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Title	Deformation and Failure of Kimachi Sandstone under Constant Strain Rate and Cyclic Loading Deformation and Failure of Kimachi Sandstone under Constant Strain Rate and Cyclic Loading
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Description	Spring Meeting of MMIJ 2015 (資源・素材学会 平成27年度春季大会、2015年3月27日(金)～29日(日)、千葉工業大学 津田沼キャンパス、習志野市)
Citation	Spring Meeting of MMIJ, 2015, 1515
Issue Date	2015-03-27
Doc URL	https://hdl.handle.net/2115/62804
Type	conference paper
File Information	MMIJ2015, Spring Meeting, 1515.pdf



一般講演

岩盤力学基礎

2015年3月27日(金) 14:15 ~ 17:00 第5会場 (千葉工業大学)

[1515] Deformation and Failure of Kimachi Sandstone under Constant Strain Rate and Cyclic Loading Deformation and Failure of Kimachi Sandstone under Constant Strain Rate and Cyclic Loading

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キーワード : Deformation, Failure, Kimachi sandstone, Constant strain rate, Cyclic loading

Rock cliffs sometimes collapse without any triggering forces. Giant earthquakes sometimes occur around neap tides. These phenomena suggest that rock masses do not have to failure under large triggering forces. To figure out the deformation and failure behaviors of rocks under varying stress level, a series of uniaxial compression tests on Kimachi sandstone was carried out. In the experiments, the constant loading rate of $1 \times 10^{-5} \text{ s}^{-1}$ for 50 s and five triangular waves consisting of $11 \times 10^{-5} \text{ s}^{-1}$ and $-9 \times 10^{-5} \text{ s}^{-1}$ for 50 s, were alternately applied to 20 specimens. Finally, 13 samples showed a stress drop during constant strain rate loading, 3 during triangular loading and 4 during triangular unloading. The possibility of specimens showing stress drop during the constant strain rate is 7.4%, assuming a random process. It was thus not statistically proved but the rock tended to break under constant strain rate rather than large stress with high strain rate.

1. Introduction

It is instinctively expected that giant earthquakes occur around spring tide because the tidal stress variation around spring tide is the largest. Fujii et al. (2013)¹⁾ however found that there were dangerous lunar phases for each subduction zones in which giant earthquakes concentrated and the lunar phases did not have to be around spring tides. Most rock slope collapses, as another example, occur during creep process rather than during earthquakes. They mean that rocks do not have to fail under larger stress. To obtain a clue to understand the above phenomena, a series of uniaxial compression tests on Kimachi sandstone was carried out. In the experiments, the constant rate loading and five triangular wave loading were alternately applied to specimens and the failure timing was observed.

2. Experiment

Kimachi sandstone was sampled at Shimane prefecture, Japan, and is a relatively well-sorted clastic rock with a typical grain size range of 0.4-1.0 mm. It mostly consists of rock fragments of andesite; crystal fragments of plagioclase, pyroxene, hornblende, biotite, and quartz; calcium carbonate and iron oxides; and matrix zeolites. The sample was made into 30 mm ϕ $\times$ 60 mm cylindrical specimens with a parallelism of 2/100 at both ends through drilling, cutting and grinding (Fig. 1). The samples were dried in 80°C oven for 48 hours and subjected to the constant loading rate of $1 \times 10^{-5} \text{ s}^{-1}$ for 50 s and five triangular waves consisting of $11 \times 10^{-5} \text{ s}^{-1}$ and $-9 \times 10^{-5} \text{ s}^{-1}$ for 50 s alternately (Figs. 2 and 3).

The maximum and minimum stress during triangular loading was larger by approx. 2 MPa and almost the same or less by approx. 1 MPa than that during constant strain rate loading (Fig. 4). Finally, 13 samples showed a stress drop during constant strain rate loading, 3 during triangular loading and 4 during triangular unloading (Figs. 4, 5 and Table 1).



Fig. 1 Kimachi sandstone samples.

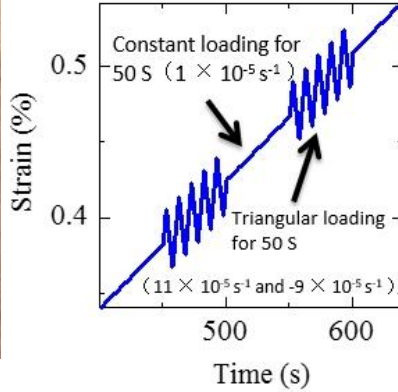


Fig. 2 Loading condition.

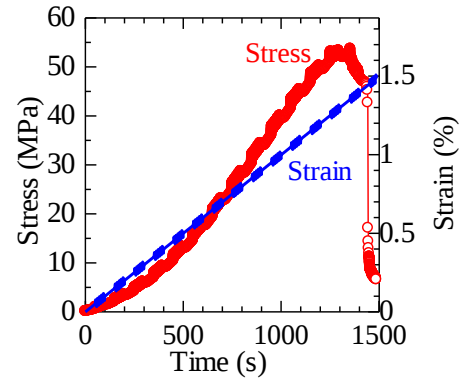
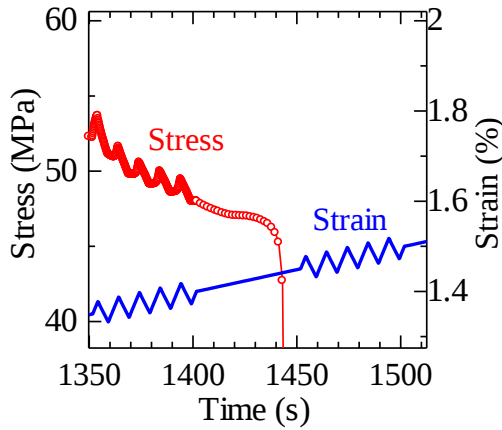
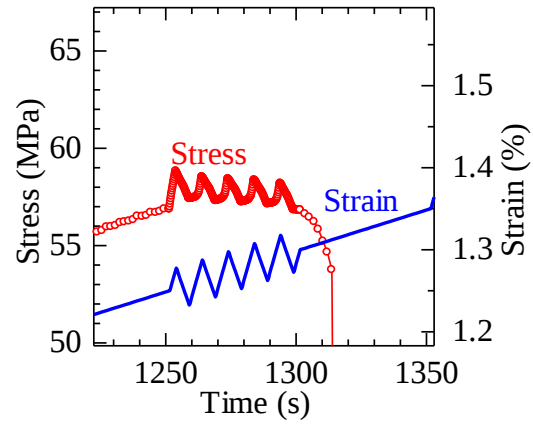


Fig. 3 Example of stress and strain variation with time (Sample 1).

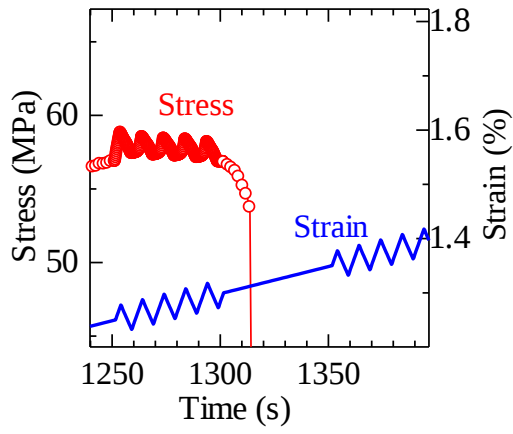


(a) Sample 1 (C)

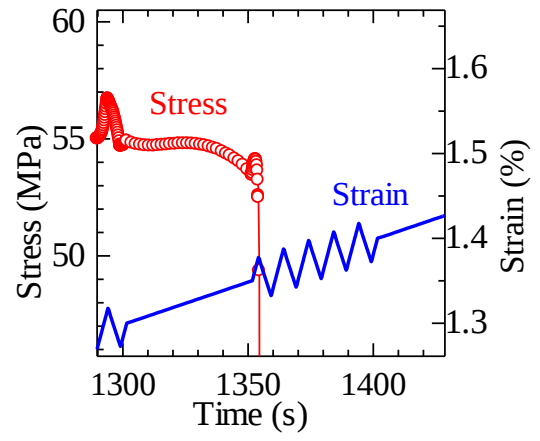


(b) Sample 2 (C)

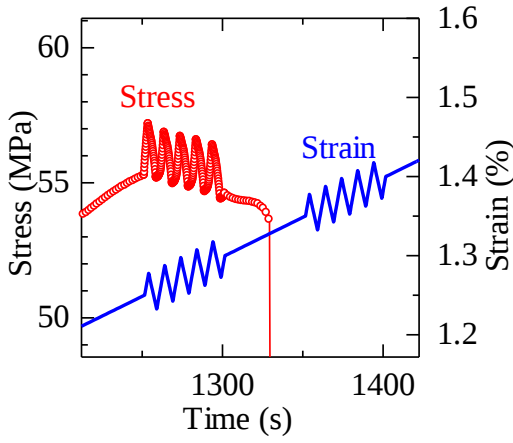
Fig. 4 Enlarged plot of stress and strain variation. (C), (L) and (U) denotes that the specimen failed during “Creep”, “Loading” or “Unloading”.



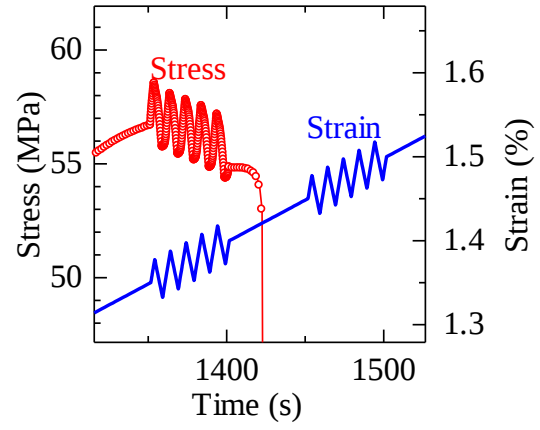
(c) Sample 3 (C)



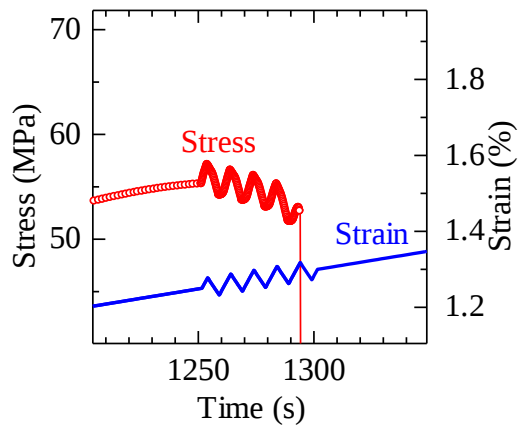
(d) Sample 4 (L)



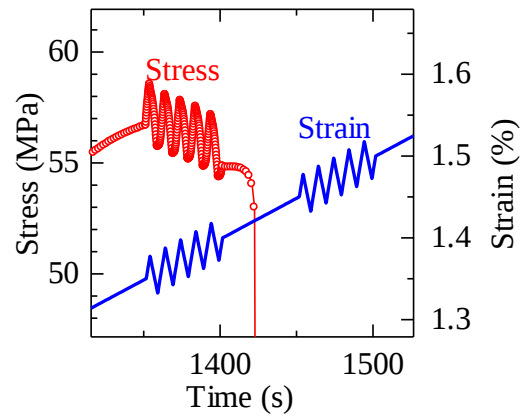
(e) Sample 5 (C)



(f) Sample 6 (C)

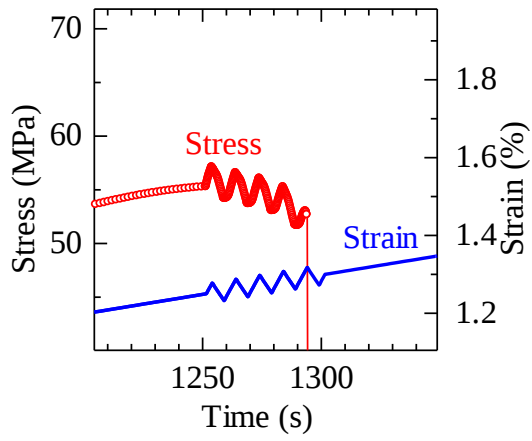


(g) Sample 7 (L)

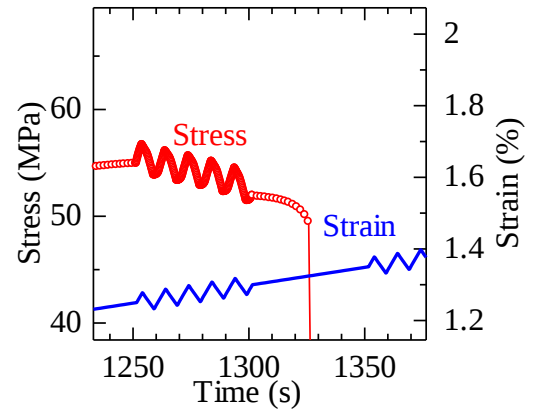


(h) Sample 8 (C)

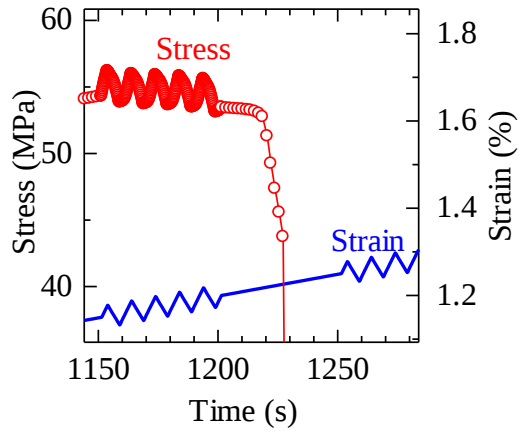
Fig. 4 Enlarged plot of stress and strain variation. (C), (L) and (U) denotes that the specimen failed during “Creep”, “Loading” or “Unloading” (continued).



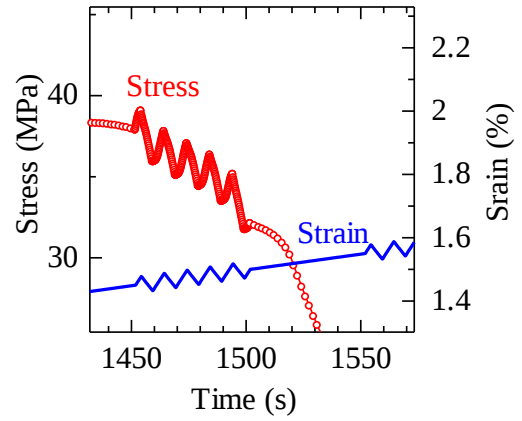
(i) Sample 9 (U)



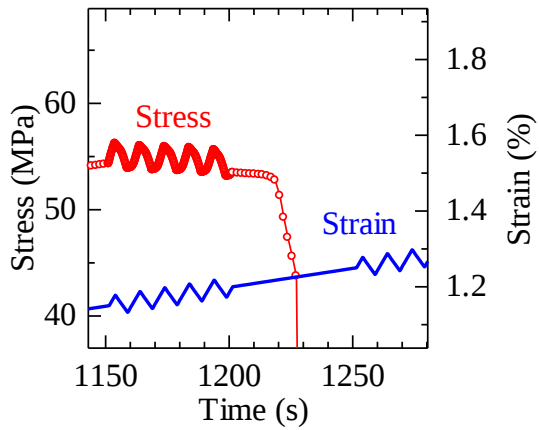
(j) Sample 10 (C)



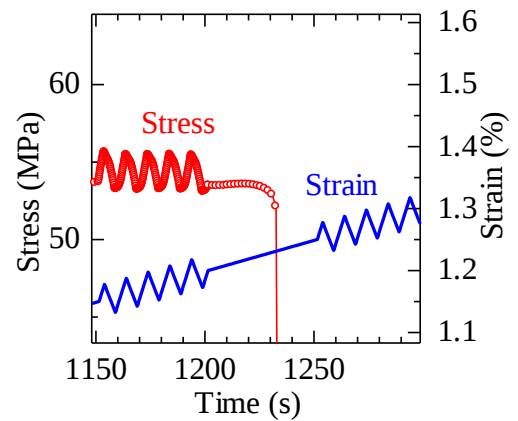
(k) Sample 11 (C)



(l) Sample 12 (C)

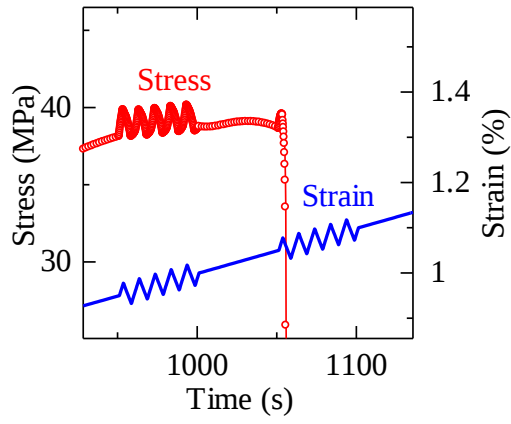


(m) Sample 13 (C)

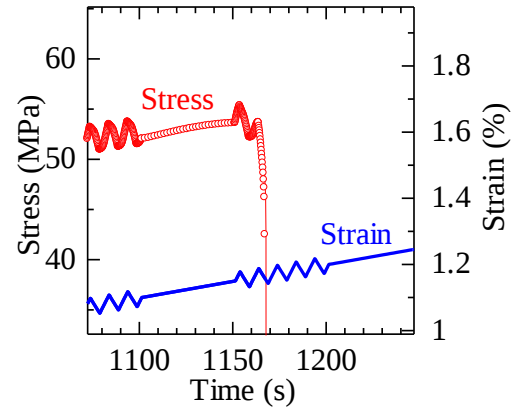


(n) Sample 14 (C)

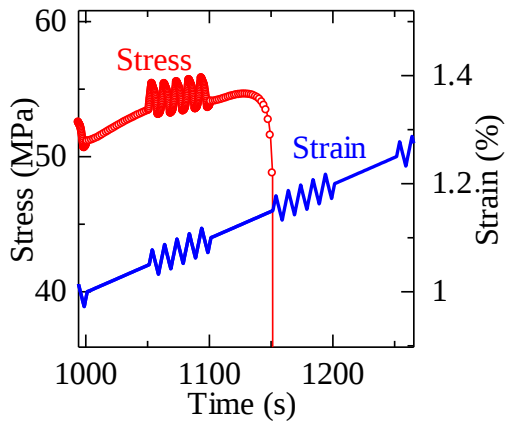
Fig. 4 Enlarged plot of stress and strain variation. (C), (L) and (U) denotes that the specimen failed during “Creep”, “Loading” or “Unloading” (continued).



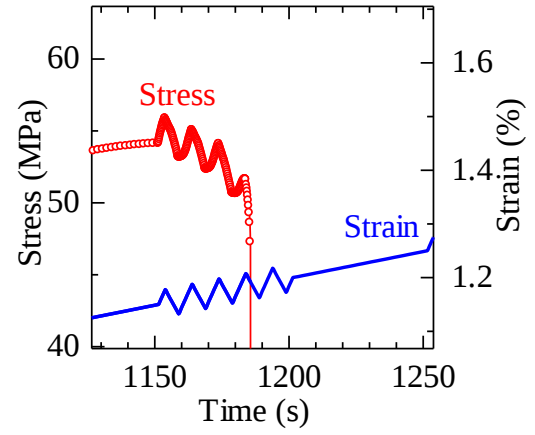
(o) Sample 15 (U)



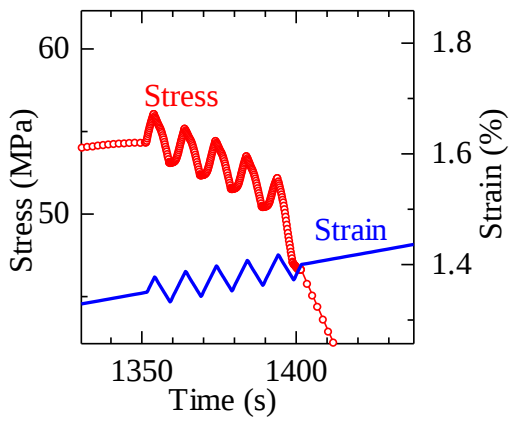
(p) Sample 16 (U)



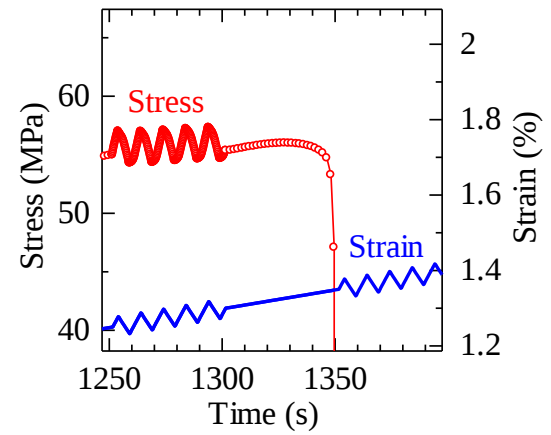
(q) Sample 17 (C)



(r) Sample 18 (U)



(s) Sample 19 (C)



(t) Sample 20 (C)

Fig. 4 Enlarged plot of stress and strain variation. (C), (L) and (U) denotes that the specimen failed during “Creep”, “Loading” or “Unloading” (continued).

Table. 1 Experimental result.

Rock failure timing	Number of specimens
Constant loading	14 (#1, #2, #3, #5, #6, #8, #10, #11, #12, #14, #17, #19, #20)
Triangular unloading	4 (#9, #15, #16, #18)
Triangular loading	2 (#4, #7)

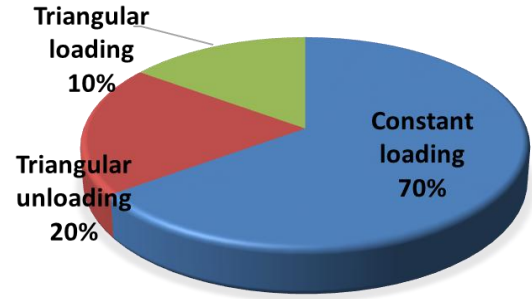


Fig. 5 Rock samples failed during different timing.

3. Mechanism of the high percentage of rock failures during constant rate loading

Rock strength $\sigma_{\max}$ can be represented as the following equation (Obara et al, 2005)²⁾,

$$\log \sigma_{\max} = A + \frac{1}{n+1} \log \dot{\epsilon} \quad (1)$$

where A is a constant, $\dot{\epsilon}$ is strain rate and n is called stress corrosion index although the mechanisms of strength increase with strain rate are not only due to the finite speed of stress corrosion but also the time-dependent deformation behavior of clay cementing materials, finite velocity of pore water migration due to water viscosity etc. It can be considered anyhow that the higher strain rate during the triangular loading prohibited rock failure and this resulted in the high percentage of rock failures during constant rate loading.

4. Statistical testing

Assuming that rock failure is a random process (random null hypothesis), probability p of m rock specimens or more fail during constant loading for total of n specimens can be obtained by the equation below.

$$p = \sum_{j=m}^n \{ h^j (1-h)^{n-j} \times {}_n C_j \} \quad (2)$$

where h is the probability of a specimen fails during constant loading and equals to 0.5 (50 s/(50 s+50 s)). For $n = 20$ and $m = 13$, $p = 5.8\% > 5\%$. Thus, the random null hypothesis is not rejected and rock failure is statistically considered to be a random process.

5. Conclusions

A series of uniaxial compression tests on Kimachi sandstone samples under alternately applied constant and five triangular wave loading were carried out and 70% specimens failed during constant loading. Namely, rock failure does not have to occur under higher stress if the stress variation is small. The mechanism of the high percentage of rock failures during constant rate loading can be explained by the strength increase due to high strain rate during triangular wave loading which prohibits rock failure. Strain rate dependency in strength of Kimachi sandstone should be further investigated.

References

- 1) Fujii, Y., Ozaki, Y., Fukuda, D. and Kodama, J. (2013), Why Do Giant Earthquakes Occur at Lunar Phases Specific to Each Subduction Zone? Proceedings of the 6th International Symposium on In-situ Rock Stress, RS2013-1021.
- 2) Obara, Y., Jeong, H. and Matsuyama, T. (2005), Stress Corrosion Index of Kumamoto Andesite. J. MMIJ, Vol. 121, pp. 84-89