第20卷 第1期 岩石力学与工程学报 20(1): 90～94
2001年1月 Chinese Journal of Rock Mechanics and Engineering Jan., 2001

Strengthening Foundation by Underwater Explosive Ram

Shan Hongxian Jia Yonggang Liu Hongjun Lei Kun
(College of Marine Geoscience, Ocean University of Qingdao, Qingdao 266003 China)

Abstract Underwater explosive ram is adopted to treat the foundation in the project of petrochemical dock in Lanshan harbor. Feasibility of this kind of foundation reinforcement method in the project of petrochemical dock in Lanshan harbor is discussed based on the analysis and comparison of the difference of sea-bottom elevation, physical and mechanical properties of sediments before and after explosive ram tests. The rational parameters of explosive ram are designed according to the result of the test. The quantitative data of underwater explosive ram are offered for large scale strengthening foundation of petrochemical dock in Lanshan harbor.

Key words underwater explosive ram, strengthening foundation, parameters of explosive ram
Category TU 472.9 **文献标识码** A **文章编号** 1000-6915(2001)01-0090-05

1 Introduction

Lanshan harbor of Rizhao city is located in southeast seashore of Shandong Province, China. A dock which can deliver fifty-thousand-ton liquid products of petroleum and chemicals is planed to be built in the harbor. The dock is about 615.145 m long. Its top surface is 16m wide. The base surface of its foundation is 23 m wide. The elevation of its top surface is 13m above Yellow Sea. The elevation of its foundation base is -10.7m. The dock belongs to gravity dock. The thin-wall cylinder structure is adopted in the dock, and it is classified as primary buildings. The construction requires that the ground bearing capacity of supporting layer is greater than 240 kPa.

The strata of the quasi-engineering area consist of marine-deposition stratum Q_4^m (including two strata ① muddy mild clay and ② coarse gravelly sand), terrestrial deposit stratum Q_3^{al+pl} (including two strata ③ mild clay and ④ clay), and the fully weathered granite-gneiss beneath. According to the features and physical and mechanical properties of these strata, marine-deposition stratum and the upper stratum of terrestrial deposit stratum ③ do not achieve engineering requirements, the ④ stratum and or the weathering stratum of the bedrock should be selected as supporting layer. Extensive excavation will be very difficult due to the deep water in working area (greater than 10 m). Thus underwater explosive ram is adopted to stabilize upper strata, in order to meet engineering requirements.

2 Design parameters of explosive ram

The underwater explosive ram adopted to stabilize foundation is one of the new methods of foundation treatment. The new method is in the period of researching and discovering and doesn't take part in relative standards of harbor engineering technique[1～4]. To understand feasibility, design rational parameters and offer quantitative data of explosive ram, five working sections are selected for test firstly. The sites and parameters of explosive

Received on Jan. 4, 2000.
作者 Shan Hongxian(单红仙) 简介: 女, 1965年生, 1986年毕业于长春地质学院水工系工程地质专业, 现任副教授, 主要从事海洋岩土力学方面的教学与研究工作。

Table 1 Working section of underwater explosive ram

Working section No.	Working section position/m	Explosive ram parameters									
		Width /m	Area /m²	Ammunition Substance /kg	Suspension height/m	Spacing interval/m	Ammunition No.	Total ammunition /kg	Explosion intensity /kg·m⁻²	Explosive ram times	Riprap thickness/m
Ⅰ	0+220～0+240	30	600	20	2	5×5	15	300	0.50	1	Non riprap filled
Ⅱ	0+210～0+220	30	300	9	1.5	4×4	24	216	0.72	1	Non riprap filled
Ⅲ	0+200～0+210	30	300	6	1	3×3	30	180	1.20	2	Non riprap filled
Ⅳ	0+190～0+200	30	300	6	1	3×3	30	180	0.60	1	Non riprap filled
Ⅴ	0+164～0+184	20	460	20	2	5×5	20	400	0.87	1	1.0

Note: The ammunition No. and total ammunition point to total utilization of 1 time explosive ram in Ⅲ Working Section.
The explosion intensity points to total utilization of 1 and 2 times explosive ram in Ⅲ Working Section.

ram of these test sections are listed in table1. In the five sections, analysis and comparison in six aspects are mainly carried out:

· In section Ⅰ, Ⅱ and Ⅳ, compare influence of different quantity of explosive ammunition (weight of singe ammunition) and different suspension height on explosive ram effect, with same times of explosive ram and same riprap conditions.

· In section Ⅲ and Ⅳ, compare influence of different times of explosive ram on explosive ram effect with same quantity of explosive ammunition and riprap conditions (non-riprap).

· In section Ⅰ and Ⅲ, compare influence extent of quantity of explosive ammunition and times of explosive ram on explosive ram effect under the condition of non-riprap.

· In section Ⅰ and Ⅴ, compare influence of riprap thickness on explosive ram effect, with same quantity of explosive ammunition.

· In section Ⅳ and Ⅴ, compare influence extent of quantity of explosive ammunition and riprap thickness on explosive ram effect, with same times of explosive ram.

· Comprehensively analyze and compare the results of all sections.

3 Analysis on effects of underwater explosive ram

Conduct underwater explosive ram in each section according to designed parameters mentioned above. After underwater explosive ram, its effects are exhibited in two aspects of changes of foundation strata. The first is deformation and subsidence of sea bed, that is, the foundation is compressed and subsided; the second is changes of physical, mechanical properties and bearing capacity of the foundation.

3.1 Analysis of sea bed subsidence after explosive ram

In each section, the water depth of offshore was measured by depth sounding bar and depth sounding hammer; adopt the forward intersection method with transit instruments to fix positions and erected level instruments by the shore to read. According to the measured sea bed elevation of selected section before and after explosive ram, decide deformation and subsidence displacement of sea bed. The changes of sea bed before and after explosive ram are shown in figure 1 (each section in figure includes 5m range of both sides), and the statistic survey table of subsidence displacement is listed in table 2.

It can be concluded from fig. 1:

· After explosive ram, the sea bed of each working section remains or becomes more flat and smooth compared to that before explosive ram. The results show that explosive waves affect the sea bottom in the form of plane waves, and their action to strata is relatively uniform, which is favorable to further construction.

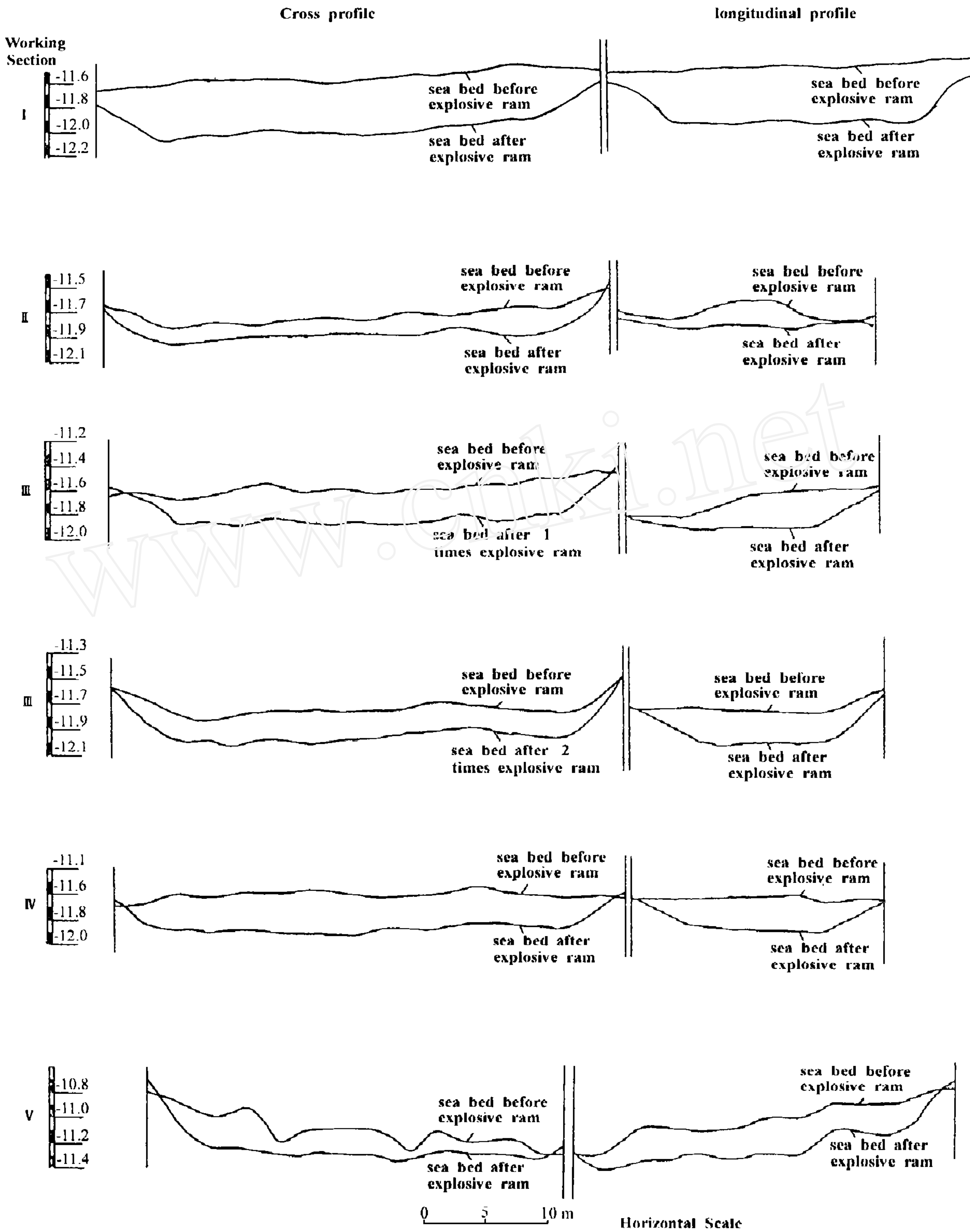

Fig. 1 Sea bed profile of each working section before and after explosive ram

· In sections of non-riprap (section Ⅰ to Ⅳ), the ground surface that is within 5 m-range of margin of most explosive area has uplifts of different extent (about 0.3 m high) after explosive ram. While in riprap section of section Ⅴ, the uplifts in margin area are relatively weak. This is because that in non-riprap sections, explosion more intensively affects the sea bottom surface, and makes it squeezed, thrown and then form uplifts in margin area. In riprap sections, the bedding cushion is thick and the diameter of riprap is relatively large (about 20～50 cm). It can absorb a great deal of explosive energy, so the margin areas do not swell apparently compared with those before explosive ram. Therefore, riprap is very favorable to later construction.

The table 2 shows that, the effects of explosive ram for section Ⅰ and Ⅲ are quite good. It is after two times of explosive ram that section Ⅲ achieves the result. Based on the analysis and comparison of subsidence displacement of test sections, it can be found that the quantity of singe ammunition substance and riprap thickness most greatly influence the subsidence displacement or the extent of foundation compression of foundation, and the times of explosive ram and suspension height of ammunition range do it secondly. In terms of analysis of subsidence displacement of the foundation, in designed parameters of explosive ram of test sections, parameters of section Ⅰ are more economical and rational, and the effects are quite good, either. If the riprap bedding cushion is chosen, the quantity of ammunition substance or times of explosive ram must be increased.

3.2 Analysis on changes of physical and mechanical properties before and after explosive ram

Main physical and mechanical parameters of test sections before and after explosive ram are listed in table 3. The improvement amplitude of physical and mechanical properties of test sections is listed in table 4 after explosive ram.

It can be concluded from table 3 and 4 as follows.

· ①muddy mild clay is pushed off and not be found in working sections. ② coarse gravelly sand in section Ⅰ and Ⅴ and ③mild clay in all sections are improved apparently. ②-1 the upper of coarse

Table 2 Statistic survey table of sea bed subsidence displacement of each section before and after explosive ram

Working section No.	Explosive ram times	Survey elevation of sea bed before explosive ram/m	Survey elevation of sea bed after explosive ram/m	Sea bed average settlement/cm	Initial thickness of compressed soil layer/m	Percent of the settlement/%
Ⅰ	1	-11.64	-12.07	+43	3.60	12
Ⅱ	1	-11.83	-11.98	+15	3.60	4.1
Ⅲ	1 2	-11.69 -11.82	-11.94 -12.04	+25 22	3.60	13
Ⅳ	1	-11.65	-11.93	+28	3.60	7.8
Ⅴ	1	-10.98	-11.21	+23	3.60	6.1

Note: The compressed soil layer points to coarse gravelly sand seam and mild clay. The percent of the settlement points to 2 explosive ram times of Ⅲ working section.

Table 3 Comparison of physical and mechanical property parameters before and after explosive ram

Working section No.	Before explosive ram								Before explosive ram							
	Soil layer number	Void ratio e	Cohesion c/kPa	Angle of internal friction φ/(°)	Coefficient of compressibility a_{1-2}/MPa^{-1}	Modulus of compressibility E_s/MPa	SPT blow count N	Standard bearing capacity/kPa	Soil layer number	Void ratio e	Cohesion c/kPa	Angle of internal friction φ/(°)	Coefficient of compressibility a_{1-2}/MPa^{-1}	Modulus of compressibility E_s/MPa	SPT blow count N	Standard bearing capacity/kPa
Ⅰ	② ③	0.660	72	36 20.2	0.27	6.46	9.7 10.6	120 190	② ③	0.667	81.6	36 19.2	0.22	8.30	20.0 11.0	250 260
Ⅱ	② ③	0.660	72	20.2	0.27	6.46	9.7 10.6	120 190	②-1 ②-2 ③	0.637	85.9	30 33 20.4	0.14	11.5	10 14.4 11.7	140 180 270
Ⅲ	② ③	0.660	72	36 20.2	0.27	6.46	9.7 10.6	120 190	②-1 ②-2 ③	0.679	98.8	30 35 20.2	0.19	9.53	10 18.3 10.6	140 200 260
Ⅳ	② ③	0.660	72	36 20.2	0.27	6.46	9.7 10.6	120 190	②-1 ②-2 ③	0.728	70.1	30 37 19.4	0.19	9.55	10 24.4 12.3	140 250 270
Ⅴ	② ③	0.660	72	36 20.2	0.27	6.46	9.7 10.6	120 190	②-1 ②-2 ③	0.619	85.6	33 19.6	0.16	10.5	14.4 14	180 280

Note: ②-1 point to coarse gravelly sand seam of loosening; ②-2 point to coarse gravelly sand seam of medium density.

Table 4 Extent of improvement of principal mechanical property for each working section after explosive ram

Working Section	Soil layer number	Principal mechanical property index						
		Void ratio *e*	Angle of internal friction	Cohesion *c*	Coefficient of Compres-sibility	Modulus of compre-ssibility	SPT blow count	Standard bearing capacity
Ⅰ	②		light				106%	108%
	③	light	light	14%	-18.5%	28.5%	A little increase	36.8%
Ⅱ	②-1		light				light	light
	②-2		Light				48.4%	50%
	③	light	Light	19%	-48.1%	77.1%	A little increase	42.1%
Ⅲ	②-1		Light				light	light
	②-2		Light				88.6%	66.2%
	③	light	Light	37%	-30%	47.5%	A little increase	36.8%
Ⅳ	②-1		Light				light	light
	②-2		Light				152%	108%
	③	light	Light	A little minus	-30%	47.6%	16%	42.1%
Ⅴ	②-2		Light				54.6%	50%
	③	light	Light	19%	-40.7%	61.5%	32.1%	47.3%

coarse gravelly sand in section Ⅱ to Ⅳ does not reach good explosive effect.

· After explosive ram, among the mechanical parameters in test sections, the internal friction angles of gravelly sand and mild clay do not change much, but cohesion force increases, which indicates that the explosive ram is effective to improve the shear strength of foundation soil.

· After explosive ram, among mechanical parameters in test sections, the bearing capacity of gravelly sand and compressible modulus are all increased violently, which indicates that the explosive ram produces good effects to increase the stability of sand foundation and clay foundation, and to reduce the subsidence of clay foundation.

· Improvement extent of mechanical property in section Ⅰ and Ⅲ is greater than that in section Ⅳ. In section Ⅰ, after explosive ram, the bearing capacity of upper stratum met the requirement of the project of petrochemical dock in Lanshan harbour.

4 Conclusions

In the point of subsidence of sea bed surface as well as physical and mechanical properties respectively, the effects of under water explosive ram are analyzed and following conclusions are obtained.

· After explosive ram, gravelly sand foundation and clay foundation are significantly stabilized, and their bearing capacity is markedly increased. Therefore, adopting underwater explosive ram to stabilize foundation in the area is effective and feasible.

· According to the analysis on subsidence of sea bed surface, changes of physical and mechanical property, the foundation stabilization effects in section Ⅰ are the best, section Ⅲ takes the second place nd the effects in another sections are general. In explosive ram construction of working areas in whole dock, the explosive ram parameters of section Ⅰ should be chosen. That is, the quantity of ammunition substance is 20 kg, suspension height of ammunition 2 m and the interval 5×5 m. The explosive ram is made for the first time under the condition of non-riprap, then the stone about 1 m thickness is ripraped, and the explosive ram is made for the second time.

References

1 Shao Kaifang, Fu Jinshui. The Influence of bedding explosion ram on project and environment[J]. Port Engineering Technology, 1996, 128(3): 57～59

2 Wu Mianba, Gao Jianguang, Hu Yuanyu. Research and practice on the underwater blasting thump about the bedding[J]. Rock and Soil Mechanics, 1996, 17(4): 8～13

3 Xie Zhunzhou, Fan Xianhe. Building Construction[M]. Beijing: Construction Industry Press of China, 1998, 60～61 (in Chinese)

4 Yang Guangxi. Underwater Engineering Explosion[M]. Beijing: Ocean Press, 1990, 66～67 (in Chinese)