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A seiche observed in the Larache port, Moroccan Atlantic coast

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Abstract. An episode of seiche, with peak-to-peak amplitudes of 6 to 11 cm, was observed and recorded in the Port of Larache, Morocco, at the mouth of the Oued Loukkos, using a Sea-Bird Electronics CTD. The CTD measurements, which exhibited characteristics of seiche, were processed to remove the much larger tidal signal and preserve the lower amplitude, higher frequency signal of the seiche. Based on spectral estimates, which were performed using the time series containing both well-defined and ill-defined seiche-like water level variations, the most energetic seiche period was approximately 17.5 minutes. A less energetic seiche period of approximately 70 minutes was also detected. The seiche is possibly sustained by reflections of a propagating gravity wave at points where there are sudden changes in the hydraulic cross-section (depth and/or width) of the Oued Loukkos. The genesis of the observed episode of seiche is unknown, but a likely prospect is that it was engendered by non-linear interaction of the tidal flow with the river bed.

Key words: Seiche, Oued Loukkos, Port of Larache, Morocco.

Un episode de seiche observe au port de Larache, côte atlantique du Maroc.

Résumé. Un épisode de seiche, avec une amplitude variant entre 6 et 11 cm, a été observé et enregistré dans le port de Larache, au Maroc, à l'embouchure de l'oued Loukkos grâce à la bathysonde « Sea Beard Electronic ». Les mesures CTD, qui présentent les caractéristiques de seiche, ont été traitées pour soustraire le signal de la marée et préserver le signal de la seiche. D'après les estimations spectrales qui ont été appliquées sur une série temporelle contenant à la fois des données d'élévation de surface (seiche) bien et mal définie, la période de seiche la plus énergique était d'environ 17,5 minutes. Une période de seiche moins énergique d'environ 70 minutes a également été détectée. La seiche est peut-être soutenue par des réflexions d'une onde de gravité se propageant dans les endroits où il y a des changements soudains dans la section hydraulique (profondeur et / ou la largeur) d'Oued Loukkos. La genèse de l'épisode observé de seiche est inconnue, mais une perspective probable c'est qu'elle a été engendrée par interaction non linéaire de l'écoulement de marée avec le lit de la rivière.

Mots clés : Seiche, Oued Loukkos, port de la Larache, Maroc.

INTRODUCTION

Seiches are standing gravity waves that occur in closed or semi-closed basins such as lakes, harbors and bays. As such, seiches can play a significant role in a board range of physical, chemical, and biological processes. They are caused by the superposition of incident waves with opposite directions of propagation. Seiche, like any type of gravity wave, is characterized by its wavelength, period and amplitude. The period of a seiche is mainly set by the geometry (depth and horizontal extent) of the basin in which the standing gravity waves are confined (Wiegel 1964, Wilson 1972). The period of a seiche can vary between a few tens of seconds to hours. The amplitude of a seiche strongly depends on the energy source that generated the propagating fluctuation in water level (Hutchinson 1957).

Seiche phenomena have been observed in many different parts of the world. An observation of seiching in Lake Constance, Switzerland, was described in 1549. The first instrumental record of seiches was obtained in 1730 in Lake Geneva, Switzerland (Wilson 1972, Miles 1974). Because seiche in a harbor can produce damaging surging (or range action) – yaw and swaying of ships at berth in the harbor – this problem has been extensively examined in the scientific and engineering literature (Miles & Munk 1962, Wiegel 1964, Raichlen 1966, 2002, Wilson 1972, Miles, 1974, Botes *et al*., 1984, Mei 1992, Okihiro 1992, Rabinovich 1992, 1993, Rabinovich & Levyant 1992, De Jong *et al.* 2003, De Jong & Battjes 2004).

This paper, which constitutes the first known specific recorded observation of seiche in Morocco, is concerned with a seiche phenomenon that was observed in the port of

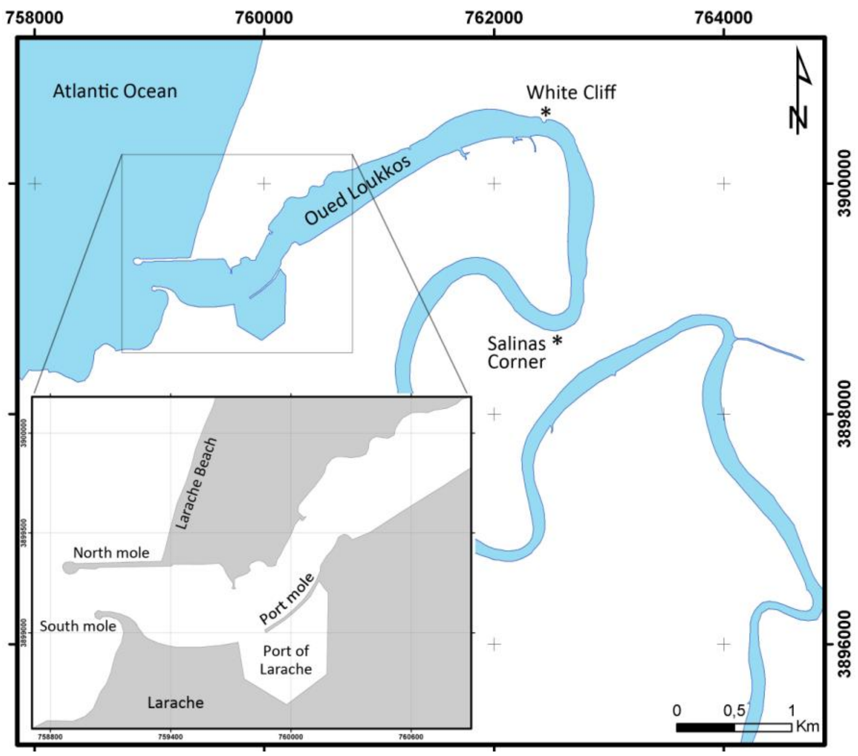

Figure 1. Location of the Port of Larache.

Larache, Morocco, in October 2010.[1] During a hydrographic survey of the Oued Loukkos, tide measurements were taken at different sites in the river in order to adjust measurements of bathymetric data to a fixed stage of the tide. Knowledge was required about changes in tidal amplitude and phase as the tide floods and ebbs throughout the estuary and the connected inland reaches of the Oued Loukkos, as was knowledge about the degree to which tidal predictions coincided with actual water level conditions in the Port of Larache.

METHODOLOGY

The Port of Larache is located on the Atlantic north coast of Morocco (35°11'N - 6°08'W). It is a river port located on the south bank of the Oued Loukkos, a few hundred meters in from the mouth of the Oued Loukkos. The port is protected by three main man-made structures (Fig. 1). There is a mole on the north bank of the river, which defines the seaward-most extent of the north bank (north mole), and two moles on the south bank of the river. One of the south bank moles is downstream of the narrow port entrance and defines the seaward-most extent of the south bank of the river (south mole). The other south bank mole extends upstream of the entrance channel and serves as the northern boundary of the port (port mole), as well as defining the south bank of the river. Large vessels use the port tip-up in an area that is along the western quay of the port basin and close to the entrance. Small vessels, which moor out in the central and southern sectors of the port are customarily moved and tied-up to the floating jetties and quay on the southwestern and southeastern sides of the port for loading/unloading. The surface area of the water body, confined within the port, is roughly 16 hectare. The depths within the port boundaries vary from 4 to 0.5 meters at the low stage of the tide.

The water level fluctuations in the port were measured with a Sea-Bird Electronics (SBE) CTD Model 16 Plus, which was fixed to the sloping seawall that defines the western wall of the port basin. The CTD instrument was placed on the seawall in the port on October 22, 2010 (Day 296 of the year 2010, hereafter noted as DOY). The water level data were measured by highly sensitive sensors in the CTD, and recorded every 10 seconds, for a time series length of 28 hours. The data record commenced at 05:56 on DOY 296 and concluded at 20:20 on DOY 297. Data recorded from the conductivity sensor in the CTD show a halocline, which vertically traversed the deployed CTD as the water depth approached low water. The presence of a halocline indicates the potential for pressure fluctuations at the location of the CTD due to an internal wave associated

[1] Although an incidence of seiche, with a period of 5 minutes, was thought to have occurred in the Port of Mohammedia, Morocco, no confirmed reports have been previously published describing an occurrence of seiche in Morocco: Ministere de l'Equipement et du transport (HISTORIQUE DU PORT DE CASABLANCA), http://www.mtpnet.gov.ma/Vpm/Maroc%20Maritime/ports/Ports Atlantiques/Casablanca/historique.htm (accessed August, 2012)

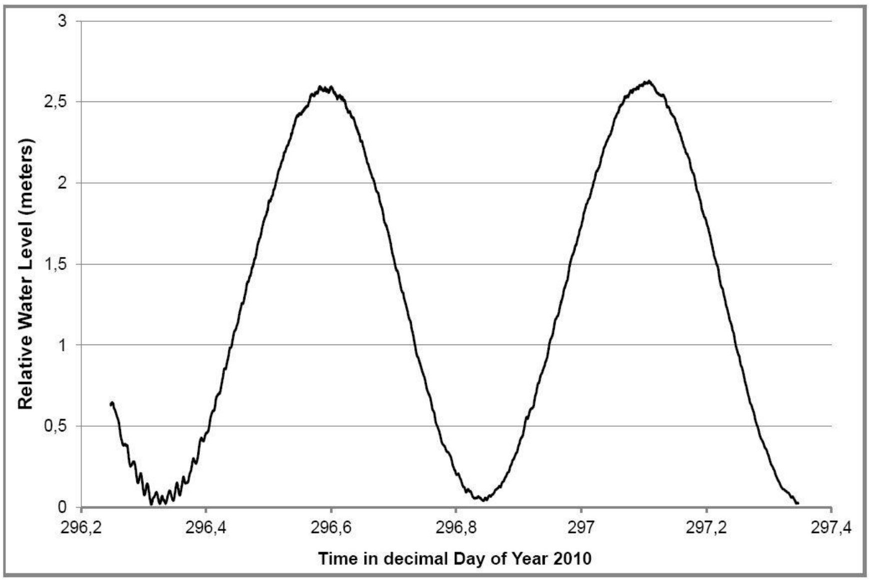

Figure 2. Relative surface elevation as measured by the Sea Bird Electronics CTD Model 16 Plus.

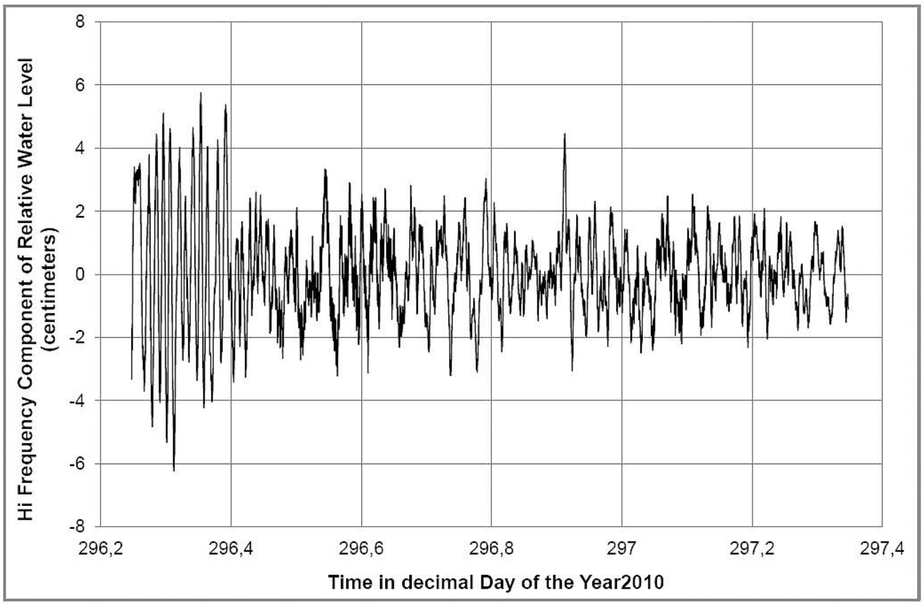

Figure 3. Seiche time series data obtained after filtration.

with the density interface created by the halocline. If such an internal wave were present it may have contributed to the conditions that led to the seiche, but it could not have produced pressure fluctuations of the magnitude and frequencies that were observed.

RESULTS

Data analysis

Initial investigations focused on data analyses to characterize the amplitude and period of the water level (pressure) fluctuations. Figure 2 presents the data that were recorded in the basin of the Port of Larache. The figure shows a semi-diurnal tidal range of 2.6 m. According to J.R.L. Allen’s 1993 classification, the tide is meso-tidal. Visual examination of the plot shows low amplitude, high frequency (non-tidal) fluctuations in the water level, especially during the first occurrence of low tide. To better identify possible episodes of seiche, the tidal component was removed in order to isolate seiche from the much larger tide. Decomposition was accomplished by removal of a single component, empirically determined cosine model of the tide signal, which provided an isolated view of the higher frequency, lower amplitude signal of the potential seiche, as shown in figure 3.

The amplitude and duration of the potential seiche signature varies throughout the recorded time series. The

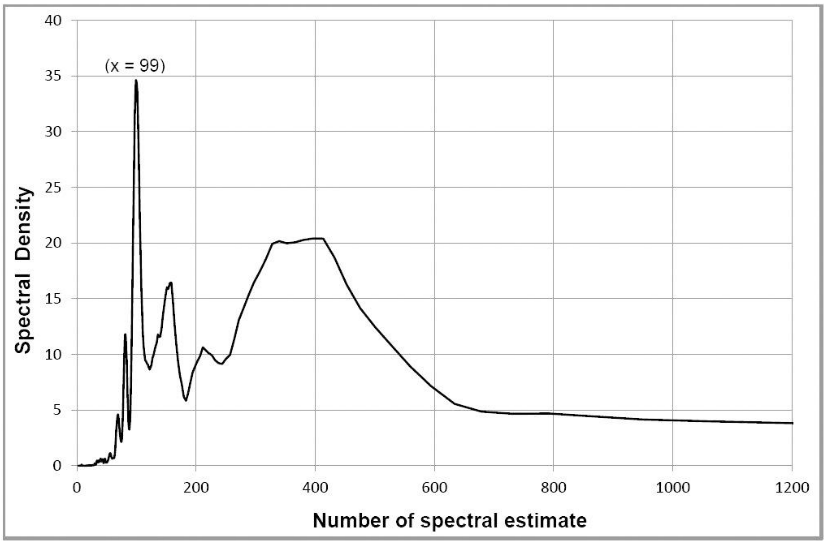

Figure 4. Spectral analysis of seiche time series data.

high frequency fluctuations showed a marked change in character from being regular and well-defined between DOY times of 296.25 and 296.4 to being ill-defined, for the remainder of the data recording, following an apparent decrease in frequency at DOY 296.45. During the well-defined episode that occurred coincident with the first low stage of the tide, the seiche persisted for approximately of 4 hours and the nominal peak-to-peak range of the seiche was 6 to 11 cm.

Spectral analysis

Spectral analysis, based on a method derived from the Fourier analysis of time series data, was applied to the seiche signal. This resulted in identifying a regular (narrow-band) spectral component during the presence of a well-defined seiche in the Port of Larache in addition to an irregular (broad-band) spectral component during the presence of an ill-defined seiche. The spectral analysis led to the graph in Figure 4, which illustrates the spectral energy that was present in the time series. The X-axis has been expanded by a factor of seven to show only periods of fluctuation less than 4 hours that were present in the recorded time series. The entire time series for this study, which was composed of 9,504 temporal samples of data recorded at 10 second intervals, could have supported a graph with spectral periods up to 14 hours. However, there was insignificant energy at spectral periods longer than 2 hours.

The spectrum contains a significantly energetic narrow-band peak at spectral estimate number 99, which corresponds to a spectral period of approximately 17.5 min, and corresponds with the most energetic fluctuations in water levels. There is also a notably energetic broad-band spectral peak that roughly corresponds to a period of 70 minutes, and corresponds with the lesser energetic fluctuations in water levels. These two spectral peaks are associated, respectively, with the initial four-hour long episode of well-defined seiche-like water level fluctuations, and the remainder of the data set, which often contained 1 to 3 irregular cycles of water level fluctuations. The differences in spectral amplitude and spectral width between the two seiche-like periods of water level fluctuations probably stem from differences in the degree to which their propagating fluctuations in water level persistently satisfied the basic requirement for resonant reinforcement in the Oued Loukkos.

DISCUSSION AND CONCLUSION

The phenomenon of a seiche requires a trigger mechanism. Typically the initiating agents are either local weather disturbances (Lamy *et al*. 1981, Gomis *et al*. 1993) or tidal (Stigebrandt 1976). An analysis of local and regional environmental data (winds and waves) did not lead to the identification of a direct link between either of them and the observed seiche phenomenon. The appearance of the seiche episode with a duration of 17.5 min, did coincide with a period of heighten wave activity. However based on the wave data, which was kindly provided by Xavier Bertin (pers. comm.) and wherein none of the wave periods exceeded 12.3 seconds, it seems unlikely that oceanic waves initiated or maintained the seiche.

The size and depth of the port of Larache, plus the fact that the port is directly connected with the lower reaches of the Oued Loukkos, suggests that the seiche in the port was associated with an eigenmode of the river. The specific morphology of the river may have a bearing on initiation of the seiche and on it having been sustained over a large number of cycles. The source of energy for the observed seiche may be a change in the hydraulic properties (width, depth and curvature) of the Oued Loukkos which led to non-linear interaction between the moving water and the sea bed. The mechanism may simply be that when the width of the river quickly changes, or when there is a sudden change in water depth, the resulting change in local resistance to the flow field causes a partial reflection of the progressive movement of the water. It is important to recognize that one of the basic requirements for a seiche is that the combination of propagation distance (physical separation) between two reflectors and the propagation time (based on the propagation speed of a shallow water gravity wave) between the two reflectors must satisfy conditions for resonant reinforcement.

In a river, if the seiche reflectors are fixed in space and the water levels are subject to tidal influence that significantly impact the propagation speed of a gravity wave, any particular episode of seiche will tend to dissipate when the resonant reinforcement is lost due to changes in water level. Consequently, in a tidally influenced river, similar to the Oued Loukkos, long episodes of seiche are unlikely, except at times that are near to low or high tide, when the water level and gravity wave propagation speed only change minimally during each cycle of the seiche.

Onset of well-defined seiche in the Port of Larache occurred near the start of the data record when the ebbing water level was approximately 35 cm above the pending low water level. That particular episode of seiche persisted until the water level had later increased to approximately 45 cm above the water level at low tide. It would seem the duration of that particular four-hour episode of well-defined seiche may have been limited by the bounds of resonate lock into a particular eigenmode of the Oued Loukkos. The irregular high frequency fluctuations in water level, which occurred outside the episode of well-defined seiche, possibly indicates the presence of an on-going non-linear process with the capability of generating fluctuations in water level that do not resonate lock into an eigenmode of the Oued Loukkos and consequently do not presist.

The presence of seiche phenomenon in the Port of Larache causes no problems regarding safety and comfort of the marine activities. However, it is possible the seiche phenomenon may have important secondary effects on the short-term and long-term hydraulic conditions in the river and consequently in the port. If the presence of seiche is a common occurrence, then it will have an important impact on the mixing of different water masses (fresh water input from the upstream reaches of the river and saline water entering the system at the mouth of the river). Such mixing effects can control the behavior and thickness of the surface layer of sediment (Luettich *et al*. 2000), and the flow of water resulting from the seiche can also affect the distribution of heat, salinity, dissolved oxygen and nutrients in the water (Wilson, 1972). As pollutants have a tendency to more readily attach to silt particles as compared to sand particles (Krumgalz *et al*. 1992, Brown & Neff 1993), the frequent presence of seiche in the Oued Loukkos and Port Larache could definitely influence the fate of pollutants which are introduced into the Oued Loukkos from point sources and/or spatially distributed sources.

FURTHER STUDIES

Based solely on the interesting and unique set of water level data, which was discussed above, it is not possible to determine the generating mechanisms that led to this episode of seiche, or that may lead to future episodes of seiche in the Port of Larache. A compelling argument exists for conducting additional hydrological studies in the Oude Loukkos and Port Larache in order to develop an information base leading to better understanding of mixing processes, as well as the fate and dispersal of mobile sediments and pollutants. Lessons learned in the Oude Loukkos and Port Larache should not only be applicable to that river, but also to the several other rivers on the Atlantic coast of Morocco, where similar hydrological factors may be prevalent. Therefore, when the required instrumentation can be allocated to re-deployment in the Port of Larache, these observations should be extended for a length of time necessary to further study the seiche in the port and establish the conditions that are associated with other instances of seiche.

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