TIDAL BORES

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Synonyms

Benak (Malaysia); Bono (Indonesia); Burro (Mexico); Mascaret (France); Pororoca (Brazil)

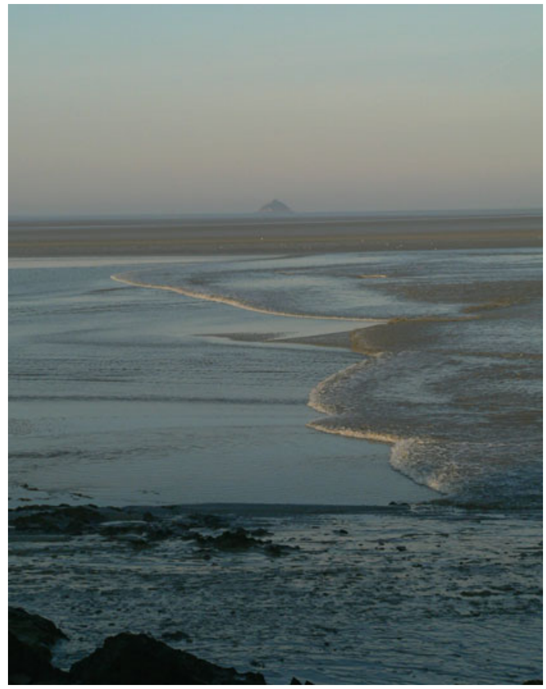
Definition

A tidal bore is a positive surge of tidal origin that may occur in an estuary when the tidal flow turns to rising; the existence of a tidal bore is linked with a large tidal range, an estuarine bathymetry that amplifies the tidal wave and a low freshwater level.

Discussion

A tidal bore is an unsteady flow motion generated by the rapid water level rise at a river mouth during the early flood tide when the flood tide waters rush into a funnel-shaped river mouth that amplifies the tidal range. A bore is a sudden increase of the water depth as illustrated in Figures 1 and 2. Figure 1 shows a tidal bore in the Bay of Mont Saint Michel (France). The tidal bore advances in the river channel and on the surrounding sand flats. Figure 2 presents the tidal bore of the Dordogne River (France). The surfers give the scale of the bore front. Worldwide, it is estimated that over 400 estuaries are affected by a tidal bore process, on all continents but Antarctica. Some famous tidal bores include the "pororoca" of the Amazon River in Brazil, the bore of the Qiantang River in China, and the 'mascaret' of the Seine River in France (Malandain, 1988).

A tidal bore is almost a mythical phenomenon because it is rare to observe. It occurs only during the flood tide under spring tidal conditions and low freshwater levels. Its passage is very rapid, that is, a few minutes at most and it is easily missed. The bore is a sharp front that propagates upstream into the river mouth and may travel several dozens of kilometers inland before vanishing. The presence of a tidal bore indicates some macro-tidal conditions (tidal range > 4.5–6 m) associated with an asymmetrical tide. The flood tide is typically shorter than the ebb tide period and the flood flow is much faster. A feature of the tidal bore is its rumble noise that can be heard from far away. Some field measurements show that the generated sounds have a low-pitch comparable to the sounds generated by bass drums and locomotive trains (Chanson, 2009).

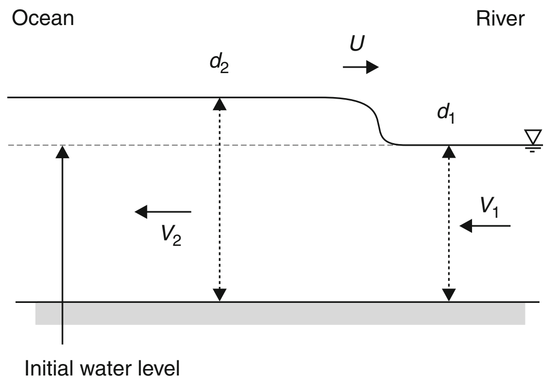


Tidal Bores, Figure 1 Tidal bore in the Mont Saint Michel Bay in France on October 19, 2008 morning – Bore propagation from right to left.

Tidal Bores, Figure 2 Tidal bore of the Dordogne River (France) at Port de Saint Pardon on September 2, 2008 evening – Looking downstream at the incoming tidal bore.

Theoretical considerations

A tidal bore may occur when the tidal range exceeds 4.5–6 m and the bathymetry of the river mouth amplifies the tidal wave. The driving process is the large tidal amplitude. The tides are forced oscillations generated by the attractions of the Moon and Sun, and have the same periods as the motion of the Sun and Moon relative to the Earth. At full moon or new moon, the attraction forces of the Sun and Moon reinforce one another, and these conditions give the spring tide conditions. The tidal range may be locally amplified further by a number of factors, such as when the natural resonance of the bay and estuary is close



Tidal Bores, Figure 3 Definition sketch of a tidal bore propagating upstream.

to the tidal period. This coincidence implies that the general sloshing of the waters around the inlet or bay becomes synchronized with the lunar tides and amplifies their effect, yielding often the best tidal bores a couple of days after the date of the maximum tidal range.

When the sea level rises with time during the flood tide, the tidal wave becomes steeper and steeper, until it forms an abrupt front: the tidal bore. The inception and development of a tidal bore may be predicted using the Saint-Venant equations and the method of characteristics (Peregrine, 1966; Chanson, 2004). After the formation of the bore, the flow properties directly upstream and downstream of the tidal bore front must satisfy the equations of conservation of mass and momentum. The integral form of the continuity and momentum principles gives a well-known relationship between the flow depth in front of and behind the tidal bore front:

$$\frac{d_2}{d_1} = \frac{1}{2}\left(\sqrt{1 + 8 \times \mathrm{Fr_1}^2} - 1\right) \qquad (1)$$

where Fr_1 is the tidal bore Froude number defined as: $Fr_1 = (V_1 + U)/\sqrt{g \times d_1}$ with g the gravity acceleration, V the flow velocity positive downstream towards the river mouth, U the bore speed for an observer standing on the bank, d the water depth, and the subscript 1 refers to the initial flow conditions whereas the subscript 2 refers to the new flow conditions (Figure 3).

The Froude number of the tidal bore is always greater than unity and the quantity (Fr_1-1) is a measure of the strength of the bore. If the Froude number is less than unity, then the tidal wave cannot become a tidal bore. For a tidal bore Froude number between unity and 1.5–1.8, the bore front is followed by a train of well-formed, quasi-periodic free-surface undulations, also called whelps. For larger Froude numbers, the tidal bore is characterized by a breaking front as seen in Figure 1 (Koch and Chanson, 2009). Some simple energy considerations show that a tidal bore can occur only with a net flux of mass from downstream to upstream. This characteristic sets apart the tidal bore from a wave or soliton.

Impacts of tidal bores

The tidal bores can be dangerous and some have had a sinister reputation. For example, in the Seine River estuary (France), more than 220 ships were lost between 1789 and 1840 in the Quilleboeuf–Villequier section. Similarly, the bores of the Petitcodiac River (Bay of Fundy, Canada) and Colorado River (Mexico) are feared by some of the populace. In China, some tidal bore warning signs are erected along the Qiantang River banks and yet a number of tragic accidents happen every year. The tidal bores affect the shipping and navigation in the estuarine zone as in Papua New Guinea (Fly and Bamu Rivers), Malaysia (Benak at Batang Lupar), and India (Hoogly bore).

However, the tidal-bore affected estuaries are the feeding zone and breeding grounds of several forms of wildlife. For example, some large predators feed behind the bore: sharks in Australia, whales in Alaska, seals in France, crocodiles in Australia and Malaysia. The estuarine zones are the spawning and breeding grounds of several fish species, while the turbulent mixing and aeration induced by the tidal bore contribute to the abundant growth of many species of fish and shrimps.

Related processes

A number of geophysical, as well as man-made, processes are related to the tidal bore. In the Bay of Bengal, the development of a *storm surge* during the early flood tide with spring tidal conditions may yield a rapid rise in water levels generating a bore front. The wind shear amplifies the tidal range and the phenomenon has been observed in Bangladesh where the storm events are called locally "tidal bores." Another related process is the *tsunami*-induced bore. After breaking, a tsunami wave propagating in shallow-water regions is led by a positive surge. In shallow rivers, the process is somehow similar to a tidal bore and the tsunami-induced bore may propagate far upstream in a river mouth as observed in Hawaii, in Japan, and more recently during the December 26, 2004 Indian Ocean tsunami catastrophe in Malaysia, Thailand, and Sri Lanka. At a smaller scale, some *swash*-induced bores may be observed on beaches when the wave run-up enters into a small creek or channel.

Positive surges and bores may be observed in irrigation channels and water power canals during gate operation. Some bores are also observed at the leading edge of violent *flash floods* propagating downstream narrow canyons. Lastly, some water theme parks include large *artificial beaches* in which man-made waves somehow similar to a bore are generated for the agreement of the visitors.

Summary

A tidal bore is a series of waves propagating upstream in the river mouth as the tide turns to rising. It forms during the spring tide conditions with a tidal range in excess of 4.5–6 m in a narrow funneled estuary with low freshwater levels. The presence of a tidal bore indicates some macrotidal conditions associated with an asymmetrical tide. Two key features of a tidal bore are (a) its rumble noise that can be heard from far away, and (b) the turbulent mixing induced by the bore propagation that stirs the sediments and matters.

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Cross-references

Flash Floods
Storm Surge
Surge
Tides
Tsunami

TILTMETERS

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Synonyms

Clinometers; Tilt sensors

Definition

Tiltmeters are devices used to monitor the change in inclination of a ground surface point; see Dunnicliff (1993) for a detailed description. The device consists of a gravity sensing transducer (e.g., servo-accelerometer, electrolytic tilt sensor, pendulum-actuated vibrating wire, etc.) capable of measuring changes in inclination as small as one arc second (0.00028 degrees). They are used to monitor slope movements where the landslide failure mode is expected to contain a rotational component. Advantages of using tiltmeters are their light weight, simple operation, and relatively low cost; tiltmeters can be read manually or automated by connecting to a data logger.

Bibliography

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Cross-references

Extensometer
Landslides
Mass Movement

TIME AND SPACE IN DISASTER

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Disasters in time and space

Early attempts to define disasters were based on the exceedence of certain loss thresholds. For instance, Sheehan and Hewitt (1996) classified as disasters all those events that killed or injured at least 100 people or caused at least US $1 million damage. This definition was further developed in more qualitative terms, e.g., by UNDRO (1984) "… an event, concentrated in time and space, in which a community undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfillment of all or some of the essential functions of the society is prevented." Other definitions reduce the term disaster to those events where ".. large numbers of people exposed to hazard are killed, injured or damaged in some way …" (Smith, 2004, p. 5). In this context, Smith also states, that "there is no universally agreed definition of the scale on which loss has to occur in order to qualify as a disaster." Further, Smith (2004, p. 22) writes that "… a disaster generally results from the interaction, in time and space, between the physical exposure to a hazardous process and a vulnerable human population." For statistical purposes some authorities require the impact of a natural event to exceed certain thresholds of areal extent, as well as lives lost, or economic costs before they are classified as disasters. In this contribution, disasters are defined as those damaging events that exceed the coping capacity of affected individuals, groups, or institutions and, in some cases, even nations. This definition avoids the use of absolute quantitative measures, which can vary dramatically between different countries, or in more general terms, between different social groups.

Thus, irrespective of the magnitude of the natural event, disasters are defined in terms of human impact and related consequences. In the contextual framework of natural hazards, disasters can be localized. They occur at a specific location or in a region as a sudden onset or as slow creeping, often unstoppable processes. Sources and affected areas can be very distinct with easy to delineate boundaries (e.g., a debris flow with source area, travel path, and deposition) or difficult to assess (e.g., pollution of ground water). Whereas the boundaries of source and impact areas may be identifiable after an event, it is not