WAVES

Wave motion is a form of disturbances which travel through a medium due to the repeated periodic motion of the particles of the medium about their mean positions. Example: Waves produced when a stone is dropped into a water tank.

Types of wave motion

Transverse wave motion

The particles of the medium vibrate about their mean position in a direction **perpendicular** to the direction of propagation of the wave. This type of waves travels in the form of crests and troughs.

The distance between adjacent crests or troughs constitutes one wave.

Transverse waves can be polarized.

Example: **Light wave, waves in stretched string**.

Longitudinal wave motion

In longitudinal wave motion, particles of the medium vibrate about their mean position in the direction **parallel** to the direction of propagation of the wave. This wave type travels in the form of compressions and rarefactions.

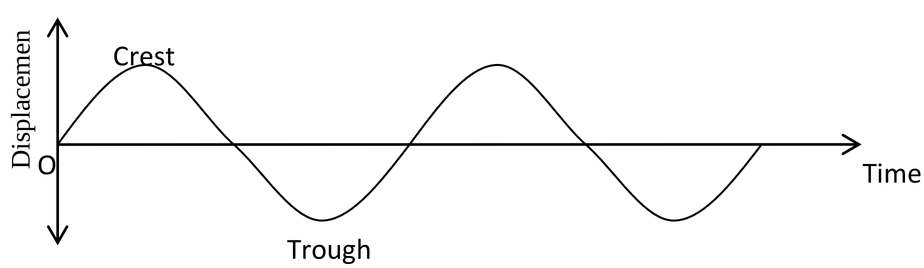
The distance between the adjacent compressions or rarefactions constitute one wave.

Longitudinal waves cannot be polarized.

Example: **Sound waves in air**.

Concept of Frequency, Wavelength and Time Period

The particles move about the mean equilibrium or mean position with time in a sinusoidal wave motion.

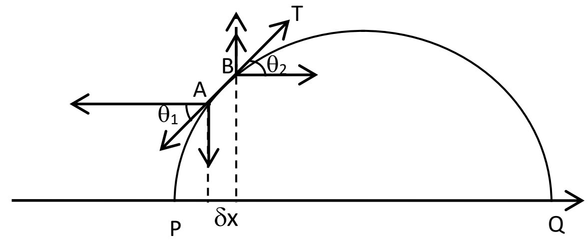


The distance between two consecutive points on a wave that are in the same phase (e.g., two crests or two troughs) is called **wavelength (λ).** It is measured in meters.

The time required for the wave to travel a distance of one wavelength is called **period**. It is measured in seconds.

The **frequency** of a wave is the number of waves per second. It's measured in hertz (Hz). $\mathbf{T = \frac{1}{\nu}}$

Transverse Vibrations of a Stretched String



Consider a flexible uniform string stretched between two points A and B by a constant tension T. Let the string lie along x-axis. Let it be plucked at the centre and is made to vibrate transversally. These vibrations are simple harmonic. Let a small element AB of length *dx*.

The magnitude of the tension will be same everywhere. (Since the string is perfectly flexible.) The tension T acts tangentially at every point.

At point A, tension T makes an angle θ_1 with horizontal and at point B, tension T makes an angle θ_2 with horizontal.

The net force acting in the y-direction is

$$F = T\sin\theta_2 - T\sin\theta_1 = T(\sin\theta_2 - \sin\theta_1)$$

Since θ is small, $\sin\theta = \tan\theta$

$\therefore$ $F = T(\tan\theta_2 - \tan\theta_1) \quad \rightarrow (1)$

But $\tan\theta_2 = \left(\frac{\partial y}{\partial x}\right)_{x+dx}$ at B (slope at B)

$\tan\theta_1 = \left(\frac{\partial y}{\partial x}\right)_x$ at A (slope at A)

$\therefore$ Equation (1) becomes, $F = T\left(\left(\frac{\partial y}{\partial x}\right)_{x+dx} - \left(\frac{\partial y}{\partial x}\right)_x\right)$

Applying Taylor's series,

$$F = T\left(\left(\frac{\partial y}{\partial x}\right)_{x+dx} - \left(\frac{\partial y}{\partial x}\right)_x\right) = T\frac{\partial^2 y}{\partial x^2}dx \rightarrow (2)$$

If '*m*' is the mass per unit length of the string, the mass of the element AB of length *dx* is given by *mdx*

Force acting on the element AB = mass of the element AB of length *dx* × acceleration

$$F = mdx \times \frac{\partial^2 y}{\partial t^2} \quad \rightarrow (3)$$

Comparing (2) and (3), we have

$$T\frac{\partial^2 y}{\partial x^2}dx = mdx \times \frac{\partial^2 y}{\partial t^2}$$

i.e., $\boldsymbol{\frac{\partial^2 y}{\partial x^2} = \frac{m}{T} \times \frac{\partial^2 y}{\partial t^2}} \quad \rightarrow (4)$

This is the wave equation in the case of waves in a stretched string.

The one dimensional wave equation $\frac{\partial^2 \psi}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 \psi}{\partial t^2} \rightarrow (5)$

Comparing equation (4) with equation (5), we get $\frac{1}{v^2} = \frac{m}{T}$

Or $v^2 = \frac{\boldsymbol{T}}{\boldsymbol{m}}$. Hence $\mathbf{v} = \sqrt{\frac{\boldsymbol{T}}{\boldsymbol{m}}}$

So, the expression for the velocity of transverse vibrations in a stretched string, $\mathbf{v} = \sqrt{\frac{\boldsymbol{T}}{\boldsymbol{m}}}$.

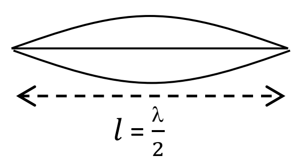
To find the frequency ν,

If a string of length 'l' vibrating in 'p' segment , length of each segment be $\frac{l}{p}$ and it corresponds to $\frac{\lambda}{2}$.

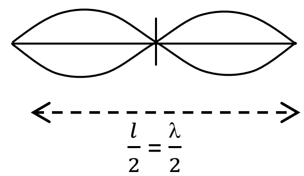
i.e., $\frac{l}{p} = \frac{\lambda}{2}$ or $\lambda = \frac{2l}{p}$

Then $\nu = \frac{v}{\lambda} = \frac{\sqrt{T/m}}{2l/p} = \frac{p}{2l}\sqrt{\frac{T}{m}}$

i.e., **frequency** $\boldsymbol{\nu = \frac{p}{2l}\sqrt{\frac{T}{m}}}$



Here only 1 segment or loop (p = 1) is present. So $l = \frac{\lambda}{2}$ or $\frac{l}{p} = \frac{\lambda}{2}$



Here 2 segments or loop (p = 2)is present. So $\frac{l}{2} = \frac{\lambda}{2}$ or $\frac{l}{p} = \frac{\lambda}{2}$

When p = 1, $\nu_1 = \frac{1}{2l}\sqrt{\frac{T}{m}}$

This the fundamental frequency of the transverse vibrations in a stretched string.

When p =2, the string will be vibrating in two segments, then $l = \lambda$, $\nu_2 = \frac{1}{l}\sqrt{\frac{T}{m}}$.

This stage is called second mode of vibration or first overtone.

Laws of transverse vibrations of stretched string

The fundamental frequency $\nu = \frac{1}{2l}\sqrt{\frac{T}{m}}$. Hence

(i) Frequency of transverse vibrations in a stretched string is inversely proportional to the length of the stretched string. $\nu \propto \frac{1}{l}$

(ii) Frequency of transverse vibrations in a stretched string is directly proportional to the square root of tension of the string. $\nu \propto \sqrt{T}$

(iii) Frequency of transverse vibrations in a stretched string is inversely proportional to the square root of mass per unit length of the string. $\nu \propto \frac{1}{\sqrt{m}}$

ACOUSTICS

It is the science of sound which deals with the process of generation, transmission and reception of sound in a room or in a hall. Sound is a form of energy and is produced by every vibrating body. The acoustic properties of building were studied by WC Sabine.

Sound is classified into music and noise.

Musical sound produces pleasant sensation to ear. They are produced by periodic waves.

Noise produces disturbing sensation to ear. They are produced by non periodic waves.

Reverberation

Sound produced by a source in a hall suffers multiple reflections from various objects in the hall, like wall, floor, ceiling etc. Hence the listeners hear a series of sound in addition to the original sound. So sound persists for a time even after the source has stopped.

The phenomenon of persistence of sound in a hall due to multiple reflections from the ceiling, floor, walls, and other materials, even after the source of sound has cut off is called **reverberation.**

Reverberation time(T)

It is defined as the time required by the sound energy to reduce its intensity to 10^{-6} times of its original intensity (or reduce its intensity by 60dB of its original intensity) from the moment the source of sound is stopped.

Sabine's formula

Sabine derived an equation for reverberation time T. According to him,

Reverberation time is (i) directly proportional to the volume of the hall (V)

(ii) inversely proportional to the total sound absorption in the hall (A).

i.e., $A = \sum \alpha S$ or $\mathbf{T} = \frac{0.163V}{A}$

where V is volume of the hall and A is total energy absorbed $\sum \alpha S$)

Significance of reverberation time(T)

Reverberation time is an important factor deciding the acoustic quality of a building.

- If reverberation time is so small, sound vanishes very rapidly. This produces dead silence in the hall.
- If reverberation time is too large, there will be multiple reflections and the sound waves will overlaps one over other producing loss of clarity.

- Hence reverberation time should have an optimum value for good acoustics of a hall. Reverberation time can be adjusted according to the purpose of the hall by arranging necessary sound absorbing materials in the hall.
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Halls	Reverberation time
Lecture hall	0.5sec – 1 sec
Conference hall	1sec – 1.5sec
Cinema theatre	1.3 sec
Music recording hall	1.5 - 2 sec
Churches	1.8sec - 3sec

Factors Affecting Acoustics Of Buildings And Their Remedies

1. Reverberation time: It is an important factor deciding the acoustic quality of a building.

- If reverberation time is so small, sound vanishes very rapidly. This produces dead silence in the hall.
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- Hence reverberation time should have an optimum value for good acoustics of a hall.
- Reverberation time can be adjusted according to the purpose of the hall by arranging necessary sound absorbing materials in the hall.
- Reverberation time or $T = \frac{0.163V}{A}$ where V is volume of the hall and A is total energy absorbed ($\sum \alpha S$)
- **Remedies:** Reverberation time can be controlled by
  (i) by selecting suitable building materials. (ii) by providing proper windows and ventilators, (iii) by covering walls and ceilings with sound absorbing materials, (iv) by covering floor with carpets (v) by using thick curtains (vi) by furnishing with upholstered seats.

2. Echoes: Echo is due to reflection of sound at different objects. Echo is produced when the time interval between the direct and reflected sound waves is about $\frac{1}{5}$th of a second. Long halls produce echo and almost all rooms produce reverberation.

- **Remedies:** Echoes can be controlled by (i) by covering distant walls and ceilings with sound absorbing materials. (ii) by providing thick curtains with folding.

3. Focussing surfaces: If there are any focussing surfaces such as concave surface, spherical, cylindrical or parabolic surfaces on the walls, floor and ceiling of the hall, the sound energy will be focussed to only certain region. This causes less sound in some other region.

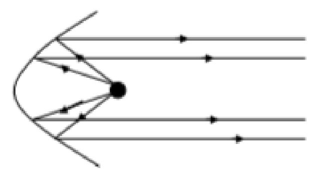
Remedies: For uniform distribution of sound energy throughout the hall,

(i) there should not be any curved surfaces in the hall. If any such surfaces are present, they must be covered with sound absorbing materials.

(ii) Ceiling must be of less height.

(iii) A parabolic surface must be arranged with the speaker at its focus

This send out a uniform sound energy in the entire hall.



4. Sufficient Loudness

* For satisfactory hearing, sufficient loudness throughout the hall is necessary.
* **Remedies:** For sufficient loudness,

  (i) By placing loud speakers at proper positions in the hall.

  (ii) Ceiling is kept low, so that the sound gets reflected from the ceiling and reaches the audience.

  (iii) By keeping large polished boards behind the speaker and facing the audience.

5. Resonance Effect

* Cavities, holes, airpockets etc in the walls and ceiling of the hall will contain air columns. These air columns are set into vibrations due to resonance and as a result sound is produced.
* In some cases, section of wooden portions, window panes etc will vibrate and produce sound waves. This will also produce resonance. Sometimes, these created sounds will interfere with original sound.
* These resonance and interference produces distortion and losses the clarity of the original sound.
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* **Remedies:** To avoid these,

  (i) cavities,airpockets,holes etc in the halls should be avoided or covered with sound absorbing materials.

  (ii) Fixing the window panes properly.

  (iii) Damping the resonant vibrations by suitable methods.

6. Echelon effect

* Regular spacing of reflecting surfaces, or steps with equal width may produce additional musical notes due to regular repetition of echoes. This is called echelon effect. This makes original sound confusing.
* Remedies: This can be reduced by
  (i) making steps and pillars of unequal width.
  (ii) covering equally spaced steps with sound absorbing materials.

7. Noise

* Unwanted sound in a hall is called noise. Noises are divided into three

  Air born noise: Noise from outside the hall through windows, door, ventilators etc are called air born noise. Eg: Vehicle moving outside produce noises.

  This can be eliminated by avoiding openings and holes, using double door and double windows on separate frame with an insulator between them etc.

* **Structure born noise:** This is caused by the vibration of the structure due to different activities going on nearer to building like drilling, working of heavy machines etc. This can be eliminated by breaking the continuity of the hall with proper sound insulators (using double walls with air in between them) etc.

* **Inside noise:** The noise produced inside the hall is called inside noise and this is produced by the machines like fan, engines etc. This noise can be eliminated by furnishing the floor with carpets and mats etc.

Acoustics- Reverberation and echo, Reverberation time and its significance - Sabine’s Formula, Factors affecting acoustics of a building. Ultrasonics- Piezoelectric oscillator, Ultrasonic diffractometer, SONAR, NDT-Pulse echo method, medical application-Ultrasound scanning (qualitative)