USE OF LOCAL STRAIN MEASUREMENTS FOR RATIONAL EVALUATION OF LOADING RATE DEPENDENCY OF GYPSUM MIXED SAND

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1. INTRODUCTION

It has been utterly acknowledged that loading rate dependent characteristics of natural soft rocks are of vital importance in their constitutive modeling, and numerous venerated studies have already been conducted globally for the evaluation of these viscous properties. Based on these studies, it has been observed that stress-strain relationships of bounded materials such as sedimentary soft rocks and stiff geomaterials, in their pre-peak regions, are generally dictated by loading rates, and such a property is typically known as Isotach, Miyashita et al. (2015). In order to overcome the undesirable inherent variations and financial constraints associated with the testing of natural soft rocks, especially for research activities, researchers are also widely accustomed to use artificially/laboratory produced soft rocks samples for the evaluation of strength and deformation characteristics of targeted natural rocks, Shou et al. (2004).

In the present study, effects of loading rate on peak strengths of laboratory produced soft rocks viz. Gypsum Mixed Sand (GMS), are studied under unconfined monotonic loading conditions, at five different loading rates. Local strain measurements are also made, and based upon the Absolute Averaged Difference (AAD)* of local strains measured at the opposite sides of specimen in the pre-peak regions, an approach has been adopted for the estimation of accuracy/reliability of test results. Lastly, loading rate dependency of GMS has been discussed by presenting a modified/refined relationship between Unconfined Compressive Strength (UCS) and the rate of axial loading.

2. MATERIALS AND TESTING PROCEDURE

A fixed proportion, by weight, of Silica Sand No. 6 (42.4%), gypsum (33.9%) manufactured by Yoshino Gypsum Co. Ltd. and water (23.7%) was used for the preparation of GMS samples. Slurry was prepared by mixing these materials and was uniformly poured into plastic molds, having height and diameter of 100 mm and 50 mm respectively. For curing under controlled temperature of 25˚C, the molds were first kept air sealed for 48 ± 2 hours and afterwards, extracted samples were further cured in air sealed plastic covering for 24 ± 2 hours before final testing. The technique of capping, using dental gypsum, was adopted to minimize the possibility of ductile failure and tensile cracking, Maqsood et al. (2015). To safeguard the loading shaft from any potential damage, the top cap of the apparatus was intentionally kept flexible throughout this testing activity. Moreover, constant moisture content was ensured throughout the tests by wrapping rubber membrane over the specimen.

The samples were tested under uniaxial compression condition at five different loading rates viz. 0.165, 0.066, 0.025, 0.011 and 0.004% per minute. In addition to axial strain measurements using conventional external transducer (EDT), local strains were also precisely recorded using a pair of local displacement transducers (LDTs), attached at the opposite sides of the specimen as shown in Fig. 1.

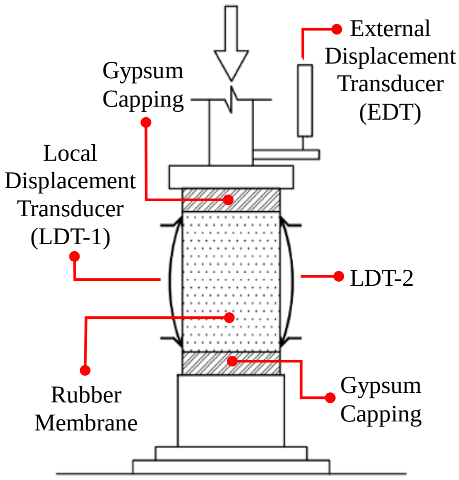

Figure 1. Schematic sketch of External (EDT) and Local (LDT) Displacement Transducers

*Absolute Average Difference of LTD Strains is AAD $=|(\text{Strain}_{LDT1}-\text{Strain}_{LDT2})/(\text{Strain}_{LDT1}+\text{Strain}_{LDT2})|$

3. RESULTS AND DISCUSSION

A brief statistical analysis of uniaxial compressive strength values corresponding to axial strain rates is presented in Table 1. As expected, Isotach property is quite evident from these results as peak strength values decrease accordingly with the decrease in axial strain rates. It is also noteworthy that substantial undesirable variations in strength values are observed under similar axial strain rates, as indicated by non-negligible values of standard deviations. Fig. 2 shows typical stress-strain relationship of two of the specimens of series S3, tested under an axial strain rate of 0.025% per minute. The unconfined compressive strength of S153 was measured to be almost 22% lesser than that of S150 under the same testing conditions.

To overcome such shortcomings in test results, locally measured strains by means of LDTs are quantitatively analyzed. As evident from Fig. 2, local strains measured by both of the LDTs of S150 show almost similar values of strains in pre-peak and near-peak regions.

Table 1. Statistical Analysis of test results

Series ID	Avg. Axial Strain Rate	No. of Tests	Uniaxial Compressive Strength (kPa)			
	% per minute		Max. Value	Min. Value	Avg. Value	Standard Deviation
S1	0.165	3	4669	4546	4625	56
S2	0.065	8	4609	3630	4240	305
S3	0.025	4	4046	3153	3795	375
S4	0.011	6	3710	2930	3370	255
S5	0.004	7	2807	2459	2685	120

Keywords: Gypsum Mixed Sand, Unconfined Compressive Strength, loading rate effects, local strain measurements
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Contrarily, a significant difference among the strains measured by each of the LDTs of S153 can easily be identified, indicating an uneven distribution of local strains, on opposite sides of the specimen, ultimately resulting into reduction in peak strength value. In an effort to obtain a possible correlation, AAD of local axial strains measured by the pair of LDTs, at four different strain levels, are plotted against peak strength values, as shown in Fig. 3 to Fig. 6.

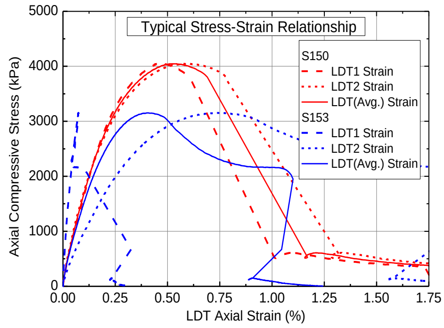

Fig. 2 Typical stress-strain relationship (Series S3)

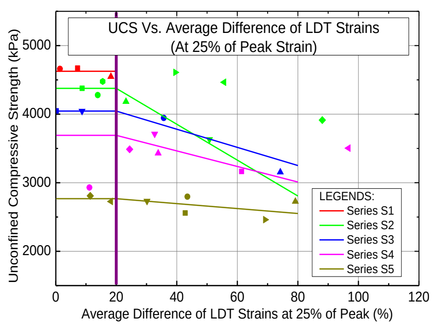

Fig. 3 UCS Vs. AAD of LDT strains (At 25% of Peak Strain)

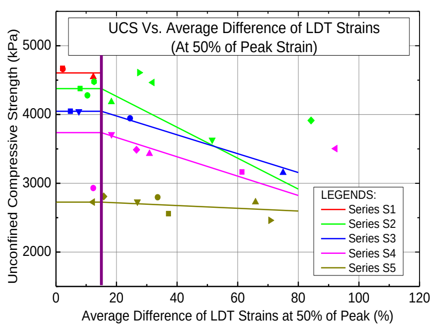

Fig. 4 UCS Vs. AAD of LDT strains (At 50% of Peak Strain)

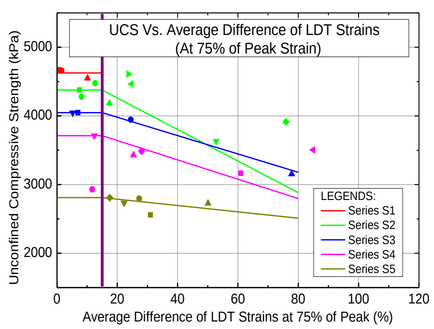

Fig. 5 UCS Vs. AAD of LDT strains (At 75% of Peak Strain)

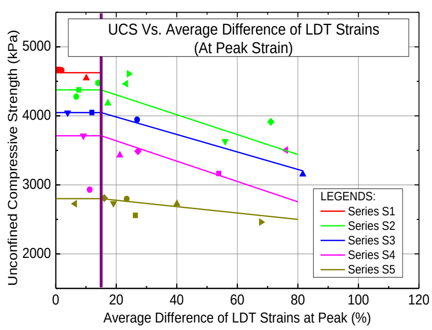

Fig. 6 UCS Vs. AAD of LDT strains (At Peak Strain)

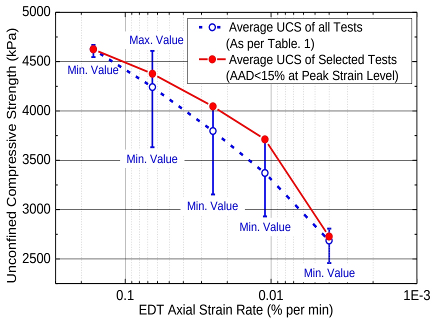

Fig. 7 Modified Relationship between UCS and Axial Strain Rate

In general, the peak strength values decrease with an increase in AAD of local strains under the same axial strain rate. However, this decrease is quite prominent under higher strain rates and becomes relatively insignificant in case of very slow strain rate, viz. in series S5. It is also observed that, in almost all of the tests, the value of AAD of local strains generally reduces with the increase of strain level, as can be seen in Fig. 3 to Fig. 6. Moreover, the analysis results also suggest that the peak strength values remain unaffected provided AAD of local strains remains lesser than 20% at 25% of peak strain level, as shown in Fig. 3, and lesser than 15% for higher strain levels till failure.

Based upon this, the strength values having ADD lesser than 15% at peak strain level are selected for the refined assessment of loading rate effects on peak strengths of GMS. Firstly, average UCS of all the tests, as per Table 1, along with their extreme (i.e. max. and min.) values are plotted in Fig. 7, which indicates a relatively higher and uniform rate of reduction in the UCS values with decrease in the loading rates. However, a relatively gentle decline in UCS values can be observed after the refinement of test results, accompanied by a sudden drop at slower strain rate viz. in series S5. Distinctive stress concentration and delayed formation of shear band may result in such an abrupt reduction of UCS at slower loading rates, Bhandari et al. (2005).

4. CONCLUSION

A number of GMS samples are tested under uniaxial monotonic loading conditions at five different loading rates. In order to overcome undesirable variations in test results, under similar testing conditions, absolute average difference of local strains, measured at the opposite sides of specimen, were rationally analyzed. It is observed that for a given loading rate, peak strength values generally decreases with the increase of AAD of local strains. However, the peak strength values remain unaffected provided AAD of local strains remains lesser than 20% at 25% of peak strain level and lesser than 15% for higher strain levels till failure. Finally, a relatively gentle decline in UCS values can be observed after the refinement of test results, accompanied by a sudden drop at slower strain rate.

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