frontiers | Frontiers in Earth Science

REVIEW
published: 13 June 2022
doi: 10.3389/feart.2022.915735

A Review of Gassy Sediments: Mechanical Property, Disaster Simulation and *In-Situ* Test

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Gassy sediments are an important cause of engineering disasters such as large-area coastal submarine landslides, excessive tilting of marine foundations, and excessive deformation of tunnels. Under different stress paths, the gassy soil exhibits different microstructure changes and mechanical responses. This paper introduces the current research status regarding the mechanical responses, numerical simulation and the *in-situ* test methods of gassy sediment. In terms of mechanical responses, it summarized the strength and deformation characteristics of gassy soil under different stress paths, tracking the study on constitutive model. The disaster simulation work using constitutive model of gassy sediment is introduced. It also analyzes the advantages and limitations of various methods in the *in-situ* test. It can provide theoretical support for further study on disaster prevention and geological risk assessment of gassy sediments.

Keywords: gassy sediments, mechanical responses, constitutive model, *in-situ* methods, disaster simulation

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Specialty section:
This article was submitted to Geohazards and Georisks, a section of the journal Frontiers in Earth Science

Received: *08 April 2022*
Accepted: *23 May 2022*
Published: *13 June 2022*

Citation:
Liu T, Yang X and Zhang Y (2022) A Review of Gassy Sediments: Mechanical Property, Disaster Simulation and In-Situ Test. Front. Earth Sci. 10:915735. doi: 10.3389/feart.2022.915735

INTRODUCTION

Gassy sediments are widely distributed in the coastal areas of all the world's continents (**Figure 1**) (P et al., 2001). The gases are usually formed by microbial degradation of organic matter under anaerobic conditions, thermogenic methanogenesis, or volcanic eruptions. Their main components include methane, carbon dioxide, and nitrogen (**Figure 2**). The gases mostly exist in the pores as dissolved or discrete bubbles (Wheeler, 1986; Grozic et al., 2000; Sánchez et al., 2017).

Unlike unsaturated soil, the saturation of gassy soil is usually in the range of 85–90%, and the gas phase usually exists in the form of discrete bubbles while the water phase is in a connected state. The size of the soil particles determines the microstructure of gassy soils, and gassy soils are mainly divided into two categories according to the size of the air bubbles (Wheeler, 1988b; Sills and Wheeler, 1992). In one category, the air bubbles are smaller than the soil particles and pore size. The air bubbles are discrete in the soil pores, which only changes the compressibility of the pore fluid and does not affect the soil structure (Wang et al., 2018; Hong et al., 2021b; Xu et al., 2022). In the other category, the air bubbles are much larger than the soil particles and pore size. The bubbles rearrange the soil particles and thus affect the soil structure (Hong et al., 2020a; Gao et al., 2020). This microstructure often exists in fine-grained air-bearing soils, as shown in **Figure 3**. Hong et al. (2017) and Guo et al. (2021) observed the microstructure of typical fine-grained gassy soil by scanning electron microscopy and computed tomography. The results are shown in **Figure 4**. The undissolved gas exists as large discrete bubbles in the saturated matrix, and the bubbles are much larger than the soil particles and pores.

Due to the structural characteristics of gassy soil, the mechanical properties are considerably different from those of saturated soils and unsaturated soils. Kaminski et al. (2020) summarized the

FIGURE 1 | Distribution of marine gassy sediments in the five continents (Fleischer et al., 2001).

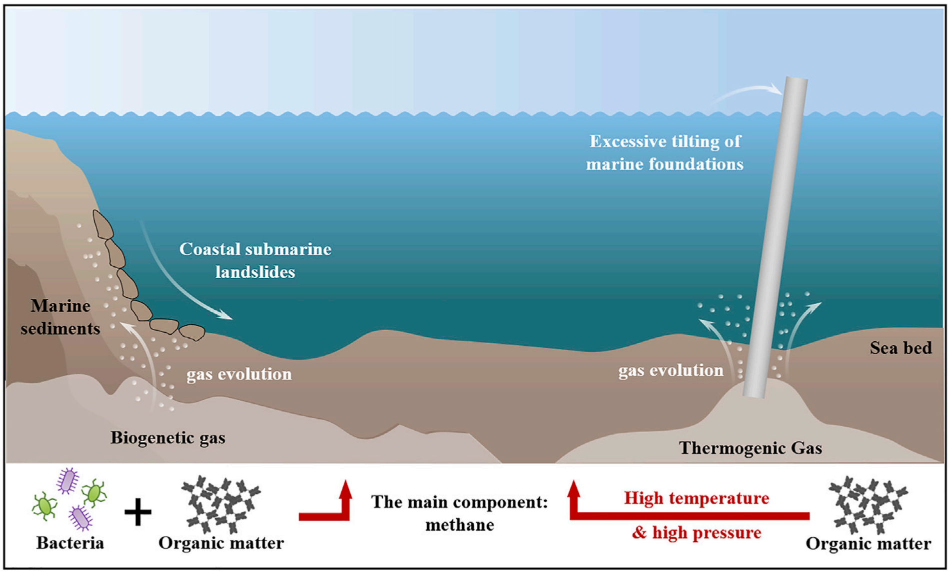

FIGURE 2 | Gassy source and geological disasters.

undrained shear strength of gassy soils under different conditions. The mechanical properties of gassy soils under different conditions change the engineering characteristics of the corresponding soil layers. During construction engineering, geological disasters have often been induced by the presence of shallow gas, and some major engineering accidents have occurred, causing serious economic losses (Sobkowicz and Morgenstern, 1984; Rad et al., 1994; Rowe et al., 2002; Kortekaas and Peuchen, 2008; Sultan et al., 2012; Xu et al., 2017; Rowe and Mabrouk, 2018; Jommi et al., 2019).

EXPERIMENTAL TESTING

In the gas-bearing soil test, due to the release of pressure caused by deep-water sampling, the gas in the soil is dissolved and

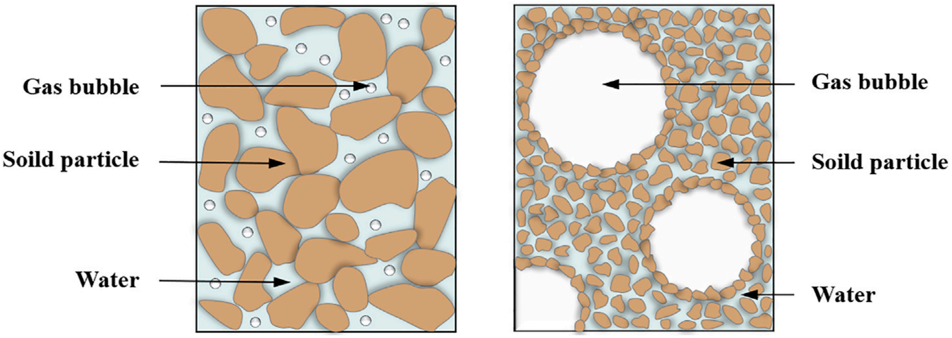

FIGURE 3 | Types of soil containing air bubbles (Wheeler, 1988b).

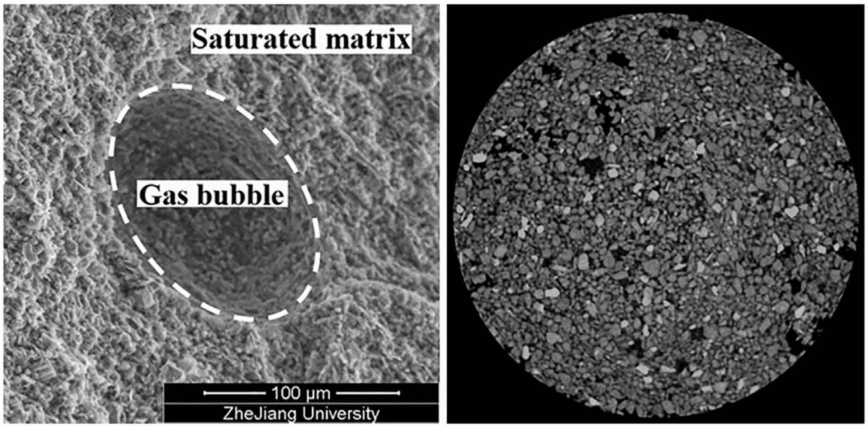

FIGURE 4 | Microscopic scan of a typical gassy soil (Hong et al., 2017; Guo et al., 2021).

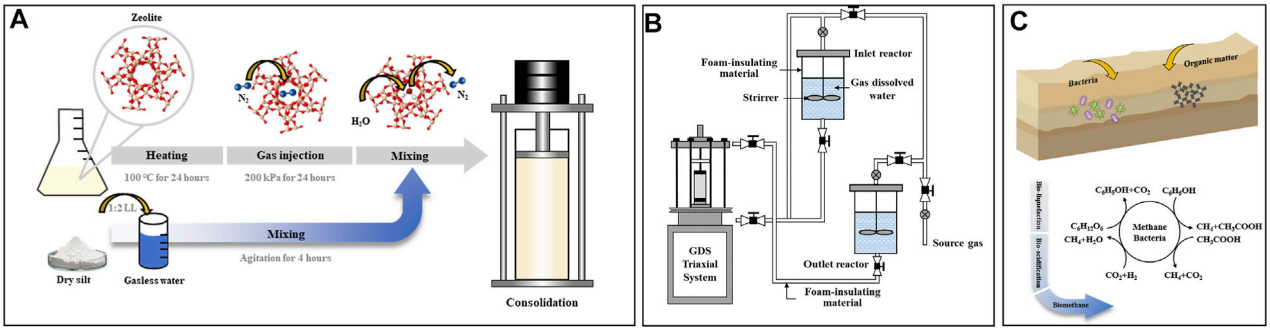

FIGURE 5 | Gassy specimen preparation methods: **(A)** the zeolite molecular sieve technique; **(B)** the axis-translation technique; **(C)** the biological anaerobic fermentation method.

expanded, which causes changes in the soil structure and even cracks (Zhang and Lunne, 2003; Sultan et al., 2012). It is therefore difficult to obtain undisturbed gassy soil samples under *in-situ* conditions. Previous experiments have mainly used remolded gassy soil samples. There are three main preparation methods: the zeolite molecular sieve technique (Sills et al., 1991; Hong et al., 2017; Hong et al., 2020b) the axis-translation technique (Sultan et al., 2012; Wang et al., 2018; Blouin et al., 2019), and the biological anaerobic fermentation technique (Sills and Gonzalez, 2001; Hu, 2010).

The zeolite molecular sieve technique replaces the adsorbed gas by adding the zeolite-absorbing gas into the slurry. This

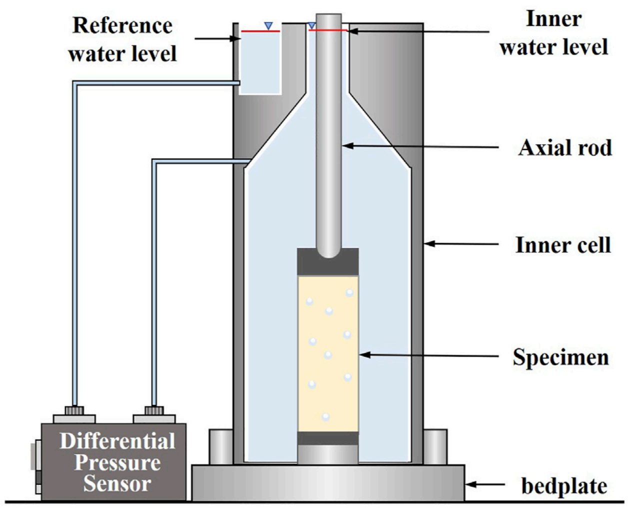

FIGURE 6 | Double-cell system.

method is simple and effective while the stress history is known. In this method, the samples can be prepared in batches with similar physical properties under *in-situ* conditions. The main principle is shown in **Figure 5A**. The gas content of the prepared samples cannot be accurately controlled, but the bubble distribution is relatively uniform.

The axis-translation technique involves replacing the internal pore water by circulating the dissolved gas water through the saturated sample and releasing the gas by unloading to form the gassy soil sample. The test system is shown in **Figure 5B**. This method is mainly applicable to coarse-grained soil, and the gas-charging effect of fine-grained soil is poor.

The principle of the biological anaerobic fermentation technique is that organic matter is decomposed by anaerobic bacteria to release methane and carbon dioxide, as shown in **Figure 5C**. Its mechanism is closest to the formation process of bubbles in the marine environment. The preparation process, however, requires certain values for temperature, pH, redox potential, and other parameters. Only by satisfying these biological requirements will the fermentation cycle be short and the gas production suitable.

Both zeolite molecular sieve technique and axis-translation technique can prepare uniform samples for triaxial test. zeolite molecular sieve technique is used for fine-grained gassy soil, which can mimic the natural formation process of free bubbles in soil. Axis-translation technique is used to prepare coarse-grained gassy soil, which can mimic the process of gas exsolution due to stress release. Although the bubble formation process of the biological anaerobic fermentation technique is the closest in the marine environment, its sample preparation method is complex and immature, so it cannot be used for triaxial test to determine the mechanical properties. It can be used for model box test, and it needs further research. The zeolite molecular sieve technique and axis-translation technique can produce specimens containing a uniform distribution of gas bubbles, but the gas saturation of gassy soil cannot be measured specifically. Therefore, the double-cell system can be installed in triaxial apparatus to measure the change of gas saturation. The accuracy of the volumetric system can reach 31.4 mm^3 (equivalent to 0.04% volumetric strain of the soil sample with a diameter of 38 mm and a height of 76 mm) (Ng et al., 2002). **Figure 6** shows the structural diagram.

MECHANICAL BEHAVIOR OF GASSY SOIL

On the basis of the soil microstructure, many researchers have analyzed the mechanical properties and discussed the relationship between those properties and the microscopic mechanism (Nageswaran, 1983; Thomas, 1987; Wheeler, 1988a; Gardner and Goringe, 1988; Sills et al., 1991; Sham, 1992; Hong et al., 2017; Bai, 2018). The bubble-water-soil skeleton microstructure interaction in fine-grained gassy soil includes two mechanisms: bubble flooding and gas intrusion into the saturated matrix (Wheeler, 1988b). The existence of bubbles make the effective stress and void ratio in the saturated matrix unevenly distributed (Sham, 1992). The bubble-water-soil skeleton interaction is affected by the initial pore water pressure (Hong et al., 2017). When the initial pore water pressure is low, the bubbles in the soil are large and the radius of the meniscus at the water–gas interface is large, which means that the water inflow value of the bubble cavity is relatively small. During the undrained shear process, with the increase of the pore water pressure, bubble flooding may occur (the water in the saturated matrix enters the bubble cavity, and partial drainage occurs), resulting in a reduction of the excess pore pressure and an increase in strength, as shown in **Figure 7A**. When the initial pore water pressure is high, the gas pressure in the soil is also relatively high, which produces micro-cracks in the surrounding saturated matrix. In the process of undrained shear, the micro-cracks may collapse, resulting in reduced strength and increased excess pore pressure, as shown in **Figure 7B**.

Bubbles in gassy soil change the compression characteristics of the pore fluid and the structure of the soil, which affects the mechanical properties, such as compression, and the static and dynamic characteristics. A large number of compression, monotonic, and cyclic shear tests of gassy fine-grained soil and gassy sand have been carried out, and the key influencing factors of the modulus, monotonic, and cyclic shear strength of gassy soil have been determined. The results show a clear influence of air content on the elastic shear modulus and shear strength of gassy soil (Duffy et al., 1994; Pietruszczak and Pande, 1996; Mathiroban, 2004; Vega-Posada et al., 2014; Hong et al., 2017). The drainage shear test of sand shows strain hardening, and the strain law of undrained shear is related to the initial state of gassy sand (Amaratunga and Grozic, 2009; Vega-Posada et al., 2014). Under dynamic load, the cyclic stress of gassy sand is linearly related to liquefied vibration times and the increase of the gas content delays the liquefaction of gassy sand (Guan, 2017). The greater the gas content, the slower the pore pressure dissipation and the smaller the amplitude of excess pore water pressure (Han, 2020). The change in the cyclic stiffness of gassy fine-grained soil is related to the initial pore

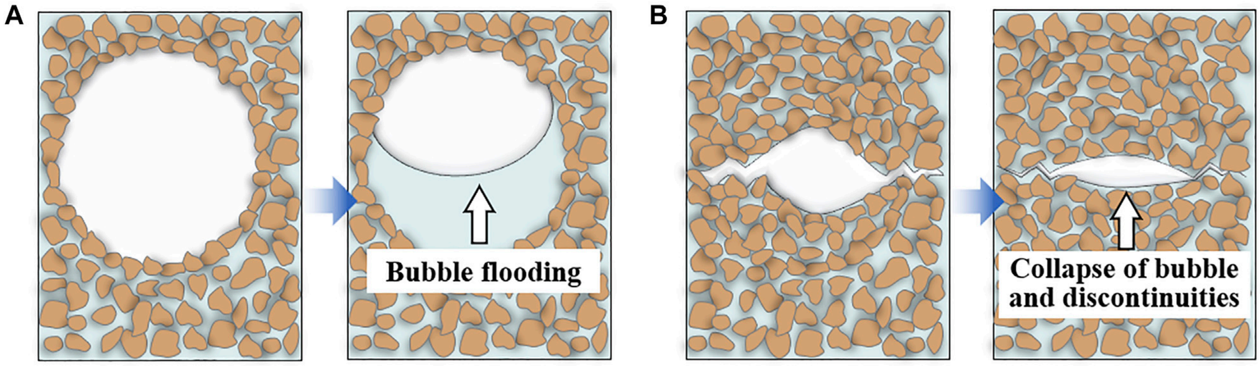

FIGURE 7 | Schematic diagrams showing fine-grained gassy soil under different back pressures (Hong et al., 2017): **(A)** Relatively low initial back pressure; **(B)** Relatively high initial back pressure.

pressure. The high pressure enhances show the stiffness enhancement and the low pressure weakens the stiffness (Hong et al., 2021a). Research into various stress-path problems in actual projects has shown that the deformation of the soil can be reduced by gradual deflation (Wang, 2009). The change direction of the confining pressure is closely related to the stress–strain characteristics of the sample. The increase of the confining pressure induces strain hardening of the sample, and the decrease induces strain softening (Zhong, 2007). The gas evolution and bubble expansion caused by pressure unloading enhances the compressibility of gassy soil, reduces the pre-consolidation pressure and the undrained shear strength. The structural change caused by gas evolution influences the effective stress path (Sultan et al., 2012). The rapid accumulation of gas leads to a rapid increase of the pore water pressure and a reduction of the effective stress of the soil, triggering the liquefaction of gassy soil (Liu, 2018; Kong et al., 2019). The change of temperature and pressure of gassy soil also affects the compressibility and permeability. After the dissipation of excess pore pressure, the consolidation time is prolonged, resulting in long-term settlement and showing a complex consolidation creep process. The lower the saturation is, the more obvious the phenomenon is (Wang, 2021; Zhu et al., 2021).

Researchers have proposed mechanical models for engineering calculations. The fine-grained gassy soil mechanical model is an improvement on the Cambridge model, while the coarse-grained gassy soil mechanical model is used to construct the mechanical analysis model by describing the compressibility of the "bubble-water" mixture. Wheeler and Gardner (1989) regarded soil containing large bubbles as a composite material containing spherical filler. They derived the calculation formulas of the shear modulus and bulk modulus of soil containing large bubbles under drainage and undrained conditions. Grozic J. L. H. et al. (2005) quantitatively simulated the enhancement effect of bubbles on the undrained shear strength of fine-grained gassy soil, but their model cannot describe the strength attenuation caused by bubbles. Hong et al. (2021b) proposed a critical-state model that takes into account both hardening and softening by defining the ratio of the deviatoric stress increment to the plastic shear strain increment. Pietruszczak and Pande (1996) introduced "gas–water interfacial tension" into the pore pressure expression and established the rotational hardening model of gassy sand. The change of pressure in gassy sand causes gas dissolution, and so Grozic J. L. et al. (2005) considered the compressibility and solubility of gas at the same time using Henry's law and Boyle's law. By introducing a volume dissolution coefficient h, they deduced the expression of pore pressure:

$$\triangle\bar{u}_g = \left\{\frac{\triangle n}{[(1-S_0)n_o + hS_0n_0 - \triangle n]}\right\}\triangle\bar{u}_{g0} \tag{1}$$

This model can accurately predict the strain softening but not the strain hardening.

Gao et al. (2020) established a critical-state model that takes into account the influence of the initial pore water pressure and initial air content on the yield and dilatancy characteristics of gassy soil. However, it is unable to predict the undrained unloading response. Sultan et al. (2012) explored the influence of gas evolution on soil in undrained unloading stress paths through triaxial tests. They also introduced the gas-phase damage parameter d (related to gas content) and proposed the following relationship between gassing volume and soil pre-consolidation pressure:

$$\frac{p'_c}{p'_0} = \exp(-\delta d) \tag{2}$$

Smith et al. (2022) proposed a model that takes into account the bubble damage effect. The anisotropic yield surface function is defined as

$$q = \frac{2}{3}p'\frac{q_0}{p'_0} \pm \sqrt{M^2\left(p'p'_0 - p'^2 + \frac{1}{9}\frac{p'}{p'_c}q_0^2\right)} \tag{3}$$

Using the non-associated flow rule, this model can simulate the strength reduction of gassy soil caused by gas evolution.

TABLE 1 | Stress–dilatancy relations assumed in the existing models for fine-grained gassy soil.

References	Dilatancy
Pietruszczak and Pande (1996)	$D = \frac{d\varepsilon_v^p}{d\varepsilon_q^p} = M\ln(\frac{p'}{p'_c}) + M$
Grozic et al. (2005b)	$D = \frac{d\varepsilon_v^p}{d\varepsilon_q^p} = \frac{M^2 - \eta^2}{2\eta}$
Sultan et al. (2012)	$D = \frac{d\varepsilon_v^p}{d\varepsilon_q^p} = \mu(M - \eta)(\frac{\alpha M}{\eta} + 1)$
Hong et al. (2019)	$D = \frac{d\varepsilon_v^p}{d\varepsilon_q^p} = [1 + \xi \frac{u_{w0} - u_{w0\_ref}}{p'_0} \exp(-\frac{\chi}{\psi_0})] \; \frac{M^2 - \eta^2}{2\eta}$

Note: $d\varepsilon_v^p$ denotes increments of plastic volumetric strain; $d\varepsilon_q^p$ denotes increments of plastic deviatoric strain; M denotes the stress ratio at the critical state; η denotes the stress ratio (i.e., $\eta = q/p$); and ξ and χ are two material constants.

At present, however, the mechanical models of gassy soil mainly focus on the description of static loading characteristics; the gas-phase damage under static unloading conditions has only been partially considered.

The theory of granular solid hydrodynamics are combined with the temperature motion equation of soil particles (Yang and Bai, 2020):

$$d_t\left(T_{gg}\right) = c_2 c_5 \frac{d_t e_{ij} d_t e_{ij}}{\rho^S} + c_3 c_5 \frac{d_t \varepsilon_v d_t \varepsilon_v}{\rho^S} + c_4 \frac{\Gamma d_t T}{\rho^S} - c_5 \frac{T_{gg}}{\rho^S} \tag{4}$$

Yang and Bai (2020) established a thermodynamic model describing the mechanical properties and temperature effect of fine-grained soil containing gas. The results show that the increase of temperature under drainage conditions increases the compression coefficient and the thermal shrinkage coefficient, and the pore water pressure under undrained conditions also increases. The influence of temperature on the undrained shear characteristics depends on the initial conditions.

Vanoudheusden et al. (2003) established a numerical model to describe the mechanical properties of unsaturated expansive soil based on the elastic-plastic model. Under undrained conditions, its characteristics are controlled by the drainage curve of gassy soil (the relationship between saturation and capillary pressure) and the solubility of the gas.

Dilatancy is an important property of the mechanical responses of gassy soil. For coarse-grained gassy soil, bubbles only change the compressibility of the pore fluid, and so the effective stress principle is still applicable to this type of soil (Pietruszczak and Pande, 1996; Grozic J. L. et al., 2005). The study of dilatancy function, plastic modulus, and related material parameters of saturated sand is still relevant for gassy sand (Yin and Chang, 2013; Xiao et al., 2015; Kong et al., 2016; Xiao et al., 2019).

However, there are few studies on the dilatancy of fine-grained gassy soil. The dilatancy function used in the existing constitutive model of gassy soil is mostly the same as that of saturated soil (Pietruszczak and Pande, 1996) and they cannot consider the potential effect of gas bubbles on dilatancy. While the dilatancy function proposed by Hong et al. (2019) introduces the initial pore water pressure and gas volume fraction on the basis of Grozic J. L. et al. (2005). To characterize the influence of gas content on the dilatancy, the relevant material parameters need to be calibrated. The Stress–dilatancy relations assumed in the existing models for fine-grained gassy soil is shown in **Table 1**.

NUMERICAL SIMULATION

The existence of gas in the soil layer affects the mechanical properties of the stratum. Thus, in the design of offshore foundations, offshore drilling, and slope stability analysis, a constitutive model that can uniformly describe the response of the gassy soil under different conditions is needed. Current research on fine-grained gassy soil mainly focuses on the unit response in the triaxial test. Few studies have been conducted on practical engineering issues and the constitutive model needs further development (Grozic J. L. H. et al., 2005; Sultan et al., 2012; Hong et al., 2017; Sánchez et al., 2017; Goao and Hong, 2019; Hong et al., 2019; Hong et al., 2020a; Gao et al., 2020). The constitutive model of coarse-grained soil is relatively mature, but the analysis is mostly base on liquefaction and landslide (Grozic, 2003; Atigh and Byrne, 2004; Mabrouk and Rowe, 2011; Hong and Xu, 2020; Thomas, 2021a; Hong et al., 2021b; Thomas, 2021b).

Grozic (2003) introduced the concept of flow potential and proposed a method to evaluate the liquefaction potential of loose sand, which can judge the potential liquefaction area according to the flow potential. The zone of potential liquefaction is shown in **Figure 8**.

Atigh and Byrne (2004) proposed a liquefied sand flow model to analyze the liquefaction-sliding flow of loose gassy sand caused by tidal changes. Dense sand slopes are more common in real environments, however. Hong et al. (2021b) established a model of coarse-grained gassy soil, quantified the influence of such soil under different initial conditions, and used the model to analyze the stability of submarine slopes under undrained conditions. For loose gassy sand, gas has an enhancing effect on the stability of submarine slopes; for dense gassy sand, it has a weakening effect, as shown in **Figure 9**.

Hong and Xu (2020) simulated the undrained shear of gassy sand using the discrete element method. They analyzed the influence of different gas solubilities, and this method can be used to effectively simulate the gas dissolution in the process of undrained unloading (**Figure 10**).

For fine-grained gassy soil, Thomas (2021a, 2021b) proposed the governing equation of porous elastic gas-bearing soil based on the modified Biot theory to simulate the changes of stress, displacement, and pore water pressure of a gassy seabed with buried pipelines under wave pressure loading. In the buried pipelines, the stress and pore pressure are concentrated, which may lead to local liquefaction.

IN-SITU INVESTIGATION

In-situ sampling of gassy sediments inevitably causes disturbances. Although temperature-preserving and pressure-

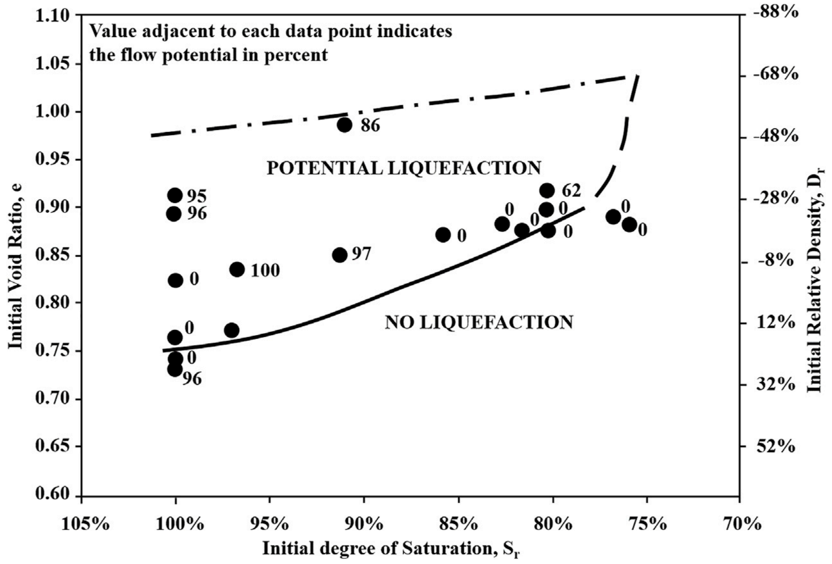

FIGURE 8 | The zone of potential liquefaction (Grozic, 2003).

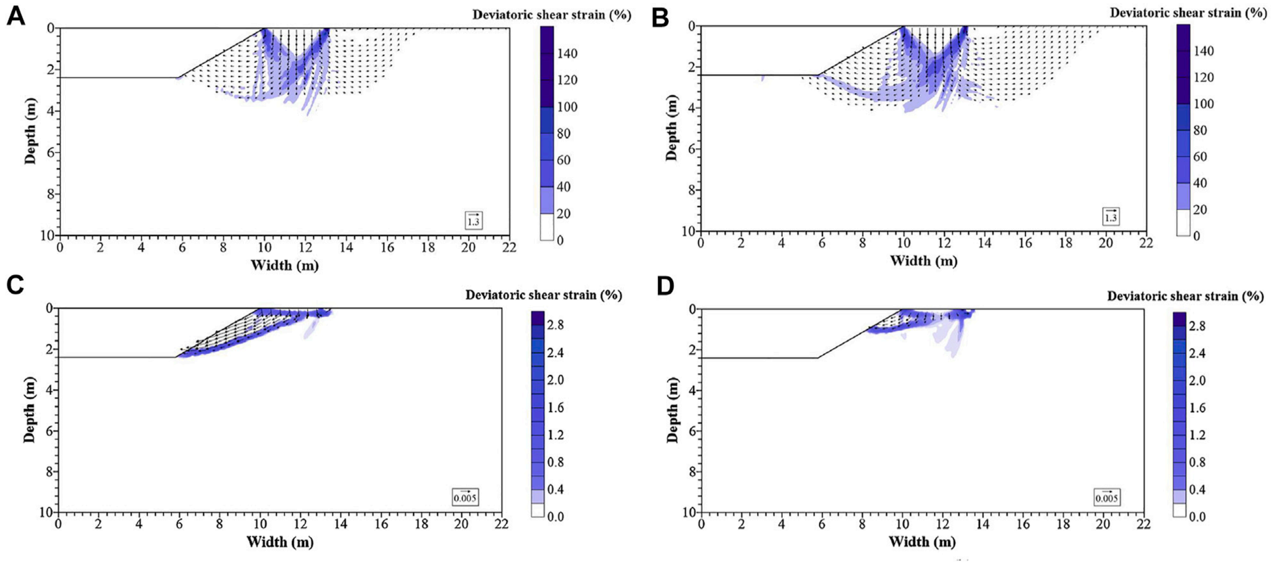

FIGURE 9 | Contours of the shear strain and displacement vectors for gassy sand (Hong et al., 2021b): **(A)** Saturated dense sand; **(B)** Gassy dense sand; **(C)** Saturated loose sand; **(D)** Gassy loose sand.

holding sampling technology can be used to obtain *in-situ* gassy sediment samples, the sampling cost is high (Bai and Li, 2010; Zhu et al., 2011; Wu et al., 2022; Zhu et al., 2022). Experiments have therefore mainly been carried out using laboratory gassy soil samples. Moreover, the current sample preparation method for gassy soil cannot effectively reproduce the gas-production process of microbial bacteria in the coastal soft soil layer under *in-situ* conditions. It is also difficult to realize the batch of gassy soil sample preparation and the quantitative introduction of gas. It is therefore essential to study the *in-situ* test equipment that can quantitatively detect the gas content in the soil. Accidents involving uncontrolled gas leaks caused by drilling in marine engineering can be avoided by researching the *in-situ* testing technology of gassy soil. The simulation parameters can be accurately established for numerical calculation.

Rad and Lunne (1994) developed a new type of offshore *in-situ* testing device, the BAT probe, which is pushed to the required depth to obtain water-air samples in the gassy soil layer. Its structure is shown in **Figure 11**. After the recovery of the device, the samples are analyzed using a gas chromatograph for gas

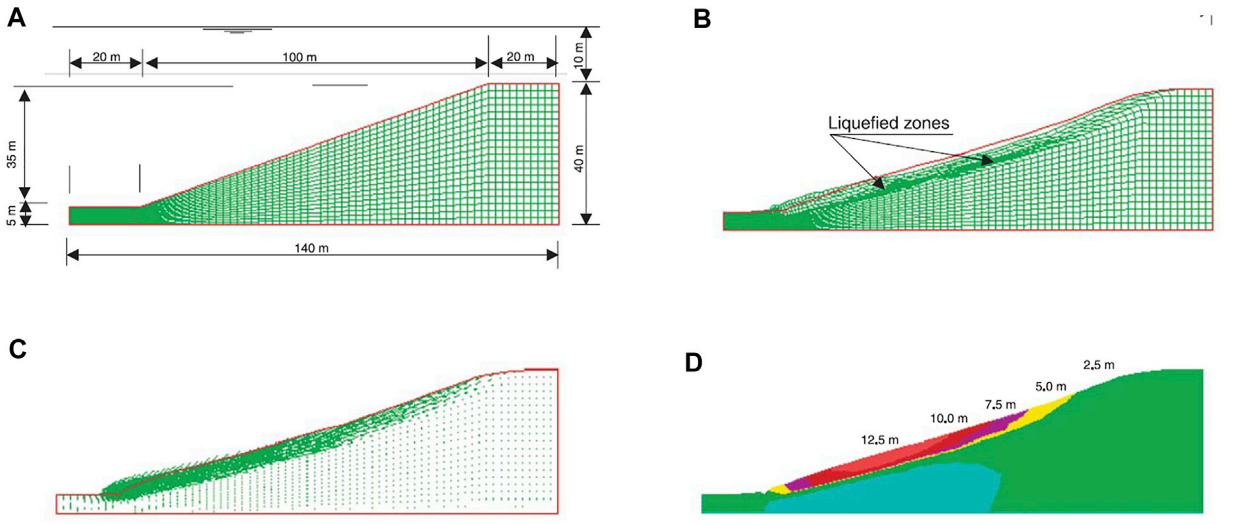

FIGURE 10 | Submarine slope of gassy soil (Hong and Xu, 2020): **(A)** grid used in analysis; **(B)** deformed mesh during low tide; **(C)** displacement vectors; **(D)** horizontal displacement contours (in m).

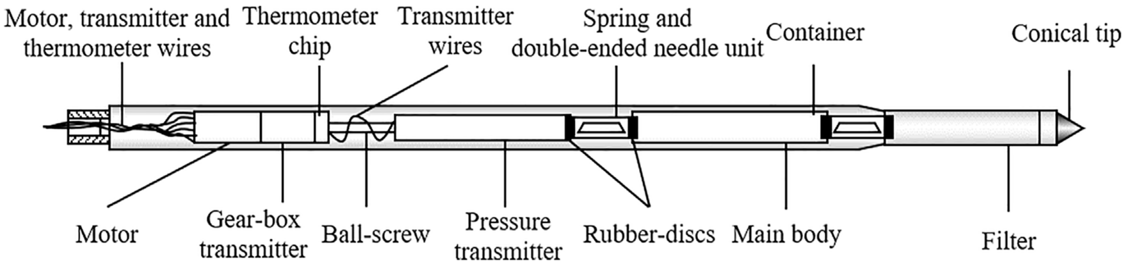

FIGURE 11 | BAT probe (Rad and Lunne, 1994).

composition and gas saturation in pore water to assess the possibility of a shallow air bladder in the soil. Hong et al. (2018) also developed a new type of device. After penetration, the device takes horizontal samples, performs *in-situ* sonic testing, and determines the gas content by *in-situ* compression to minimize the influence of sampling disturbance.

Since the BAT probe can only be used for *in-situ* water-gas sample testing and has a single function, recent research has mainly used the geophysical prospecting measurements to detect the source layer, reservoir and burial depth of gassy soil (**Figure 12A**). The gassy soil can be identified as shown in **Figure 12B**. The shear wave seismic section can delineate the boundary of the gassy sand layer (Wood et al., 2000; Pruessmann et al., 2004; Reeves, 2005; Lin et al., 2006; Zheng et al., 2006; Li et al., 2009). In addition, the change of resistivity can be used to judge the gassy layer by the electromagnetic exploration method, allowing the distribution range to be delineated (Lee and Collett, 2006; Li et al., 2007; Pezard et al., 2015). The irregular and robust reflection interface of the gassy formation can be formed by the shallow stratum cross-section method using sound-wave propagation and scattering (Mustafa et al., 2002; Wang et al., 2013; Tóth et al., 2014; Janiewicz et al., 2019).

The cone penetration test (CPT) can be used to carry out a variety of test methods, and as the scope of the investigation is extensive, CPT can be used to identify the gassy layer (Wang et al., 2019). Guo et al. (2007) found that CPT can also preliminarily determine whether biogas is present in sand. When the tip resistance increases, the friction–resistance ratio decreases, the fluctuation amplitude of the pore water pressure remains small, and there is no negative excess pore water pressure during the penetration process. It can thus be determined preliminarily that there may be shallow biogas in the sand layer.

Li et al. (2009) improved the CPT and separated the probe and probe rod to realize gas sampling and pressure measurement. Lai et al. (2016) invented a Membrane Interface Probe and Cone Penetration Technology that decomposes and passes organic matter by adding a MIP film. It uses gas chromatography to determine the organic matter's phase state and content.

CPT with different probes can be used to detect different physical properties of sediments, such as gas occurrence,

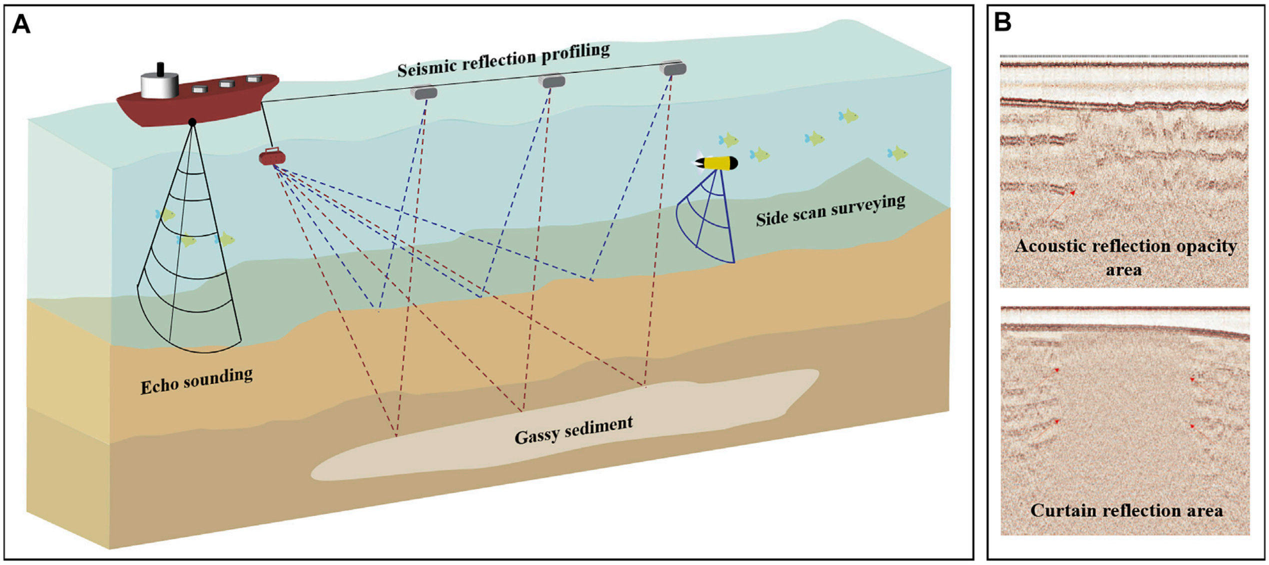

FIGURE 12 | Geophysical prospecting: **(A)** methods; **(B)** Sub-bottom profile of gassy sediment (Xing et al., 2017).

temperature gradient, acoustic characteristics, and chemical anomalies. Detecting these characteristics can improve the current conventional *in-situ* measurements in terms of the identification accuracy of gassy soils. Thus, CPT has a wide application prospect in gassy soil exploration.

RESEARCH PROSPECTS

Due to its mechanical properties, gassy sedments are an important cause of engineering disasters. The researches mainly focus on the mechanical response and development of constitutive model. From this summary of the current research, the author believes that future research on gassy soils should explore the following aspects:

1) Mechanical responses of gassy soils with different stress paths. Combined with the actual engineering or disaster, based on the soil stress path under the actual conditions of gassy soil shield, waves, landslides etc., research could be conducted into mechanics and deformation mechanism to achieve accurate prediction;
2) The constitutive model of fine-grained gassy soil. The numerical simulation of coarse-grained gassy soil is relatively mature, whereas the simulation of fine-grained gassy soil has mainly focused on the unit scale, and there is no mature constitutive model for practical engineering problems;
3) The bubble-migration mechanism in gassy soil. Under real conditions, due to soil faults and cracks, discrete bubbles may migrate, accumulate, and be released. The relationship between the triggering conditions of bubble migration and gassy soil mechanical behaviour needs to be furthur research.
4) Effect of microstructure of bubbles in gassy soil. The change of bubbles in the mechanical test can be observed by means of microscopic scanning device to clarify microcosmic mechanism.
5) Risk assessment of geological disasters such as liquefaction, landslides, and the settlement of gassy soil. Based on the research into the deformation mechanism of gassy soil under different conditions, engineers should carry out site risk assessments and implement disaster-prevention and mitigation measures;
6) *In-situ* measurements of gassy soil. At present, the *in-situ* measurements for gassy soils are mainly the gassy soil distribution range detection. It is necessary to improve the accuracy of the *in-situ* parameters of gassy soils to improve the accuracy of research into constitutive models.

AUTHOR CONTRIBUTIONS

TL, XY, and YZ contributed to conception and design of the study. TL wrote the first draft of the manuscript. XY and YZ wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version".

FUNDING

The study is supported by the National Natural Science Foundation of China (No. U2006213) and the Fundamental Research Funds for the Central Universities (201962011).

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