(*Paper No. 2416.*)

“The Bore of the T sien-tang-Kiang.”

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AMONG the periodical phenomena of Nature, none are more deserving of attention than the tides; and of the various phases of the tides, none are more worthy of study than the phenomenon of the bore. To Civil Engineers, especially those engaged in works on the sea-coast, it will probably have a peculiar interest, as it presents a marked instance of wasted power. Possibly, the day is not far distant when the energy exerted by the tides generally, and by this crowning development in particular, may be brought under control in practical affairs.

The bore,¹ called also the “Hygre” and “Eagre” in England, “Mascaret” in France, and “Pororóca” or “Prororóca” in Brazil, is well known in six or eight rivers in the British Islands, in two or three of those in France, in some of the Indian rivers, in the branches which compose the mouth of the Amazon, and in one river at least in China. It is rarely observed except at spring-tides, and, as a rule, shows itself on the days of full and of new moon, appearing with the first of every flood for three or four days succeeding those phases, after which the tide comes in with only a swift rush without noise or violent commotion.

The conditions necessary for its creation appear to be three:—(1) A swiftly flowing river; (2) An extensive bar of sand, dry at low-water, except in certain narrow channels kept open by the outgoing stream; (3) The estuary into which the river discharges must be funnel-shaped with wide mouth, open to receive the tidal-wave from the ocean.

When either of these conditions is absent, the bore is not known. Thus, in the Thames, although the third condition is present, the first and second conditions are absent; for the stream is not swift, and there is no bar dry at low-water. In the Severn, all three conditions are present, and there is a bore, not a very large one, but the highest in these islands.

¹ Derived probably from the Icelandic “báva,” a “billow”; “eagre,” from the French “eau-guerre,” or “water-war.

The bore of the T sien-tang-Kiang,¹ in China, has the three conditions developed. The estuary into which the river falls has a vast area of sand at its head, and is favourably situated for the reception of the tidal-wave from the Pacific, which approaches the coast from the east or east-south-east. The range of the tide immediately outside the Hang-chau gulf is 12 feet; but as the wave becomes compressed on advancing towards its head, at the end of the navigable waters, it is as much as 25 feet at ordinary spring-tide, and 34 feet when the wind is blowing on shore and the moon in perigee at the time of full and change. The navigable breadth of the estuary, at its head, where the tidal-wave rises to its greatest height, is about one-fifth or one-sixth what it is at the mouth; and if there were no river discharging into the bay, the range would probably be between 60 and 70 feet, as it is in the Bay of Fundy.

For the first hour the tide rises 10 to 12 feet, and the pressure is then relieved by the overflow over the bar into the river. In crossing the bar, first of course through the narrow river channels, the flood meets with the swift outgoing stream, which trips up its foot and causes an overfall; then, as more rushes of water overlie the first of the flood, the inequality of level becomes greater until the water rises to a bore, which advances with increasing velocity, but great regularity of front, towards the mouth of the T sien-tang. So far as is known, there are only two branches of the bore over the sand flats. These join 4 miles outside the mouth of the river, and here the flood again becomes compressed between the banks. At low-water the river is only 1 mile broad, and there is a great rise in the height of the approaching cascade after the junction of the two rollers.

While the flood is travelling across the sands, the water is rising steadily at the end of the navigable portion of the Hang-chau gulf; and, by the time the two branches of the bore join, there is a difference of level of 19 feet at springs between the water on the outside of the bar and that in the mouth of the river, a distance in a direct line of about 20 miles. Accordingly, the flood enters the river down a gradient of 1 foot in a mile with great force, and is assisted by the transmitted pressure of the advancing tidal-wave in the estuary. The speed, as measured by the officers of H.M.S. "Rambler," is 12·7 knots, or 14·6 statute miles, an hour. The bore has a breadth of 9 cables, or 1,800 yards, and its front is a gleaming white cascade of bubbling foam 8 to 12 feet high, pound-

¹ A more detailed account of the bore of the T sien-tang-Kiang, by the Author, of which a copy is in the Library, has been given in Vol. xxiii. (1888), of the *Journal of the China Branch of the Royal Asiatic Society*.

ing on itself and the river in front of it at an angle of from 40° to 70° , the steepest and highest portion being over the deepest part of the river, where the outgoing stream has the greatest velocity.

The noise is not the least impressive feature of this phenomenon. On a calm, still night it can be distinctly heard, when 14 or 15 miles distant, an hour and twenty minutes before arriving. The noise increases very gradually, until it passes the observer on the bank of the river with a roar but little inferior to that of the rapids below Niagara.

The bore maintains its breadth, height, speed, and regular appearance, for 12 or 15 miles above the mouth of the T sien-tang. As the bed of the river slopes gradually up from Haining, near the mouth, to the city of Hang-chau, which is 24 miles from the mouth, the range of tide gradually decreases from $19\frac{1}{2}$ feet to 6 feet; and the bore passes Hang-chau at a much reduced height, seldom exceeding 5 feet even under exceptional circumstances. It usually then breaks up. On certain rare occasions, however, after a full or a new moon in perigee, and when the opposing river is stronger than usual owing to heavy rains in the interior, it proceeds upstream beyond the city for 30 miles, before losing its distinctive character.

The peninsula situated between the Yang-tze-Kiang and the T sien-tang-Kiang is a flat, densely populated, and richly cultivated district, formed by the alluvial deposit from the former river. It is intersected with canals, which admit of journeys being made with great facility between Shanghai, Haining, the city of Hang-chau, and the numerous towns, some of which are of considerable size, between these places. If it were not for some protection, this peninsula would be flooded by the spring-tides, for the general level along the north side of the Hang-chau estuary and the T sien-tang is some 2 to 6 feet lower than high-water of ordinary spring-tide, and it is believed to be still lower at Shanghai. To protect this country from the ravages of the sea, a substantial embankment has been thrown up from the mouth of the Wu-sung river, round Yang-tze Cape to beyond Hang-chau, a distance of 120 miles. This of itself is not a sufficient barrier at that portion of the estuary and river where the bore is known, and it has been flanked for about 30 miles by a sea-wall between 30 and 40 feet thick, which is certainly a most creditable public work. It has been built eight or nine hundred years. The top varies in elevation from 3 to 9 feet above high-water of spring-tides. It is faced with blocks of stone 5 feet long, 16 inches broad, and 14 inches deep, laid at right-angles to the river, and joined together by rivets of

iron. At numerous places by the side, especially within the river, platforms have been constructed of large blocks of stone enclosed by piles, to enable the junks to ground in safety from the violence of the bore. One of these platforms at Haining is 1,100 yards long, 20 feet wide, and 7 to 8 feet above low-water of ordinary spring-tides, which reaches horizontally to within 5 or 6 feet of the foot of the piles confining the stones on the shelter. At the east end of the platform there is a semi-elliptical buttress, 253 feet long and 66 feet wide, parallel to the sea-wall, built of mud, surrounded by fascines: and there is a similar buttress at the west end. The junk platform is well inside a direct line between the tangent of one buttress and that of the other.

At the platforms the sea-wall is ascended by a succession of steps about 4 inches in width, which are sufficient to give a footing, but not sufficiently broad to permit the flat bottom of a junk catching upon them as it is hove up and down by an agitated flood.

The northern edge of the bore advances along the wall, and, when it meets with the buttress, is deflected into the middle of the river. The full force of the cascade is, therefore, not felt at the platforms. When the junk-master sees or hears the bore approaching, he summons his crew, looks to his warps, and stands by to fend off his vessel from the wall. After the passage of the bore, and of the agitated water which follows it for about a mile, the junk is afloat in comparatively still water, and the junk-master completes his loading and proceeds on his voyage.

Great skill is exhibited in the construction of the shelters. They are of different heights, some only being intended for use in the winter, when high bores are expected; never so high but what a junk floats directly it is safe for her to do so, nor so low but that she can obtain adequate protection from the force of the bore; assuming, of course, that the master does not neglect the usual warnings, and takes care to ground his junk at a high-level shelter when an unusually high cascade is anticipated. In the river there is no place where even the shallowest junks can be secured in safety from the bore two and a half hours after the water has begun to fall. Navigation for ships is out of the question; for boats, it begins directly the after-wash behind the bore has passed by, and ends two hours after high-water, a period of from three to four hours, according to the distance from the mouth of the river.

The natives at Haining state that the bore is the necessary accompaniment of the first of every flood-tide throughout the year. At 15 miles above Haining the phenomenon does not appear at neap-tides, and it is not dangerous at neaps to well-managed boats

even at Haining. Two days before new moon of December 1888, a junk was seen to ride over it at anchor. It is not safe to attempt this, even in the finest weather, between the day before and five days after, full moon and new moon. The Author saw a bore off Haining pagoda two days after new moon, in October 1888, which, in his opinion, would have sunk any vessel of 300 tons at anchor in the stream.

As a rule, two-thirds of the flood-range of tide arrives at Haining within fifteen minutes, and the top of the bore, that is, the cascade in front of the flood, is as high as the mean level. The highest recorded is about 15 feet.

Occasionally, the two branches of the bore meet with exactness, the right extreme of the one line of breakers with the left extreme of the other; and the combined roller, 2 miles broad, presents an imposing appearance as it advances towards Haining. When about 2 miles east of Haining, the flood-stream runs with great violence into the sea-wall. It appears as if the south-east branch of the flood has acquired too much impetus to adapt itself immediately to the new direction, and runs over or through the northern branch which skirts the sea-wall. The result is a rebound which raises a series of high waves, the tops of which are, for several minutes, higher than the level of high-tide; the water in the estuary being violently agitated for $1\frac{1}{2}$ mile or 2 miles; and the waves, taking a south-westerly direction, break, and by degrees subside on to the back of the bore. The sea-wall has an additional outwork of piles and stones where the flood impinges.

On entering the river, the flood has a concave transverse surface, and complete lateral equilibrium is not restored until nearly high-water.

The following Table shows the readings of the tide-poles at Haining, Rambler Island (near the western end of the navigable portion of the Hang-chau gulf), West Volcano Island, and Changtau harbour, for one tide. *Fig. 1* explains graphically these simultaneous observations of the height of the water at four stations between 8 P.M. on the 20th and 9 A.M. on the 21st of September 1888. At full and at new moon, it is high-water at Changtau at 10 hours 14 minutes; West Volcano Island 0 hour 19 minutes; Rambler Island 1 hour 27 minutes; Haining 3 hours; and Hang-chau 3 hours. The bore forms 12 to 16 miles east of Haining about 10 hours 30 minutes, passes Haining at the rate of 21 feet a second, precisely as the moon crosses the meridian of that place, or 12 hours 20 minutes after the passage of the moon to which the origin of the phenomenon is due, and reaches Hang-chau about 2 hours. At Changtau and West Volcano Island, the flood lasts

SIMULTANEOUS OBSERVATIONS of the DISTANCE of the WATER from MEAN LEVEL
at HAINING, RAMBLER ISLAND, WEST VOLCANO ISLAND, and CHANGTAU
HARBOUR, FULL MOON, SEPTEMBER 1888.

The Flood.

20th September.

Hour P.M.		Above or Below the Mean Level.			
		Haining.	Rambler I.	W. Volcano Island.	Changtau.
H.	M.	Feet Ins.	Feet Ins.	Feet Ins.	Feet Ins.
8	30	..	-11 4	- 1 1	+ 3 7
9	0	..	-10 9	+ 0 4	+ 4 5
9	30	- 8 0	- 9 6	+ 1 6	+ 4 10
10	0	- 9 0	- 4 3	+ 2 7	+ 5 4
10	30	- 9 0	+ 1 3	+ 3 6	+ 5 5
11	0	- 9 6	+ 5 9	+ 4 4	+ 5 2
11	30	- 9 6	+ 8 3	+ 4 11	+ 4 8
Midnight		- 9 9	+ 9 6	+ 5 6	+ 4 1

21st September.

0 20	Bore passed Haining.			
0 30	+ 3 0	+10 4	+ 5 7	+ 3 4
1 0	+ 6 0	+11 3	+ 5 2	+ 2 1
1 30	+ 8 0	+11 7	+ 4 6	+ 1 2
2 0	+ 9 0	+11 5	+ 3 7	+ 0 3
2 30	+ 9 6	+10 11	+ 2 5	- 1 2
3 0	+10 0	+ 9 10	+ 1 4	- 2 7

The Ebb.

21st September.

H.	M.	Feet Ins.	Feet Ins.	Feet Ins.	Feet Ins.
3	0	+10 0	+ 9 10	+ 1 4	- 2 7
3	30	+10 0	+ 7 0	+ 0 3	- 3 10
4	0	+ 9 0	+ 5 0	- 0 9	- 4 8
4	30	..	+ 2 6	- 1 10	- 5 7
5	0	..	+ 0 1	- 2 10	- 5 9
5	30	0 0	- 2 7	- 3 9	- 5 4
6	0	..	- 5 0	- 4 6	- 4 6
6	30	..	- 7 5	- 5 0	- 3 4
7	0	..	- 9 3	- 5 6	- 2 2
7	30	..	-10 5	- 4 11	- 0 10
8	0	..	-11 3	- 4 5	+ 0 7
8	30	..	-11 9	- 2 10	+ 2 2
9	0	..	-12 0	- 1 8	+ 3 0

for six hours, the ebb for six hours; at Rambler Island, the flood lasts for five hours, the ebb for seven hours; at Haining the flood for three and the ebb for nine hours; and at Hang-chau the flood lasts for about an hour and a quarter, and is nearly all in the bore. The stream commences to run out of the river along the right

or south shore an hour before high-water at Haining, though the tide continues to rise on the bank, a peculiarity which has yet to be explained; and in the middle of the stream it turns directly it

Fig. 1.

has ceased to rise at the shore. A review of the simultaneous levels shows that, at this time, the water at Rambler Island near the end of the navigable portion of the Hang-chau gulf, after

rising to its highest for that tide, has fallen just below the level of high-water at Haining; and as the estuary at Rambler Island is about four times as broad as the river at Haining, directly the water falls in the former, that in the latter must promptly obey the movement. In about five hours, the water in the river has fallen to within a foot or 18 inches of its lowest for that tide; the last foot dribbles away very slowly, and for two hours previous to the arrival of the new bore, it only falls 4 or 5 inches. The stream of the river, however, continues to make out fast along the channel, and is found opposing the incoming flood.

The readings at Haining and Changtau can only be regarded as approximate; but they are correct within 6 inches. It will be seen that the sudden rise of tide at the head of the Hang-chau estuary (Rambler Island) between 9 hours 30 minutes and 10 hours 30 minutes P.M. on the 20th of September, 1888, was the birth of the bore. The force which propels this body of water with so much violence over the bar is indicated by the difference of level of the water between Changtau and Rambler Island, which at 9 hours 30 minutes is 15 feet, and at 10 hours 30 minutes 4 feet 2 inches.

Information concerning the phenomenon in any part of the world is exceedingly meagre.

As the bore is, in all cases, the result of difference of level between the ocean and the river, it is necessary to establish tide-poles, and watch the movements of the tidal-wave at four or five points simultaneously; but this operation is seldom possible except with the resources of a surveying ship.

The time may come when the enormous power concentrated in this impetuous descent of the flood shall no longer be wasted, but be utilized, either in the storage of electricity, the compression of air, or in the working of machinery; and, instead of, as at present, being regarded as a fine spectacle at the best, and always a curse and hindrance to industry, the phenomenon, which is the subject of these remarks, may be turned to a sound practical use and benefit to humanity.

The Paper is accompanied by three illustrations from which the *Fig.* in the text has been prepared.