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RESEARCH ARTICLE

Determination of Geological Strength Index and Slake Durability Index of Jointed Rock Mass along Champhai to Zokhawthar Highway

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The Geological Strength Index (GSI) system was developed using numerical analysis in response to the demand for accurate input data regarding the characteristics of rock masses for planning slopes, tunnels, or foundations in rocks. To acquire data and information regarding the mechanical behavior of the rock masses, field studies were conducted to analyze the stability of the slopes and the geological characteristics of the research area. The Slake Durability Test measures the resistance of rocks upon weathering that include clay. The study suggested that rock resistance decreased when exposed to a continuously wet and dry environment. The rate of disintegration increases due to changes in the environment, which causes physical and chemical weathering of rock. The Geological Strength Index is found to range between 42 and 54 based on the total observation results of the Structure Rating and Surface Condition Rating.

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Introduction

The rapid descent of the earth's material down a slope is called a landslide.[1] When all of the materials that constitute the slope are immobile and unaltered, the slope is said to be stable.[2] In steep terrain, one of the most catastrophic natural disasters we encounter is a rockfall, which has affected the stability of the slope.[3] Because of challenging topographical considerations, highways in hilly locations are usually narrower than those in plain regions, thus anytime rockfall happens, a variety of problems could develop.[4]

To meet the need for dependable input data, particularly those of rock-mass properties required as inputs into numerical analysis or closed-form solutions for designing tunnels, slopes, or foundations in rocks, the geological strength index (G.S.I.) system of rock-mass characterization was developed in engineering rock mechanics.[5] The Geological Strength Index is a concept used to measure the strength and condition of rock masses developed by Hoek[6] and Hoek *et al.*[7] to link the failure criterion to engineering geology field data.[8] The Hoek-Brown criterion was developed based on model studies of jointed rock mass behavior by Brown[9] and research into the brittle breakdown of complete rock by Hoek[10]. The Hoek-Brown failure criterion and the corresponding GSI have acquired wide acceptance as a method for determining the strength and deformation properties of extensively jointed rock masses.[8] The GSI value provides a numerical representation of the overall geotechnical

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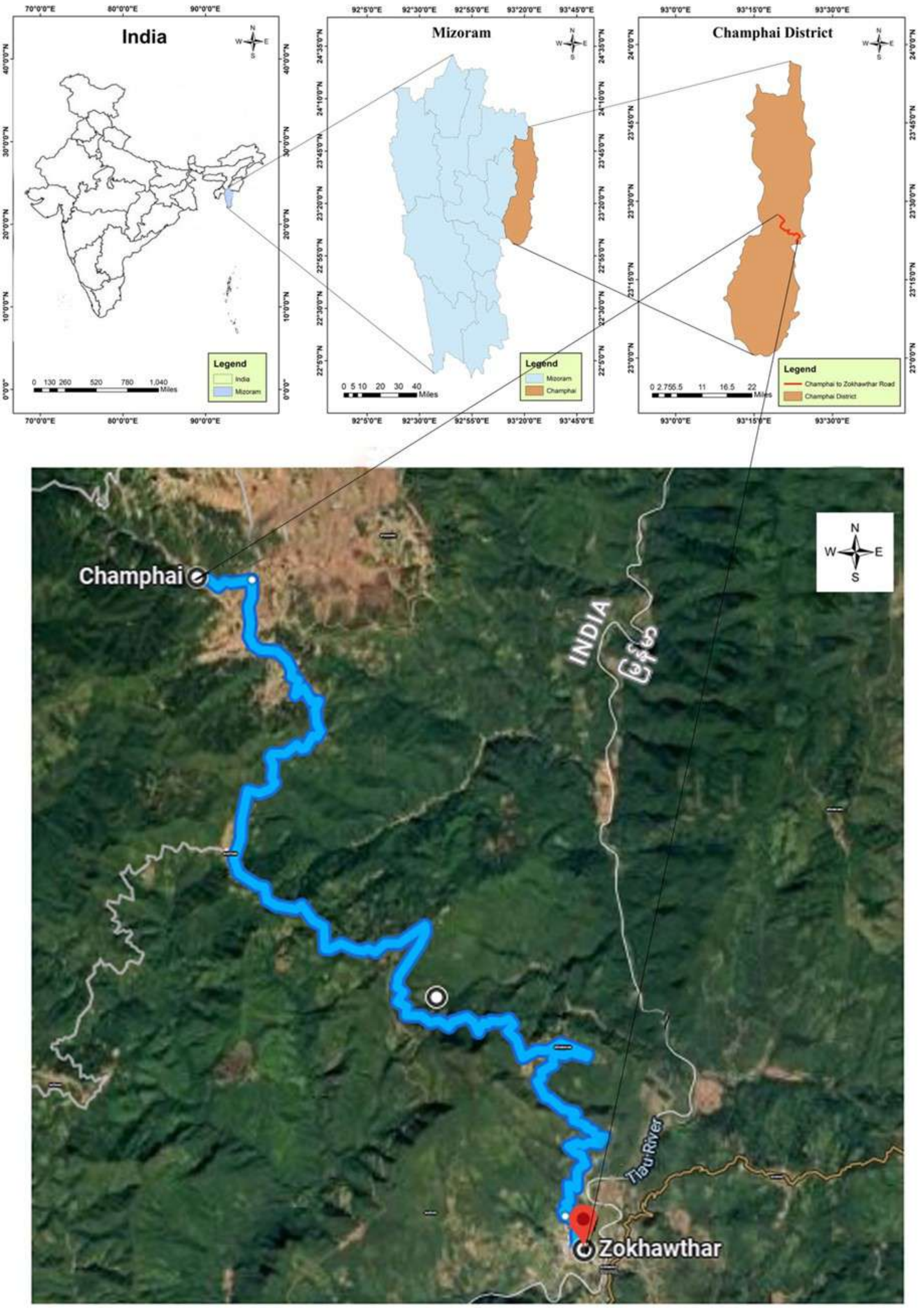

Figure 1. Location Map of Study Area

quality of rock mass and can be calculated from the standard chart provided as well as field observation of rock mass blockiness and discontinuity surface condition.[8,9] To give a more numerical, quantitative basis for assessing the GSI, Sonmez *et al.*[11] made modifications to the GSI categorization. They introduce terms like Surface Condition Rating (SCR) and Structural Rating (SR). This is based on volumetric joint count and SCR is based on RMR factors such as surface roughness (Rr), weathering (Rw), and infilling (Rf). In the chart given by Sonmez *et al.*[11] the rating of SR and SCR is plotted to generate a GSI value.[12] Any proposed classification of a rock mass must take block size into account, as it is a crucial indicator of that mass.[13]

When assessing sedimentary rocks, the degree of interbedded rock, the Slake Durability Index (SDI), and the degree of undercutting are considered.[14,15] Differential erosion caused by the intercalation of a competent and incompetent layer is referred to as the degree of undercutting.[16] This could lead to a steep decline that is very vulnerable to rockfall. High levels of surface weathering promote instability; the SDI assesses the rock slope's weathering characteristics.[17] Extended exposure of the rock slope to the atmosphere causes the slope to weather and become weaker, which increases the risk of rockfall and fractures in the rock.[18,19] For this reason, assessing the weathering condition of rock is necessary.

The study area (Fig. 1) is situated in Mizoram, India's northeastern region. A major route along the border between India and Myanmar, the state highway that runs from Champhai town to Zokhawthar village acts as a hub for trade and business. Since Zokhawthar Village is located adjacent to the international border with Myanmar, it benefits from being close to Champhai Town. Since goods and commodities from Myanmar and abroad routinely flow through Champhai town, it serves as an important connection in the commercial network for Zokhawthar and the surrounding villages .

Materials and methods

A comprehensive and effective field investigation is carried out to characterize the rock mass. While the objective of the laboratory investigations was to examine the geotechnical behaviours of the rocks present on the field concerning slope stability, the field investigations focused on the research of the geological and geotechnical aspects of the studied location. The collection of data and information about the mechanical behaviour of the rocks, the stability of the slopes, and the geology and engineering geology of the research area has been made possible by the execution of intensive field and laboratory experiments.[10]

Hoek and Brown[8] proposed the use of a more practical index called GSI as an input parameter for their empirical failure criterion. Based on visual field inquiry, it can be determined using two parameters: surface condition rating (SCR) and structure rating (SR). The volumetric joint count provided by the equation determines the SR, while the roughness, weathering, and infilling ratings determine the SCR. The quantitative GSI chart is given in Figure 2.

$$SR = -17.5 \ln (Jv) + 79.8$$

$$SCR = Rr + Rw + Rl$$

(*Where,* Jv = Volumetric Joint Count, Rr = Roughness Rating, Rl = Infilling Rating)

The slake durability index is a measurement of the rock's resistance to disintegrating under drying and wetting conditions in a slaking fluid.[14,20] This slake durability test examines how resistant clay-containing rocks are to weathering. The basic method involves immersing rock samples in water and monitoring any swelling or disintegration. The porosity and permeability of the rock, which controls the entry, retention, and migration of pore fluids inside the rock, are the characteristics that determine how stable it remains.

The Slake Durability Index (SDI) is calculated by:

$$\mathrm{Id1} = \frac{B - D}{A - D} 100$$

$$\mathrm{Id2} = \frac{C - D}{A - D} 100$$

Id1 = Slake Durability Index for First cycle
Id2 = Slake Durability Index for Second cycle
A = Weight of drum plus sample
B = Weight of drum plus retained portion of sample for first cycle
C = Weight of drum plus retained portion of sample for second cycle
D = Weight of drum

Results and discussion

Determination of the Geological Strength Index (GSI)

The improved GSI classification system[11] yielded a more quantitative and numerical evaluation of the rock bulk. Rock samples were collected from seven

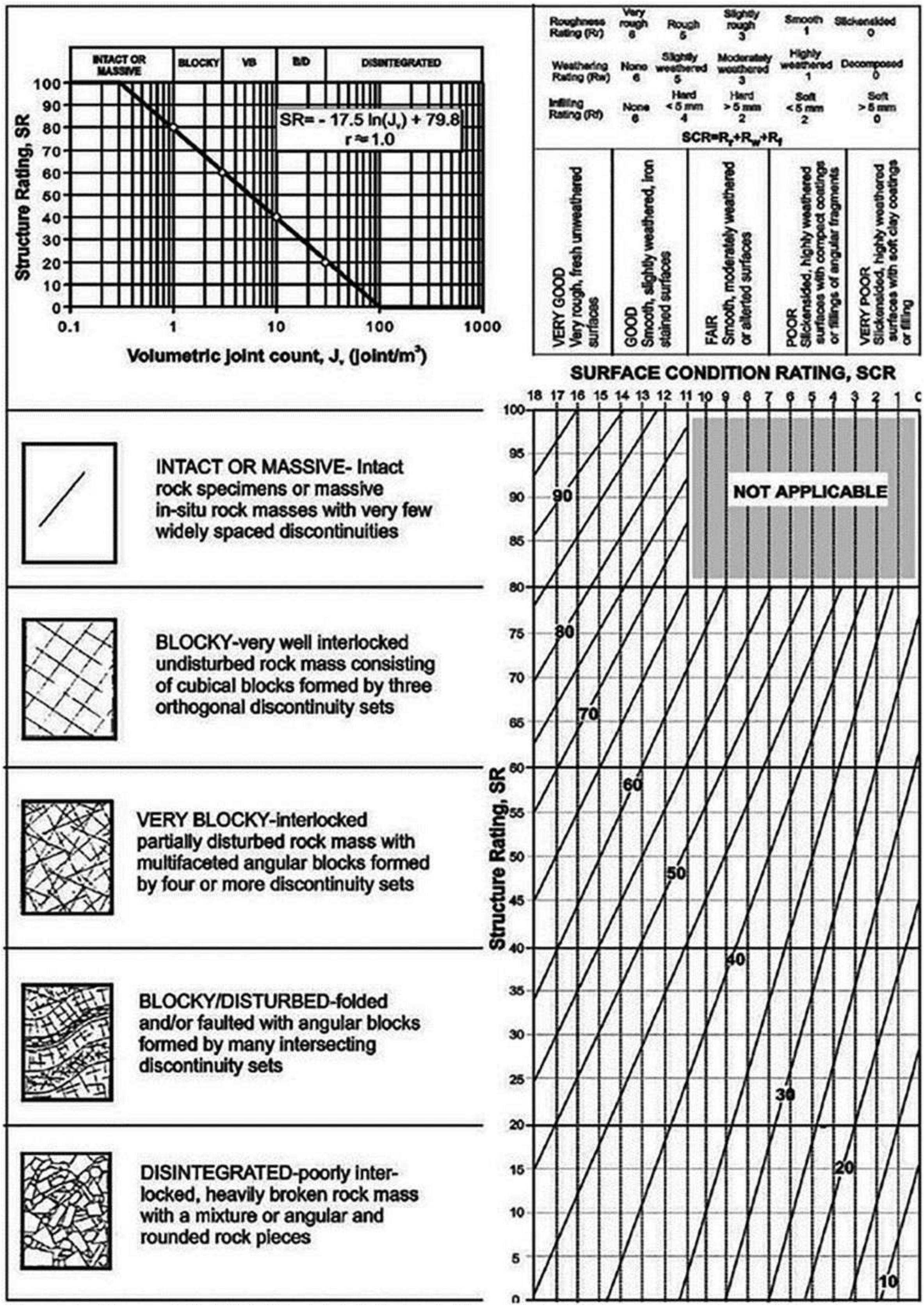

Figure 2. Geological Strength Index Chart (after Hoek and Brown[8])

Table 1. GSI Rating based on Structural Rating and Surface Condition Rating

Spot No	Structural Rating (SR) = -17.5 ln (Jv) + 79.8	Surface Condition Rating (SCR)			Total SCR Rating	GSI value from graph (SR Vs. SCR)
		Rough-ness Rat-ing (Rr)	Weather-ing Rating (Rw)	Infilling Rating (Rf)		
Spot 1	Jv=13.3	Slightly Rough	Slightly weathered	None	13	46
Rating	34.5	3	5	6		
Spot 2	Jv=13.9	Rough	Slightly weathered	None	16	54
Rating	33.7	5	5	6		
Spot 3	Jv=15.1	Slightly Rough	Slightly weathered	None	14	48
Rating	32.2	3	5	6		
Spot 4	Jv=21.8	Rough	Moderately weathered	Hard filling <5mm	12	43
Rating	25.8	5	3	4		
Spot 5	Jv=20.3	Rough	Moderately Weathered	None	14	46
Rating	27.1	5	3	6		
Spot 6	Jv=23.03	Rough	Slightly weathered	Hard filling <5mm	12	42
Rating	24.9	5	3	4		
Spot 7	Jv=18.4	Slightly Rough	Slightly weathered	None	12	44
Rating	28.8	3	3	6		

locations. Volumetric joint count was used to calculate the Surface Condition Rating (SCR). The number of joints per one-meter square within the rock mass was recorded. From the field observation and visual interpretation, the roughness rating falls between slightly rough to rough. The weathering conditions of the rock masses were assigned as slightly weathered to moderately weathered. For spot 1, 2, 3, and 5, there are no infillings between the discontinuities, whereas hard infillings were observed on spot 4 and spot 6. Therefore, Structural Rating (SR) was calculated based on surface roughness (Rr), weathering (Rw), and infilling (Rf). To generate a GSI value, the rating of SR and SCR is plotted in Figure 3. Each research site's detailed assessment is displayed in Table 1, and the GSI value is shown in Figure 3. From the GSI value obtained, the rock mass for each spot can be described as blocky/ disturbed – folded and/ or faulted with angular blocks formed by many intersecting discontinuity sets .

Determination of Slake Durability Index (SDI)

The capability of rock to withstand the weakening and disintegration under repeated cycles of wetting and drying in a slaking fluid; typically water, is tested using the slake durability test. Table 2 displays the slake durability index for each cycle. Using IS:10050-1981, the slake durability test was conducted for seven rock samples. The rock types for locations 2 and 3 are siltstones, whereas all the other rock samples for the remaining locations were sandstones. Based on the laboratory analysis, siltstones are observed to possess high durability, whereas sandstones are observed to possess very high durability. The rock sample for location 4 has the highest retention percentage of 94.05, whereas samples 3 have the lowest retention percentage of 85.71 after the second cycle, respectively. Figure 4 shows the slake durability index of the second cycle for each rock sample.

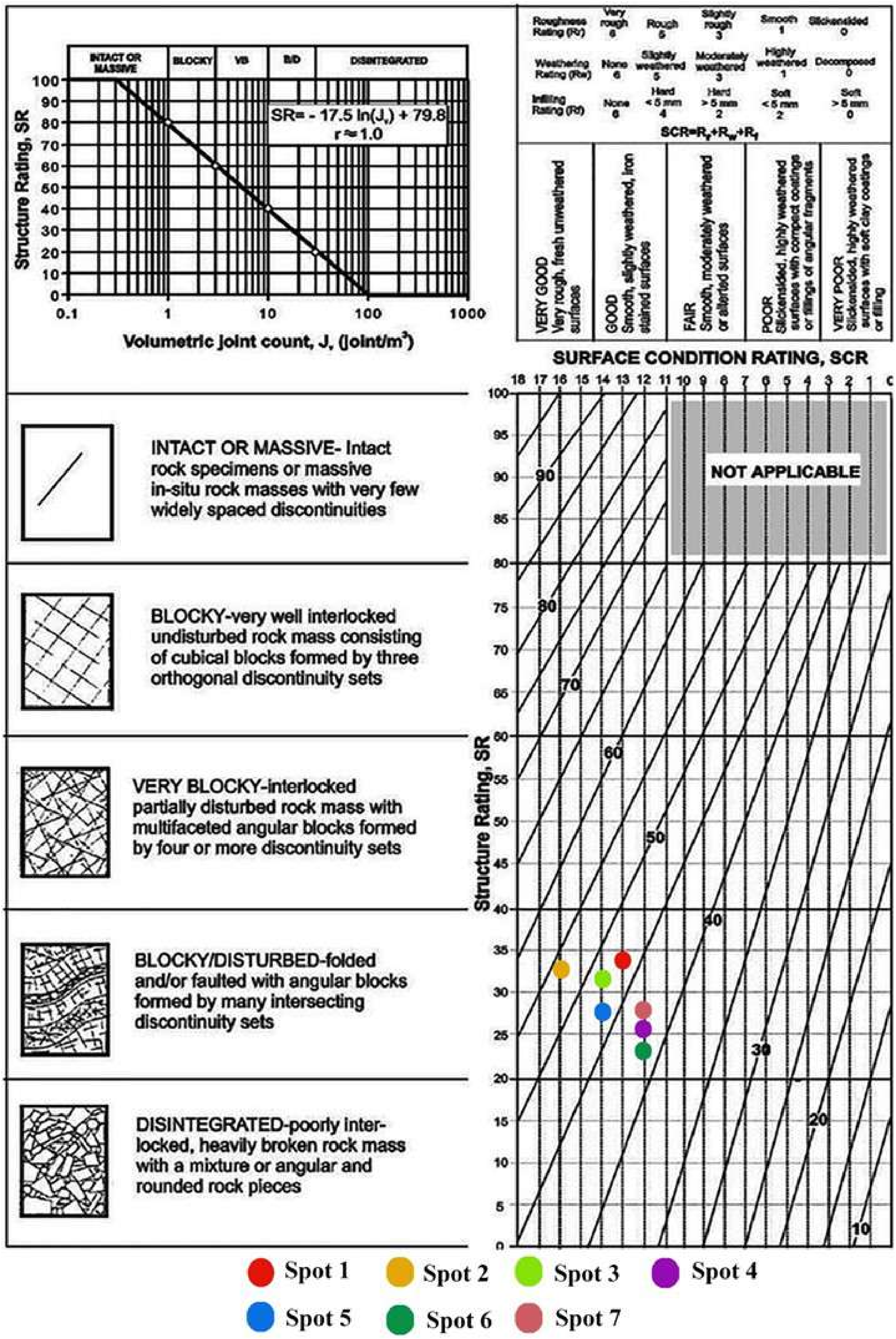

Figure 3. GSI Rating for each study sites

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Table 2. Slake Durability Index for each cycle

Sample No.	Rock Type	SDI (%) In each cycle				ID_2	Durability
		1	2	3	4		
1.	**Sandstone**	96.46	93.55	91.22	90.63	93.55	Very High
2.	**Siltstone**	92.84	89.65	88.56	84.23	89.65	High
3.	**Siltstone**	88.45	85.71	80.81	79.12	85.71	High
4.	**Sandstone**	97.65	94.05	93.44	91.74	94.05	Very High
5.	**Sandstone**	98.12	92.62	91.83	89.24	92.12	Very High
6.	**Sandstone**	95.00	92.31	87.42	87.31	92.31	Very High
7.	**Sandstone**	94.12	92.80	90.64	89.50	92.80	Very High

Discussion

The total observation values based on the Structure Rating and Surface Condition Rating show that the Geological Strength Index ranges between 42 and 54. Study site spot 6 has the lowest GSI value, while the study site spot 2 has the highest GSI value. From the field and laboratory observation, the rock mass at each location can be characterized as blocky, disturbed, jointed, and folded with angular blocks made up of numerous intersecting discontinuity sets. The stability of the rock slope decreases and vulnerability to failure increases due to the presence of numerous jointed rock masses.

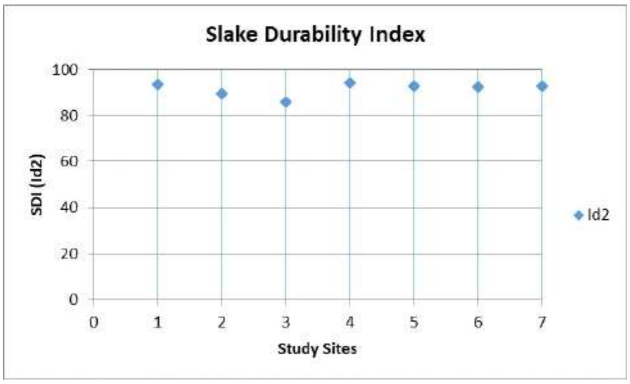

Figure 4. Slake Durability Index for 2^{nd} Cycle

The slake durability index shows that the rate of weathering of rocks is very high for each location. As the size of the rock fragments decreases with each additional cycle of the slake durability test, the number of pieces of rock increases. It suggested that once the rock was exposed to an environment of constant wetting and drying, rock resistance decreased. The rate of physical and chemical weathering of rock accelerated by changes in the atmosphere enhanced the disintegration rate.

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