Marine Geology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Geology

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

Experimental characterization of storm liquefaction deposits sequences

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ARTICLE INFO

Article history:
Received 3 June 2016
Received in revised form 22 October 2016
Accepted 28 October 2016
Available online xxxx

Keywords:
Storm liquefaction deposits
Silt sediment
Liquefaction
Re-stratification
Seabed

ABSTRACT

The collapse depressions in waters of the Yellow River delta are the result of silty sediment liquefaction produced by storm waves. The internal characteristics and formation process of the strata in collapse depressions were studied with consideration of re-stratification caused by sediment liquefaction in coastal areas. In wave flume experiments, silty sediment collected from the Yellow River Delta was shaped into a model seabed. The original uniform sediment stratum was re-stratified and formed into a new structure characteristic of liquefied sediments fluctuating with wave movement. Wave action appears to cause silty sediment liquefaction. Liquefied sediment moved elliptically with wave action, leading to granularity-based deposit differentiation in situ to re-form sedimentary strata. This is probably the cause of collapse depressions in the Yellow River delta. Based on these results and comparison with the stratum under the collapse depressions in the Yellow River delta, we propose that liquefaction deposits are responsible for the bottom to top sequence of graded bedding, convolute bedding, and parallel bedding.

1. Introduction

Turbidite deposition in deep aquatic basins can lead to the formation of Bouma, Lowe, or Stow and Piper sequences (Kuenen and Migliorini, 1950; Bouma et al., 1962; Lowe, 1982; Stow and Piper, 1984). Storm action in shallow marine basins can result from redeposition of storm deposit turbidites (Aigner, 1979). Storm deposits have typical sedimentary characteristics which include hummocky-cross bedding (Harms, 1975) and decreasing grain size in deposits from the bottom to the top (Aigner, 1982; Monaco, 1992). Research on storm deposits has focused on on-site deposition power, sediment transport, and deposition processes (Li et al., 1997; Williams and Rose, 2001; Pepper and Stone, 2004; Guillén et al., 2006; Palinkas et al., 2010; Aagaard et al., 2012). The characteristics of sediments formed under storm conditions often correspond to the specific data obtained (Roberts et al., 2013; Palinkas et al., 2014). Under the actions of tidal waves, the sedimentary stratum on tidal flats consists of flow rolls and water-escape structures (Greb and Archer, 2007; Fan et al., 2014)

The major issue related to storm sediment in shallow water is the erosion and transportation of surface sediments on the seafloor made by storm induced currents, then sediments are re-sorted and deposited between the normal wave base and storm wave base (or in the lower part of the storm wave base). Sediments are transported by flow from the source region of erosion to the sediment deposition site and, during this process, the stratification characteristics (such as hummocky-cross bedding)and graded structure of storm sediment were formed. If storm waves in shallow water can liquefy seabed sediment, then how does the liquefied region vary, and what are the characteristics of the resulting strata (Fig. 1)?

Storm waves can cause liquefaction of the seabed sediment resulting in cyclic loading. Cyclic loading from waves can lead to the liquefaction of seabed sand (Ishihara and Yamazaki, 1984). The process of coastal zone sediment liquefaction has been studied with pore pressure record probes (Zen and Yamazaki, 1990, 1991; Obermeier et al., 2005). Dynamic triaxial testing in combination with analysis of seabed sediment liquefaction demonstrated that the maximum liquefaction depth for sand in 8 m of water during a storm event was 6.1 m(Chang et al., 2004). Significant collapse was found in the silty sediments of Yellow River delta waters with slopes <1 degree (Prior et al., 1986). The collapsing of the sedimentary dynamics equipment buried in the Yellow River delta seabed under the storm wave action (Prior et al., 1989) may be caused by sediment liquefaction. In liquefaction studies of the seabed sediment in the Yellow River delta, the liquefaction depth, in 8 m of water, could reach 4.1 m, and collapses occurred in the liquefied seabed (Sun et al., 2008; Xu et al., 2008; Xu et al., 2009). We report a simulation of the strata reconstruction process of liquefied silty sand under wave action using an indoor flume experiment. We develop the concept of storm liquefied sediment and provide the structure, construction, and engineering geology features of storm liquefied sediment strata.

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http://dx.doi.org/10.1016/j.margeo.2016.10.015
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Please cite this article as: Xu, G., et al., Experimental characterization of storm liquefaction deposits sequences, Marine Geology (2016), http://dx.doi.org/10.1016/j.margeo.2016.10.015

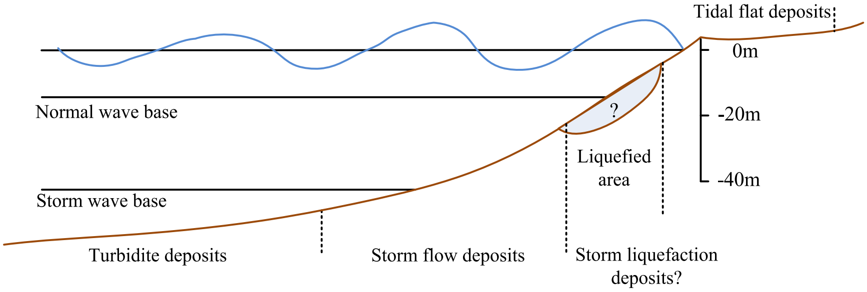

Fig. 1. The positional relationship between turbidite deposits, storm flow deposits and storm liquefaction deposits (modified by Deng et al., 1997).

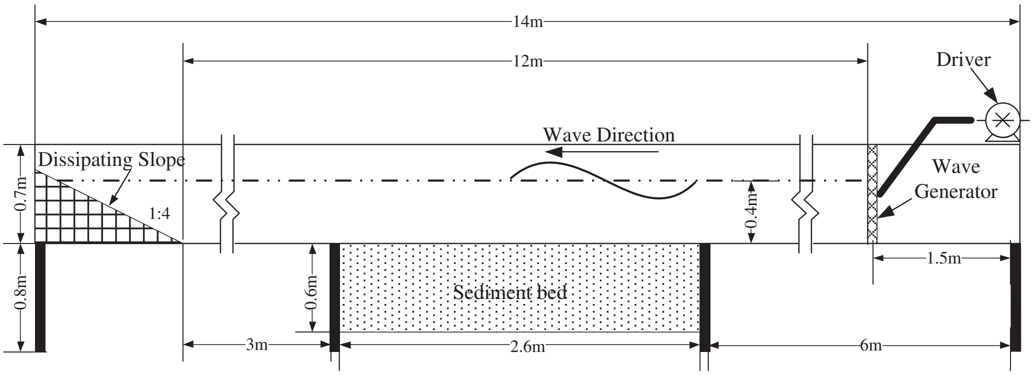

Fig. 2. Experimental flume.

2. Methodology

Liquefied seabed sediment was re-stratified due to fluctuant sorting, in situ, under wave action. We conducted most wave flume experiments in duplicate and obtained results that were consistent and highly reproducible. This report summarizes experiments performed on May 12, 2015.

2.1. Instruments and equipment

The major equipment used was a wave flume with a middle section that contained sediment. Dimensions are shown in Fig. 2. Regular waves were generated by a wave generator installed at one end of the flume, while a wave dissipating slope was placed at the opposite end. Wave heights and wave periods were measured by a WG-55 wave- height instrument (RBR Ltd., Canada). Sediment samples, collected using a piston-sampler, were measured for density and water content. Sediment strength was tested using a WG-VI platts penetrometer (Jianke Instruments Ltd., China). Sediment grain size distribution was measured with an MS 3000 laser particle sizer (Malvern Instruments Ltd., UK). The inner structures of columnar samples were studied by a Brilliance 16 CT device (Philips Ltd., Netherlands).

2.2. Preparation of test bed

Test-specific sediments were sampled from the tidal flats where sediments were formed during the rapid construction of the Yellow River delta. As the influences of later ocean dynamic action on transformation and sorting were weak, the sediments contained complete sediment components from the Yellow River. Thus, the samples may represent the delta sediments formed in short time and are suitable for studying its subsequent reconstruction under dynamic ocean action. The sediments were confirmed as sandy silt by grain size analysis (Fig. 3). Sediment samples were air-dried, crushed, and then mixed with water in a mixer to form a uniform slurry containing 33% water. The slurry was then transferred slowly along a sloping panel into the sediment section of the flume to form a slurry bed of 2.6 m (L) × 0.5 m (W) × 0.6 m (H). A sediment sampler of 0.4 m (L) × 0.4 m (W) was placed at the bottom of the flume at 1.05–1.45 m before the bed (the left and right insides of the flume were defined as the Left zero (0) point and the Right 2.6 point, respectively, Figs. 2 and 5). At a point where the sampler top was 0.45 m away from the bottom (Fig. 5), 20 g of gravel markers and 100 g of sand markers with grain sizes from 0.25 to 0.5 mm were sprinkled evenly in an area 0.2 m (L) × 0.2 m (W) to investigate the sinking behavior of coarse deposits in the sediments. The layout and the position are illustrated in Figs. 4 and 5. After the test bed was completed, water was added to the flume to a depth of 0.40 m. After the test bed had settled in the flume for 10 d, the test bed thickness was reduced to 0.55 m.

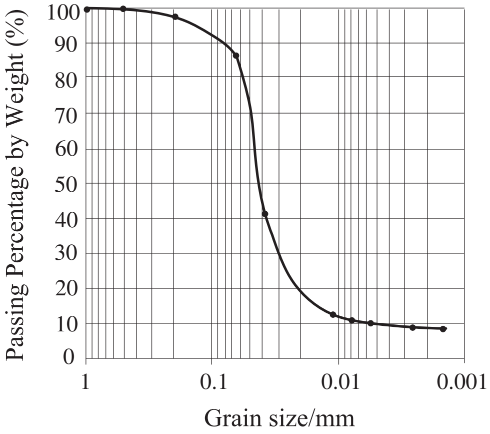

Fig. 3. Grain diameter accumulation curve of sample.

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