Improvement of an Existing Shoreline Evolution Numerical Model

MARINE 2019

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Key words: LTC, User interface, programming, coastal erosion, coastal interventions

Abstract. The coastal areas are facing serious erosion problems. The increasing urban pressure on coastal areas and the continuous shoreline retreat, lead to the anticipation of significant investments to protect the population living in the littoral. In order to avoid coastal erosion and flooding, and their consequent social, economic and environmental negative impacts, it is essential to accurately characterize the coastal evolution trends. The importance of the numerical modelling in civil engineering has been increasing in the last years, being the coastal engineering a relevant example. Since the 1970s, several types of numerical models have been developed for engineering applications with the purpose of analyze and predict the coastal morphology. One-line models based on the Peinard-Considère [1] theory are commonly used to simulate the shoreline position variability of sandy beaches. LTC (Long-Term Configuration) is a numerical model developed to support coastal zone planning and management regarding erosion problems [2, 3]. LTC combines a simple classical one-line model with a rule-based model for erosion/accretion volumes distribution along the cross-shore profile. This model was designed for sandy beaches, where the main cause of the coastal dynamics and shoreline evolution is the alongshore sediment transport gradients, depending on the wave climate, water levels, sediment sources and sinks, sediment’s characteristics and boundary conditions. The model inputs are the wave climate, the water level, and the bathymetry and topography of the landward adjacent zones which is changed during calculation. Extensive areas can be analyzed up to 100 years. LTC code was developed in Fortran language and both input and output data were done through notepad files. Therefore, a graphical interface and the improvement of specific aspects on the initial code have been developed, being presented in this work. The knowledge of wave characteristics at the wave breaking depths (output data in the new interface), the representation of the cross-shore active width of the profiles along the coast and along time, and the introduction of new options to read bathymetric data, are some examples of the model updates. The development of the graphical interface is performed in C# language. It was intended that the new interface is resourceful and intuitive, aiming to allow new useful tools for the users. In conclusion, this work presents the new interface of LTC model, highlighting some of the improvements made possible in the numerical model due to the new interface characteristics.
1 INTRODUCTION

A growing trend of erosion problems in coastal areas is being observed worldwide due to important sediment deficit, the increasing urban pressure on coastal areas and the continuous shoreline retreat. LTC (Long-Term Configuration) is a numerical model developed to support coastal zone planning and management regarding erosion problems, by estimating the shoreline evolution in a medium to long-term time horizon, under different coastal intervention scenarios. Using 3D topographic data, which is continuously updated during the simulation, the model assumes that each wave acts during a certain period of time (computational time step) and it is able to distribute erosion or accretion resulting from the longshore sediment transport gradients along the active cross-shore profile, between the depth of closure and the wave run-up limit. The main limitations of the model are inherent to the current knowledge about cross-shore profile evolution under persistent erosion or accretion.

LTC code was developed in Fortran language and both input and output data were done through notepad files. Therefore, this work aimed to develop a graphical interface that allows visualizing the main results of the shoreline evolution when simulating different coastal intervention scenarios. The graphical interface should also allow an easier evaluation of other parameters related to sediment dynamics (breaking wave characteristics, depth of closure, wave run-up limit, longshore sediment transport volumes, etc.), enabling improvements of the performance of the model and supporting the development of associated tools, namely of cost-benefit analysis tools based on shoreline evolution and correspondent accretion or erosion areas, consequence of different coastal intervention scenarios.

To achieve the proposed goals, the next section of this work presents a brief description of one-line model theory to support shoreline evolution simulations, and the following section describes the main assumptions adopted in the LTC numerical model. Then, LTC graphical interface is described in detail and finally some conclusions are presented, related with the potential achievements resulting from the developed graphical interface.

2 NUMERICAL MODELLING OF THE SHORELINE EVOLUTION

The numerical modelling of the shoreline evolution is necessary, not only to understand and predict the coastal systems dynamics, but also to assist an effective decision-making. There are no universal models for the analysis and prediction of the shoreline evolution on a scale of tens of years [4]. The coastal morphology evolution is the result of the interaction of complex physical processes that, in most cases, cannot be numerically represented accurately. Numerical formulations are deterministic, based on known or semi-empirical physical laws obtained from field or laboratory measurements [5]. The analytical models of shoreline evolution are closed solutions of the differential equation of continuity, simplified for the transport of sediments under constant wave climate conditions, in space and time [5]. The first model of this type was introduced by the one-line theory [1], which considers that the cross-shore beach profile, limited to offshore by the depth of closure, beyond which there is no significant changes in the bottoms, moves parallel to itself. Several works [6-10] are examples of other analytical models referred by Rosati et al. [11].

The numerical approach for the simulation of coastal and beaches morphology evolution...
are diverse, with varying degrees of complexity, from simple one dimension models, to sophisticated three-dimensional (3D) models. Due to the high computational demands, 3D models can only be used in short-term applications, while the shoreline evolution models can be used for long-term analysis [5]. Coelho et al. [12] classify the coastal morphology evolution in short, medium and long-term temporal scales, according to Table 1.

One of the most used and simple models to predict the shoreline evolution is based on the one-line theory, which, as referred, assumes a constant profile shape that can be moved perpendicular to the coast, as a result of erosion or accretion phenomena. Multiple-line models were developed to describe the contours movement at certain depths, analogous to the one-line models. Despite the additional detail, these models were unsuccessful due to the difficulty of adequately reproduce the cross-shore sediment transport. These models require more calibration and do not represent a significant increase in results quality [4].

**Table 1:** Numerical models classification, considering the time and spatial scales of the simulation [12].

<table>
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<th>Hours</th>
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According to Vicente and Clímaco [13], one-line models used to estimate longshore sediment transport rates and long-term shoreline changes generally assume that the profile is displaced parallel to itself in the cross-shore direction. These models are formulated based on the sediments conservation equation in a control volume or shoreline stretch and on longshore sediment transport equation [11]. It is assumed that there is an offshore depth of closure and an onshore upper end of the active profile, defining the limits where no significant changes happen. A constant profile shape moves in the cross-shore direction between these two limits, implying that sediment transport gradients are uniformly distributed over the active portion of the profile [14]. Following the previous assumptions, and according to Figure 1, sediments volume continuity for an infinitely small length of shoreline can be formulated [15].

**Figure 1:** One-line model definition scheme [14].
The continuity equation can be solved for simple boundary conditions and simplified hypothesis, obtaining analytical solutions to the problem of the shoreline evolution [1]. It is important to emphasize that the coastal management and planning primarily work with temporal scales of years or decades, in stretches with tens or hundreds of kilometers. The generality of current models is validated in schematic situations and when applied to real cases, they are calibrated based on specific data. After calibrated, the models are applied differently, in situations of analysis, evaluation of coastal intervention scenarios and prediction of future shoreline conditions [4].

3 NUMERICAL MODEL LTC

LTC (Long-Term Configuration) is a numerical model to simulate the shoreline evolution in a medium to long-term perspective. It was primary developed at Aveiro University, Portugal, version LTC CC2005 [2], and then improved at Faculty of Engineering of Porto University, version LTC-RS2010 [5] and again Aveiro University, in 2012, version LTC-CC2012. LTC was developed to support coastal zone planning and management in relation to coastal erosion problems [16-20]. It was firstly presented at the ICCE 2004 [21] and has been improved and extensively applied since then [20, 22]. LTC combines a simple classical one-line model with a rule-based model for erosion/accretion volumes distribution along the beach profile [17]. This model was designed for sandy beaches, where the main cause of shoreline evolution is the alongshore sediment transport gradients, dependent on the wave climate, water levels, sediment sources and sinks, sediment characteristics and boundary conditions. The model inputs are the wave climate, water level and the bathymetry and topography of the landward adjacent zones (updated during calculation).

The sediment transport volumes are estimated by formulae that consider the shoreline’s angle to oncoming breaking waves and the breaking wave height (CERC formula). The sediment volume variation in a coastal stretch is caused by sediment transport gradients between modeled cells where, similar to one-line models, the balance of volumes is defined through the continuity equation. This difference between sediment transport volumes represents a variation in the bottom level of the grid points in the same profile of the modeled domain [17]. LTC assumes a uniform cross-shore distribution of the alongshore sediment transport along the active width of the cross-shore profiles, thus performing a uniform variation of the vertical coordinates of the active profile grid points, adjusting the active profile at the boundaries based on the sediments friction angle defined by the users [18]. This way, the variation of the shoreline position depends, not only, on the sediment volume variation, but also, on the topography and bathymetry associated with each cross-shore profile [2]. With the LTC numerical model, the 3D topo-hydrographic data are continuously updated during simulation, allowing the model to distribute erosion or accretion sediment volumes for each wave action (computational time step). Due to the importance of the boundary conditions in the model simulations, several options can be made: constant sediment volumes going in or out the study area; constant volume variations in the domain border sections; extrapolation from nearby conditions. Moreover, different coastal protection works combinations may be considered with almost no limitation for the number of groins, breakwaters and seawalls, the number of sediment sources/sinks sites, and artificial
nourishments.

The Figure 2 scheme represents the computational structure of the LTC model, developed in Fortran programming code. The topo-hydrography should be provided at the beginning of the simulation, being updated in each time step. The propagation of the waves is carried out on the actual bathymetry, being estimated the wave breaking characteristics. The longshore sediment transport rates are computed alongshore and the sediment transport volumes balance for each coastal stretch is calculated, after which the bottom coordinates are updated, and the new topo-hydrography is calculated. In order to facilitate changes and to promote alternatives in computational methods, the program is composed by small subroutines, increasing the simplicity and comprehension of each of them. The main program uses these subroutines throughout the calculation process [2].

![Computational structure of the LTC model](image)

**Figure 2:** Computational structure of the LTC model [5].

### 4 LTC GRAPHICAL INTERFACE

The developed graphical interface is described in this section, referring to its use and main potentialities. The main window of the interface can be considered divided into two main zones, allowing visualizing the study area domain, as the remaining input data sections are alternated (Figure 3). After the input data definition, several simulation results can also be visualized in the new developed graphical interface.

#### 4.1 Input data definition

The input of data is divided into six principal groups: 1) spatial domain characteristics definition; 2) wave regime; 3) tidal regime; 4) boundaries conditions; 5) coastal defense interventions; and 6) simulation characteristics and intended outputs. In the "Spatial Domain" window, all the parameters related to the study area are defined, namely the bathymetry/topography. For the immediate determination of the initial shoreline position, the user must also indicate the mean sea water level. Finally, the annual rate of sea level rise due to climate change should be indicated. The user has also the option to import an image with a representation of the spatial domain, which is loaded and is displayed when the user wishes.
Figure 4 (left) shows an example of the options available for the introduction of wave characteristics. The user can choose one of five available options (in "Wave climate definition"): a fixed wave climate, where the wave height and wave direction will be constant throughout the calculation; generation of a random sequence of waves, based on the occurrence percentages of different wave heights classes, representative of a typical year of wave climate. Based on this option, the user can define a systematically equal wave sequence, maintaining the occurrence percentages, by activating the "Consider the same sequence wave" check box (if this option is not considered, in each simulation the wave classes frequency is the same, but the waves characteristics and its sequence are changed, so the resulting wave climate is different). In the fourth option the user defines a maximum and minimum limit for the wave heights and directions, being these limits automatically represented in the respective graphs and being generated a random wave climate, which respects the defined limits. The last option allows importing a wave data file (Excel® or text file) with recorded data.

The data for the tidal regime characterization is divided in astronomical and meteorological tides (Figure 4, right). For the astronomical tide, the user may choose to consider that the mean sea level remains fixed (value defined in the "Spatial Domain" window) or that it is variable and must therefore define the maximum amplitude for spring and neap tides. For the definition of the meteorological tide, the user has three options: 1) sea level remains fixed throughout the calculation, and the user just need to define the sea level elevation changes due to high or low meteorological pressures; 2) sea water level varying randomly between two limits, which must be defined by the user; 3) sea water level varying randomly between
previously defined limits, but respecting a correspondence with the wave heights verified at the same time instant.

**Figure 4:** Windows to define the wave and tide climate: left) waves; right) tides.

With respect to boundary conditions, data entry is divided into the definition of sediment volumes at the northern (updrift) and the southern (downdrift) boundaries of the area to be modeled (Figure 5, left). At each border the user can choose one of three options: 1) sediments fixed volume going in or leaving the section that defines the boundary; 2) erosion or accretion fixed rate in the cross-section (the user must define the value of the volume variation, which will be assumed constant throughout the calculation); 3) extrapolation of sediment transport volumes conditions in the vicinity of the border, based on the average of the transport volumes in the adjacent sections (the user may also add/subtract a fixed sediment transport volume to the average of the transport volumes in the adjacent sections).

The LTC model also allows the definition of four different types of coastal defense interventions: punctual alluvial sources, artificial nourishments, defense works perpendicular to the shoreline, like groins or breakwaters, and adherent longitudinal defense works or seawalls (Figure 5, right). In order to add a new coastal defense intervention, the user must click on the "Edit" corresponding to each intervention type, being directed to fill a table with the characteristic of each one of the interventions. After completing the required data, each of the interventions will be automatically represented in the spatial domain window.

The "Outputs" window allows the user to define the characteristics of the simulation and graphic outputs. It is also in this window that the user has the possibility to start the calculation ("Run" button) and where can easily access each of the parameter windows (briefly described in the next section), and check which formulations have been chosen for the calculation. After all data have been entered, the "Run" button will be available. While the simulation is in progress, the program does not allow any change of the data, or the visualization of the windows of the model.
4.2 Calculation parameters

The calculation parameters and formulation choices are complete by default and the user only needs to access their windows if intending to change them. Three windows have been developed. The user can access those three windows through the main window by clicking on "Calculation Parameters": General Parameter’s window (water and sediments characteristics); Formulations choice window; and Slope Angles (sediments friction angle).

4.3 Drawing domain

After the user has entered the calculation domain, the shoreline and topo-bathymetric contour lines are automatically represented in the drawing area. The display characteristics can be changed by the user, accessing the "Properties" button. It is possible to change the properties related to the shoreline (initial and final), depth of closure, wave breaking depth line, wave run-up limit and envelope of the active profile width throughout the simulation. It should be noticed that, in addition to the shoreline and initial contours, the remaining options are only visible after running the simulation. The user can define the scale in which the domain is displayed. Regarding the spatial domain visualization options, it is possible for the user to view/hide the grid points, the coastal interventions at their locations, topo-bathymetric contours and shoreline. Optionally, the user can view a picture of the spatial domain (Figure 6), which automatically becomes the background of the working area. Finally, in the spatial domain representation area, the "Export" button is also available which allows the user to save the graphical representation of the study zone as an image file.
4.4 Simulation results

After the simulation, a new window is available to visualize the results (Figure 7). This window contains information on the evolution of topo-bathymetry in the spatial domain, shoreline evolution, wave characteristics at breaking, cross-shore profiles and access to AutoCAD® and Excel® files.

In the "Bathymetry and Topography" tab (Figure 7) it is possible to select the time instant corresponding to the result to be displayed. For each of the time instants defined in the data input window "Outputs" (in "Time space between bathymetry/topography") is visible in the drawing area, the bathymetry and topography of the spatial domain. All of the display options available in the drawing area are active for each of the outputs. The user can also see the envelope of the active profile width along the entire length of the domain, allowing identifying the extreme limits obtained during the simulation for the depth of closure and for the wave run-up. Finally, the user can export to a data file (Excel® or text file) the topo-bathymetry obtained in the represented instants of time. This function enables this file to work as input data to characterize the domain of any future simulation, starting from that time instant. It is also possible to visualize an animation with the shoreline evolution over time.

To evaluate the wave breaking characteristics, the user can visualize the results obtained for the wave height and direction, for each cross-shore profile and time instants defined in the window "Outputs". Through an Excel® file, the user can also access for each profile and instant: the wave height and direction at breaking, breaking depth position, breaking contour orientation, shoreline position, depth of closure and wave run-up positions, width of the cross-shore active profile envelope, potential sediment transport capacity, effective longshore sediment transport volumes, vertical displacement of the grid points of the profile, and
information on the accretion and erosion areas between profiles.

Figure 7: Window with the results of the simulation (“Results”).

The results for the cross-shore profiles are generated in an independent window (Figure 8). For each profile shown, the user can identify the boundaries of the profile, the depth of closure, the wave breaking depth and the wave run-up limit. Depending on the profile and/or time instant chosen, the user can also interactively view an animation with the evolution of the profile over time, or the variation of profiles shape alongshore, at a given time instant.

Figure 8: Cross-shore profile results representation.
5 CONCLUSIONS

In spite of extensively applied in the past, LTC was missing a friendly graphical interface, which was a limitation factor to the analysis of all the potential results produced by the model. Thus, efforts were made to facilitate the data introduction by the users, but mainly to make easier the results analysis. The knowledge of wave characteristics at the wave breaking depths (output data in the new interface), the representation of the cross shore active width of the profiles along the coast and along time, and the schematic representation of each cross-shore profile and time instant are some examples of the model updates. The work developed allowed to facilitate the evaluation of important properties in the calculation of the shoreline evolution, namely the characteristics of hydrodynamics (waves at breaking, wave run-up limits) and longshore sediment transport patterns (depth of closure, active profile width and sediment transport rates) during the analyzed time horizon.

It was intended that the new interface is resourceful and intuitive, aiming to allow new useful tools for the users. The results allow anticipating that the LTC model can continue to be developed and may integrate complementary tools, which together with the design of interventions and the analysis of its costs and benefits will facilitate the identification of adequate coastal erosion mitigation scenarios, helping on planning and management of the coastal zones.

REFERENCES

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