CEDA-WEDA International Seminar

UNDERWATER ROCK BLASTING FOR DREDGING

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Dredging Industry Challenges

- Ports and waterways are involved in deepening projects
- Dock bigger ships
- Dredging of hard materials
- Rock hardness and the rock geotechnical characteristics at any dredging site have a major influence on the performance of a dredge

Rock Hardness Description

- No standard, universal system of descriptors that will directly indicate, or infer, the dredgeability of a rocky subbottom
- All geotechnical engineering soil/rock classification systems were developed for land-based earthwork construction
- There are not directly applicable rock hardness description to the needs of the dredging industry

Relative Strength	Unconfined Compressive Strength	
	MPa	Tons/sq ft.
Very weak	< 1.25	< 12.5
Weak	1.25 - 5.0	12.5 - 50
Moderately weak	5.0 - 12.5	50 - 125
Moderately strong	12.5 - 50.0	125 - 500
Strong	50 - 100	500 - 1,000
Very strong	100 - 200	1,000 - 2,000
Extremely Strong	> 200	> 2,000

Rock Hardness Description

Consistency Term	Unconfined Compressive Strength		
	USCS (HQUSACE 1960)		PIANC (1984)
	Tons/sq ft.	KPa	Kpa
Very soft	0 - 0.25	0 - 25	0 - 40
Soft	0.25 - 0.50	25 - 50	40 - 80
Medium (firm)	0.50 - 1.00	50 - 100	80 - 150
Stiff	1.00 - 2.00	100 - 200	150 - 300
Very stiff	2.00 - 4.00	200 - 400	
Hard	> 4.00	> 400	> 300

WATER BORNE SHOCKWAVES

- Detonation of an explosive charge results in a rapidly expanding gas filled cavity
- The maximum pressure reaches a value of about 100,000 atm in the boundary layer of the explosive charge. At some feet distances from the charge the value of 1000 atm is reached (Zoltan, 1976). At greater distances the value decreases below 100 atm
- The pressure within the resulting explosion gas bubble eventually falls below the ambient hydrostatic pressure, at that point the process is reversed and the bubble is compressed
- Due to buoyancy, this oscillating bubble keeps on rising at the same time until it reaches the surface
- Each re-expansion of the bubble is similar to an explosion of decreasing strength
- These results in a series of bubble pulses. The result is a pulsating bubble of gas slowly rising to the surface, with each expansion of the bubble creating a shock wave

WATER BORNE SHOCKWAVES ENERGY

- ET=Eb+Es (Mohanty, 2000).
- **$Es=((4\pi r^2)/\delta C_w)\int tP_t^2dt$**
- **$Eb=(1/8C^3L_1^3)((1+4CT_b(P_h/P_{hh})^{5/6})-1)^3$ (Cameron and Alastair, 1990).**
- The maximum pressure of the shock wave from an enclosed charge is only 10 to 14% of the maximum pressure of a shock wave from an explosive hanging free in the water

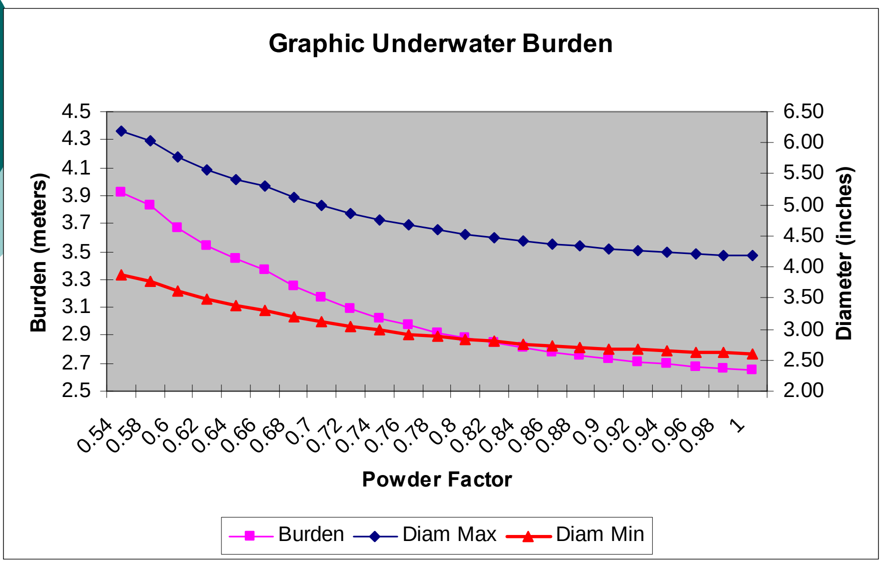
"Sub Blast" Burden formula

$$B^{1.28}=[5.2x10^{2}\ \delta\ (\sqrt[3]{W})^{1.28}]/0.7\sigma$$ ©

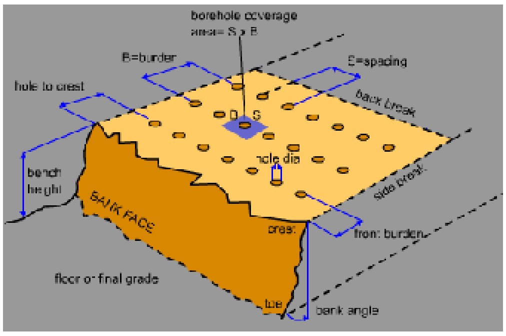
- Valid for rocks with USCS not less that 30 MPa
- Loading factors are therefore bigger when compared to normal bench blasting,
- Uniform rock fragmentation can also be obtained
- Subdrilling underwater must exceed 60% of the burden length

Underwater Burden

Power Factor (kg/m3)	UCS (kg/cm²)	Explosive Charge kg (Pound)	Burden (m)	Diameter	
				Min. (in)	Max. (in)
0.54	305.7	32 (70)	3.93	3.86	6.18
0.58	356.65	36 (79)	3.83	3.77	6.02
0.6	407.6	40 (88)	3.67	3.61	5.77
0.62	458.55	44 (96)	3.54	3.49	5.58
0.64	509.5	48 (105)	3.44	3.39	5.42
0.66	560.45	52 (114)	3.36	3.31	5.29
0.68	611.4	54 (118)	3.26	3.20	5.13
0.7	662.35	56 (123)	3.17	3.12	4.98
0.72	713.3	58 (127)	3.09	3.04	4.87
0.74	764.25	60 (132)	3.03	2.98	4.76
0.76	815.2	62 (136)	2.97	2.92	4.68
0.78	866.15	64 (140)	2.92	2.88	4.60
0.8	917.1	66 (145)	2.88	2.83	4.53
0.82	968.05	68 (149)	2.84	2.80	4.47
0.84	1019	70 (154)	2.81	2.76	4.42
0.86	1069.95	72 (158)	2.78	2.74	4.38
0.88	1120.9	74 (162)	2.75	2.71	4.34



Drilling Pattern



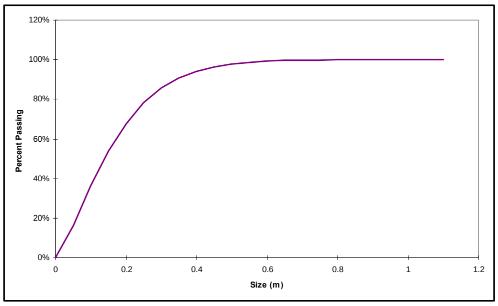
Fragmentation Analysis

Blastability Index	6.345
Average Size of Material	14 cm
Uniformity Exponent	1.34
Characteristic Size	0.18 m

Fragmentation Target Parameters	
Oversize	0.5 m
Optimum	0.3 m
Undersize	0.1 m

Predicted Fragmentation Distribution	
Percent Oversize	2.1% m
Percent In Range	61.8% m
Percent Undersize	36.1% m

Percent Passing	Size (m)
0.0%	0
16.3%	0.05
36.1%	0.10
53.7%	0.15
67.7%	0.20
78.2%	0.25
85.7%	0.30
90.8%	0.35
94.2%	0.40
96.4%	0.45
97.9%	0.50
98.7%	0.55
99.3%	0.60
99.6%	0.65
99.8%	0.70
99.9%	0.75
99.9%	0.80
100.0%	0.85
100.0%	0.90
100.0%	0.95
100.0%	1.00
100.0%	1.05
100.0%	1.10



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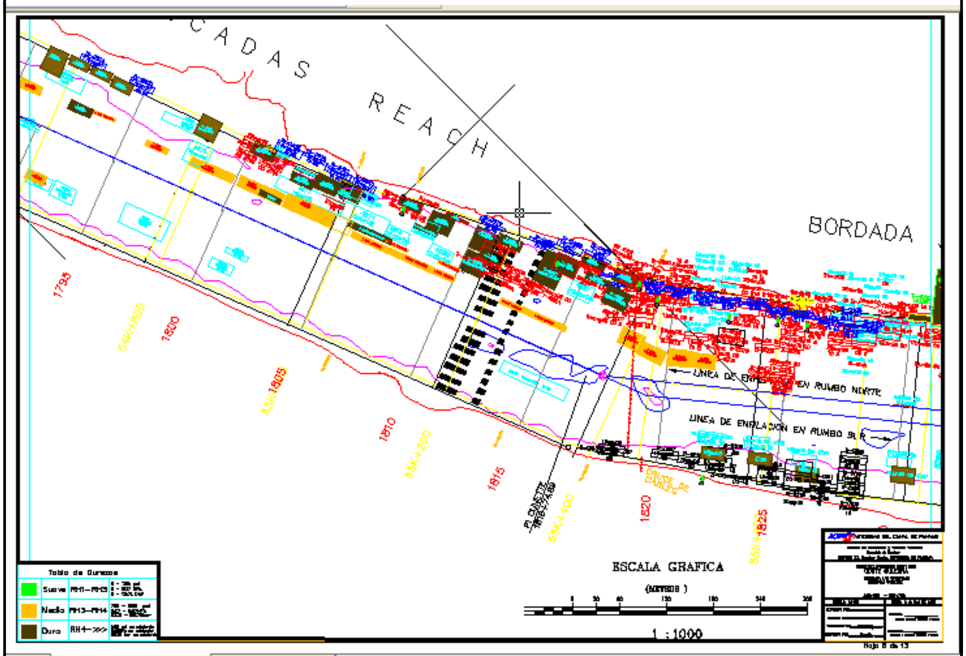


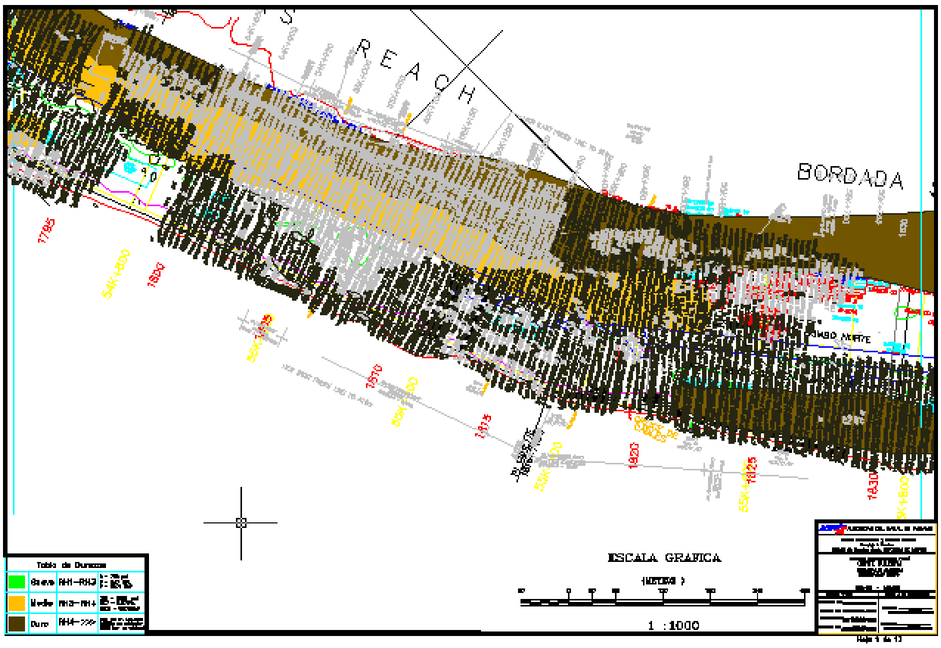
ROCK HARDNESS REFERENCE TABLE

	Thor	Barú
SOFT	0 – 250 lbs/in^2	0 – 17 bar
MEDIUM	250– 500 lbs/in^2	17 – 34 bar
HARD	> 500 lbs/in^2	> 34 bar

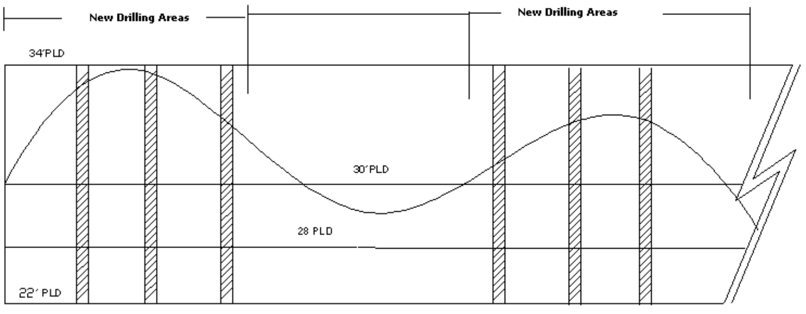
Drilling Rate

$$Dr = ((R_f - 28\log(\boldsymbol{\sigma}/100))((P/1000)d_{in})(r/300))/60$$

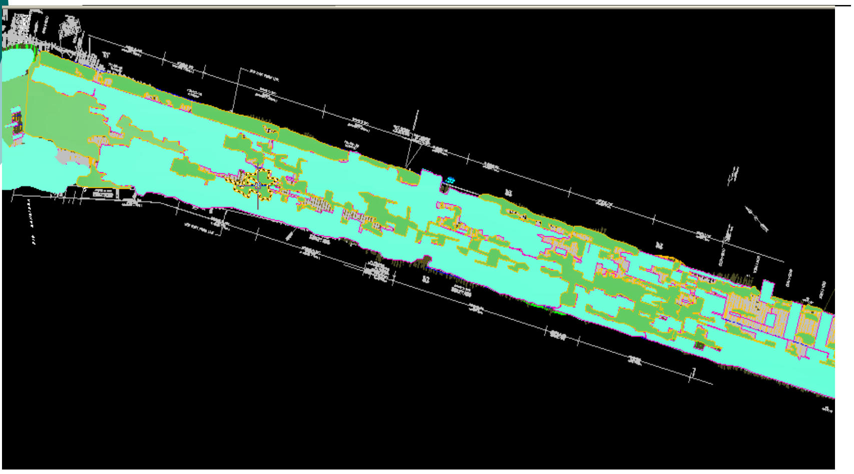
Location	Rock Formation	Rock Hardness	Rock Type	Compressive Strengh (PSI)	Rotation Speed (RPM)	Bit Load (lb./in. dia.)	Rock Factor	Pull Down (Lbs)	Diameter inches	Rotation Torque ft.-lb
La Pita Hill	Las Cascadas	Medium Hard	Andesite	2950.35	80	1000 to 4000	150	20000	6.5	3000
La Pita Hill	Las Cascadas	Medium Hard	Aglomerate	2436	90	1000 to 4000	165	20000	6.5	3000
La Pita Hill	Las Cascadas	Soft	Aglomerate	418.83	80	1000 to 4000	200	20000	6.5	2700
La Pita Hill	Las Cascadas	Medium Hard	Ash-Flow	2191	80	1000 to 4000	170	20000	6.5	3000
Culebra East	Cucaracha	Soft	Clay Shale	281	110	1000 to 4000	230	20000	6.5	2700
Culebra East	Cucaracha	Soft	Lignic Shale	378	105	1000 to 4000	230	20000	6.5	3000
Culebra East	Cucaracha	Soft	Sandstone	345	105	1000 to 4000	230	20000	6.5	3000
Culebra East	Cucaracha	Mod. Soft	Conglomerate	626.5	100	1000 to 4000	230	20000	6.5	3000
Las Cascadas	La Boca	Mod. Soft	Sandstone	771	100	1000 to 4000	230	20000	6.5	3000
Las Cascadas	La Boca	Soft	Limestone	1836	95	1000 to 4000	230	20000	6.5	3000
Las Cascadas	La Boca	Soft	Silstone Carb.	493	105	1000 to 4000	230	20000	6.5	3000
Las Cascadas	La Boca	Soft	Sandstone Carb.	503	105	1000 to 4000	230	20000	6.5	3000
Cerro Nitro	Basalt	Hard	Basalt	11684	70	5400	90	37000	6.5	5500
Cerro Nitro	Basalt	Medium Hard	Basalt/weak plane	3058	70	3000 to 5000	125	27000	6.5	4200
Contractor	Basalt	Hard	Basalt	15000	60	5400	80	37000	6.5	5500
Gold Hill	Basalt	Medium Hard	Basalt/weak plane	3058	70	3000 to 5000	125	27000	6.5	4200



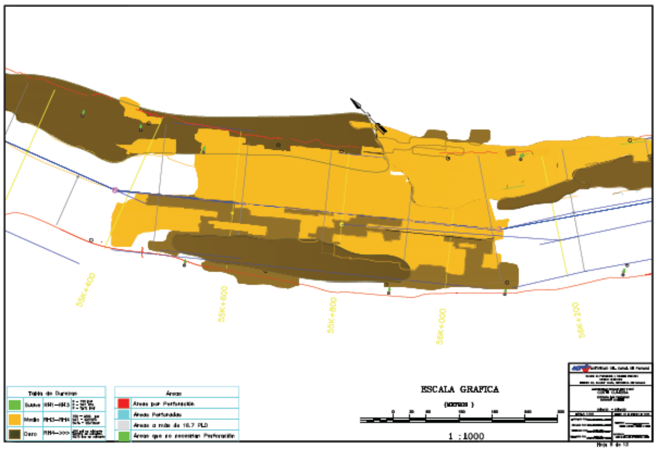
Scheme of Drilling Areas



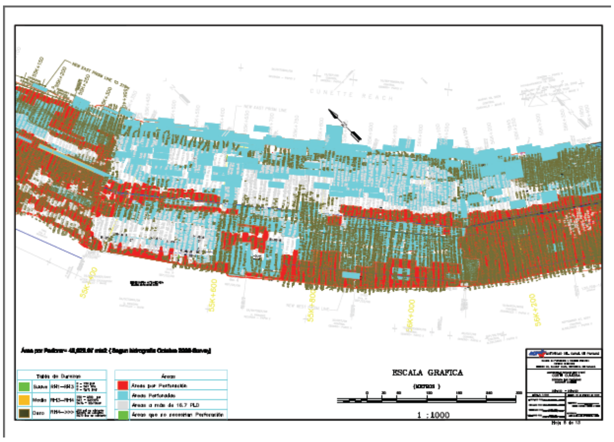
Effective Areas to D&B



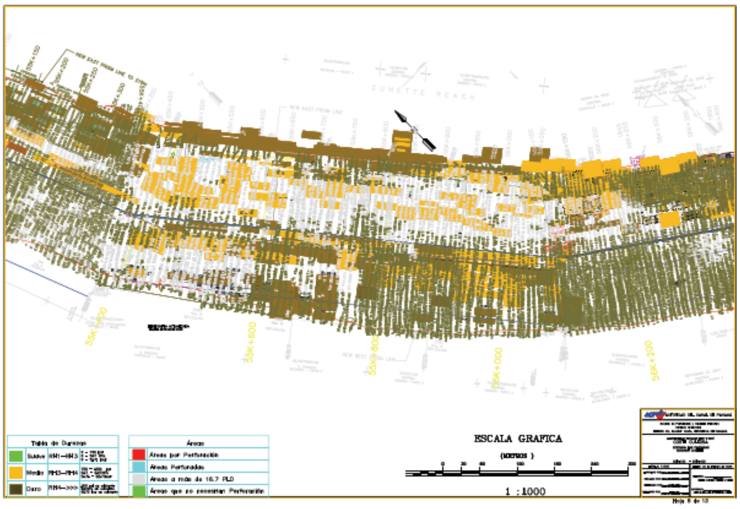
Cunette Reach



Cunette Reach



Cunette Reach



Conclusions

- The dredging industry is facing an increasing use of underwater blasting for deepening projects
- Rock characteristics at a dredging site have a major influence on a dredge performance.
- Feasibility and cost competition for final removal prices depend on fragmentation and the variety dredging equipment.
- With the offered approach, it is possible to set initial drilling and blasting geometrical patterns and explosive charge parameters related with rock mass characteristics.
- Variables guide the blasting strategies that match or sustain appropriate competitive dredging plans.