Use of concrete formulations based on dredging sand in the fabrication of tetrapods for protection of harbour dykes

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Abstract: Port structures (quays and dykes) need an enormous consumption of materials, in particular concrete and its components, as well as sand, hence the need to develop alternative solutions using port dredging sand, estimated at thousands of tonnes through its use in the concrete that forms the blocks of the quay walls. After having demonstrated in a previous work the possibility of using the dredged sand from the port of Agadir in concrete formulations, the present work consists in showing the possibility of using the dredged sand from the port of Agadir in concrete formulations that can be used in the construction of concrete tetrapods from a concrete formulation based on dredged sand, more precisely 50% of the sand entering in the formulation is dredged sand extracted from the port of Agadir. The eventual use of dredged sand in the concrete of the tetrapods will lead to enormous gains in the quantities of sand and thus to a lower consumption of construction materials, and will also play a more important role in the preservation of the marine environment by avoiding the trapping of the dredged materials.

1 INTRODUCTION

Wave protection structures are structures that protect a port or part of a port against the actions of waves (direct attack, crossings, submersion, erosion, etc.). They are man-made structures, except for natural structures which may have the same functions, among these structures are tetrapod dikes, which are structures that provide protection against waves by placing tetrapods in a shell and a core made of riprap. Tetrapods are four-legged structures, used particularly in hydraulic engineering as part of breakwaters to resist waves and swells.

Typically, tetrapods are made of concrete, not reinforced, and have four members with a curved profile designed to minimize the impact of marine flows. The design of the structure allows the blocks to be interlocked, which, when used in masses, allows coastal protection to be reinforced or even to gain surface areas out of the water on the sea.

The use of tetrapods in particular is very widespread, and their fabrication requires large quantities of concrete and subsequently large quantities of sand, which is why it was necessary to look for alternative solutions to substitute sand

and why it is proposed subsequently to replace the sand in the concrete formulations with dredging sand extracted from the port of Agadir. By analysing the different constituents of the concrete formulations studied afterwards, as well as the results obtained, we will conclude on the possibility of finding concrete formulations based on dredging sand able to be used in concrete for tetrapods.

Figure 1: Tetrapod breakwater for protection against swells

2 THE STUDY OF THE CONCRETE COMPOSITION OF TETRAPODS BASED ON THE DREDGED SAND OF THE PORT OF AGADIR

2.1 Origin of materials

The materials used in the fabrication of tetrapods concrete from the dredged sand of the port of Agadir are composed of :

- Crushed aggregates from the Ynoub quarry located in Ighoud in the Agadir region;
- Dredging sand from the port of Agadir;
- Crushing sand;
- Cement CPJ55PM from the CIMAR Aït Baha plant in the Agadir region;
- Viscocrete Tempo 1000M admixtures from the company SIKA MAROCCO;
- Mixing water which is well water.

2.2 Characteristics and materials performance testing

2.2.1 Aggregates

The values of the intrinsic and production characteristics of the aggregates are given in the table below:

Table 1: Characteristics of the aggregates

Identification of gravel			
Samples	Origin	flattening factor %	Cleanliness
GI	Ech 1	15<30	0,9<1,5
GII	Ech 1	17<30	0,8<1,5

2.2.2 Sands

The characteristics of the sands are given in the following tables

Table 2: CHARACTERISTICS OF THE SANDS

Samples	Dma x mm	%<0,080 mm	Sand equivalent (SE) %	Fineness modulus
Dredging sand	1,6	0,9	-	-

Crushing sand	8,0	11,2	-	-
Mixing (50% dredging sand + 50% crushing sand)	6,3	6,6	80	2,46

2.2.3 Other tests carried out on the aggregates and sands of the studied formulation

Laboratory tests were also carried out for the GI and GII aggregates, the crushing sand and the dredging sand from the port of Agadir in order to enable us to make a preliminary decision on the effectiveness of the tetrapod concrete formulation studied.

The autoclave test carried out on the mixture made up of 50% crushed sand and 50% dredging sand qualified the mixture as non-reactive (NR).

Table 3: GENERAL CHARACTERISTICS OF AGGREGATES AND SAND

Designation	GII 16/31.5	GI 4/16	SC 0/4	SD	Standard
Flattening A (%)	21	20	--		< 25 *
Absorption Ab (%)	0.5	0.8	0.8	0.6	< 2.5 *
Cleanliness (%)	0.2	1.1	--		< 1.5 *
ESV mixture * (%)	--	--	79		ESV > 75 ou VB < 1
Mf of mixture* (%)	--	--	2.1		2 < Mf < 3
Content of fines F*(%)	--	--	7.8		≤ 12
Organic materials	--	--	—		negatif
Alkali reaction	NR		NR		C Level

Table 4: AUTOCLAVE TEST RESULTS

Tests	Value %	Requirement %	Test method
Alkali	0,06	0,15	NM

reaction (Expansion in % C/G= 0.5)			10.1.279
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The expansion value obtained on the mixture (50%SC + 50%SD) is lower than the maximum limit value set by the standard NM 10.1.271, version 2008. Therefore, this mixture is non-reactive with respect to the alkali reaction (NR).

2.2.4 Cement

The cement used is CPJ55 Prise Mer with limestone filler manufactured by the CIMAR plant located in Aït Baha-Agadir. The summary of the results of the cement self-checking tests is attached below. The cement used for the study formulas has a resistance at 28 days is 51.7MPa.

Table 5: CEMENT TEST RESULTS CPJ 55

	p.a.f	MgO	SO ₃	Na ₂ O	K ₂ O	Cl
Average	5,98	1,58	2,85	0,12	1,47	0,01
Standard deviation	0,60	0,25	0,14	0,04	0,13	0,0
Max	6,98	1,96	3,09	0,17	1,81	0,02
Min	4,72	0,92	2,61	0,0	1,29	0,01

	Insoluble dans HCl	SSB	% water	Start of setting	RC2J	RC7J	RC28J
Average	0,96	4100,70	28,17	183,38	29,90	40,05	50,03
Standard deviation	0,09	191,15	0,25	8,92	2,01	1,78	1,97
Max	1,14	4559,0	28,70	198,0	32,60	44,20	52,90
Min	0,85	3807,0	27,70	165,0	25,30	36,60	45,60

2.2.5 Admixture

The admixture used for this concrete is Sika Maroc's Viscocrete Tempo 1000M, which is a new generation superplasticizer with high water reducer properties.

In self-compacting concretes, SIKA VISCOCRETE TEMPO 1000 M improves stability, limits concrete segregation and makes the formulas less susceptible to variations in water and constituents.

SIKA VISCOCRETE TEMPO 1000 M allows a significant reduction of the W/C ratio which improves the durability of the hardened concrete (reduced permeability, increased mechanical resistance, reduced shrinkage).

SIKA VISCOCRETE® TEMPO 1000 M does not contain chlorides or other substances that may cause or promote chloride reactions. The table below lists the characteristics taken from the technical data sheet:

Table 6: CHARACTERISTICS OF ADMIXTURE

Designation	Technical Data Sheet
Extrait Sec	28.5 ± 1.5%
PH	4 ± 1
Alcalins	≤ 1%
Density	1.07 ± 0.02

2.2.6 Compatibility tests Admixture and Concrete Constituents

Concrete formulations were studied by analyzing the change and variation in the percentage of admixture in the concrete formulation.

The table below summarizes the results found:

Table 7: COMPATIBILITY TESTS ADMIXTURE AND CONCRETE CONSTITUENTS

Designation	Test concrete	Same W/C		Same consistence	
		0.5* Ad m.	2 Ad m.	0.5 Ad m.	2 Ad m.
Gravels 16/31.5mm	750 Kg	750Kg	750Kg	750Kg	750Kg
Gravels 4/16mm	455 Kg	455 Kg	455 Kg	455 Kg	455 Kg
Crushing sand.0/4mm	390 Kg	390 Kg	390 Kg	390 Kg	390 Kg
Dredging Sand	390 Kg	390 Kg	390 Kg	390 Kg	390 Kg

0/0.63 mm					
Cement CPJ55 PM	300 Kg	300 Kg	300 Kg	300 Kg	300 Kg
Total water	163 L	161 L	157 L	149 L	114 L
Viscocrète Tempo 1000M	--	1.65 Kg	6.6 Kg	1.65 Kg	6.6 Kg
W/C	0.50	0.50	0.50	0.47	0.35
Slump à T0	30mm	90mm	*NM	55mm	65mm
Density of fresh concrete (T/m ³)	2.40	2.41	2.40	2.42	2.45
Air content (%)	3.1	2.6	2.3	2.4	1.9
T° Concrete	23.2	23.6	24.1	23.7	23.0
T° of constituents (°C)	water=20.8 ; SC0/4=22.1 ; SD=23.2 ; Gravels=22.0 ; T° Admixture=21.7 ; T° Cement=23.9				
RC à 3j (MPa)	13.7	15.3	18.4	19.6	32.8
RC à 28j (MPa)	32.8	34.1	36.7	38.2	54.4

2.3 Nominal composition of the studied concrete formulations of tetrapods based on dredged sand from the port of Agadir

The composition of the studied concrete formulation was carried out by the method of Deux Goriss, thus three formulations were carried out to find the composition of each constituent of the concrete of the tetrapods based on dredged sand and using a 3rd generation admixture to significantly improve the results found.

Table 8: NOMINAL COMPOSITION OF THE STUDIED CONCRETE FORMULATIONS OF TETRAPODS BASED ON DREDGED SAND

Designation	Concrete (d=2.40T/m ³)		
	Formula1	Formula2	Formula3
Gravels 16/31.5mm	750 Kg	750 Kg	750 Kg
Gravels 4/16mm	455 Kg	455 Kg	455 Kg
S.C. 0/4mm	390 Kg	390 Kg	390 Kg
Dredging Sand	390 Kg	390 Kg	390 Kg
CementCPJ55PM	300 Kg	300 Kg	300 Kg
Total water	140 L	140 L	140 L
Viscocrète Tempo 1000M	3.3 Kg	3.3 Kg	3.3 Kg
E.eff. / cement	0.43	0.43	0.43
Slump-test T0	180mm	170mm	180mm
Slump-test T30	140mm	130mm	150mm
Slump-test T60	60mm	60mm	70mm
Air occluded (%)	2.1	2.3	2.3
Density of fresh concrete (T/m ³)	2.44	2.42	2.43

2.4 Results found for the concretes of the studied formulations

The results of the hardened concretes of the studied formulations are summarized in the following table:

Table 9: RESULTS OF THE HARDENED CONCRETE OF THE FORMULATIONS STUDIED BASED ON DREDGING SAND

Designation	Concrete (d=2.40T/m ³)		
	Formula1	Formula2	Formula3
RC à 7j (MPa)	34.1	32.7	31.9

RC à 28j (MPa)	43.9	43.2	42.6
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The arithmetic mean f_{cE} of the 9 measurements (3 measurements per formula) of the compressive strength measured at 28 days shall satisfy the following 2 conditions:

- $f_{cE} > f_{c28} + (C_{e_Cmin})$
- $f_{cE} > f_{c28} + 3$

Table 10: RESISTANCE OF THE STUDIED CONCRETE

Concrete	f_{c28}	f_{cE}	C_e
Concrete B25 $d=2.4T/m^3$	25	43.2	51.7

Concrete	C_{min}	$f_{c28} + (C_e - C_{min})$	$f_{c28} + 3$
Concrete B25 $d=2.4T/m^3$	42.5	34.2	33

For Concrete B25, we therefore have :

- $43.2 > 34.2$ MPa conform;
- $43.2 > 33$ MPa conform.

3 Conclusion

The studied formulation based on dredged sand from the port of Agadir in percentage with crushed sand and materials from the region gave good results and characteristics in terms of mechanical resistance, the formulation has shown that it can be used in the fabrication of tetrapods and that they can be used as protection against swells in port protection works.

The use of dredging sand in the production of tetrapods will allow to make a gain in terms of the deposit of construction materials and to develop the resource of dredging sand of the port of Agadir generally considered as waste.

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References

- Moore, R., Lopes, J., 1999. Paper templates. In *TEMPLATE'06, 1st International Conference on Template Production*. SCITEPRESS.
- Smith, J., 1998. *The book*, The publishing company. London, 2nd edition.
- J. Xiao, C. Qiang, A. Nanni, and K. Zhang, "Use of sea-sand and seawater in concrete construction : Current status and future opportunities," *Constr. Build. Mater.*, vol. 155, pp. 1101–1111, 2017. <https://doi.org/10.1016/j.conbuildmat.2017.08.130>
- M. HASSOUNE, G. CHRAIBI, H. FATMAOUI, J. CHAOUI, 2019. Requalification of dredging sediments through their use in concrete formulations based on a 3rd generation admixture. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2019.08.065>
- Plan qualité de dragage d'entretien du port d'Agadir-drapor / Data from the National Ports Agency at the port of Agadir
- P. Ozer-Erdogan, H. M. Basar, I. Erden, and L. Tolun, "Beneficial use of marine dredged materials as a fine aggregate in ready-mixed concrete: Turkey example," *Constr. Build. Mater.*, vol. 124, pp. 690–704, 2016. <https://doi.org/10.1016/j.conbuildmat.2016.07.144>
- Girish.C.G, "dredged offshore s and as a replacement for fine," vol. 8, no. 3, pp. 88–95, 2015.
- R. Mahendran, K. Godwin, T. G. Selvan, and M. Murugan, "experimental study on concrete using sea sand," vol. 7, no. 5, pp. 49–52, 2016.
- G. Dreux, J. Festa, , "Nouveau guide du béton et de ses constituants."
- Bathymetric surveys at the port of Agadir, Agence Nationale des Ports.
- C. Julien, "Gestion d ' un sédiment de dragage marin contaminé : Caractérisation de la réactivité biogéochimique , valorisation en mortier et évaluation environnementale Julien Couvidat To cite this version : HAL Id : tel-01368438," 2016.
- C. Sheehan and J. Harrington, "Management of dredge material in the Republic of Ireland - A review," *Waste Manag.*, vol. 32, no. 5, pp. 1031–1044, 2012. <https://doi.org/10.1016/j.wasman.2011.11.014>
- J. Limeira, L. Agullo, and M. Etxeberria, "Dredged marine sand in concrete: An experimental section of a harbor pavement," *Constr. Build. Mater.*, vol. 24, no. 6, pp. 863–870, 2010. <https://doi.org/10.1016/j.conbuildmat.2009.12.011>
- E. C. De Lille and E. C. De Lille, "Inertage et valorisation des sédiments de dragage marins," 2006.
- M. G. S. Dias, D. a R. Dolage, and C. T. Ariyawansa, "Offshore Sand as a Fine Aggregate for Concrete Production," vol. 3, no. 4, pp. 813–825, 2013. <https://doi.org/10.9734/bjast/2014/3290>
- J. Mindeguia, P. Pimienta, and C. La Borderie, "European Journal of Environmental and Civil

- Engineering,” no. May, pp. 37–41, 2012.
<https://doi.org/10.1080/19648189.2012.667682>
- EN 206-1, Norme européenne: béton-partie 1: spécifications, performances, production et conformité, AFNOR, jan.2000.
- P 18-542, Fascicule de documentation: Granulats courants pour béton hydraulique-critères de qualification des granulats vis-à-vis de l'alcali-réactions, AFNOR, mai 1994.
- Dragage en milieu marin , immersion et code de l'environnement: le guide des procédures préalables.
- R. Polder, “Durability of marine concrete structures_field investigations and modelling,”.
- Northern Ireland Environment Agency and Scottish Environment Protection Agency, “Interpretation of the definition and classification of hazardous waste,” 2005.
- A.R. Roeder, Some technical data on sea-dredged aggregates, in: Proceedings of the Symposium: Sea-dredged Aggregates for Concrete. Sand and Gravel Association Great Britain, Buckinghamshire, UK, 1968.
- S. Marmin, J. Dauvin, P. Lesueur, Ocean&coastal management collaborative approach for the management of harbour-dredged sediment in the Bay of Seine (France), *Ocean Coast. Manage.* 102 (2014) 328–339,
<http://dx.doi.org/10.1016/j.ocecoaman.2014.10.012>.
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