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Review

Risk and impacts on the environment of free-phase biogas in quaternary deposits along the Coastal Region of Shanghai

Ye-Shuang Xu[a], Huai-Na Wu[a,*], Jack S. Shen[a,b,*], Ning Zhang[a]

[a] State Key Laboratory of Ocean Engineering and Collaborative Innovation Center for Advanced Ship and Deep Sea Exploration (CISSE), School of Naval Architecture, Ocean, and Civil Engineering, Shanghai Jiao Tong University, 800 Dong Chuan Road, Minhang District, Shanghai 200240, China

[b] Department of Civil and Construction Engineering, Swinburne University of Technology, Hawthorn, Victoria 3122, Australia

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ABSTRACT

Shallow organic free-phase biogas is distributed in the Quaternary deposit along the coastal region of Shanghai, particularly in the Yangtze River Estuary and Hangzhou Bay. This biogas exerts a significant effect on the environment because of the existence of gas reservoir pressure. Some offshore engineering works, *e.g.*, drainage pipelines, cross-river bridges, and tunnels, have been constructed in the gassy soils around Shanghai. Once the gas cap layer and reserve layer are disturbed during construction, biogas may be released, which will influence the characteristics of the surrounding soils, endanger the engineering safety, and create a harmful environment for the workforce on such projects. Exploration and construction technologies are adopted to control the effects of this hazardous biogas during underground construction. Pre-exhausting technology is frequently used to release the shallow free-phase gas to the ground through pre-exhausted borehole(s) before starting construction. Three case histories constructed in such gassy soils, e.g. Shanghai Sewerage Project, Hangzhou Metro Line No. 1, and Hangzhou Bay Bridge, are introduced to avoid failure. Since the characteristics of shallow gas in practical engineering operations differs from those encountered at smaller scales, field tests were undertaken before pre-exhausting to predict the gas-exhausting effect in these cases.

1. Introduction

Biogas has the characteristics of being found at a shallow depth and existing in low reserves. Shallow biogas is widespread and can be found worldwide in sediments of offshore areas (Fleischer et al., 2001). These include the California shelf (Richmond and Burdick, 1981), the Amazon delta (Figueiredo et al., 1996), the Gulf of Mexico (Anderson and Bryant, 1990), the Bay of Fundy in Canada (Fader, 1991), the Thames Estuary in U.K. (Taylor, 1992), the Ria Cosat in Spain (Acosta, 1984), the Italian central Adriatic Sea (Hovland and Curzi, 1989), the west coast of India (Karisiddaiah et al., 1993), the southern Korea Peninsula (Gorgas et al., 2003), Wellington Harbour in New Zealand (Lewis and Mildenhall, 1985). Shallow biogas is also widely distributed in the coastal regions of China, eg. East China Sea (Ye, 2012; Zhang et al., 2004, 2015), Yellow Sea (Ye, 2012; Zhang et al., 2004), South China Sea (Ye, 2012; Huang et al., 2012), Yangtze River Estuary (Zhang et al., 2008; Wang et al., 2009), and Pearl River Estuary (Chen et al., 2008; Zhou et al., 2009).

Shallow biogas has been widely reported because it is related to the global study of climate change as one of the important greenhouse gases (Hovland et al., 1993; Judd, 2003; McGinnis et al., 2006). The characteristics of gas reservoir pressure can be described by pressure coefficient, which means the proportionality coefficient between gas pressure and hydrostatic pressure at the depth of gas reservoir. Generally the pressure coefficient is 0.7–1.2 in China (Ren, 1999). Recently the problem of geohazards induced by shallow free-phase gas has been causing concern. With increased urbanization, more and more projects will need to be built on or through gassy soil (Wang et al., 2014; Wu et al., 2015c; Tan et al., 2016). The impact on the mechanical properties of soils, soil compression, and ground stability due to the existence of gas is related to the following factors, such as gas pressure, thickness of gas layer, soil permeability, and so on. Moreover, flammable shallow gas can easily leak during engineering construction and can become harmful to human health and engineering safety. Some researchers have studied the dangers to the exploration of offshore petroleum, the layout of pipelines, the construction of bridges, and the excavation of foundations in gassy soil (Rowe and Goveas, 2002; Tang et al., 2003; Lin et al., 2004, 2010; Du et al., 2014b; Chen et al., 2015; Tan et al., 2015a, 2015b; Ye et al., 2015).

Shanghai is surrounded by Jiangsu Province and Zhejiang Province

* Correspondence authors.
E-mail addresses: xuyeshuang@sjtu.edu.cn (Y.-S. Xu), wu-hn@sjtu.edu.cn (H.-N. Wu), sshen@swin.edu.au (J.S. Shen), sdyszn@sjtu.edu.cn (N. Zhang).

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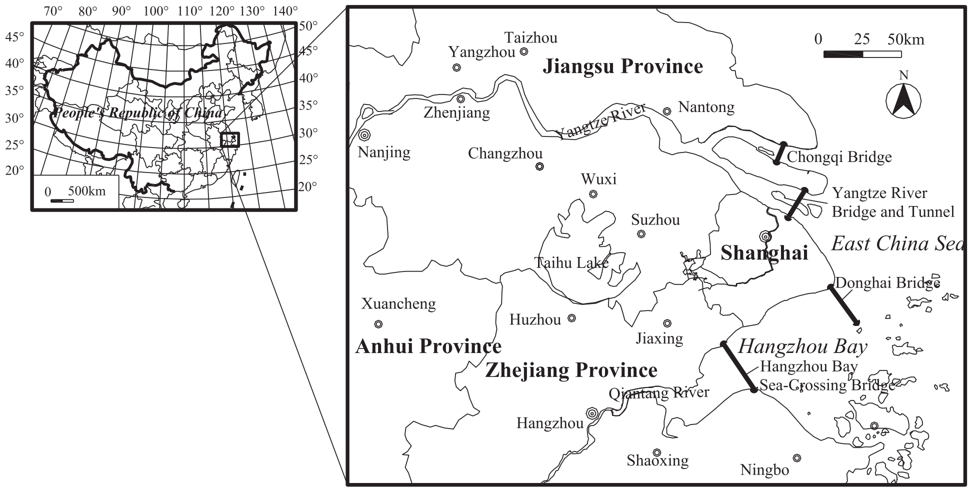

Fig. 1. Plan view of the location of Shanghai in China.

to the north and west, Hangzhou Bay in the south and the East China Sea in the east, as illustrated in Fig. 1. The quaternary sediment in Shanghai is a soft deltaic deposit with a depth of over 300 m (Shen and Xu, 2011; Xu et al., 2012a, 2012b; Shen et al., 2015; Tan and Wang, 2015a, 2015b). The quaternary deposits in Shanghai have a high water content with high compressibility (Wu et al., 2016), high sensitivity (Shen et al., 2013b; Wang et al., 2013b;), low strength (Shen et al., 2013c, 2013d), and creep behaviour (Yin et al., 2010, 2011, 2013a). There are many potential geohazards during construction and operation of underground structures around Shanghai, for example, quicksand and piping hazards (Xu et al., 2009b), land subsidence (Shen et al., 2013a, b; Xu et al., 2013, 2014, 2015, 2016), soil deformation (Tan et al., 2016; Wu et al., 2015d, 2015e, 2016), settlement of underground structures (Shen et al., 2010, 2014; Wu et al., 2015a, 2015b), tunnel leakage (Wu et al., 2014), and methane gas hazard (Preston et al., 2008; Xu et al., 2009a; Huang et al., 2015). Since the soft soil in Shanghai contains many geohazards, so the characteristics of Shanghai clay, which is similar to other marine clayss, such as Singapore clay (Bo et al., 2007, 2015; Arulrajah et al., 2009; Chu et al., 2009), Japanese Ariake clay (Du et al., 2008, 2014a; Shen et al., 2008), Bangkok clay (Horpibulsuk et al., 2007, 2010), have attracted more attention (Wu et al., 2015a, 2015d; Huang et al., 2015). Shallow biogas, widely distributed in the Quaternary deposit around Shanghai, especially in the coastal zones of the East China Sea, is another disaster-inducing factor, which should be studied (Xu et al., 2009a).

Several organic-rich silt and sand layers were formed in process of the transgression-regression in the Quaternary around Shanghai. Biogas produced in the silt layers after biochemical reaction. Free-phase biogas generally reserves in the soil as the type of gasbags through migration and accumulation and these gasbags reserves in the adjacent sand lens or at the top of sand layers (Cheng et al., 2014). The silt layer is not only gas produce layer but also cap layer. The pressure factor is 0.7–0.8 around Hangzhou Bay (Ren, 1999). Generally the buried depth of these gas reservoirs is less than 60 m with an gas reservoir pressure ranges from 120 to 460 kPa (Wang et al., 2010a). Some offshore engineering projects, for example, the Yangtze River Bridge and Tunnel and the Hangzhou Bay sea-crossing bridge, were constructed in the gassy soils which ordinarily would endanger engineering safety. Once the gas-capping layer, and reserve layer, are disturbed during construction, biogas may be released. So when these infrastructure projects were constructed in this gassy soil, many countermeasures needed to be adopted to ensure safety during construction (Preston et al., 2008; Xu et al., 2009a).

The objectives of this study are: (i) to give a general introduction on the natural distribution of shallow free-phase gas in the Quaternary sediment around Shanghai; (ii) to present the impact on the environment and potential geohazards due to shallow free-phase gas during construction and operation of underground structures and infrastructure; (iii) discuss the countermeasures needed to protect the workforce and the environment during underground construction.

2. Storage of free-phase biogas around Shanghai

2.1. Distribution of free-phase biogas around Shanghai

Shallow biogas is widely distributed around Shanghai, in both the terrestrial and marine areas. Fig. 2 shows the distribution of shallow gas in the coastal waters around Shanghai where it is mainly distributed in the Yangtze River Estuary and Hangzhou Bay. Fig. 3 shows the distribution of shallow gas in the terrestrial areas north of Shanghai. Shallow gas is mainly distributed to the north and south sides of the Yangtze River. According to the distribution of density of gas-seepage, the distribution of shallow gas is divided into three areas: a dense distribution area along the river, a uniform distribution area in the middle, and an isolated distribution area in the outer area. There are three stable soil layers with shallow gas in Shanghai (Tang et al., 2007). The buried depth of the first layer is 12–25 m, which has the most influence on underground structures. The buried depth of the second layer is greater than 30 m and the third layer is greater than 50 m. The latter two layers have little influence on underground structures. Fig. 4 shows the distribution of shallow gas around Hangzhou Bay. Since 1991, six gas fields have been discovered in northern Zhejiang around Hangzhou Bay, which include those at

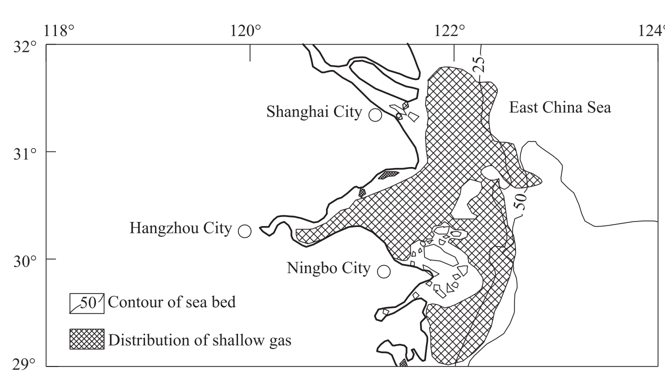

Fig. 2. Distribution of shallow gas in the coastal waters around Shanghai (modified from Ye, 2012