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Risk Assessment and Remedial Solutions of Coastal Flooding: Case Study of Hammam Lif Coastline, Northern Tunisia

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Abstract

This study focused on the coastal area of Hammam Lif, an urban zone – about 20 kilometers to the south of the capital city Tunis - threatened by flooding caused by rainwater and water generated by the wave run up on the shoreline area. In this study we evaluated the potential flood threat using in the calculation of runoff flow rate in the area of Hammam Lif caused firstly by rain and partly by the wave run up. The study, also, tried to highlight the wrong conceptual characteristics of the urban area infrastructure in Hammam Lif. In order to be able to face the potential flood threats caused by the rain in Hammam Lif, some adequate protective solutions were proposed and other soft protective solutions were suggested to face the wave run originating at the sea.

Keywords: Coastal flooding; Rain; Wave run up; Urban coastal zone; Beach nourishment; Artificial reef submerged formed by geotextile; Borrow site

Abbreviations: SC_1: Core Drilling 1; SC_2: Core Drilling 2; SC_3: Core Drilling 3; EI_{11}: Intact Sample Number 1 of the Core Sampling Number 1; EI_{12}: Intact Sample Number 1 of the Core Sampling Number 2; EI_{21}: Intact Sample Number 2 of the Core Sampling Number 1; EI_{31}: Intact Sample Number 3 of the Core Sampling Number 1; ER1d: Overhauled Sample Number 1 taken from the Carry Sand Drijet; ER2d: Overhauled Sample Number 2 taken from the Carry Sand Drijet; ER3d: Overhauled Sample Number 3 taken from the Carry Sand Drijet; ER1b: Overhauled Sample Number 1 taken from the Carry Sand Borj Hfaieth; ER2b: Overhauled Sample Number 2 taken from the Carry Sand Borj HJaieth; ER3b: Overhauled Sample Number 3 taken from the Carry Sand Borj Hfaieth; R: Wave Run Up

Context of the Study

It seems obvious from previous studies that the Tunisian coastal zone is subject to a risk of coastal flooding, mainly during storm periods, where the premium sea level can reach 1.13 m NGT for a 50-year old return period. The northern coastline, especially the beaches of the southern area of Greater Tunis, for the coasts that are relatively characterized by low altitude, the highly urbanized Rades, Ezzahra and Hammam Lif are threatened by flooding caused firstly by waves that can exceed the protective dikes (the action of wave run up) and secondly by resulting rain water, which in its greater percentage, flows through a highly urbanized area [1]. However, this area is rather a waterproof urban zone which sanitation networks are mostly old inadequate and easily over flown. Such a situation promotes the high chances of the flooding of the Wadi Méliane, the nearest to the study area [2].

This study focused on the evaluation of the flooding potential of the Hammam Lif coastline. This study is, therefore, made up of the component: Risk assessment of coastal flooding on the coastline of Hammam Lif and proposition of some protective solutions.

Flooding was studied relying on three simulations. The first highlighted only the rain component and its effect on the urban zone whereas the second dealt with the wave run up (the waves overcoming the breakwater to reach the area of habitats).

Two types of solutions were figured out: either solution by adding adequate coastal defense structures such as breakwaters, other rock fill dams, coastal protection cobs and or others through strengthening the already existing maritime structures against the ascending waves [3]. The choice of the solution obviously depends on several parameters such as the impact of the strength of the wave on the existing wall, the wave quality (beachcomber or not) and the crossing flow rate.

Location of the study area

The Beach of Hammam Lif is located in the central part and in the Gulf of Tunis NE / SW axis, between the restaurant called « la SIRENE » and the Municipal Stadium. The beach has a length of 1540 m and a width of 45 m (Figure 1).

The restricted area of study of the rain component and the wave run up component is 125,000 m^2 thus 12.5 Ha (Figure 2).

Materials and Methods

Study of the rain component: runoff flow rate calculation

Our calculations were carried out according to Eq. (1):

Runoff flow rate:

$$Q=K\times A\times W\times Pc \quad (1)$$

With K: conversion factor, A: Area, I: Intensity, PC: runoff coefficient.

Flow estimation by using transformation method of rainfall in runoff: the rational method in hydraulics: The oldest method of estimating peak flow from rainfall is called rational method (Figure 3). The rain is supposed with a constant intensity over rain intensity (ip) a time t=tc and flood volume is proportional to the rain volume. The answer is a flow hydrograph triangular of duration is 2TC and peak

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Figure 1: Location of the beach of Hammam lif.

Figure 2: The limited study area of Hammam Lif (hatched area: Clear study area).

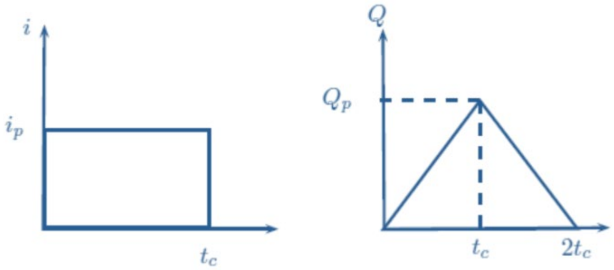

Figure 3: Flow rain transformation principle by the rational method.

flow Qp. The rain volume Vp=tcipS. The flood volume is (see Eq. (2)):

$$Vc = 2\times\frac{1}{2}Qptc \qquad (2)$$

With S is the surface of the watershed. It is assumed that the coefficient of proportionality is C ($0<C \leq 1$), also known as peak runoff coefficient. S from the equality Vc=CVp such that Eq. (3):

$$Qp=Cip\ S \qquad (3)$$

Note that ip is usually expressed in mm/h while Qp is in m^3/s. For the previous formula to be expressed be in these units, it could be modified as follows in Eq. (4):

$$\text{Qp}=\frac{\text{CipS}}{3,6}\ (\text{m}^3/\text{s}) \qquad (4)$$

Study of the component wave run up

For the calculation of wave run up of the coast of Hammam Lif, field trips to the study area were organized during the period between 01st March 2012 and 1st March 2013 (for a monthly output average) 13 follow up months of the wave of Hammam Lif in different weather conditions suitable for the calculation of the wave run up.

The choice of days depended on the weather conditions in the site. In fact, to achieve good measures we had to choose the days following the storms in the time when the sea is in a high tide state [4]. Our study area is limited to the case of sea bright water (wet part of the beach) for the calculation of maximum run up of the wave in the Swach area.

Calculation of the wave runs up from measurement of the sea foreshores and the corresponding tide: The dividing line is that between the dry sands (irregular surface made up of dry sands) and the wet sands (smooth surface). This boundary is a precise and easily identifiable limit of the foreshore to calculate the level reached by the sea waves.

On the beach of Hammam Lif, the levels achieved by the sea foreshores were measured along the profile only. Sea foreshores were measured between 1st March 2012 and 1st March 2013 [5]. The surveys were geo referenced and connected to the Tunisian general leveling system (NGT) using GPS (Figure 4).

To deduce the run up values from the altitude of the sea foreshores, it was necessary to obtain observed tidal values. The run up values observed for each survey were, in fact, obtained by subtracting the maximum rise of the tide observed from the sea foreshores altitude (Figure 5).

For the range of Hammam Lif, the observed tidal data were obtained from the Tunis _Carthage station. The sea level observed is measured by the tide gauge and corrected at the study site.

Muller's method for the calculation of wave runs up: Relying on 200 laboratory experiments, Müller calculated the lift height (run up)

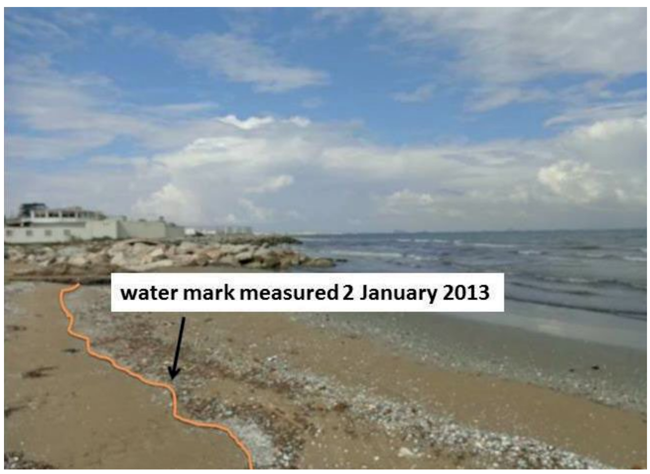

Figure 4: Sea foreshores reflecting the maximum level reached by the run up in the full previous sea in the beach of Hammam Lif.

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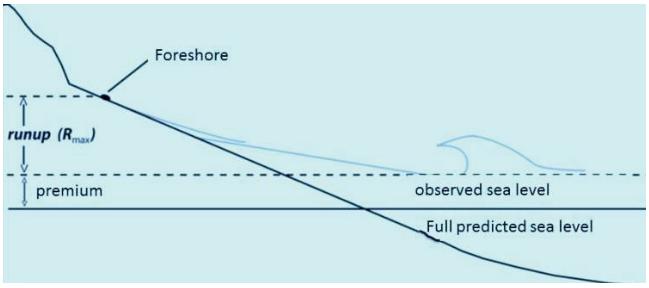

Figure 5: Diagram summarizing the principles of the method A used in this study. Each observed run up value is obtained by subtracting the level of sea observed from the sea foreshores altitude.

R of a pulse wave along an obstacle (such as that facing a dam) [6] as follows in the Eq. (5):

$$R=1.25h\left(\frac{\pi}{2\delta}\right)^{\frac{1}{5}}\left(\frac{H}{h}\right)^{\frac{4}{5}}\left(\frac{H}{\lambda}\right)^{\frac{-3}{20}} \quad (5)$$

With δ the facing angle relative to the horizontal (18° ≤ δ ≤ 90) in Müller's experiments,

H is the maximum height of the wave, and λ is the wave length of which estimation is given by Stokes (Figure 6).

δ: The angle of the facing relative to the horizontal=45°.

H: The maximum wave height given by (3.40) =3.65 m to 10 m.

If we take the (λ / h) ratio (with λ the wavelength and h the height of water), then:

- (λ / h) ≤ 2, the deepwater wave or short wave;

- 2 < (λ / h) ≤ 20, the intermediate wave (the transition wave);

- (λ / h)>20, the shallow water waves or long waves;

- Short waves are usually studied using the Stokes theory, which consists of researching solutions in the form of a truncated series. In principle, the higher the order of development is, the better the accuracy will be, but it is necessary that the wavelength is relatively short for a rapid convergence to be ensured (Figure 7).

According to the STOKES theory (shortwave deep water theory) we get (Eq. (6)):

$$\frac{H\lambda^2}{h^3}=26 \quad (6)$$

λ: The wavelength $\sqrt{((26*(25)3)/(3.65))}=10.45\text{m}$ (7)

h: Height of water=2.5 m for Moving about 250 m to the seabed.

Study of adequate protection solutions for the coast of Hammam Lif

Artificial Recharge and characterization of the Hammam Lif beach sands: Sampling by onsite coring: Artificial recharging requires a study of the nature of the existing materials in the study area and also a study of the materials from different possible borrow areas to ensure the right choice of sand that should have good size characteristics to be adequate for the Hammam Lif beach type [7].

Three coring holes SC1, SC2 and SC3 were made on the beach of Hammam Lif, each was 20 m deep (Figure 8). These core drilling are made using a hydraulic drill for geotechnical soil investigation and small water wells. (Teredo DC 123) showed in Figure 9.

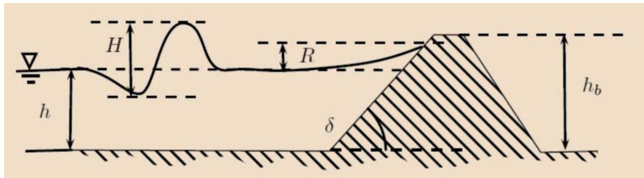

Figure 6: A wave run up against a breakwater.

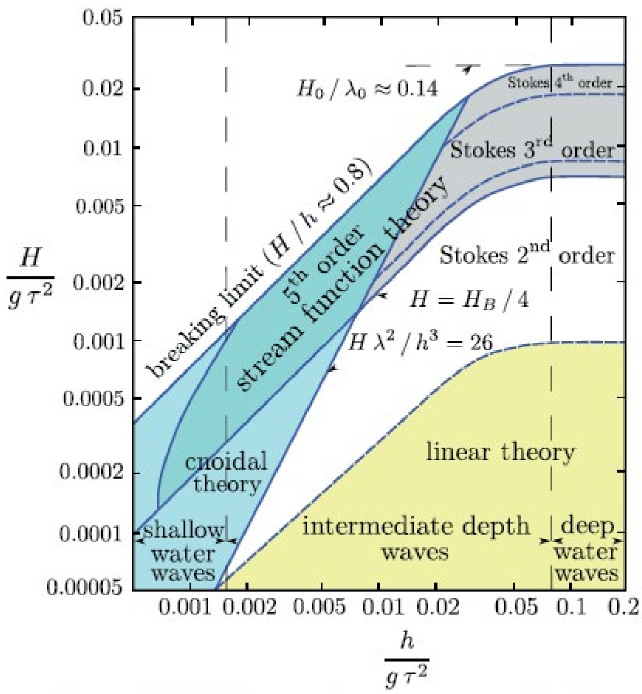

Figure 7: Range of validity of the various theories based on the wave height H of the water height h, the time τ = λ / c. The light blue area is the area of conoïdal waves. The yellow area is the Airy theory. The blue area is the Stokes wave theory. According to a classification proposed by Le Méhauté.

Materials needed for grain size analysis

Metallic square-shaped ordinary dimensions sieves were fabricated in order to achieve reproduceable satisfactory results. An electric screening machine able to perform horizontal vibratory movement as well as vertical shakes along the sieves' column was used as well.

The procedure is defined by AFNOR standards (wet and dry) to establish a grading curve representing the respective proportions of the grains aggregate sizes classes.

A 200 g sample was split into several categories of decreasing grains diameters by means of a series of 21 square mesh sieves (AFNOR standard).

Determination of the shape parameters

The shape parameters provide information on the shape of the curve:

-The uniformity coefficient or Hazen coefficient (Cu) was determined as follows in Eq. (8):

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Figure 8: Hydraulic drill for geotechnical soil investigation and small water wells (Teredo DC 123).

Figure 9: Location of coring holes SC_1, SC_2 and SC_3 drilled on the beach of Hammam Lif.

$$Cu=\frac{D_{60}}{D_{10}} \quad (8)$$

-The curvature coefficient (CC) was determined as follows in Eq. (9):

$$Cc=\frac{D_{30^2}}{(D60*D10)} \quad (9)$$

The geotextile Artificial submerged reef

Calculation of the transmission coefficient across the structure: The offshore underwater installed dykes in the sea grass deprived zone would favor not only the surge of strong waves, but also the dispersion of the masses breaking of water before reaching the dykes [8]. Let's introduce the state of the art theory on the design of a submerged breakwater. The theoretical transmission coefficient through the structure can be calculated by standard formulas of Angremond, Van der Meer and Jong (Eq. (10)), assuming that, the structure form of the design to be a single trapeze (Figure 10).

$$\text{Kt}=-0.4\left(\frac{\text{F}}{H_S}\right)+C_P\left(\frac{B^{-0.31}}{H_S}\right)*\left(1-\exp(-0.5\xi_B)\right) \quad (10)$$

where:

Kt: is the transmission coefficient

F: is the water height between the water surface and the top of the structure

HS: is the incident significant height

B: is the width of the reef top

CP: is the coefficient of permeability (CP=0.64 in the case of a permeable structure, and

CP=0.80 in the case of a waterproof structure)

εB is the number of Iribarren unfurling as (Eq. (11)):

$$\xi_B=\frac{\tan(\alpha)}{\sqrt{\frac{\text{H}_\text{S}}{\lambda_0}}} \quad (11)$$

With α the embankment slope and λ_0 the swell of the offshore wavelength (Eq. (12)):

$$\lambda_0=gT^2/2\pi \quad (12)$$

Results and Discussion

Rates interpretation of rain component

A close examination of the rain rates reveals a continuous increase over the years. In fact, during the 1931 storm; Q=2713l/s, as for the 1981 storm, Q=3824 l / s while that of 2003; Q=4000 l / s. The runoff flow has been on the increase after storms over the years, which has caused the flooding of the area.

The main causes of the flooding are essentially:

-The increase in soil sealing rates and in the urbanization rates through the years.

-The overwhelmed sewerage network of the area should generate a rate of 88900 m^3/day of which 75% that is 66 675 m^3/day is strictly waste water. Being filled with wastewater, the sanitation systems could drain a flow of 22,225 m^3/day of rainwater which makes them unable to drain the whole quantities.

In 2012 the Q rain was 35 923.801 m^3/day>22 225 m^3/day. Therefore,

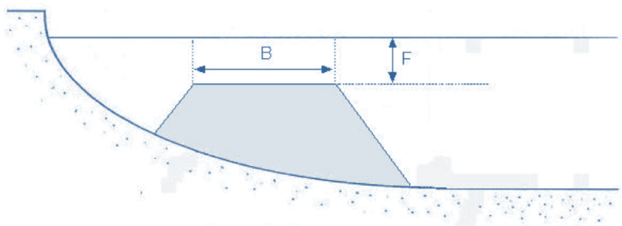

Figure 10: Schematic illustration of the parameters used for the design of an underwater structure.

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the remainder of the water (13,698,801 m^3/day) would run off and cause extensive flooding in the area HammamLif.

Unfortunately, as shown in Figure 11, the existing remedies, digging the casing of sewerage networks in the northern area of Hammam Lif to form a channel to discharge the polluted water into the sea, is harmful for the environment and the aesthetics of the beach.

The wave runs up component

Calculation of wave runs up from measurements of the sea foreshores and the corresponding tide: The following Table 1 and the Figure 12 shows the water mark observed and the values of the corresponding tides:

According to this diagram the wave run up is: R=2.50 m.

Study of adequate protection solutions for the coast of Hammam Lif

Artificial Recharge and characterization of the Hammam Lif beach sands: Sampling by coring on site: The core drilling performed along the Hammam lif Beach showed the following lithology (Figures 13-15):

According to the litho-stratigraphical drills achieved during this survey, the floor of the HammamLif coastline of is noticed to be homogenous for the different studied drills [9]. The lithological column of the field is characterized by a yellowish layer of fine shelly sand with a thickness varying between 0,70 m to 1.00 m followed by a layer of brown silty clay of 1.30 m thick, underneath which is a layer of silty sand that reaches 3.00 m depth. All of these layers lie on a layer of fine slimy sand of 3.00 m thick [10]. The lithological column ends with a layer of naturally grayish sand that starts from the depth of 6.00 m extending to the end of the exploration.

Figure 11: Hole in the drainage pipe forming a discharge channel of polluted water into the sea.

Days	The water mark (m)	Corresponding tide (m)
1 March 2012	3.3	1.2
5 April 2012	4.5	3.3
8 May 2012	3.8	1.7
16 June 2012	4	2
01 July 2012	3.5	2.5
02 August 2012	5	2.5
6 September 2012	5.5	3
28 October 2012	3.5	2.1
28 November 2012	3.5	2.5
31 December 2012	4.5	1.5
02 January 2013	5.5	2.5
06 February 2013	4.2	1.5
01March 2013	5	2

Table 1: The water mark and the values of the corresponding tides observed between 1st March 2012 and 1st March 2013 in Hammam Lif.

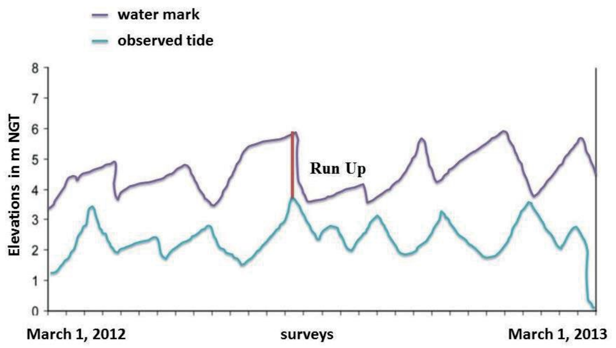

Figure 12: Run up identified from water line subtraction and tide observed.

Results of grain size analysis performed on the samples

The Table 2 summarizes the particle size parameters of samples taken.

The Hammam Lif shoreline consists of bad quality sand which grain size is characterized by a high percentage of fine sand particles depriving the beach from any form of stability.

*2<Cu<5: the particle size is tightened.

*CC>2: This sand is characterized by a poor particle size with a dominance of fine fractions.

Artificial recharge is required using a coarser sand to promote the stability of the beach. The borrowing site should not be from the area of Hammam lif because of the bad size characteristics of this sand [11]. Hammam lif beach rather needs a size correction intake of better and mainly coarser sand from another area.

Research of borrow areas of possible suitable sand for beach nourishment of Hammam Lif

Charging the beach of Hammam Lif is necessary for its stability and its correction, Hammam Lif must return to its original appearance, bathing area with good sand.

The search for good sand requires the completion of sampling in different areas proposed in order to choose the right sand for beach nourichment.

Earthly origin sand borrow area (sand quarry DRIJET)

Characterization of the sands of the sand quarry DRIJET: surface sampling: The DRIJET sand quarry is located at a distance of 48.09 kilometers from the beach of Hammam Lif. She is old:

*M3: upper Miocene undifferentiated.

*O: Oligocene Limestone sandstone bioclastique, green clay and sandstone.

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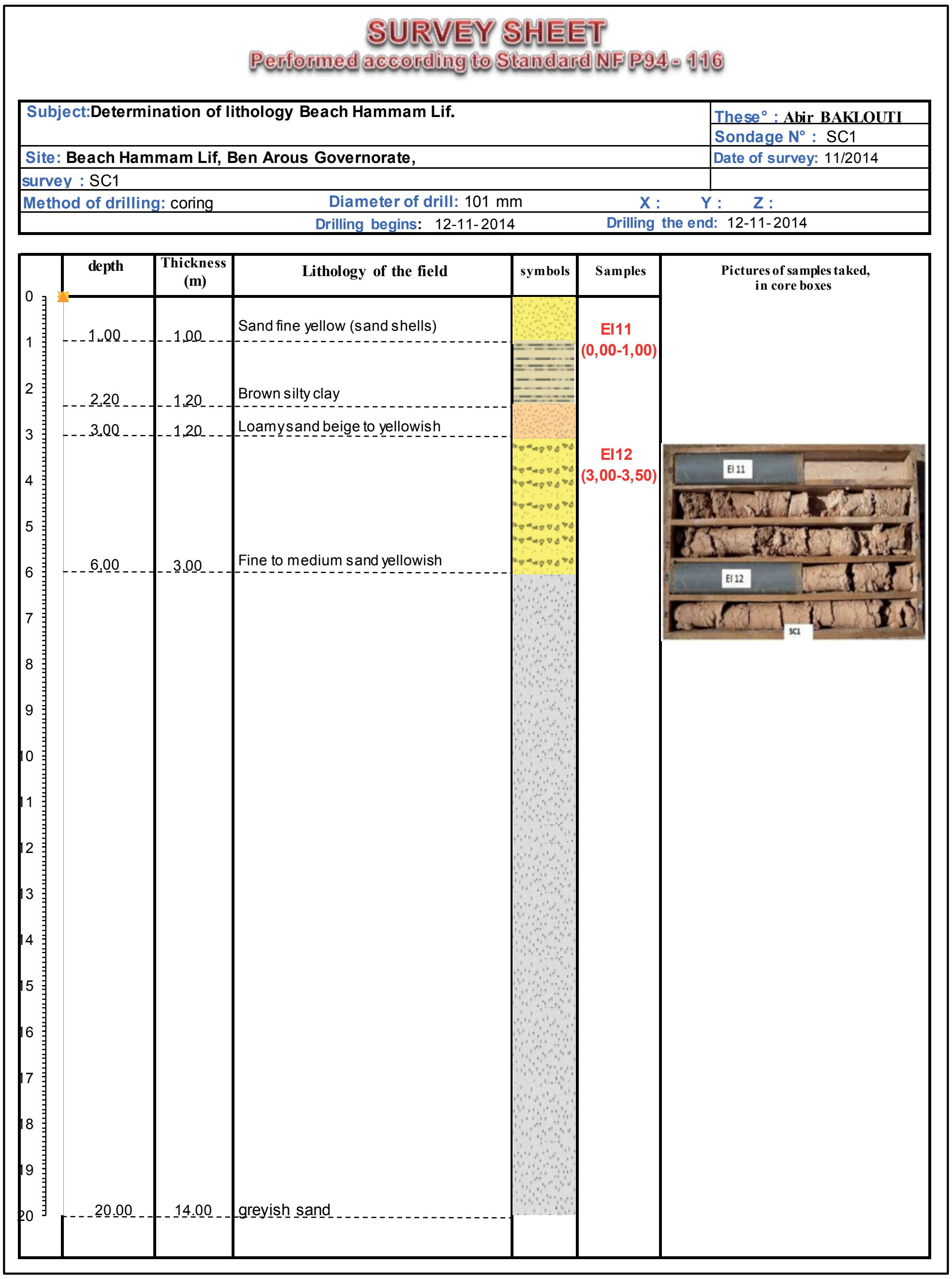

Figure 13: Lithology provided by the core sampling SC_1.

Three samples were taken from quarry sand DRIJET, redesigned Sample ER1d, ER2d and redesigned Sample revamped ER 3d, particle size analysis gave the results:

Interpretation: The sand of the quarry sand DRIJET is good sand with a particle size with a high percentage of coarse particles so this sand is a sign of stability of the beach.

*2<Cu<5: The particle size is tight.

*CC<2: was a dominance of the coarse fraction, the curve is asymmetrical.

The sand of DRIJET career is good sand for beach nourishment of Hammam Lif.

Earthly origin sand borrow area (sand quarry Borj hfaiedh)

Characterization sand quarry sand Borj hfaiedh: surface sampling: The BorjHfaieth sand quarry is located at a distance of 34.15 kilometers from the beach of Hammam Lif. She is old:

*M2S-1: Middle Miocene (Tortonian to Serravallian).

Three samples were taken from the quarry sand Borj Hfaieth, redesigned Sample ER1b, ER2b and redesigned Sample Sample revamped ER3b, particle size analysis gave the following results:

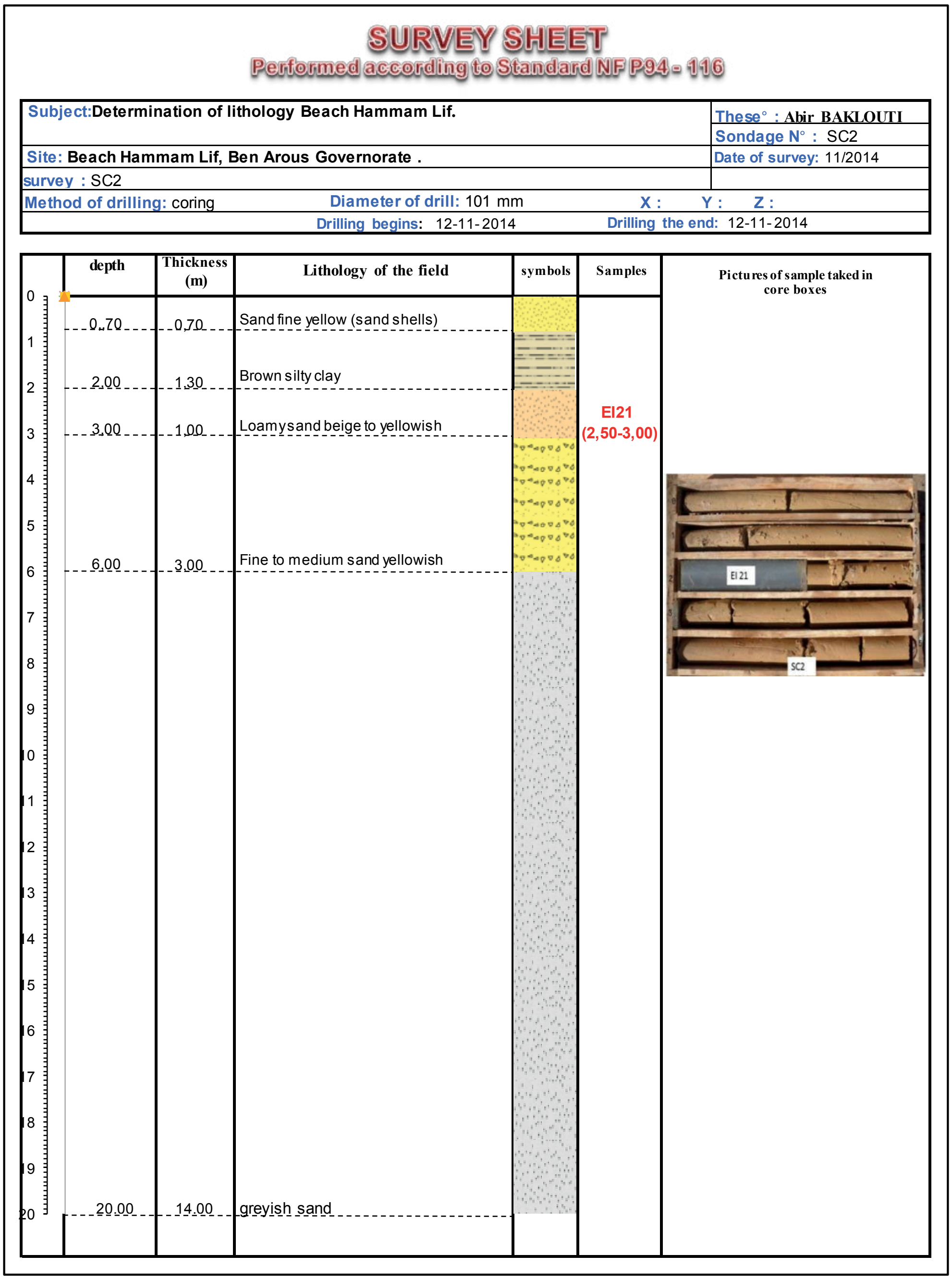

Figure 14: Lithology provided by the core sampling SC_2.

Interpretation: The sand of the quarry sand Borj hfaeith is good sand with a particle size with a high percentage of coarse particles so this sand is a sign of stability of the beach.

*2<Cu <5: The particle size is tight.

*CC<2: was a dominance of the coarse fraction, the curve is asymmetrical.

The sand of the quarry sand BORJ Hfaiedh is a good sandfor beach nourishment of Hammam Lif.

A geotextile underwater artificial reef

Calculation of the coefficient of transmission across the structure: We should have a good knowledge on the swell of the sea waves and their significant heights.

Indeed the positioning of the reef has to be adequately chosen. If it is chosen too close to the dyke, water would not have enough time to withdraw after the wave breaking and harmful "bagging" phenomenon would then be produced. Too far from the dike, the deshoaling effects would tend to amplify the wave transmitted to the back of the reef. Kt=0.170.

The method consists in considering a reef implanted at h=10 m deep, a hundred meters off the sea wall, with a varied wide side slope

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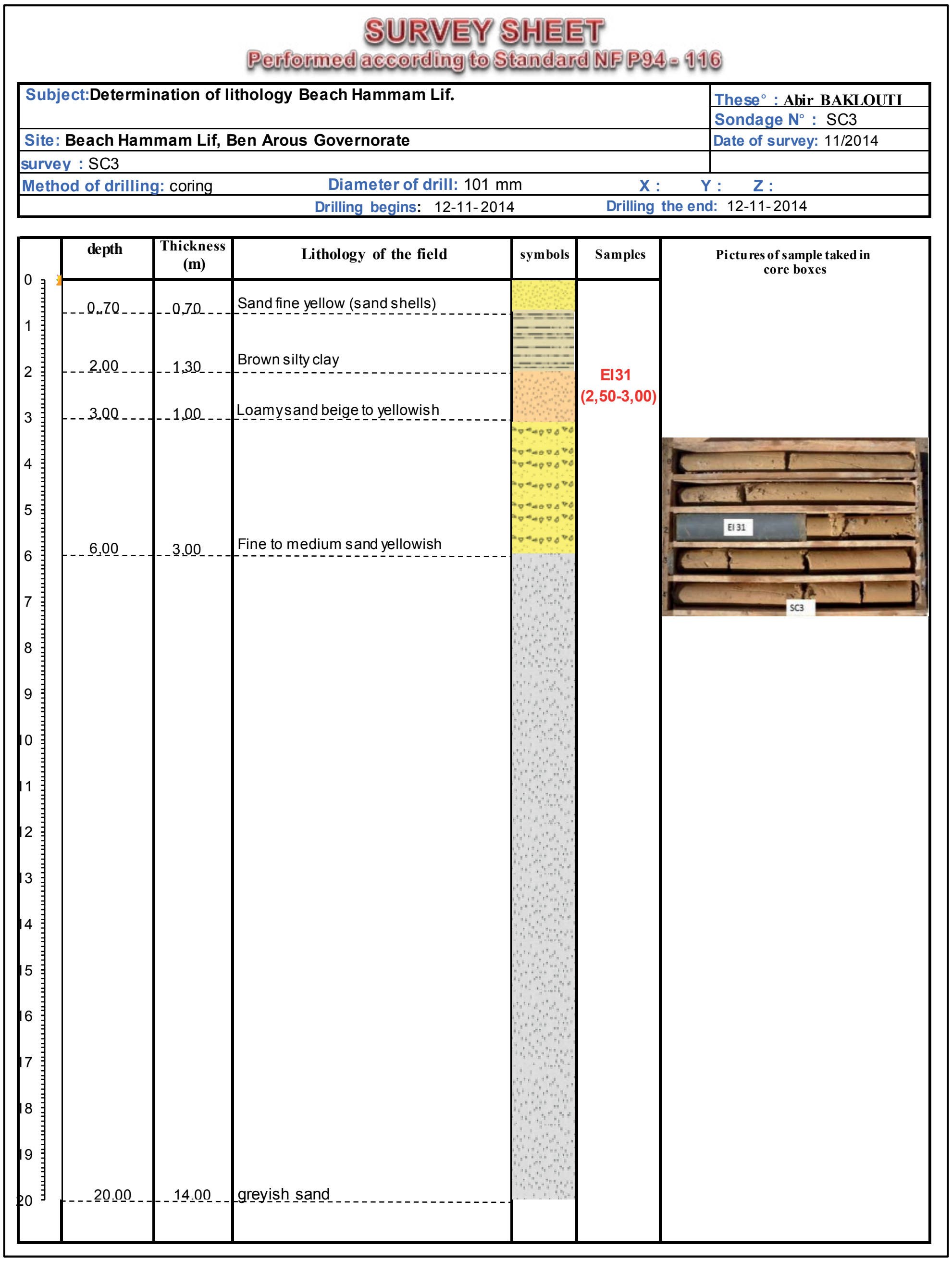

Figure 15: Lithology provided by the core sampling SC_3.

Samples	Nature of samples	Depth (m)	D50	D60	D30	D10	Cu	Cc
EI11	Fine yellowish sand	0.00-1.00	0.17	0.20	0.10	0.075	2.66	3.33
EI12	Sandy yellowish means	3.00-3.50	0.18	0.22	0.13	0.085	2.58	3.47
EI21	Sandy loam	2.50-3.00	0.003	0.055	-	-	-	-

Table 2: Summary table of particle size parameters of samples taken.

(its slope rating side is set to 2/1), the draft (water withdrawal), and its berm length (Figure 16).

The characteristics of a successful artificial reef for this study in the Hammam Lif area are summarized in the Table 3.

The trapezoidal shape is not necessarily the most appropriate if the objective is to dissipate a maximum energy of incidental waves [12] (Figures 17 and 18) (Table 4). However, the benefit of such a shape is simplicity and ease to implement, and cost effective compared to a more complex solution, especially the goal here is to sufficiently reduce the

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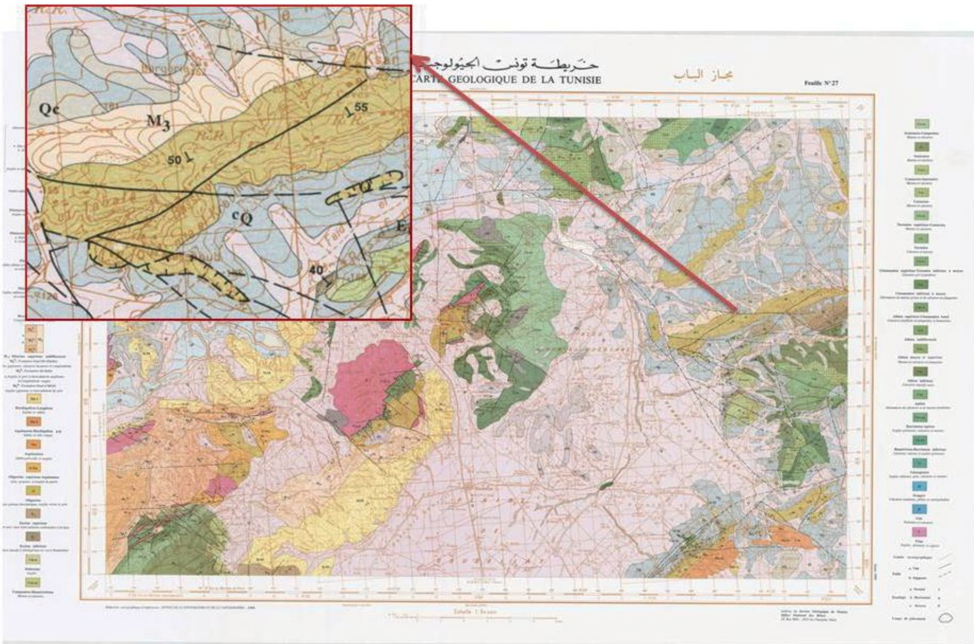

Figure 16: Geological map of Drijet sand quarry (drawn from national service TUNIS (OTC 1991).

Samples	Depth (m)	D50	D60	D30	D10	Cu	Cc
ER1d	0.00-1.00	0.29	0.3	0.19	0.09	3.48	1.05
ER2d	0.00-1.00	0.25	0.3	0.19	0.1	2.9	1.24
ER3d	0.00-1.00	0.3	0.4	0.23	0.14	3.08	0.85

Table 3: Size characteristics of the sand samples taken from the quarry sand DRIJET.

Figure 17 : Distance between sand quarry DRIJET and Hammam Lif.

significant height of the waves to prevent them from overtopping the dike [13] (Figures 19 and 20) (Table 5).

Conclusion

Faced with adverse characteristics, a highly urbanized coastal area of Hammam Lif with 90% urbanization coefficient, overwhelmed and clogged sewerage systems being a unit type draining both of rainwater and waste water, the beach needs immediate intervention. Added to that, the design and choice of protection structures to protect the beach are rather inadequate and badly conceived. This study confirmed

Figure 18: Distance between sand quarry BORJ HFAEITH and Hammam Lif.

Échantillons	Depth(m)	D50	D60	D30	D10	Cu	Cc
ER1b	0.00-0.50	0.23	0.27	0.18	0.1	2.83	1.04
ER2b	0.00-0.50	0.25	0.28	0.2	0.1	2.33	1.07
ER3b	0.00-0.50	0.29	0.32	0.22	0.15	2.29	0.98

Table 4: Size characteristics of the sand samples taken from the quarry sand BORJ HFAIETH.

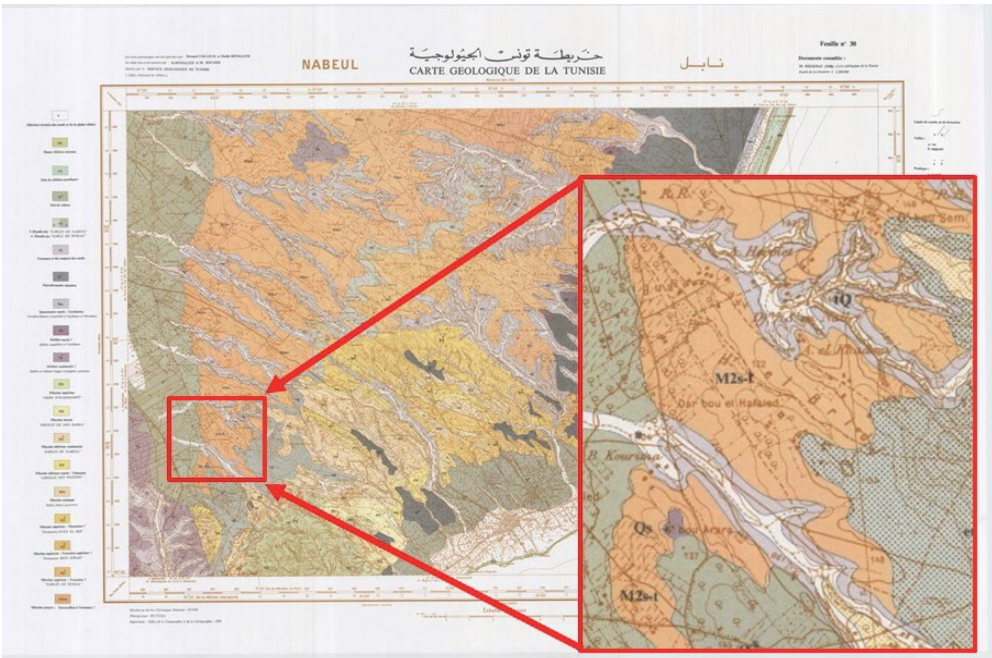

Figure 19: Geological map of the quarry sand BORJ Hfaiedh (drawn from national service TUNIS (OTC 1991).

Berm width	Slope	Reef width	Sectional area	Total volume for a 200m long reef	Transmission coefficient Kt
10 m	1-Feb	30 m	160 m^2	32000 m^3	0.170

Table 5: Dimensions selected for the estimated reef in the sea of Hammam Lif.

that the beach of Hammam lif is highly threatened by beach flooding and over time has presented major problems caused by flooding due primarily to the stormy rain, as well as the action of wave run up that crosses the existing breakwaters to populated areas.

The choice of a coastal protection solution has to be preceded by studies of the characteristics of the wave in the area of Hammamlif. Two solutions were remarked to be suitable: artificial recharge and artificial

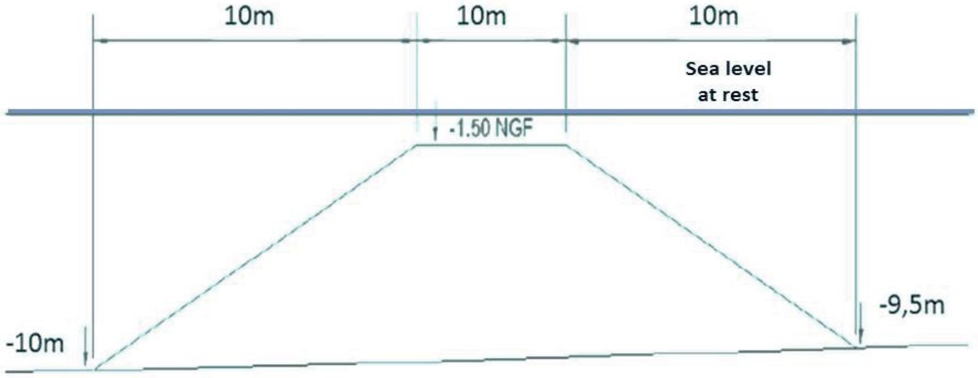

Figure 20: Sectional view of the proposed reef in the sea of Hammam Lif of a trapezoidal shape.

reef submerged geotextile. The application of one of these two solutions is enough to remedy against flooding due to the action of wave run up.

The artificial recharge is needed to Hammam Lif using coarse sand from one another than the sea to promote the stability of the beach. Generally the borrow site should not be of marine origin of the zone itself because the size characteristics are bad as the sand of Hammam Lif has rather it needs a size adjustment by supplying better and especially coarse sand of a other place.

The search of good sand borrows areas for Hammam lif is necessary.

Among the proposed sand areas, the area of OUTHNA but it is a closed area by the Ministry of Environment since 2014 because they became exhausted. The second area is that of DRIJET sand quarry. Samples taken from this area have good size characteristics (D50 is ranged between 0.25 mm and 0.30 mm). The third area is that of the BORJ HFAIETH sand quarry whose samples taken also exhibit good granulometric characteristics (D50 is varied between 0.23 mm and 0.29 mm).

So the tow borrow sites are adequate because their sands are coarser than the original sand of Hammam Lif beach so they promote its stability.

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