UNIT V : DIMENSIONAL ANALYSIS AND MODEL STUDIES

1. Define dimensional analysis.

Dimensional analysis is a mathematical technique which makes use of the study of dimensions as an aid to solution of several engineering problems. It plays an important role in research work.

2. Write the uses of dimension analysis?
   - It helps in testing the dimensional homogeneity of any equation of fluid motion.
   - It helps in deriving equations expressed in terms of non-dimensional parameters.
   - It helps in planning model tests and presenting experimental results in a systematic manner.

3. List the primary and derived quantities.

Primary or Fundamental quantities: The various physical quantities used to describe a given phenomenon can be described by a set of quantities which are independent of each other. These quantities are known as fundamental quantities or primary quantities. Mass (M), Length (L), Time (T) and Temperature (θ) are the fundamental quantities.

Secondary or Derived quantities: All other quantities such as area, volume, velocity, acceleration, energy, power, etc are termed as derived quantities or secondary quantities because they can be expressed by primary quantities.

4. Write the dimensions for the followings.

Dynamic viscosity (μ) – $ML^{-1}T^{-2}$

Mass density (ρ) – ML^{-3},
Force (F) - MLT^{-2},
Power (P) - $ML^{2}T^{-3}$

5. Define dimensional homogeneity.

An equation is said to be dimensionally homogeneous if the dimensions of the terms on its LHS are same as the dimensions of the terms on its RHS.

6. Mention the methods available for dimensionalanalysis.

Rayleigh method,
Buckinghum π method

7. State Buckingham's π theorem.

It states that "if there are 'n' variables (both independent & dependent variables) in a physical phenomenon and if these variables contain 'm' functional dimensions and are related by a dimensionally homogeneous equation, then the variables are arranged into n-m dimensionless terms. Each term is called π term".

8. List the repeating variables used in Buckingham π theorem.

Geometrical Properties – l, d, H, h, etc,
Flow Properties – v, a, g, ω, Q, etc,
Fluid Properties – ρ, μ, γ, etc.

9. Define model and prototype.

The small scale replica of an actual structure or the machine is known as its Model, while the actual structure or machine is called as its Prototype. Mostly models are much smaller than the corresponding prototype.

10. Write the advantages of model analysis.

- Model test are quite economical and convenient.
- Alterations can be continued until most suitable design is obtained.
- Modification of prototype based on the model results.
- The information about the performance of prototype can be obtained well in advance.

11. List the types of similarities or similitude used in model anlaysis.

a) Geometric similarities,
b) Kinematic similarities,
c) Dynamic similarities

12. Define geometric similarities

It exists between the model and prototype if the ratio of corresponding lengths, dimensions in the model and the prototype are equal. Such a ratio is known as "Scale Ratio".

13. Define kinematic similarities

It exists between the model and prototype if the paths of the homogeneous moving particles are geometrically similar and if the ratio of the flow properties is equal.

14. Define dynamic similarities

It exits between model and the prototype which are geometrically and kinematic similar and if the ratio of all forces acting on the model and prototype are equal.

15. Mention the various forces considered in fluid flow.

- Inertia force,
- Viscous force,
- Gravity force,
- Pressure force,
- Surface Tension force,
- Elasticity force

16. Define model law or similarity law.

The condition for existence of completely dynamic similarity between a model and its prototype are denoted by equation obtained from dimensionless numbers.

The laws on which the models are designed for dynamic similarity are called Model laws or Laws of Similarity.

17. List the various model laws applied in model analysis.

- Reynold’s Model Law,
- Froude’s Model Law,
- Euler’s Model Law,
- Weber Model Law,
- Mach Model Law

18. State Reynold’s model law

For the flow, where in addition to inertia force the viscous force is the only other predominant force, the similarity of flow in the model and its prototype can be established, if the Renold’s number is same for both the systems. This is known as Reynold’s model law. $\mathbf{Re_{(p)} = Re_{(m)}}$

19. State Froude’s model law

When the forces of gravity can be considered to be the only predominant force which controls the motion in addition to the force of inertia, the dynamic similarities of the flow in any two such systems can be established, if the Froude number for both the system is the same. This is known as Froude Model Law. $\mathbf{Fr_{(p)} = Fr_{(m)}}$

20. State Euler’s model law

In a fluid system where supplied pressures are the controlling forces in addition to inertia forces and other forces are either entirely absent or in-significant the Euler’s number for both the model and prototype which known as Euler Model Law.

21. State Weber’s model law

When surface tension effect predominates in addition to inertia force then the dynamic similarity is obtained by equating the Weber’s number for both model and its prototype, which is called as Weber Model Law.

22. State Mach's model law

If in any phenomenon only the forces resulting from elastic compression are significant in addition to inertia forces and all other forces may be neglected, then the dynamic similarity between model and its prototype may be achieved by equating the Mach's number for both the systems. This is known Mach Model Law.

23. Classify the hydraulic models.

The hydraulic models are classified as: Undistorted model & Distorted model

24. Define undistorted model

An undistorted model is that which is geometrically similar to its prototype, i.e. the scale ratio for corresponding linear dimensions of the model and its prototype are same.

25. Define distorted model

Distorted models are those in which one or more terms of the model are not identical with their counterparts in the prototype.

26. Define Scale effect

An effect in fluid flow that results from changing the scale, but not the shape, of a body around which the flow passes.

27. List the advantages of distorted model.

- The results in steeper water surface slopes and magnification of wave heights in model can be obtained by providing true vertical structure with accuracy.

- The model size can be reduced to lower down the cast.

- Sufficient tractate force can be developed to produce bed movement with a small model.

28. Write the dimensions for the followings.

Quantities	Symbol	Unit	Dimension
Area	A	m^2	L^2
Volume	V	m^3	L^3
Angle	A	Deg. Or Rad	$M^0L^0T^0$
Velocity	v	m/s	LT^{-1}
Angular Velocity	ω	Rad/s	T^{-1}
Speed	N	rpm	T^{-1}
Acceleration	a	m/s^2	LT^{-2}
Gravitational Acceleration	g	m/s^2	LT^{-2}
Discharge	Q	m^3/s	L^3T^{-1}
Discharge per meter run	q	m^2/s	L^2T^{-1}
Mass Density	ρ	Kg/m^3	ML^{-3}
Sp. Weight or Unit Weight		N/m^3	$ML^{-2}T^{-2}$
Dynamic Viscosity	μ	$N\text{-}s/m^2$	$ML^{-1}T^{-1}$
Kinematic viscosity		m^2/s	L^2T^{-1}
Force or Weight	F or W	N	MLT^{-2}
Pressure or Pressure intensity	p	N/m^2 or Pa	$ML^{-1}T^{-2}$
Modulus of Elasticity	E	N/m^2 or Pa	$ML^{-1}T^{-2}$
Bulk Modulus	K	N/m^2 or Pa	$ML^{-1}T^{-2}$
Workdone or Energy	W or E	N-m	ML^2T^{-2}
Torque	T	N-m	ML^2T^{-2}
Power	P	N-m/s or J/s or Watt	ML^2T^{-3}

PART - B

1. Explain Buckingham's theorem.
2. The resisting force (R) of a supersonic flight can be considered as dependent upon length of aircraft (l), velocity (V), air viscosity 'μ', air density 'ρ', and bulk modulus of air ' k'. Express the functional relationship between these variables and the resisting force.
3. A ship is 300 m long moves in sea water, whose density is 1030 kg/m3. A 1:100 model of this to be tested in a wind tunnel. The velocity of air in the wind tunnel around the model is 30 m/s and the resistance of the model is 60 N. Determine the velocity of ship in sea water and also the resistance of the ship in sea water. The density of air is given as 1.24 kg/m3. Take the Kinematic viscosity of sea water and air as 0.012 stokes and 0.018 stokes respectively.
4. A 7.2 m height and 15 m long spillway discharge 94 m3/s, under a head of 2.0m. If a 1:9 scale model of this spillway is to be constructed, determine model dimensions, head over spillway model and the model discharge. If model experience a force of 7500 N (764.53 Kgf), determine force on the prototype.
5. A quarter scale turbine model is tested under ahead of 12 m. The full scale turbine is to work under a head of 30 m and to run at 428 rpm. Find N for model. If model develops 100 kW and uses 1100 l/s at this speed, what power will be obtained from full scale turbine assuming its n is 3% better than that of model.
6. Using Buckingham's π theorem, show that the drag force FD = ρ L2V2φ (Re,M) which Re = ρ LV/μ; M = V/C; ρ = fluid mass density; L = chord length: V= velocity of aircraft; μ = fluid viscosity; C = sonic velocity = √K/ ρ where K = bulk modulus of elasticity.
7. The resistance ' R' experienced by apartially, submerged body depends upon the velocity 'V', length of the body 'l', viscosity of fluid 'μ', density of the fluid 'ρ', and gravitational acceleration 'g'; obtain expression for R.
8. Derive the relation using Buckingham's π theorem F = ρ U2D2f (μ/UD ρ), ND/U).
9. State the reasons for construction distorted model of rivers and discuss the various types of distortion in models. What are the merits and demerits of distorted models as compared to undistorted model?
10. In an aeroplane model of size 1/10 of its prototype the pressure drop is 7.5 kN/m3. The model is tested in water. Find the corresponding pressure drop in the prototype. Take density of air is 1.4 kg/ m3, density of water is 1000 kg/ m3, viscosity of air is 0.00018 poise and viscosity of water is 0.01 poise.