Proceedings of The Seventh (2007) ISOPE Ocean Mining Symposium
Lisbon, Portugal, July 1-6, 2007
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ISBN 978-1-880653-69-2; ISBN 1-880653-69-9

Variable-Compliance-Type Constitutive Model for Toyoura Sand Containing Methane Hydrate

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ABSTRACT

In this study, the applicability of variable-compliance-type constitutive model to triaxial compression test of Toyoura sand containing synthetic methane hydrate was examined as the first step towards formulation of mechanical properties of methane hydrate reservoirs. Parameters used in the constitutive model were determined by alternating strain rate triaxial compression tests. The calculated results by the model were compared with the previously experimental results. It was found that the model examined was one of promising models for sand containing methane hydrate.

KEY WORDS: Methane hydrate; triaxial compression test; stress-strain curve; peak strength; loading-rate dependency; time-dependent behavior; constitutive model.

NOMENCLATURE

C Strain rate in constant strain rate test
C_1 Lower strain rate in alternating strain rate test
C_2 Higher strain rate in alternating strain rate test
E_i Initial elastic modulus
n Parameter that determines time-dependency of material
S_h Methane hydrate saturation
t Time
$\Delta\varepsilon$ Strain interval for switching strain rate
ε Axial strain
ε^* Normalized axial strain
λ Compliance
λ_0 Initial compliance (Inverse of initial elastic modulus)
λ^* Normalized compliance
σ Deviator stress
σ_C Triaxial compressive strength (Maximum deviator stress)
σ_{C1} Triaxial compressive strength under a constant strain rate C_1
σ_{C2} Triaxial compressive strength under a constant strain rate C_2
σ^* Normalized deviator stress

INTRODUCTION

Methane hydrate is speculated to be a promising energy resource replacing conventional fossil fuel resources, since a large amount of reservoir exists in marine sediments or in permafrost regions worldwide (Kvenvolden, 1988; Kvenvolden et al., 1993; Okuda, 1993). In purpose of efficient extraction of natural gas from the reservoirs, some methods for in-situ dissociation of methane hydrate has been proposed; depressurization, thermal stimulation and inhibitor injection. Currently we are engaged in development of the numerical simulator for evaluating productivity of methane gas from the reservoirs. For precise assessment of gas production, it is necessary to predict the mechanical behaviors such as consolidation and deformation of the reservoirs. Therefore, it is important to develop a model representing the constitutive relationship (stress-strain relationship) of hydrate bearing sediments and to introduce it into the simulator predicting gas production.
In this study, experimental results obtained from triaxial compression tests of Toyoura sand containing synthetic methane hydrate (Masui et al., 2005) have been reviewed and the stress-strain relationship has been formulated using variable-compliance-type constitutive model which can be applicable to various time-dependent behaviors of rock (Okubo et al., 2002; Okubo et al., 2003).

REVIEW OF TRIAXIAL COMPRESSION TESTS

Host Specimen

A host specimen, in which synthetic methane hydrate was formed afterward, was produced by compacting water-saturated Toyoura sand densely in a mold on a vibration table. The initial water content which had a great influence on methane hydrate saturation of the specimen was adjusted by draining excess water with a syringe pump. The size of produced specimen was 50 mm in diameter and 100 mm in length and its porosity ranged from 36 % to 39 %.

Experimental Apparatus

The experimental apparatus illustrated in Fig. 1 was used for methane hydrate formation in host specimens and following triaxial compression tests. The apparatus is a digital servo-controlled testing machine with a capacity of 200 kN for axial load, 20 MPa for confining pressure and 20 MPa for back pressure. The temperature of a specimen in the triaxial vessel can be controlled at the range of 243 K to 293 K with an