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Beach profiling Emery method improved with eyeholes

Método de perfilación de playas de Emery mejorado con mirillas

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Abstract

An improved beach profiling procedure based on the Emery method is presented. Two graduated wood sticks with eyeholes are used to obtain the level difference based on the alignment of the eyehole, the scale, and the horizon line. Depending on the beach irregularities and the desired accuracy, the sticks are placed at the required distances and measured with a reel measuring tape. The necessary equations to apply the method are included. It was tested that there are not significant profile differences compared with an Electronic Total Station. The results show the feasibility of the proposed method, as a practical tool to survey beach profiles.

Resumen

Se presenta un procedimiento de perfilación de playas basado en el Método de Emery. Dos postes de madera graduados con mirillas son usados para obtener las diferencias de nivel basado en la alineación de la mirilla, la escala y la línea de horizonte. Dependiendo de las irregularidades de la playa y de la precisión deseada, los postes se colocan a la distancia requerida, medida con una cinta métrica de carrete. Se incluyen las ecuaciones necesarias para aplicar el método. Se probó que no hay diferencias significativas en el perfil comparado con una Estación Total Electrónica. Los resultados muestran la factibilidad del método propuesto, como una herramienta práctica para realizar levantamientos de perfiles de playa.

Keywords:
Beach profile; Eyehole-Emery method; Low cost profiling; Electronic total station; Profiling equations

Palabras clave:
Perfil de playa; Método Mirillas-Emery; Perfilación de bajo costo; Estación total electrónica; Ecuaciones para perfilado

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Introduction

Beach profiles are one of the main characteristics of beach morphology. They are represented as differences in elevation on the orthogonal path to the coast. By making continuous profile measurements in a particular area, the temporal variability in the beach slope is recorded, as well as the height of dunes and berms, in addition to providing a basis for estimating the beach volume [1].

The spatial and temporal evolution of the beach profiles provides useful information for the understanding of coastal processes, and therefore for the maintenance of the coasts. When investigating the coasts, the measurements of the beach profiles provide important information on erosion and accretion phenomena; the effect of storms, coastal developments and global warming. The profile information can also be used to estimate the location of scarps, which is important for evaluating long-term trends in coastal erosion [2].

Beaches are important in reducing the impact of storms. Large beaches reduce the degree of erosion in the dune area, as well as preventing damage to coastal properties. They also provide attraction for visitors, which contributes to the local economy, so it is important to know what happens to them [3]. There are shaped by the tides, waves and wind that deposit or remove sediment, which changes the morphology of the beach [4].

The influence of natural forces that affect beach morphology can be divided into long-term or short-term processes. The long-term processes shape the coast in a scale of kilometers. Those of short duration, such as storms, cause a considerable impact in an area within a few hours [5].

Measuring beach profiles and beach dynamics is useful for modeling future impacts that could arise from rising sea levels. This is especially important in storms due drastic tide changes can negatively affect human activities [6]. The ideal way to monitor changes in beach morphology is by calculating the total volume of sediment that is lost or recovered. Achieving this calculation accurately and reliably requires the collection and processing of an immense amount of data over time and space.

Beach profiles have been a useful tool for monitoring beach volume and shoreline changes for research or planning purposes. The volumetric changes to the beach front are used as an indicator of the effects of erosion by storms, El Niño-La Niña cycles, changes in sea level or coastal protection works such as beach filling [7].

A variety of methods have been developed, some of them laborious, but the simplest was proposed by Emery [8]. This method uses two graduated vertical poles linked by a string of a relatively short length. A perpendicular line to the sea along the beach is established to set the profile transect. One pole is placed on a benchmark or first point, and the other at a second point determined by the tense string above the ground. These graduated poles are placed vertically to observe the height difference between the two points aligned to the horizon. The first pole is then moved to a third point and so on, until the profiler comes near the tide level of the sea.

The Emery approach has been modified by different researchers. For instance, Delgado and Lloyd [9] describe how a single person modified Emery method by means of a vertical graduated and stationary aluminum pole with a level attached, and a right angle aluminum setsquare, 2 m horizontally long and 0.80 m vertical with another level. The pole is fixed on the profile line and its verticality established. The user then takes the setsquare using the 2 m side, levels it horizontally and places it against the stationary post, allowing the short end of the setsquare to rest on the sediment and the measurement is taken in the graduated post.

Puleo *et al*. [1] proposed a profiler based on the Emery method, using a pound sign structure consisting of four aluminum square poles of 0.025 m width attached with bolts and nuts. The separation between the vertical poles is 1 m. To ensure that the profiler is upright, a spirit level was placed on the front leg, attached with a graduated one-meter aluminum stick. In the rear leg, a level bar made with aluminum is attached to a bubble level. When leveling, the intersection between the level bar and the graduation on the front leg indicates the difference in elevation. For this method, a 100-m tape was placed along the cross-shore line of interest.

Another simple profiling method was developed by Andrade and Ferreira [10]. It uses a water-filled graduated hose, it is placed vertically aside two poles, and the water level reading indicates the differential elevation of the ground.

In this paper, a beach profiler based on the Emery method [8] idea is proposed. The approach uses two graduated sticks similar to Emery. The sticks have been modified, including several eyeholes drilled in each stick. The eyeholes are used to sight towards the second stick scale, by using the horizon line to point out the measurement of the height difference. Distance between the sticks is defined by the beach morphology, and it is measured with a reel-graduated tape. Profiles obtained through the proposed method are compared with an Electronic Total Station (ETS). Results show that the differences are negligible. In addition, the derived equations of the method are included for a variety of common situations found in the field. The proposed Eyehole-Emery (EE) method was conceived as a versatile and low-cost profiling alternative using portable and light components for easy beach access. This method provides enough accuracy rather than the use of a heavy and expensive ETS and it is unconstrained to a fixed distance.

Method

The proposed method named Eyehole-Emery uses two graduated sticks with several drilled eyeholes to conduct the beach profile. The eyeholes permit to sight the horizon line. The elevations along the beach are measured through the height difference between both sticks, named the observer and the pointer. The observer stick is used to view the horizon line through the appropriate eyehole and sight the scale of the pointer stick. Low heights variations due the Earth curvature are negligible in short distances.

The beach profile is generated by selecting the start and end points on a straight-line perpendicular to the coastline. The observer stick is placed at the starting point to see the horizon and the pointer stick is placed wherever a relevant slope change is perceived by eyesight. One of the eyeholes must be selected to see the horizon line and indicate where it matches the scale of the pointing stick. The graduation of the used eyehole and the measurement on the pointer-stick scale are recorded, together with the distance between the sticks. Iteratively, the rest of the profile is generated, measuring the consecutive points required until the coastline is reached, as previously described. Both sticks must be placed vertically at the same depth to minimize errors.

The verticality of the stick is referred at two planes (y-z) and (x- z), according to a Cartesian reference frame. The eyehole view of the observer stick is a circular vision field. The observer-stick verticality in the y- z plane is achieved by halving the view with the horizon line (Fig. 1a).

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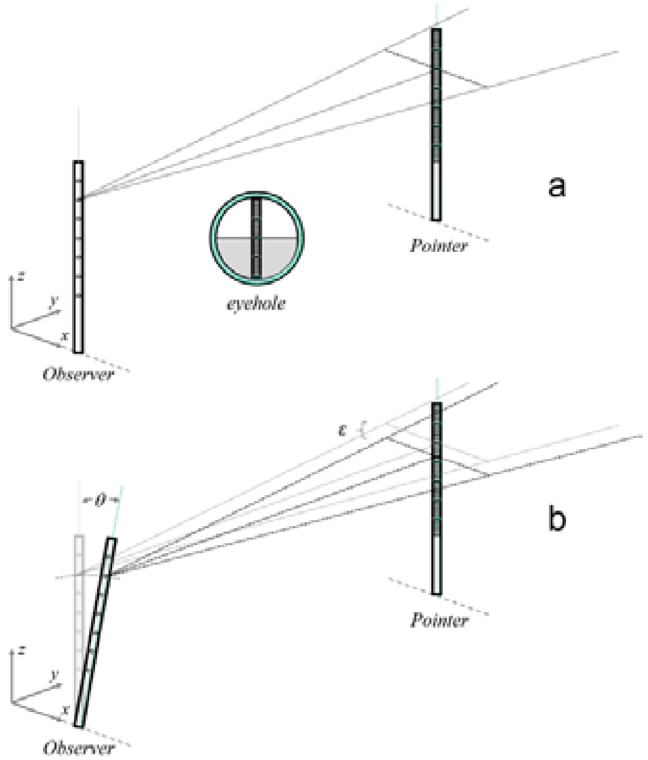

Fig. 1. a) Vertically aligned sticks using the eyehole and b) involuntary tilted stick in the *x-z* plane.

An involuntary inclination in the *x- z* plane can be minimized with empirical advice among the operators, because the error ε is insignificant when the inclination angle θ is small (Fig. 1b).

Eyehole Sticks

The implementation of the EE method in the field requires minimum simple tools. In this work, cylindrical wooden sticks of the same length of about 2 m and 0.03 m diameter were employed (Fig. 2). A vertical graduated scale along each stick is marked in centimeters, starting at the top.

Fig. 2. Portable components employed in the EE method.

Several equidistant transverse holes every 0.10 m and about 0.002 m diameter have been drilled in each stick and used as eyeholes. Each eyehole is identified according to the distance from the stick top.

A peripheral line 0.10 m from the bottom of the sticks should be marked to indicate the limit of the inserted length in the ground. For highly compacted sands, the sticks should be placed on the surface.

A reel-graduated tape of about 20 to 30 m length is used to measure the distance between the observer and pointer sticks and a 5 m retractable measuring tape as a stick extender.

Formula Development

The interval notation is used to describe consecutive measured points $[P_i, P_{i+1}]$ of the beach (Eq. 1), according to the profile shape (Fig. 3, Table 1):

$$[P_i, P_{i+1}] = \{x | P_i \leq x \leq P_{i+1}\} \tag{1}$$

and for the distance d_i between consecutive points:

$$d_i = d(P_i, P_{i+1}) = |P_i - P_{i+1}| \tag{2}$$

Table 1. Schematic representation of possible conditions of segments perpendicular to the coastline, on a typical beach of Baja Peninsula, Pacific Ocean coast.

Id	Interval	Beach Characteristics	Approximate Measurements
Z_1	$[P_0, P_1]$	Landmark height	$h_o < 1$ m
Z_2	$[P_1, P_2]$	Stable vegetation zone	W variable; $\alpha \cong 0$
Z_3	$[P_2, P_3]$	Considerably damaged (e.g. transit zone)	$h > 0.30$ m
Z_4	$[P_3, P_4]$	Moderate damage (e.g. people, fishermen, …)	$h < 0.10$ m
Z_5	$[P_4, P_5]$	Negative slope	$-1° < \alpha < -3°$; $1 \leq W \leq 5$
Z_6	$[P_5, P_6]$	Short distance slope	$\alpha < 5°$
Z_7	$[P_6, P_7]$	Old smoothed scarp	$\alpha < 45°$
Z_8	$[P_7, P_8]$	Moderated long distance slope	$\alpha < 5°$; $5 \leq W \leq 20$
Z_9	$[P_8, P_9]$	Terrace (almost horizontal zone)	$\alpha \cong 0°$
Z_{10}	$[P_9, P_{10}]$	Scarp due to a recent storm	$\alpha \cong 90°$
Z_{11}	$[P_{10}, P_{11}]$	Unstable terrace	$\alpha \cong 0°$
Z_{12}	$[P_{11}, P_{12}]$	Front beach	$\alpha > 45°$

Meaning of symbols: α = slope (degrees); h_o = fixed stick height; W = width of sector (m), perpendicular to the coastline; h = elevation; $\cong$ means "equal or almost equal".

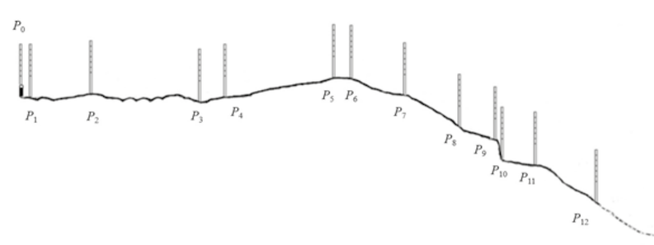

Fig. 3. Selected points according to beach characteristics.

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The elevation of the beach h_i between two points will be positive for ascending trajectories and negative for descents. A benchmark used as the reference level in the initial point P_o is located at x=0 in the Cartesian coordinate axis, with elevation or landmark height h_o and distance d_o=0.

The changes in the beach elevations are represented in (x,y) coordinates, the distances d_i from the benchmark to each point towards the coastline are in the x-axis, and elevations h_i are in the y-axis.

Let L_1 and L_2 the lengths of the two sticks, $L_1<L_2$, there are two ways to use the sticks, depending on whether the profile at a determined point of the beach is descending (Fig. 4a) or ascending (Fig. 4b). The derivation of the formula to calculate elevation from a reading on the pointer stick scale will be made separately for each case. Using the auxiliary variables H_1 and H_2 indicated in Fig. 4, an elevation h<0 is calculated from the following (Fig. 4a):

$$L_1 = H_1 + M \tag{3}$$

$$L_2 = H_2 + R \tag{4}$$

$$-h + H_1 = H_2 \tag{5}$$

subtracting:

$$h = H_1 - H_2 = (L_1 - M) - (L_2 - R) \tag{6}$$

then, elevation is:

$$h = R - M - (L_2 - L_1) \tag{7}$$

where:

h= Beach elevation (m)

R= Reading on the pointer stick (m)

M= Distance (m) from the top of the observer stick to the sighting eyehole

Similarly, in the case of an ascending slope h>0, the same identities are obtained (Fig. 4b), and Eq. (7) is used.

For same length sticks L_1=L_2, beach elevation at each selected point of the beach is:

$$h = R - M \tag{8}$$

The use of two sticks of same length is the most common case for a beach profiling project.

In the case of a scarped beach or with an abrupt slope change, the pointer stick will be below the horizon line, and it is necessary to prolong its length. The pointer stick can be extended an additional distance T, by means of a retractable measuring tape (Fig. 5a). These stepped slopes are characteristics of beaches with high-energy waves.

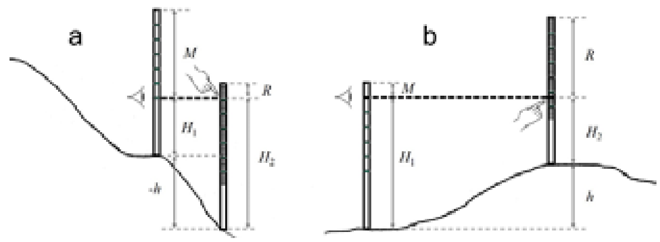

Fig. 4. Parameters to deduce the general formulas a) Descending profile and b) ascending profile.

Then, Eq. (7) for sticks of the same length L, and because the horizon line is above the pointer stick L_2=L+T and R=0:

$$h = 0 - M - (L + T - L) = -T - M \tag{9}$$

Instead of a retractable measuring tape, a third stick of the length L can be attached to the pointer stick (Fig. 5b), using Eq. (7) with L_1=L and L_2=2L-Q, where Q is the overlapping length (m):

$$h = R - M - (L - Q) \tag{10}$$

The benchmark can be referenced to the mean lower low water (MLLW) using the time of the tide in the last point. The MLLW is obtained from tide tables and is the zero level reference for the profile elevations.

The time is recorded when the last position P_n of the pointer stick reaches the water. An additional point P_{n+1} is added at a distance d_{n+1}, extending the last slope m to intersect the MLLW and h_{n+1} is calculated using the tide tables. A constant slope can be assumed because the method is inappropriate to use under the water due to the stick instability generated by the waves (Fig. 6a), then:

$$m = \frac{h_n}{d_n} = \frac{h_{n+1}}{d_{n+1}} \tag{11}$$

and for d_{n+1} :

$$d_{n+1} = \frac{h_{n+1}}{m} \tag{12}$$

Calculating the new coordinates (d_i', h_i') at the zero level mentioned above, in a reverse order from the original (d_i, h_i). The transformations to obtain the new elevations and distances are:

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From the initial values $d_0'=0$ and $h_o'=0$, and for $i=1,\ldots, n+1$:

$$d_i' = d_{n-i+2} \quad (13)$$

$$h_i' = h_{n-i+2} \quad (14)$$

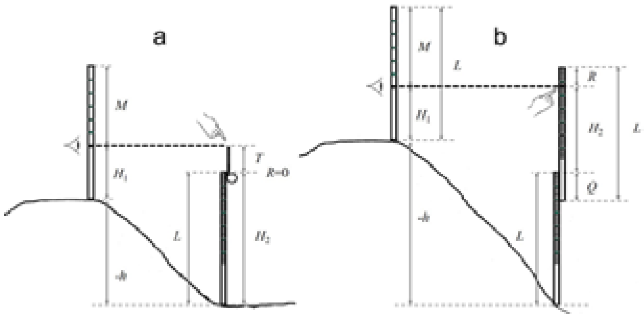

Fig. 5. Pointer-stick extension with a) A retractable measuring tape and b) a graduated 3rd stick.

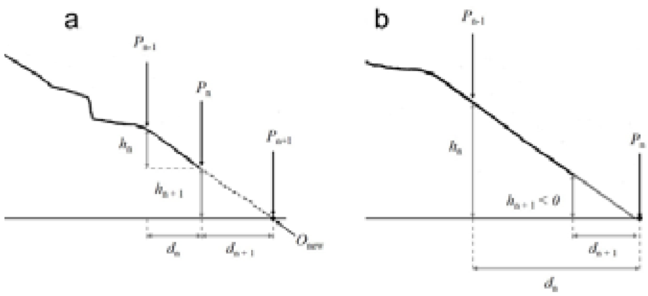

Fig. 6. Use of the tide height to estimate the zero level of the profile a) Above MLLW level and b) below MLLW level.

Analogously, in the rare case that the sampling is finished below the MLLW level (Fig. 6b) it suffices to adjust the last measurement:

Let $h_{n+1}<0$ the sea tide level at the time when the last point of the profile is reached, the auxiliary values for the adjustment are:

$$\frac{-h_{n+1}}{d_{n+1}} = \frac{h_n}{d_n} \quad (15)$$

then,

$$d_{n+1} = -\frac{d_n h_{n+1}}{h_n} \quad (16)$$

and the corrected values of the last measurement are:

$$d_{new} = d_n - d_{n+1}$$

$$h_{new} = 0$$

When the tide is lower than the MLLW, the figure is negative, as reported in the prediction tide tables. In geographical zones where the tide corresponds to a micro-tidal classification, the tides are reported in centimeters [11].

Results

The profilers executing the EE approach are shown in Fig. 7, the 3rd eyehole at 0.30 m from the top of the observer stick is used to sight the horizon line and indicate the measurement at 0.25 m on the pointer stick.

Fig. 7. Profilers executing the EE method.

In Fig. 8, an eyehole view of the horizon line aligned with the half of the vision field avoids the inclination error in the y- z plane. For a scarp, it is required to prolong the pointer stick using the retractable measuring tape (Fig. 9).

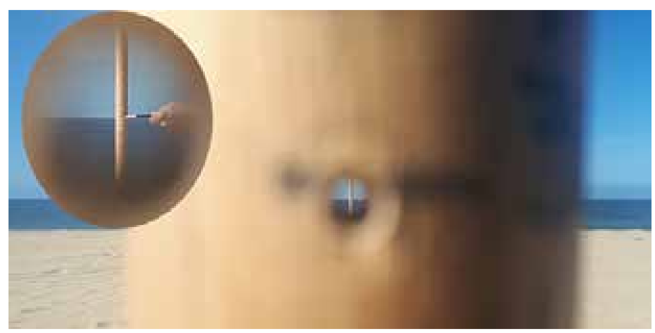

Fig. 8. Eyehole vision field used to sight and center the horizon line, and measure in the pointer stick.

Fig. 9. Retractable measuring tape used in a scarp.

Four beach profiles using the proposed EE method and an Electronic Total Station (ETS) Sokkia model Set

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III-B were performed over 4 months in Agua Blanca beach (23° 34.301' N, 110° 20.550' W), Baja California Sur.

The selected benchmark was located about 70 m from the coastline. The distance between two consecutive measured points was selected where noticeable height differences existed. The resulting profiles are shown in Fig. 10. Difference between the two approaches are more relevant at the final points, because of the cumulative error of the EE method. The beach morphology has a significant change near the coastline because of recent hurricane effects (John, Rosa, and Sergio), which occurred in 2018.

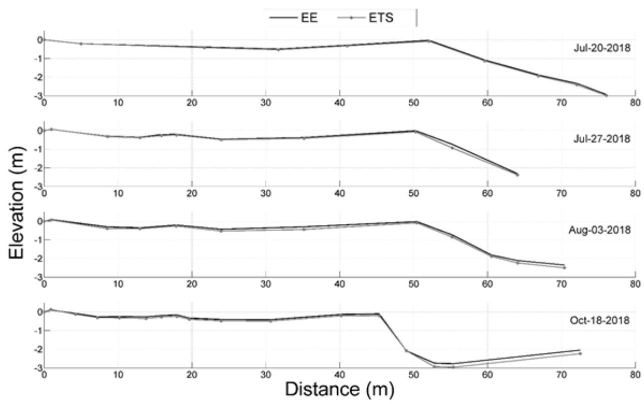

Fig. 10. Profiles compared between ETS and EE method.

Paired observations were used to compare the evaluations performed with the EE and the ETS. An average difference of 0.006625 m with a standard deviation of 0.00489728 m were obtained. Using the t-student test [12], there were not significantly difference (t=1.3528, n=15, p=0.0981).

The beach profiling EE method is proposed to be used with variable distance between points; nevertheless, it can be performed with a fixed distance, resembling the Emery [8] method. A comparison was performed with a variable distance of 17-point profile and a 77-point profile using one meter fixed distance, shown in Fig. 11. The difference between both resulting profiles is negligible.

The profile can be plotted seaward using the benchmark as starting point. In some cases, it could be required to start inversely near the tide level. A beach profile is shown when the benchmark is the origin (Fig. 12a), and when is the coastline defined by MLLW (Fig. 12b).

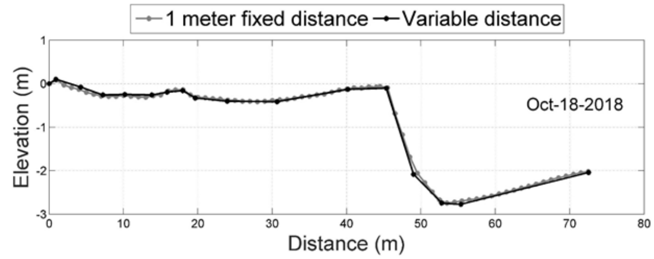

Fig. 11. Profiles with fixed and variable distance between points.

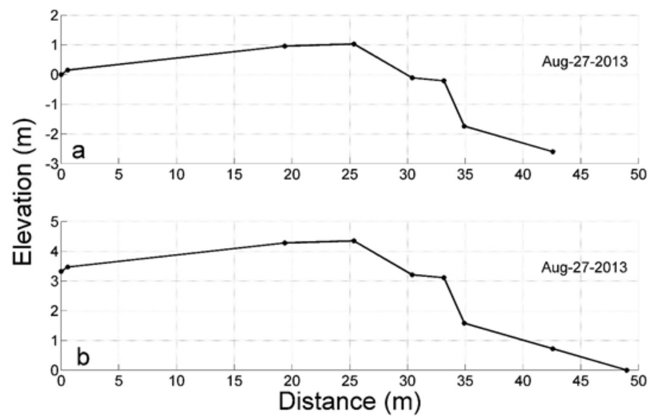

Fig. 12. Profiles using as start point: a) Landmark and b) MLLW.

Fig. 12b includes an additional point according to Eqs. (11)-(12). For that place, the MLLW was 0.718 m.

The involuntary non-verticality error of the sticks in the plane *y-z* was measured, sighting the horizon line from a solid plane floor. The observer and pointer sticks were placed at 5° and 10° of inclination (θ) and a separation distance of 1, 5, 10, and 20 m. The results show that for any distance, the error was of about 0.05 m for θ = 5° and 0.02 m for θ = 10°. Nevertheless, the height error (ε) can be calculated:

$$\varepsilon = (L - M)(1 - \cos\theta) \tag{17}$$

From Eq. (17), for L=2 m and using the eyehole M=0.30 m, for θ=5°, ε=0.0064 m and for θ = 10°, ε=0.0258 m. These figures are similar to the measured error. However, a stick tilted by more than 5° would be easily perceived and corrected by the profilers.

Discussion

The eyeholes are one of the innovative parts of the proposed EE method that serve to visualize the horizon line through a circular vision field. These allow a practical and precise observation of the horizon, a fundamental condition for leveling the pointer-stick scale and the horizon. The eyeholes serve to minimize the error due to the non-verticality of the stick in the *y-z* plane, and by the advice between profilers for the involuntary tilt in the *x- z* plane.

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The use of variable distances between points is another innovative characteristic of the method, in comparison to the Emery which can result in fewer points in the profile; besides, it saves time and reduces the inherent cumulative error.

This method permits to measure scarps using an additional extension attached to the pointer stick. For short extensions, it is preferable to use a retractable metal tape and otherwise, a third stick.

The different conditions of sand compaction on a beach provoke that the sticks may be inserted outside the fixed mark. These variations produce a difference in the elevation measurements that entails into an error.

In this work, the sticks were made of wood, but other materials can be used, according to the convenience of the user. However, the use of wooden sticks is cheap, lightweight, easy to drill, mark, and cut to a particular height. These profiling components are easily transportable to be taken on hard-to-reach sites.

The formula integrates the sign that simplify the notation of the ascending or descending slope, reducing interpretation and annotation errors of the field data.

To compare profiles of the same section in a beach, it is necessary to have the same starting point using a dependable benchmark. Comparison between profiles at different sections should use the MLLW datum or the benchmarks of each profile referenced among them. When the landmarks are near each other, the sticks can be used to know their differences in height and distance. If the profiles are far away, the MLLW is an acceptable reference.

To use MLLW as reference, it is necessary to identify the tide level on the beach when the readings were performed, which may be influenced by swash processes produced by waves breaking on the beachfront. When the tide level is properly obtained, this strategy could be a precise technique for comparing profiles.

On high-energy beaches where strong waves prevent a person entry into the sea, the uncertainty of the tide level reading can contribute errors in the elevation and profile length. For these beaches, an alternative method must be developed to know the end-point of the track into the swash zone, and to continue under the sea until the bathymetry can be measured of conventional way.

The dependency of horizon visibility is an inherent limitation of the proposed method.

Conclusions

The proposed Eyehole-Emery (EE) method has been conceived as a low-cost alternative with enough accuracy for beach profiling.

The EE method provides enough accuracy rather than the use of a heavy and expensive equipment, such as the Electronic Total Station. This method uses portable and light components, which enables easy beach access, unlike the ETS that is impractical to use in difficult access areas. Additionally, the ETS requires a setup when relocations are necessary.

The eyeholes permit not only to sight the horizon line but also to align the stick vertically in one plane *y-z*. On the other plane *x-z*, an involuntary stick inclination may occur, but it can be corrected with the proper advice among the operators.

In this method, the profile points are defined according to the beach morphology without the constraint of a fixed distance.

For stepped beaches, it may be necessary to extend the scale of the pointer stick, with a spring metallic measuring tape or a third graduated stick.

The cumulative error, which is inherent in this kind of methods, can be minimized if the sticks are buried in the sand at the same depth during the profiling labor.

The presented formulas can be applied in a wide variety of beach profiles.

The results show the feasibility of the EE method, as a practical tool to survey beach profiles.

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