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E-mail: hyxbe@263.net

The difference analysis of physical-mechanical properties of sediments in the central South Yellow Sea and Zhe-Min coastal area in China

XU Yuanqin[1, 2], LI Ping[1, 2], LI Peiying[1, 2], DU Jun[2, 3*], LIU Lejun[2, 4], GAO Wei[1, 2], LIU Jie[1, 2]

[1] Key Laboratory of Marine Sedimentology and Environmental Geology, The First Institute of Oceanography, State Oceanic Administration, Qingdao 266061, China

[2] Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266061, China

[3] Research Center for Islands and Coastal Zones, The First Institute of Oceanography, State Oceanic Administration, Qingdao 266061, China

[4] Marine Engineering Environment and Geomatic Center, The First Institute of Oceanography, State Oceanic Administration, Qingdao 266061, China

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Abstract

The difference analysis of physical-mechanical properties of muddy sediments is made in the central South Yellow Sea and the Zhe-Min (Zhejiang Province to Fujian Province of China) coastal area. The results show that sediments in the two regions are both dominated by mud. There are perfect negative power function correlations between the water content and the density, the compression coefficient and the compression modulus; a good positive power function correlation between the liquid limit and the plastic limit, a perfect positive linear correlation between the water content and the void ratio, and a perfect polynomial function correlation between the miniature vane shear strength and the pocket penetration resistance. In general, compared with sediments in the Zhe-Min coastal area, sediments in the central South Yellow Sea possess high water content, high void ratio, low density, high plasticity, high compressibility, low shear strength. The causes of the differences between physical-mechanical properties of sediments are analyzed from the topographic features, material sources, hydrodynamic conditions, deposition rate, and material composition. Compared with the Zhe-Min coastal area, the central South Yellow Sea is far from the Mainland and low-lying; has poor hydrodynamic condition; the materials diffused to the area are less and dominated by fine clay, have the high content of smectite and organic matters. These factors lead to sediments of the central South Yellow Sea has the higher water content, the higher plasticity, the lower density, and the lower strength than sediments in the Zhe-Min coastal area.

Key words: sediment, Zhe-Min coastal area, central South Yellow Sea, physical-mechanical properties, difference analysis

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1 Introduction

Physical-mechanical properties refer to the numerical indexes of geotechnical properties of soil, which directly reflect the geotechnical properties of soil. The study on physical-mechanical properties of submarine soil is the key technology to decrease the risks in an ocean development, prevent various geological hazards, and avoids casualties and assets losses (Zheng et al., 2004).

With the increasing number of offshore wind plants construction, the Zhe-Min coastal area becomes the key region of an offshore development. The central South Yellow Sea is the prospective region of oil and gas resources, and also the key region of the future ocean oil and gas engineering construction. To develop the resources, the predecessors have made some researches on the geotechnical properties of sediments in the mud area of the Zhe-Min coastal area and the central South Yellow Sea (Xu et al., 2011; Li et al., 2012; Keller and Ye, 1985; Lee et al., 1987; Liu et al., 2013). However, the two typical mud areas fall into different sea areas, so there are certain differences in the material sources, hydrodynamic conditions and other factors of the sediments. As a result, there are differences between the physical-mechanical properties of sediments in the two regions. This paper selects gravity cores collected from these two areas as research objects, analyzes the differences of physical-mechanical properties of sediments, and make causes analysis from topographic features, material sources, hydrodynamic conditions, deposition rate, and material composition.

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*Corresponding author, E-mail: dujun@fio.org.cn

2 Materials and methods

In the study, 11 gravity cores collected from the Zhe-Min coastal area in December 2007 and 105 gravity cores collected from the central South Yellow Sea in June 2008 and July 2009 are used as research objects; the length of gravity samples vary from 0.9 to 3.0 m, with an average of 2.1 m. Figure 1 is the study area and the sampling locations. In the Geotechnical Laboratory of FIO (The First Institute of Oceanography), miniature vane shear tests, pocket penetrometer tests, water content tests, density tests, Atterberg limts tests, oedometer tests, shear tests (UU: undrained and unconsolidated) were conducted on each subsample(length: 25–30 cm). The water content was determined by an oven drying method; the density was determined by a cutting ring method; the miniature vane shear tests were conducted by a vane-shear apparatus (product model: SGL); the pocket penetrometer tests were conducted by an electronic digital penetrometer (product model: WG II); the atterberg limts tests were conducted by a digital liquid-plastic tester (product model: GYS-2); the oedometer tests were conducted by a low pressure consolidation apparatus, the pressure levels were 50 kPa, 100 kPa, 200 kPa and 400 kPa respectively; the shear tests (UU) were conducted by triaxial shear apparatus, the pressure levels were 100 kPa, 200 kPa and 300 kPa respectively. This paper uses *Test Methods of Soil* (SL237–1999) for the test standard, and refers to *Specifications for Oceanographic Survey–Part 11. Marine Engineering Geological Investigation* (the standardization law of the People's Republic of China, GB/T 12763.11-2007) for classification and designation of sediments (Table 1).

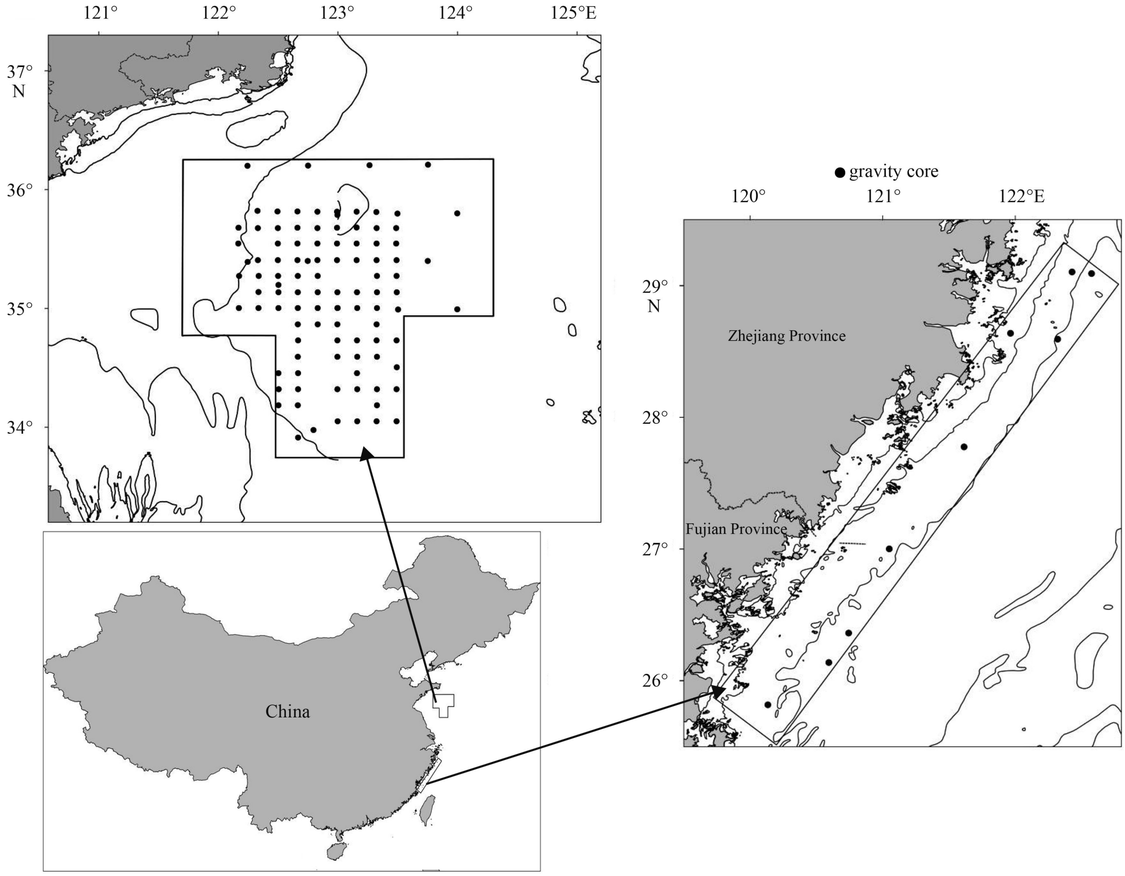

Fig. 1. The map of study area and sampling locations.

3 Differences of physical–mechanical properties

The physical properties of soil are the proportional correlation between quality and volume of three phases (gas, liquid, solid phases) matter in the soil, as well as the properties manifested by the interaction of solid and liquid phases. The former refers to the basic physical properties of soil, and mainly studies the degree of denseness and dry-wed conditions of soil; the latter reflects the interaction of solid and liquid phases, which is called water-physical properties of soil. The mechanical properties of soil refer to a series of properties presented by the soil under an external force (Tang et al., 1999). The basic physical properties include water content, density, void ratio; the water-physical properties include liquid limit, plastic limit, plasticity index and liquidity index; the mechanical properties include compression coefficient, compression modulus, cohesion, internal friction angle, miniature vane shear strength and pocket penetration resistance.

According to the analysis of the gravity cores (Table 2), it has been discovered that sediments in the central South Yellow Sea are dominated by mud, which accounts for appropriately 80% of analytical samples, followed by muddy clay, which accounts for appropriately 17% of analytical samples. The sediments of the Zhe-Min coastal area are also dominated by mud, which accounts for appropriately 65% of analytical samples, followed by muddy clay, which accounts for appropriately 25% of analytical samples. Thus it can be concluded that sediments in the central South Yellow Sea have the higher content of muddy soil (including mud and muddy clay) than sediments in the Zhe-Min coastal area.

Table 1. The classification of sandy soil, silty soil, and cohesive soil

Name of soil		Particle component		i_p/%	c_w/%	r_v
		d/mm	c_p/%			
Sandy soil	coarse sand	>0.5	>50			
	medium sand	>0.25	>50			
	fine sand	>0.075	>85			
	silty sand	>0.075	>50			
Silty soil	sandy silt	>0.075 <0.005	<50 <10	$3<i_p\leqslant 7$		
	clayey silt	>0.075 <0.005	<50 >10	$7<i_p\leqslant 10$		
Cohesive soil	silty clay			$10<i_p\leqslant 17$		
	clay			>17		
	muddy clay			>10	$>l_l$	$1.0\leqslant r_v<1.5$
	mud			>10	$>l_l$	$\geqslant 1.5$

Note: d is the grain size, c_p the particle content, i_p the plasticity index, l_l the liquid limit, c_w the water content, and r_v the void ratio.

Table 2. Classification and number of sediment

Area	Mud	Muddy clay	Clay	Silty clay	Clayey silt
Central South Yellow Sea	482	103	3	13	2
Zhe-Min coastal area	59	23	2	4	3

3.1 *Differences of basic physical properties*

3.1.1 *Water content and void ratio*

There are perfect positive linear correlations between the water content and the void ratio of sediments in the Zhe-Min coastal area and the central South Yellow Sea, and the correlation curves are very close to each other (Fig. 2). However, the variation range for the void ratio of sediment in the Zhe-Min coastal area is small, which is between 0.62 and 2.61 with an average value of 1.57; accordingly, the variation range of the water content is also small, which is between 6.15% and 22.69% with an average value of 57.70%. The variation range of the void ratio of sediment in the central South Yellow Sea is lage, which is between 0.77 and 3.46 with an average value of 2.20; accordingly, the variation range of the water content is also lager, which is between 27.03% and 130.28%, with an average value of 82.70%.

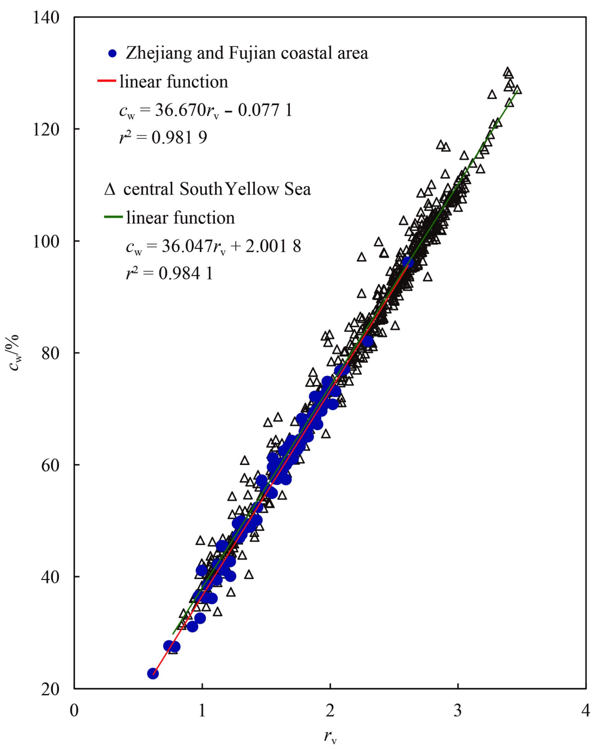

Fig. 2. Relationships between the water content and the void ratio.

3.1.2 *Water content and density*

An analysis shows that a perfect negative power function correlations exist between the water content and density of sediments in the Zhe-Min coastal area and the central South Yellow Sea (Fig. 3). In addition, the change range of the density for sediments in the Zhe-Min coastal area is small, which is between 1.50 and 2.05 g/cm^3 with an average value of 1.69 g/cm^3. The change range of the density for sediments in the central South Yellow Sea is larger, which is between 1.40 and 2.01 g/cm^3 with an average value of 1.58 g/cm^3.

3.2 *Difference of water-physical properties*

3.2.1 *Liquid limit and plastic limit*

There are good positive power function correlations between the liquid limit and the plastic limit of sediments in the two regions (Fig. 4). The variation range for the plastic limit of sediment in the central South Yellow Sea is large, which is between 13.96% and 38.90% with an average value of 26.14%; the variation range for the liquid limit is also large, which is between 23.30% and 73.40% with an average value of 50.14%. The variation range for the plastic limit and the liquid limit of sediments in the Zhe-Min coastal area is small, its plastic limit is between 13.00% and 32.60% with an average value of 23.77%; its liquid limit is between 22.80% and 54.90% with an average value of 42.12%.

3.2.2 *Plasticity chart*

Plasticity chart is a good tool for the classification of sediments (Holtz and Kovacs, 1981). The concept of the plasticity chart is proposed by American Professor Casagrande A, and has become the basis of a fine-grained soil classification in many countries (Li, 1979a). The Casagrande's plasticity chart takes the plasticity index as y coordinate and the liquid limit as x coordinate, with two straight lines [A line: i_p=0.73 (l_l–20); B line: l_l=50%], the plasticity chart is divided into four areas, sorted out six soil

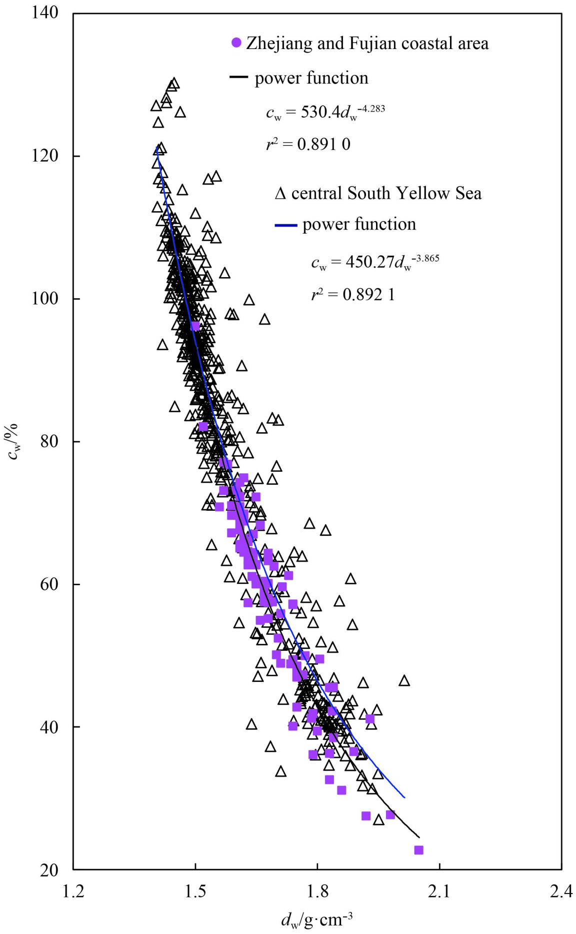

Fig. 3. Relationships between the water content and the density. d_w is the density.

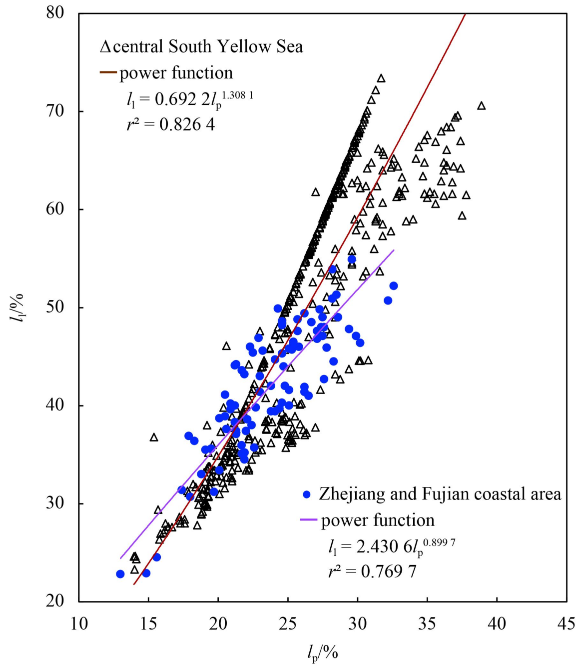

Fig. 4. The correlation diagram of the liquid limit and the plastic limit. l_l is the liquid limit and l_p the plasticity limit.

categories. In consideration of the effect on the fine-grained soil properties from the organic content, plasticity indexes, liquid limit of soil, etc., Casagrande's plasticity chart can comprehensively reflect the classification principles of fine-grained soil. The disadvantage of simply considering the particle sizes or plasticity indexes can be avoided through classification with the Casagrande's plasticity chart (Li, 1979b). Since the liquid limit in Casagrande's plasticity chart is measured by the Casagrande's liquid limit device which is different with the result determined by a common cone penetrometer, according to the correlation of results determined by the two devices, A line and B line in the Casagrande's plasticity chart shall be converted and modified (Tang, 1981). For the liquid limit measured through a fall cone liquid limit device with 76 g cone, 30° cone angle and 10 mm embedded depth, A line and B line are modified to A line: i_p=0.63 (l_l–20), B line: l_l=40%.

From Fig. 5, we can see that the sediments in the two regions mostly belong to the CH with some CL, the result suggests that most of sediments are clay-dominant. Compared with sediment in the Zhe-Min coastal area, sediment in the central South Yellow Sea possesses higher liquid limit and plasticity.

3.3 *Difference of mechanical properties*

3.3.1 *Compression property*

Figure 6 shows that there exist negative power function correlations between the compressions coefficient and the compression modulus of sediments in the two regions, and both correlation coefficients are high. However, the correlation curve for the compression coefficient and compression modulus of sediments in the Zhe-Min coastal area is low, which means the compression coefficient of sediments in this area is smaller under same compression modulus. Figure 6 also shows that the variation range for the compression coefficient of sediments in the Zhe-Min coastal area is small, which is mainly between 0.37 and 2.48 MPa^{-1} with an average value of 1.29 MPa^{-1}, and is mainly composed of medium-high compressibility soil; the variation range for the compression coefficient of sediments in the central South Yellow Sea is large, which is mainly between 0.27 and 7.81 MPa^{-1} with an average value of 1.88 MPa^{-1}, and is largely composed of high compressibility soil.

3.3.2 *Shear strength*

Figure 7 shows that the correlations between the cohesion (p_c) and the internal friction angle (φ) of sediments in the two regions are not obvious. However, the overall trend is that the internal friction angle increases while the cohesion decreases. The variation range for the internal friction angle of sediments in the central South Yellow Sea is large, which is between 0.02° and 6.75° with an average value of 2.12°; the cohesion is small which is between 0.02 and 10.00 kPa with an average value of 4.05 kPa. The variation range for the internal friction angle of sediments in the Zhe-Min coastal area is small, which is between 0.29° and 3.76° with an average value of 2.06°; the cohesion is large which is between 0.28 and 11.60 kPa with an average value of 4.59 kPa.

3.3.3 *Miniature vane shear strength and pocket penetration resistance*

There exist perfect polynomial function correlations between the miniature vane shear strength (S_s) and the pocket penetration resistance (R_p) (Fig. 8). The variation range for the pocket penetration resistance of sediments in the central South Yellow Sea is between 0.10 and 6.43 N with an average value of 1.64 N;

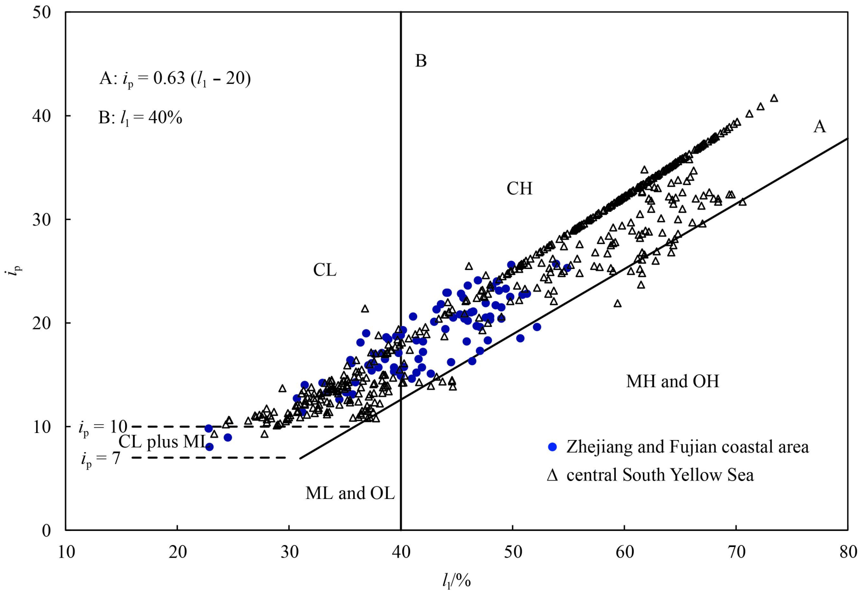

Fig. 5. Plasticity chart. CH is clay of high plasticity, CL clay of low plasticity, MH silt of high plasticity, ML silt of low plasticity, OL organic clay, and OH organic silt.

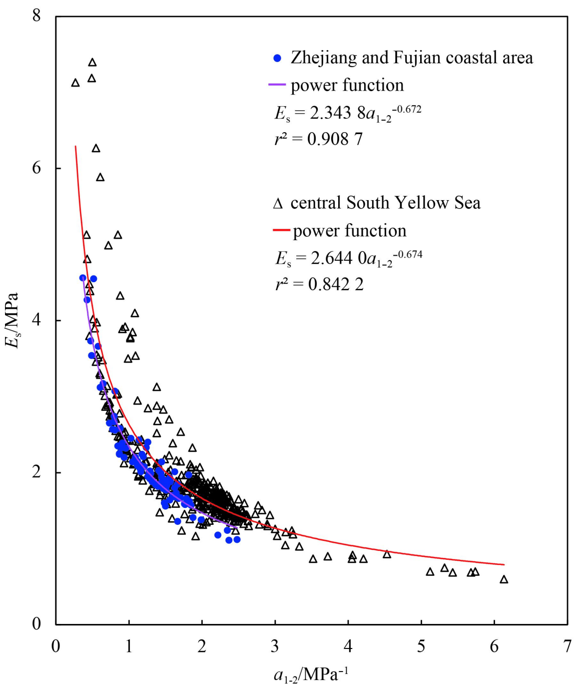

Fig. 6. The relationship between the compression coefficient and the compression modulus. E_s is the compression modulus and $a_{1\text{-}2}$ the compression coefficient.

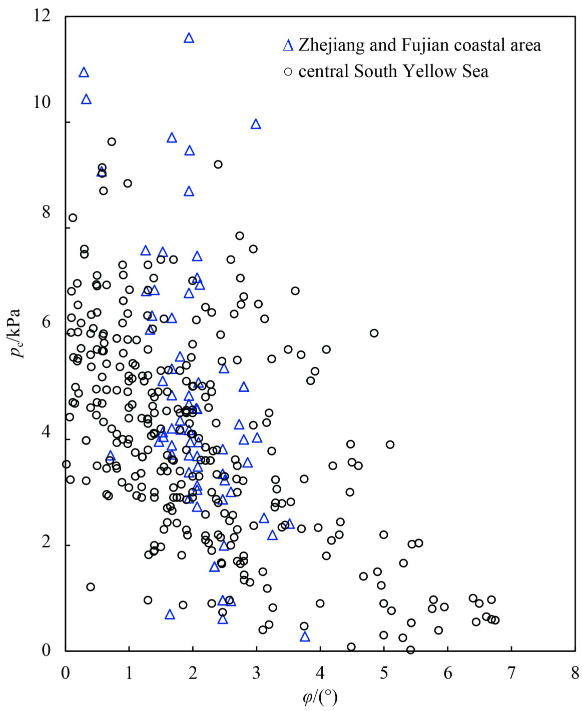

Fig. 7. The scatter plot between the cohesion and the internal friction angle.

the variation range for the miniature vane shear strength is between 0.09 and 14.12 kPa with an average value of 4.74 kPa. The variation range for the pocket penetration resistance of sediments in the Zhe-Min coastal area is between 0.05 and 6.28 N with an average value of 2.26 N; the variation range for the miniature vane shear strength is between 2.35 and 12.75 kPa with an average value of 7.20 kPa.

3.4 *Conclusions*

Through the difference analysis of the physical-mechanical properties of sediments in the two regions, it has been found that there are the perfect negative power function correlations between the water content and the density, the compression coefficient and the compression modulus; the good positive power function correlation between the liquid limit and the plastic limit; the perfect positive linear correlation between the water content and the void ratio, and the perfect polynomial function correlation between the miniature vane shear strength and the pocket penetration resistance. The correlation between the cohesion and the internal friction angle of sediments in the

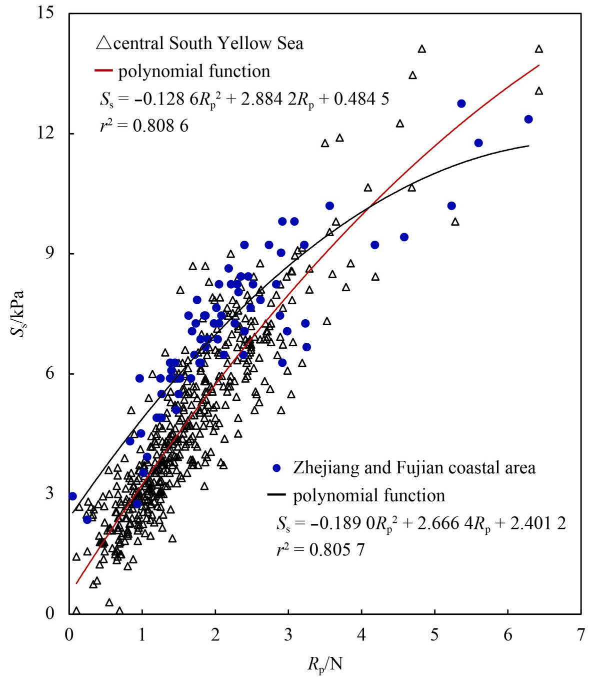

Fig. 8. Relationships between the miniature vane shear strength and the pocket penetration resistance.

two regions is not obvious.

In general, compared with sediments in the Zhe-Min coastal area, sediments in the central South Yellow Sea possess higher water content, higher voider ratio, lower density, higher plasticity, higher compressibility, lower shear strength and lower penetration resistance.

4 Cause analysis on the difference of physical–mechanical properties

The sedimentary environment, hydrodynamic conditions and other factors which provide certain inspiration and help to analyze the properties of sediments should be well understood while analyzing the geotechnical properties (Wu et al., 2004). In the paper, the causes of the difference between the physical-mechanical properties of sediments in the two regions are analyzed from the topographic features, the material sources, the hydrodynamic conditions, the deposition rate, and the material composition.

4.1 *Submarine topographic feature*

4.1.1 *Topographic feature of the central South Yellow Sea*

The central South Yellow Sea is a flat plain with deep water, and the submarine topography inclines from the east and the west to the middle, so it is the flattest and low-lying region of the South Yellow Sea (Lan and Shen, 2000). This region is far from China’s Mainland with an open water body, the exchange between the water body and the open sea is unobstructed, materials that can be diffused here through a long distance transport are dominated by clay particles, so sediments in this region are mainly composed of mud with high water content.

4.1.2 *Topographic feature of the Zhe-Min coastal area*

The submarine topography in the Zhe-Min coastal area is characterized by a platform, which inclines from China’s Mainland to sea, and the exchange between the water body and the open sea is unobstructed. The materials that can be diffused here through the long distance transport by the Changjiang River are dominated by clay particles. However, there are many coastal rivers, islands and it is relatively close to China’s Mainland, the clay content in sediments is lower than sediments in the central South Yellow Sea, so the sediments in the Zhe-Min coastal area have a relative low water content.

4.2 *Material source*

4.2.1 *Material source of sediments in the central South Yellow Sea*

As to how the continental materials carried by the Huanghe River and the Changjiang River as well as the terrigenous materials from the Korean Peninsula affect the sedimentation of the South Yellow Sea, the conclusion that the three sources of materials have different impact on different regions has been made on the basis of a lot of researches (Lan and Shen, 2000; Qin et al., 1989; Lan et al., 2007, 2009). In this paper, it is considered that the central South Yellow Sea is mainly composed of materials originating from the modern and the old Huanghe River, and the sediments inherit the characteristics of a Huanghe River source. Because of the modern Huanghe River material has experienced a long distance transportation and the old Huanghe River material has experienced a resuspension transportation, the materials deposit in the central South Yellow Sea are dominated by fine grains and have a high smectite content, so the sediments are generally characterized by high water content, high plasticity, high compressibility, etc.

4.2.2 *Material source of sediments in the Zhe-Min coastal area*

In the Zhe-Min coastal area about 32% of materials carried by the Changjiang River to sea have deposited since a high sea level (7 000 a BP) (Liu et al., 2006, 2007). The research on element geochemistry and clay mineral shows that in recent 2 000 a, about 83%–85% sediments in the Zhe-Min coastal area originates from the Changjiang River, and the remaining 15%–17% materials mainly originate from coastal streams (Xiao et al., 2005). The land streams in the Zhe-Min coastal area lie in South China where features obvious subtropical and tropical climate. With a high temperature, plentiful rain, damp and hot weather, the chemical weathering is strong (Niu et al., 2008), dissolution and hydrolysis will occur on rocks and make them become fine materials. Therefore, the sediment injected into the Zhe-Min coastal area shows a high clay content, which will significantly affect the capillary action, water permeability and strength of submarine soil (Zheng et al., 2004).

4.3 *Hydrodynamic condition*

4.3.1 *Hydrodynamic condition of the central South Yellow Sea*

The control effect of hydrodynamics on a sediment distribution in the South Yellow Sea is mainly characterized by the YSWC, the YSCC and the Yellow Sea circulation (Fig. 9). The Yellow Sea Warm Current interacts with the Yellow Sea coastal current during transportation to generate a series of vortexes (Mao and Hu, 1986). The vortex on the bottom of the central South Yellow Sea is the famous “Yellow Sea Cold Water Mass” (Shen et al., 1993). The central South Yellow Sea is a weak tide region, so its circulation can only affect fine-grained suspended materials over 4Φ (Shen et al., 1996). Therefore, the sediments in this region have fine grained, water-saturated, and show extremely high water content (Shen et al., 1993).

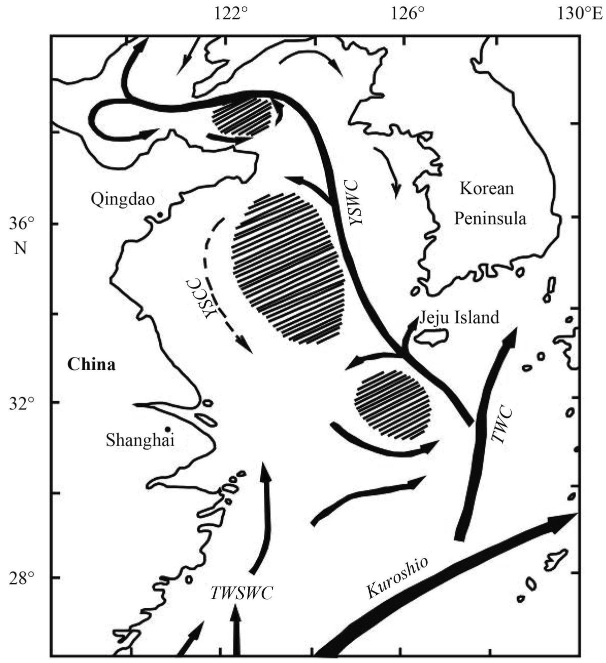

Fig. 9. The Yellow Sea flow system (Hu, 1984). YSWC represents Yellow Sea Warm Current, YSCC the Yellow Sea Coastal Current, TWSWC the Taiwan Warm Current, and TWC Tsushima Current.

4.3.2 *Hydrodynamic condition of the Zhe-Min coastal area*

The ocean current system in the Zhe-Min coastal area is mainly composed of the Kuroshio branch (CUWC, SUWC), TWSWC, MZCC (Fig. 10). The formation of a mud sedimentary zone on inner continental shelf is directly controlled by winter MZCC and TWSWC (Xiao, 2004). In summer the MZCC flows northward, but in winter it flows in an opposite direction. During winter, the terrigenous clastics or suspensions from the Changjiang River are transported southward by the MZCC; they cannot disperse eastward because they are blocked by the TWSWC that flows northward. As a result, a zone with a weak dynamic force

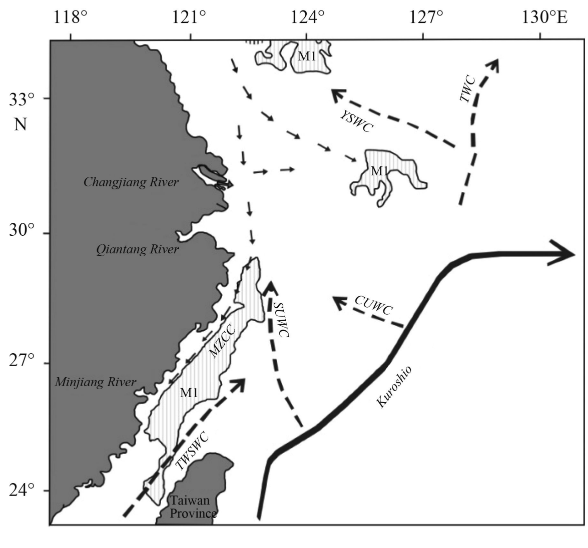

Fig. 10. Circulation of the East China Sea (Li et al., 2005). CUWC represents uplifting warm current over the central East China Sea shelf, SUWC uplifting warm current over the southern East China Sea shelf, and MZCC Min-Zhe coast current.

and a stable sedimentary environment will form between the TWSWC and the MZCC. The salinity, pH value and other water chemical properties in this sedimentary zone change dramatically, so the suspensions flocculate physically-chemically, and deposit on the seabed to form a fluid mud body, which floats along the seabed and deposits when the flow intensity decreases to a certain extent (Hu and Yang, 2001). Because the sediments were formed in a still water environment, they have only experienced a depositional phase and have not been compacted and dewatered, so they contain a lot of water that is not easy to discharge. These are the dynamic factor for the sediments in the region characterized by loose structure, high water content, low strength and strong compressibility.

4.4 *Deposition rate*

4.4.1 *Deposition rate of the central South Yellow Sea*

Over the past 100 a, the deposition rate in most regions of the central South Yellow Sea is low, generally below 0.2 cm/a (Li et al., 2002). It means that there is less material supply, and the region is in a low energy environment (Hu et al., 2011). The position of such region with a low deposition rate overlaps with the South Yellow Sea cold water mass. The deposition rate of the central South Yellow Sea is relatively low.

4.4.2 *Deposition rate of the Zhe-Min coastal area*

Over the past 100 a, the deposition rate of the Zhe-Min coastal area is between 0.79 and 3.34 cm/a with an average value of 1.97 cm/a (Shi et al., 2010; Liu et al., 2009). The distribution of the deposition rate is characterized by high in the central part and gradual decrease from middle to south and north (Shi et al., 2010). The distribution feature of the deposition rate corresponds to the thickness of mud area revealed by a shallow seismic profile (Liu et al., 2007, 2009; Shi et al., 2010). Compared with the central South Yellow Sea, the deposition rate of the Zhe-Min coastal area is higher.

4.5 *Material composition*

The material composition, especially a hydrophilicity, an adsorbability and other characteristic components, plays an important role in controlling the geotechnical properties of sediments. In this paper, three indicators (clay content, clay mineral assemblages and organic content) are selected to analyze the differences between the physical-mechanical properties of sediments.

4.5.1 *Clay content*

The finer the sediment particle is, the stronger the action with water. As the particle size reduces, the viscosity, plasticity and expansibility of sediment increase; the strength of sediment decreases gradually. Compared with sediment in the Zhe-Min coastal area, the clay content of sediment in the central South Yellow Sea is higher (average content is 51.76%), so sediments have higher water content, higher plasticity and lower strength than sediments in the Zhe-Min coastal area.

4.5.2 *Assemblage features of clay mineral*

Clay minerals are characterized by strong adsorbability and hydrophilicity, and are composed of illite, kaolinite, chlorite and smectite, of which, smectite shows the strongest adsorbability and hydrophilicity. Only a few percent of hydrophilic clay minerals (smectite or illite) in sediments can reduce the internal friction angle by more than 50% (Zheng et al., 1994). Compared with sediment in the Zhe-Min coastal area, the clay content and smectite in clay mineral assemblages of sediments in the central South Yellow Sea is higher (Table 3), so the sediments in this region have the higher water content and lower strength than sediments in the Zhe-Min coastal area.

4.5.3 *Organic content*

The impact of organic matters on the geotechnical properties of sediment substantially lies in that they can absorb water and cause to form an open structure for clay particles cluster (Wu, 2007). Organic matter possesses stronger colloidal properties and higher hydrophilicity than clay particles, so it has greater impact on the geotechnical properties of sediment than smectite (Kong et al., 2002). When organic matter in sediments accounts for 1%–2%, it will exert great impact on the geotechnical properties. Specifically, it will enlarge the dispersity of soil (Li et al., 2009), decrease the density, the plasticity and the permeability coefficient, and increase the water content, void ratio and cohesion of sediment (Lü et al., 2011; Mu and Li, 2008). Table 4 shows the content of organic matter of sediments in the two regions. Sediment in the central South Yellow Sea has the higher content of organic matters than sediment in the Zhe-Min coastal area.

Table 3. Clay content and clay mineral assemblages of sediment

Area	Clay content/%		Illite content/%		Smectite conten/%		Kaolinite conten/%		Chlorite conten/%	
	range	average	range	average	range	average	range	average	range	average
Central South Yellow Sea	8.30–91.40	51.76	48.01–75.06	60.99	3.70–16.78	8.00	9.19–18.13	13.94	9.85–22.87	17.06
Zhe-Min coastal area	13.67–80.41	34.26	32.55–75.06	62.25	0.22–8.00	2.48	1.40–60.82	7.82	3.84–37.86	27.44

Table 4. Contents of organic matter

Area	Content range/%	Average content/%
Central South Yellow Sea (Liu et al., 1987)	0.07–3.09	1.35
Zhe-Min coastal area (Liu, 2009)	0.00–1.94	0.75

Note: The organic matter content in sediment is the product of the organic carbon content determined by a TOC analyzer method multiplied by coefficient (conversion coefficient of total organic carbon and organic matter) 1.724 (Qian et al., 2011).

5 Conclusions

(1) There are perfect positive linear correlation between the water content and the void ratio, perfect negative power function correlations between the water content and density, compression coefficient and compression modulus, good positive power function correlation between the liquid limit and the plastic limit, and perfect polynomial function correlation between the miniature vane shear strength and the pocket penetration resistance. The correlation between the cohesion and the internal friction angle of sediments in the two regions is not obvious.

(2) Sediments in the Zhe-Min coastal area and the central South Yellow Sea are mainly mud and muddy clay. Compared with sediments in the Zhe-Min coastal area, sediments in the central South Yellow Sea generally have the higher water content, plasticity, compressibility; larger void ratio; lower density, shear strength and smaller penetration resistance.

(3) Compared with the Zhe-Min coastal area, the central South Yellow Sea is far from China's Mainland and low-lying; has poor hydrodynamic condition; the materials diffused to the area are less and dominated by fine clay, have high content of smectite and organic matters. These factors lead to sediments of the central South Yellow Sea have the higher water content, higher plasticity, lower density, and lower strength than sediment in the Zhe-Min coastal area.

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