Underground Space Technology
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Module No # 02
Lecture No # 06
Basics of Rock Engineering: Classification of Rock Mass: Rock Mass Quality (Q-system) and Geological Strength Index (GSI)

Hello everyone, in the previous class, we discussed about the RMR system for the classification of rock mass. And today, we will extend that discussion, and we will learn about the other classification system of rock mass, which is the q system. And also, we will learn about the geological strength index that is GSI. So to start with, let us first understand about this rock mass quality Q-system.

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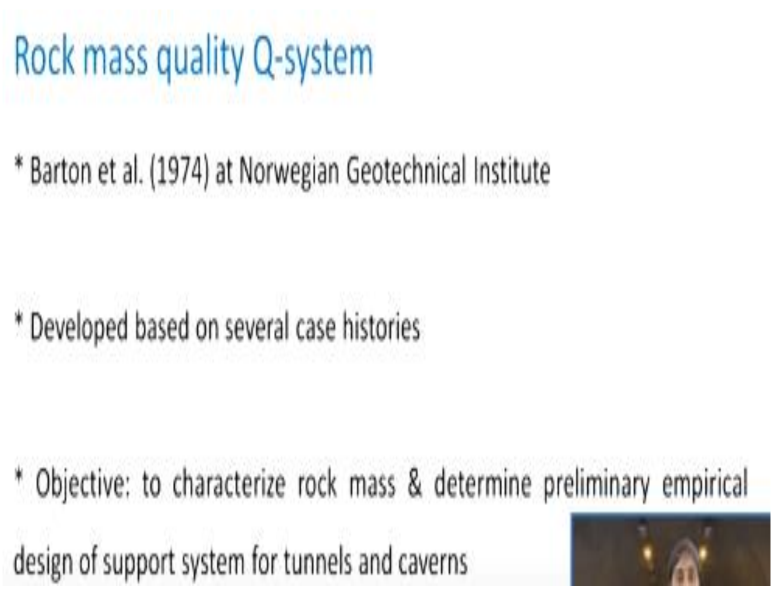

This was given by Barton and his team in 1974 at Norwegian Geotechnical Institute, which was developed on the basis of several case studies. And the objective was to characterize the rock mass and to determine the preliminary empirical design of support systems for the tunnels and caverns.

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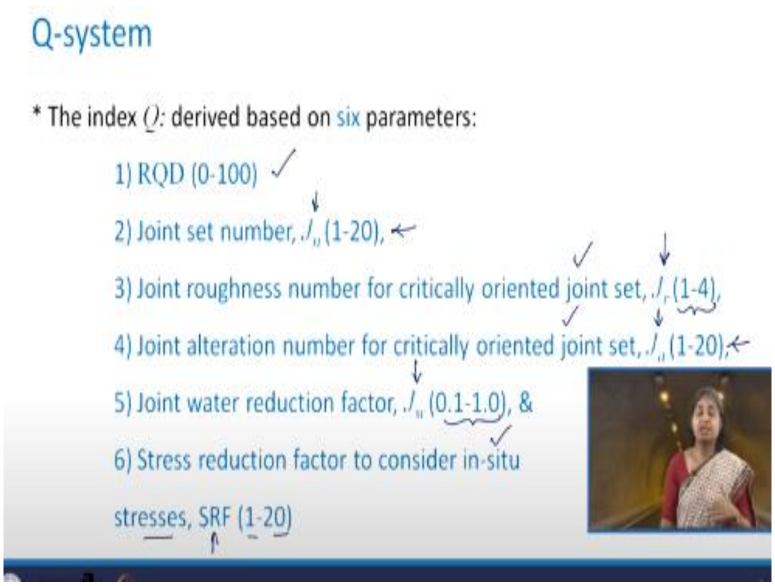

So, the index is defined and denoted as Q. This index is derived based on the 6 parameters. The first parameter is rock quality designation that is RQD which assumes a value between 0 to 100. The second parameter is joint set number that is denoted by J_n and it takes the value between 1 to 20. The third parameter is joint roughness number for critically oriented joint sets. So you see that in a rock mass, if you have more than one joint set which will be there in the field.

So, in that case first our task is going to be to identify that which joint set is critically oriented then we will use the property of that join in classification of that rock mass. So, this joint roughness is represented by $J_{r,}$ and it takes the value between 1 to 4. Then the fourth one is joint alteration number. Again, for critically oriented joint set, this is represented by $J_{a,}$ and it can take the value between 1 to 20.

Then the fifth one is joint water reduction factor represented as $J_{w,}$ and it can take the value between 0.1 to 1. And the final one is the stress reduction factor and this is used to consider the in-situ stresses and denote it as SRF strength reduction factor and its value varies between 1 to 20. So, these are the 6 parameters which are to be needed for each geological structural unit at the site to find out this index Q based upon which we are going to classify the rock mass.

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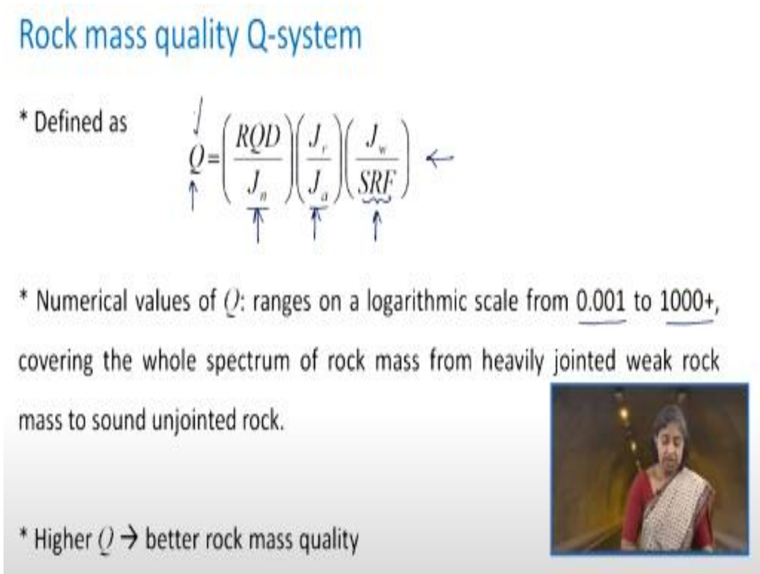

Now, this index Q is defined as the 3 quotients: first one is RQD by J_n, second one is J_r upon J_a, and the third one is J_w upon SRF. Are the numerical values of Q it ranges on a logarithmic scale from 0.001 to 1000 plus. So, this basically covers the whole spectrum of rock mass from heavily jointed weak rock mass to sound unjointed rock. So, when you have the larger values of Q that represent better quality of the rock mass.

So, the larger values of Q if you take a look here at this expression, the 3 parameters which are there in the denominator that is J_n, J_a, and SRF. If their values are low, the values of Q is going to be high.

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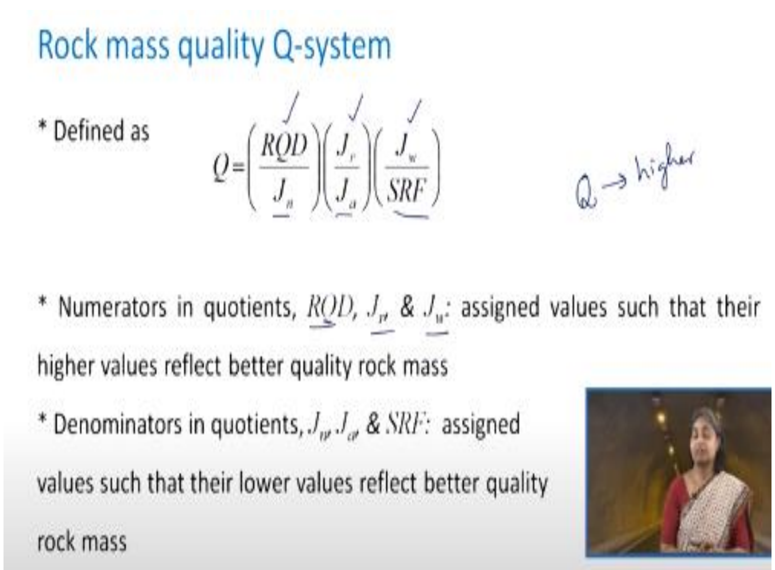

So, numerators RQD, $J_{,r}$ and J_w assigned values are such that that their higher values they reflect better quality rock mass. And in the denominator, you have J_n, $J_{a,}$ and SRF so as I mentioned that these are assigned in such a manner that their lower values reflect the better-quality rock mass. So, if you have the better quality of the rock mass, Q-value is going to be higher, and in case if the rock mass quality is poor, that would be given as or the Q-value for that is going to be quite small.

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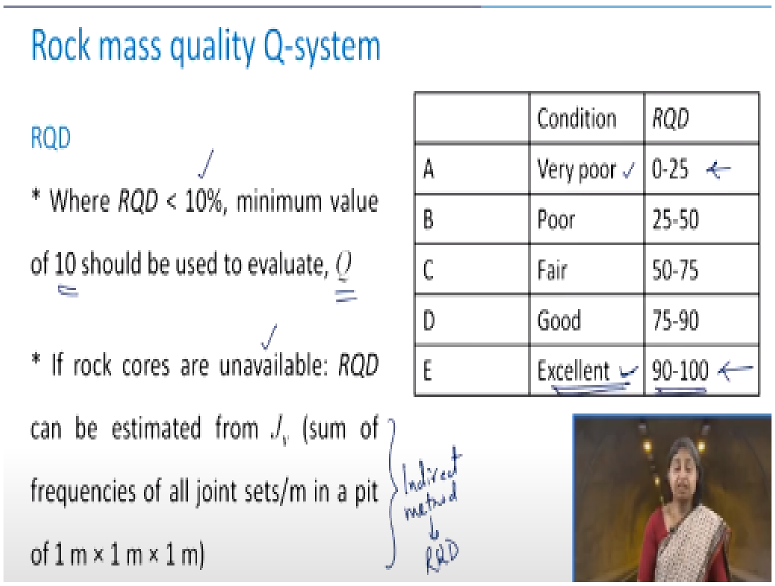

Coming to the RQD, so when RQD is less than 10%, the minimum value of 10 should be used to evaluate the value of Q. Now, if the rock cores are unavailable, then RQD can be estimated from J_v which is the sum of the frequency of all joint sets per meter in a pit of 1 meter cube size. This we have discussed when we were discussing about the methods for determination of RQD, so this was the part of the indirect methods for the determination of RQD.

So based upon the value of RQD, you have the various conditions which are defined, so very poor will have RQD as 0 to 25 and excellent will have the RQD between 90 to 100. So as I mentioned just in the previous slide only that these values are assigned in such a manner that higher values of the parameters which are there in the numerator they give the indication of the better quality of the rock mass, so you see here larger the value of RQD and better is the description for the rock mass.

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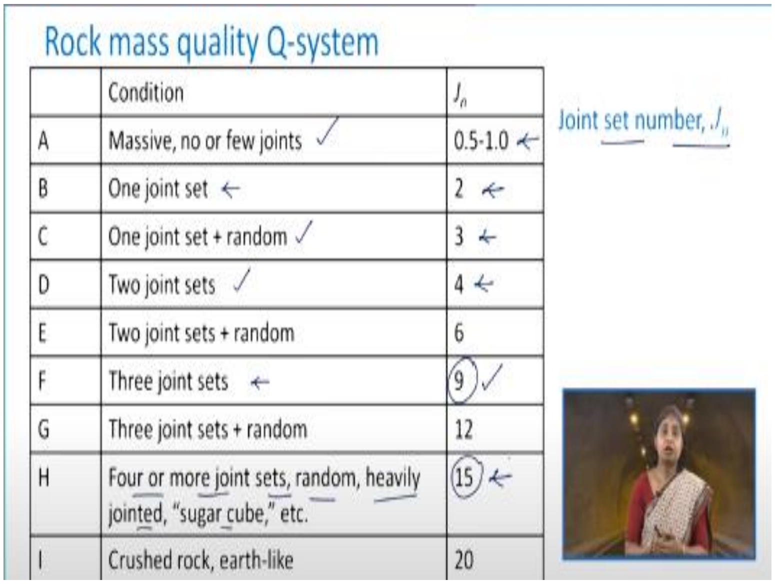

Coming to the next parameter, that is the joint set number, so in case if you have the massive rock where you have no or very few joints. then, in that case, your J_n is going to be varying between 0.5 to 1. In case, if you have one joint set, then J_n would be assign a rating of 2. In case if you have one joint set plus some random joints then it is 3. In case if you have 2 joint sets it is 4. Take a note here that roughly the rating for J_n is the square of the number of joint sets roughly.

Say for example here you have 3 joint sets so roughly it is square so 3 square is 9. So in case if you have 4 or more joint sets, random or maybe heavily jointed for example sugar cube. So there you have approximately 4 square which are 16, but the rating is given as 15. So more or less, when the square of the number of joints sets that are there in the rock mass the rating for J_n is going to be the square of those many number of joint sets.

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Rock mass quality Q-system

Joint roughness number, J_r

	Condition	J_r
	a) Rock wall contact and b) Rock wall contact before 10 cm shear	
A	Discontinuous joint	4.0
B	Rough or irregular, undulating	3.0
C	Smooth, undulating	2.0
D	Slicken sided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slicken sided, planar	0.5
	c) No rock wall contact when sheared	
H	Zone containing clay minerals thick enough to prevent rock wall contact	1.0
J	Sandy, gravelly, or crushed zone thick enough to prevent rock wall contact	1.0

Add 1.0 if the mean spacing of relevant joint set is greater than 3 m. J_r = 0.5 can be used for planar, slickensided joints having lineation, provided the lineations are favorably oriented

Coming to the joint roughness number, so here I will not read out each and every row of this particular table. This will be available to you, and when you know the characteristic of the roughness of a particular joint, from there you just pick the respective row to assign the rating to J_r here. For example, let us say that you have smooth and undulating joints, so what is the rating that you will assign that is going to be 2. J_r will be equal to 2 in this case. So likewise, you have various categories here, so you can refer to this table and pick the appropriate value of J_r.

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Rock mass quality Q-system

Joint alteration number, J_a

	Condition	ϕ_r approx. (deg)	J_a
	b) Rock wall contact before 10 cm shear (thin mineral fillings)		
F	Sandy particles, clay-free disintegrated rock, etc.	25-30	4.0
G	Strongly over-consolidated, non-softening clay mineral fillings (continuous, <5 mm in thickness)	16-24	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, <5 mm in thickness)	12-16	8.0
I	Swelling clay fillings, i.e., montmorillonite (continuous, <5 mm in thickness); value of Ja depends on percent of swelling clay-size particles, and access to water, etc.	6-12	8-12

In case of the joint alteration number, you have the condition of the joint in terms of let us say the first category is rock wall contact that is in this case there is no mineral filling only the coating is there. So, in that case further various categories are defined in terms of these alphabets you can take a look A, B, C, D, and E. So say, for example, it is the unaltered joint walls, and there is there is only surface staining.

So J_a is going to be 1 in this case, so likewise, whatever is the category for the case that you are handling thing appropriately, you pick the rating or the value of J_a. In case if you have the rock wall contact before 10-centimeter shear. So this is another category, so here also you have various classes that is F, G, H, and I based upon the description that is given here, so accordingly pick the value of J_a.

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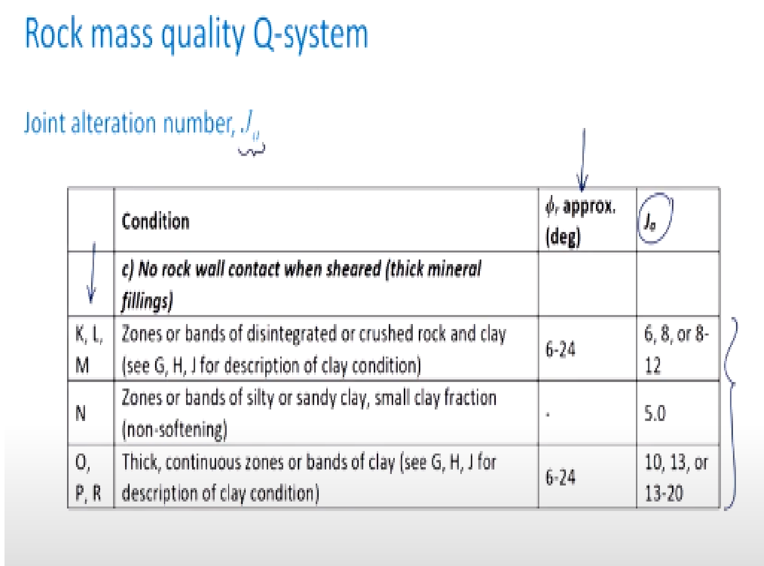

	Condition	ϕ_r approx. (deg)	J_a
	c) No rock wall contact when sheared (thick mineral fillings)		
K, L, M	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition)	6-24	6, 8, or 8-12
N	Zones or bands of silty or sandy clay, small clay fraction (non-softening)	-	5.0
O, P, R	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	6-24	10, 13, or 13-20

You have the third one that is when you do not have any rock wall contact when it is sheared that means that the joints are open and there is a thick mineral filling in them. So accordingly, you have the various classes varying from K to R, and appropriately, you pick the value of J_a from these rows. So you must have noticed that there is also some idea about the friction angle for the joint that you can obtain on the basis of the condition of the alteration of the joint. So that is also given in this particular table, so this is how we assign the value to the joint alteration number that is J_r.

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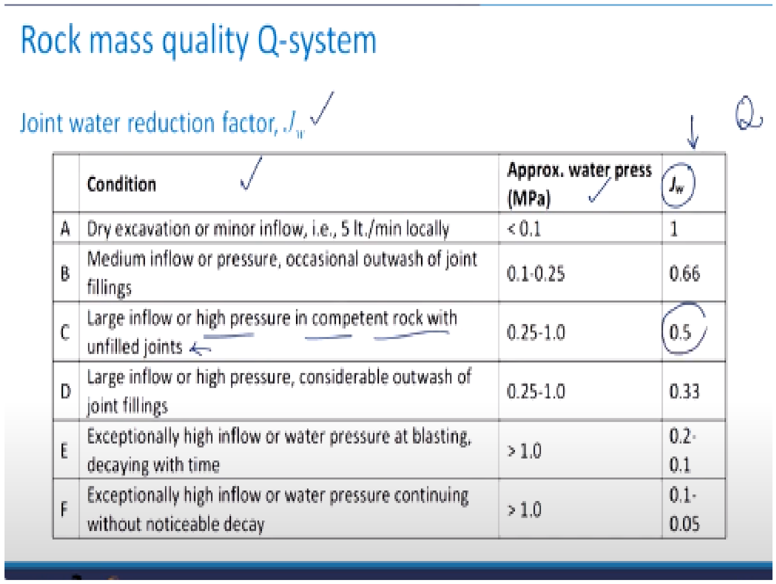
Rock mass quality Q-system

Joint water reduction factor, J_w

	Condition	Approx. water press (MPa)	J_w
A	Dry excavation or minor inflow, i.e., 5 lt./min locally	< 0.1	1
B	Medium inflow or pressure, occasional outwash of joint fillings	0.1-0.25	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	0.25-1.0	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	0.25-1.0	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	> 1.0	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	> 1.0	0.1-0.05

Coming to the next parameter, which is the joint water reduction factor J_w. So the description of the conditions are given here in this column, and approximate water pressure is mentioned in the next column, and accordingly the values of J_w are given in this last column. So, for example, let us say that you have the condition with large inflow or high pressure in competent rock with unfilled joints. So, what will be the value of J_w that you will use to calculate the index Q that is going to be 0.5.

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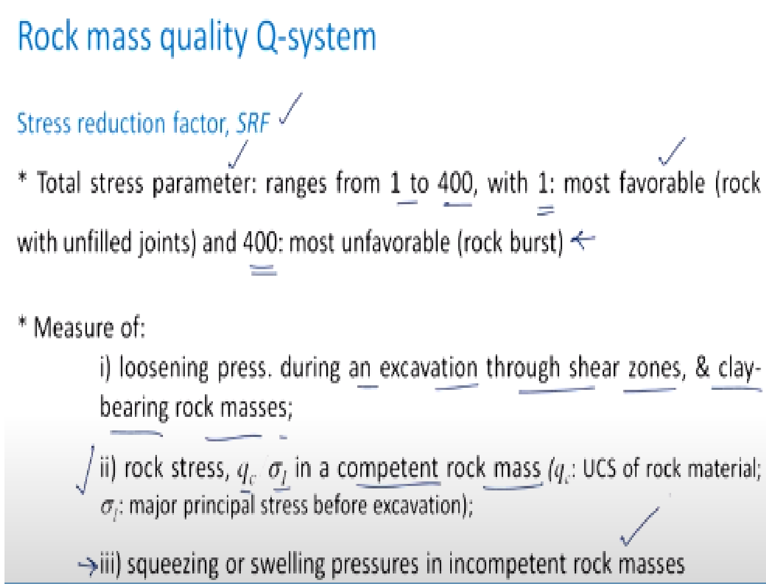

Coming to the stress reduction factor now, this is the most difficult factor, and we have to be extremely careful when we use the rating for SRF. Basically, it is the total stress parameter, and it ranges from 1 to 400; with 1 as the most favorable rock with unfilled joints and 400 be the most unfavorable situation, such as rock bust. Now, this SRF is measure of 3 quantities. The first one is the loosening pressure during an excavation through shear zones and clay-bearing rock masses.

The second one is the rock stress which is defined as q_c upon sigma 1 in a competent rock mass. Where your q_c is the UCS of the rock material, and of course, sigma 1 is the major principle stress which is before excavation. Then the third condition which SRF considers is the squeezing or swelling pressures in incompetent rock masses. So, you see it is covering wide range of various parameters related to stresses.

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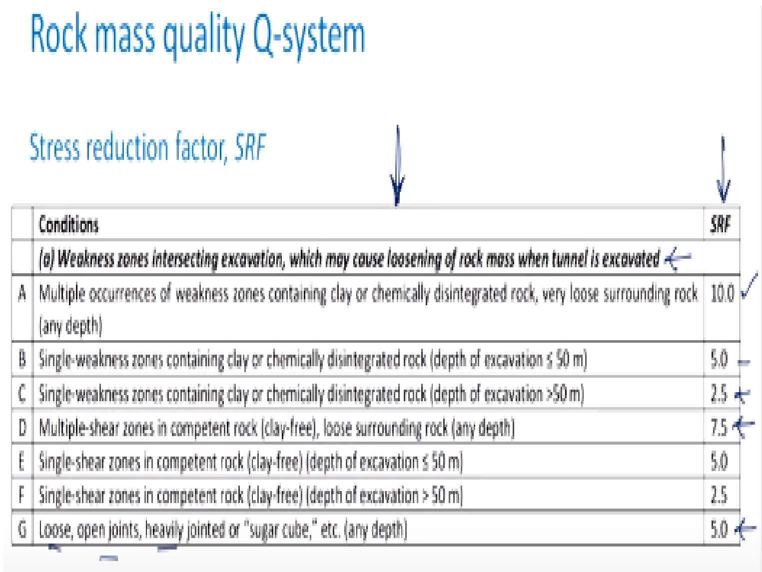

	Conditions	SRF
	(a) Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	
A	Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10.0
B	Single-weakness zones containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m)	5.0
C	Single-weakness zones containing clay or chemically disintegrated rock (depth of excavation >50 m)	2.5
D	Multiple-shear zones in competent rock (clay-free), loose surrounding rock (any depth)	7.5
E	Single-shear zones in competent rock (clay-free) (depth of excavation ≤ 50 m)	5.0
F	Single-shear zones in competent rock (clay-free) (depth of excavation > 50 m)	2.5
G	Loose, open joints, heavily jointed or "sugar cube," etc. (any depth)	5.0

Now take a look at these tables so the first category deals with this particular part that is weakness zone intersecting excavation which may cause loosening of the rock mass when the tunnel is excavated. So based upon whatever is the condition that is mentioned in this column, you pick the appropriate value of SRF from the last column. And it varies from say 10, and somewhere it there is no trend that it is either increasing or reducing see it goes to 5 and then 2.5, again 7.5.

And then for the last condition, that is when you have loose open joints or heavily jointed rock mass then in that case, you have to go for the rating as 5.

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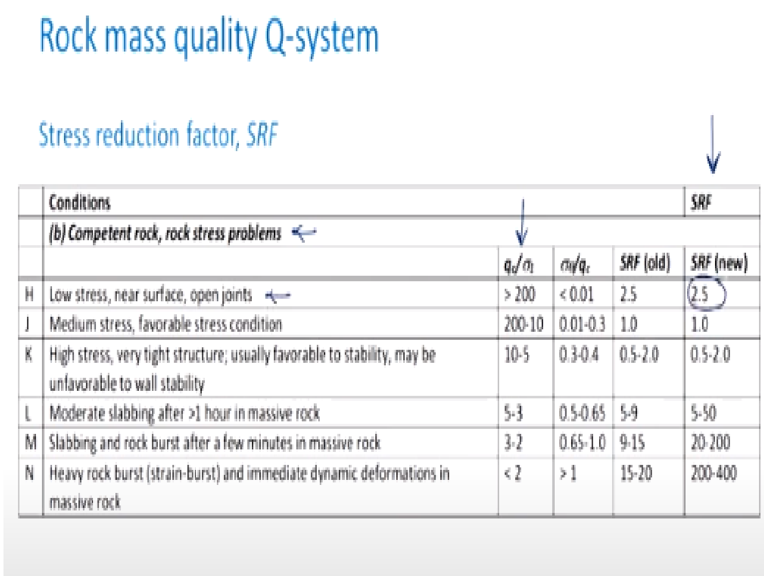

Rock mass quality Q-system

Stress reduction factor, SRF

	Conditions				SRF
	(b) Competent rock, rock stress problems				
		q_c/σ_1	σ_θ/q_c	SRF (old)	SRF (new)
H	Low stress, near surface, open joints	> 200	< 0.01	2.5	2.5
J	Medium stress, favorable stress condition	200-10	0.01-0.3	1.0	1.0
K	High stress, very tight structure; usually favorable to stability, may be unfavorable to wall stability	10-5	0.3-0.4	0.5-2.0	0.5-2.0
L	Moderate slabbing after >1 hour in massive rock	5-3	0.5-0.65	5-9	5-50
M	Slabbing and rock burst after a few minutes in massive rock	3-2	0.65-1.0	9-15	20-200
N	Heavy rock burst (strain-burst) and immediate dynamic deformations in massive rock	< 2	> 1	15-20	200-400

In case if you have the competent rock then the rock stress problems they occur so based upon the value of q_c upon sigma 1, you will have the value of SRF here. So in case if you have let us say the low stress, which is near surface and open joints so in that case you have to assign the value of SRF as 2.5.

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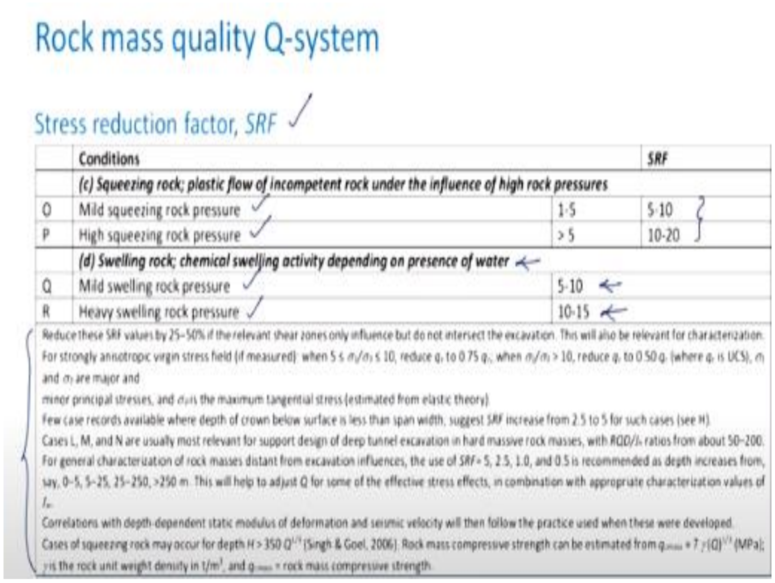

Rock mass quality Q-system

Stress reduction factor, SRF

	Conditions		SRF
	(c) Squeezing rock; plastic flow of incompetent rock under the influence of high rock pressures		
O	Mild squeezing rock pressure	1-5	5-10
P	High squeezing rock pressure	> 5	10-20
	(d) Swelling rock; chemical swelling activity depending on presence of water		
Q	Mild swelling rock pressure	5-10	
R	Heavy swelling rock pressure	10-15	

Reduce these SRF values by 25–50% if the relevant shear zones only influence but do not intersect the excavation. This will also be relevant for characterization.
For strongly anisotropic virgin stress field (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, reduce q_c to $0.75\,q_c$; when $\sigma_1/\sigma_3 > 10$, reduce q_c to $0.50\,q_c$ (where q_c is UCS), σ_1 and σ_3 are major and
minor principal stresses, and σ_θ is the maximum tangential stress (estimated from elastic theory).
Few case records available where depth of crown below surface is less than span width, suggest SRF increase from 2.5 to 5 for such cases (see H).
Cases L, M, and N are usually most relevant for support design of deep tunnel excavation in hard massive rock masses, with RQD/J_n ratios from about 50–200.
For general characterization of rock masses distant from excavation influences, the use of SRF = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from, say, 0–5, 5–25, 25–250, >250 m. This will help to adjust Q for some of the effective stress effects, in combination with appropriate characterization values of J_w.
Correlations with depth-dependent static modulus of deformation and seismic velocity will then follow the practice used when these were developed.
Cases of squeezing rock may occur for depth $H > 350\,Q^{1/3}$ (Singh & Goel, 2006). Rock mass compressive strength can be estimated from $q_{mass} = 7\,\gamma(Q)^{1/3}$ (MPa); γ is the rock unit weight density in t/m³, and q_{mass} = rock mass compressive strength.

Coming to the next condition that is I mentioned that SRF takes care of the squeezing and the swelling rocks also. So in case of the squeezing rocks, if you have mild squeezing rock pressure or high squeezing rock pressure accordingly, SRF will be assigned like this. Now, what are these swelling pressures? How to determine these? We will learn this in due course of time.

So for the swelling rock, it is whether it is mild swelling rock pressure or heavy swelling rock pressure based upon that you assign the rating to SRF as either 5 to 10 or 10 to 15. And then there are some notes which are given. I will not be reading these out but then when you use these stable, you should be extra careful that how are you assigning the value to this parameter SRF. Be careful that you do not count for any of these parameters twice which may happen in case of these stress reduction factor.

For example, if you are taking care of these stress-related issues while analyzing, then you do not really need to consider SRF here in the Q-system, and that results into say, some modified Q-system, so we will come to that later.

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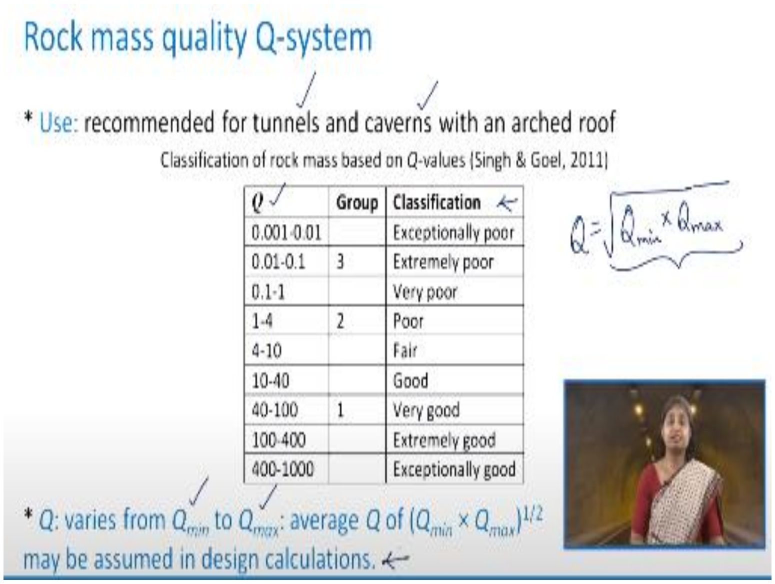

Q	Group	Classification
0.001-0.01		Exceptionally poor
0.01-0.1	3	Extremely poor
0.1-1		Very poor
1-4	2	Poor
4-10		Fair
10-40		Good
40-100	1	Very good
100-400		Extremely good
400-1000		Exceptionally good

So coming back to this Q-system, this is recommended for tunnels and caverns with an arched roof. So based upon the rating of these 6 parameters, you can use the expression which was given earlier and find out the index Q. Based upon this value you can decide that what is a classification for the particular rock mass. Now it may not be that easy for you to pick a pinpointed one value to the various assigned parameters, or maybe you can always get a range for the values of various parameters.

So that would also result in the range of Q value, so this Q may vary from Q minimum to Q maximum. So which one should we use in the design calculation? So what we do is? We take the average Q as Q to be equal to square root of Q minimum into Q maximum. So rather than taking

Q minimum or Q maximum, we take the value of Q average in this particular manner to be used in various design calculations as and when needed.

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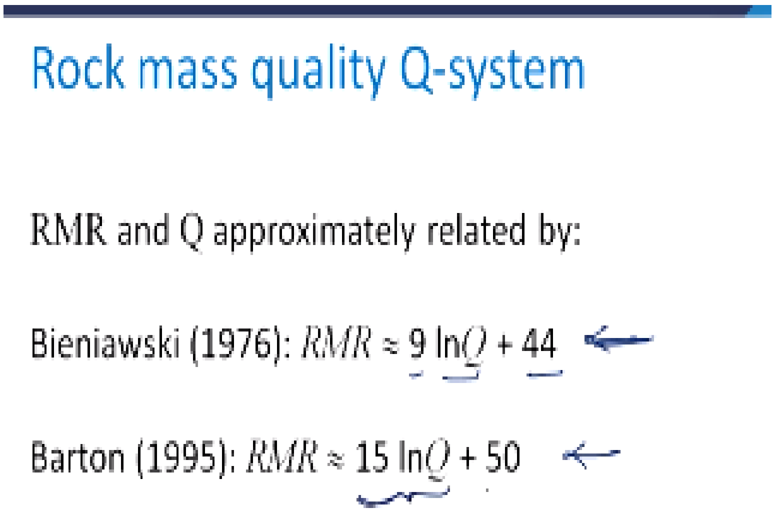

Now this RMR and the Q values, they are approximately related by some of the empirical correlations which were developed based on various case histories. So some of these are given here, like as per Bieniawski in 1976 ,this RMR can approximately be written as:

$$RMR = 9lnQ + 44$$

This is a very important expression. And all of you must remember this that how if you know the RMR, how you can find out Q, and if you know Q, how you can find out RMR. This Barton in 1995, again proposed another empirical correlation which says that RMR is approximately equal to:

$$RMR = 15lnQ + 50$$

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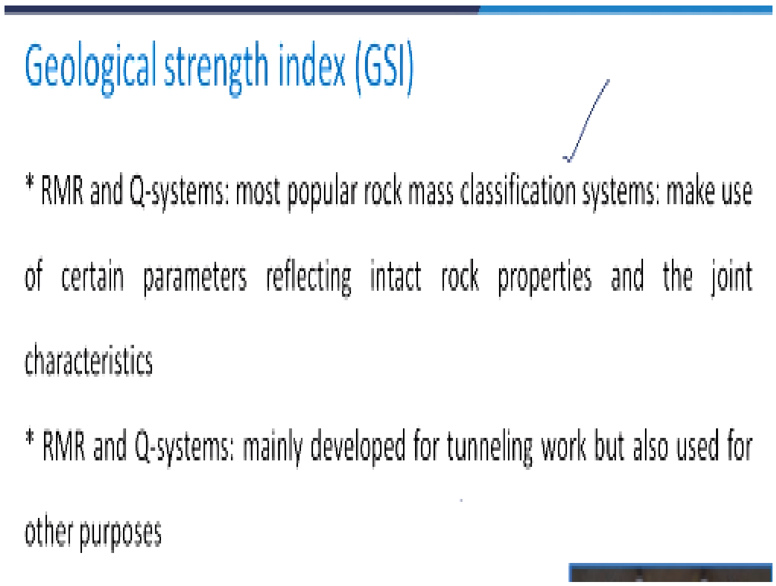

So this RMR and Q-systems they had their share of advantages and disadvantages. So let us discuss these, and to overcome some of these disadvantages, we came across another classification system, that is geological strength index. So this RMR and Q-systems they are most popular rock mass classification systems. These make use of certain parameters which reflect the intact rock properties as well as the joint characteristic.

So basically, these 2 systems were mainly developed for the tunneling work. So you see that the ratings of various parameters they were assigned from the case studies or the experience for from these studies based on tunnels but then these are used for other purposes also.

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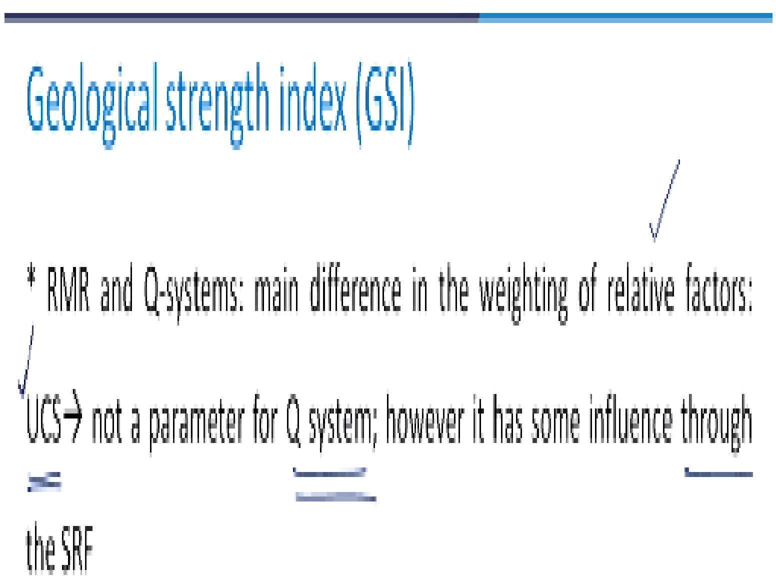

That is one of the major disadvantage of use of RMR and Q-system for other projects such as, say the foundation design or the slope related issues. The main difference is in the waiting of relative factors and say for example, UCS is not a parameter for Q-system; however it has some influence through the SRF. So basically, directly we do not use the unconfined compressive strength in Q-system but when we use this strength stress reduction factor so they are indirectly this influence of UCS comes.

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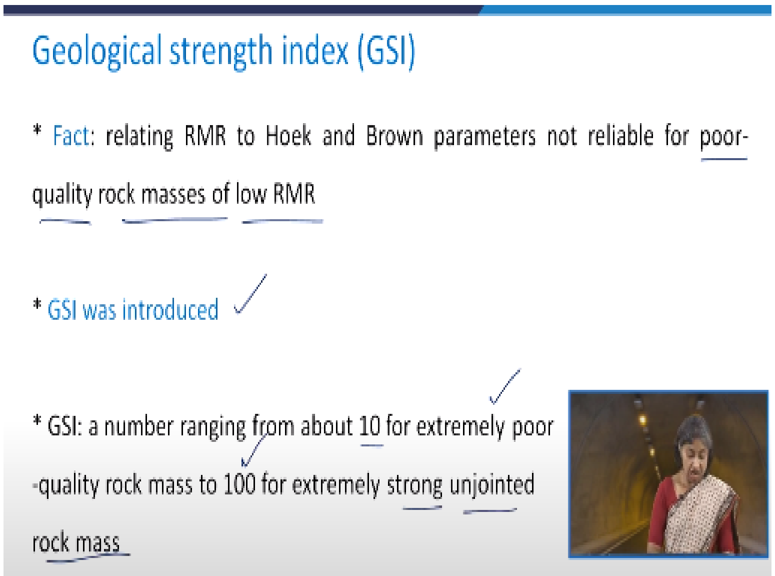

The fact is that that when we relate this RMR to Hoek and Brown parameters, what are these parameters that you will learn probably in the subsequent classes. So basically, when you relate this RMR to Hoek and Brown parameters, it is really not reliable for poor quality rock mass, which has low value of RMR. And to do away with some of these disadvantages, GSI was introduced. GSI is a number that is ranging from about 10 for extremely poor-quality rock mass to 100 for extremely strong unjointed rock mass.

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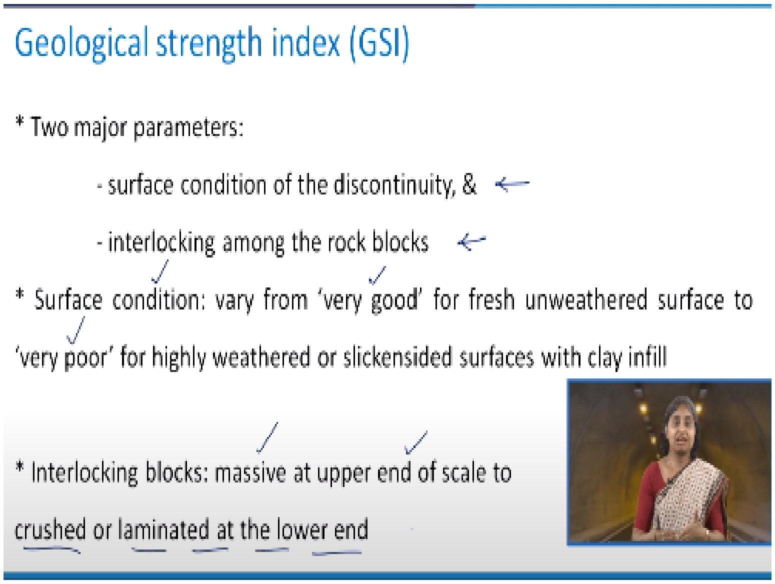

Let us take a look that what all are the major parameters which gives us the idea about the GSI. So, 2 major parameters are there. First one is the surface condition of the discontinuity and the second one is the interlocking among the rock blocks. As far as surface condition is concerned, it can vary from very good for fresh un-weathered surfaces to very poor for highly weathered or slickenside surfaces with clay infill.

The second part that is interlocking blocks. It is the massive at the upper end of scale to crushed or laminated at the lower end. So, when we say that it is interlocking block so the scale that we use I will show you in the subsequent slides. There if you have the upper side, it represents the massive blocks, and to the lower side, it has crushed or laminated rock mass.

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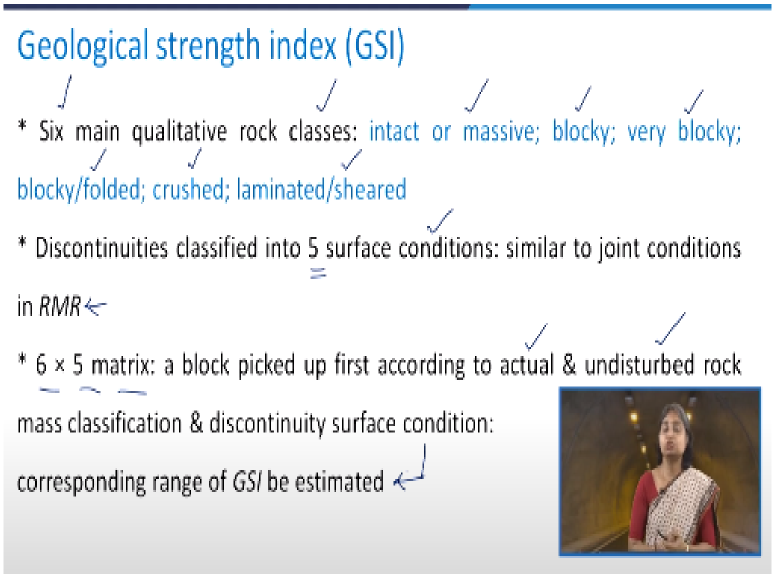

So based upon this 6 main qualitative rock classes they are defined intact or massive, blocky, very blocky, blocky or folded crushed and laminated or sheared. Furthermore, discontinuities were classified into 5 surface conditions which were quite similar to the joint conditions that were defined in the RMR system. So basically, here you have 6 types of the qualitative rock classes and 5 types of surface conditions.

So basically, this forms a 6 by 5 matrix so based upon the 2 parameters in this 6 by 5 matrix you pick a block. First, according to the actual and undisturbed rock mass classification and discontinuity surface condition and based upon this, you can get the corresponding range of GSI.

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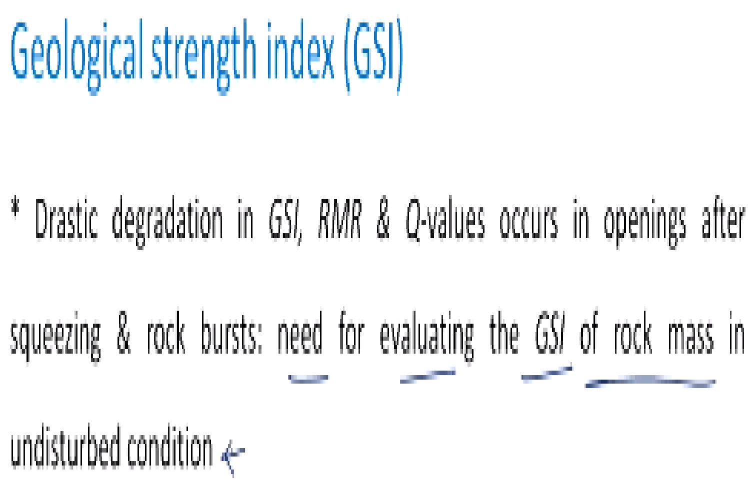

When you have the squeezing ground condition or the condition of rock burst in that case, there is a drastic degradation in GSI or RMR or Q-values, when you go for the excavation. So therefore, there is a need for evaluation of GSI of rock mass in undisturbed condition.

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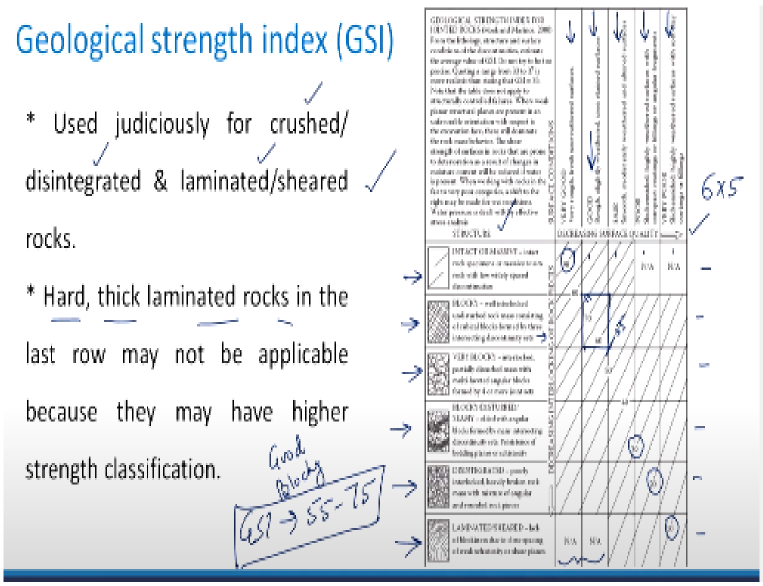

Take a look here on this particular figure so 6 qualitative rock structure that is intact or massive, blocky, very blocky, blocky or disturbed or seeming disintegrated here it is laminated or sheared. 5 surface quality very good, good, fair, poor and very poor so basically this makes as 6 rows and 5 columns. So it is 6 by 5 matrixes as I was mentioning you earlier. So when we refer to this particular chart, we should use this judiciously for crushed, disintegrated, and laminated, or sheared rocks.

Hard or thick laminated rocks in the last row here may not be applicable because they may have higher strength classification. So you see that, let us say we take maybe the good surface quality say and we have the blocky structure. So, you see that it is this one good and blocky, so basically, we are going to pick this block. Now you see various lines are there, so here it is corresponding to 10 this is 20, 30, and so on it goes up to 90. So, these values are the values of GSI.

So when I pick this block, how will I say that what is a GSI for this rock mass so you see that it is here this line is say 55, so it is basically varying from 60 to 75. So we can say that the GSI, in this case, is 55 to 75, so it you will never get a particular value or one value in case if you want to get the GSI value. So it will always be a range based upon the surface quality and the structure of the rock mass.

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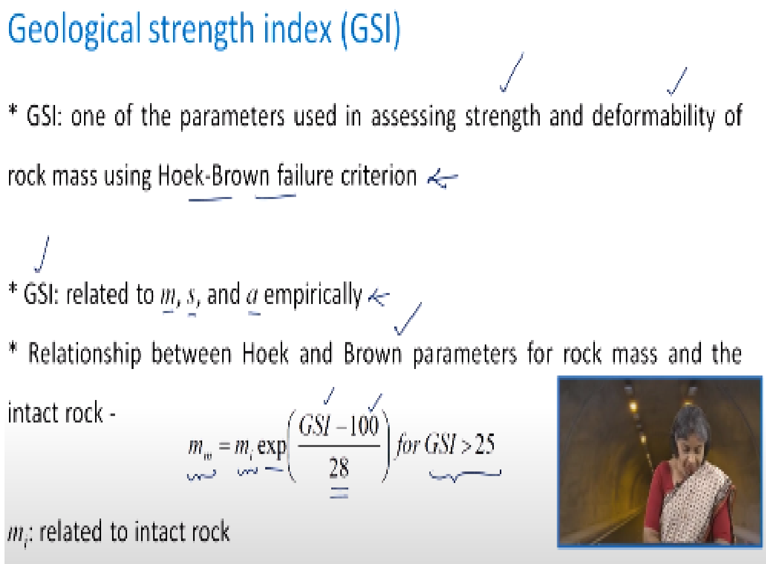

Now, this GSI is one of the parameters which is used in assessing the strength and deformability of the rock mass using Hoek and Brown failure criterion which is quite widely used in case of the intact rocks as well as for rock masses. So these the parameters of the Hoek and Brown failure criterion. We will learn that in subsequent classes. So these parameters include m, s, and a, so this GSI is related to Hoek and Brown criteria empirically.

So the relationship between these parameters for rock mass and the intact rock is given by this expression that is:

$$m_m = m_i \, exp\left[\frac{GSI - 100}{28}\right]$$

Where, m_m which is for the rock mass, m_i is related to the intact rock. This is applicable when you have GSI to be greater than 25.

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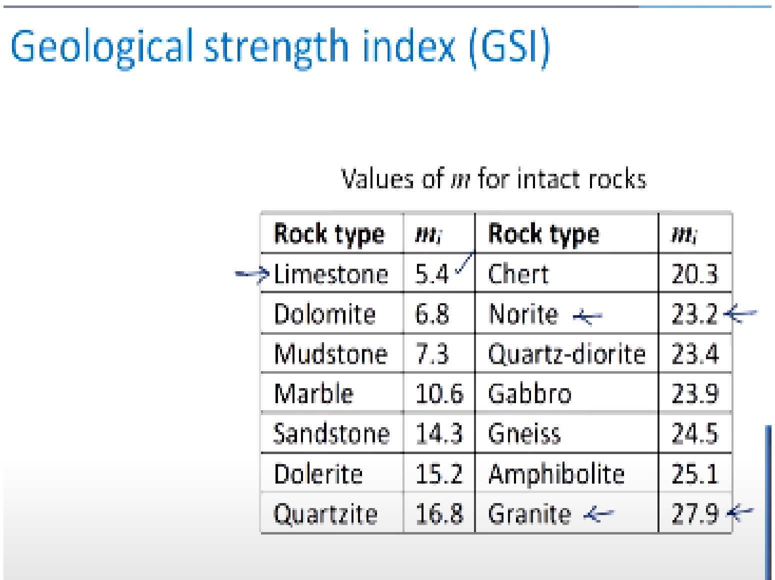

Rock type	m_i	Rock type	m_i
Limestone	5.4	Chert	20.3
Dolomite	6.8	Norite	23.2
Mudstone	7.3	Quartz-diorite	23.4
Marble	10.6	Gabbro	23.9
Sandstone	14.3	Gneiss	24.5
Dolerite	15.2	Amphibolite	25.1
Quartzite	16.8	Granite	27.9

Now, how to determine the values of m_i because to obtain the value of m_m, which is there for the rock mass, I need to have m_i and also GSI. So GSI I can obtain using the chart that I showed you how to get this m_i, so the typical values for the various types of intact rocks they are given here. For example, if it is a limestone, you have a 5.4 value as the value of m_i say in case if you have Norite, so it is 23.2. In case of Granite, it is even larger 27.9.

So, if you have in general the type of the rock is known to you, then maybe you can get the idea about the m for the intact rock from this table.

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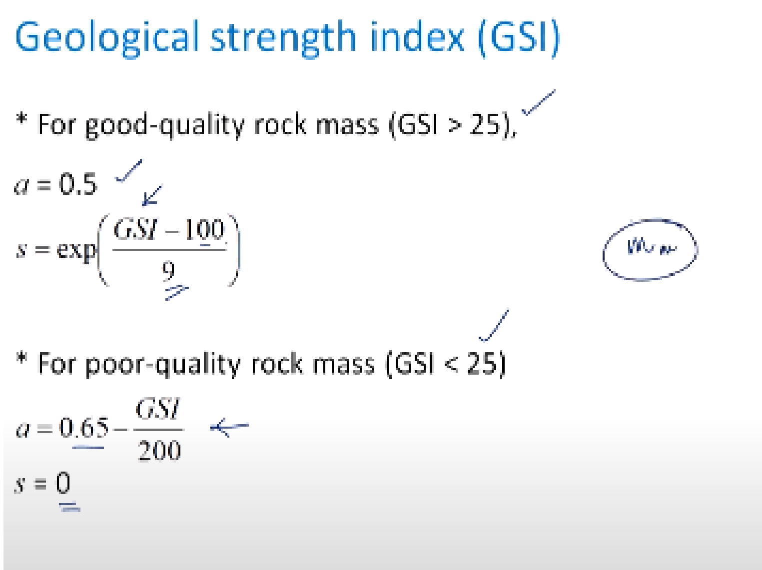

Now, for the good quality rock mass that is when you have GSI greater than 25, the Hoek and Brown parameter a can be determined as 0.5, and the other parameter s is defined as:

$$s = exp\left[\frac{GSI - 100}{9}\right]$$

In case if there is the poor-quality rock mass which is indicated by GSI having a value less than 25 in that case A is defined as:

$$s = 0.65 - \frac{GSI}{200}$$

and s is going to be equal to 0. Other parameters, which is m for that I already gave you the expression that it is related to the m for the intact rock and also the GSI. So that is how you can calculate m_m.

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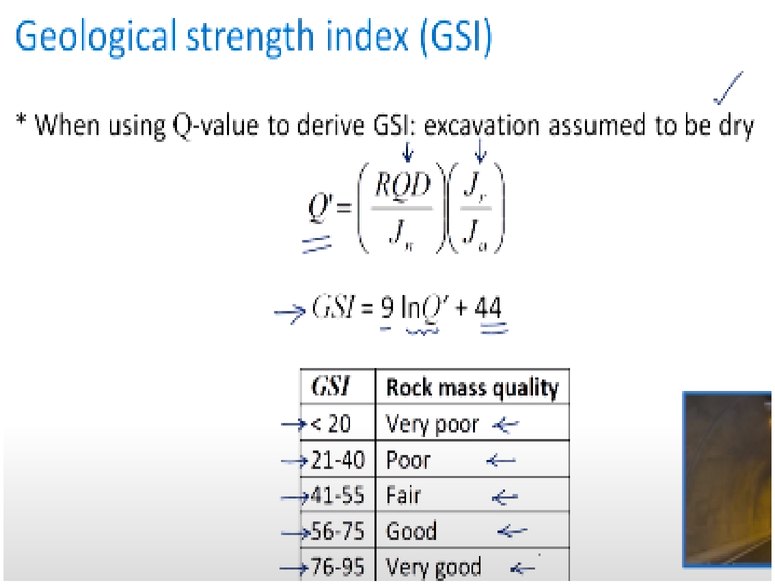

Now, when you use the Q-value to derive GSI, it is assumed that the excavation will be dry. Then we define another parameter that is Q' where the third quotient is not present. So, you have only the two quotients; that is first one is RQD by J_n, and the second one is J_r upon J_a. and hence GSI can be determined using this expression that is:

$$GSI = 9lnQ' + 44$$

Now once I know GSI, how can we classify the rock mass?

So, in case if you have the GSI value less than 20 the rock mass quality is very poor, for 21 to 40 this is classified as a poor-quality rock mass; from 41 to 55, it is fair, 56 to 75 it is good quality of the rock mass, and from 76 to 95 this is the very good rock mass quality. So this is what is all about the geological strength index. So in today's class, we discussed about the 2 classification systems for rock mass; one is the Q-system, another is the GSI.

So in the next class now, we will take up the failure criterion for the intact rocks as well as for the rock mass. Thank you very much.