Costs for Construction of Coastal Defence Works

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Abstract

The necessity of inserting a coastal defence system implies a careful analysis of all aspects that make this intervention useful for community. The authorities choose, among different typologies of intervention, the one that satisfy, at the same time, requirements of efficacy, economy, quickness of operation and less environmental impact. These qualifications can't be often satisfied simultaneously, the achievement of one of them implies a cut of the others. An example is the necessity of building coastal defence works that are able to guarantee a good wave motion resistance with a consequent reduction of beach erosion for a long period of time. These qualifications can be satisfied by a rigid system (for example a longitudinal rock barrier) that causes an unavoidable increase of costs and times of construction (Ferrante A., 1997). Indeed between the choice of a soft kind of defence (pure nourishment) and the choice of a rigid project (nourishment defended by hard structures), the economical aspect will have very different peculiarities: while the first solution involves a limited investment of money at the beginning but high costs of maintenance; the second one is characterized by great expenses at the beginning with the result of more efficacy end length of the work. The purpose of this analysis is to delineate the costs of intervention relative to four different typologies of coastal defence works and to provide an analysis of the investment by the comparison of current costs.

Introduction

After a description of the four typologies of intervention analyzed, we introduce the analysis method, based of the current investment costs. Successively we report the results obtained. These are developed also in function of their sensitivity in relation of the variation of fundamental parameters as the unit cost of nourishment sand, the interest rate, the depth of barrier crest and the median grain size of borrow send.

Description of Defence Works

Among different typologies of intervention used for the protection and maintenance of coasts, we consider remarkably interesting the sand nourishment both soft or pure kind (without protective structures) and rigid kind (defended by longitudinal rock barrier or normal groin on the beach). We present quickly the features of the four typologies of nourishment chosen as patterns of comparison in this analysis.

Pure nourishment (Typology A)

The sand fill along the coast in quantitative able to provide a positive contribution on the solid coastal balance determines a more artificial extension of beach area (Fig. 1). The duty of "defence" by this kind of intervention is bound to the increase of the beach area that will be quantified in terms of extension not only of the portion of emerged beach but also of the submerged beach in order to guarantee a great distance between the action of wave motion and the elements of interest put along the coast behind the nourishment area. Leaving out considerations about the possible drawbacks of ambient type due to the temporary increase of turbulence of coastal waters (above all during the executive stages), the main bound of nourishment interventions is connected with technical and economical difficulties joined with finding material suitable for nourishment, and also with its durability and its resilience (above all in comparison with the extreme meteorological sea phenomenon) that condition the longevity of intervention and make the necessary ground to define renourishment interventions to adopt in the following years. In the valuation of the costs there will be included also the burden of necessary renourishment intervention in order to guarantee the functionality in the long run of this kind of coastal defence works (Dean R.G., 1992). Volume parameters of initial fill and quantity of sand for annual renourishment change according to regional characteristics of wave climate and the relationship between the median grain size of native sand and borrow sand. In this analysis we hypothesize a volume of 425 m3/m of sand, necessary to guarantee a beach width project Y = 50 m, berm height B = 1,5 m and depth of closure H = -7 m. For simplicity the hypothesise is a good relation between the borrow and native sand, considering that the material loss is null cause overfill phenomenon (EM 1110-2-1100, 2003). This aspect will be study in depth in the paragraph "Sensitivity of CV in relation to the grain size of borrow sand".

The annual sand loss are estimated in function of monitoring results obtained by Regione Lazio especially in the experience of Ostia Levante works from 1999 until today. The data obtained from the Monitoring Centre of Coastal Observatory of Regione Lazio through the volumetric comparison from DTM are brought back in table 1. An aspect useful for evaluating the entity of annual sand losses that is connected with considerable differences between the losses during the first year of employment and the losses of the following years (Contini P., 2001). In absence of rigid works protection, we value that nourishment is subject to losses in the scheme of 120 m^3/m during the first year of employment and of 20 m^3/m in the following years (Scaloni P., 2003). These losses will result remarkably reduced in the case of protected nourishment.

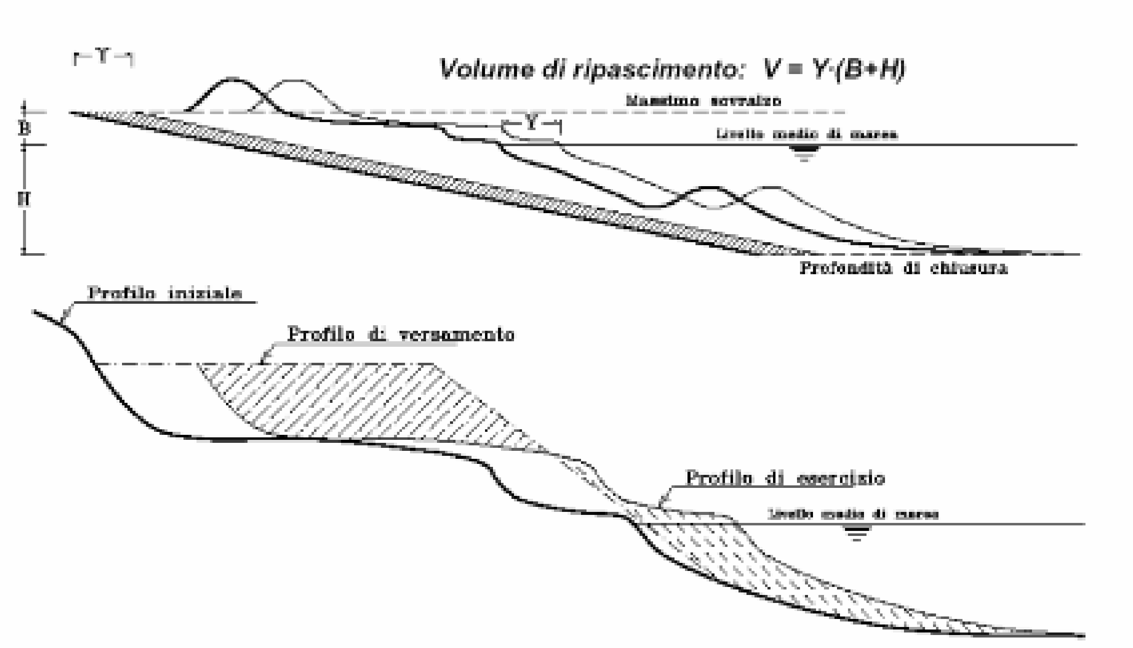

Fig. 1: Outline of the beach nourishment profile (from “Beach Fill Volume required to produce specified dry beach width”, CETN 2-32, ASCE 1995)

Table 1: Ostia levante – Beach feature comprised between the “Pescatori” Canal and the “Capannina” beach.

Representative cell (not-erosional line and the bathymetry -4,5 m s.l.m.m included, total length = 3400 m)	**Volumetric variations of sand (DTM) [m^3]**			
	oct/1999 feb/2000	**feb/2000 oct/2000**	**oct/2000 may/2002**	**may/2002 dec/2002**
ZONE 1 (not-erosional line and shore line included)	-242.495	28.361	-94.321	-24.152
ZONE 2 (shore line and submerged barrier crest included)	41.488	-160.063	-50.736	83.078
ZONE 3 (submerged barrier crest and bathymetry -4,5 m s.l.m. included)	60.094	-117.256	26.936	-77.996
Total [m^3/Km]	**-140.913**	**-248.958**	**-118.121**	**-19.070**
Erosional trend [m^3/Km year]	***-124.335***	***-109.834***	***-21.942***	***-9.615***

Nourishment protected by a high cost underwater longitudinal barrier and by normal groins (Typology B)

The sand fill is protected by an underwater rock barrier parallel to the shoreline, and by normal groins that the geometric characteristics are the followings:

a) Underwater longitudinal barrier (Fig. 2):

- Depth of base of the rock barrier $h = 4\text{-}5$ m
- Altitude of achievement of the rock barrier $Rc = -1$ m
- width of achievement of the rock barrier $B = 30$ m
- slope on shore $n_t = 3$
- slope off shore $n_m = 5$

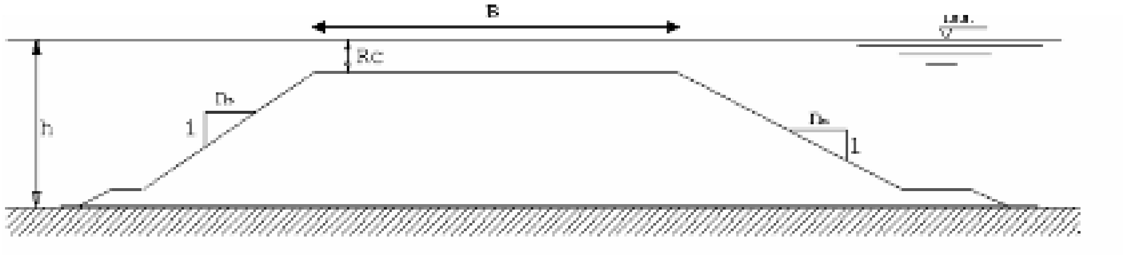

Fig. 2: Geometry of underwater longitudinal barrier (Typology B)

b) Submerged normal groin (Fig. 3):

- length groin emerged $L_{pe} = 160$ m
- length groin submerged $L_{ps} = 90$ m
- distance of the groins $IP = 300$ m
- Altitude of achievement of the groin submerged $R_{cs} = -1$ m
- Altitude of achievement of the groin $R_c = +0{,}5$

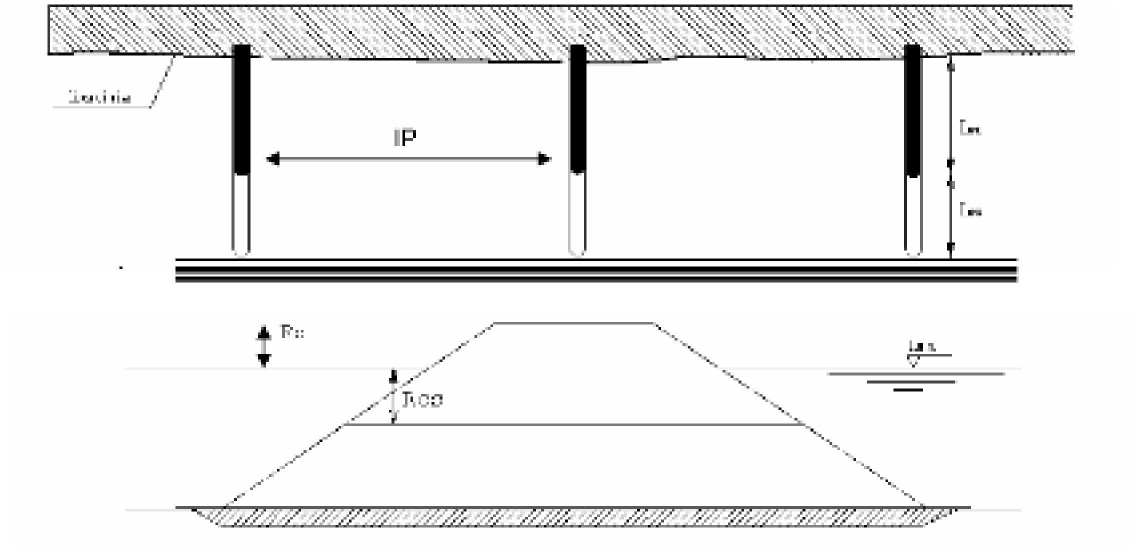

Fig. 3: Geometry of underwater normal groin (Typology B)

The parameter of groins has slopes of ½ width of the top is 4 m and the section has an area of 25 m^2. The groins have the function of control of the sediments transported by the longitudinal currents.

The hard work is made with rocks of category 2 (1-3 t) and the middle distance of the is of 60 Km. In order to guarantee a valuable working, this kind of submerged structure has to reach big dimensions that will result often onerous both for the economical side and for environmental impact. It's expected a decrease of sand nourishment volume in the scheme of 30% in comparison with the case of soft nourishment. Therefore we value initial sand contributions about 300 m^3/m. The annual losses of sand are estimated on the ground of results of numerical modelling application of beach area that, based on wave climate data and grading of sand nourishment, simulate migration of littoral sediments exposed to the actions of wave motion. These method are calibrated by the use of morphologic beach parameters drawn from local bathymetric monitoring and then used in such a way as to reproduce the real historical evolution of the littoral examined. Therefore has been estimated a loss of 25 m^3/m during the first year and of 4 m^3/m durings the followings years.

Nourishment protected by low cost longitudinal rock barrier and by normal groins (Typology C)

The longitudinal standard section is made slender, with a 15 m wide crest berm at m.s.l. -1 m, based on variable depth between m.s.l. -3 to -4 m. The rocks are placed with slope of 1/2 and the total section area is about 50 m^2 (Fig. 4). The normal groins are 150 m length with toe level at m.s.l. -3 m, a 4 m wide crest berm at m.s.l. +0,5 m. The standard section area is about 20 m^2 (Fig. 5). The function of normal groins is to reduce sand long shore transport and for this reason the normal groins are placed with a distance of 300 m one from another.

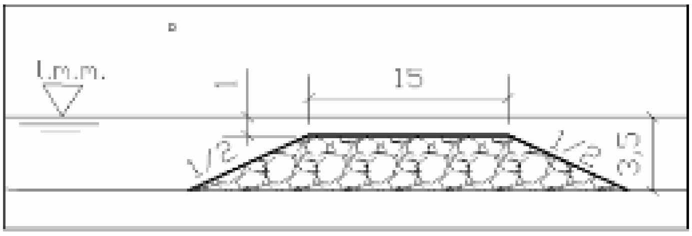

Fig. 4: Geometry of underwater longitudinal barrier (Typology C)

This projectile choice, similar to the preceding about the geometric diagram has smaller volume. Consequently the carrying out costs reduces itself proportionally to the reduction of the volumes required to realize the structures. Also in this case, the sand nourishment volume is about 300 m^3/m, and the loss estimated are of 25 m^3/m during the first year and of 13 m^3/m year durings the followings years.

Nourishment protected by normal groins to shoreline (Typology D)

These structures, normal to the shoreline, are 150 m length and are placed with a distance about 300 m one from another. Reaching toe level at m.s.l. -3 m and a wide crest berm at m.s.l. +0,5 m. Considering a slope equal to 1/2, the standard section area is about 20 m^2 (Fig. 5). In this case, the sand nourishment volume is about 425 m^3/m, and the loss estimated are of 36 m^3/m during the first year and of 15 m^3/m during the followings years.

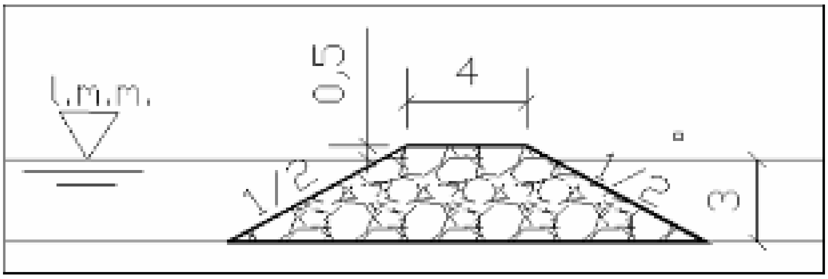

Fig. 5: Geometry of underwater normal groin (Typology C and D)

In Table 2 we present, in synthesis, data and parameters of each defence works described until now. These parameters will be determined on the computation of costs analysis in the following paragraph.

Table 2: Description of each defence works described until now.

Typ.	**Intervention Description**	**Longitudinal Rock barrier parameters**	**Normal groins parameters**	**Value of annual Sand losses (m^3/m year)**	**Example of project**
A	Pure nourishment 425 m^3/m	-	-	1st year 120 2nd year 20	Ostia Levante year 1999
B	Nourishment of 300 m^3/m of sand, protected by high cost underwater longitudinal barrier and normal groins	- Depth of medium toe level -4,5 m - Wide crest berm 30 m - Depth wide crest berm -1,0 m s.l.m. - Landward slope 1/3 - Seaward slope 1/5 - Section area 150 m^2	- Length 250 m - Distance of 300 m one from another - Wide crest 4 m - Wide crest berm +0,5 m s.l.m. - Landward slope ½ - Seaward slope ½ - Section area 25 m^2	1st year 25 2nd year 4	Ostia Centro year 1990 (Granata M.G., 1995)
C	Nourishment of 300 m^3/m of sand protected by low cost submerged longitudinal barrier and normal groins	- Depth of medium toe level m.s.l. -3,5 m - Wide crest berm 15 m - Depth wide crest berm m.s.l. -1 m - Landward slope 1/2 - Seaward slope 1/2 - Section area 50 m^2	- Length 150 m - Distance of 300 m one from another - Wide crest 4 m - Wide crest berm m.s.l. +0,5 m - Landward slope 1/2 - seaward slope ½ - Section area 20 m^2	1st year 25 2nd year 13	Fosso Mascarello, Terracina -Circeo year 2002
D	Nourishment of 425 m^3/m of sand protected by normal groins	-	- Length 150 m - Distance of 300 m one from another - Wide crest 4 m - Wide crest berm +0,5 m s.l.m. - Landward slope ½ - Seaward slope ½ - Section area 20 m^2	1st year 36 2nd year 15	Focene year 2003

Evaluating Current Investment Costs

The investment costs are different according to different period of time. Consequently the same thing happens to the financial expenses. To make a comparison, in order to establish the advantage of investment, it's necessary to provide homogeneous values. The investment cost is shown with the decision of investing, while the money necessary to the maintenance of the realized work are shown in following times, that is to say during the life of investment. The values homogenizing takes place bringing the future financed values to the supposed value that they should have at the time of investment. This process of revision carried out through the discount, is based on the presupposition that the value of an amount of money changes according to the time when this amount is available. To calculate the current value of a series of cost that will be faced in the future, we introduce the concept of discount rate, which value is given by interest rate on the loans granted by short or long credit institutes. The CV of the cost relative to the generic year "t" is calculated in this way:

$$CV_t = C_t / (1+s)^t \qquad (1)$$

where "C_t" is the cost of the year "t" and "s" is the discount rate. The sum of all current values during the life of investment is an efficient tool to establish the advantage to invest in different typologies of coastal defence interventions. When the parameters of average life of a coastal defence work at low cost are fixed, the valuation of the current costs is connected with the valuation of building and maintenance costs of the different typologies of works. The first is connected with geometry of rigid structures and with the sand nourishment volume, the second one depends on the valuation of annual sand losses and on the damage suffered by rock barriers, both dependent on the action of the local wave motion.

Description of the Proceeding Adopted for Costs Analysis

The valuation of economic advantage, among the four works illustrated, results from the comparison between the amounts of current values of costs during the whole life of the work. We pay a particular attention to the definition of realization and maintenance costs. The first are connected with furniture costs, execution of materials and realization times, the second are connected with the working and efficacy of different works measurable with the annual sand losses.

The sand costs are established by taking, transporting and depositing. In the European sphere, the unit dredger costs take on different values in function of the geographical position of nourishment project. In the northern Europe region, the sand costs also less than 2 euro/m^3, while in Italy the price fluctuates between 5 to 7 euro/m^3. This non homogeneity is strictly dependent of fixed cost of mobilization demobilization of vessel, the equipment inclusive. The vessels come from the north region of the Europe (Belgium, Sweden, Holland etc.). The choice of the united costs interval for the sensitivity studies, must shows regards for this aspect. The sand cost interval is established in the range of 2 and 10 euro/m^3.

As regards supply and put down the rocks, the costs is established even 40 euro/m^3. About realization times, we consider that the execution of a protected nourishment should required a time of two years for building the rock barriers and transporting of sand fill taken from sea cave, while both pure nourishment and that protected by groins, require short times.

More complex is the definition of annual sand losses, unavoidable for the littoral, both in presence of big defence structure (Typology B) and in presence of structure with less environmental impact (Typology C and D). To keep in mind this aspect, the maintenance costs are distinguished between the first year after the fill and the following years. The capacity of containing of rigid works, already described in the previous paragraph, has been inserting in the computation of maintenance costs, which result reduced for protected nourishment.

The use of software of calculation makes possible the introduction of geometric, economic and working parameters on the ground of which are calculated the costs relative to every years of life of the work. Then these costs, distributed in time, are made current thanks to the formula, already describe, of the Current Value. The amount of costs is the economic investment necessary to building and maintenance of defence works.

Results of Comparison among Current Costs of Four Typologies of Intervention

On a portion of littoral of 1 km, supposing that the average life of a defence work is 25 years, the more convenient economic investment is the nourishment protected by normal groins, while the nourishment protected by high cost longitudinal barrier results economically more heavy. On Table 3 we report the comparison of CV and the graphic of investment (Fig. 6), obtained supposing a cost of sand taken from a sea cave of 7 euro/m3 and an annual interest rate of 2%.

Table 3: Current Investment in million euro

TIPOLOGY	WORK DESCRIPTION	CV [milllion euro]
A	Pure Nourishment	6,1
B	Nourishment protect by high cost underwater end long. barrier	10,3
C	Nourishment protect by low cost underwater end long. barrier	6,2
D	Nourishment protect by transversal groins	5,3

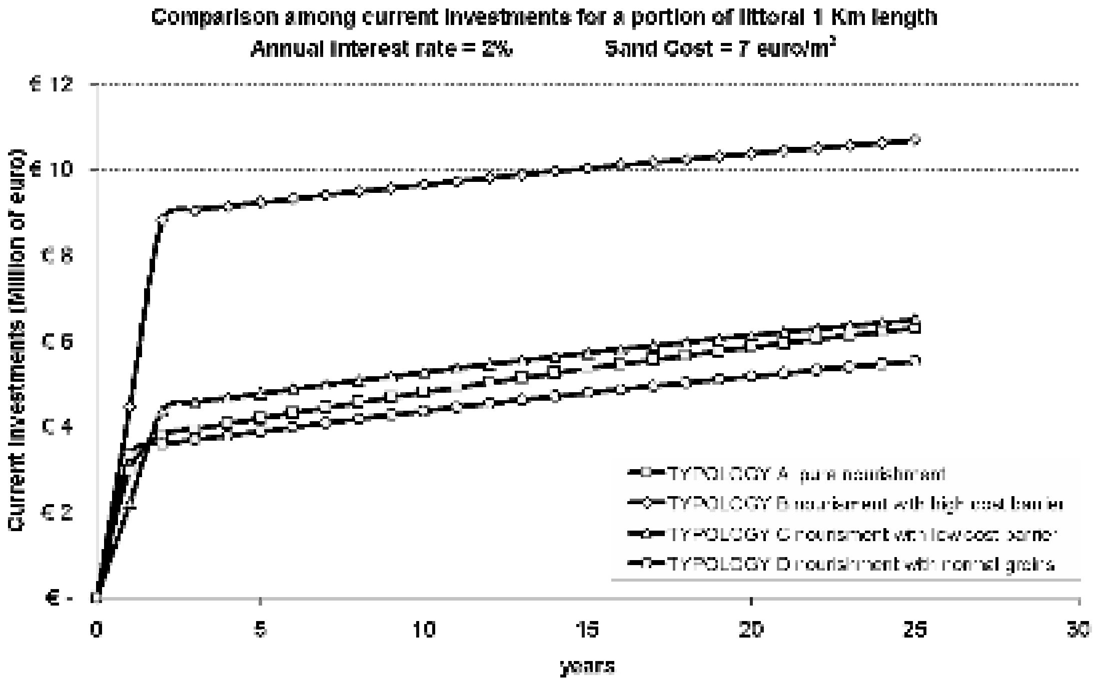

Fig. 6: Current costs curves

This result suffers the parameter of sand nourishment cost. A rising of the sand cost value causes a greater increase of pure nourishment cost than protected nourishment one. For the volatility of "sand cost" parameter, becomes necessary to find a value that make pure nourishment CV greater than the protected one. In the following paragraph there is the analysis of sensitivity in comparison with unitary cost of sand.

Sensitivity of CV in Relation to the Unitary Sand Price

The unitary cost of sand nourishment is subjected to remarkable changes for the typology of the sand, for its source, for the system of drawing and for the execution. The increase of unitary cost involves the increase of current investment costs. It's expected that the CV of pure nourishment suffers an increment proportionally greater than the CV of a protected nourishment for the great amount of annual sand volumes necessary for the work maintenance (20.000 m^3/year in comparison with 4.000 m^3/year of nourishment protected by high cost barrier). With this analysis we want to establish the way which these investments suffer changes of sand unitary cost, and we wonder if a soft defence intervention (Typology A) has economic advantage, as that apparently should seems. But the reality is different, because it should reveals less convenient than a rigid work intervention (Typology B,C and D) for the high cost of the sand. In the table of sand costs, we chose an interval of values that ranges from a minimum of 5,83 to a maximum of 11,73 euro with regular increase of 10%. The CV estimate was calculated for a littoral portion of 1 Km for an investment of maximum longevity of 25 years with interest rate of 2%.

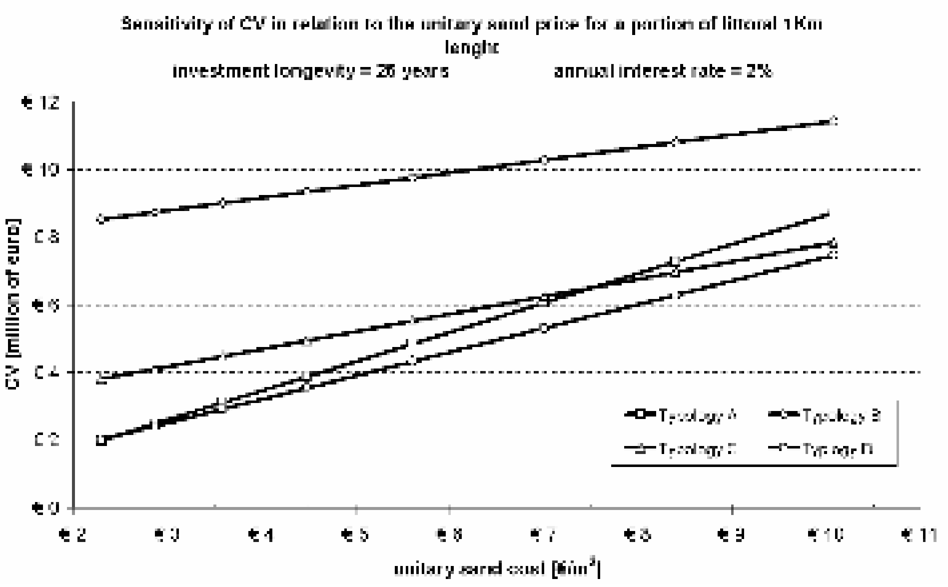

Fig. 7: Current cost curve in function of the sand cost

As we expect the pure nourishment CV suffers increases proportionally greater than the others typologies (Fig. 7).

Sensitivity of CV in Relation to Discount Rate

The interest rate is an economic parameter that suffers the variability of local economic politics, for this reason the results of the costs analysis of a long term investment depend on the interest conditions to the discount applied by local authorities. It’s interesting to consider the way which this volatility weighs on the project choices connected with the discount analysis. We have chosen an interval of costs that ranges from a minimum of 0,5% to a maximum of 4,5%, we have calculated again the CV of four intervention typologies. The results, related in the next paragraph, reveals that the sensitivity of intervention costs in relation to the interest rate doesn’t effect the project choices among four options analyzed. Indeed from the following graph we point out the changes of costs proportionally equal in the four cases analyzed. The lines in the graphic that represent four typologies CV never cross each other and the economic advantage of an intervention in comparison with another is not altered by changes of interest rate.

Sensitivity of CV in relation to depth of barrier crest

The depth of the barrier crest is a parameter that in stage of project choice has a big importance both for reasons of work functionality and for economic reasons. The functional aspect is still object of analysis and searches that will be not analyzed in this study. The economic incidence of berm depth will be valued by a comparison with the CV calculated for each value of the depth. We choose an interval that ranges from a minimum of 0 m to a maximum of m.s.l. -1,5 m, under which we consider the rock barrier defence practically useless (Fig. 8).

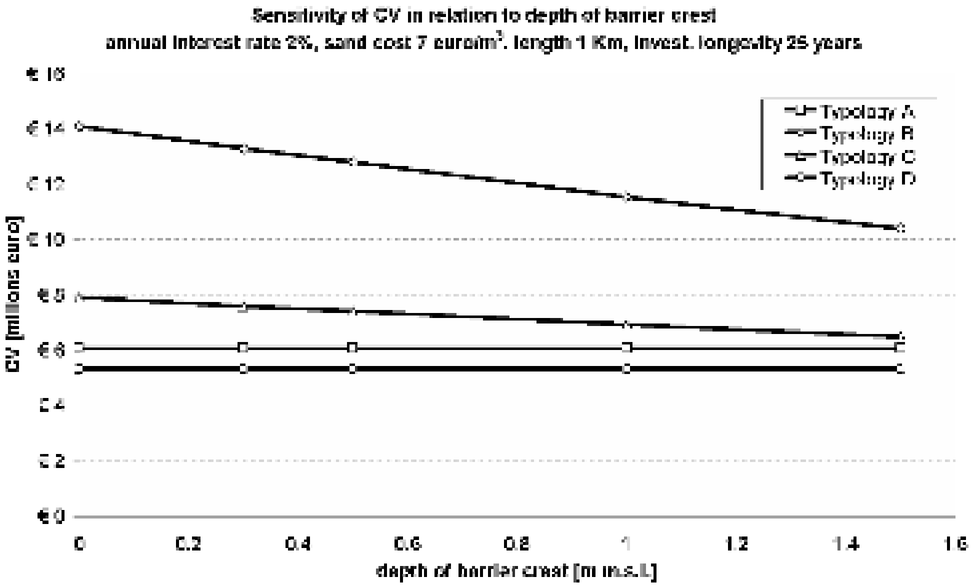

Fig. 8: Current Cost curves in function of crest berm depth

Sensitivity of CV in Relation to Median Grain Size of Borrow Sand

The CV depends also by the nourishment project volumes, therefore from the medium grain size of the loan sand. The necessary volumes to the reconstruction of the beach have been calculate with the "Equilibrium Profile Comparison" Method (Dean, 1974). The sensitivity of CV in relation to the median grain size of the borrow sand, is calculated for the four typology of defence work described so far. Increases of 0,05 mm of the borrow sand median diameter (D_{50P} = 0,2 ÷ 0,4 mm), maintaining fixed the value of native median grain size. The following example is obtained fixing the D_{50N} = 0,25 mm (Fig. 9).

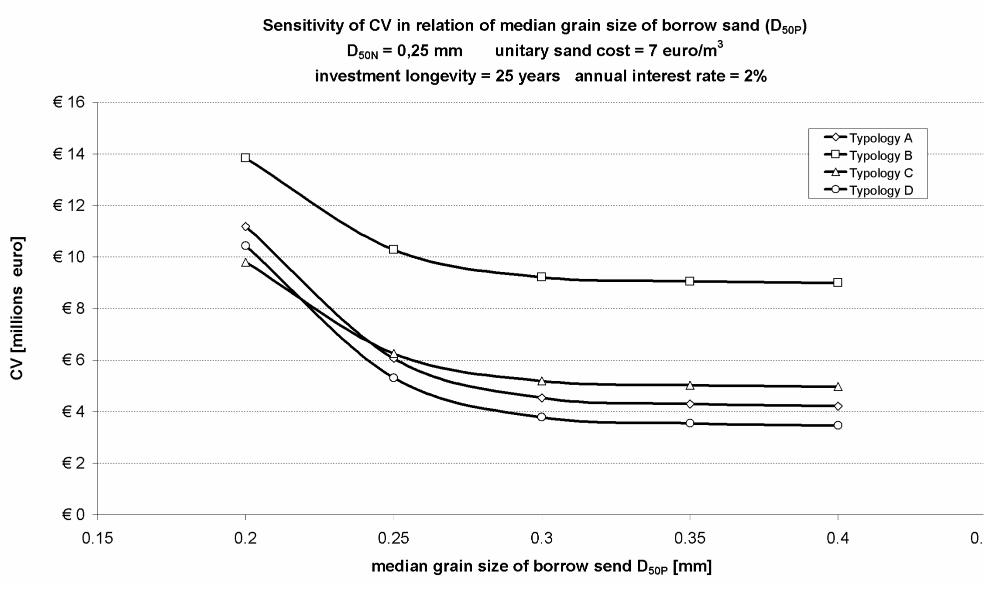

Fig. 9: Current Cost curves in function of grain size

Conclusions

This kind of analysis should consider, for being complete, all the elements that make these works useful for community and determine (in computing of intervention cost) a costs decrease that is also a benefit for community:

- the greatest use of beach
- the greatest satisfaction of people
- the increase of profits for managers of tourist activities
- etc

Those elements are of difficult valuation and nowadays we aren't able to give a monetary quantification. For this reason this analysis must be considered a term of comparison of costs for realization and maintenance of different typologies of intervention, to place, if available the others parameters as above.

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