta \Rightarrow \frac{P}{lh} = G\theta \Rightarrow P = G\theta lh$

VEDO  $\frac{\Delta L}{h} = \tan \theta \sim \theta$

DUNQUE $\theta \sim \frac{\Delta L}{h} = \boxed{0,02}$

$$P = G\theta l L = 157752 \text{ N} = \boxed{157,752 \text{ kN}}$$

5

$$d = 15 \text{ mm}$$

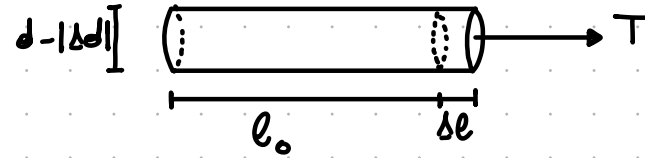
$$T = 3.5 \text{ kN}$$

$$l_0 = 120 \text{ mm}$$

$$\Delta l = 11 \text{ mm}$$

$$\Delta d = -0.62 \text{ mm}$$

DETERMINA : • γ • G • ν



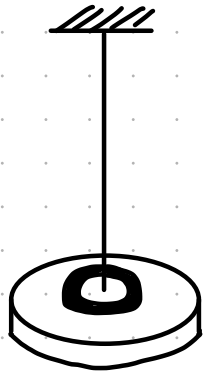
$$\text{Poisson} : \frac{\Delta d}{d} = -\nu \frac{\Delta l}{l_0} \Rightarrow \nu = -\frac{\Delta d l_0}{d \Delta l} = \boxed{0.45}$$

$$\text{Young} : \gamma = \frac{\sigma}{\epsilon} = \frac{T}{A} \cdot \frac{1}{\frac{\Delta l}{l_0}} = \frac{4T}{\pi d^2} \frac{l_0}{\Delta l} = 216064892.44 \frac{\text{N}}{\text{m}^2}$$

$$\gamma = 216.065 \frac{\text{MN}}{\text{m}^2}$$

$$\text{RIGIDITÀ} : G = \frac{\gamma}{2(1+\nu)} = \boxed{74.508 \frac{\text{MN}}{\text{m}^2}}$$

6



$$I, m, R = ?$$

$$T = 3 \text{ s}$$

$$M = 3 \text{ kg}$$

$$r = 10 \text{ cm}$$

$$T_2 = 4 \text{ s}$$

$$\text{SO } I_{\text{ANELLO}} = mR^2 \Rightarrow I_{\text{ANELLO}} = Mr^2 = 0,03 \text{ Kg m}^2$$

$$I_{\text{DISCO}} = \frac{1}{2} mR^2$$

$$\text{PER UN PENDOLO DI TORSIONE: } T = 2\pi \sqrt{\frac{I}{K}} \quad \text{CON } K = \frac{\pi G r^4}{2\ell} \sim \text{cost}$$

PRIMA E DOPO AVER MESSO L'ANELLO AVRO':

$$I_1 = I_{\text{FILO}} + I_{\text{DISCO}} \sim I_{\text{DISCO}} \quad ; \quad I_2 \sim I_{\text{DISCO}} + I_{\text{ANELLO}}$$

$$T_1 = 2\pi \sqrt{\frac{I_{\text{DISCO}}}{K}} \quad ; \quad T_2 = 2\pi \sqrt{\frac{I_{\text{DISCO}} + I_{\text{ANELLO}}}{K}}$$

$$\Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{I_{\text{DISCO}}}{I_{\text{DISCO}} + I_{\text{ANELLO}}}} \Rightarrow \left(\frac{T_1}{T_2}\right)^2 (I_{\text{DISCO}} + I_{\text{ANELLO}}) = I_{\text{DISCO}}$$

$$\Rightarrow \left(\frac{T_1}{T_2} \right)^2 I_{\text{ANELLO}} = I_{\text{DISCO}} \left(1 - \left(\frac{T_1}{T_2} \right)^2 \right)$$

$$\Rightarrow I_{\text{DISCO}} = \frac{\left(\frac{T_1}{T_2} \right)^2}{1 - \left(\frac{T_1}{T_2} \right)^2} I_{\text{ANELLO}} = 0,0386 \text{ Kg m}^2$$

7

$$l = 9,5 \text{ m}$$

$$m = 32 \text{ g}$$

$$T = 8,6 \text{ N}$$

$$t = ?$$

so $v = \sqrt{\frac{T}{\rho_e}}$ VELOCITÀ DI PROPAGAZIONE ONDE ELASTICHE IN UNA
CORDA TESA

$$\rho_e = \frac{m}{l} = 0,0034 \frac{\text{kg}}{\text{m}}$$

QUINDI $v = 50,29 \frac{\text{m}}{\text{s}}$

MAI: $l = vt \Rightarrow t = \frac{l}{v} = 0,189 \text{ s}$

8

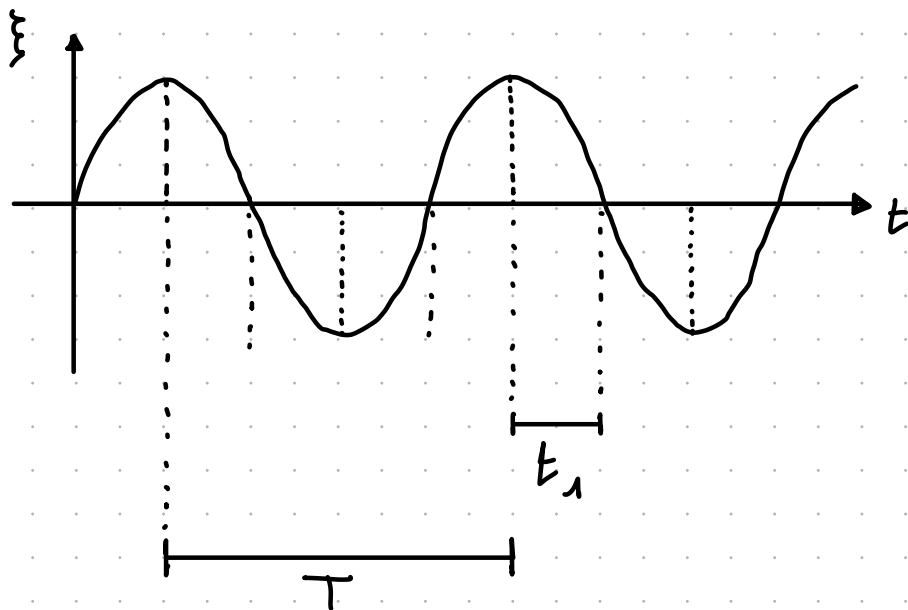
$$\xi(x, t) = A \sin(kx - \omega t) \quad , \quad \text{CORDA TESA}$$

$$t_1 = 0.17 \text{ s}$$

$$\lambda = 140 \text{ m}$$

DETERMINA :

- T
- ν
- v



SI VEDE CHE

$$T = 4t_1 = 0,68 \text{ s}$$

$\Rightarrow$

$$\nu = \frac{1}{T} = 1,47 \text{ Hz}$$

HO

$$\lambda = \frac{v}{\nu} \Rightarrow$$

$$v = \lambda \nu = 2.058 \frac{\text{m}}{\text{s}}$$

9

$$A = 0.16 \text{ m} \quad \lambda = 2.1 \text{ m} \quad T = 1.8 \text{ s}$$

ONDA ARMONICA, TRASVERSALE, VERSO $x > 0$, $\xi(0,0) = 0.16 \text{ m} = A$

• SCRIVI L'ONDA

AVRO' $\xi(x,t) = A \sin(kx - \omega t + \varphi)$

SO $T = \frac{2\pi}{\omega} \quad \lambda = \frac{2\pi}{k}$

DUNQUE

$$\omega = \frac{2\pi}{T} = 3.5 \frac{\text{rad}}{\text{s}} \quad k = \frac{2\pi}{\lambda} = 2.99 \frac{1}{\text{m}}$$

QUINDI

$$\xi(x,t) = (0.16 \text{ m}) \sin\left((2.99 \text{ m}^{-1})x - (3.5 \frac{\text{rad}}{\text{s}})t + \varphi\right)$$

POSSO ANCORA IMPORRE

$$\xi(x=0, t=0) \equiv A = 0.16 \text{ m} \Rightarrow (0.16 \text{ m}) \sin \varphi = (0.16 \text{ m})$$

$$\Rightarrow \varphi = \frac{\pi}{2} + 2m\pi, \quad m \in \mathbb{Z}$$

HO DETERMINATO DUNQUE

$$\boxed{\xi(x,t) = A \sin(kx - \omega t + \varphi)}$$

10

$$\lambda = 60 \text{ cm}$$

$$\nu = 0.5 \text{ Hz}$$

$$v = 1.5 \frac{\text{m}}{\text{s}}$$

DETERMINA:

- ω spostamento δ_y
 $\xi(x=0, \tau) = \text{MINIMO}$

$$A \quad x_1 = 1.2 \text{ m}$$

QUANDO

$$\nu = \frac{1}{T} \Rightarrow T = \frac{1}{\nu} = 2 \text{ s}$$

$$T = \frac{2\pi}{\omega} \Rightarrow \omega = \frac{2\pi}{T} = 3.14 \frac{\text{rad}}{\text{s}}$$

$$\omega = kv \Rightarrow k = \frac{\omega}{v} = 2.09 \text{ m}^{-1}$$

$$\lambda = \frac{2\pi}{k} = 3.01 \text{ m}$$

DUNQUE POSSO SCRIVERE

$$\xi(x, t) = A \sin(kx - \omega t)$$

VOGLIO τ T.C. $\xi(0, \tau) = -A \Rightarrow A \sin(-\omega\tau) = -A$

$$\Rightarrow -\sin(\omega\tau) = -1 \Rightarrow \sin(\omega\tau) = 1 \Rightarrow \omega\tau = \frac{\pi}{2} + 2m\pi \quad m \in \mathbb{Z}$$

$$\Rightarrow \tau = \frac{\pi}{2\omega} + \frac{2m\pi}{\omega}$$

DUNQUE

$$\begin{aligned} \xi(x_1 = 1.2, \tau = 0.5) &= A \sin(kx_1 - \omega\tau) = (0.6 \text{ m}) \sin\left(2.09 \cdot 1.2 - \frac{\pi}{2} - 2m\pi\right) \\ &= (0.6 \text{ m}) \sin\left(2.5 - \frac{\pi}{2}\right) \end{aligned}$$

$$\Rightarrow \boxed{\delta_y \equiv \xi(x_1, \tau) = 0.48 \text{ m}}$$

11

ONDA sin

$$\nu = 25 \text{ Hz}$$

$$\lambda = 24 \text{ cm}$$

$$A = 0,3 \text{ cm}$$

TROVA

- ν

- DETERMINA $\xi(x, t)$ (SE $\xi(0, 0) = 0$)

HO $\xi(x, t) = A \sin(kx - \omega t)$

$$T = \frac{1}{\nu} \quad \omega = \frac{2\pi}{T} \Rightarrow \omega = 2\pi\nu = 157,08 \frac{\text{rad}}{\text{s}}$$

$$\lambda = 24 \text{ cm}$$

$$\lambda = \frac{v}{\nu}$$

$$\Rightarrow v = \lambda\nu = 6 \text{ m/s}$$

$$k = \frac{\omega}{v} = 26,18 \text{ m}^{-1}$$

DUNQUE

SCRIVO

$$\xi(x, t) = (0,3 \text{ cm}) \sin\left((26,18 \text{ m}^{-1})x - (157,08 \frac{\text{rad}}{\text{s}})t\right)$$

12

$$\rho_L = 6 \frac{g}{cm}$$

$$y = 3 \cos\left(\frac{\pi}{6}(x - 360t) + 2\right)$$

$$[x] = [y] = cm$$

$$[t] = s$$

ONDA IN UNA FUNE TESA

DETERMINA:

- AMPIEZZA, λ , ν , v

- TENSIONE, v_T

- Δx se $\Delta \phi = \frac{\pi}{6}$

- $\Delta \phi$ in x_1 con $\Delta t = 10^{-2} s$

IN GENERALE SCRIVO

$$y(x, t) = y_0 \cos\left(\frac{2\pi}{\lambda}(x - vt) + \phi\right)$$

QUINDI:

$$y_0 = 3 \text{ cm}$$

$$\frac{2\pi}{\lambda} = \frac{\pi}{6} \Rightarrow \lambda = 12 \text{ cm}$$

$$\phi = 2 \text{ rad}$$

$$v = 360 \frac{cm}{s}$$

$$\nu = \frac{v}{\lambda}$$

$\Rightarrow$

$$\nu = 30 \text{ Hz}$$

IN UNA CORDA TESA SO

$$v = \sqrt{\frac{T}{\rho_L}}$$

$\Rightarrow$

$$T = \rho_L v^2$$

$$\Rightarrow T = 6 \frac{10^{-3}}{10^{-2}} \frac{kg}{m} \cdot (360 \cdot 10^{-2})^2 \frac{m^2}{s^2}$$

$\Rightarrow$

$$T = 7.776 \text{ N}$$

$$v_T = \frac{\partial \xi}{\partial t} = 3 \frac{\pi}{6} (-360) \left(-\sin\left(\frac{\pi}{6}(x - 360t) + 2\right) \right) \\ = 180\pi \sin\left(\frac{\pi}{6}(x - 360t) + 2\right)$$

$$\text{MAX} \Rightarrow \sin = 1 \Rightarrow v_T^{\text{MAX}} = 180\pi = 565.49 \frac{\text{cm}}{\text{s}} = \boxed{5.65 \frac{\text{m}}{\text{s}}}$$

$$\text{HO} \quad \phi_1 = \frac{\pi}{6}(x_1 - 360\tau) + 2$$

$$\phi_2 = \frac{\pi}{6}(x_2 - 360\tau) + 2$$

$$\text{Vogliamo} \quad \Delta\phi = \phi_2 - \phi_1 = \frac{\pi}{6} \Rightarrow \frac{\pi}{6}(x_2 - 360\tau - x_1 + 360\tau) = \frac{\pi}{6}$$

$$\Rightarrow \boxed{x_2 - x_1 = 1 \text{ cm}}$$

$$\text{ORA HO} \quad \phi_1 = \frac{\pi}{6}(x_1 - 360t_1) + 2$$

$$\phi_2 = \frac{\pi}{6}(x_1 - 360t_2) + 2$$

$$\text{Vogliamo} \quad \Delta\phi = \phi_2 - \phi_1 = \frac{\pi}{6}(x_1 - 360t_2 - x_1 + 360t_1) = \frac{\pi}{6} 360(t_1 - t_2)$$

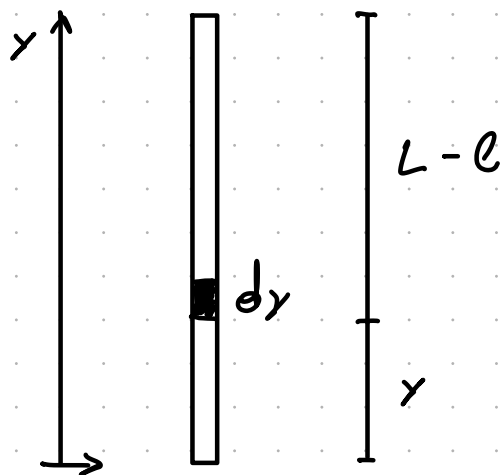
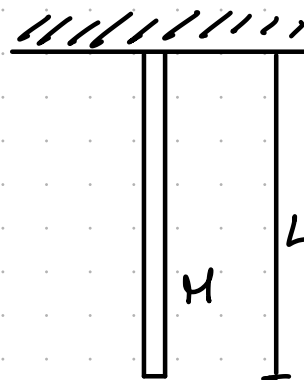
$$\Rightarrow \Delta\phi = -60\pi \Delta t \Rightarrow \Delta t = 10^{-2} \text{ s} \quad \boxed{\Delta\phi = -0.6\pi \text{ rad} = -1.88 \text{ rad}}$$

13

M, L

Dimostra:

- $v = \sqrt{g y}$
- $t = 2 \sqrt{\frac{L}{g}}$



$$\Rightarrow \rho_L = \frac{M}{L}$$

dy sente $F_G = m g$

$m = \text{MASSA CONTENUTA IN } y = \rho_L y$

$$\Rightarrow F_G = \rho_L y g$$

Dunque so $v = \sqrt{\frac{T}{\rho_L}}$ per una curva tesa, per cui

$$v = \sqrt{\frac{F_G}{\rho_L}} = \sqrt{\frac{\rho_L y g}{\rho_L}} \Rightarrow \boxed{v = \sqrt{y g}}$$

ricordo

$$v = \frac{dy}{dt} \Rightarrow dt = \frac{dy}{v} \Rightarrow \int_0^t dt' = \frac{1}{\sqrt{g}} \int_0^L \frac{dy}{\sqrt{y}} = \frac{1}{\sqrt{g}} \left. \frac{\sqrt{y}}{\frac{1}{2}} \right|_0^L = \boxed{2 \sqrt{\frac{L}{g}}}$$

Entrambi i risultati non dipendono dalla massa M della fune.

ESERCITAZIONE 2

1 $\rho = 2.7 \frac{\text{g}}{\text{cm}^3}$ ONDA SIN
 $k = 0.5 \frac{\text{rad}}{\text{m}}$ $\omega = 2530 \frac{\text{rad}}{\text{s}}$

DETERMINA:

- γ
- $\xi_0 = 2 \cdot 10^{-6} \text{ m}$, F_{MAX}
- I

TROVO $v = \frac{\omega}{k} = 5060 \frac{\text{m}}{\text{s}}$

IN UNA SBARRA SOLIDA SO CHE PER LE ONDE LONGITUDINALI VALE

$$\begin{aligned} v &= \sqrt{\frac{\gamma}{\rho}} \Rightarrow \gamma = \rho v^2 = 2.7 \frac{10^{-3}}{10^{-6}} \frac{\text{kg}}{\text{m}^3} \cdot (5060)^2 \frac{\text{m}^2}{\text{s}^2} \\ &= 2.7 \cdot (5060)^2 \cdot 10^3 \frac{\text{kg}}{\text{m} \cdot \text{s}^2} \\ &= 6.9 \cdot 10^{10} \frac{\text{kg}}{\text{m}^2} \frac{\text{m}}{\text{s}^2} = 6.9 \cdot 10^{10} \frac{\text{N}}{\text{m}^2} \\ &= \boxed{69 \frac{\text{GN}}{\text{m}^2}} \end{aligned}$$

con $\xi_0 = 2 \cdot 10^{-6} \text{ m}$ so SCRIVERE L'ESPRESSIONE DELL'ONDA

$$\xi(x, t) = \xi_0 \sin(kx - \omega t)$$

ORA UTILIZZO LA LEGGE DI HOOKE:

$$\sigma = Y \frac{\partial \xi}{\partial x} = \frac{F}{S} \quad (\text{SFORZO})$$

QUINDI

$$\frac{\partial \xi}{\partial x} = k \xi_0 \cos(kx - \omega t)$$

$$\sigma = Y \frac{\partial \xi}{\partial x} = k Y \xi_0 \cos(kx - \omega t)$$

$$\sigma = \sigma_{\max} \quad \text{SSE} \quad \cos(kx - \omega t) = 1 \quad \Rightarrow \quad \sigma_{\max} = k Y \xi_0 = 69 \frac{\text{N}}{\text{m}^2}$$

VALE

$$I = \omega_e v \quad \text{DOVE} \quad \omega_e = \frac{1}{2} \rho_e \omega^2 \xi_0^2$$

QUINDI

$$I = \frac{1}{2} \rho_e \omega^2 \xi_0^2 v = 174.89 \frac{\text{W}}{\text{m}^2}$$

2

IN ACQUA, $v = 1420 \frac{m}{s}$

$$A = 10^{-3} \text{ mm}$$

$$\lambda = 50 \text{ cm}$$

$$(x=0, t=0)$$

S. TROVA CON L'ONDA IN $x = -0.001 \text{ mm}$

DETERMINA:

- L'ESPRESSIONE DELL'ONDA
- TROVA LA POSIZIONE A $t = 0.75 \text{ s}$ DI $x_1 = 1 \text{ m}$, $x_2 = 1.25 \text{ m}$
- EQ. ONDA PER $x = 1 \text{ m}$
- β
- I E Δp_{MAX}
- ESPRIMERLA COME ONDA DI PRESSIONE

TROVO: $k = \frac{2\pi}{\lambda} = 12.56 \frac{\text{rad}}{\text{m}}$

$$\omega = kv = 17835.2 \frac{\text{rad}}{\text{s}}$$

POSSO IMPORRE: $(x=0, t=0)$ CON L'ONDA VOGLIO CHE SIA
IN $x = -0.001 \text{ mm}$

$$\delta x(x, t) = A \sin(kx - \omega t + \varphi)$$

$$\delta(x=0, t=0) = A \sin \varphi \equiv -0.001 \text{ mm} \Rightarrow \sin \varphi = -1$$

$$\Rightarrow \varphi = \frac{3\pi}{2} + 2m\pi, \quad m \in \mathbb{Z}$$

VALE $\sin\left(\frac{3\pi}{2} + 2m\pi + \alpha\right) = -\cos \alpha$

PER CUI

$$\delta x(x, t) = -A \cos(kx - \omega t)$$

HO $\tau = 0.75 \text{ s}$, $x_1 = 1 \text{ m}$, $x_2 = 1.25 \text{ m}$

$$\delta(x_1, \tau) = -A \cos(k - 0.75\omega) = -0.879 A = -0.88 \cdot 10^{-3} \text{ mm}$$

$$\delta(x_2, \tau) = -A \cos(1.25k - 0.75\omega) = +0.88 A = 0.88 \cdot 10^{-3} \text{ mm}$$

DUNQUE SI RITROVANO IN

$$x'_1 = x_1 + \delta(x_1, \tau) = 0.99999912 \text{ m}$$

$$x'_2 = x_2 + \delta(x_2, \tau) = 1.25000088 \text{ m}$$

SE $x = 1 \text{ m}$:

$$\delta x(1 \text{ m}, t) = -A \cos(k - \omega t)$$

SO CHE VALE $v = \sqrt{\frac{\beta}{\rho_0}} \Rightarrow \beta = \rho_0 v^2 = 2.01 \text{ GPa}$

CONOSCO $I = \omega_T v = \frac{1}{2} \rho_0 \omega^2 A^2 v = \frac{(\Delta p_{\max})^2}{2 \rho_0 v}$

DUNQUE

$$I = 225.17 \frac{W}{m^2}$$

$$\Rightarrow \Delta p_{\max} = \sqrt{2 \rho_0 v I} = 25250.03 \text{ Pa}$$

L'ONDA DI PRESSIONE È :

$$\Delta p = -\beta \frac{\partial(\delta x)}{\partial x} = -\beta A k \sin(kx - \omega t) = -A k (\rho_0 v^2) \sin(kx - \omega t)$$

NOTO

$$\Delta p_{\max} = \sqrt{2 \rho_0 v \cdot \frac{1}{2} \rho_0 \omega^2 A^2 v} = \sqrt{\rho_0^2 v^2 \omega^2 A^2} = \rho_0 v \omega A$$

$$\omega = kv \Rightarrow \Delta p_{\max} = \rho_0 A k v^2$$

QUINDI HO L'ONDA DI PRESSIONE

$$\Delta p = -\Delta p_{\max} \sin(kx - \omega t)$$

3 ONDA SFERICA IN $\Sigma = \frac{\pi}{2}$ sterad

$$x_1 = 12, \quad B_1 = 110 \text{ dB}$$

$$x_2 = 12 - 10 \text{ m} \quad B_2 = 115 \text{ dB}$$

DETERMINA : • R , P_m

• ATTENUAZIONE ARIA = $3 \frac{\text{dB}}{\text{km}}$; $B_3 = ?$ A $x_3 = 2 \text{ km}$

• LUNGHEZZA DI ASSORBIMENTO

$$\text{HO} \quad B_1 = 10 \log\left(\frac{I_1}{I_0}\right) \quad B_2 = 10 \log\left(\frac{I_2}{I_0}\right)$$

$$B_2 - B_1 = 10 \left(\log\left(\frac{I_2}{I_0}\right) - \log\left(\frac{I_1}{I_0}\right) \right) = 10 \log\left(\frac{I_2}{I_0} \frac{I_0}{I_1}\right)$$

$$\Rightarrow \log\left(\frac{I_2}{I_1}\right) = \frac{B_2 - B_1}{10} \Rightarrow \frac{I_2}{I_1} = 10^{\frac{B_2 - B_1}{10}} \Rightarrow \boxed{\frac{I_2}{I_1} = \sqrt{10}}$$

IN GENERALE VALE

$$I(r) = \frac{P_m}{\Sigma(r)} = \frac{P_m}{\Sigma r^2}$$

$$I_2 = \frac{P_m}{\frac{\pi}{2} (12-10)^2} \quad I_1 = \frac{P_m}{\frac{\pi}{2} 12^2}$$

$$\Rightarrow \frac{I_2}{I_1} = \sqrt{10} = \frac{R^2}{(R-10)^2} \Rightarrow (R^2 + 100 - 20R)\sqrt{10} = R^2$$

$$\Rightarrow (\sqrt{10} - 1) R^2 - 20\sqrt{10} R + 100\sqrt{10} = 0$$

$$R_{1,2} = \frac{20\sqrt{10} \pm \sqrt{4000 - 400(\sqrt{10}-1)\sqrt{10}}}{2(\sqrt{10}-1)} = \frac{63,25 \pm 35,56}{4,32} = \begin{cases} 22,9 \text{ m} \\ 6,40 \text{ m} \end{cases}$$

LA SOL ACCETTABILE È

$$R = 22,9 \text{ m}$$

RICORDO CHE $I_0 = 10^{-12} \frac{\text{W}}{\text{m}^2}$ PER CUI

$$B_1 = 10 \log\left(\frac{I_1}{I_0}\right) \Rightarrow I_1 = I_0 10^{\frac{B_1}{10}} \Rightarrow I_1 = 0,1 \frac{\text{W}}{\text{m}^2}$$

DUNQUE

$$I_1 = \frac{P_m}{\frac{\pi}{2} R^2} \Rightarrow P_m = \frac{\pi}{2} I_1 R^2 \Rightarrow P_m = 82,37 \text{ W}$$

A $x_3 = 2 \text{ km}$ POSSO CALCOLARE $I_3 = \frac{P_m}{\frac{\pi}{2} x_3^2} = 1,31 \cdot 10^{-5} \frac{\text{W}}{\text{m}^2}$

PER CUI $B'_3 = 10 \log\left(\frac{I_3}{I_0}\right) = 71,17 \text{ dB}$

CHE NON È ATTENUATO, $A = 3 \frac{dB}{km}$

$$B_3 = B'_3 - A \times x_3 = 65,17 \text{ dB}$$

LA LUNGHEZZA DI ASSORBIMENTO:

$$\frac{1}{\alpha} ; \quad \alpha = 0.23 \frac{A}{x} = 0,69 \text{ km}^{-1}$$

$$\Rightarrow \frac{1}{\alpha} = 1,45 \text{ km}$$

4

$$\delta x(x, t) = A \cos(kx - \omega t - \frac{\pi}{3}) \quad , \quad \text{SBARRA CILINDRICA}$$

$$\rho = 7.8 \cdot 10^3 \frac{\text{kg}}{\text{m}^3}$$

$$S_b = 1 \text{ dm}^2 = 10^{-2} \text{ m}^2$$

$$\nu = 200 \text{ Hz}$$

$$Y = 2 \cdot 10^{11} \text{ N/m}^2$$

$$P_m = 100 \text{ W}$$

- DETERMINARE :
- $\omega, k, \nu, T, \lambda, A$
 - v_L, a_L LONGITUDINALI
 - P_{IST} IN $x = \lambda/4$ A $t = T/2$
 - DISEGNA INSIEME $\delta x(x, 0), v(x, 0), a(x, 0), P_{\text{IST}}(x, 0)$

CALCOLO

$$\nu = \sqrt{\frac{Y}{\rho}} = 5063.7 \frac{\text{m}}{\text{s}}$$

$$\omega = 2\pi\nu = 1256.63 \frac{\text{rad}}{\text{s}}$$

$$k = \frac{\omega}{\nu} = 0.248 \frac{\text{rad}}{\text{m}}$$

$$T = \frac{1}{\nu} = 5 \cdot 10^{-3} \text{ s}$$

$$\lambda = \frac{2\pi}{k} = 25.33 \text{ m}$$

so

$$P_m = \frac{1}{2} \rho \omega^2 \nu S_b A^2 \Rightarrow A = \sqrt{\frac{2 P_m}{\rho \omega^2 \nu S_b}}$$

$$\Rightarrow A = 1.79 \cdot 10^{-5} \text{ m}$$

SCRIVO L'ESPRESSIONE DELL'ONDA

$$\delta x(x, t) = A \cos\left(kx - \omega t - \frac{\pi}{3}\right)$$

VALE

$$v_L = \frac{\partial(\delta x)}{\partial t} = A\omega \sin\left(kx - \omega t - \frac{\pi}{3}\right)$$

$$a_L = \frac{\partial(v_L)}{\partial t} = -A\omega^2 \cos\left(kx - \omega t - \frac{\pi}{3}\right) = -\omega^2 \delta x(x, t)$$

(OSCILLATORE
ARMONICO)

IN UNA SBARRA SOLIDA VALE

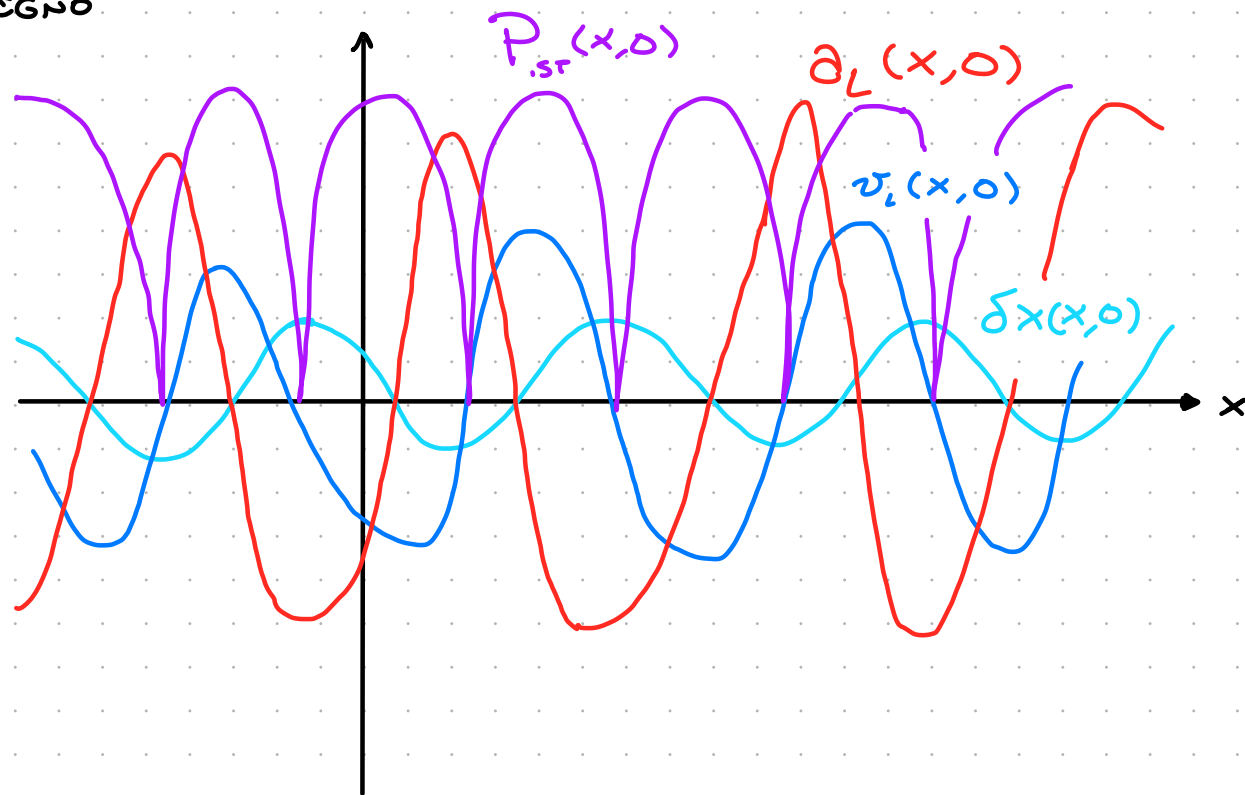
$$\begin{aligned} P(x, t) &= \vec{F} \cdot \vec{v}_L = -F v_L = -\left(Y S_b \frac{\partial(\delta x)}{\partial x}\right) \left(A\omega \sin\left(kx - \omega t - \frac{\pi}{3}\right)\right) \\ &= -Y A \omega S_b \left(-A k \sin\left(kx - \omega t - \frac{\pi}{3}\right)\right) \sin\left(kx - \omega t - \frac{\pi}{3}\right) \\ &= Y A^2 \omega k S_b \sin^2\left(kx - \omega t - \frac{\pi}{3}\right) \end{aligned}$$

RICORDO $k = \frac{\omega}{v}$; $Y = \rho v^2$

$$P(x, t) = \rho v A^2 \omega^2 S_b \sin^2\left(kx - \omega t - \frac{\pi}{3}\right)$$

$$\Rightarrow \boxed{P\left(\frac{1}{4}, \frac{T}{2}\right) = 49,9 \text{ W}}$$

Disegno



$$\delta x(0,0) = 8,9 \cdot 10^{-6} \text{ m}$$

$$v_L(0,0) = -0,0195 \text{ m/s}$$

$$a_L(0,0) = -14,13 \text{ m/s}^2$$

$$P_{sr}(0,0) = 149,8 \text{ W}$$

5

$$\lambda = 10 \text{ cm}$$

$$\rho_L = 300 \text{ g/m}$$

$$P = 400 \text{ W}$$

$$T = 120 \text{ N}$$

DETERMINA : $\bullet \nu_{\text{MAX}}$

SO IN UNA CORDA TESA : $v = \sqrt{\frac{T}{\rho}} = 20 \text{ m/s}$

$$P_{\text{IST}} = T A^2 \omega k \cos^2(kx - \omega t) \Rightarrow P_{\text{IST MAX}} = T A^2 \omega k$$

SO ANCHE $\omega = kv \Rightarrow P_{\text{IST MAX}} = T A^2 k^2 v \Rightarrow k = \sqrt{\frac{P_{\text{IST MAX}}}{T A^2 v}} = 4,08 \frac{\text{rad}}{\text{m}}$

PER CUI $\omega = 81,65 \text{ rad/s}$

DUNQUE $\nu = \frac{\omega}{2\pi} = 12,99 \text{ Hz}$

6

IN ACQUA

$$T = 10^\circ\text{C}$$

$$\rho = 50 \text{ Atm}$$

$$v_{\text{SUONO}} = 1420 \text{ m/s}$$

$$\nu = 1 \text{ kHz}$$

$$\Delta = 1 \text{ mm}$$

DETERMINA : • Δp_{max}
• ω_τ , I

VALE

$$I = \omega_\tau v = \frac{1}{2} \rho \omega^2 \Delta^2 v = \frac{(\Delta p_{\text{max}})^2}{2 \rho_0 v}$$

MI

SERVE

$$\omega = 2\pi\nu = 6283,19 \frac{\text{rad}}{\text{s}}$$

DUNQUE

$$I = \frac{1}{2} \rho \omega^2 \Delta^2 v = 2,79 \cdot 10^{-5} \frac{\text{W}}{\text{m}^2}$$

$$\Rightarrow \omega_\tau = \frac{I}{v} = 1,965 \cdot 10^{-8} \frac{\text{W}}{\text{m}^3}$$

$$\Rightarrow \Delta p_{\text{max}} = \sqrt{2 \rho_0 v I} = 8,88 \text{ Pa}$$

7 ONDA TRASVERSALE ARMONICA, $y_m = 1 \text{ cm}$, $\nu = 80 \text{ Hz}$
 IN UNA CORDA, $P = 10 \text{ W}$, $k = 25,1 \frac{\text{rad}}{\text{m}}$

DETERMINA:

- λ , v
- T , ρ_L
- y'_m se $\nu' = 20 \text{ Hz}$ e $P' = P/2 = 5 \text{ W}$

so $\lambda = \frac{2\pi}{k} = \boxed{0,25 \text{ m}}$; $v = \frac{\omega}{k} = \frac{2\pi\nu}{k} = \boxed{20,03 \frac{\text{m}}{\text{s}}}$

$\omega = 2\pi\nu = 502,65 \frac{\text{rad}}{\text{s}}$

IN UNA CORDA TESA HO

$$P_m = \frac{1}{2} T \omega k y_m^2 = \frac{1}{2} v^2 \rho_L \omega k y_m^2 \Rightarrow \begin{cases} T = \frac{2P_m}{\omega k y_m^2} = \boxed{15,85 \text{ N}} \\ \rho_L = \frac{2P_m}{v^2 \omega k y_m^2} = \boxed{0,0395 \frac{\text{kg}}{\text{m}}} \end{cases}$$

SFRUTTO

$P'_m = \frac{1}{2} v'^2 \rho_L \omega' k y_m'^2$; $\omega' = 2\pi\nu'$; $v' = \frac{2\pi\nu'}{k}$

$P'_m = \frac{v'^2}{2} \omega' k y_m'^2 \frac{2P_m}{v^2 \omega k y_m^2} \Rightarrow P'_m = \frac{v'^2 \omega' k y_m'^2 P_m}{v^2 \omega k y_m^2}$

$$\Rightarrow \gamma_m'^2 = \frac{P_m' v^2 \omega k \gamma_m'^2}{v'^2 \omega' k P_m}$$

$$\Rightarrow \gamma_m' = \sqrt{\frac{P_m' v^2 \omega k \gamma_m'^2}{v'^2 \omega' k P_m}} = \sqrt{\frac{P_m' v^2 \omega k \gamma_m'^2}{\frac{\omega'^2}{k^2} \omega' k P_m}} = \sqrt{\frac{P_m' v^2 \omega k^2 \gamma_m'^2}{\omega'^3 P_m}}$$

$$\Rightarrow \gamma_m' = \boxed{0,0566 \text{ m}}$$

8

$$\xi(t) = 0,1 \sin(6t) = \xi_0 \sin(6t)$$

$$[\xi_0] = \text{m}$$

$$[t] = \text{s}$$

$$T = 4 \text{ N}$$

$$\rho_L = 0,01 \text{ kg/m}$$

DETERMINA:

- v , ν

- Δx di due punti t.c. $t = \tau$ $\xi(x_1, \tau) = \xi(x_2, \tau) = 0,02 \text{ m}$

- L'EQUAZIONE DELLO SPOSTAMENTO di Q, $x_Q = 40 \text{ m}$

PER UNA CORDA SO

$$v = \sqrt{\frac{T}{\rho_L}}$$

$\Rightarrow$

$$v = 20 \text{ m/s}$$

L'ONDA È DEL TIPO

$$\xi(x, t) = \xi_0 \sin(kx + \omega t + \varphi)$$

$$\Rightarrow \omega = 6 \frac{\text{rad}}{\text{s}}$$

PER CUI

$$\nu = \frac{\omega}{2\pi}$$

$\Rightarrow$

$$\nu = 0,955 \text{ Hz}$$

TROVO $k = \frac{\omega}{v} = 0,3 \frac{\text{rad}}{\text{m}}$

;

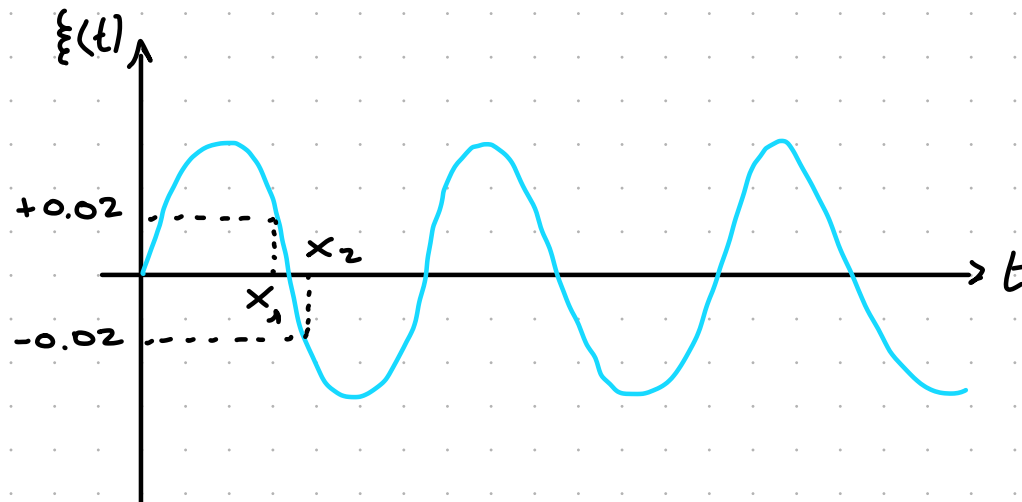
$$\lambda = \frac{2\pi}{k} = 20,94 \text{ m}$$

MI CONVIENE SCRIVERE

$$\xi(x, t) = \xi_0 \sin(\omega t - kx)$$

COSÌ POSSO VEDERE

$$\xi(x_a, t) = \xi_0 \sin(\omega t - kx_a) = 0,1 \cdot \sin(6t - 12)$$



CERCO UNA CONDIZIONE SULL'ARGOMENTO

$$\xi(x_i, \tau) = \xi_0 \sin(\omega \tau - kx_i) \Rightarrow \omega \tau - kx_i = \sin^{-1} \left(\frac{\xi(x_i, \tau)}{\xi_0} \right)$$

PER x_1 VOGLIO $\xi(x_1, \tau) = 0.02 \text{ m}$

PER x_2 VOGLIO $\xi(x_2, \tau) = -0.02 \text{ m}$

QUINDI

$$\begin{cases} \omega \tau - kx_1 = \sin^{-1} \left(\frac{0.02}{\xi_0} \right) \\ \omega \tau - kx_2 = \sin^{-1} \left(\frac{-0.02}{\xi_0} \right) \end{cases}$$

FACCIO LA DIFFERENZA

$$k(x_2 - x_1) = \sin^{-1}\left(\frac{0.02}{\xi_0}\right) - \sin\left(\frac{-0.02}{\xi_0}\right)$$

$$\Rightarrow \Delta x = \frac{1}{k} \left(\sin^{-1}\left(\frac{0.02}{\xi_0}\right) - \sin\left(\frac{-0.02}{\xi_0}\right) \right)$$

$$\Rightarrow \Delta x = 1.34 \text{ m}$$

ESERCITAZIONE 3

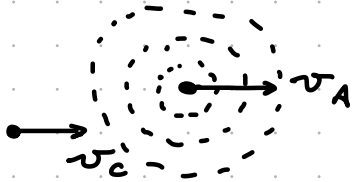
1

$$\nu_A = 1,602 \text{ kHz}$$

$$\nu_A = \text{cost} = 0$$

$$\nu_C = 2.63 \frac{\text{m}}{\text{s}}$$

$$\nu_C = 1590 \text{ Hz}$$



DETERMINA:

- ν_A
- ν_A' PRIMA DEL SORPASSO
- CON 2 AMBULANZE CON ν_A E ν_A' APPREZZA IL BATTIMENTO? TROVA ν_{CL} TC LO APPREZZI.

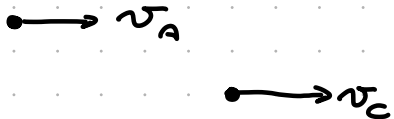
EFFETTO DOPPLER :

$$\nu_C = \nu_A \frac{c_s + v_C}{c_s + v_A} \Rightarrow c_s + v_C = \frac{\nu_C}{\nu_A} (c_s + v_A)$$

$$\Rightarrow \nu_A = \frac{\nu_A}{\nu_C} (c_s + v_C) - c_s$$

$$\Rightarrow \boxed{\nu_A = 5.24 \frac{\text{m}}{\text{s}}}$$

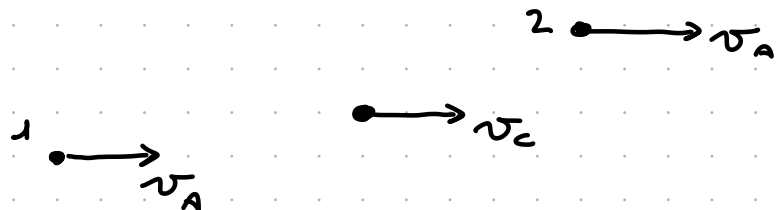
PRIMA DEL SORPASSO



$$\nu_C' = \nu_A \frac{c_s - v_C}{c_s - v_A} \Rightarrow$$

$$\boxed{\nu_C' = 1614.38 \text{ Hz}}$$

SE CI FOSSE RO 2 AMBULANZE :



IL CICLISTA SENTE $v_1 = v_C$ $v_2 = v_C$
 DUNQUE UNA FREQUENZA DI BATTIMENTO

$$v_b = |v_1 - v_2| = 12.38 \text{ Hz}$$

DUNQUE NON APPREZZABILE.
 PER APPREZZARLO

$$v_b = \left| v_a \frac{c_s - v_{cl}}{c_s - v_a} - v_a \frac{c_s + v_{cl}}{c_s + v_a} \right|$$

$$\Rightarrow \frac{v_b}{v_a} = \frac{(c_s - v_{cl})(c_s + v_a) - (c_s + v_{cl})(c_s - v_a)}{c_s^2 - v_a^2}$$

$$\begin{aligned} \Rightarrow \frac{v_b}{v_a} (c_s^2 - v_a^2) &= c_s^2 + c_s v_a - c_s v_{cl} - v_a v_{cl} - (c_s^2 - c_s v_a + c_s v_{cl} - v_a v_{cl}) \\ &= \underline{c_s^2} + c_s v_a - c_s v_{cl} - \underline{v_a v_{cl}} - \underline{c_s^2} + c_s v_a - c_s v_{cl} + \underline{v_a v_{cl}} \\ &= 2c_s v_a - 2c_s v_{cl} \end{aligned}$$

$$\Rightarrow 2c_s v_{cl} = 2c_s v_a - \frac{v_b}{v_a} (c_s^2 - v_a^2)$$

$$\Rightarrow v_{cl} = v_a - \frac{v_b}{v_a} \frac{1}{2c_s} (c_s^2 - v_a^2)$$

$$\Rightarrow v_{cl} = 4.17 \frac{\text{m}}{\text{s}}$$

2

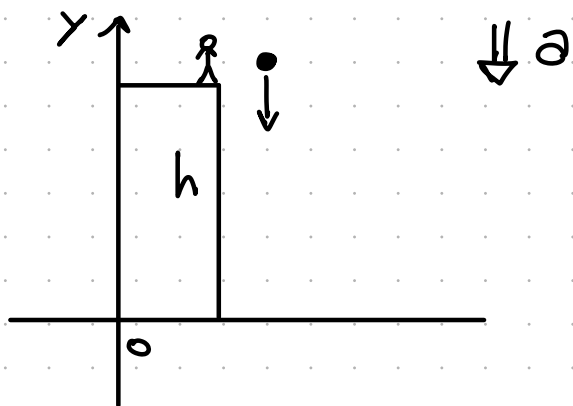
$$f = 512 \text{ Hz}$$

$$|\vec{a}| = 9,80 \text{ m/s}^2$$

$$h = 100 \text{ m}$$

DETERMINA:

- h' se $f' = 485 \text{ Hz}$
- $h'' = 0 \text{ m}$ $f_m = ?$ $t_m = ?$



$$\vec{a} = -9,8 \text{ m/s}^2$$

LEGGE ORARIA DI CADUTA

$$y(t) = h - \frac{1}{2} |a| t^2 \quad (t_0 = 0)$$

$$v(t) = -at$$

$y(\tau) = h'$ AVRÀ UNA CERTA v_d DA DOPPLER HO

$$f' = f \frac{c_s + v_r}{c_s + v_d}, \quad v_r = 0 \frac{\text{m}}{\text{s}} \Rightarrow f' = f \frac{c_s}{c_s + v_d}$$

$$\Rightarrow \frac{f c_s}{f'} = c_s + v_d \Rightarrow v_d = c_s \left(\frac{f}{f'} - 1 \right) = 19,09 \frac{\text{m}}{\text{s}}$$

CHE IL DIAPASON HA A : $|v(\tau)| = v_d = |a| \tau \Rightarrow \tau = \frac{v_d}{|a|} = 1,95 \text{ s}$

$\Rightarrow$ SPAZIO PERCORSO IN τ : $s(\tau) = \frac{1}{2} |a| \tau^2 = 18,63 \text{ m}$

MA IL SUONO CI METTE UN CERTO Δt PER ANDARE DA

$$y(\tau) = h - s(\tau) = 81.37 \text{ m} \quad \text{FINO ALLA SOMMITÀ:}$$

$$s(\tau) = c_s \Delta t \Rightarrow \Delta t = \frac{s(\tau)}{c_s} = 0.054 \text{ s}$$

TEMPO DURANTE IL QUALE IL DIAPASON CONTINUA A CADERE E
QUINDI QUANDO L'OSSERVATORE SENTE f' IL DIAPASON NON SI
TROVA PIÙ A $y(\tau)$ MA PIÙ IN BASSO.

È CORRETTO CONSIDERARE ANCHE IL Δt DI PROPAGAZIONE DEL
SUONO POICHÉ È UN TEMPO NON TRASCURABILE

$$\frac{\Delta t}{\tau} = 0.028 = 2.8\%$$

$$\text{PER CIÒ HO } h' = y(\tau) - \frac{1}{2} |a| \Delta t^2 = 81.356 \text{ m}$$

ARRIVA A TERRA

$$y(\tau_2) = 0 = h - \frac{1}{2} |a| \tau_2^2 \Rightarrow \tau_2 = \sqrt{\frac{2h}{|a|}} \Rightarrow \boxed{\tau_2 = 4.52 \text{ s}}$$

$$|v(\tau_2)| = 44.29 \text{ m/s}$$

$$\text{QUINDI CON DOPPLER: } f'' = f \frac{c_s}{c_s + |v(\tau_2)|} \Rightarrow \boxed{f'' = 453.45 \text{ Hz}}$$

COME PRIMA DEVO CONSIDERARE ANCHE IL TEMPO PER SALIRE

$$\Delta t' = \frac{h}{c_s} = 0.29 \frac{\text{m}}{\text{s}} \Rightarrow t_{\text{TOT}} = \tau_2 + \Delta t' = \boxed{4.81 \text{ s}}$$

3

$$L = 300 \text{ m}$$

$$\nu_s = 2000 \text{ Hz}$$

$$T = 40^\circ \text{C}$$

$$\Delta \nu_{\min} = 1 \text{ Hz}$$



DETERMINA :

- ν_R, ν'_s , $\nu_R = 2 \text{ m/s}$
- $\tau_{\min}$

LA VELOCITÀ DEL SUONO SARÀ : $c_s = 331.4 + 0.6T = 355.4 \frac{\text{m}}{\text{s}}$
USO DOPPLER

$$\nu_R = \nu_s \frac{c_s + \nu_R}{c_s} \Rightarrow \boxed{\nu_R = 2011.25 \text{ Hz}}$$

ORA PER ONDE SFERICHE ν'_s IMMAGINO R COME SORGENTE CHE RIFLETTE CON ν_R :

$$\nu'_s = \nu_R \frac{c_s}{c_s - \nu_R} \Rightarrow \boxed{\nu'_s = 2022.63 \text{ Hz}}$$

LA VELOCITÀ ν'_R PER NON ESSERE INDIVIDUATO DEV'ESSERE :

$$\nu''_s = \nu_{RL} \frac{c_s}{c_s - \nu_{RL}} \leq \nu_{SL} = 2001 \text{ Hz} \Rightarrow \nu_s \frac{c_s + \nu_{RL}}{c_s} \frac{c_s}{c_s - \nu_{RL}} = \nu_{SL}$$

$$\Rightarrow \frac{c_s + \nu_{RL}}{c_s - \nu_{RL}} = \frac{\nu_{SL}}{\nu_s} \Rightarrow c_s + \nu_{RL} = \frac{\nu_{SL}}{\nu_s} (c_s - \nu_{RL})$$

$$\Rightarrow C_s \left(1 - \frac{v_{SL}}{v_s} \right) = -v_{RL} \left(1 + \frac{v_{SL}}{v_L} \right)$$

$$\Rightarrow C_s \left(\frac{v_s - v_{SL}}{v_s} \right) = -v_{RL} \left(\frac{v_L + v_{SL}}{v_L} \right)$$

$$\Rightarrow v_{RL} = \frac{v_{SL} - v_s}{v_{SL} + v_s} C_s \quad \Rightarrow$$

$$v_{RL} = 0.089 \frac{m}{s}$$

LA LEGGE ORARIA È : $s(t) = v_{RL} t$

$$\Rightarrow s(T_m) = L = v_{RL} T_m \Rightarrow T_m = \frac{L}{v_{RL}} \Rightarrow$$

$$\begin{aligned} T_m &= 3370.79 \text{ s} \\ &= 56.18 \text{ min} \\ &= 56 \text{ min}, 11 \text{ s} \end{aligned}$$

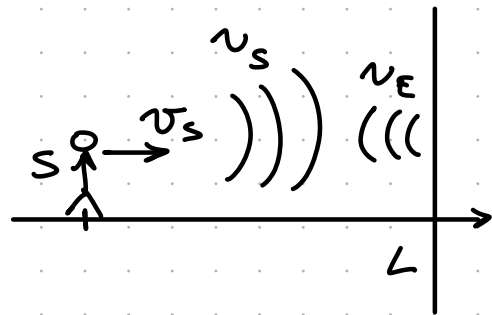
4

$$\nu_s = 256 \text{ Hz}$$

$$\nu_s = 1,33 \text{ m/s}$$

DETERMINA :

- ν_b TRA ν_s ED ECO
- $\nu = ?$ T.C. $\nu'_b = 5 \text{ Hz}$



$$HO \quad c_s = 343 \text{ m/s}$$

USO DOPPLER PER TROVARE L'ECO

$$\nu_E = \nu_s \frac{c_s}{c_s - v_s} = 256,99 \text{ Hz}$$

RIFLETTE LE ONDE A ν_E E S SENTE L'ECO

$$\nu'_E = \nu_E \frac{c_s + v_s}{c_s} = 257,98 \text{ Hz}$$

DUNQUE SENTIRA I BATTIMENTI :

$$\nu_B = |\nu_s - \nu'_E| = 1,99 \text{ Hz}$$



ORA

RUTILIZZO LE STESSA VARIABILI
IMPONGO (CON S CHE SI ALLONTANA):

$$\nu_B = |\nu'_E - \nu_s| = 5 \text{ Hz}$$

QUELLA CHE EMETTE : $\nu_s = 256 \text{ Hz}$

QUELLA CHE ASSORBE E RIMETTE IL MURO: $\nu_E = \nu_s \frac{c_s}{c_s + v_s}$

L'ECO CHE SENTE S : $\nu'_E = \nu_E \frac{c_s - v_s}{c_s}$

DONQUE

$$\nu_B = \left| \nu_E \frac{c_s - v_s}{c_s} - \nu_s \right| \Rightarrow \nu_B = \left| \nu_s \frac{c_s}{c_s + v_s} \frac{c_s - v_s}{c_s} - \nu_s \right|$$

$$\Rightarrow \nu_B = \left| \nu_s \frac{c_s - v_s}{c_s + v_s} - \frac{c_s + v_s}{c_s + v_s} \nu_s \right| = \left| \nu_s \left(\frac{c_s - v_s - c_s - v_s}{c_s + v_s} \right) \right|$$

$$\Rightarrow \nu_B = \left| \nu_s \frac{-2v_s}{c_s + v_s} \right| \Rightarrow \nu_B = \nu_s \frac{2v_s}{c_s + v_s}$$

$$\Rightarrow \nu_B c_s + \nu_B v_s = 2\nu_s v_s$$

$$\Rightarrow \nu_B c_s = \nu_s (2\nu_s - \nu_B)$$

$$\Rightarrow \nu_s = \frac{\nu_B}{2\nu_s - \nu_B} c_s \Rightarrow \boxed{v_s = 3.38 \frac{\text{m}}{\text{s}}}$$

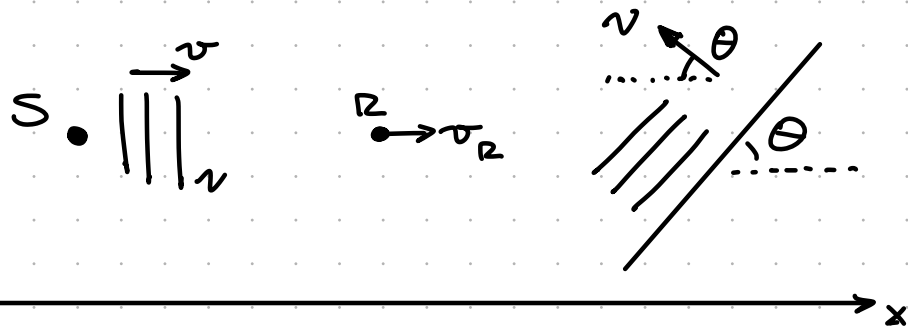
5 ONDE PIANE, $\nu = 800 \text{ Hz}$, $\lambda_0 = 0.03 \text{ mm}$, IN ARIA $\rho_0 = 1.225 \frac{\text{kg}}{\text{m}^3}$
 $\nu = 340 \frac{\text{m}}{\text{s}}$

$$\theta = 45^\circ$$

$$\nu_R = 10 \frac{\text{m}}{\text{s}}$$

DETERMINA :

- $\sim$ BATTIMENTO
- I , L ENERGENZA E RIFLESSA
- EQUAZIONI ONDE E BATTIMENTO



TIRO FUORI E INFORMAZIONI DALL'ONDA ENERGENZA DA S

$$\omega = 2\pi\nu = 5026.55 \frac{\text{rad}}{\text{s}}$$

$$k = \frac{\omega}{\nu} = 14.78 \frac{\text{rad}}{\text{m}}$$

$$\lambda = 0.425 \text{ m}$$

L'EQUAZIONE DELL'ONDA EMessa È :

$$\xi_E(x, t) = \xi_0 \sin(kx - \omega t + \varphi_E) = (0.03 \text{ mm}) \sin(14.78 x - 5026.55 t + \varphi_E)$$

R VIENE INVESTITO DA UN ONDA (DA S) DI FREQUENZA :

$$\nu_R^E = \nu \frac{v - v_R}{v} = 776.47 \text{ Hz}$$

L'ONDA EMessa DA S ARRIVA ALLA PARETE E VIENE RIFLESSA
ALLA STESSA ν , MA IN DIREZIONE $\theta = 45^\circ$ QUINDI R
SARÀ INVESTITO DA UN'ONDA RIFLESSA DI FREQUENZA :

$$\nu_R^R = \nu \frac{v \cos \theta + v_R}{v \cos \theta} = 833.28 \text{ Hz}$$

QUINDI SENTO UNA ν_B DI BATTIMENTO :

$$\nu_B = |\nu_R^R - \nu_R^E| = 56.81 \text{ Hz}$$

CERCO INFORMAZIONI DELL'ONDA RIFLESSA (REGRESSIVA)

$$\nu = 800 \text{ Hz}$$

$$\omega^R = \omega = 5026.55 \frac{\text{rad}}{\text{s}}$$

$$|\vec{k}^R| = |k| = 14.78 \frac{\text{rad}}{\text{m}}$$

$$\lambda^R = \lambda = 0.429 \text{ m}$$

$$|\vec{v}^R| = v = 340 \text{ m/s}$$

MA ATTENZIONE PERCHÈ NELL'ESPRESSIONE AVRÒ $\vec{k}^R \cdot \vec{x}$

$$\begin{cases} v_x^R = |\vec{v}^R| \cos \theta = 240.4 \frac{\text{m}}{\text{s}} \\ v_y^R = |\vec{v}^R| \sin \theta = 240.4 \frac{\text{m}}{\text{s}} \end{cases} \Rightarrow \begin{cases} k_x^R = k \cos \theta = 10.45 \frac{\text{rad}}{\text{m}} \\ k_y^R = k \sin \theta = 10.45 \frac{\text{rad}}{\text{m}} \end{cases}$$

METTENDO APPOSTO, SEGNI HO:

$$\vec{k} = (-k_x^R, k_y^R, 0) = (-10.45, 10.45, 0)$$

L'EQUAZIONE SARÀ DUNQUE:

$$\xi(\vec{x}, t) = \xi_0 \sin(-k_x^R x + k_y^R y - \omega t + \varphi_E)$$

L'INTENSITÀ È: $I = \frac{1}{2} \rho_0 \omega^2 \xi_0^2 v$

$$I^E = 4.74 \frac{\text{W}}{\text{m}^2}$$

$$\begin{cases} I_x^R = 3.35 \frac{\text{W}}{\text{m}^2} \\ I_y^R = 3.35 \frac{\text{W}}{\text{m}^2} \end{cases} \Rightarrow I^R = I^E = 4.74 \frac{\text{W}}{\text{m}^2}$$

IL LIVELLO SONORO $L = 10 \log\left(\frac{I}{I_0}\right)$, $I_0 = 10^{-12} \frac{\text{W}}{\text{m}^2}$

$$L^R = L^E = 126.75 \text{ dB}$$

L'ESPRESSIONE

PER

1

BATTIMENTI

È :

$$\omega = \frac{\omega_E - \omega_R}{2} = 0$$

$$\omega_T = \frac{\omega_E + \omega_R}{2} = \omega$$

$$S(t) = \xi_E + \xi_R = \boxed{2 \xi_0 \sin(\omega t)}$$

6

$$\nu_s = 100 \text{ Hz}$$

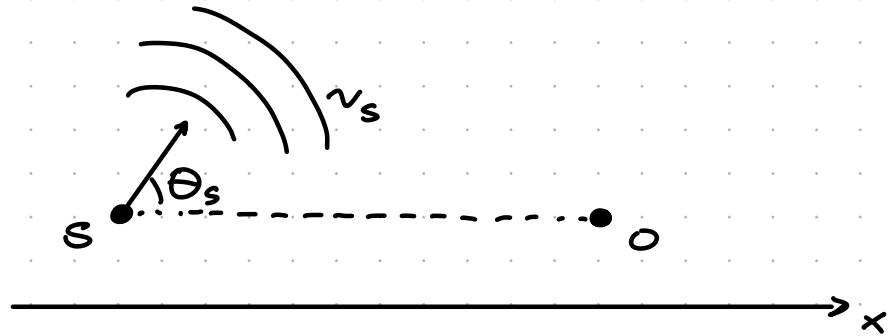
$$v_s = 19 \text{ m/s}$$

$$\theta_s = 60^\circ$$

$$\nu_o = 0 \text{ m/s}$$

$$c_s = 330 \text{ m/s}$$

DETERMINA : • ν_o



DEVO APPLICARE DOPPLER :

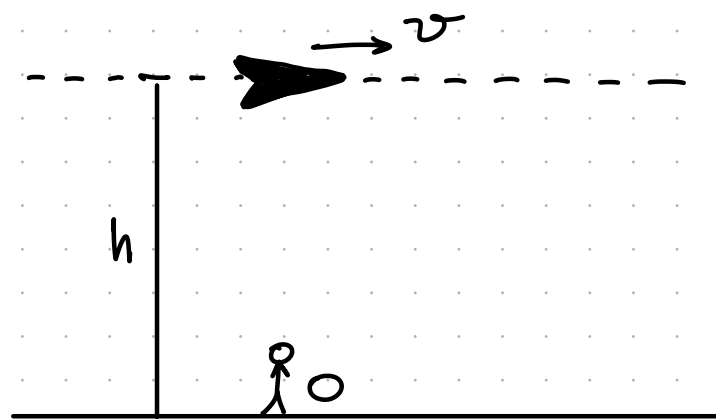
$$\nu_o = \nu_s \frac{c_s}{c_s - v_s \cos \theta} = \boxed{102,96 \text{ Hz}}$$

7

$$MACH = M_1 = 2$$

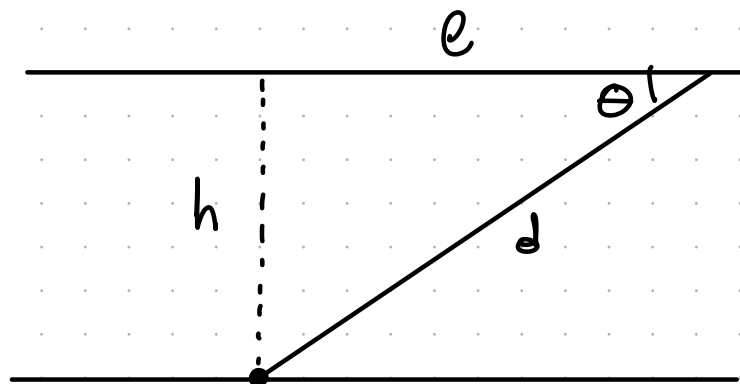
$$h = 9500 \text{ m}$$

DETERMINA : $x(t)$ SE $t = \text{TEMPO}$ IN
CUI O SENTE IL SUONO



$$M_1 = \frac{v}{c_s} \Rightarrow v = 2c_s = 686 \text{ m/s}$$

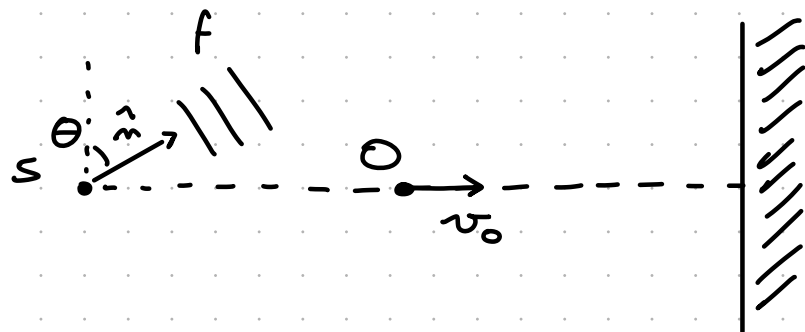
$$\sin \theta = \frac{c_s}{v} = \frac{1}{2} \Rightarrow \theta = \sin^{-1}\left(\frac{c_s}{v}\right) = \frac{\pi}{6}$$



$$h = d \sin \theta \Rightarrow d = \frac{h}{\sin \theta} = \frac{h v}{c_s} = 2h$$
$$= 19000 \text{ m}$$

$$e = d \cos \theta = \boxed{16454.5 \text{ m}}$$

8



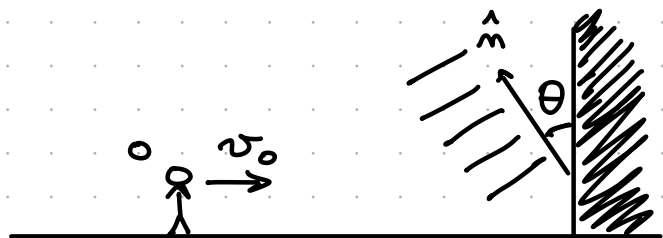
$$\theta = 30^\circ$$

$$f_0 = \frac{11}{8} f$$

CONSIDERARE SOLO L'ONDA RIFLESSA

LA SORGENTE EMETTE ONDE PIANE VERSO IL MURO, CHE ASSORBE E RIMETTE ALLA STESSA f .

LA LEGGE DELLA RIFLESSIONE CI DICE CHE LE ONDE SONO RIFLESSE CON UN ANGOLO RISPETTO LA VERTICALE UGUALE A QUELLO DELLA SORGENTE S , OSSIA, θ .



O SENTE SOLO LE ONDE CHE VENGONO DAL MURO

$$\hat{m} = (-\sin\theta, \cos\theta, 0)$$

USO DOPPLER:
IN COMPONENTI

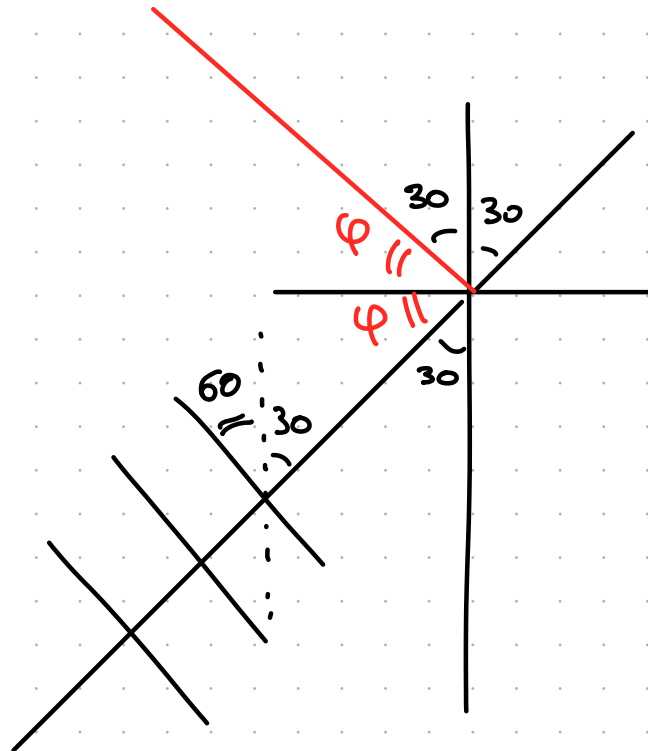
$$f_0 = f \frac{c_s \sin\theta + v_0}{c_s \sin\theta}$$

$$\Rightarrow c_s f_0 \sin \Theta = c_s f \sin \Theta + f v_0$$

$$\Rightarrow c_s \sin \theta (f_0 - f) = f v_0 \quad \Rightarrow c_s \sin \theta \left(\frac{v}{\lambda} - 1 \right) f = f v_0$$

$$\Rightarrow c_s \sin \Theta \frac{11-8}{8} = v_0 \quad \Rightarrow v_0 = \frac{3}{8} \sin \Theta c_s$$

$$\sin(30) = \frac{1}{2} \Rightarrow v_0 = \frac{3}{16} C_s$$



119

$$\rho_1 = 10^{-2} \text{ kg/m}$$

DETERMINA:

$$\bullet v_1, v_2$$

$$\bullet Y_R, Y_T \quad \text{AMPIEZZE RIFLETTE E TRASMESSE}$$

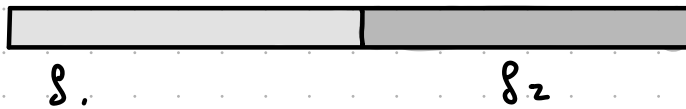
$$\bullet \text{ ONDA R ED I SONO IN FASE? }$$

$$\rho_2 = 2\rho_1$$

$$Y_m = 0.5 \text{ cm}$$

$$T = 30 \text{ N}$$

HO



SO IN UNA CORDA TESA:

$$v = \sqrt{\frac{T}{\rho_L}}$$

DUNQUE

$$v_1 = 54.77 \frac{\text{m}}{\text{s}}$$

$$v_2 = 38.73 \frac{\text{m}}{\text{s}}$$

LE EQUAZIONI D'ONDA SONO

$$\begin{cases} Y_I(x, t) = Y_m \sin(k_1 x - \omega t) \\ Y_R(x, t) = Y_R \sin(k_1 x + \omega t) \\ Y_T(x, t) = Y_T \sin(k_2 x - \omega t) \end{cases}$$

$$k_i = \frac{\omega}{v_i}$$

BISOGNA IMPORRE LA CONTINUITÀ DELLA FUNZIONE D'ONDA E DELLA FORZA NEL PUNTO DI GIUNZIONE (PONGO $x=0$)

$$\begin{cases} Y_I(0, t) + Y_R(0, t) = Y_T(0, t) \\ \frac{\partial}{\partial x} (Y_I(x, t) + Y_R(x, t)) \Big|_{x=0} = \frac{\partial}{\partial x} (Y_T(x, t)) \Big|_{x=0} \end{cases} \quad (F = YS \frac{\partial y}{\partial x})$$

$$\begin{cases} -Y_m \sin(\omega t) + Y_R \sin(\omega t) = -Y_I \sin(\omega t) \\ Y_m k_1 \cos(k_1 x - \omega t) \Big|_{x=0} + Y_R k_1 \cos(k_1 x + \omega t) \Big|_{x=0} = Y_I k_2 \cos(k_2 x - \omega t) \Big|_{x=0} \end{cases}$$

$$\begin{cases} Y_R = Y_m - Y_I \\ Y_m k_1 \cos(\omega t) + Y_R k_1 \cos(\omega t) = Y_I k_2 \cos(\omega t) \end{cases} ; \begin{cases} Y_R = Y_m - Y_I \\ Y_m k_1 + (Y_m - Y_I) k_1 = Y_I k_2 \end{cases}$$

$$\Rightarrow \begin{cases} Y_R = Y_m - Y_I \\ Y_m 2k_1 = Y_I (k_1 + k_2) \end{cases} ; \begin{cases} Y_R = \left(1 - \frac{2k_1}{k_1 + k_2}\right) Y_m \\ Y_I = \frac{2k_1}{k_1 + k_2} Y_m \end{cases}$$

$$\Rightarrow \boxed{\begin{cases} Y_R = \frac{k_2 - k_1}{k_1 + k_2} Y_m \\ Y_I = \frac{2k_1}{k_1 + k_2} Y_m \end{cases}} \quad k_1 = \frac{3}{v_1} \Rightarrow \begin{cases} Y_R = \frac{\frac{3}{v_2} - \frac{3}{v_1}}{\frac{3}{v_1} + \frac{3}{v_2}} Y_m \\ Y_I = 2 \frac{\frac{3}{v_1}}{\frac{3}{v_1} + \frac{3}{v_2}} Y_m \end{cases}$$

$$\Rightarrow \begin{cases} Y_R = \frac{\frac{1}{v_2} - \frac{1}{v_1}}{\frac{1}{v_1} + \frac{1}{v_2}} Y_m \\ Y_I = \frac{2}{v_1} Y_m \frac{1}{\frac{1}{v_1} + \frac{1}{v_2}} \end{cases} ; \begin{cases} Y_R = \frac{1}{v_1 v_2} (v_1 - v_2) \frac{v_1 v_2}{v_1 + v_2} Y_m \\ Y_I = \frac{2 Y_m}{v_1} \frac{v_1 v_2}{v_1 + v_2} \end{cases}$$

$$\Rightarrow \boxed{\begin{cases} Y_R = \frac{v_1 - v_2}{v_1 + v_2} Y_m \\ Y_I = \frac{2v_2}{v_1 + v_2} Y_m \end{cases}}$$

$$\Rightarrow \boxed{\begin{cases} Y_R = 8.58 \cdot 10^{-4} \text{ m} \\ Y_I = 4.14 \cdot 10^{-3} \text{ m} \end{cases}}$$

CALCOLO

IL

RAPPORTO

DI

RIFLESSIONE

$$r = \frac{Y_R}{Y_m} = 1.716 > 0 \Rightarrow$$

ONDA RIFLESSA IN
OPPOSIZIONE DI FASE
CON L'ONDA INCIDENTE

10

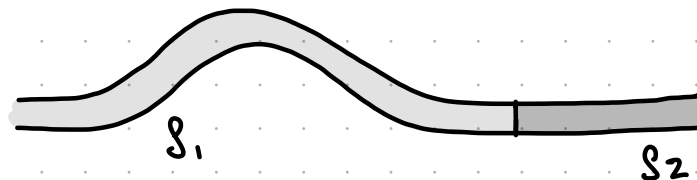
ONDA TESA OMOGENEA

$$y(x,t) = 0.25 \cos(17x - 82t)$$

TUTTO IN UN O

IN $x=0$ È COLLEGATA CON
UN'ALTRA CORDA

STESSA TENZIONE



DETERMINA:

- λ_I, ν_I, v_I
- $I_R = \frac{1}{4} I_I$ $\gamma_{OT} = \frac{1}{2} \gamma_{OI}$
- λ_T, ν_T, v_T
- $s_1 > s_2$ o $s_2 > s_1$?

HO $y_I(x,t) = 0.25 \cos(17x - 82t)$

DELLA FORMA $y(x,t) = y_0 \cos(kx - \omega t)$

DUNQUE HO:

$$\begin{cases} y_{0I} = 0.25 \text{ m} \\ k_I = 17 \frac{\text{rad}}{\text{m}} \\ \omega = 82 \frac{\text{rad}}{\text{s}} \end{cases}$$

CALCOLO

$$v_I = \frac{\omega}{k_I} = 4.82 \frac{\text{m}}{\text{s}}$$

$$\nu_I = \frac{\omega}{2\pi} = 13.05 \text{ Hz}$$

$$\lambda_I = \frac{2\pi}{k_I} = 0.37 \text{ m}$$

NOTA CHE VALGONO

$$\begin{cases} Y_{OR} = \frac{k_2 - k_1}{k_1 + k_2} Y_{OI} = \frac{v_1 - v_2}{v_1 + v_2} Y_{OI} \\ Y_{OT} = \frac{2k_1}{k_1 + k_2} Y_{OI} = \frac{2v_2}{v_1 + v_2} Y_{OI} \end{cases}$$

$$r = \frac{Y_{OR}}{Y_{OI}} = \frac{\sqrt{g_2} - \sqrt{g_1}}{\sqrt{g_2} + \sqrt{g_1}} \quad t = \frac{Y_{OT}}{Y_{OI}} = \frac{2\sqrt{g_1}}{\sqrt{g_2} + \sqrt{g_1}}$$

$$\begin{cases} r < 0 & \text{ONDA R IN FASE CON I} \\ r > 0 & \text{ONDA R OPP. DI FASE CON I} \end{cases}$$

$$\begin{cases} I_I = \frac{1}{2} g_1 \omega^2 Y_{OI}^2 v_I \\ I_R = \frac{1}{2} g_1 \omega^2 Y_{OR}^2 v_R \\ I_T = \frac{1}{2} g_2 \omega^2 Y_{OT}^2 v_T \end{cases}$$

$$R = \frac{I_R}{I_I} = \frac{Y_{OR}^2}{Y_{OI}^2} = r^2 = \left(\frac{\sqrt{g_2} - \sqrt{g_1}}{\sqrt{g_2} + \sqrt{g_1}} \right)^2$$

$$T = \frac{I_T}{I_I} = \frac{g_2 v_2 Y_{OT}^2}{g_1 v_1 Y_{OI}^2} = \frac{\sqrt{g_2}}{\sqrt{g_1}} t^2$$

LE ONDE SONO:

$$\begin{cases} y_I(x, t) = Y_{OI} \cos(k_1 x - \omega t) \\ y_R(x, t) = Y_{OR} \cos(k_1 x + \omega t) \\ y_T(x, t) = Y_{OT} \cos(k_2 x - \omega t) \end{cases}$$

MI VIENE DETTO:

$$\begin{cases} I_R = \frac{1}{4} I_I \\ Y_{OT} = \frac{1}{2} Y_{OI} \end{cases}$$

$$I_R = \frac{1}{4} I_I \Rightarrow \frac{1}{2} g_1 \omega^2 \gamma_{0R}^2 v_R = \frac{1}{4} \frac{1}{2} g_1 \omega^2 \gamma_{0I}^2 v_I$$

$$\text{MA} \quad v_I = \frac{v}{k_1} = v_R \Rightarrow \gamma_{0R}^2 = \frac{1}{4} \gamma_{0I}^2 \Rightarrow \boxed{\gamma_{0R} = \frac{1}{2} \gamma_{0I} = 0.125 \text{ m}}$$

POSSO GIÀ RISPONDERE ALLA DOMANDA 3:

$$r = \frac{\gamma_{0R}}{\gamma_{0I}} = 0.5 \Rightarrow r > 0 \Rightarrow \boxed{g_2 > g_1}$$

$$\gamma_{0T} = \frac{1}{2} \gamma_{0I} \Rightarrow \text{SFRUTTO} \quad R = \frac{I_R}{I_I} = \frac{1}{4} \quad \text{E} \quad 1 = R + T$$

$$\Rightarrow T = 1 - R = \frac{3}{4} \Rightarrow \frac{3}{4} = \frac{I_T}{I_I} \Rightarrow I_T = \frac{3}{4} I_I$$

$$\Rightarrow \frac{1}{2} g_2 \omega^2 \gamma_{0T}^2 v_T = \frac{3}{4} \frac{1}{2} g_1 \omega^2 \gamma_{0I}^2 v_I$$

$$\Rightarrow g_2 \frac{\gamma_{0I}^2}{4} \sqrt{\frac{T}{g_2}} = \frac{3}{4} g_1 \gamma_{0I}^2 \sqrt{\frac{T}{g_1}}$$

$$\Rightarrow \sqrt{g_2} = 3 \sqrt{g_1} \Rightarrow \boxed{g_2 = 9 g_1}$$

ANCHE

$$\boxed{\gamma_{0T} = \frac{1}{2} \gamma_{0I} = 0.125 \text{ m}}$$

PER TROVARE k_2 E v_2 SFRUTTO LA CONOSCENZA DI:

$$\begin{cases} \gamma_{0R} = \frac{v_1 - v_2}{v_1 + v_2} \gamma_{0I} \\ \gamma_{0T} = \frac{2k_1}{k_1 + k_2} \gamma_{0I} \end{cases} ; \begin{cases} \gamma_{0R}(v_1 + v_2) = (v_1 - v_2) \gamma_{0I} \\ \gamma_{0T}(k_1 + k_2) = 2k_1 \gamma_{0I} \end{cases}$$

$$\begin{cases} v_2(\gamma_{0R} + \gamma_{0I}) = v_1(\gamma_{0I} - \gamma_{0R}) \\ \gamma_{0T}k_2 = k_1(2\gamma_{0I} - \gamma_{0T}) \end{cases} ; \begin{cases} v_2 = \frac{\gamma_{0I} - \gamma_{0R}}{\gamma_{0I} + \gamma_{0R}} v_1 \\ k_2 = \frac{2\gamma_{0I} - \gamma_{0T}}{\gamma_{0T}} k_1 \end{cases}$$

DUPOI

$$\begin{aligned} v_2 &= 1,6 \text{ m/s} \\ k_2 &= 51 \text{ rad/m} \end{aligned}$$

$$\omega = k_2 v_2 = 81,6 \frac{\text{rad}}{\text{s}}$$

$$\nu = \frac{\omega}{2\pi} = 12,99 \text{ Hz}$$

$$\lambda_2 = \frac{2\pi}{k_2} = 0,123 \text{ m}$$

PROVO A RIFARE I CONTI SENZA ESPlicitARE I CONTI:

$$v_2 = \left(\gamma_{0I} - \frac{1}{2} \gamma_{0I} \right) \frac{1}{\gamma_{0I} + \frac{1}{2} \gamma_{0I}} v_1 = \frac{\gamma_{0I}}{2} \frac{1}{\frac{3}{2} \gamma_{0I}} v_1$$

$$\Rightarrow \boxed{v_2 = \frac{v_1}{3}}$$

$$k_2 = \frac{2\gamma_{0I} - \frac{1}{2}\gamma_{0I}}{\frac{1}{2}\gamma_{0I}} k_1 = \frac{3}{2}\gamma_{0I} \frac{2}{\gamma_{0I}} k_1 \Rightarrow \boxed{k_2 = 3k_1}$$

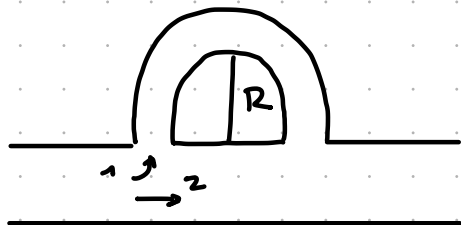
$$\omega_2 = k_2 v_2 = 3k_1 \frac{v_1}{3} \Rightarrow \boxed{\omega_2 = \omega_1}$$

$$\lambda_2 = \frac{2\pi}{k_2} = \frac{2\pi}{3k_1} \Rightarrow \boxed{\lambda_2 = \frac{1}{3}\lambda_1}$$

$$v_2 = \frac{\omega_2}{2\pi} \Rightarrow \boxed{v_2 = v_1}$$

1

$$\lambda = 42 \text{ cm}$$



DETERMINA : • R T.C. $I = I_{\text{max}}$

HO IL SUONO CHE SI DIVIDE IN 2 $\rightarrow$ SONO COERENTI

$$\lambda \Rightarrow k = \frac{2\pi}{\lambda} = 14,95 \frac{\text{rad}}{\text{m}}$$

LE ONDE HANNO STESSA AMPIEZZA $\Rightarrow I = 4 I_0 \cos^2 \frac{\delta}{2}$

$$\text{CON } \delta = \alpha_1 - \alpha_2$$

SEGUONO DUE PERCORSI DIVERSI :

ONDA 2 : (METTO $x=0$ NEL PUNTO IN CUI SI DIVIDONO)

$$x_2 = 2l$$

$$\text{ONDA 1 : } x_1 = \frac{1}{2} 2\pi l = \pi l$$

$$\text{PER CUI } \Delta x = (\pi - 2)l$$

$$\alpha_i = \omega t - kx_i - \varphi_i \quad \text{MA HO } \varphi_i = \varphi \quad \forall i$$

$$\Rightarrow \delta = k(x_2 - x_1) = k \Delta x = k l (\pi - 2)$$

10 VOGLIO INTERFERENZA DISTRUTTIVA

$$\cos\left(\frac{\delta}{2}\right) = 0 \Rightarrow \frac{\delta}{2} = \frac{\pi}{2} m \Rightarrow k l (\pi - 2) = m \pi$$

$$\Rightarrow l = \frac{m \pi}{k(\pi - 2)}$$

$$(m=1) \Rightarrow l = \frac{\pi}{k(\pi - 2)} = 0.184 \text{ m}$$

2

$$A = 0.1 \text{ mm}$$

$$\lambda = 20 \text{ cm}$$

$$\nu = 500 \text{ Hz}$$

$$\rho = 4 \text{ g/cm}^3$$

$$I_{\text{TOT}} = 59.16 \frac{\text{KW}}{\text{m}^2}$$

DETERMINA : • δ

UGUAL AMPIEZZA $\Rightarrow I_{\text{TOT}} = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta = 2I_0(1 + \cos \delta)$

$$\Rightarrow I_{\text{TOT}} = 4 I_0 \cos^2 \frac{\delta}{2}$$

L'INTENSITÀ DI UNA SOLA ONDA : $I = \frac{1}{2} \rho \omega^2 A^2 \nu$

$$\omega = 2\pi\nu = 3141.6 \frac{\text{rad}}{\text{s}}$$

$$\nu = \frac{\omega}{\lambda} = 100 \text{ m/s}$$

DUNQUE

$$I_0 = 19739.3 \text{ W/m}^2$$

PER CUI

$$\Rightarrow \frac{I_{\text{TOT}}}{2I_0} = 1 + \cos \delta \Rightarrow \cos \delta = \frac{I_{\text{TOT}}}{2I_0} - 1$$

$$\Rightarrow \cos \delta = \frac{1}{2} \quad \Rightarrow \quad \boxed{\delta = \frac{\pi}{3} + 2m\pi}$$

$$a) \quad x_1 = x_2 \quad \Rightarrow \quad \delta = \varphi_1 - \varphi_2 = kx_1 - \omega t + \phi_1 - kx_2 + \omega t - \phi_2 \\ = \Delta \phi$$

$$\Rightarrow \Delta \phi = \frac{\pi}{3} + 2m\pi$$

$$b) \quad \Delta x = 1 \text{ cm} \quad \Rightarrow \quad \delta = k \Delta x + \Delta \phi$$

$$\Rightarrow \Delta \phi = \frac{\pi}{3} + 2m\pi - k \Delta x$$

$$c) \quad \Delta \phi = 0 \quad \Rightarrow \quad \delta = k \Delta x \quad \Rightarrow \quad \Delta x = \frac{\delta}{k} = \frac{1}{k} \left(\frac{\pi}{3} + 2m\pi \right)$$

3

$$\Delta\varphi = 0 \quad \nu = 170 \text{ Hz}$$

$$\nu = 340 \text{ m/s} \quad \text{ISOTROPE}$$

$$P = 12.56 \text{ mW}$$

DETERMINA:

- δ in C $r_A = 3 \text{ m}$ $r_B = 4 \text{ m}$
- I in C
- B in C
- CHE CAMBIA SE $P_B = 35.12 \text{ mW}$

$$\omega = 2\pi\nu = 340\pi = 1068.14 \frac{\text{rad}}{\text{s}}$$

$$k = \frac{\omega}{\nu} = \pi = 3.14 \frac{\text{rad}}{\text{m}}$$

$$\lambda = \frac{\nu}{\nu} = 2 \text{ m}$$

$$\text{HO} \quad \delta = \alpha_1 - \alpha_2 = k(r_2 - r_1) + \Delta\varphi = k\Delta r = \boxed{\pi \text{ rad}}$$

ORA POSSO CALCOLARE

$$I_0 = \frac{P_m}{4\pi} = 0.999 \text{ mW}$$

$$\text{IN C AVREMO} \quad I_A = \frac{I_0}{r_A^2} = 1.11 \cdot 10^{-4} \frac{\text{W}}{\text{m}^2}$$

$$I_B = \frac{I_0}{r_B^2} = 6.24 \cdot 10^{-5} \frac{\text{W}}{\text{m}^2}$$

POICHÈ ONDE SFERICHE

$$\xi_i(r, t) = \frac{\xi_{0i}}{r} \cos(kr_i - \omega t)$$

$$I_{TOT} = I_A + I_B + 2\sqrt{I_A I_B} \cos \delta = 6.95 \cdot 10^{-6} \text{ W/m}^2$$

LIVELLO

SONORO

$$\beta = 10 \log \left(\frac{I_{TOT}}{I_0} \right) = 68.42 \text{ dB}$$

4 $T_0 = 150 \text{ N}$ $\nu = 440 \text{ Hz}$ $L (2\text{m}) = 53 \text{ dB}$

DETERMINA:

- T_1 TC $\nu_B = 4 \text{ Hz}$
- EQ ONDE IN PRESSIONE

$c_s = 343 \text{ m/s}$
 $\rho = 1.21 \text{ kg/m}^3$

VOGLIO $\nu_B = |\nu_2 - \nu_1| = 4 \text{ Hz}$ ν_2 LA FISSO A 440 Hz

$\Rightarrow \nu_B = \nu_1 - \nu_2 = 4 \text{ Hz} \Rightarrow \nu_B + \nu_2 = 444 \text{ Hz} = \nu_1$

PER UNA CORDA TESA HO $\nu = \sqrt{\frac{T}{\rho}}$

$\Rightarrow$ CORDA TESA, LA ν FONDAMENTALE È $\nu_F = \frac{\nu}{2L}$

$\Rightarrow \frac{\nu_0}{\nu_1} = \frac{\nu_0}{2L} \frac{2L}{\nu_1} = \sqrt{\frac{T_0}{T_1}} \Rightarrow \frac{T_0}{T_1} = \left(\frac{\nu_0}{\nu_1} \right)^2$

$\Rightarrow T_1 = \left(\frac{\nu_1}{\nu_0} \right)^2 T_0 \Rightarrow \boxed{T_1 = 152.74 \text{ N}}$

$\Delta T = 2.74 \text{ N}$

so $L = 10 \log\left(\frac{I}{I_0}\right) \Rightarrow I = I_0 \cdot 10^{\frac{L}{10}} = 1.99 \cdot 10^{-7} \frac{W}{m^2}$

so $I = \frac{1}{2} \rho \omega^2 \frac{A^2}{r^2} v^2 \Rightarrow A^2 = \frac{2 I r^2}{\rho \omega^2 v^2}$

$\omega = 2\pi\nu = 2789.73 \frac{rad}{s}$

QUINDI L'AMPIEZZA DELL'ONDA È

$$A = \sqrt{\frac{2 I r^2}{\rho \omega^2 v^2}} = 1.199 \cdot 10^{-9} m$$

QUINDI SO

$$\Delta p = \frac{\rho v \omega A}{r} \cos(kr - \omega t)$$

$\rho v \omega A = 1.388 \cdot 10^{-3} Pa$

ALTRO MODO



UN ONDA SONORA IN UN GAS È

$$I = \frac{(\Delta p_{\max})^2}{2 \rho v}$$

$$\Rightarrow \Delta p_{\max} = \sqrt{2 \rho v I} = 0.013 \text{ Pa}$$

NOTA $\Delta p_{\max} = \sqrt{2 \rho v \frac{1}{2}}$

L'ONDA DI PRESSIONE È $\Delta p = -\beta \frac{\partial(\xi)}{\partial r}$

$$\xi(r, t) = \frac{\lambda}{r} \cos(\kappa r - \omega t)$$

$$\frac{\partial \xi}{\partial r} = -\frac{\lambda \kappa}{r} \sin(\kappa r - \omega t)$$

$$\Rightarrow \Delta p = \beta \lambda \kappa \frac{1}{r} \sin(\kappa r - \omega t)$$

RICORDO $v^2 = \frac{\beta}{\rho} \Rightarrow \beta = \rho v^2$

$$\kappa = \frac{\omega}{v}$$

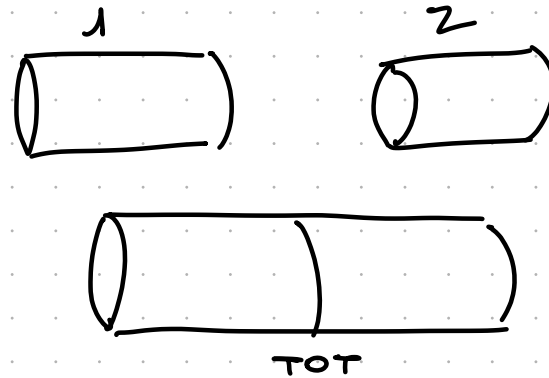
$$\begin{aligned} \Rightarrow \Delta p &= \rho v^2 \lambda \frac{\omega}{v} \frac{1}{r} \sin(\kappa r - \omega t) \\ &= \rho \omega v \lambda \frac{1}{r} \sin(\kappa r - \omega t) \\ &= \frac{\Delta p_{\max}}{r} \sin(\kappa r - \omega t) \end{aligned}$$

5 $f_{1,1} = 256 \text{ Hz}$

$f_{1,2} = 440 \text{ Hz}$

$f_{1, \text{TOT}} = ?$

$L = ?$



CONOSCO

$$f_m = m \frac{v}{2L} = m f_1$$

$$\Rightarrow f_1 = \frac{v}{2L}$$

DUNQUE

$$\begin{cases} f_{1,1} = \frac{v}{2L_1} \\ f_{1,2} = \frac{v}{2L_2} \\ L_1 + L_2 = L \end{cases} ;$$

$$\begin{cases} f_{1,1} = \frac{2L_2 f_{1,2}}{2L_1} \\ 2L_2 f_{1,2} = v \\ L_1 + L_2 = L \end{cases} ; \begin{cases} \frac{f_{1,1}}{f_{1,2}} = \frac{L_2}{L_1} \\ v = 2L_2 f_{1,2} \\ L_1 + L_2 = L \end{cases}$$

$$\begin{cases} L_1 = L - L_2 \\ v = c_s = 2L_2 f_{1,2} \\ \frac{f_{1,1}}{f_{1,2}} = \frac{L_2}{L_1} \end{cases} ;$$

$$\begin{cases} L = L_1 + L_2 \\ L_2 = \frac{c_s}{2f_{1,2}} \\ L_1 = L_2 \frac{f_{1,2}}{f_{1,1}} \end{cases}$$

$$\Rightarrow \begin{cases} L_1 = 1,058 \text{ m} \\ L_2 = 0,389 \text{ m} \\ L = 0,669 \text{ m} \end{cases}$$

$$f_0 = \frac{v}{2L} = 162.098 \text{ Hz}$$

6

GALLERIA RETTILINEA

$$\nu_1 = 135 \text{ Hz}, \nu_2 = 138 \text{ Hz}, L = 10^{-6} \text{ m}$$

DETERMINA:

- L
- ϕ_1
- FUNZIONE D'ONDA

$$c_s = 343 \text{ m/s}$$

SCRIVO LA FUNZIONE D'ONDA 1

$$\omega_1 = 2\pi\nu_1 = 848,23 \frac{\text{rad}}{\text{s}}$$

$$k_1 = \frac{\omega_1}{v} = 2,47 \frac{\text{rad}}{\text{m}}$$

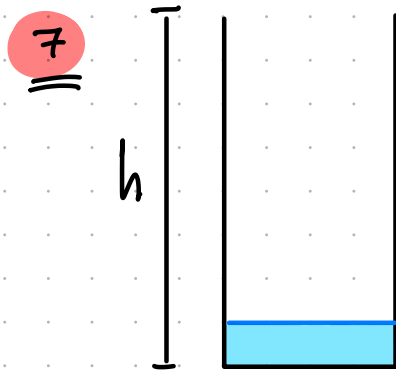
$$\xi_1(x, t) = A \sin(k_1 x) \cos(\omega_1 t)$$

LA GALLERIA AMPLIFICA ν_1 , CHE IMPIZZO ν_m , E ν_2 , HA
NON QUELLE INTERMEDIE, QUINDA È GIUSTO SUPPORRE $\nu_2 = \nu_{m+1}$
IN QUESTO MODO

$$\begin{cases} \nu_1 = m \frac{v}{2L} \\ \nu_2 = (m+1) \frac{v}{2L} \end{cases} \Rightarrow \Delta\nu = \nu_2 - \nu_1 = \frac{v}{2L} \Rightarrow L = \frac{v}{2\Delta\nu} = 57,16 \text{ m}$$

DUNQUE

$$\nu_0 = \frac{v}{2L} = 3 \text{ Hz}$$



$$\nu = 7 \text{ Hz}$$

$$\rho = 1.1 \text{ kg/m}^3$$

$$\beta = 1.33 \cdot 10^5 \text{ Pa}$$

DETERMINA: • h

SO PER UN TUBO APERTO/CHIUSO

$$\nu_m = (2m+1) \frac{v}{4L}$$

$$\Rightarrow \text{IO HO } \nu = \frac{v}{4h} \quad (m=0)$$

$$\text{MI SERVE } v : v = \sqrt{\frac{\beta}{\rho}} = 347.7 \frac{\text{m}}{\text{s}}$$

$$\Rightarrow h = \frac{v}{4\nu} = 12.42 \text{ m}$$

NOTA CON ρ_{mol} SI PUO' USARE $v = \sqrt{\frac{\gamma R T}{M}}$

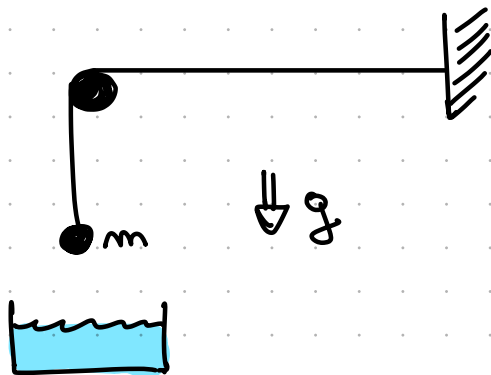
8

CORRDA FISSA

$$m = 4 \text{ kg}$$

v_2 SENZA H_2O

v_5 CON H_2O



DETERMINA IL RAGGIO DELLA SFERA.

$$v_2 = \frac{v_2}{2L} = 2v_1 \quad \text{con} \quad v_2 = \sqrt{\frac{mg}{g_L}}$$

$$v_5 = \frac{v_5}{2L} = 5v_1 \quad \text{con} \quad v_5 = \sqrt{\frac{T_5}{g_L}}, \quad T_5 = mg - \rho_{H_2O} g \frac{4}{3} \pi r^3$$

RAPPORTANDO

$$\frac{v_2}{v_5} = \frac{v_2}{2L} \frac{2L}{v_5} = \sqrt{\frac{mg}{g_L}} \sqrt{\frac{g_L}{T_5}} = \sqrt{\frac{mg}{T_5}}$$

$$\Rightarrow \frac{2}{5} \frac{v_1}{v_1} = \sqrt{\frac{mg}{T_5}} \Rightarrow \frac{4}{25} T_5 = mg$$

$$\Rightarrow \frac{4}{25} mg - \frac{16}{75} \rho_{H_2O} g \pi R^3 = mg \quad \Rightarrow \quad \frac{16}{75} \rho_{H_2O} g \pi R^3 = \frac{21}{25} mg$$

$$\Rightarrow \frac{16}{3} \rho_{H_2O} \pi R^3 = 21 m \quad \Rightarrow \quad R^3 = \frac{63}{16} \frac{m}{\pi \rho_{H_2O}}$$

$$\Rightarrow R = \sqrt[3]{\frac{63}{16} \frac{m}{\pi \rho_{H_2O}}} = \underline{\underline{0,1711 \text{ m}}}$$

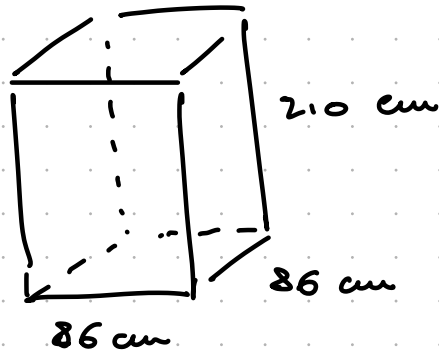
9

$$86 \times 86 \times 210 \text{ cm}^3$$

~ TUBO CHIUSO

$$130 \text{ Hz} \leq \nu_{\text{voce}} \leq 2000 \text{ Hz}$$

$$\nu_s = 355 \text{ m/s}$$



voce in $L_1 = 2,1 \text{ m}$, $L_2 = 0,86 \text{ m}$ QUALI FREQUENZE VENGONO ESALTATE

$$\nu_m = m \frac{\nu}{2L_i}$$

uso L_1 : $130 \text{ Hz} \leq m \frac{\nu}{2L_i} \leq 2000 \text{ Hz}$

$$\Rightarrow \frac{2L_i}{\nu} 130 \text{ Hz} \leq m \leq \frac{2L_i}{\nu} 2000 \text{ Hz}$$

$$\Rightarrow 1.94 \leq m \leq 23.66$$

QUINDI SU L_1 SI ESALTANO LE ARMONICHE DALLA 2 ALLA 23

su L_2 :

$$\frac{2L_2}{v} 130 \text{ Hz} \leq m \leq \frac{2L_2}{v} 2000 \text{ Hz}$$

$$\Rightarrow 0,63 \leq m \leq 9,7$$

su L_2 si ESALTANO DALLA 1 ALLA 9

COMPRESSIVAMENTE QUINDI DALLA 2 ALLA 9

10

$$L = 1.12 \text{ m}$$

APERTO/CHIUSO, ν_F

$$\ell = 33.2 \text{ cm}, m = 9.57 \text{ g}, \nu_F, \text{ FISSA AGLI ESTREMI}$$

FILO:

$$\nu_F^F = \frac{v}{2\ell}$$

$$\rho_L = \frac{m}{\ell} = 0.029 \frac{\text{kg}}{\text{m}}$$

$$v^F = \sqrt{\frac{T}{\rho}}$$

COLONNA D'ARIA : $\nu_F^A = \frac{c_s}{4L} = \boxed{72.67 \text{ Hz}} = \nu_F^F$

METTO TUTTO A SISTEMA

$$\begin{cases} \nu_F^F = \frac{v}{2\ell} \\ v^F = \sqrt{T/\rho} \\ \nu_F^A = \frac{c_s}{4L} \end{cases}$$

$$; \begin{cases} \frac{v^F}{2\ell} = \frac{c_s}{4L} \\ \rho v^{F2} = T \end{cases}$$

$$\Rightarrow \begin{cases} v^F = \frac{\ell}{2L} c_s = 48.25 \frac{\text{m}}{\text{s}} \\ T = \rho (v^F)^2 = \boxed{67.51 \text{ N}} \end{cases}$$