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INFLUENCE OF STRESS LARGER THAN PRELOAD BUT ACTED FOR SHORTER DURATION IN TANGENT MODULUS METHOD - A NEW METHOD TO MEASURE IN-SITU ROCK STRESS

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Influence of stress concentration at rock sampling on the in-situ rock stress value estimated by tangent modulus method, which is one of the oriented core methods for in-situ rock stress measurement, was experimentally investigated. Cylindrical specimens of Kimachi sandstone were preloaded at 30% UCS for 24 hour simulating in-situ stress and then a triangular shape-loading up to 40% UCS simulating stress concentration which took approx. 1 min. were carried out. Loading up to 50% UCS was applied to the specimen twice after certain delay time. Bending points were observed at 40% UCS for 0 to 1 hour delay time, at 30% UCS and 40% UCS for the 3 hour delay time, and at 30% UCS for 1 and 3 day delay time. The bending point was not observed for 1 week delay time. It is considered that the memory of concentrated stress acted at rock sampling for a short time can be lost and in-situ rock stress which acted for geological long-term can be accurately estimated if the test is carried out after an appropriate delay time.

1. INTRODUCTION

Tangent modulus method (TMM) is one of the oriented core methods for in-situ rock stress measurement. The following procedure will be used to determine in-situ rock stress.

(1) Oriented rock cores are sampled from the site.

(2) Cylindrical rock specimens are made.

(3) The specimens are uniaxially or triaxially compressed twice to a certain stress level.

(4) The stress value of the bending point in the stress-tangent modulus curve in the first loading cycle or the point where the first and the second stress-tangent modulus curves begin to separate (this point is also called bending point later for convenience) is regarded as the normal component of the in-situ rock stress in the direction of the specimen.

In order to check the validity of the tangent modulus method, rock specimens were compressed to a certain stress level and the stress was kept for certain time (preloading). The specimens were cyclically compressed to a higher stress level twice after certain delay times. Comparison between the stress value at the bending point and the preloading stress value was made.

It was confirmed that bending point appeared at the preloading stress level for dry Shirahama sandstone (Fig. 1), Shikotsu weleded tuff, Inada granite and Kimachi sandstone. Bending points became vague with delay time. However, bending points were observed at the preloading stress level even the delay time was 6 weeks for 17 hour preloading (Fig. 2).

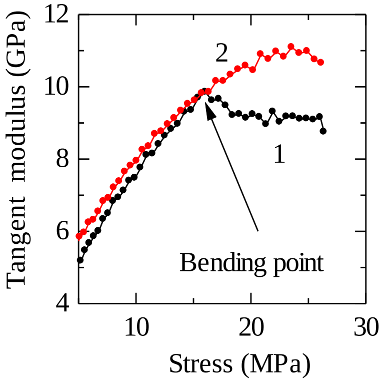


Fig. 1 An example of stress-tangent modulus curve in cyclic loading for Shirahama sandstone. 1 and 2 mean the first and the second loading cycle, respecively. The bending point is observed at the prestress of 15.4 MPa [1].

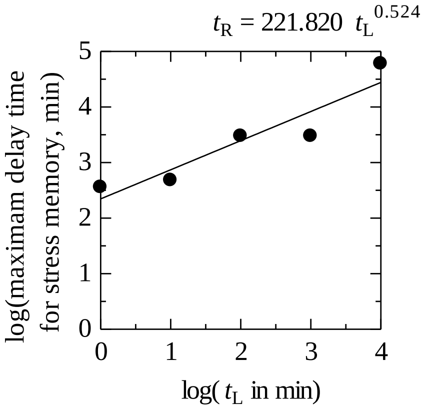
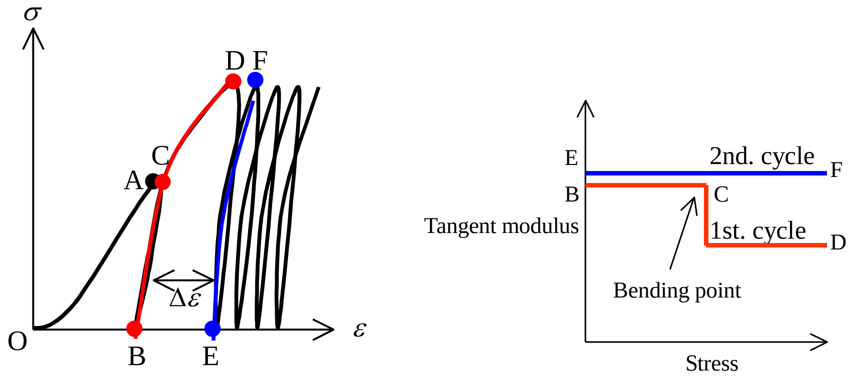


Fig. 2 Maximum delay time for stress memory with duration of load application t_L for Shirahama sandstone [1].

The mechanism of tangent modulus method can be explained by nearly irrecoverable closures of such voids as microcracks and pores in rock. Let's assume that A in Fig. 3a is the in-situ condition. Some voids which are tabular enough and large enough are partly closed at the in-situ stress level. A few voids would slightly open with stress relief by rock sampling (B). Rock is stiff during the first cyclic loading up to in-situ stress level (B to C) because nearly no more void closure. However, stiffness decreases in the further compression (C to D) by more closure of the partly closed voids and closure of other voids. This is why bending point appears at C (Fig. 3b). No more closure in the second loading cycle results in the high stiffness throughout the second loading cycle (E to F). The above mechanism also well explains the principle of DRA (deformation rate analysis) which is also one of the oriented core methods for in-situ stress measurement. We have to plot stress-tangent modulus curves for tangent modulus method or strain difference functions for DRA because the nonlinearity is not so clear for most realistic rocks.



(a) Stress-strain curve (b) Stress-tangent modulus curve

Fig. 3. Schematic figures showing deformation of a very nonlinear rock.

Influences of number of factors have to be investigated before practically using tangent modulus method. The factors would be in-situ stress components other than the normal stress components in the direction of rock specimen, in-situ pore pressure, stress concentration at rock sampling, temperature difference between in-situ and laboratory, strain rate of cyclic loading etc. Some of them will be reviewed first based on our previous studies and then influence of stress disturbances at rock sampling will be described.

2. INFLUENCES OF VARIOUS FACTORS

2.1 Strain rates for cyclic loading

Influences of strain rates for the cyclic loading between 10^{-6} s^{-1}∼10^{-3} s^{-1} (Fig. 4) or water temperature between 20^{o}C and 80^{o}C for preloading (Fig. 5, cyclic loading was promptly done in air) were not clearly observed. The specimen forgot the stress memory by the long experiment time (several days) for the slowest strain rate of 10^{-7} s^{-1}.

2.2 Change in water content

Stress memory was very easily lost when water content of specimens was changed. For example, specimens which were preloaded in water soon forgot stress memory after they were dried. Similarly, preloaded dry specimens forgot stress memory after they were immersed into water. The results mean that water content of rock cores have to be kept as unchanged as possible until stress measurement by cyclic loading finishes.

2.3 Triaxial cyclic loading under changed confining pressure

Bending point was observed at smaller stress level than triaxial prestress level when cyclic loading was carried out under smaller confining pressure for dry Shirahama sandstone (Fig. 6). However, clear bending point was not observed when the cyclic loading was carried out under larger confining pressure. Prestress was precisely estimated for smaller confining pressure and bending point was observed at smaller stress level when the confining pressure was larger than preloaded value for Kimachi sandstone (Fig. 7). These results would seem to be contradicted, however, the greatest bending point stress in triaxial cyclic loadings under several confining pressure values would be regarded as in-situ rock stress.

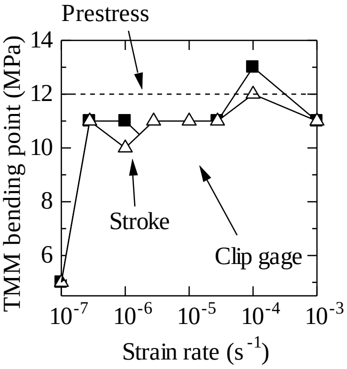


Fig. 4 Influence of strain rates for the cyclic loading between 10^{-7} /s～10^{-3} /s [2]

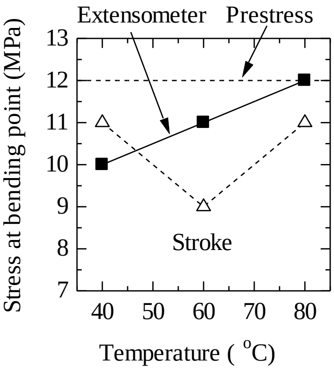


Fig. 5 Influence of water temperature between 20°C and 80°C for preloading [2]

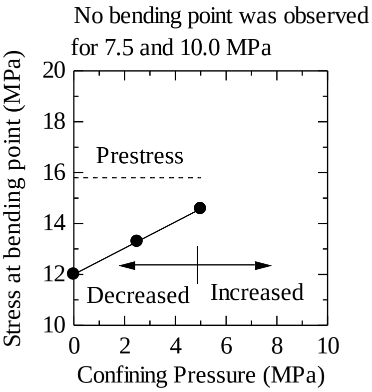


Fig. 6 Influence of confining pressure change at cyclic loading. Confining pressure for preloading and preload is 5 MPa and 15.8 MPa, respectively. Dry Shirahama sandstone.

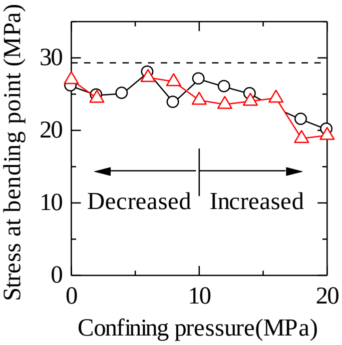
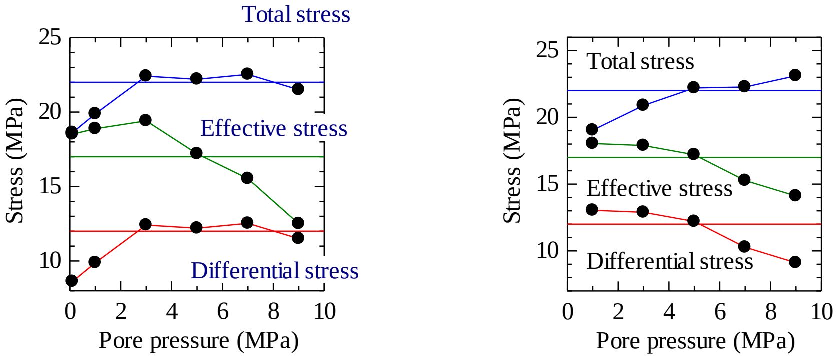


Fig. 7 Influence of confining pressure change at cyclic loading. Confining pressure for preloading and preload is 10 MPa and 29 MPa, respectively. Dry Kimachi sandstone.

Total and differential stress values at bending point were precisely obtained by triaxial cyclic loading for triaxial preloaded saturated Kimachi sandstone under pore pressure between 60% and 140% pore pressure for preloading (Fig. 8a) keeping a constant confining pressure. Smaller total and differential stress values at bending point were obtained under pore pressure of $\leq$ 20% or $\geq$ 180% pore pressure for preloading. On the other hand, smaller total prestress was evaluated under pore pressure for cyclic loading which was smaller than that for preload when the effective confining pressure was kept constant (Fig. 8b). Effective and differential prestress was evaluated smaller when the pore pressure which was larger than that for preloading was used. True triaxial in-situ rock stress as well as pore pressure would be estimated by carrying out triaxial cyclic loading tests at various confining and pore pressures.



(a) Constant total confining pressure of 10 MPa

(b) Constant effective confining pressure of 5 MPa

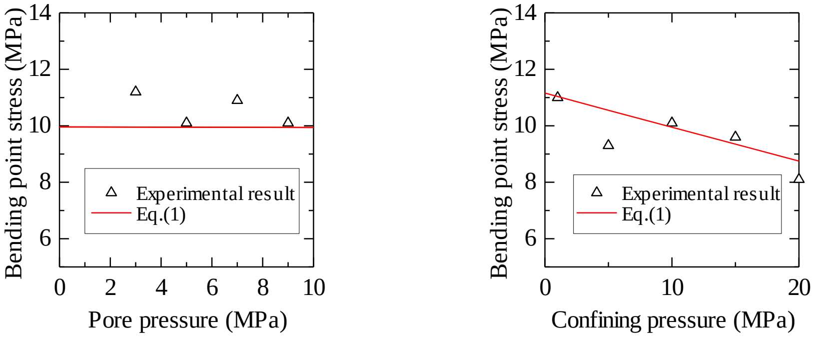
Fig. 8 Influence of pore pressure on bending point stress for saturated Kimachi sandstone. Total confining pressure, pore pressure and total axial stress for preload were 10 MPa, 5 MPa and 22 MPa, respectively

2.4 Uniaxial cyclic loading under changed confining pressure

Uniaxial cyclic loading was carried out for triaxially preloaded saturated Kimachi sandstone under various confining and pore pressures. Preloaded differential axial stress was 12 MPa for all specimens. Influence of pore pressure was negligible (Fig. 9). Small bending point stress was obtained for larger confining pressure in preloading. Approximating the results by a linear superposition of axial stress, confining pressure and pore pressure in preloading, we have,

$$\begin{aligned}\sigma_{\mathrm{B}} &= (0.93 \pm 0.07)\sigma - (1.05 \pm 0.11)P_{\mathrm{C}} - (0.002 \pm 0.15)P_{\mathrm{P}} \\ &= (0.93 \pm 0.07)\Delta\sigma - (0.11 \pm 0.11)P_{\mathrm{C}} - (0.002 \pm 0.15)P_{\mathrm{P}}\end{aligned} \tag{1}$$

where σ_{B}, σ, P_{C}, P_{P} and $\Delta\sigma$ are bending point stress, preloaded axial total stress, preloaded confining pressure, preloaded pore pressure and preloaded axial differential stress, respectively. The influence of pore pressure is negligible in this test series by chance, however, at least we would like to say that it is very dangerous to regard bending point stress itself as the normal stress component in the specimen direction of generally true triaxial in-situ rock stress ignoring the influence of other stress components and pore pressure.



(a) Constant confining pressure of 10 MPa (b) Nearly constant pore pressure of 5 MPa

Fig. 9 Bending point stress by uniaxial cyclic loading for triaxially preloaded saturated Kimachi sandstone. Preloaded diffrential axial stress was 12 MPa for all specimens. Preloaded pore pressure was 0.9 MPa and 4.9 MPa for confining pressure of 1 MPa and 5 MPa, respectively in (b).

3. EFFECT OF STRESS LARGER THAN PRELOAD BUT ACTED FOR SHORTER DURATION

30 mm thick rock cores were drilled along the axis of the fastest P-wave velocity from a Kimachi sandstone block. The cores were cut and the ends were ground to make 60 mm long specimens. The specimens were dried at 80^{o}C for 24 hours and then placed in the laboratory for more than a day before the experiments.

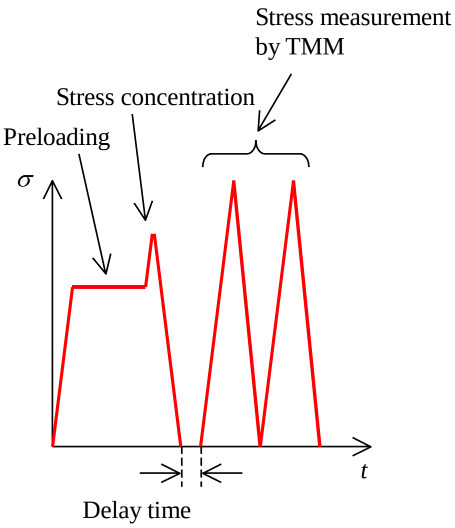


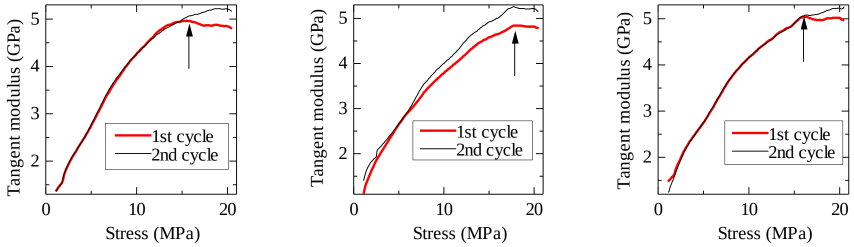
Fig. 10 Loading pattern

The specimens were;

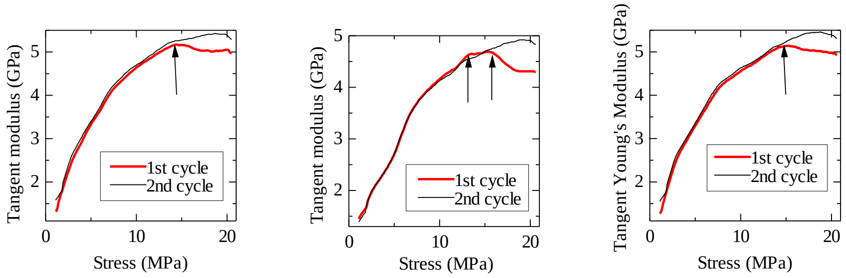
(1) compressed at 30% UCS for 24 hours as preload, simulating in-situ rock stress (Fig. 10);
(2) compressed up to 40% UCS by a triangular loading pattern for approx. 1 min, simulating the stress concentration at rock sampling;
(3) unloaded and kept for certain delay times; and then,

(4) cyclic loaded twice up to 50% UCS to obtain stress-tangent modulus curves.
All loading and unloading were done at 0.36 mm/min platen speed.

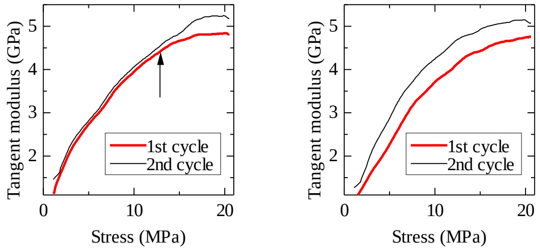
Strain as well as load should be measured to calculate tangent modulus. Strain can be typically measured by attaching a clip type-extensometer, dividing stroke (platen displacement) by specimen length or gluing strain gauges. The latter could not be used because this research includes experiments on saturated specimens. It was pointed out in our previous studies that clip type-extensometers gave clearer bending points. Dividing stroke by specimen length was however used in this test series because our extensometer was not in a good condition at the experiments.



(a) No delay (b) 10 min. delay (c) 30 min. delay



(d) 1 hour delay (e) 3 hour delay (f) 1 day delay



(g) 3 day delay (h) 1 week delay

Fig. 11 Stress-tangent modulus curves. Prestress and short time-larger stress are 12 MPa and 16 MPa, respectively

Bending points were observed at 40% UCS (16 MPa) for delay time between 0 and 1 hour (Fig. 11a-d). This means that the memory of the long time-preload was covered by the memory of the short time-larger stress. Bending points were observed at 30% UCS (12 MPa) and 40% UCS for delay time of 3 hours (Fig. 11e). This means that the both memories of the long time-preload and the short time-larger load were detected. Bending points were observed at only 30% UCS for delay time of 1 day and 3 days (Fig. 11f and g). This means that the memory of the short time-larger stress was lost and only the memory of the long time-preload was detected. No bending point was observed for delay time of 1 week (Fig. 12h). This means that the memories of the both loads were lost.

4. CONCLUDING REMARKS

It is estimated that the memory of large stress for a short time at rock sampling can be lost and precise value of the normal component of in-situ rock stress which had been acted for a geological long-term in the specimen direction can possibly be evaluated if an appropriate delay time is set. We did not select only good data for publication. The data shown here, however, are too nice for people who are trying to put tangent modulus method in practical use. We don't deny the possibility that the data were obtained by chance. More experiments should be done to confirm the finding here.

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