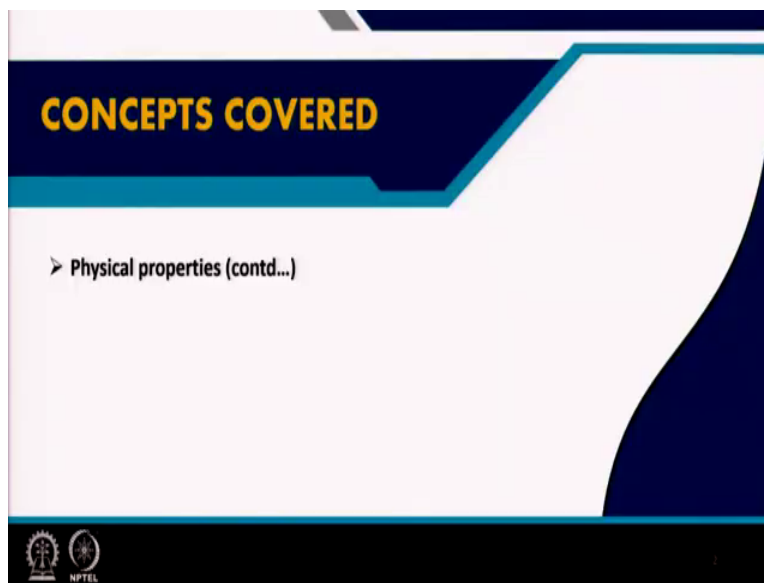


**Rock Mechanics and Tunneling**  
**Professor Debarghya Chakraborty**  
**Department of Civil Engineering**  
**Indian Institute of Technology, Kharagpur**  
**Lecture 13**  
**Topic - Physical properties (Continued)**

Hello everyone, I welcome all of you to the second lecture of module 3. So, in our previous lecture, we have started discussing the different physical properties of rock. Now, we will continue our discussion in that topic only.

(Refer Slide Time: 0:51)



So, we will continue with the physical properties of rock.

(Refer Slide Time: 0:55)

**Physical or Index Properties of Rock (contd...)**


**Problem on weight – volume relationship**

Q1. The mass of a moist limestone sample having volume  $0.006 \text{ m}^3$  is  $15 \text{ kg}$  and the mass of the oven dried sample is  $13.5 \text{ kg}$ . The degree of saturation is found to be  $65\%$ . Determine (a) Water content; (b) Porosity; (c) Void ratio; (d) Specific gravity.

Assume  $g = 10 \text{ m/s}^2$  and  $\gamma_w = 10 \text{ kN/m}^3$

**Solution:**

Moist mass of lime stone ( $M$ ) =  $15 \text{ kg}$  ✓  
Oven dried mass of the lime stone ( $M_d$ ) =  $13.5 \text{ kg}$  ✓  
Volume of sample ( $V$ ) =  $0.006 \text{ m}^3$   
Degree of saturation ( $S$ ) =  $65\% = 0.65$   
Weight of the dry limestone ( $W_d$ ) = ( $M_d \times g$ ) = ( $13.5 \times 10$ )  
 $= 135 \text{ N} = W_s$



NPTEL

We have learned and discussed different weight-volume relationships in our previous class. Those expressions were essential for obtaining the other properties. For better understanding, a couple of problems will be solved in today's lecture because they are relevant and practical.

So, let us see the first problem. So, what does it say? The mass of a moist limestone sample having a volume of  $0.006 \text{ m}^3$  is  $15 \text{ kg}$ , and the mass of the oven-dried sample is  $13.5 \text{ kg}$ . The degree of saturation is found to be  $65\%$ . So, we have to determine water content, porosity, void ratio, and the specific gravity.

It is also stated that for this problem, we can assume acceleration due to gravity ( $g$ ) as  $10 \text{ m/s}^2$ , though we know it is generally  $9.81$ . However, let us consider it as  $10 \text{ m/s}^2$  for simplicity and the unit weight of water ( $\gamma_w$ ) as  $10 \text{ kN/m}^3$ . So, these are the two assumptions.

So, what are the key things about this problem? The weight of the moist sample is provided. The total volume of the sample is provided. Then oven-dried sample weight is provided, and the degree of saturation is also provided. So, we have to obtain water content, porosity, void ratio, and specific gravity with this data.

So, it is given in terms of mass, so we will convert it to weight and solve it. The moist mass of the limestone ( $M$ ) is given as  $15 \text{ kg}$ . Now, we have to convert it into weight. For now, we will write it down as  $15 \text{ kg}$ .

Then the oven-dried mass of the limestone, which is  $M_d$ . The oven-dried mass means the sample is free from water, and we are neglecting the weight of air. So,  $M_d$  is the oven-dried mass of limestone. Thus,  $M_d$  is nothing but the weight of the rock solids. We can represent the mass of the oven-dried sample as  $M_s$ , which is the mass of the rock solids. In this problem, it is 13.5 kg.

Now, the total volume of the sample ( $V$ ) is  $0.006 \text{ m}^3$ , and the degree of saturation ( $S$ ) is  $65\% = 0.65$ . Whenever we see  $S$ , we have to replace it with 0.65. Now, we know that the mass of the moist sample is 15 kg and the mass of the oven-dried sample is 13.5 kg.

So, the weight of the dried rock limestone sample or the weight of rock solids = mass of the oven-dried sample ( $M_d$ )  $\times g = 13.5 \times 10$  since  $g$  is given as  $10 \text{ m/s}^2$ . So, we can get the weight of the dry limestone ( $W_d$ )  $= M_d \times g = 13.5 \times 10 = 135 \text{ N}$ , and we can also write it as  $W_s$  as it is nothing but the weight of rock solids.

(Refer Slide Time: 7:56)

**Physical or Index Properties of Rock (contd...)**

Mass of water ( $M_w$ ) =  $(15 - 13.5) = 1.5 \text{ kg}$


Weight of water ( $W_w$ ) =  $(M_w g) = (1.5)(10) = 15 \text{ N} \checkmark$

Water content ( $w$ ) in % =  $(W_w/W_s) 100\% = \frac{15}{135} \times 100\% = 11.11\% \text{ [Ans (a)]}$

Bulk unit weight ( $\gamma$ ) =  $\frac{W}{V} = \frac{(15)(10)}{(0.006)(1000)} = 25 \text{ kN/m}^3$

As we know  $\gamma = \frac{(G_s + es)\gamma_w}{1+e}$        $(G_s w = es) \Rightarrow G_s = \frac{es}{w}$

$\Rightarrow \frac{(\frac{es}{w} + es)\gamma_w}{1+e} = \gamma$



**Physical or Index Properties of Rock (contd...)**

**Problem on weight – volume relationship**

Q1. The mass of a moist limestone sample having volume  $0.006 \text{ m}^3$  is 15 kg and the mass of the oven dried sample is 13.5 kg. The degree of saturation is found to be 65%. Determine (a) Water content; (b) Porosity; (c) Void ratio; (d) Specific gravity.

Assume  $g = 10 \text{ m/s}^2$  and  $\gamma_w = 10 \text{ kN/m}^3$


**Solution:** Moist mass of lime stone ( $M$ ) =  $15 \text{ kg} \checkmark$

Oven dried mass of the lime stone ( $M_d$ ) =  $13.5 \text{ kg} \checkmark$

Volume of sample ( $V$ ) =  $0.006 \text{ m}^3$

Degree of saturation ( $S$ ) =  $65\% = 0.65$

Weight of the dry limestone ( $W_d$ ) =  $(M_d \times g) = (13.5 \times 10)$   
 $= 135 \text{ N} = W_s \checkmark$



Now, we can also find out the mass of water because the moist mass of limestone is provided, and the oven-dried mass is also provided. So, we can find out the mass of water from there. The mass of water ( $M_w$ ) =  $15 - 13.5 = 1.5 \text{ kg}$ . So, we can write the weight of water ( $W_w$ ) =  $M_w \times g = 1.5 \times 10 = 15 \text{ N}$ .

So, the first question was to find out the water content. So, water content ( $w$ ) =  $\frac{W_w}{W_s}$ . We already

have  $W_s$ , and we have obtained  $W_w$ . Hence, we will find out the water content first. So, the water

content ( $\omega$ ) in % =  $\frac{W_w}{W_s} \times 100\% = \frac{15}{135} \times 100\% = 11.11\%$ . This is the answer of part (a) = 11.11 %.

The second question was porosity, then void ratio, and then specific gravity. Let us focus on the porosity. To determine the porosity, we will first find out the bulk unit weight ( $\gamma$ ), and from there we have to go for some derivation. Then we can get the value of porosity.

So, the bulk unit weight ( $\gamma$ ) =  $\frac{W}{V}$ . Now,  $W = 15 \times 10 = 150$  N. We convert the mass to weight by multiplying it with  $g$ . The total volume of the sample ( $V$ ) is  $0.006 \text{ m}^3$ .

The weight of the moist sample is in N, and the total volume of the sample is in  $\text{m}^3$ . We want to present the sample's bulk unit weight in terms of  $\text{kN/m}^3$ . So, again we have to divide it by 1000, i.e.,  $\gamma = \frac{150}{0.006 \times 1000}$ . So, if we do that, we will get it as  $25 \text{ kN/m}^3$ .

From the previous lecture, we know that the bulk unit weight,  $\gamma = \left( \frac{G_s + Se}{1 + e} \right) \times \gamma_w$ . Now, in this expression, what are the things known to us?  $G_s$  can be represented as  $\frac{Se}{\omega}$ .

(Refer Slide Time: 14:02)

Physical or Index Properties of Rock (contd...)

$$\frac{\left(\frac{eS}{\omega} + Se\right) \gamma_w}{1+e} = \gamma$$

$$\Rightarrow \frac{\left(\frac{eS}{0.1111} + Se\right) 10}{1+e} = 25$$

$$\Rightarrow \frac{(9Se + Se) 10}{1+e} = 25$$

$$\Rightarrow \frac{10Se}{1+e} = 2.5$$

$$\Rightarrow \frac{Se}{1+e} = 0.25$$

$$\Rightarrow \frac{0.65e}{1+e} = 0.25$$

$$\Rightarrow \frac{e}{1+e} = \frac{0.25}{0.65}$$

$$\Rightarrow \eta = 0.3846 \quad [\text{Ans. (b)}]$$

$$\Rightarrow \eta = 38.46\%$$

$$e = \frac{\eta}{1-\eta} = \frac{0.3846}{1-0.3846} = 0.625 \quad [\text{Ans. (c)}]$$

$$G_s = \frac{Se}{\omega} = \frac{(0.65)(0.625)}{0.1111} = 3.6566 \quad [\text{Ans. (d)}]$$

Let us go to the next page. So, if we replace  $G_s = \frac{Se}{\omega}$  in the expression, we will get

$$\gamma = \left( \frac{\frac{Se}{\omega} + Se}{1+e} \right) \times \gamma_w. \text{ So, let us write down } \gamma = \left( \frac{\frac{Se}{0.1111} + Se}{1+e} \right) \times \gamma_w \text{ as we have calculated the}$$

moisture content as 11.11%, which is nothing but 0.1111.

Now, we can replace  $\gamma_w$  as 10, and the bulk unit weight as 25. And  $\frac{Se}{0.1111}$  will give  $9Se$ . Thus,

$$\text{we will get } 25 = \frac{9Se + Se}{1+e} \times 10. \text{ If we simplify it, we will get } 2.5 = \frac{10Se}{1+e}$$

After further simplification, we can get  $0.25 = \frac{Se}{1+e}$ . Now, we know that the degree of saturation

(S) is equal to 65%. So, we can write,  $S = 0.65$ . Thus,  $\frac{0.65 \times e}{1+e} = 0.25$ . If we further simply it, we

will get  $\frac{e}{1+e} = \frac{0.25}{0.65}$ . Now,  $\frac{e}{1+e}$  is nothing but the porosity ( $\eta$ ).

So,  $\frac{e}{1+e}$  gives the porosity of the sample, which is equal to 0.3846, i.e., 38.46%. Hence, this is

the answer of part (b). Next, we need to find out the void ratio. As we know,  $e = \frac{\eta}{1-\eta}$ .

So,  $e = \frac{0.3846}{1-0.3846} = 0.625$ . Hence, this is the answer to part (c). And last one, we have to

calculate the specific gravity of the rock solids. The specific gravity of the rock solids ( $G_s$ ) =  $\frac{Se}{\omega}$ ,

$$\text{i.e., } G_s = \frac{0.65 \times 0.625}{0.1111}.$$

So, if we simplify, we will get it as 3.6566. Hence, it is the answer to part (d). So, several things we could able to know from the given data. So, in this way you can solve these problems.

(Refer Slide Time: 18:49)

**Physical or Index Properties of Rock (contd...)**  
**Problem on weight - volume relationship (contd...)**

Q2. The volume of a cube of oil shale is  $5 \text{ m}^3$ . The porosity of the oil shale is 45%. The saturated unit weight of the oil shale is  $30 \text{ kN/m}^3$ . By assuming the dry unit weight of shale as  $27 \text{ kN/m}^3$ , determine the specific gravity of the oil. Consider, the unit weight of water as  $10 \text{ kN/m}^3$ .

**Solution:** Total volume of oil shale ( $V$ ) =  $5 \text{ m}^3$ ,  
 Porosity ( $\eta$ ) =  $0.45$ ;  $\gamma_{\text{sat}} = 30 \text{ kN/m}^3$   
 $\gamma_d = 27 \text{ kN/m}^3$

Volume of void = ( $V_v$ ) =  $(0.45)(5)$   
 $= 2.25 \text{ m}^3$

$\eta = \frac{V_v}{V}$   
 $\Rightarrow V_v = \eta V$

Now, we will solve another practical and exciting small problem. The volume and the porosity of a cube of oil shale are  $5 \text{ m}^3$  and 45%, respectively. The saturated unit weight of the oil shale is  $30 \text{ kN/m}^3$ . Assuming the dry unit weight of shale as  $27 \text{ kN/m}^3$ , determine the specific gravity of the oil. So, only one question is the specific gravity of oil that we need to find out. Consider the unit weight of water as  $10 \text{ kN/m}^3$ .

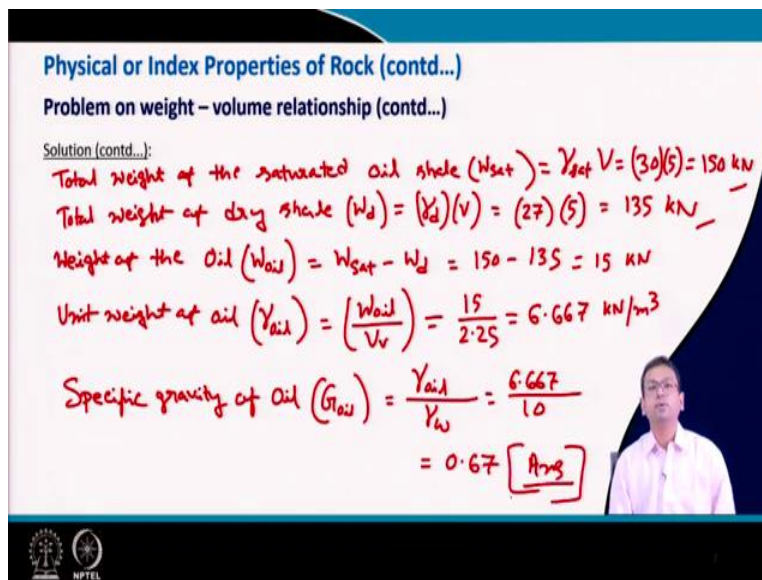
So, it is a straightforward problem but quite helpful. So, what are the things given to us? The total volume of oil shale ( $V$ ) equals  $5 \text{ m}^3$ . Then porosity is given as 0.45. The saturated unit weight ( $\gamma_{sat}$ ) is given as  $30 \text{ kN/m}^3$ , and the dry unit weight ( $\gamma_d$ ) is given as  $27 \text{ kN/m}^3$ . So, we are provided with these are the pieces of information.

Now, first, we can find out the volume of voids. So, how to get the volume of void ( $V_v$ )? As we know, the porosity of a sample  $\eta = \frac{V_v}{V}$ . So, the volume of voids ( $V_v$ ) =  $\eta \times V$ . So, the porosity of the oil cube is given as 0.45, and the total volume is  $5 \text{ m}^3$ . So, the volume of voids ( $V_v$ ) =  $0.45 \times 5 = 2.25 \text{ m}^3$ .

(Refer Slide Time: 22:28)

**Physical or Index Properties of Rock (contd...)**  
**Problem on weight - volume relationship (contd...)**  
Solution (contd...):

Total weight of the saturated oil shale ( $W_{sat}$ ) =  $\gamma_{sat} V = (30)(5) = 150 \text{ kN}$   
 Total weight of dry shale ( $W_d$ ) =  $(\gamma_d)(V) = (27)(5) = 135 \text{ kN}$   
 Weight of the oil ( $W_{oil}$ ) =  $W_{sat} - W_d = 150 - 135 = 15 \text{ kN}$   
 Unit weight of oil ( $\gamma_{oil}$ ) =  $\left(\frac{W_{oil}}{V_v}\right) = \frac{15}{2.25} = 6.667 \text{ kN/m}^3$   
 Specific gravity of oil ( $G_{oil}$ ) =  $\frac{\gamma_{oil}}{\gamma_w} = \frac{6.667}{10}$   
 $= 0.67$  [Ans]



The slide contains handwritten calculations in red ink. A small video inset in the bottom right corner shows a man in a light blue shirt speaking. The NPTEL logo is visible in the bottom left corner of the slide.

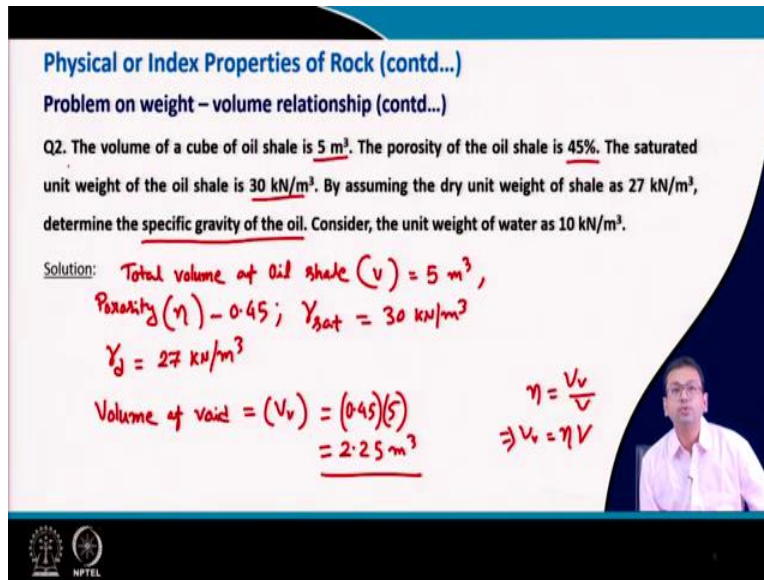


**Physical or Index Properties of Rock (contd...)**  
**Problem on weight – volume relationship (contd...)**

Q2. The volume of a cube of oil shale is 5 m<sup>3</sup>. The porosity of the oil shale is 45%. The saturated unit weight of the oil shale is 30 kN/m<sup>3</sup>. By assuming the dry unit weight of shale as 27 kN/m<sup>3</sup>, determine the specific gravity of the oil. Consider, the unit weight of water as 10 kN/m<sup>3</sup>.

Solution: Total volume of oil shale ( $V$ ) = 5 m<sup>3</sup>,  
 Porosity ( $\eta$ ) = 0.45;  $\gamma_{sat} = 30 \text{ kN/m}^3$   
 $\gamma_d = 27 \text{ kN/m}^3$   
 Volume of void = ( $V_v$ ) =  $(0.45)(5)$   
 $= 2.25 \text{ m}^3$

$\eta = \frac{V_v}{V}$   
 $\Rightarrow V_v = \eta V$



Finally, we have to obtain the specific gravity of the rock sample. So, the total weight of saturated rock shale is  $W_{sat} = \gamma_{sat} \times V$ .

So,  $\gamma_{sat} = 30 \text{ kN/m}^3$  and  $V = 5 \text{ m}^3$ . The weight of the saturated oil shale ( $W_{sat}$ ) =  $30 \times 5 = 150 \text{ kN}$ .  
 The total weight of dry shale ( $W_d$  or  $W_s$ ) =  $\gamma_d \times V = 27 \times 5 = 135 \text{ kN}$ .

So, the saturated weight of the oil shale = 150 kN, and the dry unit weight of the shale = 135 kN.  
 The weight of the oil present in the shale =  $W_{sat} - W_d = 150 - 135 = 15 \text{ kN}$ .

So, the unit weight of oil ( $\gamma_{oil}$ ) =  $\frac{W_{oil}}{V_v} = \frac{15}{2.25} = 6.667 \text{ kN/m}^3$ . So, therefore the specific gravity of

oil ( $G_{oil}$ ) =  $\frac{\gamma_{oil}}{\gamma_w} = \frac{6.667}{10} = 0.67$  (approximately). So, the specific gravity of oil = 0.67. So, this

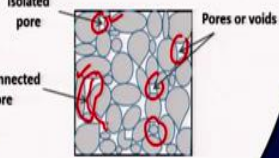
way we can solve the problems with the help of these things.

(Refer Slide Time: 26:39)

### Physical or Index Properties of Rock (contd...)

#### Porosity

- Storage capacity of rock depends on its porosity.
- Pores or voids may be or may not be interconnected.
- In general as compared to sedimentary rocks, the igneous and metamorphic rocks are having lesser porosity.
- It depends on:
  - 1) Size of grains
  - 2) Shape of the grains
  - 3) Orientation of the grains
  - 4) Degree of cementation of the grains
  - etc.



The diagram illustrates the concept of porosity in a rock. It shows a collection of grains (represented by circles and polygons) with spaces between them called pores or voids. Some pores are isolated, meaning they are not connected to other pores. Other pores are interconnected, forming a network. The diagram is labeled with 'Isolated pore', 'Interconnected pore', and 'Pores or voids'.

Now we will discuss the porosity. The physical significance of porosity is that the storage capacity of rock depends on the porosity. As expected, if the porosity of a rock sample is more, the storage capacity will increase.

As we can see from the three-phase diagram, some pores are isolated, and some pores are interconnected. So, now the oil or water may be stored inside these pores. So, the storage capacity of rock depends on its porosity.

Now, these pores or voids may or may not be interconnected. We can see that these are interconnected, whereas here, they are isolated, which is very important. In general, as compared to sedimentary rock, the igneous and metamorphic rocks have lesser porosity. However, there may be exceptions.

Now, the porosity depends on several things, such as the size and shape of the grains. Apart from these, porosity may depend on the orientation of the grain. The size and shape of grains may be the same for two rock samples, but their porosity may change depending on orientation.

Apart from the orientation of the grains, the porosity depends on the degree of cementation. These are the prime factors upon which the porosity of rock samples depends. We can also observe the interconnectivity among the pores from the phase diagram. It is evident that if the interconnectivity is more, the permeability will be more. It will be explored in the latter part of the course.

(Refer Slide Time: 29:58)


**Physical or Index Properties of Rock (contd...)**  
**Porosity (contd...)**

➤ Typical values of **porosity** of some common rocks

| Rocks               | Porosity (%) |
|---------------------|--------------|
| Fractured sandstone | 15 ✓         |
| Cavernous limestone | 5            |
| Shale               | 3            |
| Granite             | <u>1</u> ✓   |

Source: Waltham (2002)\*

\*Waltham, T., 2002. *Foundations of Engineering Geology*, Spon Press, London.



Some of the typical porosity values of some common rocks are given here. We can see fracture sandstone and cavernous limestone, shale, and granite. Four typical rocks are considered. We can see that the porosity of sandstone is 15%, whereas, for granite, it is only 1%.

So, it indicates that the storage capacity, whether it is water or oil, the storage capacity of granite must be significantly less means 15 times less than the fractured sandstone. So, in the case of sandstone, it is pretty high. So, let us stop here today, and we will continue our lecture on these physical properties in our next class. Thank you.