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Gas Hydrates as Potential Energy Resource and Trigger of Submarine Slope Failure

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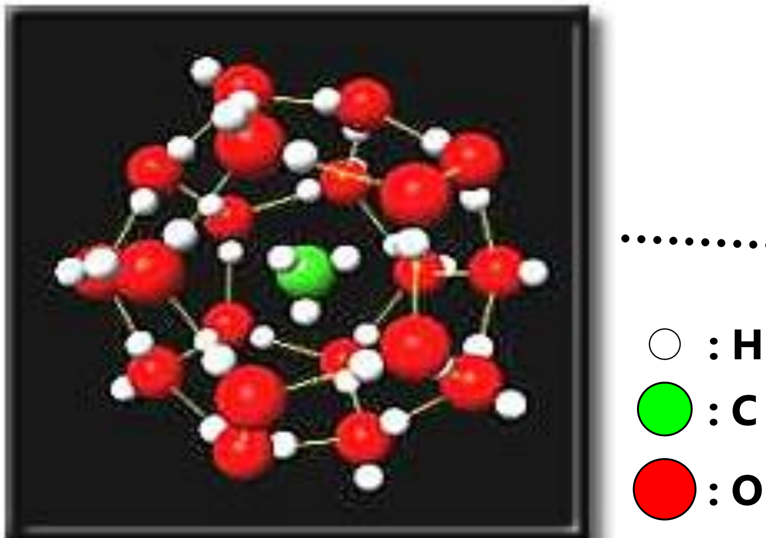
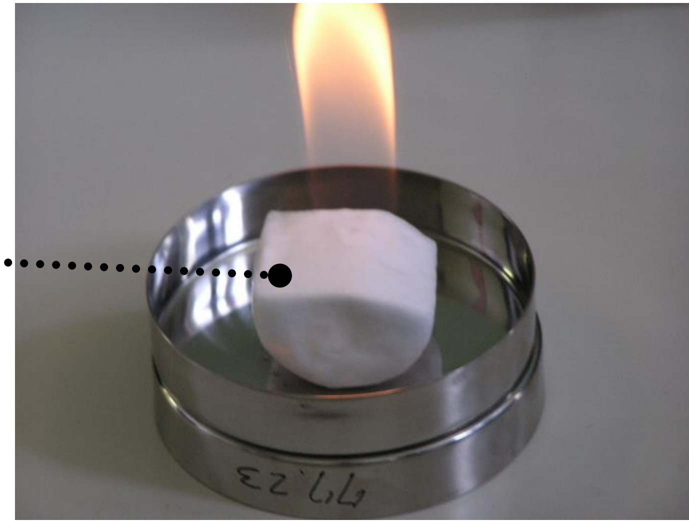
What is Gas Hydrate ?



$$CH_4 \cdot nH_2O\ (hydrate)$$

n=5.75 for *structure I* hydrate



Burning MH

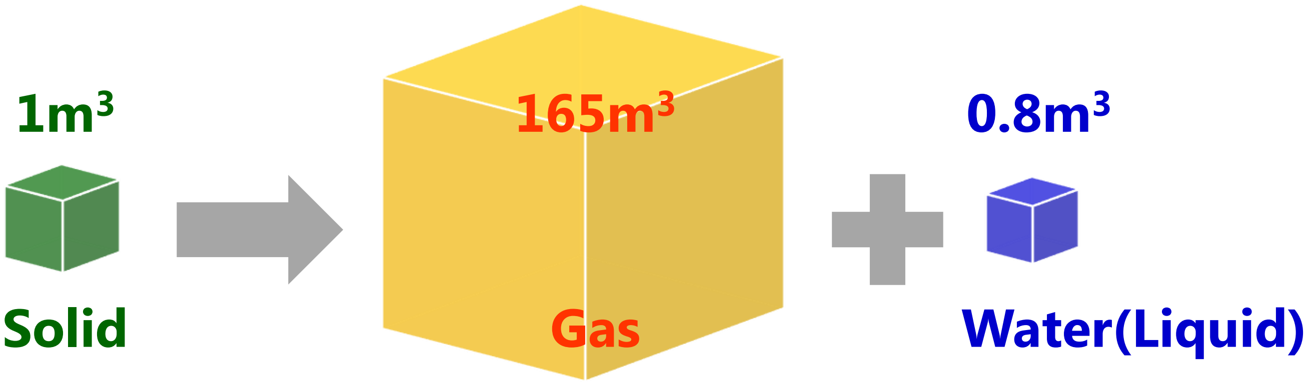
$$nH_2O\ (water) + CH_4\ (gas)$$

Gas Hydrate consists of guest gas trapped inside cage-like structures of water molecules.

The gas interacts with the water under the conditions of low temperature and high pressure to form ice-like structure.

Gas Hydrate dissociation process

$$CH_4 \cdot nH_2O\ (hydrate) \Leftrightarrow CH_4\,(gas) + nH_2O\,(liquid)$$



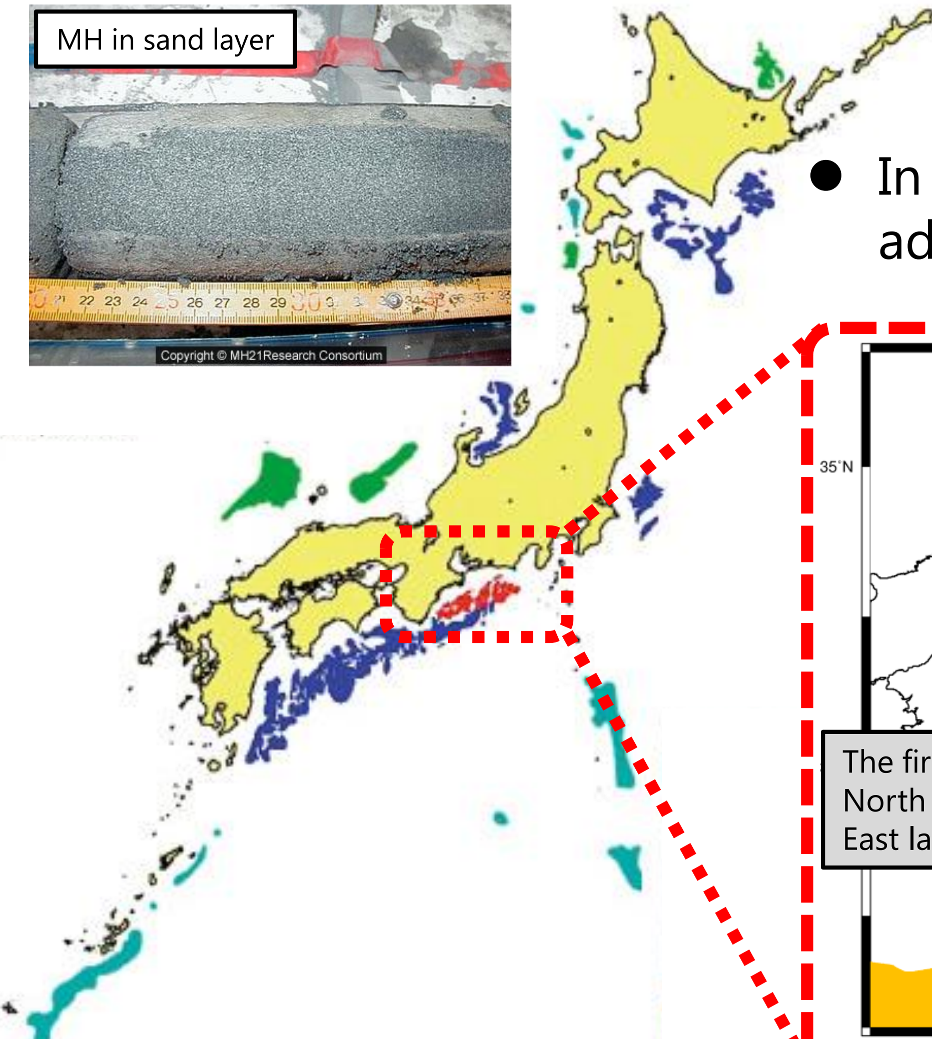
- A unit volume of **gas hydrate** dissociates into approximately 165 times the volume of **guest gas** and 0.8 times of **water** (at 0°C and atmospheric pressure).
- Gas hydrate can exist only in a low temperature and high pressure conditions. The gas hydrate will dissociate by heating and depressurizing

Methane Hydrate ($CH_4 \cdot nH_2O$) : Recognized as a potential future energy resource

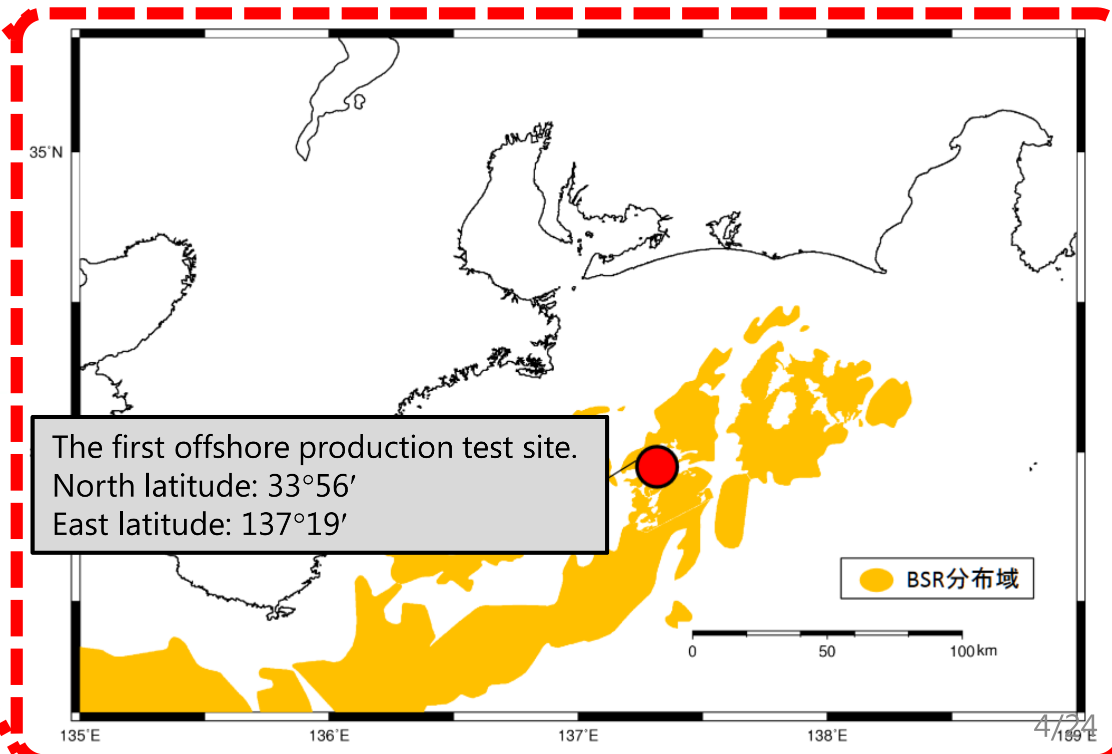
Carbon Dioxide Hydrate ($CO_2 \cdot nH_2O$) : Recognized as a new material for CCS

MH production test in Japan

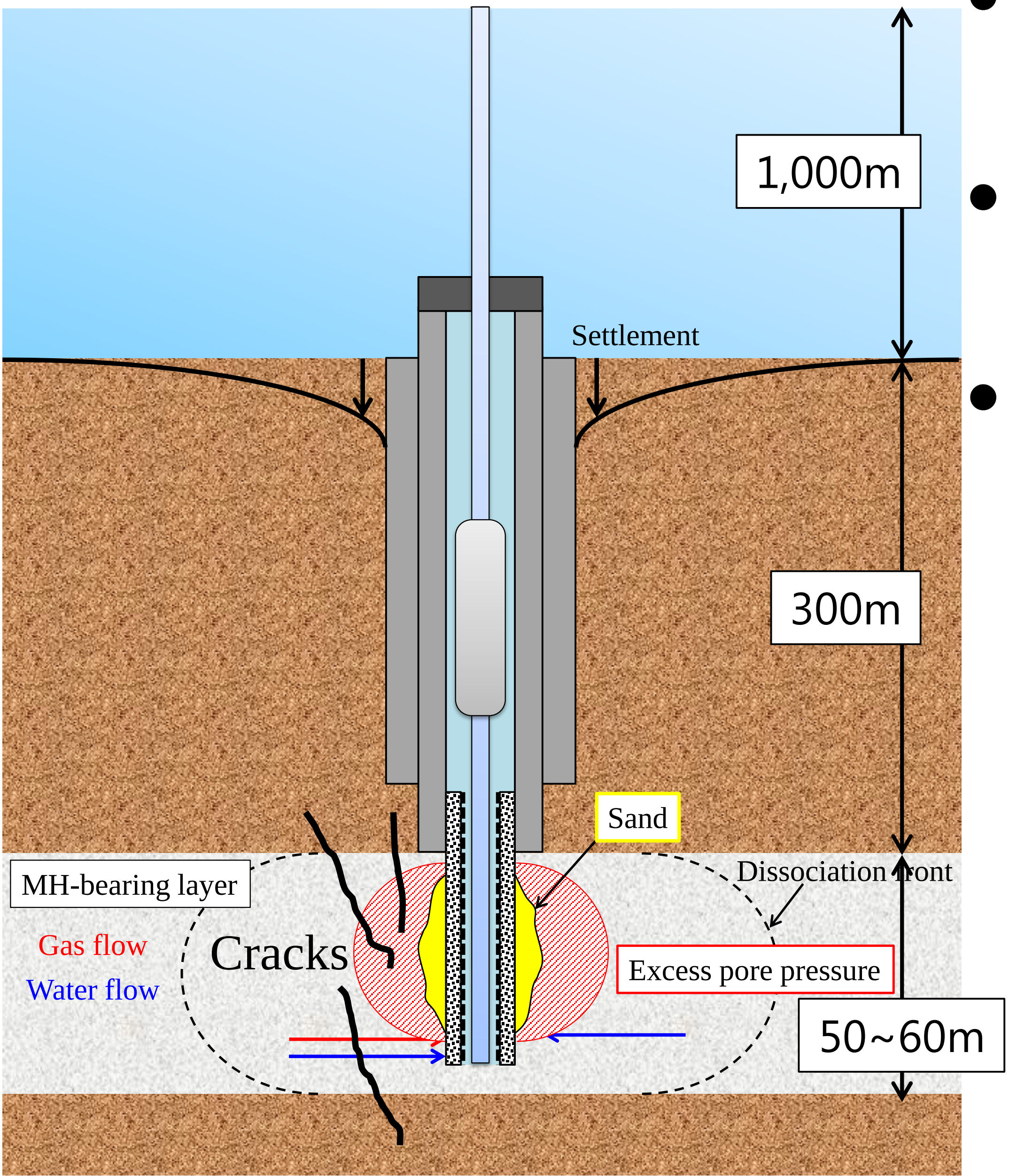
- Japan Oil Gas, and Metals National Corporation (JOGMEC) conducted the first offshore methane hydrate production trial in March 2013 in the eastern Nankai-Trough, Japan.



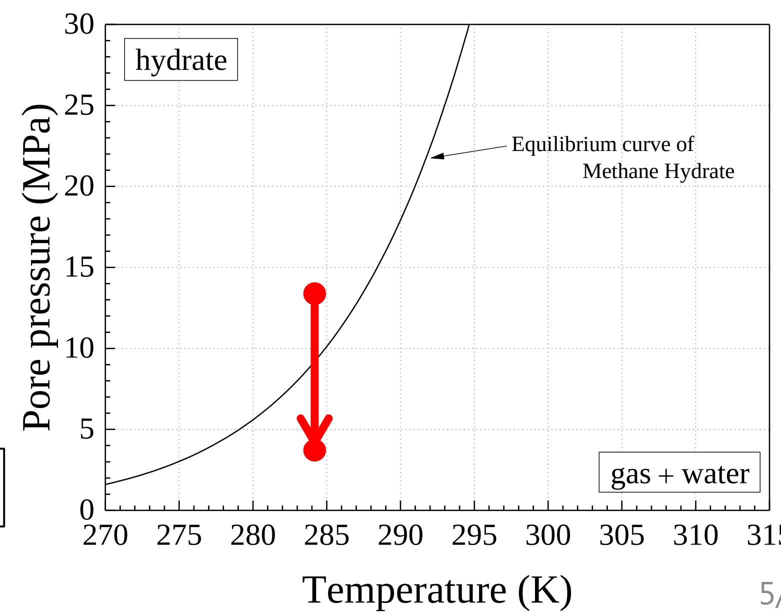
- In the test, **depressurization method** was adopted for methane gas production.



Depressurization method



- The seabed ground surface is at a water depth of about 1,000m in eastern Nankai-Trough.
- MH-bearing layer lies at a depth of 300m from the top of the ground surface with a thickness of 50 or 60m.
- Pump up the sea-water inside the production well, and the pore pressure in the MH-layer will decrease.



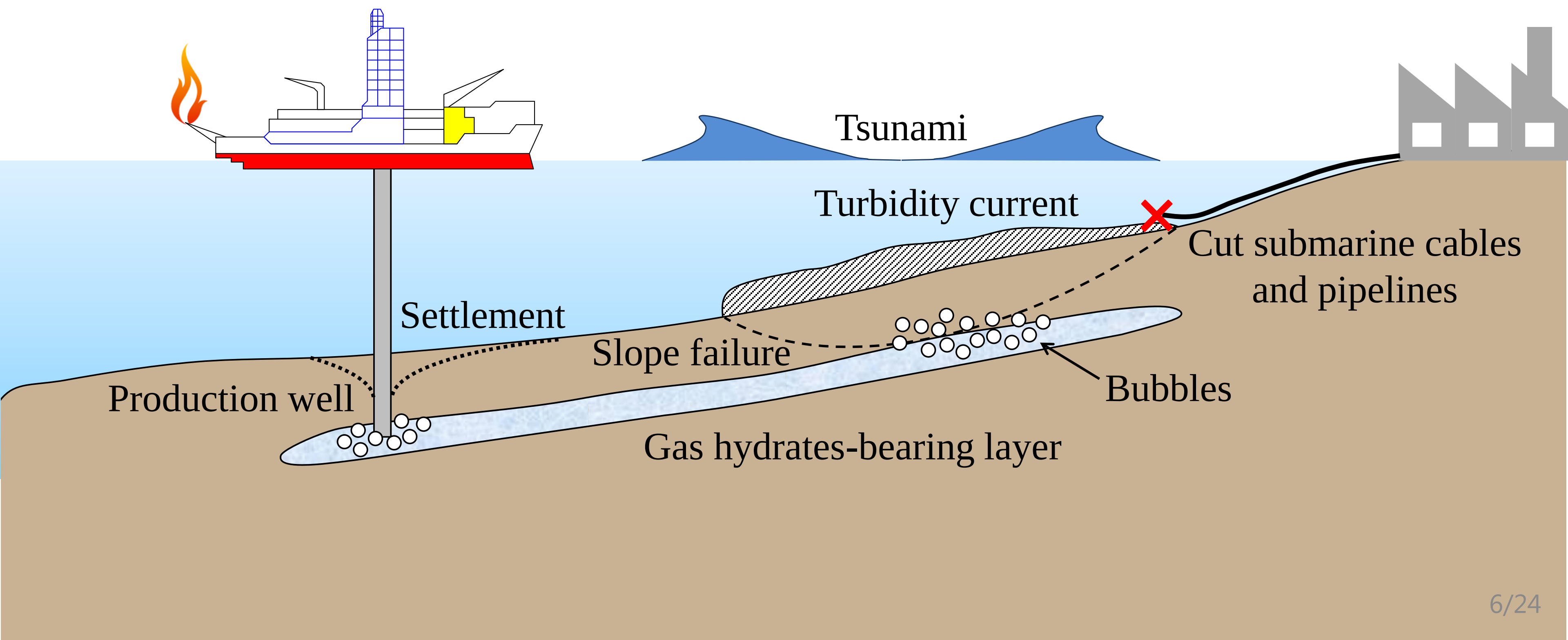
Geological and Geotechnical problems

In contrast to the aspects of the expected energy source, gas hydrates have been believed to play a important role in the failure of submarine sediments.

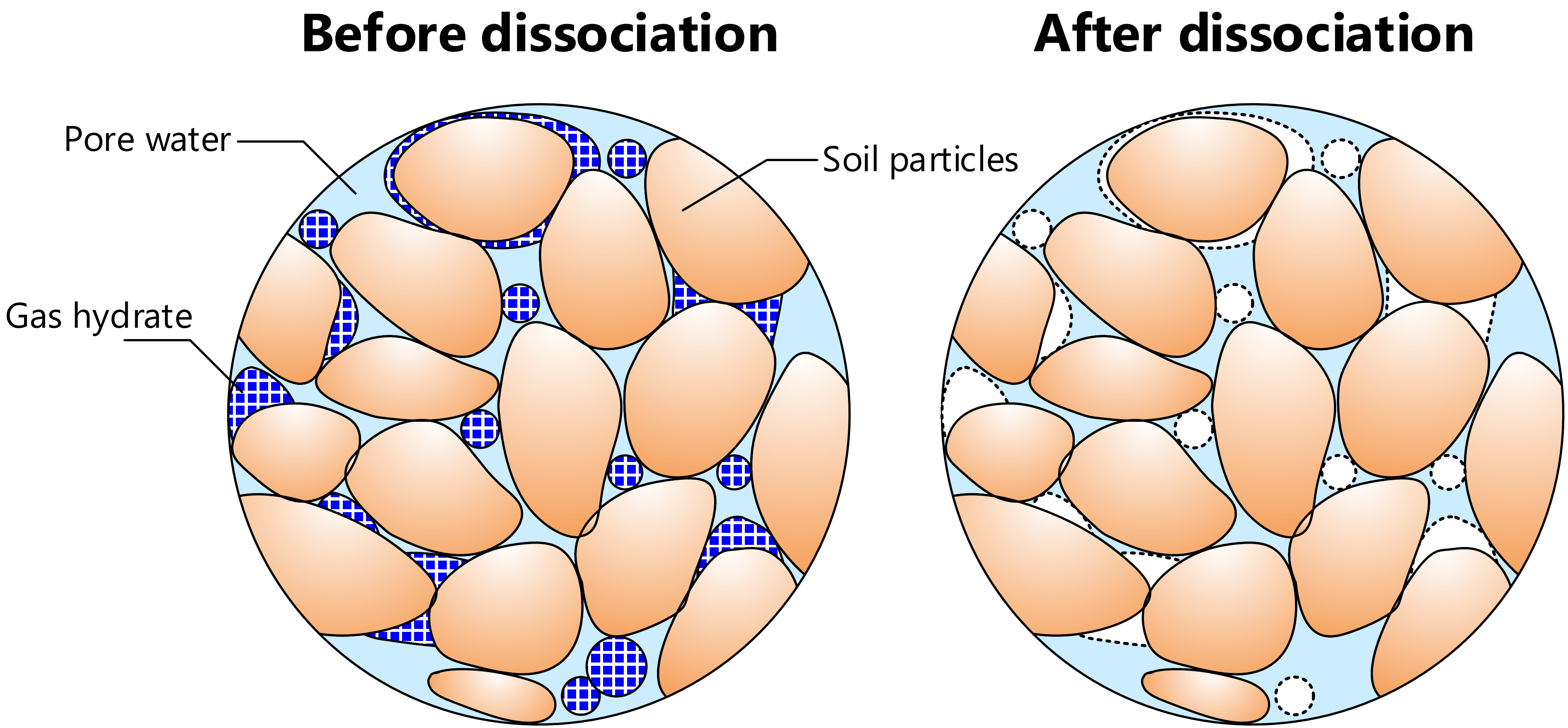
Gas hydrates break down was involved in the creation of the megaturbidite.

- The slides can cause tsunami…
- "In 1979 a 0.15-km^3 slide off Nice airport caused **a tsunami that killed 11people.**"

Nisbet, E.G. and Piper, D.J.W. 1998, *Nature*, **392**(6674), pp.329-330.



Gas hydrate morphology in sediments



- ➢ Gas hydrate in the pores works as additional soil particles.
- ➢ Bond between soil particles.
- ➢ Hydrate morphology affects the stiffness, strength, and dilation.

- ➢ Dissipation of the hydrate particles will cause decrease of the material density.
- ➢ Lost of bonding effects or load bearing effects will reduce the stiffness and strength.

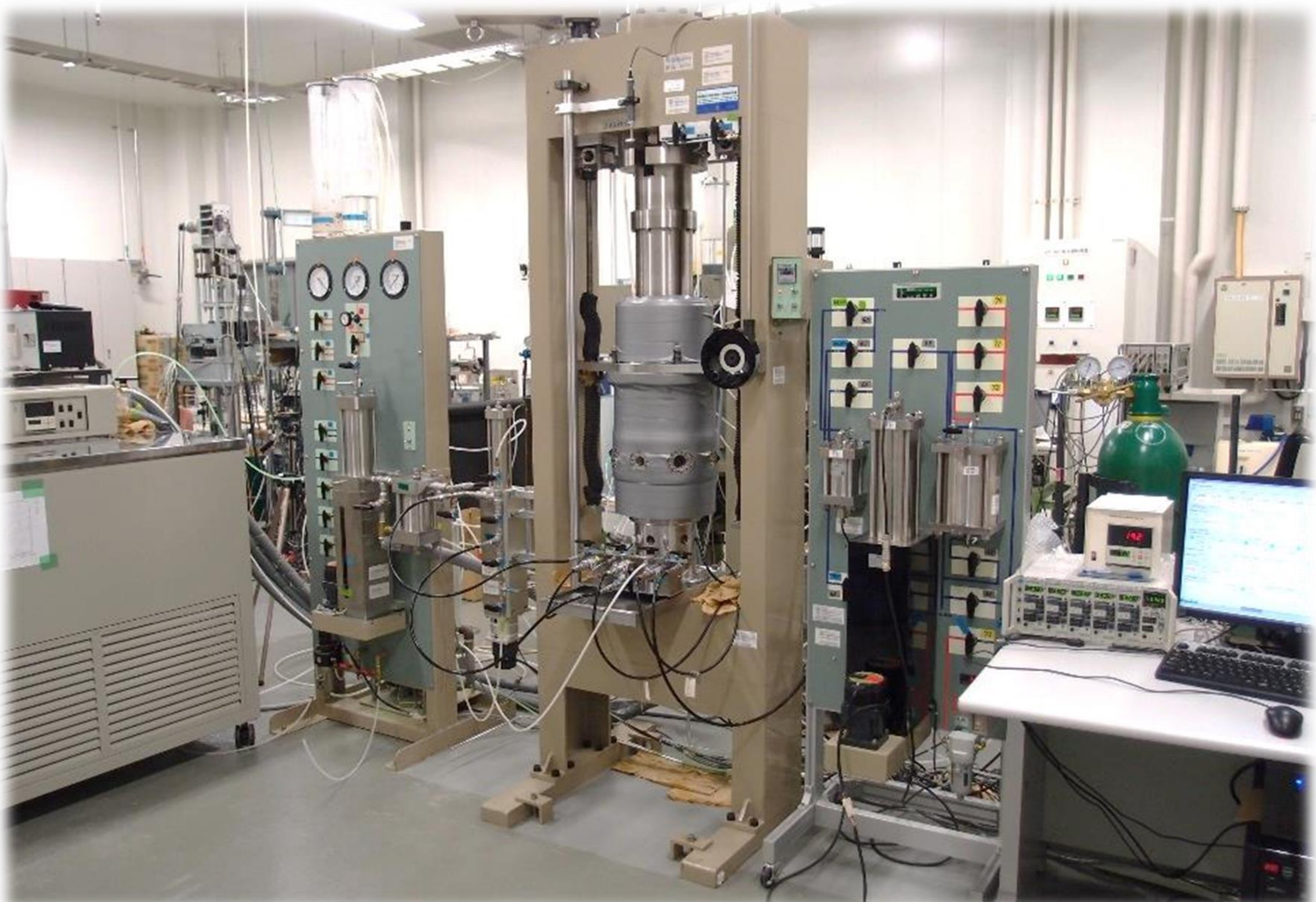
Main objectives for this research

- For the purpose of safe and economical production of methane gas from the MH reservoir, further investigations related to **mechanical properties of gas hydrate-bearing sediments** are required
- In addition, it is essential to **understand dissociation-deformation behavior**, in order to clarify the relationship between gas hydrate dissociation and submarine slope failure.

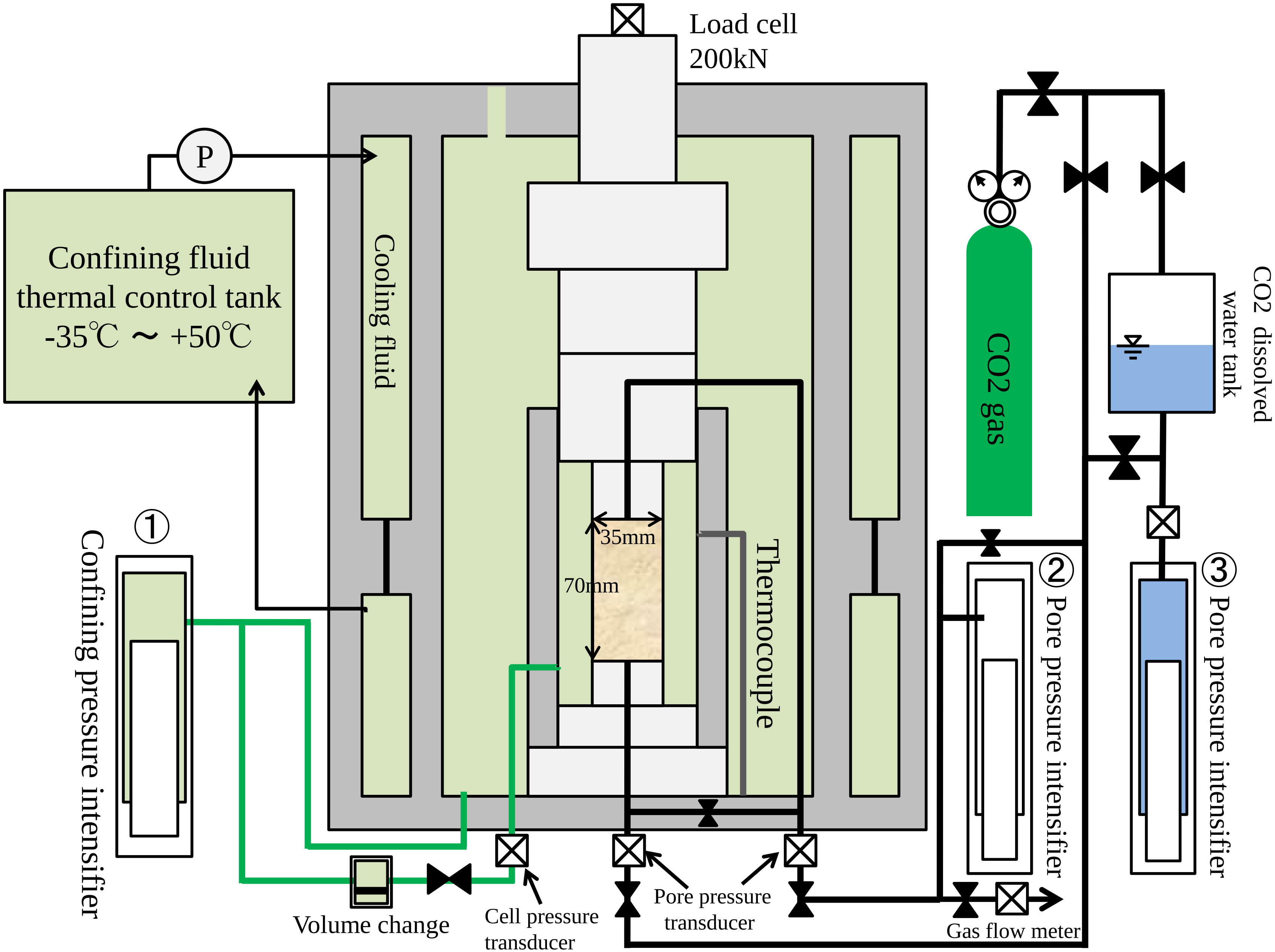
- We have developed a temperature pressure controlled triaxial apparatus, which can recreate low-temperature and high-pressure environment like deep seabed-ground.
- We have conducted a series of **undrained triaxial compression tests** and **dissociation tests** on gas hydrate-containing sand specimens.
- CO_2-hydrate is used instead of methane hydrate considering safety of the experiment, because it is non-flammable gas.

Testing Apparatus

Temperature and pressure controlled triaxial apparatus



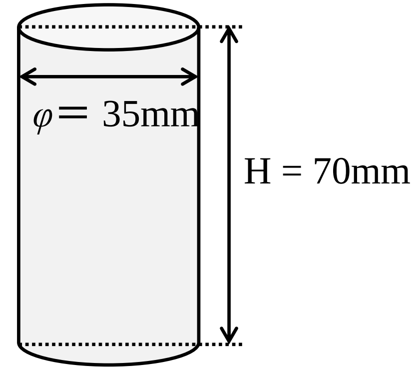
Schematic diagram of the apparatus

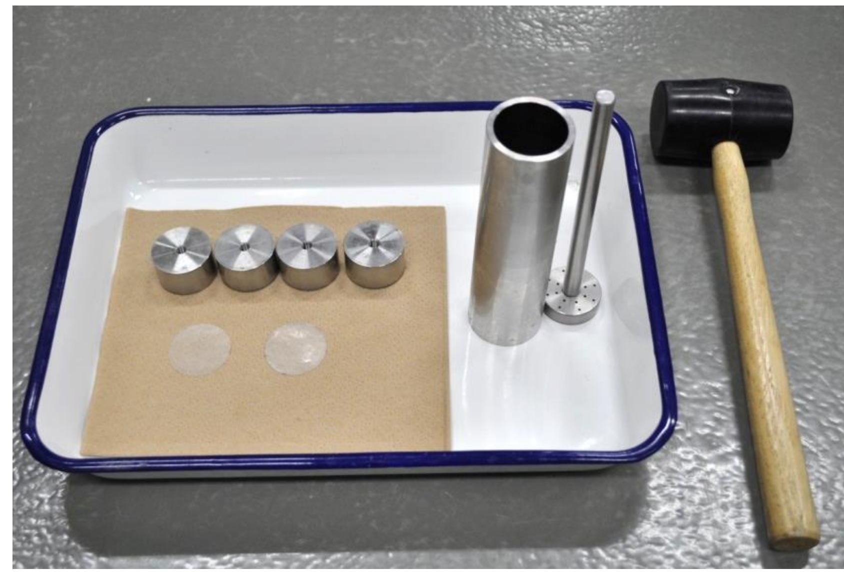


Sample preparation

- Toyoura sand for the host material.
- Initial moisture content : 11%
- Initial void ratio : 0.67

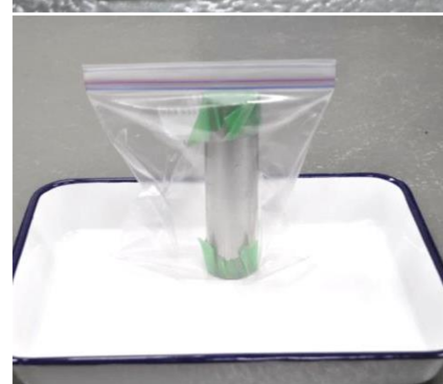
compacted in a stainless mold using the moist tamping method with **a diameter of 35mm and height of 70mm**.



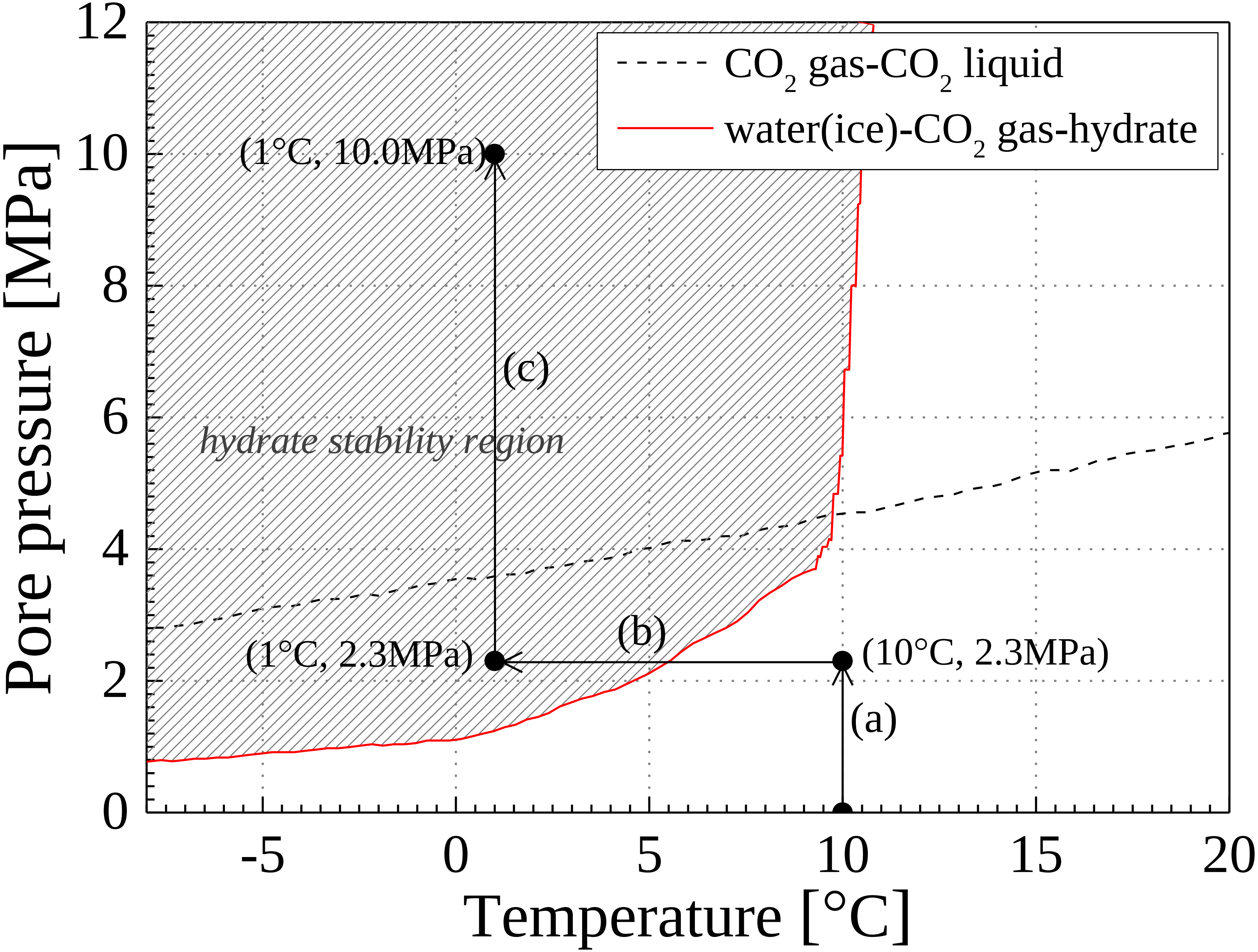


***Hydrate saturation** $$S_r^H = \frac{V^H}{V^V}$$

Material properties	
Density of soil particles $\rho_s\left(g/\mathrm{cm}^3\right)$	2.64
D_{50} (mm)	0.197
Diameter (mm)	35
Height (mm)	70
Initial void ratio e_0	0.67
Density of CO2 hydrate $\rho^H\left(g/\mathrm{cm}^3\right)$	1.12
Target value of initial hydrate saturation S_r^H	0.55
Initial moisture content w (%)	11.0



Formation process



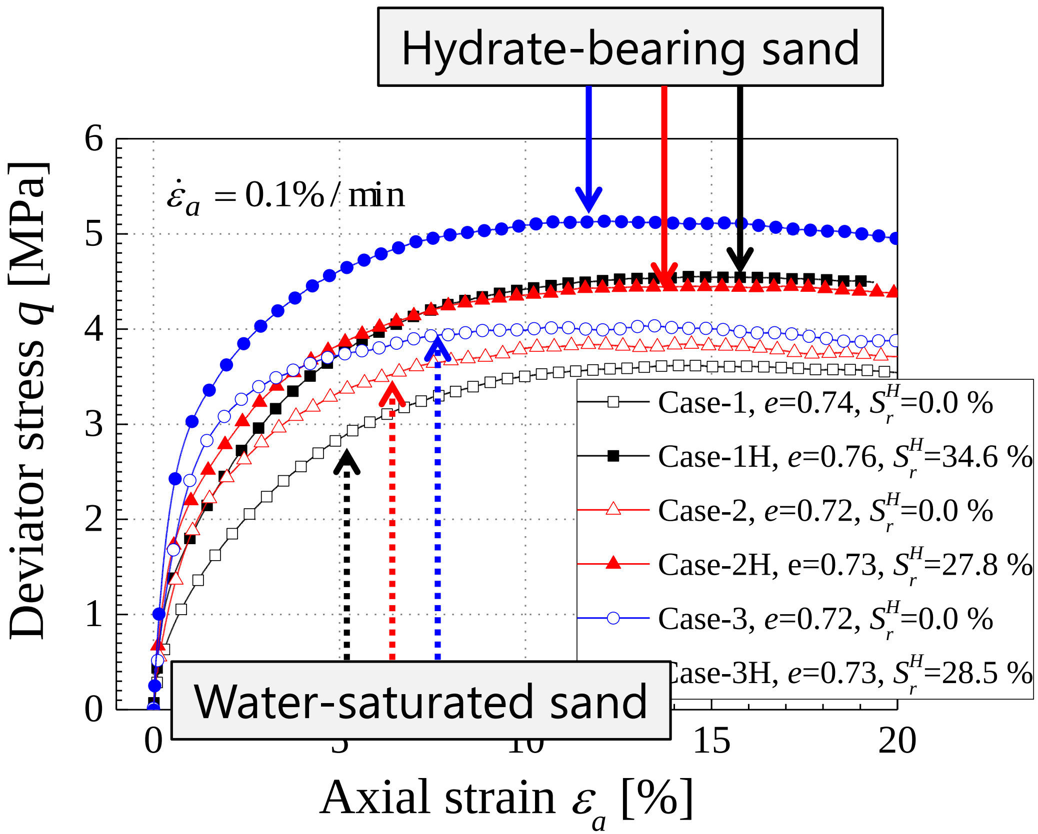
Experimental conditions

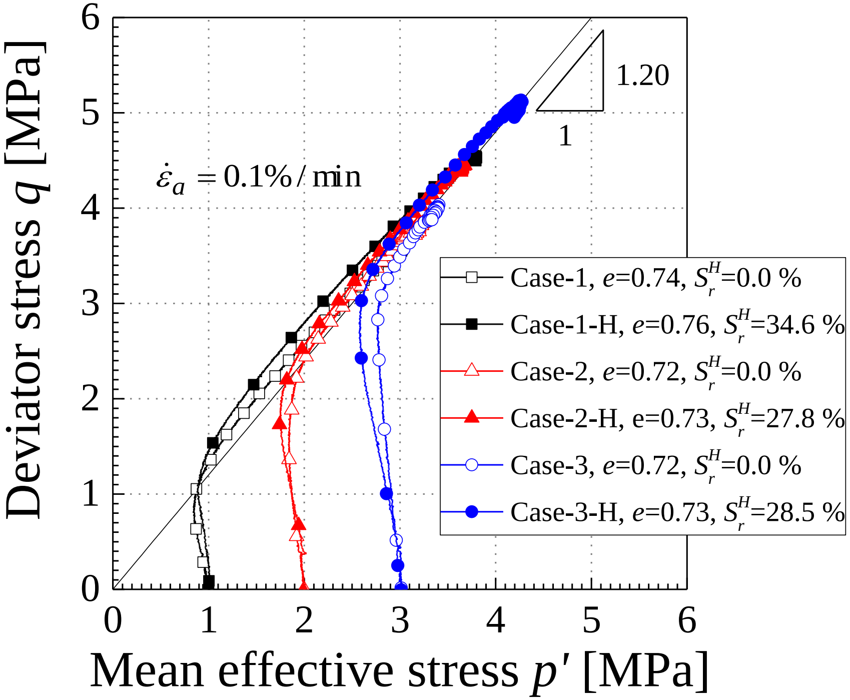
6 cases of undrained triaxial compression tests are conducted.

Case-No.	Void ratio	Back pressure	Initial mean effective stress	Temperature	Hydrate saturation
	e_0	u_0^w [MPa]	p_0' [MPa]	T [$^\circ$C]	S_r^H
Case-1	0.74	10	1.0	1.0	**0.0**
Case-2	0.72	10	2.0	1.0	**0.0**
Case-3	0.72	10	3.0	1.0	**0.0**
Case-1H	0.76	10	1.0	1.0	**34.6**
Case-2H	0.73	10	2.0	1.0	**27.8**
Case-3H	0.73	10	3.0	1.0	**28.5**

- **Case-1**, **Case-2**, **Case-3** : water saturated sand specimens (without hydrate)
- **Case-1H**, **Case-2H**, **Case-3H** contain CO_2-hydrate in the pores.
- Initial mean effective stresses are set to be **1.0MPa**, **2.0MPa**, **or** **3.0MPa**.
- Strain rate is set to be 0.1%/min among all the cases.

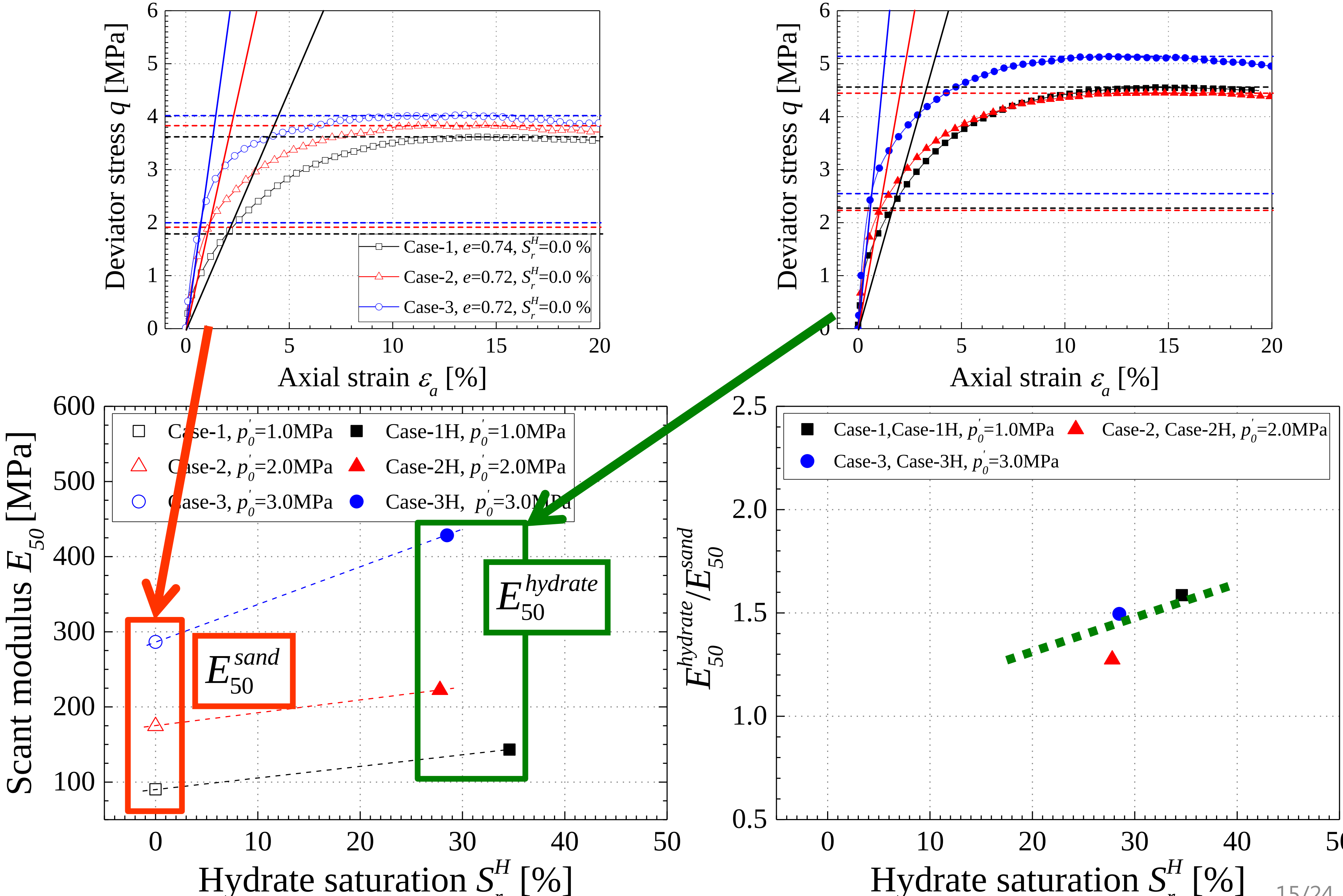
Stress-strain relationship & stress path



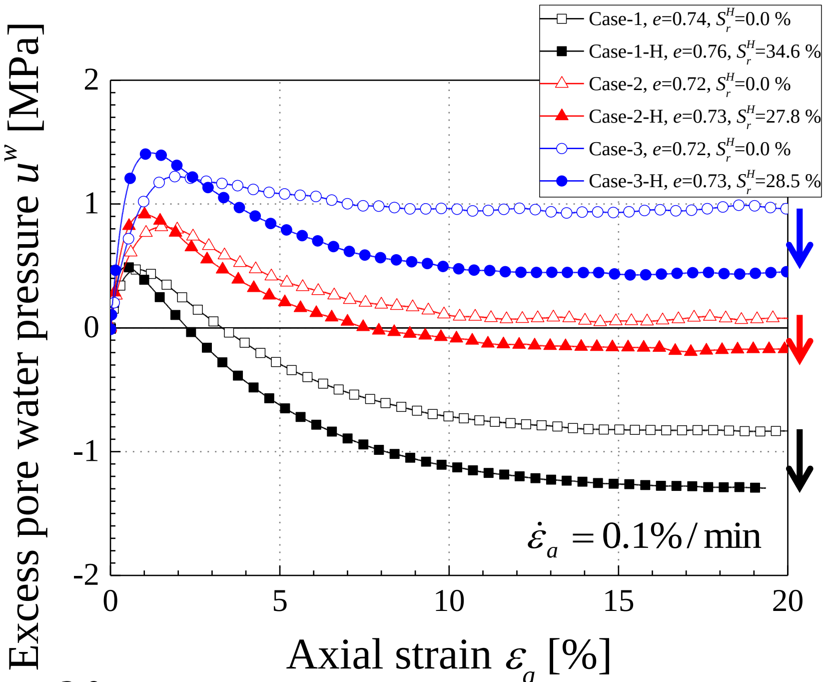


- Both stiffness and strength in hydrate-bearing sand are greater than that of water-saturated sand specimens.
- The stress paths in hydrate-bearing specimens express larger dilation than that of water-saturated specimens in each confining pressure.
- The hydrate may act like additional small particles in the sand structure.

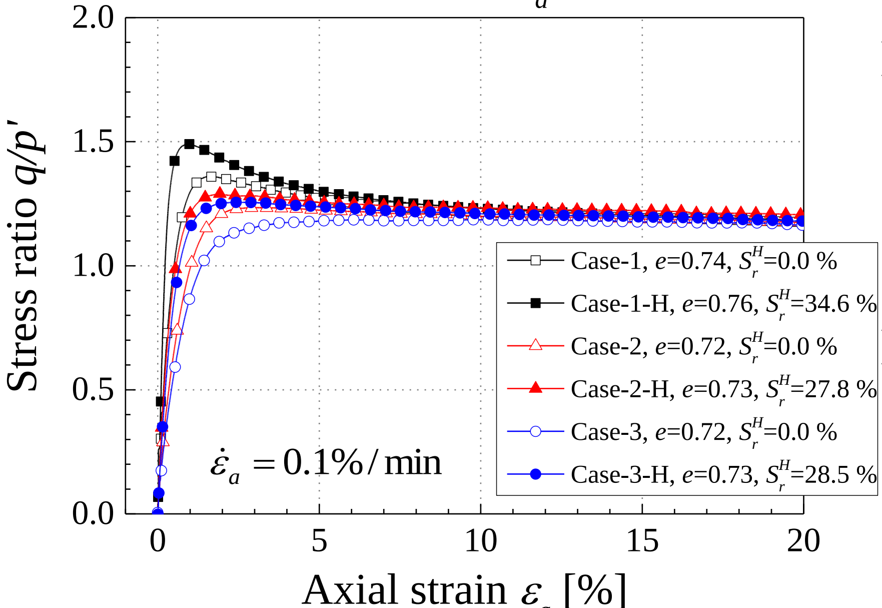
Scant modulus E_{50}



Excess P.W.P. vs strain, Stress ratio vs strain

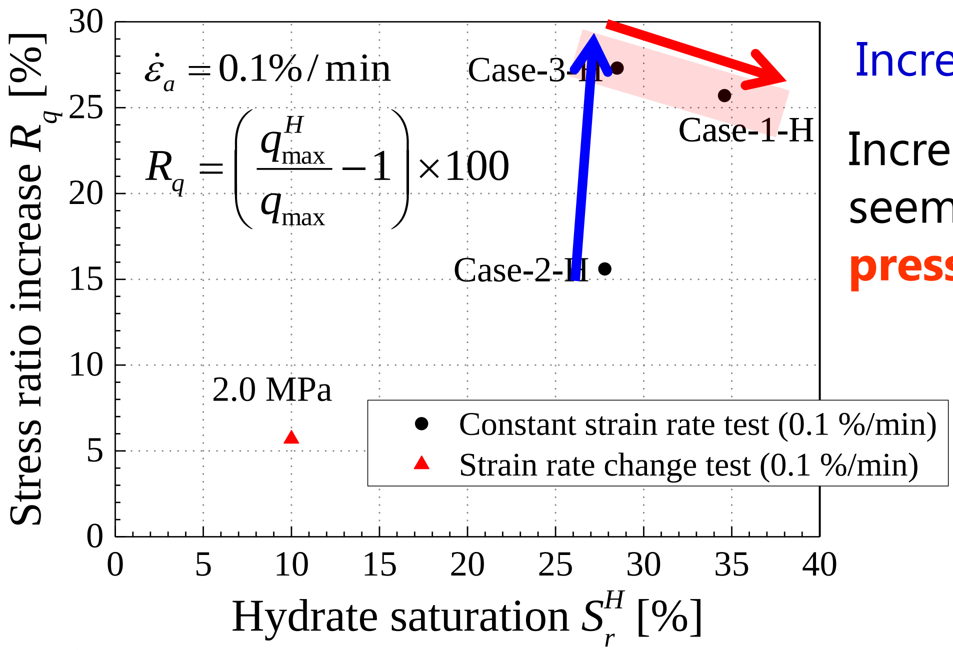


- The reduction in the pore water pressure becomes larger in the specimen with hydrate.
- The P.W.P profile in the hydrate-bearing specimen behaves like a dense sand comparing the one without hydrate.



- In the case of the same confining pressure, the maximum stress ratio of the hydrate-bearing specimen becomes larger than that of the water-saturated specimen.
- In the critical state, the stress ratio settled at the same value, namely, 1.2, among all the cases.

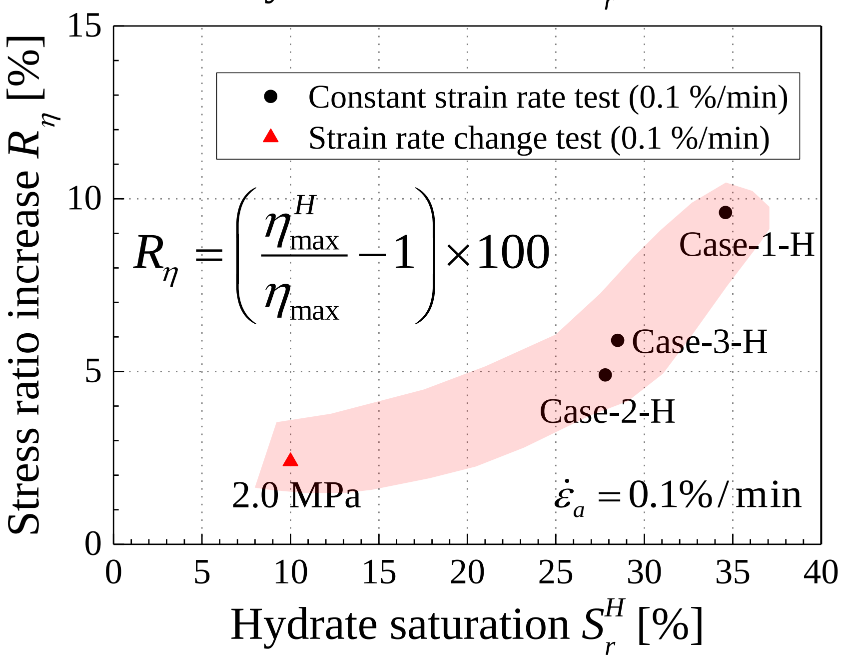
Strength increase ratio vs Hydrate saturation



Increase ration in the maximum deviator stress

Increase ration in the maximum deviator stress seems to depend on both the **confining pressure** and the **hydrate saturation**.

Not only sand particles but also gas hydrate might have the dependency on the confining pressure.



Increase ration in the maximum stress ratio

Increase ration in the maximum stress ration increases with increase in the hydrate saturation.

Summary – undrained triaxial tests –

In order to clarify the mechanical properties of gas hydrate-bearing sediments, we conducted undrained triaxial compression tests with different confining pressure and different hydrate saturation.

ー Conclusions ー

1. Both stiffness and strength of hydrate-bearing specimen becomes larger comparing with that of the specimens without hydrate.
2. In the case of hydrate-bearing sand, the excess pore water pressure is reduced largely. It may be because that the hydrate acts like additional small particles, and the apparent density of the sample increases.
3. Increase ratio in the maximum deviator stress may depend on both the confining pressure and hydrate the saturation.
4. Increase ratio in the maximum stress ratio increase with increase in the hydrate saturation.

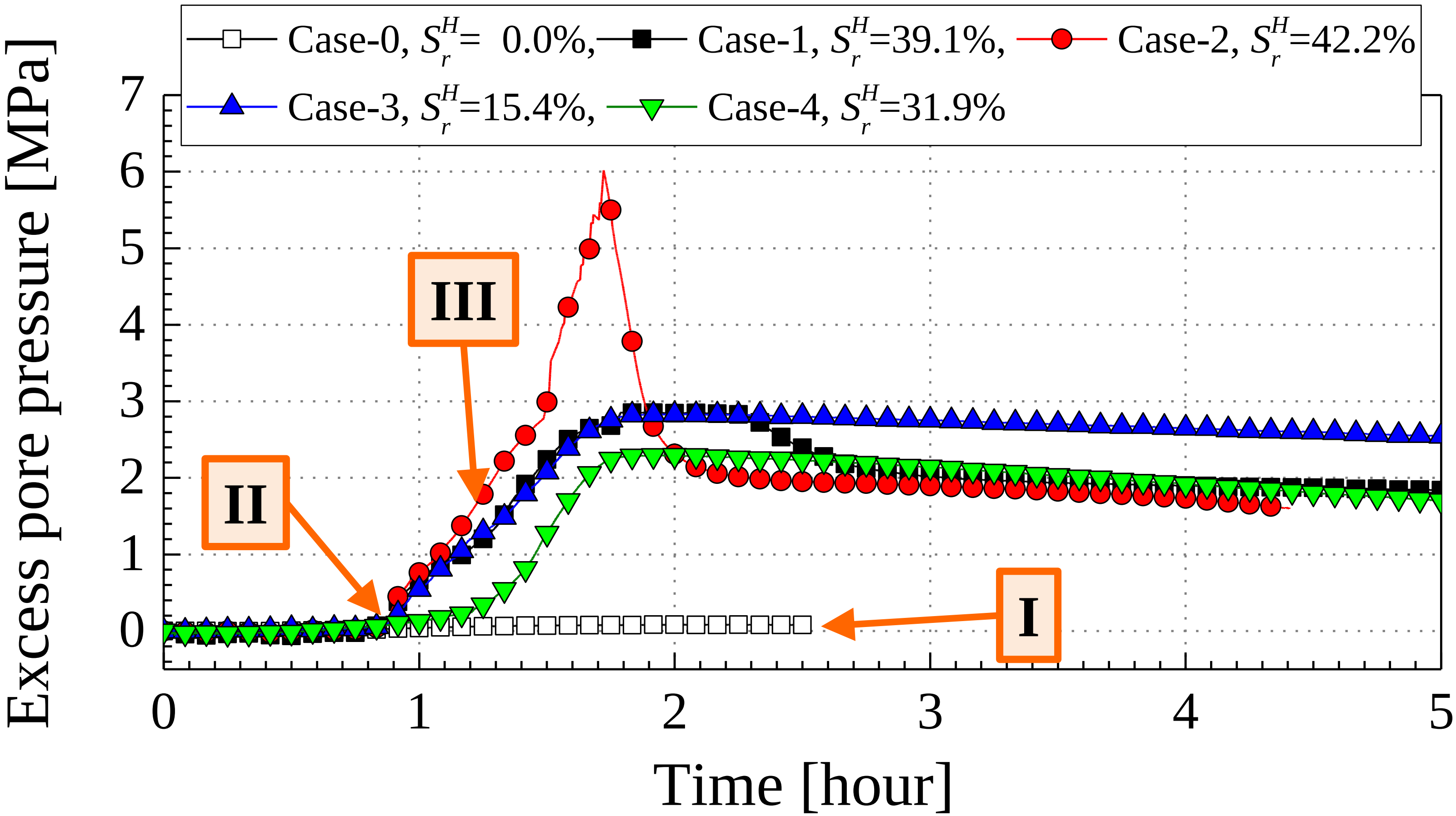
Experimental conditions

Case-No.	Initial void ratio	Initial pore pressure	Effective confining pressure	Temperature	Hydrate saturation
	e_0	P_{ini} [MPa]	σ'_c[MPa]	T [$^\circ$C]	S_r^H
Case-0	0.69	2.0	0.1	18.0	**0.0**
Case-1	0.75	**4.0**	3.0	18.0	39.1
Case-2	0.75	**4.0**	3.0	18.0	42.2
Case-3	0.79	**4.0**	3.0	18.0	15.4
Case-4	0.76	**6.0**	3.0	18.0	32.1

Undrained conditions for water and gas

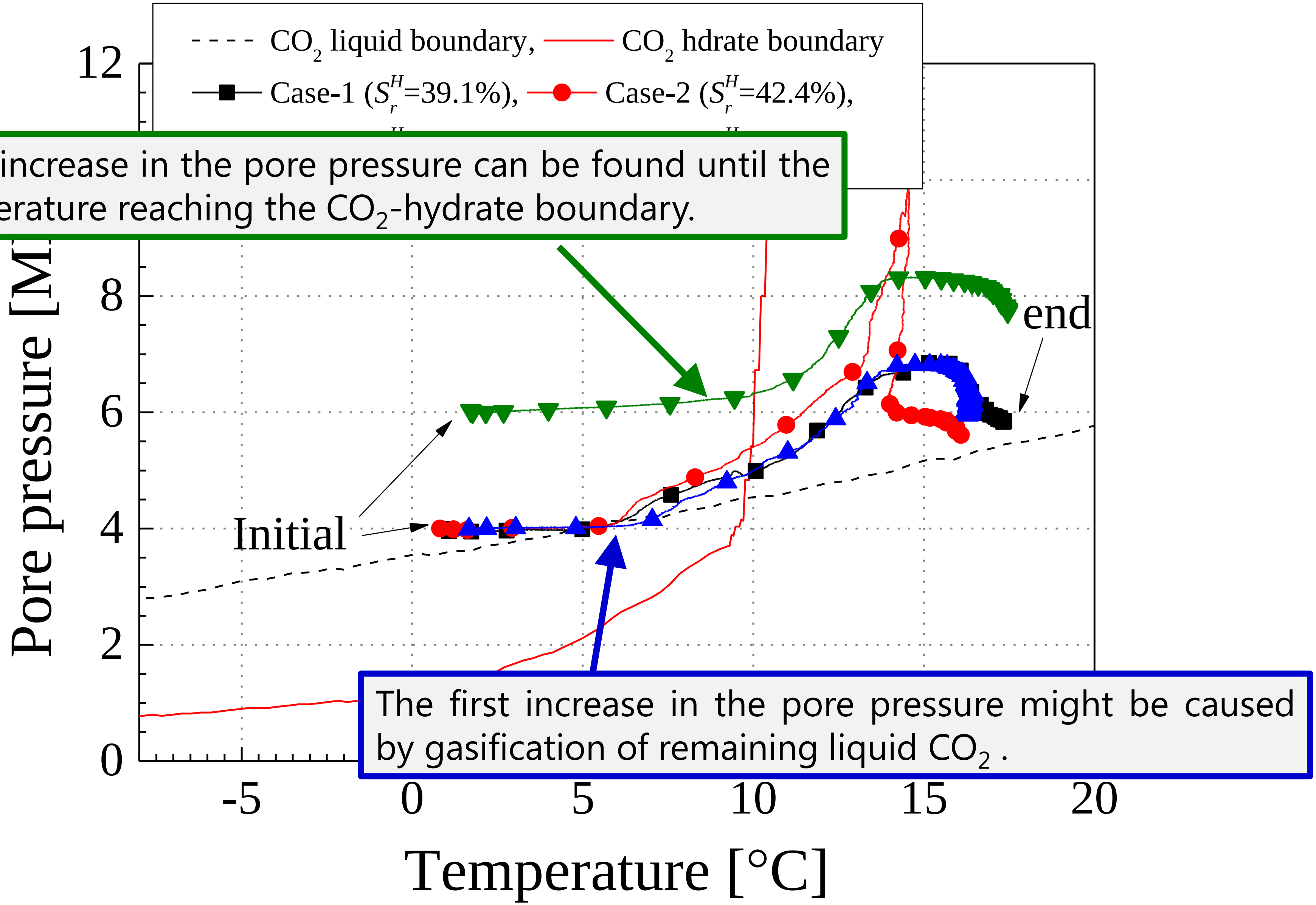
- Case-0 is the one **without hydrate**
- Case-1~Case-3: the initial pore pressure is **4.0MPa**
- Case-6: the initial pore pressure is **6.0MPa**
- **Case-1~Case-4: the effective confining pressure are the same; 3.0MPa**

Experimental results -Pore pressure-



I. In Case-0(without hydrate) , any buildup of the pore pressure was not observed.
II. The pore pressure is almost constant until one hour. After 1-hour the pore pressure begins to increase drastically, in Case-1~Case-4.
III. In Case-2, increase rate of the pore pressure seems to be the largest. It is because that the hydrate saturation is the largest among the cases

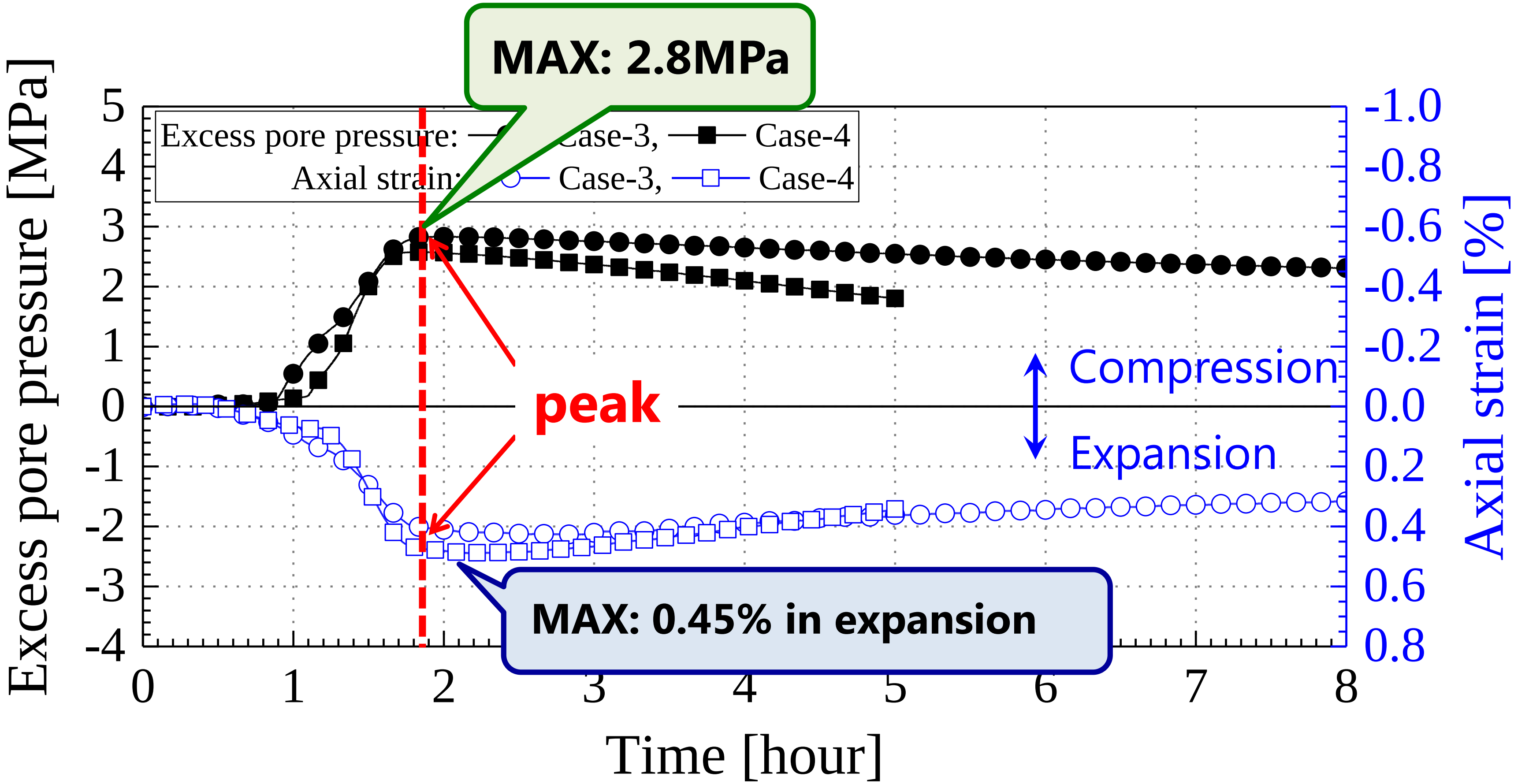
Temperature-pore pressure path



Little increase in the pore pressure can be found until the temperature reaching the CO_2-hydrate boundary.

The first increase in the pore pressure might be caused by gasification of remaining liquid CO_2 .

Excess pore pressure and axial strain



- Tensile strain can be observed with increase in the excess pore pressure.
- When the pore pressure reaches at the maximum, the tensile strain also reached at the peak.
- Under undrained conditions, the hydrate dissociation may lead the large build up of the pore pressure, and decrease in the density of the sediments, simultaneously.

Summary – dissociation tests –

In order to investigate the fundamental behavior of the gas hydrates containing soils associated with hydrates dissociation …

1. We have developed a temperature and pressure controlled triaxial apparatus.
2. This new triaxial cell can make the environment where gas hydrates can form, and we have carried out formation and dissociation tests using carbon dioxide hydrate.

— Conclusions —

1. The hydrates dissociation will cause <u>a significant increase in the pore pressure</u>, and result in <u>a significant reduction in the effective confining pressure</u> under undrained conditions.
2. The reduction in the effective confining pressure is a kind of liquefaction phenomena, which may lead to instability of the marine sediments.
3. The result indicates that both <u>increase in the pore pressure</u> and <u>decrease in the density of the sediments</u> might be caused simultaneously.

Thank you for your kind attention.