Applied Ocean Research 58 (2016) 135–145

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Evaluation of storm wave-induced silty seabed instability and geo-hazards: A case study in the Yellow River delta

Hu Wang[a,b], Hong-jun Liu[b,c,*]

[a] School of Marine Science and Technology, Tianjin University, Tianjin 300072, China
[b] Key Laboratory of Marine Environment and Ecology, Ministry of Education, Qingdao 266100, China
[c] College of Environmental Science and Engineering, Ocean University of China, Qingdao 266100, China

ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form 21 March 2016
Accepted 21 March 2016
Available online 27 April 2016

Keyword:
Soil mechanics
Storm wave
Silt
Seabed instability
Geo-hazards
Yellow River delta

ABSTRACT

Models based on the theoretical framework of soil mechanics are presented to evaluate storm wave-induced silty seabed instability and geo-hazards through a case study in the Yellow River delta. First, the transient and residual mechanisms of wave-induced pore pressure are analyzed. Three typical models (i.e., elastic model, pore pressure development mode and elasto-plastic model) are proposed to calculate wave-induced stresses in the seabed. Next, mechanisms and calculation methods of wave-induced seabed instability modes such as scour, liquefaction, seepage instability and shear slide are proposed. Typical results of storm wave-induced excess pore pressure and seabed instability are given and relevant discussions are made. At last, the formation mechanism of geo-hazards in the Yellow River delta is analyzed based on the proposed mechanism and calculated results. Results and analysis indicate that both transient and residual mechanisms are important to storm wave-induced response of silty seabed and hence the elasto-plastic model is more appropriate. Complete liquefaction does not happen, while other types of instability occur mostly within 2–6 m under the seabed surface. Wave-induced scour, seepage instability and shear slide are all possible instability modes under the 1-year storm waves, and scour is predominant for the 50-year storm waves. The formation mechanism of geo-hazards such as shallow slide and storm wave reactivation, pockmarks, silt flow and gully, disturbed stratum and hard crust in the Yellow River are well explained based on the proposed mechanisms and calculated results of storm wave-induced silty seabed instability.

1. Introduction

Wave-induced seabed instability such as scour, liquefaction and shear slide may cause large amount of sediment mass transport, strongly affects the sedimentary dynamic process in coastal areas, and threaten the security of offshore structures [1,2]. Submarine geo-hazards and hazardous landforms such as landslide, silt flow, pockmarks and disturbed layers [3–6] are just the processes and results of seabed instabilities. The failure of coastal structures may also be caused by the instability of seabed foundations [7,8]. Thus, the evaluation of wave-induced seabed instability is important for both geologic and engineering problems.

The seabed covered with seawater is a typical saturated soil consisting of soil particles and pore water, which is suitable to be analyzed by the principle of effective stress in soil mechanics. Thus, the wave-induced pore pressure, especially the excess pore pressure (EPP), is critical for analyzing seabed instability. The wave-induced EPP is divided into the transient and the residual mechanisms, and the models to calculate wave-induced EPP include the elastic model (EM), the pore pressure development mode (PPDM) and the elasto-plastic model (EPM) [1,2,9]. Complete liquefaction occurs with an EPP large enough to reduce the effective stress to zero [7]. Shear failure can be promoted as the effective shear strength of seabed soil is reduced by EPP [10]. Scour and transport of seabed soil may also be enhanced by the EPP-induced upward seepage force [11]. The wave-induced scour, in the field of sediment dynamics, focuses on the incipient motion and re-suspension of sediments near the seabed surface [12,13]. On the other hand, the wave induced liquefaction and shear failure emphasize more on the internal response of seabed [10,14], which are within the scope of soil mechanics. Most existing studies focus on individual pore pressure mechanism, or on individual instability mode, however, systematic comparison of pore pressure mechanisms and seabed instability modes through a case study is rarely reported. Moreover, most previous works of wave-induced

* Corresponding author at: Ocean University of China, No. 238, Songling Road, Laoshan District, Qingdao 266100, China. Fax: +86 532 66782571.
E-mail address: hongjun@ouc.edu.cn (H.-j. Liu).

http://dx.doi.org/10.1016/j.apor.2016.03.013
0141-1187/

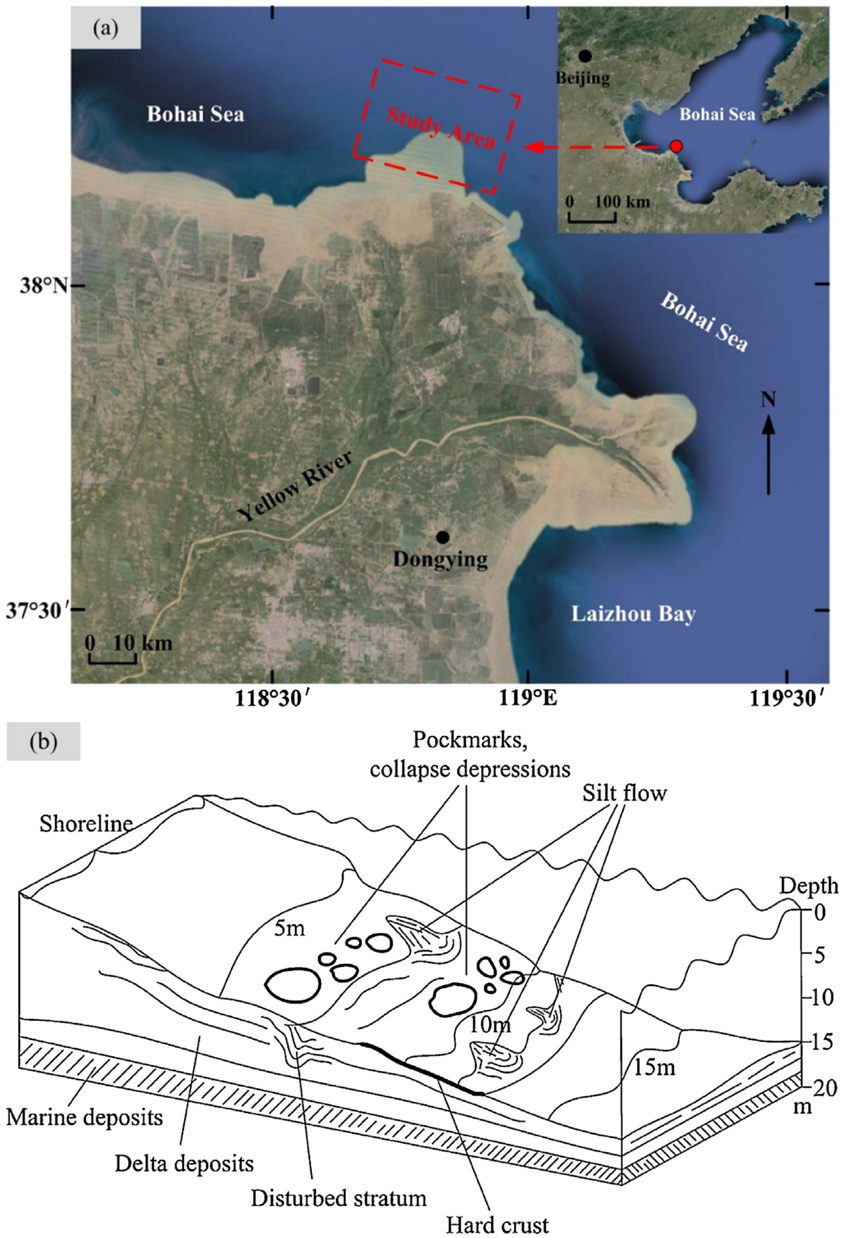

Fig. 1. (a) Location of study area; (b) schematic representation of seabed instability features (Modified from Ref. [3]). (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)

seabed instability are concerned with sand or clay, while the systematic study of wave-induced instability of silty seabed is relatively fewer. Silt is a kind of soil in between sand and clay, with relatively special physical properties and mechanical behaviors, defined as the amount of particles with sizes greater than 0.075 mm below 15% of the total weight and the plasticity index less than 10 [15]. Silt is widely distributed in coastal areas, and the response of silty seabed due to wave loads differs from that of sand or clay seabed [16–18].

The modern Yellow River delta, which is formed by the rapidly-deposited sediments since 1855, is mainly composed of silt [19,20]. The Yellow River delta, which is located in the north of Shandong Province (Fig. 1a), is abundant of wetlands, oil and gas, and offshore wind power. The silty seabed in the Yellow River delta has been revealed with special properties such as high water content, high compressibility, thixotropy, liquefaction and inhomogeneous consolidation [19–23]. Furthermore, submarine geo-hazards and hazardous landforms such as shallow landslide, pockmark, silt flow, disturbed stratum and hard crust are widely developed there [24–29], a typical profile of these geo-hazards is shown in Fig. 1b. The seabed where geo-hazards developed has a short history (since 1855), a flat slope (less than 0.4°) and a shallow water depth (4–15 m, particularly 8–12 m). On-site investigations show no evidence of hydrate decomposition or natural gas leakage, and hardly reveal any fault activities since 1855. However, the Yellow River delta suffers from frequent storm surges [30] and the seabed with water depth of 8–12 m can certainly be affected by storm waves, which are believed to be important external loads causing seabed instability and geo-hazards there [3–6,24,27–29]. Therefore, the Yellow River delta, with storm wave and silty seabed as the external and internal factors respectively, and with geo-hazards as typical seabed instability phenomena, is an ideal background to study the problem of storm wave-induced silty seabed instability. The Chengdao area (red box in Fig. 1a), where typical geo-hazards develop