APPENDIX 'C'

Historical Sampling Data

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PROJECT 3NB07005

NAVFAC EUROPE AND SOUTHWEST ASIA
Public Works Department Rota

NATO UNCLASSIFIED

GEOTECHNICAL REPORT

FOR

HARBOR AND CHANNEL DREDGING

IN

ROTA NAVAL BASE

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March of 2009

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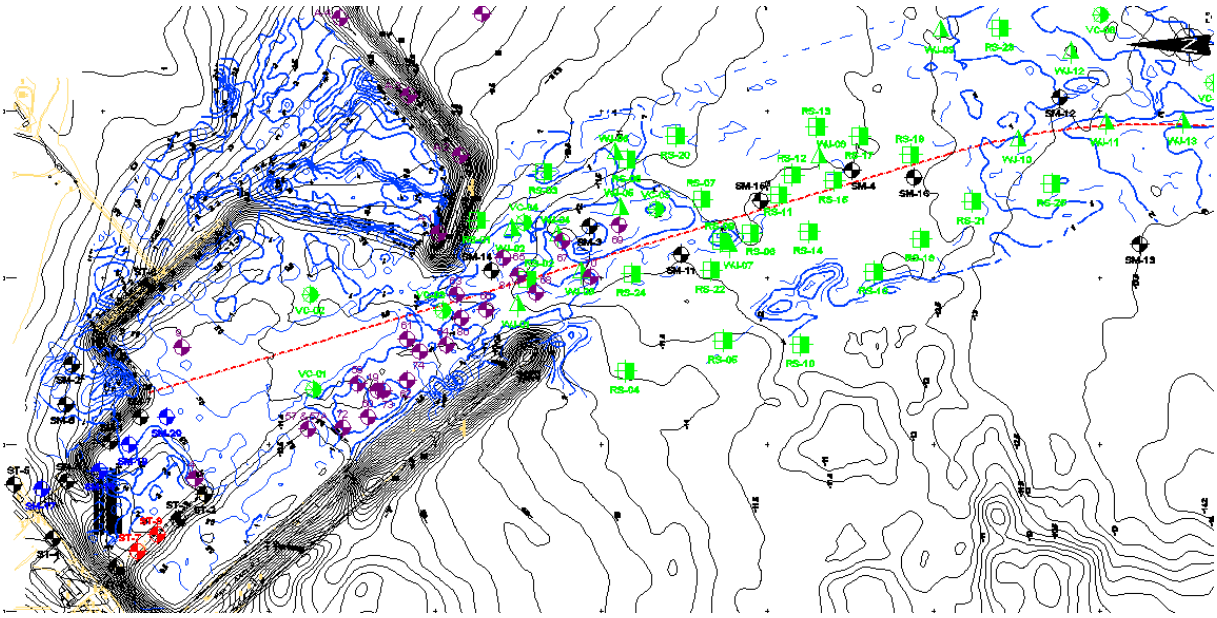
1. INTRODUCTION

This report is developed as part of the project for Harbor and Channel dredging in Rota Naval Base. Specifically, it defines the geotechnical recommendations for project design. The studied area is located inside the Bay of Cadiz, located in south-west Andalusia, between the mouths of the rivers Guadalquivir and Guadalete.

This study describes the characteristics of the terrain and the recommended geotechnical parameters for the materials on which the dredging is designed, as well as the study of the stability of the recommended slopes.

The *figure No.1* shows the harbor and part of the access channel with the site investigations carried out.

Figure No.1: Site investigations



2. PURPOSE AND SCOPE OF THE STUDY

The object of this study is obtaining the data and the necessary geotechnical parameters for the correct definition of the material characteristics on which the work will be executed. This way, the following aspects have been defined:

- Nature, thickness and geotechnical characteristics of the superficial mud and Quaternary materials that covers the Tertiary substratum.
- Nature, thickness and geotechnical characteristics of the Tertiary materials that will be affected by dredging.
- Characteristics of the materials to be dredged to define the most appropriate dredging systems.
- Study of the most appropriate dredging slopes and stability calculations of the recommended slopes.
- Slope stability of the breakwaters that can be affected by the dredging.
- Other recommendations for the design or the appropriate execution of the works.

All the information and the obtained data along the study are included in this report with the conclusions and the design recommendations.

3. AVAILABLE SITE INVESTIGATIONS

3.1. PREVIOUS SITE INVESTIGATIONS

Historical site investigations have been consulted, with the aim of having most complete information about the materials in the project area, and that way make a most precise characterisation of them. The following list shows the consulted site investigations and the designs for which they have been carried out:

- Geotechnical site investigation carried out in 1955 (21 rotary borings).
- Geotechnical site investigation carried out in 1963 (7 rotary borings) for the design of the *Southeast breakwater*.
- Geotechnical site investigation carried out in 1960 (rotary borings) for the design of the *berth, channel and approach dredging*.
- Geotechnical site investigation carried out in 1987 (13 rotary borings) for the design of the *harbor maintenance dredging*.
- Geotechnical site investigation carried out in 2003 (9 surface samples) for the *harbor dredging (phase II) in the entrance channel*.

3.2. GEOTECHNICAL SITE INVESTIGATION FOR THE DESIGN

The available geotechnical information has been obtained in five different site investigations. The first four of them were carried out in a larger area which included the construction of the new Pier 4 and the remodelling of the existing Pier 1 and Pier 2, as well as the dredging of the harbor and its access channel. The last site investigation has had the object of completing the available information for the dredging of the harbor and the channel.

The first site investigation was carried out from December of 2002 to January of 2003, making four boreholes with sampling and testing during the drilling on the floating drill boat (SM-1, SM-2, SM-3 y SM-4), and six boreholes on land (ST-1, ST-1Bis, ST-2, ST-3, ST-4 y ST-5).

The second site investigation was carried out in February of 2003. This time, four boreholes with sampling and testing were undertaken on the floating drill boat (SM-5, SM-6 y SM-7) and 6 underwater trial pits (SM-11 to SM-16), carried out by the firm GIJONESA DE ACTIVIDADES SUBACUÁTICAS.

In July of 2005, the third site investigation was performed. In this occasion, 4 boreholes were carried out with sampling and testing on the floating drill boat (SM-17, SM-18, SM-19 y SM-20), in the works of the design of the new Pier 4.

To complete the site investigation in the current place of Pier 2, another site investigation was done in April of 2007. This one consisted in two boreholes with sampling and testing (boreholes ST-7 and ST-8), both of them made from the present level of Pier 2.

For the boreholes in the first two site investigations the firm GEOCISA was engaged, and for the last ones it was SONDEOS DEL SUR. In all cases the drilling of the boreholes was overseen by specialized technicians of TYPSA, displaced in the area for such a purpose.

Table No.1 sums up the main characteristics of the boreholes drilled by TYPSA in the project area in the four site investigations described above.

Table No.1. Main characteristics of TYPSA boreholes.

BOREHOLE	COORDINATES			LENGTH (m)	LOCATION (AIM)
	X (UTM)	Y (UTM)	Z (MLTL)		
SM-1	739.008	4.056.477	-10,6	19,8	Floating Drill Boat (Pier 4)
SM-2	739.241	4.056.593	-1,0	21,7	Floating Drill Boat (Beach)
SM-3	739.655	4.055.036	-12,3	5,0	Floating Drill Boat (Access channel)
SM-4	739.823	4.054.246	-12,2	5,0	Floating Drill Boat (Access channel)
SM-5	738.891	4.056.607	-3,2	20,4	Floating Drill Boat (Pier 4)
SM-6	739.119	4.056.610	-1,0	2,5	Floating Drill Boat (Beach)
SM-7	739.083	4.056.387	-11,4	15,1	Floating Drill Boat (Pier 4)
SM-17	738.868	4.056.683	0,0	20,2	Floating Drill Boat (Pier 4)
SM-18	738.921	4.056.510	-10,6	19,7	Floating Drill Boat (Pier 4)
SM-19	739.001	4.056.420	-10,9	20,6	Floating Drill Boat (Pier 4)
SM-20	739.084	4.056.308	-11,1	19,7	Floating Drill Boat (Pier 4)
ST-1	738.634	4.056.458	+6,0	29,6	Level Pier 2

BOREHOLE	COORDINATES			LENGTH (m)	LOCATION (AIM)
	X (UTM)	Y (UTM)	Z (MLTL)		
ST-2	738.853	4.056.193	+6,0	21,0	Level Pier 2
ST-3	738.776	4.056.273	+6,0	24,5	Level Pier 2
ST-4	738.718	4.056.650	+5,5	21,4	Access to seacoast (Pier 2)
ST-5	738.881	4.056.767	+6,6	24,4	Access to seacoast (Pier 4)
ST-6	739.478	4.056.363	+6,0	35,0	Level Pier 3
ST-7	738.680	4.056.395	+6,0	31,9	Level Pier 2
ST-8	738.730	4.056.337	+6,0	30,2	Level Pier 2

While drilling the boreholes, on-site sampling and testing (standard penetration test, SPT) were carried out, as well as unaltered sample (MI) or rock core (TP). Samples were taken with the Shelby Tube Sampler and altered samples in plastic recipients (MB) in those parts of the boreholes where the material characteristic made it necessary so as to get the sample.

Table No.2 shows the different samples taken in each borehole.

Table No.2. Samples taken in different site investigations.

BOREHOLE	TYPE OF SAMPLE				
	MI	SPT	TP	SHELBY	MB
SM-1	0	8	0	2	0
SM-2	2	7	0	1	0
SM-3	0	0	0	0	3
SM-4	0	0	0	0	3
SM-5	1	7	0	0	0

BOREHOLE	TYPE OF SAMPLE				
	MI	SPT	TP	SHELBY	MB
SM-6	3	7	0	0	0
SM-7	0	7	0	0	0
SM-17	3	5	0	0	1
SM-18	2	6	0	0	3
SM-19	0	8	4	0	1
SM-20	0	9	1	0	1
ST-1	0	10	0	1	0
ST-2	0	8	0	1	0
ST-3	0	11	0	2	0
ST-4	1	10	0	0	0
ST-5	5	7	0	0	0
ST-6	0	9	0	1	0
ST-7	4	13	1	0	0
ST-8	5	12	0	0	0
TOTAL:	**26**	**144**	**6**	**8**	**12**

Table No.3 shows the main characteristics of the underwater trial pits carried out in the access channel.

Table No.3. Main characteristics of the underwater trial pits.

UNDERWATER TRIAL PIT	COORDINATE			RECOGNIZED THICKNESS (m)	
	X (UTM)	Y (UTM)	Z (MLTL)	SOILS	ROCK
SM-11	739.571	4.054.760	-11,9	0,1	0,4

UNDERWATER TRIAL PIT	COORDINATE			RECOGNIZED THICKNESS (m)	
	X (UTM)	Y (UTM)	Z (MLTL)	SOILS	ROCK
SM-12	740.042	4.053.620	-12,8	2,15	---
SM-13	739.602	4.053.380	-13,5	2,3	---
SM-14	739.522	4.055.331	-11,2	2,0	0,1
SM-15	739.731	4.054.520	-11,7	0,9	0,2
SM-16	739.802	4.054.060	-12,4	1,9	0,1

To complete the geotechnical information from the four site investigations described before, a fifth site investigation has been carried out from September to December of 2007.

This site investigation consisted of 15 vibrocores, 13 water jets and 25 samples in rock taken in the seabed in the project area.

The rock sampling has been centralized in the access channel, in which a geophysical study had detected the smallest mud thickness, loose granular materials and soft cohesive materials. 25 points have been studied in the area where an Ostionera rock outcrop was possible, in which 15 rock samples have been taken.

The main characteristics of these 25 points are shown in *table No.4*.

Table No.4. Rock Points investigated.

ROCK SAMPLES	COORDINATES			SAMPLE WEIGTH (kg)	MUD THICKNESS (m)
	X (UTM)	Y (UTM)	Z (MLTL)		
RS-1	739.673	4.055.373	-10,5	---	1,50
RS-2	739.497	4.055.223	-11,5	---	1,45
RS-3	739.820	4.055.173	-10,5	1,4	---

ROCK SAMPLES	COORDINATES			SAMPLE WEIGTH (kg)	MUD THICKNESS (m)
	X (UTM)	Y (UTM)	Z (MLTL)		
RS-4	739.221	4.054.927	-11,1	3,3	---
RS-5	739.312	4.054.633	-11,4	1,8	---
RS-6	739.634	4.054.551	-11,9	2,8	---
RS-7	739.736	4.054.699	-11,9	---	0,40
RS-8	739.856	4.054.922	-11,4	2,6	0,20
RS-9	739.609	4.054.642	-12,2	---	0,40
RS-10	739.300	4.054.400	-12,2	2,0	---
RS-11	739.750	4.054.466	-12,1	3,6	---
RS-12	739.809	4.054.425	-12,1	---	0,30
RS-13	739.954	4.054.353	-11,8	---	0,45
RS-14	739.639	4.054.376	-12,2	---	0,40
RS-15	739.792	4.054.300	-12,1	4,2	0,60
RS-16	739.519	4.054.180	-12,3	1,1	0,30
RS-17	739.925	4.054.223	-12,0	1,4	0,35
RS-18	739.617	4.054.040	-12,4	4,0	---

ROCK SAMPLES	COORDINATES			SAMPLE WEIGTH (kg)	MUD THICKNESS (m)
	X (UTM)	Y (UTM)	Z (MLTL)		
RS-19	739.871	4.054.070	-12,2	6,0	---
RS-20	739.926	4.054.776	-11,3	0,2	---
RS-21	739.729	4.053.884	-12,7	2,2	---
RS-22	739.524	4.054.670	-12,1	7,3	---
RS-23	740.250	4.053.801	-12,6	---	1,10
RS-24	739.513	4.054.908	-12,0	---	---
RS-25	739.783	4.053.644	-13,1	---	0,90

Water jets were carried out to study the thickness of the Quaternary materials (mud and loose granular materials) that are covering the rocky materials in the access channel.

The main characteristics of the 13 points investigated with water jets are shown in *table No.5*.

Table No.5. Water jets.

WATER JETS	COORDINATES			REACHED DEPTH (m)
	X (UTM)	Y (UTM)	Z (MLTL)	
WJ-1	739.402	4.055.252	-11,4	1,60
WJ-2	739.629	4.055.270	-11,2	1,50 (Rock)
WJ-3	739.500	4.055.061	-12,0	1,85
WJ-4	739.610	4.055.132	-11,8	1,30 (Rock)

WATER JETS	COORDINATES			REACHED DEPTH (m)
	X (UTM)	Y (UTM)	Z (MLTL)	
WJ-5	739.692	4.054.943	-12,2	1,00
WJ-6	739.859	4.054.958	-11,2	0,30 (Rock)
WJ-7	739.580	4.054.615	-12,2	0,10 (Rock)
WJ-8	739.845	4.054.345	-12,0	0,15 (Rock)
WJ-9	740.225	4.053.979	-12,5	0,40 (Rock)
WJ-10	739.896	4.053.746	-12,8	0,90
WJ-11	739.948	4.053.481	-13,1	1,65
WJ-12	740.161	4.053.588	-13,0	1,35 (Rock)
WJ-13	739.951	4.053.249	-13,2	1,30

The main characteristics of the 15 points investigated with vibrocores are shown in *table No.6*:

Table No.6. Vibrocores.

VIBROCORES	COORDINATES			REACHED DEPTH (m)
	X (UTM)	Y (UTM)	Z (MLTL)	
VC-1	739.166	4.055.866	-11,5	1,30
VC-2	739.450	4.055.875	-11,4	1,70
VC-3	739.402	4.055.476	-11,4	2,40

VIBROCORES	COORDINATES			REACHED DEPTH (m)
	X (UTM)	Y (UTM)	Z (MLTL)	
VC-4	739.667	4.055.233	-11,3	1,80
VC-5	739.707	4.054.835	-12,1	1,75
VC-6	740.290	4.053.497	-12,9	2,60
VC-7	740.086	4.053.160	-13,2	3,00
VC-8	739.835	4.052.837	-13,6	3,40
VC-9	740.023	4.052.543	-13,7	4,00
VC-10	740.191	4.052.212	-13,9	4,00
VC-11	739.910	4.051.944	-14,3	2,00
VC-12	739.621	4.051.677	-14,5	3,00
VC-13	739.791	4.051.353	-14,7	3,30
VC-14	739.955	4.051.028	-14,9	4,00
VC-15	739.701	4.050.762	-15,00	3,40

3.3. GEOPHYSICAL STUDY

From the information collected in the geophysical investigation carried out by the FONDEMAR during the month of September of 2007, it has been obtained a range of thicknesses of unconsolidated sediments that varies between 0,00 and 7,6 m. In *drawing 2. Geotechnical profile*, these levels of unconsolidated fillings have been identified with the levels of mud and surface sand that have been detected in boreholes and underwater trial pits.

The thickness of fillings defined from the geophysics concurs in most of the cases with those identified in the latest geotechnical investigation carried out in the studied area.

Minors thicknesses, from 0,00 to 1,00 m, have been detected in zones next to the harbor entrance. The major thicknesses have been located in the most remote from the access channel (between 4,00 and 7,60 metres). In the inner harbor and in the intermediate section of the access channel, the thicknesses are between the 2.00 and 4.00 m.

The thickness of fillings (isopacs) defined in the geophysical investigation and the consulted geotechnical site investigation, have been represented in *drawing 1. Geotechnical site investigation.*

3.4. LABORATORY TESTING

Laboratory testing have been undertaken to characterize the terrain with accuracy. In the first three site investigations the engaged laboratory was GEOCISA. For the testing of the site investigation in April of 2007, the engaged laboratory was CEPASA and for those in December of 2007, SEINGO.

Taking the samples has been a complex work because of the granular nature of the material and the underwater conditions. This circumstance has conditioned the choice of the laboratory test, even though they have reasonably characterized the terrain.

The type of testing carried out in the samples is chosen in function of the material nature and the aim of the borehole or other investigation system. The executed procedure follows the current standards for each test, and always in accordance with the established rules of good practice.

Table No.7 shows a listing of the laboratory tests carried out on the samples and the standard of each test.

Table No.7. Laboratory Testing carried out.

Laboratory Testing	STANDARD	Number of testing
Grain Size Distribution	UNE 103-101:95	94
Atterberg Limits	UNE 103-103:94 UNE 103-104:93	94
Natural water content	UNE 103-300:93	12
Dry density	UNE 103-301:94	10
Direct Shear	UNE 103-401:98	13
Soluble salt content	NLT-114:99	5
Sulphate content	UNE 103201:96	16
Organic matter content	UNE 103-204-93	14

Laboratory Testing	STANDARD	Number of testing
Carbonates content	UNE 103200	5
Compressive strength	UNE-22950-1	10
Point load test	UNE-22950-5 NLT-252	15
Cerchar Abrasivity	NF P94-430-1	3
Mineralogical test	----	3

The test results are listed In the *Appendix 2.1. Summary laboratory tests*.

4. GEOLOGY

4.1. REGIONAL GEOLOGICAL FRAMEWORK

4.1.1. The Betics Mountain Range

From the geological point of view, this region is located at the western end of the so-called Betics Mountain Range. The term Mountain Range understood as a geological connotation rather than a geographic one. In the geographic sense is the group of mountains that extends from the Gulf of Cadiz to the southern coasts of Valencia Country and the Baleares Islands. To the North it is limited by the Guadalquivir basin and the southern edge of the Iberian Massif and the Iberian System, while the Southern border is the Alborán Sea. However, in the geological sense, it extends beyond the geographical limits and is prolonged to the South under the Alborán Sea and towards the NE part of its structures continues without interruption on the Mediterranean seabed and the Balearic promontory to the island of Mallorca.

The Betics Mountain Range, together with the Rif Mountain Range in North Africa, form the most western segment of the Alpine Mediterranean Orogeny. These two mountain ranges are at present separated by the neogenic basin of Alborán and are located between two Hercynian shelves, the Iberian to the north and the African to the south. It is an unstable region affected in part from the Mesozoic and during a great part of the Tertiary by major tectonic phenomena, and located between the important European and African cratones.

This chain was formed as a consequence of the compression system that started at the end of the Cretaceous and mainly affected the N and S edges of the Iberian plate. The Betic area was the result of the interaction of two large plates and a continental block (Alborán microplate) that was displaced towards the W and finally collided with the Mesozoic margins of Iberia and NW Africa, forming the Andalusian-Rif Mountain Range.

At the cortical level, the most remarkable fact is that no notable root was detected under the mountain range as occurs with other alpine orogenies and, although a certain thickening of the crust was observed, this did not exceed 40 km in any case. The lack of a cortical and clear lithospheric root can be explained if it is supposed that what we observe today is only a part of a large orogeny that was located further to the E and which, through a series of geo-dynamic processes was partially broken up, in such a way that part of this orogeny would have been submerged under the Mediterranean Sea. Another remarkable fact is the rapid slimming down observed towards the coastal area where the thickness of the crust is around 20-22 km, the slenderising process being continued inwards towards the Alborán basin, where it reaches minimum values of around 15 km.

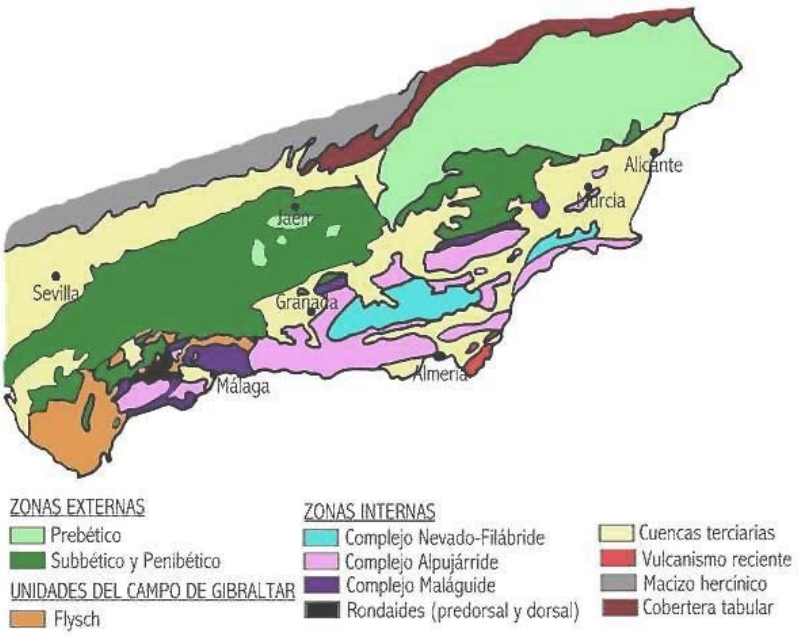
This concept of cortical domain, together with the petroleum and structural criteria, lead to differentiating two large areas separated by a tectonic contact, that also has a different paleogeographic origin; traditionally the «Internal Areas» are distinguished from the «External Areas», in comparison with Mountain Ranges in geosyncline development, that is, an external part with folded cover and, at times, with thrust-outlier structures, and an internal part, with deeper deformations that affect the shelf and are accompanied by metamorphism.

- Southern Iberian domain or External Areas. Formed of Mesozoic and Cenozoic materials overthrusted and folded without metamorphosing, that correspond to the sediment from the

marine basin that existed, the Tethys Sea. This corresponds to the Prebetic Area and the Subbetic Area.

- Alborán domain or Internal Areas. Composed of a piling up of thrust-outliers with materials that are essentially metamorphic, whose origin is related to the migration of the Apulica or Alborán microplate, located at its origin further to the E. These are the Circumbetic Area and the Betic Area.

Figure No.2. Betics Mountain Ranges



4.1.2. Subbetic Area

The studied area, the Rota Naval Base, is located within the Subbetic Area

The most spectacular tectonic event in the Betics Mountain Ranges took place at the end of the Aquitanian, as it affected all the areas although, logically, not with equal intensity. This was the compression that caused the collision of the European and African plates, by means of the movement of a miniplate, the Betic Area.

In the Subbetic Area, due to this collision, cuttings were originated to the North that caused some domains to fold over others. On the basis of these overthrust units the Trias suffered an extrusion and became extended in various laminas covering wide areas, supporting restructuring of their cover, which suffered various mechanical decollement processes. These Trias and their unidentified cover, or which were difficult to relate to a particular domain, could be considered Undifferentiated Subbetic.

Later «silexite» and «albarizas» were deposited in the western sector and on the most deprived parts of this structured whole, and it was done indifferently on the Triasic, Cretaceous or Tertiary Subbetic, or on certain units in the Circumbetic Area, already moved.

It would appear that a certain elevation occurred in the Subbetic Area during the Mid-Miocene, perhaps as an isostatic adjustment after the collision. This elevation caused a glide of the uprooted allocthonous formations, from one side of their axis to the other, which were mixed together, giving rise to a series of more or less chaotic aspects (Clays with blocks) in which the «silexite» and the «moronitas» from the a Burdigalian age were already involved. This formation, which for some is the origin of the Tertiary sedimentary, is for others purely tectonic. This last important event could have blurred the existing structures, and it complicated the interpretation of the contradictory observations made today in the field enormously.

The Page on Cadiz (IGME 1.061, Scale 1:50,000), located in the western sector, includes materials from the Subbetic Area that run in a W, NW direction, but of unsure assignation to a particular domain in this Area. It also shows abundant deposits of «albarizas» or «moronitas» of a para-autocthonous nature.

During the post-tectonic process (Upper Miocene – Upper Pliocene) the region passed through a period of expansion from which the Guadalquivir Basin originated, where many of the aforementioned allocthonous units came to rest, which brought with it «albarizas», leading to large «olistostromic» formations. A result of this process of expansion was also the origin of the Bay of Cadiz, which was installed on the sunken block of a normal ENE-WSW fault that passed by the foot of the San Cristóbal Sierra.

The generalised regression that occurred during the Upper Pliocene, in the Cadiz region, lead to conglomerates with oysters (“ostiones” in local terminology), that are known in the area by the name of “Ostionera” rock, and which form the pre-coastal plain which at the end of the Pliocene or the passing to the Plio/Pleistocene had already drawn the route of the Guadalquivir River.

During the Upper and Medium Pliocene, the sea occupied a wide strip of the Cadiz coastline, with extensive inlets that, in general, coincided with the outlets of rivers from the most important valleys of the region at that time, it started to retreat during the Upper Pliocene in such a way that, during this period of a clear retrogressive nature, an open marine system would only last here while, towards the interior extensive lakes were formed, totally disconnected from the sea.

Throughout the Quaternary and coinciding with a tectonic stage of compression that has lasted to the present time, the regression continued with slight interruptions occasioned by small positive oscillations of an eustatic nature, whose maximum transgressions did not exceed those of the Upper Pliocene.

The contributions of the Guadalete in part clogged the deprived areas previously occupied by the sea, creating low areas that formed tidal plains in which a still existing mixed-salty environment reigned. The wind moved the sand from the beach and the coastal Pliocene formations, giving rise to large blankets of dunes.

4.2. LOCAL GEOLOGICAL FRAMEWORK

The Rota Naval Base is located at the upper end (North) of the Bay of Cadiz. From a geological point of view this is a Pliocene base formed of “ostionera” rock, sandy conglomerates, and sands with highly variable cementation.

The Pliocene base is made of materials deposited after the opening for the Strait of Gibraltar and the regression of the Miocene Sea that occupied the Guadalquivir Depression, whose age ranges between 5 and 1.5 million years. Lithologically it is made of materials deposited in marine coastal and mixed environments, with continental lake episodes, argillaceous silt, sand and sandstone with

pectinides and conglomerates (“ostionera” rock) predominating, together with sand, gravel and limestone. Marls, sand and conglomerates, that can be easily eroded, predominate in the area of Rota.

These Tertiary materials are covered by a range of Quaternary sedimentary soils of varying from sandy, silty to clayey with an increase of fine contents with depth, although every layer can be inter-mixed with others. They have a brown colour at the more superficial levels (under the initial blackish mud) changing to grey tones at depth.

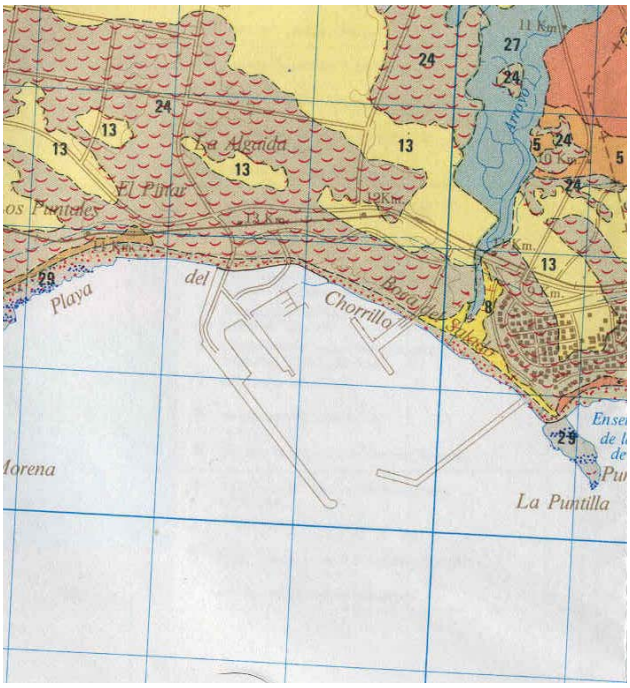
“Ostionera” rock is the local name for a limestone with shells that is full of small cavities. In spite of being very porous, it can be fairly impermeable if its pores are not intercommunicated. If the pores are intercommunicated it can have very high permeability (a kind of minikarst) that is difficult to detect in a geo-technical site investigation.

The Cadiz coast within the Naval Base has a NO-SE direction and is a very flat and sandy coastline, because the materials have been worn and the cliff has fallen, forming a small marine abrasion platform. Deposits of sand have been deposited over this platform, coming mostly from the erosion of the material that was Pliocene former coastal cliffs. The main feature is the presence of wide beaches of fine and white sand, with the presence of abundant coastal dunes, as the result of strong winds in the area.

As the Base is located on the sea, in an off-shore area, logically, the page in the Geological Map of Spain (1,061 Cadiz) on a scale of 1:50,000 does not give any geological information on the materials where the harbor installations are located, as can be seen in figure nº 2, for which reason the geological analysis carried out is considered to be sufficient for the study, with an in-depth geo-technical analysis of the materials in the following sections.

Figure No.3 shows sheet 1.061 (Cadiz) of the Geological Map of Spain at a scale of 1:50.000 for the area of the base at Rota.

Figure No.3. Details of the geological sheet 1.061 Cadiz of IGME 1:50.000 (not to scale).



5. DESCRIPTION OF AFFECTED LITOLOGIES

5.1. INTRODUCTION

Many geotechnical site investigations have been carried out for various design projects in the inner harbor and in the access channel to the Base.

The main litologies that have been found in the design zone are:

- Litology 1: Mud. Soft cohesive materials with high content of organic matter.
- Litology 2: Sands. Loose granular materials with a variable content in fine soils.
- Litology 3: Altered rock (altered Ostionera rock).
- Litology 4: Bedrock (Ostionera rock).

5.2. LITOLOGY 1 (MUD)

In this area a first level of mud, formed by silt with variable contents of sands, has been identified. These materials appear in a widespread manner and present a dark gray colour and important content of organic matter. These cohesive materials have a consistency of very soft.

These materials have a thickness of 0,40 m in the area next to the harbor entrance, and thickness from 2,00 to 4,00 in the inner harbor and in the access channel further offshore than 1.900 m.

Table No.8 sums up the laboratory testing made on this litology samples.

Table No.8. Laboratory testing litology 1.

Litology 1	Grain size distribution			Plasticity	
	Gravel (%)	Sands (%)	Fines (%)	LL	IP
Tets number	6	6	6	4	4
Average	0	26	74	62	32
Maximum	2	42	97	101	61
Minimum	0	3	58	32	12
Estandar deviation	0,83	15,12	15,24	30,72	21,64

These materials have been classified (using the USCS classification) as CH, CL, ML and MH.

5.3. LITOLOGY 2 (SANDS)

These materials are situated underneath the superficial level of mud (litology 1). This litology is made of sands with variable content of fine material. Samples of sands have been taken using vibrocores so the compactness of the sand is from *loose* to *very loose*.

In the rest of the access channel (further offshore than 1.900 m), the thickness of the sand that covers the “ostionera” rock increases depending of the distance to the entrance of the harbor. This thickness can be between 2,00 and 8,00 m.

Table No.9 sums up the laboratory testing made on this litology samples.

Table No.9. Laboratory testing on litology 2.

Litology 2	Grain size distribution			Plasticity	
	Gravel (%)	Sands (%)	Fines (%)	LL	IP
Tets number	9	9	9	1	1
Average	5	79	15	33	13
Maximum	29	95	45	33	13
Minimum	0	55	4	33	13
Estandar deviation	9,78	14,93	15,03	---	---

In eight other Atterberg limits tests results have been achieved not plastic samples.

These materials have been classified (using the USCS classification) as CH, CL, ML and MH.

5.4. LITOLOGIES 3 AND 4 (ALTERED ROCK AND BEDROCK)

In the different site investigations, a zone with outcrops of cemented materials has been located between the entrance of the harbor and a distance of approximately 1.900 m offshore. These materials have been initially identified as “ostionera” rock. In this area these materials also appear with an overlying layer of sand with a thickness between 0,50 and 1,00 m. For Ostionera rock a 30 cm thickness of the packages was taken.

The ostionera rock has a fairly erratic distribution; it is made up of layers from the sedimentation of shells with different degrees of alteration. In this way, levels with very low values of resistance to compression can be found of around 0,2 to 0,5 MPa next to layers with values of 5 MPa and, very occasionally, values of 15 MPa).

Table No.10 sums up the compressive strength and Point Load Test made on these litologies samples.

Table No. 10. Point load test and Compressive strength.

Litologies 3 and 4	Load point test		Comp. strength (MPa)
	Is(kPa) (MPa)	Is(50) (MPa)	
Tets number	15	15	10
Average	1	0	4
Maximum	2	2	16
Minimum	0	0	1
Estandar deviation	0,40	0,41	4,48

It is verified that the results of compressive strength tests match with the typical values that have been obtained on samples of this litology for other studies.

6. GEOTECHNICAL RECOMMENDATIONS FOR THE DESIGH

6.1. RECOMMENDED GEOTECHNICAL PARAMETERS

The geotechnical parameters needed to develop this project have been defined from the information of the site investigations carried out in the area of the Naval Base of Rota.

These parameters have been estimated taking into account:

- Boreholes with sampling.
- On-site testing while drilling.
- Laboratory testing.
- Specialized bibliography (ROM 0.5-05, Geotechnical recommendations for the design of maritime and harbor works. Grundbau-Taschenbuch, 3th ed. 1st Part, 1980. Geotecnia y Cimientos Tomo III, J.A. Jiménez Salas).

Table No.11 shows the geotechnical parameters used to make the calculus.

Table No.11. Geotechnical parameters.

Litology	Bulk saturated unit weight (kN/m^3)	Effective cohesion c' (kPa)	Internal friction angle ϕ' (º)
1 (Mud)	17,0	5	15
2 (Sands)	19,0	5	25
3 (Altered rock)	20,0	50	45
4 (Bedrock)	20,0	150	45

The parameters that will be used for the stability calculation will be defined starting from these values, using the recommended calculation hypothesis and simplifications.

6.2. RECOMENDATIONS FOR DREDGING

6.2.1. Excavability

The Quaternary materials that will be affected in the dredging process are mud (litology 1) and sands (litology 2). Based on the testing made on samples of these litologies (grain size distribution and Atterbeg limits), it is recommended to be used suction dredging for these materials.

The main rock materials that will be affected by the dredging are lithologies 3 and 4 (altered rock and bedrock). In both cases it is the ostionera rock with different cementation and alteration degrees depending on the proximity to the seabed. The nearer the material is to the seabed, the less cemented and more altered the material is.

To evaluate the excavability of theses material Compressive Strengh and Load Point Test have been done.

To evaluate the rock excavability from the tests above, the following methods have been considered:

- Franklin Method (1971).
- Franklin Method modified by Romana (1995) from the data of Abdullatif and Crudden.

6.2.1.1. Franklin Method (1971).

Franklin et al. (1971) intended to classify the rock mass with two parameters:

- Load-Point Index (I_s)
- Spacing between fractures or Fracture Index (I_f)

Figure No.12 shows the "Size–Strength" rock mass classification after Franklin, to study the excavation methods and the relation between the load-point index and other tests and geomechanical parameters.

Figure No.4. Rock mass classification for Compressive strength (Franklin et al. 1971)

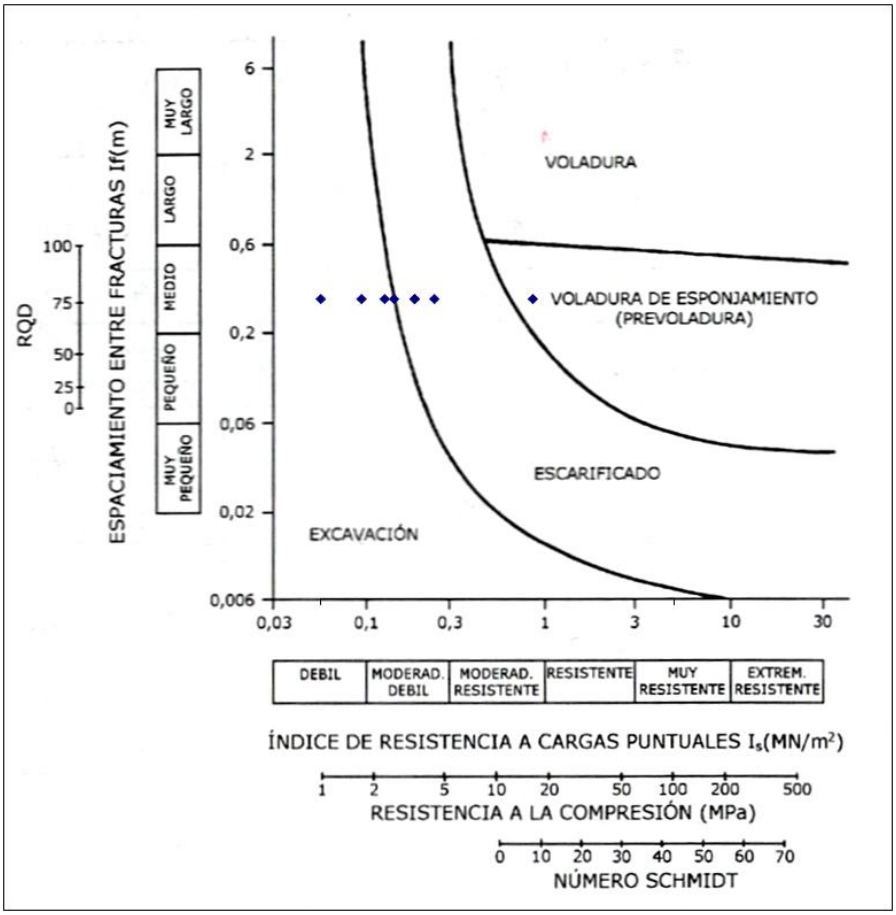
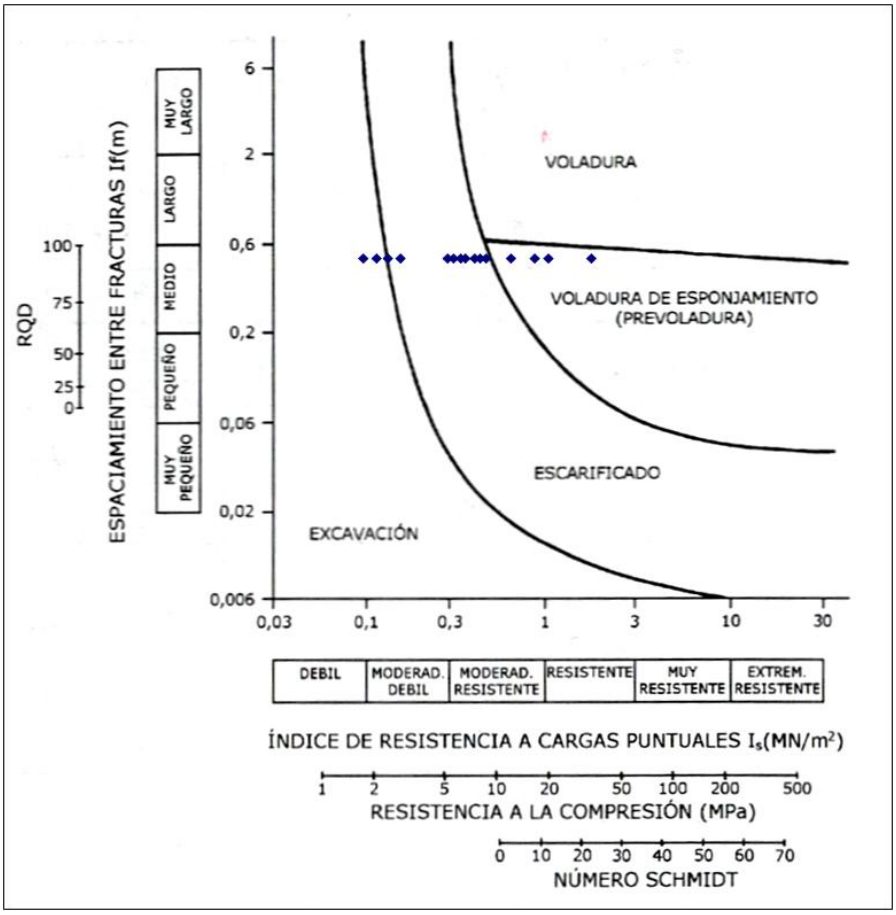


Figure No.5. Rock mass classification for Point Load Test (Franklin et al. 1971)

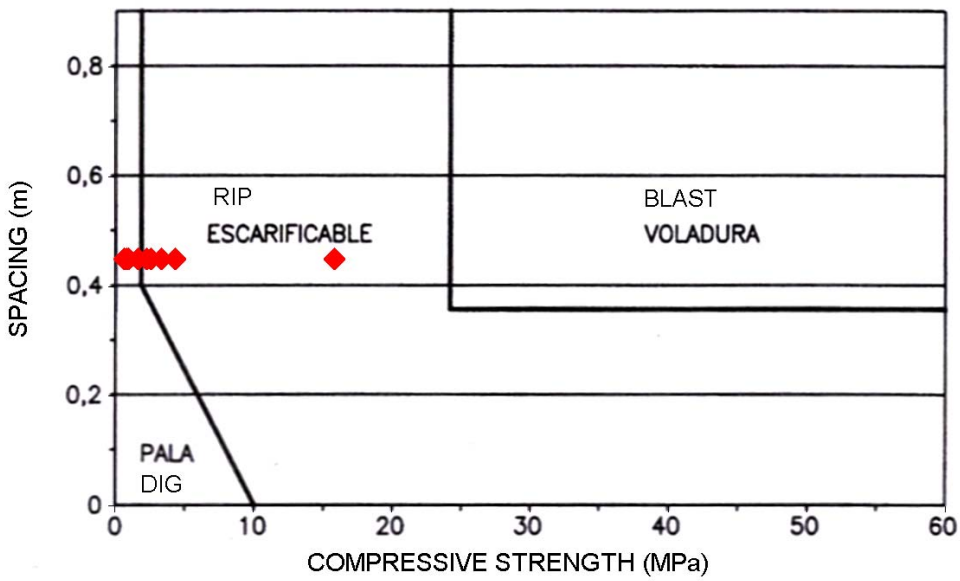


As it can be seen, there are four zones, according with the measured parameters. It is observed that most of the points are in the excavations and rip zones, except one of the point which is in the blast fragmentation zone.

6.2.1.2. Franklin Method (1974) modified by Romana (1995) from the data from Abdullatif and Crudden

Romana combines the data from Abdullatif and Crudden with the Franklin diagram based in the compressive strength and the spacing between fractures. This modification is shown in *figure No. 13*.

Figure No.6. Classification for the excavability (Romana, 1997)



As it is observed, all the points are in the DIG or RIP zone.

6.2.2. Abrasivity of the materials

The way of breaking a rock has an important influence on the wear of the cutting or excavations tools as I can produce complex process.

Although it exists an interrelation between the hardness and the abrasiveness in the rocks, in some soft materials, if the rock breaking is done with continuous equipment for cutting, the wears can be an important item in the excavation cost.

There are several methods to determine the abrasiviness of rockmaterial, according to the method that will be used in the breaking. Taking into account the characteristics of the rock samples, it has been considered appropriate to evaluate this property with the Cerchar abrasiveness test.

In the Cerchar test, a sharp steel indenter of 90º cone angle is applied to the surface of a rock specimen with a static force of 70 N (7 kg). The steel point is then slowly moved on 10 mm. The abrasivity of the rock is obtained by measuring with a microscope the resulting wear flat on the steel cone. The unit of abrasivity is defined as a wear flat of 0,1mm diameter.

The abrasivity scale is given in the *Table No.12* below:

Table No.12. Abrasivity scale

ABRASIVITY SCALE	CERCHAR
Extremely abrasive	>4,50
Very high abrasive	4,25 – 4,50
Abrasive	4,0 – 4,25
Moderately abrasive	3,50 – 4,00
Medium abrasive	2,50 – 3,50
Little abrasive	1,20 – 2,50
Not very abrasive	<1,20

From the obtained results (1.1, 0.9 and 1.5) these materials are classified as little abrasive or not very abrasive.

6.2.3. Conclusions

From what has been said in the previous paragraphs, the materials belonging to the altered rock and bedrock lithologies can be ripped in the first 2 meters. As the samples have been taken from the superficial zones, it is recommended to use blasting (blast with prefisuring) in the materials with a depth of more than 2 meters in litologies 3 and 4.

6.2.4. Recommended dredging slopes

6.2.4.1. Introduction

The dredging, depending on its main aim, can be of the following types:

- The one with the aim of increasing the draught in the basin and in the sailing channels.
- The one to obtain borrow materials for harbor our coastal backfilling and regeneration of beaches.
- The one necessary to execute the maritime works with the aim of reaching soils with higher quality for its foundation, taking out the soft soils, or the one necessary in the constructive process as it can be the removal of the provisional fillings.

At the same time, the dredging of the first two types can be of the first planting or for maintenance, but this classification has not a geotechnical point of view.

The dredging in this project is of the first type as it pretends to increase the draught in the harbor and in the access channel.

6.2.4.2. Dredging slopes

Although the analyses of dredging stability have to follow the usual calculation criterions, the works of dredging are however specific and they require some special considerations to keep in mind while calculating.

For the study of dredging slope stability, it is considered long-term conditions both for the cohesive materials, corresponding to the superficial muds (lithology 1) and for the granular materials (lithology 2, sand)

This calculation will take the values of cohesion and angle friction recommended in the paragraph 6.1. Recommended geotechnical parameters, and the unit weight will be the submerged unit weight of the material (it is one of method that considers the presence of water).

To be on the security side, it will be considered a seepage gradient of pore water from the inside to the outside part of the slope. Under this consideration the angle of internal friction used in the calculations is the following:

$$\tan \phi_{design} = 0{,}5 \tan \phi$$

To recommend the dredging slope, two type sections have been analysed with the program SLOPE/W, using the Spencer method.

This program allows to calculate with the theory of limiting equilibrium a factor of safety to the slope failure in soils or altered rock. This program has been developed bay Geo-Slope International to calculate the slope stability by the resolution of the equations of equilibrium with different methods: Fellenius, Bishop, Janbu, Spencer, Morgenstern-Price, Lowe-Karafiath and U.S. Corps of Engineers. All this allows to calculate any kind of slip surface.

The first type section has a depth of 4,00 m. The superficial muds (lithology 1) has a thickness of 1,50m and the sand level 2,5m.

The second type section has a depth of 4,00 m. The superficial muds (lithology 1) has a thickness of 1,00m, the sand level is 1,5m thick and the rock material has a thickness of 1,50m.

For these materials, in the two sections, the following parameters in *table No.13* have been used.

Table No.13. Calculation parameters.

Litology	Submerged unit weight (kN/m^3)	Effective cohesion c' (kPa)	Internal friction angle ϕ' (º)
1 (Mud)	7,0	0,25	7,5
2 (Sands)	9,0	0,25	13
3 (Altered rock)	10,0	50	45

Litology	Submerged unit weight (kN/m^3)	Effective cohesion c' (kPa)	Internal friction angle ϕ' (º)
4 (Bedrock)	10,0	150	45

Table No.14 shows the safety factors obtained in the two calculations sections.

Table No.14. Safety factors for dredging slopes.

SECTION	SLOPES (H:V)	SAFETY FACTORS
1	Litology 1: (5H:1V) Litology 2: (5H:1V)	1,512
	Litology 1: (6H:1V) Litology 2: (6H:1V)	1,766
2	Litology 1: (5H:1V) Litology 2: (5H:1V) Litology 3: (1H:1V)	1,794
	Litology 1: (6H:1V) Litology 2: (6H:1V) Litology 3: (1H:1V)	2,020

The calculations are shown in the *Appendix 3. Stability calculations for recommended dredging slopes*.

The obtained factors of safety are higher, in all cases, than those minimum recommended in the ROM 0.5-05 (1,3, for the long-term). According to the results, it is reasonable to recommend a slope of 5H:1V or 6H:1V for the dredging in lithologies 1 and 2. In the rock materials a slope of 1H:1V is recommended.