Rock Engineering
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Lecture – 25
Classification of Rock Mass: Geological Strength Index (GSI)

Hello everyone. In the previous class we discussed about rock mass quality index that is Q-system as far as the classification of rock mass is concerned. So, today we will learn about a new classification system for rock mass which is called geological strength index. In short, this is also called as GSI. Today, we will learn about GSI and then we will see some of its application.

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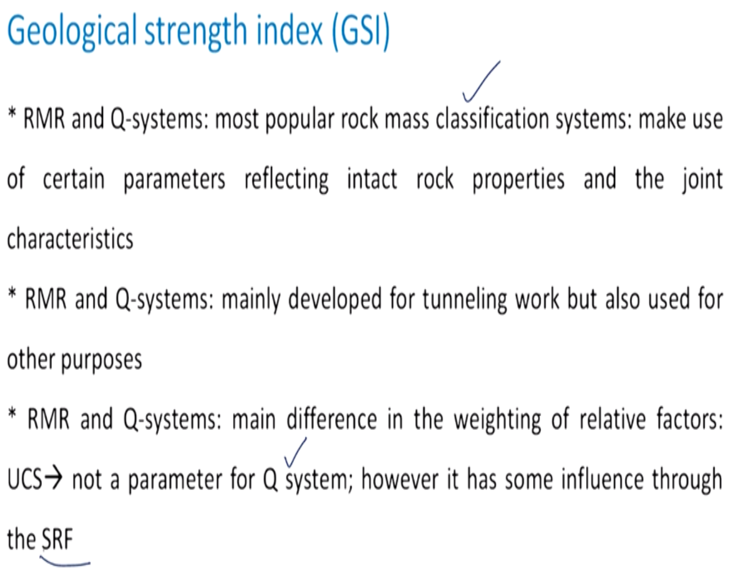

So, to start with basically this RMR and Q-systems, they are most popular rock mass classification systems and we have seen that they make use of certain parameters which reflect intact rock properties and the characteristics of the joint. We saw that you had to use our RQD, then joint roughness, joint wall strength and many such parameters for RMR and Q-systems.

These two systems were mainly developed for tunneling work, but they are also used for other purposes. And I mentioned to you that when you use it for other purposes, you need to be careful and one needs to use a lot of engineering judgment while applying these two systems for other purposes like the slope stability analysis or the foundation analysis. The main difference between RMR and Q-system was the weighting of relative factors.

For example, UCS was not a parameter in the Q-system, but it has some influence through the factor SRF which was stress reduction factor and through this factor this UCS had the influence on the Q-system. Otherwise UCS was not there directly as one of the parameters.

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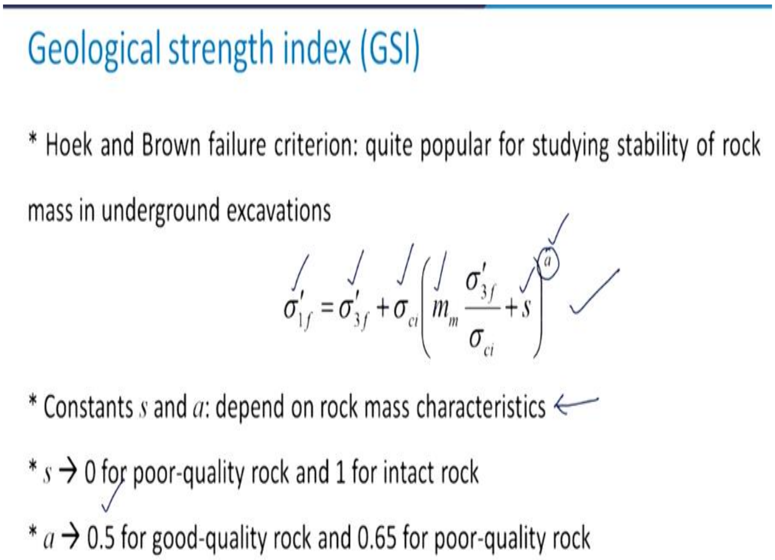

Now, we have some of the failure criteria and one of the failure criteria is Hoek and Brown failure criteria, we will learn in detail about this little later, but for the time being in order to make you understand about this index GSI, I need to introduce it here. So, this Hoek and Brown criterion is quite popular in studying the stability of rock mass in underground excavations.

$$\sigma'_{1f} = \sigma'_{3f} + \sigma_{ci}\left(m_m \frac{\sigma'_{3f}}{\sigma_{ci}} + s\right)^{a}$$

And it is given by the above expression in which the sigma 1 f prime (σ'_{1f}) and sigma 3 f prime (σ'_{3f}) they are major and minor principal stresses at the failure when you conduct the triaxial test. Sigma ci (σ_{ci}) is the uniaxial compressive strength of the intact rock and s and a they are the parameters of this Hoek and Brown criteria. They depend upon the rock mass characteristic and also this m_m that is also one of the parameters.

Now as far as this parameter s is concerned, it is equal to 0 for poor quality rock and equal to 1 for the intact rock and this parameter a = 0.5 for good quality rock and 0.65 for poor quality rock.

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Geological strength index (GSI)

$$\sigma'_{1f} = \sigma'_{3f} + \sigma_{ci}\left(m_m \frac{\sigma'_{3f}}{\sigma_{ci}} + s\right)^a$$

* Hoek and Brown constant, m: takes separate values of m_i for intact rock and m_m for the rock mass

* Before 1994: parameters of Hoek and Brown criterion: derived from RMR assuming dry conditions at the excavation with no adjustment for discontinuity orientations wrt the project

This Hoek and Brown constant *m* which is here as this in this equation. So, this takes separate value for intact rock as m i and for the rock mass as m_m. That means this criterion can be applied to intact rock as well as to the rock mass, the change will be there in its parameter. So, one of that is m_m. So, right now this has been written for the rock mass. Now before 1994, the parameters of Hoek and Brown criterion, they were derived from RMR.

Assuming that dry conditions at the excavation with no adjustment for discontinuity orientations with respect to the project, but subsequently as the research took place in this direction this criterion was modified.

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Geological strength index (GSI)

* Fact: relating RMR to Hoek and Brown parameters not reliable for poor-quality rock masses of low RMR

* GSI was introduced

* GSI: a number ranging from about 10 for extremely poor-quality rock mass to 100 for extremely strong unjointed rock mass

Keeping that in mind with the fact that using that RMR in the determination of Hoek and Brown parameters; was not that reliable for poor quality rock masses which had low values of RMR. So, keeping this fact in mind the index GSI was introduced. This GSI is a number which is ranging from about 10 for extremely poor-quality rock mass, 200 for extremely strong unjointed rock mass. So here as GSI increases, it represents the better quality of the rock mass.

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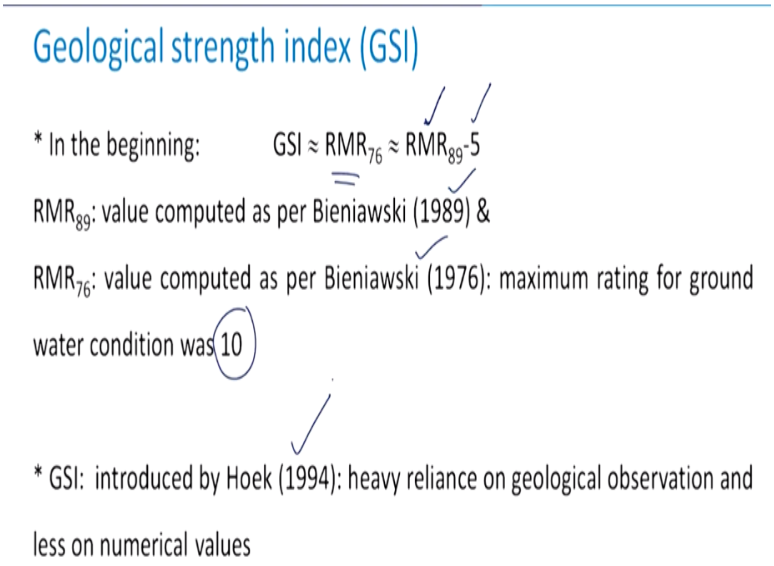

In the beginning, GSI was defined as equal to RMR$_{76}$ or RMR$_{89\ -\ 5}$ where this RMR 76 corresponds to the value of RMR which were computed as per Bieniawski 1976 where the maximum rating for groundwater condition was assigned as 10. And this RMR$_{89}$ was the value of RMR computed as per Bieniawski 1989, which we have already discussed in some of the earlier lectures.

So, this GSI was introduced by Hoek in 1994 and this system has heavy reliance on geological observation and less on the numerical values. So, let us see that what all are those geological observation on which this index GSI relies on.

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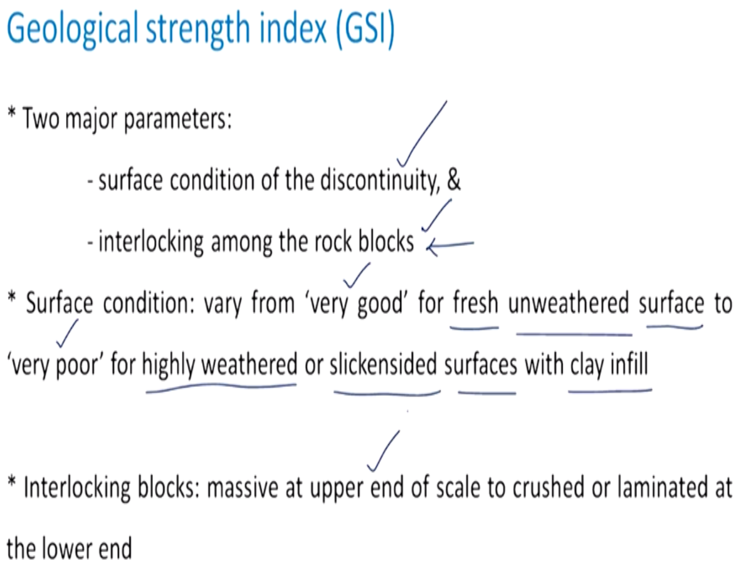

So, there are two major parameters. One is the surface condition of the discontinuity and another one is the interlocking among the rock blocks. Now as far as surface condition is concerned, it varies from very good for the fresh un-weathered surface to very poor for highly weathered or slicken-sided surfaces with clay infill. I mentioned to you in some of the earlier classes that how the joint characteristic or the wall characteristic influence the strength characteristic of the rock mass.

So, here you can see that if we have the very good surface condition, this represents the fresh unweathered surface and if we have very poor surface condition it represent highly weathered or slickensided surfaces with the clay infill. Now as far as the second parameter is concerned which is interlocking among the rock blocks, it can be defined as massive at the upper end of scale to crushed or laminated towards the lower end of the scale. So, basically on the basis of these two parameters mainly this GSI is determined.

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Geological strength index (GSI)

* Six main qualitative rock classes: intact or massive; blocky; very blocky; blocky/folded; crushed; laminated/sheared 6

* Discontinuities classified into 5 surface conditions: similar to joint conditions in *RMR* 5

* 6 × 5 matrix: a block picked up first according to actual & undisturbed rock mass classification & discontinuity surface condition: corresponding range of *GSI* be estimated

So, the six main qualitative rock classes are there which are defined as intact or massive, blocky, very blocky, blocky or folded, crushed and the last one is laminated or sheared. As far as the discontinuities are concerned, they are classified into 5 surface conditions which are very much similar to the joint condition that we discussed when we had the discussion about the rock mass rating or RMR system.

So, basically here it is 6 and here it is 5. So, we have 6x5 matrix and out of this 6x5 matrix based upon these two parameters on which this index relies on. We pick the block and these conditions, they depend upon the actual and undisturbed rock mass classification and the discontinuity surface condition and from this matrix which is 6x5 in size, we find out the corresponding range for GSI.

How this is done I will be explaining this to you in a short while. There is going to be the drastic degradation in GSI, RMR and *Q* values which occurs in the opening after squeezing or the rock burst. So, we need to evaluate the GSI of the rock mass in the undisturbed condition and that only we should use. So, when the excavation takes place if that excavation is through let us say squeezing ground condition or if there is a release of immense energy, which phenomena is called as the rock burst.

So, in that case we do not need to consider the conditions which are there after the excavation, but we should evaluate the GSI on the basis of the condition of the rock mass which was there in the undisturbed situation.

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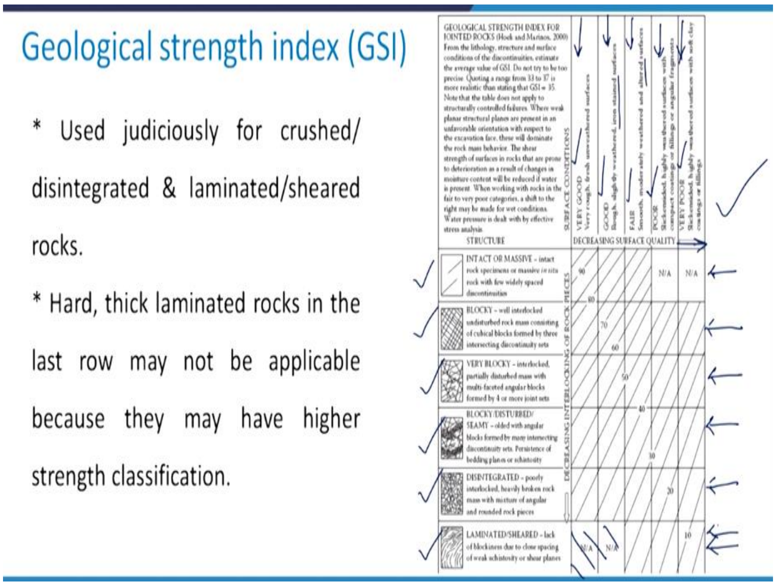

Take a look at this picture, where you have the matrix 6x5, how? See here, you have **six** 6 rows; 1, 2, 3, 4, 5 and 6 and these rows they correspond to intact or massive blocky, very blocky, blocky disturbed or semi disintegrated and laminated or sheared as I mentioned that 6 conditions on the structures of the rock mass and then take a look here along the column size you have the 5 columns 1, 2, 3, 4 and 5.

And these represent the surface quality, and in this direction the surface quality decreases. That means here you have the very good quality of the surface that means it is very rough, fresh and unweathered surface. Then the next one is the good surface condition which signifies rough slightly weathered, iron-stained surfaces. Third one is the fair surface condition and it is representing smooth moderately weathered and altered surfaces.

Then you have poor and very poor surface conditions. So, we need to use this matrix judiciously for crushed, disintegrated and laminated shear rocks, especially you see this portion where it is written not applicable. So hard, laminated rocks in the last row means this one may not be applicable because they may have higher strength classification which cannot be taken care by this index GSI.

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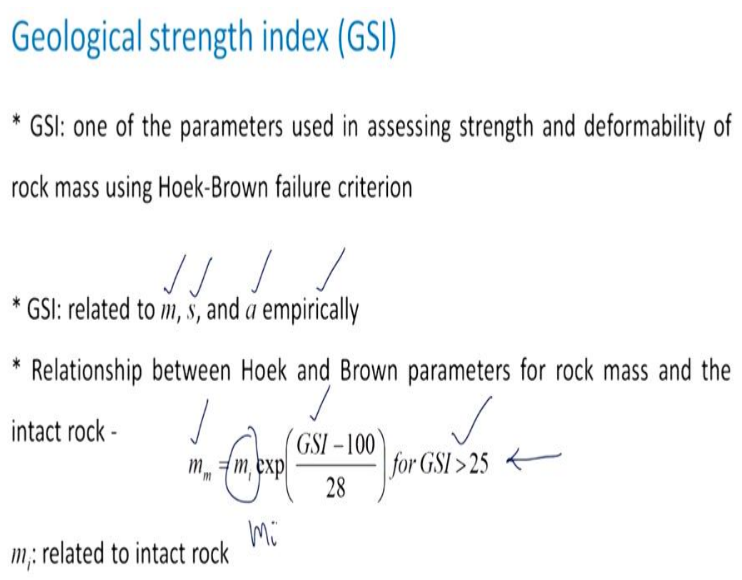

This GSI is one of the parameters which is used in assessing the strength and deformability of rock mass using Hoek and Brown failure criterion. So, depending upon the structure of the rock mass and the surface condition, you have seen that 6 by 5 matrix and whatever is the condition that is relevant in the field. You go to that chart and pick the range corresponding to those field condition, pick the range for GSI.

Now, this GSI is related to Hoek and Brown failure criterion parameters that is *m*, *s* and *a* and this is related empirically. The relationship between Hoek and Brown parameters for the rock mass and the intact rock is given by this expression

$$m_m = m_i \exp\left(\frac{GSI-100}{28}\right) \; for \; GSI > 25$$

and this expression is valid for GSI greater than 25. So, first we go to the field, we take the observations there and then depending upon if the value of GSI is greater than 25, here we can find out the Hoek and Brown parameter for the rock mass.

Which is m_m using this value of GSI, which we have obtained from the field condition and that 6 by 5 matrix. This expression also makes use of the Hoek and Brown parameter for the intact rock which is m_i.

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Geological strength index (GSI)

Values of m for intact rocks

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

Various values of m for the intact rock are given here. You can see that for the limestone it is 5.4, dolomite 6.8 and likewise for sandstone you see it is so 14.2 and for granite it is even higher it is 27.9. So, you know that the granite has better shear strength characteristic and therefore you are having the larger value of this parameter m in case of the better-quality rocks.

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Geological strength index (GSI)

* For good-quality rock mass (GSI > 25),

$a = 0.5$

$$s = \exp\left(\frac{GSI - 100}{9}\right)$$

* For poor-quality rock mass (GSI < 25)

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

$s = 0$

Now for good quality rock mass that is if you have GSI more than 25, a is going to be 0.5 and s can be obtained as exponential of ($s = \exp\left(\frac{GSI - 100}{9}\right)$) and for poor quality rock mass a is going to be ($a = 0.65 - \frac{GSI}{200}$) and s = 0.

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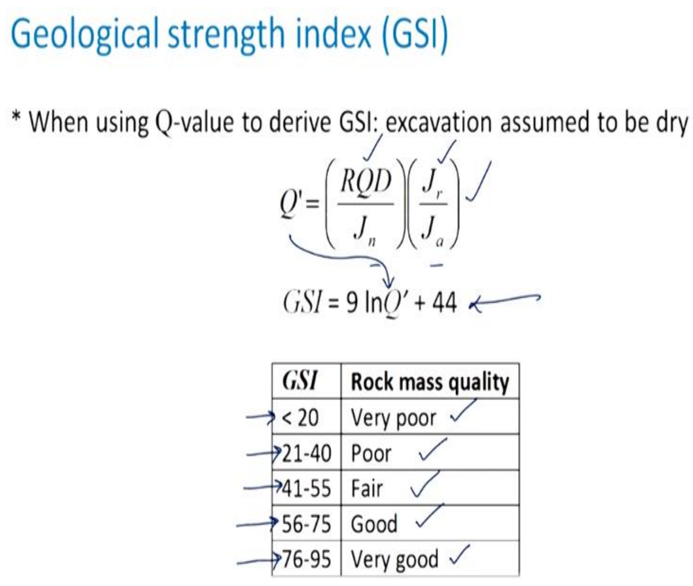

This Q-system also can be used to derive GSI and the assumption which is involved while doing so is that the excavation is going to be dry. So, we obtain the modified *Q* using this expression

$Q' = \left(\frac{RQD}{J_n}\right)\left(\frac{J_r}{J_a}\right)$. If you recall our earlier discussion, we saw that this Q index had 3 quotient and there was one more quotient with these two which was having the factor SRF also.

So, here we assume that the excavation is going to be dry and accordingly the ratings to these are assigned and this GSI can be determined by making use of this Q prime in this particular manner that is:

$GSI = 9 \ln Q' + 44$

So, once we obtain this GSI, I can find out the parameters of Hoek and Brown failure criterion. Now, based upon the values of GSI, the quality of the rock mass can be determined.

If the GSI value is less than 20, the rock mass is called as very poor. If it is varying between 21 and 40, this is poor. If it is 41 to 55 it falls under the category of fair rock mass. If it is 56 to 75 it is the good quality of rock mass and for very good quality of the rock mass the range of GSI varies from 76 to 95. So, based upon these two parameters that is the structure of the rock mass and the surface condition, we can make use of that 6 by 5 matrix.

And find out the range of GSI for that particular rock mass and this value of GSI will be used to obtain the parameters of the Hoek and Brown criteria, which is one of the most popular failure criteria in case of the rock mass. So, this was all about that I wanted to discuss with you as far as engineering classification of the rocks and rock masses are concerned.

So, in this chapter we learned about the engineering classification of the intact rock that was done using Deere and Miller classification system. Then, we discussed in detail 3 classification systems for the classification of rock mass. These include RMR system, Q-system and GSI. Along with these classification systems, I discussed with you that what all are the limitations of each of these. And we also learned about some of the application of these classification systems. So, in the next class we will start our discussion on a new chapter which will deal with the strength behaviour of isotropic and anisotropic rocks. Thank you very much.