Strength and Stiffness of Claystone Specimens Tested with Neoprene Capping

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Abstract

Cylindrical core specimens of Maha Sarakham claystone were uniaxially loaded to failure under various length-to-diameter ratios (L/D). Compressive strength of the specimens tested without neoprene capping decreases from 50.6 MPa for L/D = 0.5 to 36.5 MPa for L/D = 3.0. This end effect is caused by friction at the rock-steel platen interfaces, creating shear stresses near both ends of the specimen, as evidenced by the results of finite difference analyses that the shear zones in rock near the loading ends become predominant for specimens with a low L/D ratio. The claystone strengths obtained from neoprene capped specimens with different L/D ratios show a lower intrinsic variation and tend to be consistent at 32.4 MPa. For the specimen with L/D ratio less than 2.0, the strengths from neoprene capped specimens may be more representative than those with shape-correction from the uncapped specimens. Elastic modulus values measured from both capped and uncapped specimens tend to increase with L/D ratio.

1. Introduction

The effect of length-to-diameter ratio (L/D) on the mechanical behavior of rock specimens has long been recognized [1]. The behavior of rock specimens which are short compared to their diameter is affected strongly by contact with the platens between which they are compressed. Even when the surfaces of specimen and the platens are flat and parallel, the rigidity of the platens usually restricts the lateral expansion of the ends of the specimen. The strength then decreases with increasing length in relation to the diameter. It can therefore be concluded that the true strength of rock should be determined from tests on cylinders with a ratio between length and diameter in excess of 2, where the stresses in the central portion of the specimen are affected only slightly by contact with the platens.

For soft rocks (such as shale, mudstone and claystone), obtaining core samples with the minimum L/D requirement is often difficult because they are easily broken into small pieces either by drilling and handling processes or by the separation of pre-existing cracks and fractures. For this situation two alternatives have been commonly practiced. For the first alternative, the short core samples are tested and correction factor is applied to the strength result [2]. The second alternative involves application of capping material on both loading ends of the core samples.

According to ASTM (D7012) [3] the L/D correction for the unconfined compressive strength of rock samples that are shorter than the specifications is: $\sigma_{c2} = \sigma_c / [0.875 + (0.25\ D/L)]$, where σ_{c2} = calculated compressive strength for L/D = 2.0. It should be noted that the single set of multiplied factors as proposed by ASTM may not be universally applicable to all rock types. This is because different rocks exhibit different mechanical responses in terms of the friction and shear zone at the loading interfaces.

Thuro et al. [4] applied end caps to reduce the friction at the loading ends by introducing various types of materials such as paraffin, cardboard rubber sheets, teflon and wood fiber [5]. Grosvenor [6] and Lundborg [7] state that the use of cardboard end caps is not recommended because they may produce tensile stresses at the interface and considerably reduce the load-bearing characteristics of the specimen.

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Ojo [5] uses end caps of various types to determine compressive strength of rocks. The samples with end caps produce more consistent results with smaller standard deviations than those without the caps. The end caps can absorb the initial shock of stress on the surface the specimens. They reduce friction between platens and rock specimen. Soft-board end caps are suitable for stresses less than 100 MPa, hard-board or cardboard can be used up to 125 MPa. For rock strengths above 125 MPa no end cap is required. Attempt to remove frictional restraint by lubricating the contact with graphite, molybdenum disulphide, and other solid lubricant is not recommended [2]. It is clear from the previous studies that there are uncertainties about applications of appropriate capping materials. Different capping materials minimize different degrees of the induced shear and friction at the loading interfaces, and hence the capped specimens yield different failure stresses. In addition the effect of end capping on the measured elastic modulus of the rock sample has rarely been investigated.

The objective of this study is to assess the effects of length-to-diameter ratio on the compressive strength and elasticity of the Maha Sarakham claystone specimens. The task mainly involves laboratory mechanical testing of the cylindrical specimens under a variety of L/D ratios and numerical analysis to determine the stress distributions within the specimens. An alternative method and appropriate material for end capping are proposed to obtain rock strengths equivalent to those from the standard testing.

2. Rock Specimens

The specimens used here are the Cretaceous claystone. The rock belongs to the Middle Clastic member of the Maha Sarakham formation in the Khorat Basin. They were obtained from 64-mm diameter cores drilled from the depth ranging between 185.20 m and 189.20 m at Non Thai district, Nakhon Ratchasima province. Warren [8] gives detailed description of the formation and geology of the basin. The claystone is reddish brown and relatively homogeneous. X-ray diffraction analysis shows that the rock has clastic texture with an average grain size of about 0.1 mm. It composes of 39.7% quartz, 13.2% mica, 30.9% kaolinite and 16.2% Halite. Cementing materials are mostly halite and iron oxides. The average density is 2.62 g/cc.

3. Uniaxial Strength Testing

Series of uniaxial compressive strength tests were performed on cylindrical claystone specimens with and nominal diameter of 64 mm and L/D ratio varied from 0.5, 1.0, 1.5, 2.0, 2.5 to 3.0 (Figures 1 and 2). Test procedure follows the ASTM (D7012) [3] and

Figure 1. Some claystone specimens with L/D ratios of 1.5, 2.0, 2.5 and 3.0.

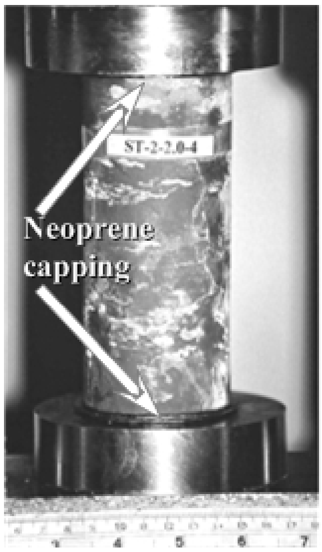


Figure 2. Claystone specimen capped with neoprene during uniaxial compressive strength test.

the suggestion method by ISRM [9]. Two sets of specimens were prepared; one for testing without ends capping, and the other for testing with neoprene capping. Neoprene sheet is a type of synthetic rubber, developed in the 1930s. Since then it has been incorporated into numerous products in daily life. It is strong, durable, water-proof and somewhat stretchable. The neoprene used in this experiment is cut from file folders commercially available in any bookstore and stationary shops.

The test results are summarized in Tables 1 and 2. Post-tested specimens with L/D = 2 shown in Figure 3 suggest that shear fractures are induced in the specimens tested without capping, while extension failure or longitudinal splitting is predominant in the specimens tested with neoprene capping. Figure 4 plots the compressive strengths (σ_c) as function of L/D. The strengths from specimens tested with end capping are averaged as 32.4 MPa, and tend to be independent of L/D within the range used here.

Table 1. Uniaxial compressive strengths of claystone tested here.

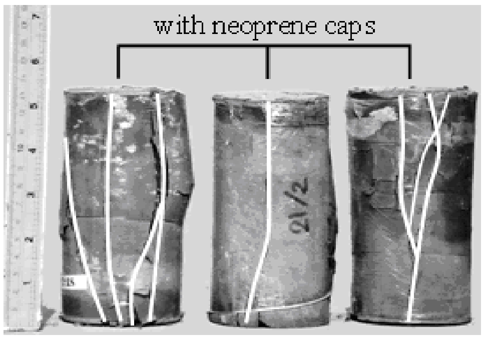
L/D	Uniaxial Compressive Strength (MPa)	
	Without neoprene capping	With neoprene capping
0.5	50.6 ± 2.96	34.0 ± 0.02
1.0	42.9 ± 3.95	33.7 ± 1.82
1.5	35.4 ± 12.12	32.3 ± 3.63
2.0	32.9 ± 8.87	28.9 ± 2.39
2.5	37.7 ± 13.97	31.4 ± 1.39
3.0	36.5 ± 5.31	34.1 ± 2.38

Table 2. Modulus of elasticity of claystone tested here.

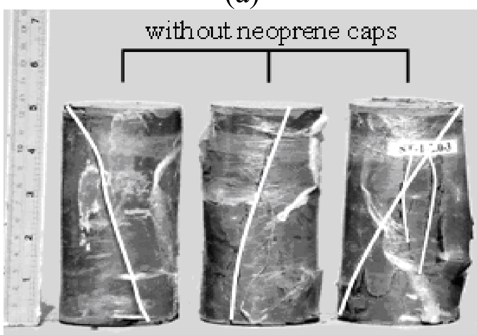
L/D	Elastic Modulus (GPa)	
	Without neoprene capping	With neoprene capping
0.5	2.25	1.72 ± 0.17
1.0	3.80 ± 0.12	2.45 ± 0.26
1.5	4.28	4.40
2.0	6.05 ± 0.99	4.71
2.5	7.76	6.50
3.0	7.96 ± 0.46	7.48

For the specimens tested without capping, the averaged strength decreases from 50.6 MPa for L/D = 0.5, to 36.5 MPa for L/D = 3.0. The decrease of rock strength (σ_c) can be best described by a power equation: $\sigma_c = 42.18 (L/D)^{-0.199}$. The decrease of the strength with increasing L/D can be explained by the specimens failed by longitudinal failure mode yield a lower strength than do the specimens failed by shear fractures.

The correction equation of ASTM is applied to the strength results obtained from uncapped specimens. The corrected strengths (equivalent to L/D = 2) are plotted as a function of L/D in Figure 5. Regression analysis shows that the corrected strengths are averaged as 36.5 MPa, and tend to be independent of L/D. This suggests that the correction factor works well for the Maha Sarakham claystone. The corrected strength obtained from uncapped specimens is still higher than that from the capped specimens.



(a)



(b)

Figure 3. Failures of rock specimens with L/D 2.0 after testing with (a) and without (b) neoprene caps. Induced fractures are highlighted with white lines.

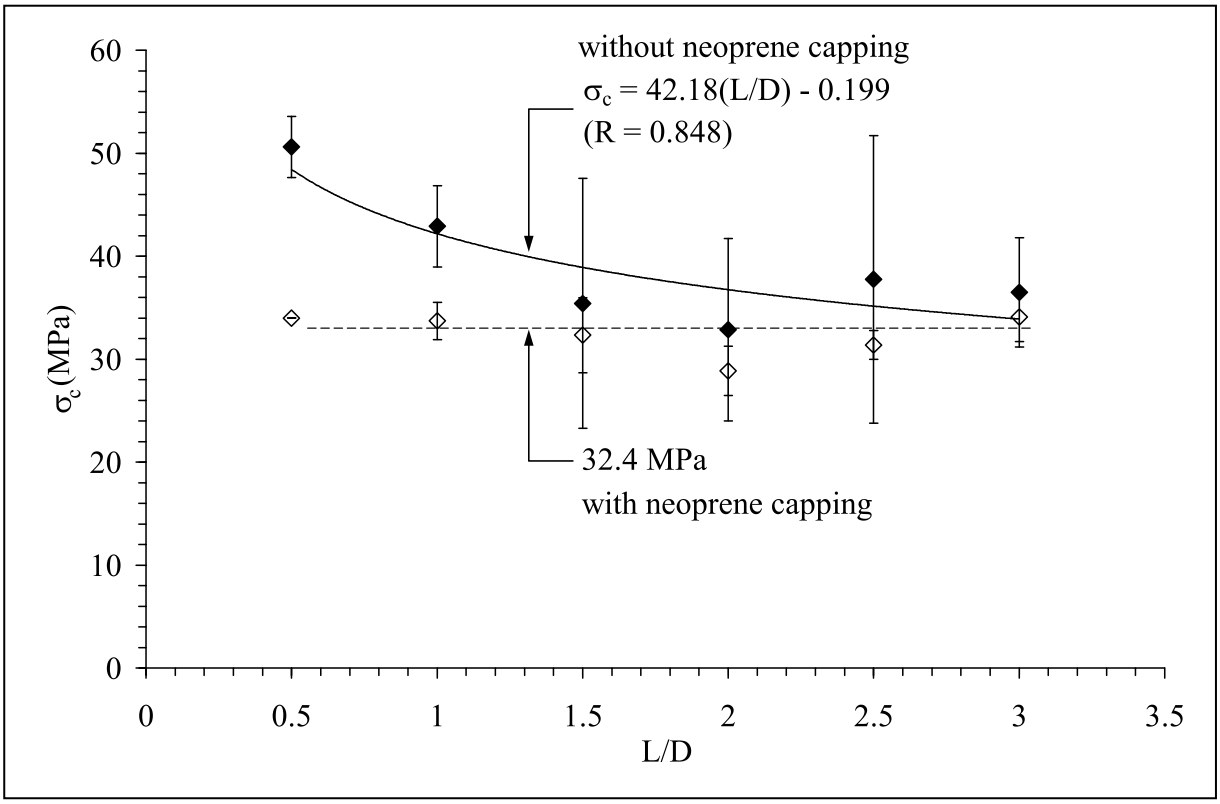


Figure 4. Uniaxial compressive strength as a function of L/D.

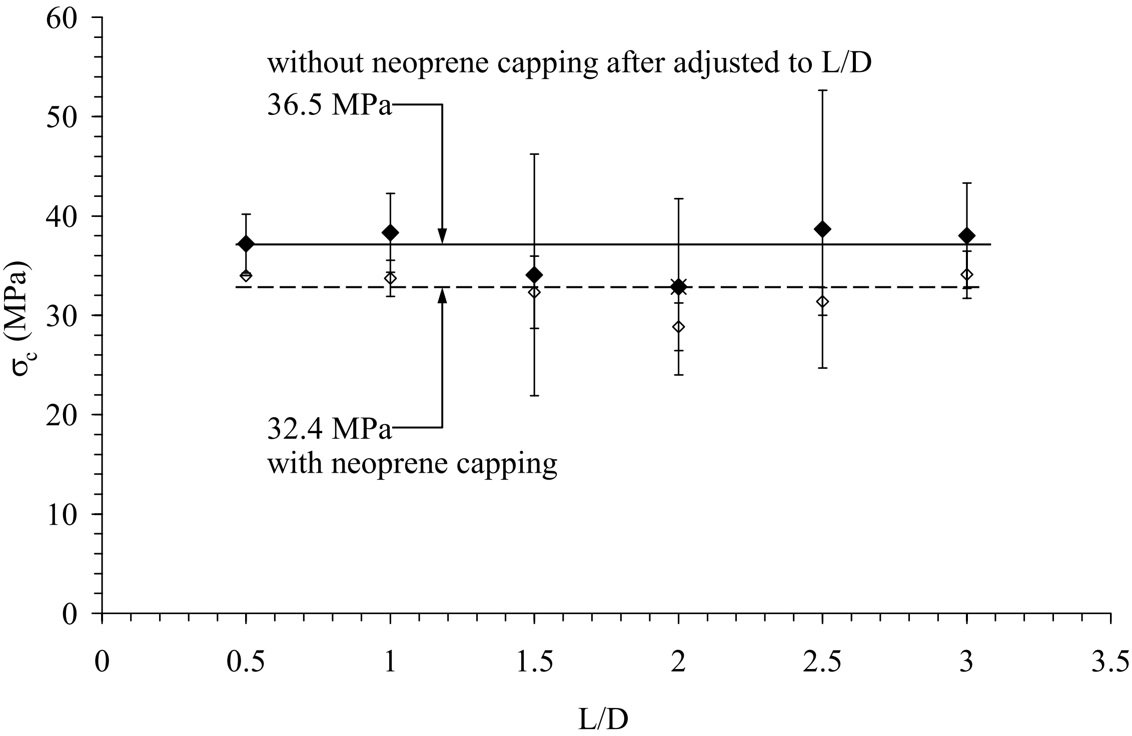


Figure 5. Corrected compressive strengths as a function of L/D for uncapped specimens.

Figure 6 plots the elastic modulus as a function of L/D ratio for both capped and uncapped specimens. The rock elasticity tends to increase with increasing L/D ratio. The uncapped specimens yield elastic modulus values slightly higher than those of the capped specimens. This agrees with experimental results by Thuro et al. [4] who explain that the increase of elasticity is because the applied axial stress induces a higher plastic strain in the shear zone near the ends of the uncapped specimens. These shear zones deform more than does the intact portion at the mid-section of the specimen.

4. Numerical Modeling

Series of finite difference analyses has been carried out to show the distribution of shear stresses induced by the friction resistance at the interface of the capped and uncapped specimens with L/D ratios varying from 0.5, 1.0, 2.0 to 3.0. Finite difference code FLAC [10] is used. The analyses include the steel platen, rock specimen and neoprene into the simulations (Figure 7). The simulations are made in axis symmetry and assume that all materials are linearly elastic, continuous and homogeneous. The elastic modulus of claystone specimen is taken from the uniaxial testing performed earlier. The elastic modulus of neoprene cap is measured by subjecting a neoprene sheet under uniform normal load and measuring the displacement. Normal stress and strain are then calculated from the measurements. The test result shown in Figure 8 indicates that the elastic modulus of the neoprene under compression is about 0.07 GPa. For all simulations the elastic modulus of the steel platen is assumed as 200 GPa [11].

Figure 9 shows the shear stress distribution within the capped and uncapped uniaxial specimens with various L/D ratios. The steel and neoprene are cropped out of the Figure. The magnitudes of shear stress indicated on the contour are normalized by the applied axial stress (τ/σ_{axail}). For the specimens capped with neoprene the shear stress is significantly low – less than 2.5% of the applied axial stress

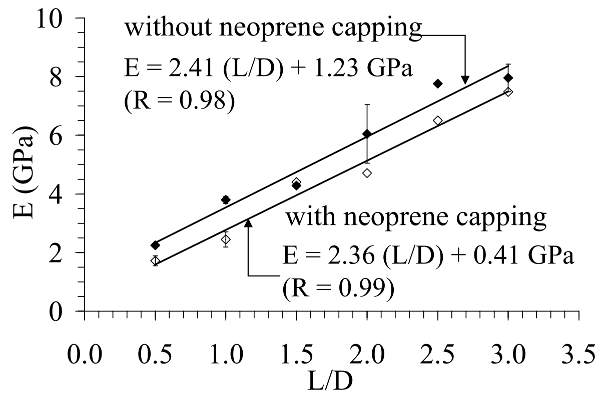


Figure 6. Elastic modulus plotted as a function of L/D.

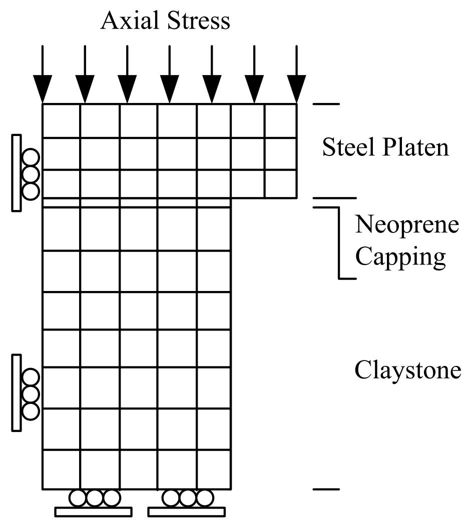


Figure 7. Mesh for numerical simulation.

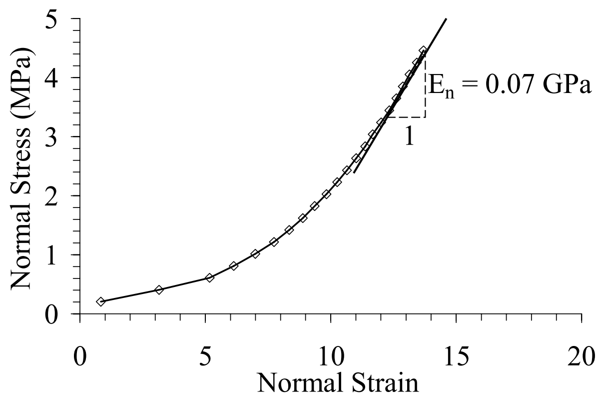


Figure 8. Result from determination elastic modulus of neoprene sheet.

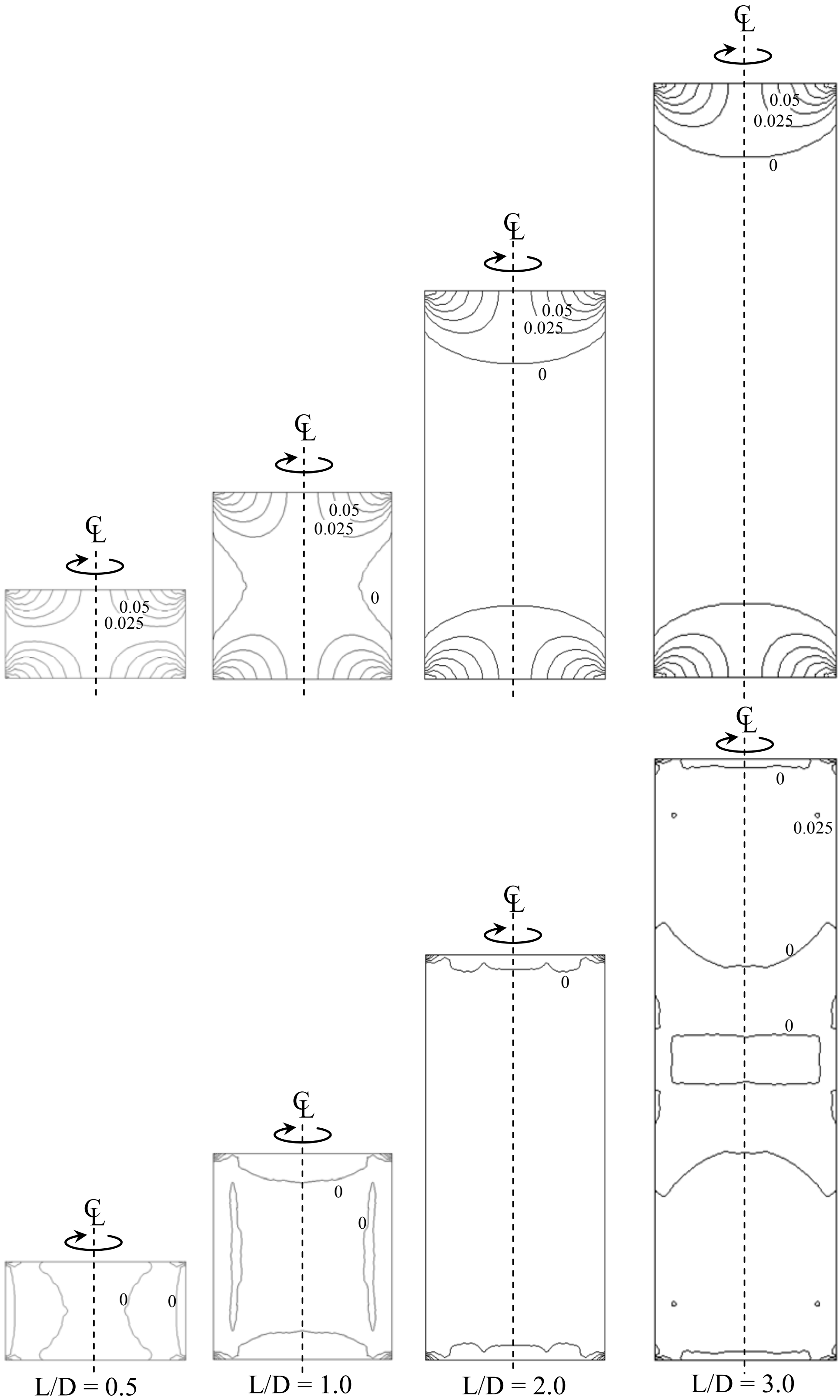


Figure 9. Normalized shear stress (τ/σ_{axial}) distribution from numerical modeling of uniaxial specimens at various L/D ratios. Specimens without neoprene capping (top row) and with neoprene capping (bottom row).

(τ/σ_{axial} less than 0.025) regardless the L/D ratio. For the uncapped specimens, large normalized shear stresses concentrated near the outer corners of the specimens with the maximum value of over 0.15.

5. Discussions and Conclusions

It should be noted that the correction parameters in the equation as given by the ASTM standard have been averaged from those of various rock types. The application of these average parameters to a specific rock type therefore may not yield a true strength or stiffness of the rock. The results from testing of the Maha Sarakham claystone specimens indicate that the neoprene caps can effectively reduce the shear stress within the specimens. This is also evidenced by the results from computer simulation.

This study shows that the true strengths of rock specimens can be disclosed by using an appropriate capping material. The strengths are then independent of the specimen shape (L/D ratio). Testing on capped specimens also reduces the intrinsic variation (standard variation) of the strength results. It is recommended here that neoprene capping be applied at the loading interfaces when short specimens (L/D < 2.0) of soft rocks are tested under uniaxial compression.

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