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Research Paper

Effects of ship waves on riverbank erosion in the Mekong delta: A case study in An Giang province

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ABSTRACT

The Mekong Delta is facing with more and more serious riverbank landslides which have a great impact on people's lives, assets and lives, as well as the socio-economic development of local people. There are many causes of riverbank landslides. This study focuses on the causes of riverbank erosion by ship waves. With increasing traffic density, erosion resulting from increasingly serious. In this study, surveying and collecting wave parameters generated by different means were carried out, and the simulation data using laboratory models was also used. Riverbank erosion is assessed through two criteria: the amount of suspended material in the water and the surface erosion of the soil sample. The results show that the ship waves have a significant impact on the erosion of the riverbank and it is possible to predict the level of the erosion by the time.

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1. Introduction

In the Vietnamese Mekong Delta, due to specifically geographical condition, the road traffic systems are not able to be developed properly. Instead, with a dense river system, with a total length of 4,952 km, the highest density of 1,253 km / km^2 (Southern Institute of Water Resources Research, 2015), with the dense system of rivers and canals, it is a great advantage for the socio-economic and environmental development of the Mekong Delta provinces. The important roles that the river and canal system brings to the water areas in the Mekong Delta area to mention: (1) Water supply for domestic use, public production, agriculture; (2) Flood drainage route, alum washing; (3) Supply of construction materials to the area and surrounding areas; (4) Water transportation routes connecting regional provinces and international trade; (5) Create a good environment for developing freshwater, brackish and saltwater aquatic products; (6) Potential for development of river tourism; (7) Create ecological landscape, etc….

In addition to the great benefits brought by the river network, the Mekong Delta is also facing the situation of river banks erosion and canals occurring on a large scale, increasingly complicated and serious. especially rivers and canals flowing through densely populated areas (towns, cities,...), with high density of waterway traffic, causing significant damage to land, houses and properties. people's properties, infrastructure, public constructions built on both sides of rivers and canals.

According to the Circular 46/2016 / TT-BGTVT [4] on the regulation on technical inland waterways, the total length of inland fields and rivers (from canals of grade III or lower) accounts for over 70% of the total length of the river system. The system of rivers and canal nationwide, particularly for the South, has a total length of rivers and canal of 2,968.9 km, of which 68% are intra-field rivers and canals (2,026.1 km). Through surveys, the total length of the river and canal erosion in the Mekong Delta is more than 1,000 km, of which rivers and canals in the field account for more than 45% of the total length of erosion. Therefore, it is urgent and necessary to pay attention to the protection of river banks and inland canals.

Through the study of documents combining field surveys and measurement surveys in a number of different areas on the system of rivers and canals, it is possible to summarize the main causes of erosion of river banks, canals and canals in the Mekong Delta, including: (1) Erosion due to flow velocity greater than the permissible non-erosion velocity; (2) Erosion due to runoff in the river bank; (3) Erosion due to waves hitting the shoreline (waves caused by ships and boats running on rivers and waves caused by wind); (4) Erosion due to excessive loading on the edge of canals and ditches (construction of houses, stocking of goods, etc.); (5) Erosion due to depletion of sediment due to upstream hydropower construction; (6) Erosion due to excessive sand mining (Southern Institute of Water Resources Research, 2015). The above stated reasons find an agreement with results studied by and US Army Corps of Engineers (1984), Maa et al. (1998) and Hamill et al. (1999 and 2004) to explain for the phenomenon of bed and/or bank erosion.

Especially for the restricted waters, due to the relatively small size of the river, the impact of the waves has a significant impact on riverbank erosion. Previous studies showed that waves generated by boats contain a massive amount of energy that can erode seriously the riparian and coastal environment (Bonham, 1983; Coops et al., 1996; Belibassakis, 2003). However, the issue of landslides on inland rivers and canals has not been studied, invested and properly protected. There have not been many researches and solutions to protect river banks and canals in the field. In particular, very few studies have analyzed the effects of boat waves on the river bank erosion.

This study focuses on analyzing typical parameters of the boat and waves in the Mekong Delta, the case study on Long Xuyen - Rach Gia canal in Thoai Son district, An Giang province.

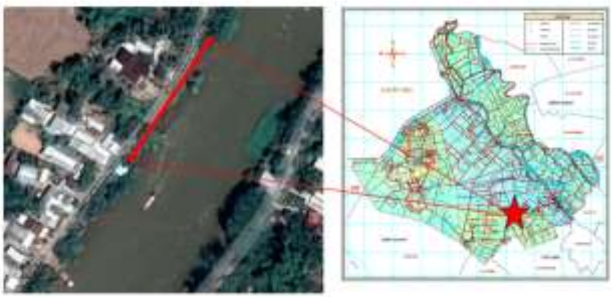


Fig 1. *Diagram location of the study*

The results of the study are important in assessing the impact of boat waves on riverbank erosion. It is also possible through this to estimate the level of river bank erosion over time.

2. The theory background of ship wave

2.1. The theory of ship wave formation

When the ship moves, it creates tension on the surface of the liquid, the liquid on the bow is most stretched, the size of the part in the direction of the ship's movement can be several times larger than the length of the ship. The open surface does not prevent the liquid elements from moving in the vertical direction when the ship moves in the bow area and the stern increases, the water surface rises, while the middle part of the pressure vessel decreases as the water surface. descending corresponding to line 1, Under the influence of gravity and surface tension of loose particles lying around the unbalanced vessel begin to perform oscillations. Due to the effect of inertial forces and their phases are reduced compared to the initial phases, the vibrations are respectively lines 2 and 3, causing the surface to deform repeatedly. Therefore, the combination of open surface deformations, which is called the wave crest, is called the wave crest and the middle part of the ship is lowered. The entire deformed surface area is characterized by long waves and is defined as a source of waves generated by ship waves.

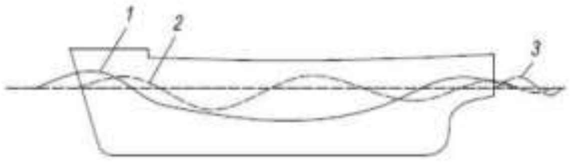


Fig 2. *The theory of ship wave formation*

Ship waves have their own characteristics compared to those caused by wind. The ship wave exists only for a finite time and its basic features such as propagation direction, wave height and cycle vary in the direction of the ship's motion as well as the distance to the ship's direction. Ship waves are divided into two wave systems:

The primary wave system.

Secondary wave system.

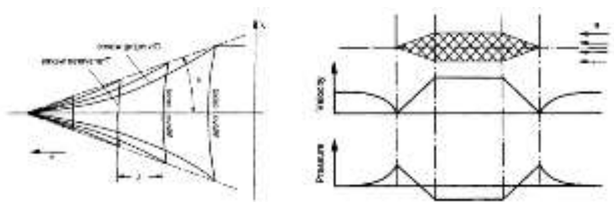


Fig 3. *Wave system of ship waves and velocity pressure due to water around the ship*

The primary wave system appeared along the hull as the ship moved on the canal, the farther the wave went away the faster the boat turned off.

The shape of the primary wave depends on very much on the shape of the bow as the ship moves. When the ship has a pointed bow moving in the canal. The bow of the ship turned to form thin screen waves that tended to be rolled to the sides. For ships with a bow, the waves tend to form turbulent waves in front of the ship.

Pointed bow ship Blunt bow ship

Fig 4. *Pointed bow and blunt bow ship*

Secondary wave system consists of two types: transverse waves and stern waves. In which, the transverse tidal wave is formed at the aft of the ship as the ship moves, while the diverging waves are formed at the tip of the bow when the ship moves and the shape of the bow also affects the shape of the wave. The secondary wave is called the Kelvin trail and the secondary wave propagates with the boat path at an angle θ[7]. The intersection of the transverse waves at the stern and the diverging waves forms a straight line connecting these vertices, the vertices of the wave are not outside the limits of this fan-shaped line.

2.2. Parameters of ship waves

Like other mechanical waves, the ship waves also include parameters such as wave velocity, wave height, frequency, period, wavelength and especially ship waves with moving or opening angles of waves. In addition to the above parameters, we also have other parameters such as the speed of the ship, Froude coefficient also affects the parameters of waves, these are the parameters to determine the characteristic factors of each type of ship waves. It corresponds to different types of ships in order to find out the characteristics of each train type when travelling on the canal. In addition to these parameters, there are also other parameters that can affect the wave parameters such as the speed of the ship, the load as the ship moves and the shape parameters of the channel cross-section.

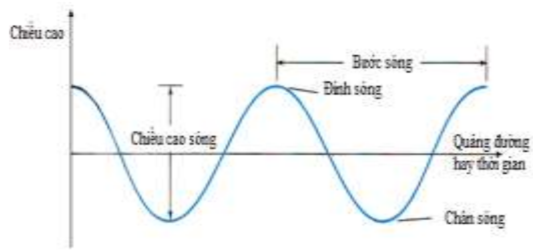


Fig 5. *Typical parameters of ship waves.*

The formula calculates the characteristic parameters of ship waves

Froude coeficient

In certain waters, the propagation angle of the ship waves varies depending on the Froude depth coefficient denoted by Fd in shallow water and is FL in deep water.

Froude coefficient is determined by the following formula:

In shallow water, the Froude coefficient depends on the depth of the water.

$$F_d = \frac{V}{\sqrt{gh}} \quad [1]$$

In deep water, the Froude coefficient depends on the length of the ship.

$$F_d = \frac{V}{\sqrt{gL_s}} \quad [2]$$

Where:

v: Ship velocity relative to water velocity.

g: Acceleration due to gravity

h: Still water depth.

Ls: Ship length.

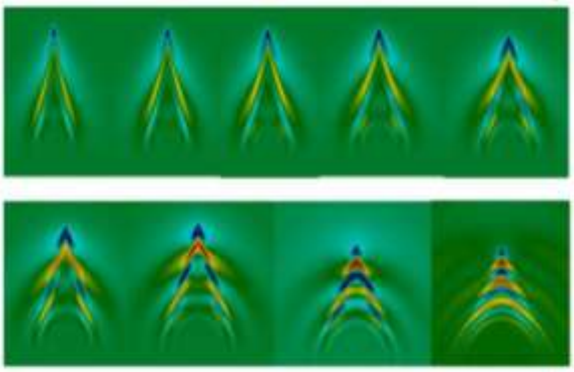


Fig 6. *Effect of Froude coefficient on the shape of ship waves.*

The wavelength and speed of the wave are calculated according to each specific formula depending on the region in which the wave is active. The water area is divided into 3 zones depending on the water depth ratio h and the wavelength L length. From the results of the wave zone classification, we apply the formula of each region according to the following table:

Table 1. *Summary of formulations which may be applied to determine wavelength and celerity for linear wave theory (US Army Corps of Engineers 1984).*

Water conditions	Relative depth: $\frac{h}{L}$	Wave length, L(m)	Celerity, C(m/s)
Shallow water	$\frac{h}{L} < \frac{1}{25}$	$L = T\sqrt{gh}$	$C = \sqrt{gh}$
Transitional water	$\frac{1}{25} \le \frac{h}{L} \le \frac{1}{2}$	$L = \frac{gT^2}{2\pi} tanh\left(\frac{2\pi h}{L}\right)$	$C = \frac{gT}{2\pi} tanh\left(\frac{2\pi h}{L}\right)$
Deep water	$\frac{h}{L} > \frac{1}{2}$	$L = \frac{gT^2}{2\pi}$	$C = \frac{gT}{2\pi}$

3. Research, survey and measurement in the field

The study site is located on the West bank of Long Xuyen - Rach Gia canal in Dinh My commune, Thoai Son district, An Giang province. This is an important waterway from Long Xuyen - An Giang to Rach Gia - Kien Giang and vice versa.

For the point of dealing with erosion, the construction item of "Long Xuyen - Rach Gia canal belongs to Dinh My commune, Thoai Son district, An Giang province". Through field survey shows, the embankment route has a width of about 4m, the embankment surface to make rural roads, a plastic carpet structure of 3.0m wide. Bank erosion has intruded into the embankment route and reached the edge of the road, sometimes encroaching on the asphalt. In the coming time, if there is no solution to treat and protect the shore, the erosion will increasingly penetrate deep into the dyke body, causing unsafe for people to travel, affecting households and farming areas. inside the dyke.

Fig 7. *Current state of erosion in the study area*

Through surveying data, the construction site is an important waterway connecting from Long Xuyen - An Giang to the West Sea of Kien Giang Province. According to the field survey, every day, more than 85 boats travel at a cross-section of the canal. The waves generated by the ship hit the river bank at high frequency, plus weak geology is the main cause of landslides on this channel section.

The results of calculating the frequency line for max and min water levels at research locations are shown in the following figure.

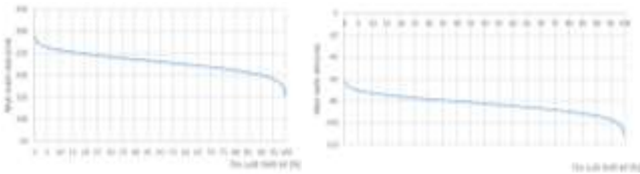


Fig 8. *Frequency water level curve at the research location.*

Select the frequency of hydrological calculations for the study is 5% for maximum water level and 95% for min water level. Thus, we have the results of the maximum water level corresponding to the frequency of 5% is 2.63 m, this level corresponds to the typical flood year in 2000; the minimum water level is 95% -0.97 m, corresponding to the five typical low water levels in 2005.

Use topographic survey materials made by a regional company in 2018 as part of the Southwest Program. We have river cross-section at the survey site.

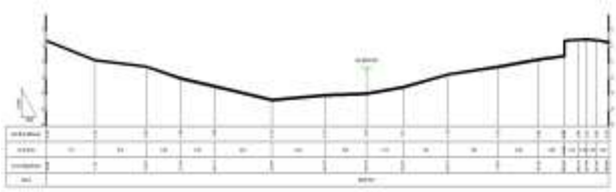


Fig 9. *The typical cross section at the study site.*

According to field survey documents and experimental results, with a depth of 30m, the geology at the survey site is distributed with a soft clay layer up to 3m deep followed by a clay layer in flowing state. extending up to 20m and less compacted sand layer distributed throughout the remaining survey depth.

4. Experimental program

4.1. Field experiments

At each transect, three hydraulic parameters including wave height, wave velocity and still water depth were measured in-situ and repeated three times for the precision.

The wave chart will be recorded with a Canadian-made Levelogger M3001 self-levelling device. The device is activated by software provided by the manufacturer.

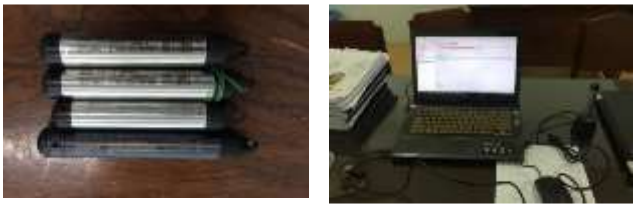


Fig 10. *Device to record and read wave data.*

The device is fixed to the iron frame system and is located at the location of the measurement of wave parameters. The measuring position is about 1.5 m from the shore with the purpose of obtaining data of waves close to the wave impacting the shore causing erosion.

Fig 11. *Installing field measuring equipment.*

The device is then connected to a computer to record data for analysis and evaluation.

a) b)

Fig 12. *Conducting experiments: a) Monitoring data collection, b) Processing and evaluating wave data.*

The movement speed of a ship is determined by using a stopwatch to determine the time it takes for a ship to travel through two fixed points located on a river bank.

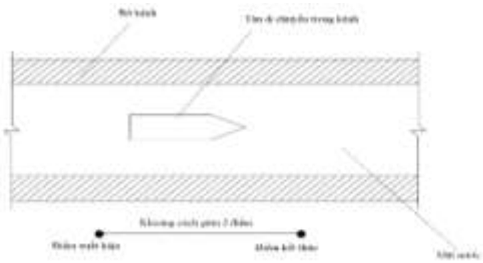


Fig 13. *Describe how to measure velocity when the boat is moving.*

4.2. Laboratory simulation experiments

4.2.1. Experimental setup

4.2.2.

The glass trough with dimensions of 4.8m x 0.6m x 0.3m has a wave generator designed to simulate boat waves with two basic criteria that are focused on wave height and wave velocity. Make sure the wave power is closest to reality.

Fig 14. *Wave generator***.**

The wave generator is designed to include a waveform face, motor and control box. With the high frequency of oscillation, wave generators can simulate waves up to 30cm in height.

The installed equipment includes a turbidity meter and wave measuring device.

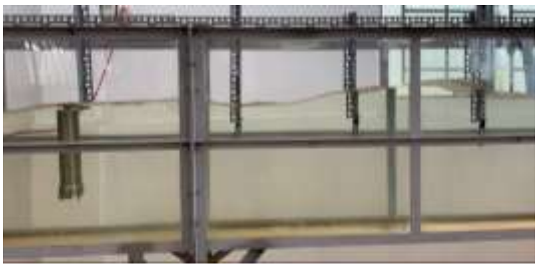


Fig 15. *Arrangement of measuring devices.*

Conducting field sampling, samples were taken to ensure the right position of geological survey and wave measurement of ships. Soil samples were taken in accordance with the effect of the waves and kept in the original state.

Fig 16. *Taking soil sample in the field*

Place soil samples into the glass trough, fill with water until half of the soil sample is submerged, turn on the power switch, the engine switch and adjust the oscillation frequency according to the data calculated in the model adjustment.

4.2.3. Turbidity test

The sediment content in water is determined by turbidity meter. The INFINITY-Turbi ATU75W2-USB (self-cleaning function) manufactured in Japan is a self-recording device for automatic turbidity measurement for a long time. With two low (0 to 1,000 FTU) and high (0 to 100,000 ppm) probes, it provides high precision turbidity readings both in normal and turbid environments.

Fig 17. *Device to measure water turbidity (The INFINITY-Turbi ATU75W2-USB).*

4.2.4. Erosion test

Use a steel ruler with a scale measuring up to millimetres. Position the ruler perpendicular to the soil sample and at the position adjacent to the water. Record the initial index on the scale corresponding to the surface of the soil sample.

Fig 18*. Steel ruler determines the thickness of the eroded soil layer.*

5. Results and discussion

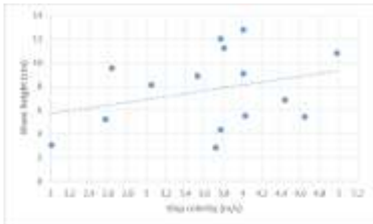
5.1. Ship wave parameter

Survey results show that the speed of the ships moving in the surveyed river ranges from 2.01 to 4.98 m / s. The wave height also varies considerably from 1.18cm to 28.79 cm.. besides boat speed, other factors such as the size, shape of the bow, load and measurement distance also have certain effects on wave height.

Kirkegaard et al. (1998) showed that waves generated by high-speed boat in shallow water are substantially different from the waves generated by conventional ships as a consequence of the higher speed and the size of these modern vessels.

Velegrakis et al. (2007) conducted a field observation of waves generated by passing ships and compared how influence the wave, induced by conventional ferry and fast ferry, Their results demonstrated that the fast ferry could generate a much more energetic event, which not only did include much higher waves, but it was also an order of magnitude longer.

Another analysis was performed to minimize the influencing factors. In this analysis, we only consider the type of Ca Vom vessel with 15 moves and these ships of similar size, shape and load.



Ca vom vessels

Fig 19*. Effect of train velocity on wave height*

The chart illustrates the relative relationship between ship speed and wave height, the higher the ship speed, the bigger the wave height generated by the ship.

According to the survey, the average impact time of the wave is about 15 seconds, the average wave height corresponding is 8.4 cm.

Average wave height is an important factor and is used to simulate ship wave in the laboratory.

5.2. Turbidity measurement results

Water turbidity represents the concentration of suspended sediments in the water. Water turbidity data help assess the slope erosion under the effect of waves.

The test was carried in 72 hours to get turbidity every 4 hours. Some pictures of changing water turbidity are recorded as follows.

Fig 20. *Image of turbidity of water after 24 hours.*

Fig 21. *Image of turbidity of water after 72 hours.*

The study of wave influence on soil slope erosion was assessed by turbidity, performed on 3 samples. The results are summarized and presented in the chart below.

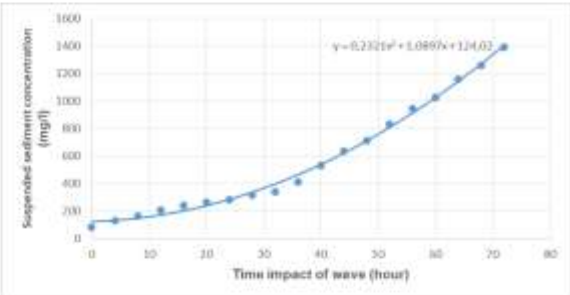


Fig 22. *Average sediment content over time of wave action*

5.3. Erosion results

Research results show that when placing soil samples affected by waves for 72 consecutive hours, soil samples will be eroded up to 12 cm.

With an average ship frequency of about 85 times a day and impact time of wave on the bank of about 15 seconds, corresponding to the research results we can estimate after about 7 months, the slope of the riverbank will be eroded. about 12 cm due to the influence of the ship wave. This result only considers the effect of ship waves, while the fact that the bank erosion is also affected by other factors and can actually reduce the amount of erosion caused by sediment deposition. , accretion.

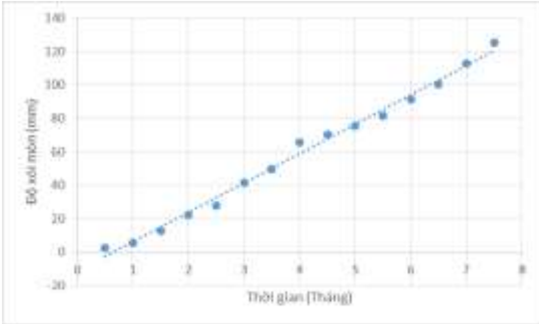


Fig 23. *Diagram showing bank erosion caused by ship waves over time*

6. Conclusions

Waves caused by boats have an impact on the erosion of slope of river banks and canals. The results of the study recorded the wave height caused by boats at the study site ranging from 1.18cm to 28.79cm. The average impact time is approximately 15 seconds

The study noted the results of water turbidity (eroded sediment content) showing that the slope of soil erosion is proportional to the duration of wave action. After 72 hours of continuous-wave effect, the sediment content in the water increased from about 70mg/l to nearly 1400mg/l. This result confirms that generated boat waves cause erosion of river banks.

The level of erosion was recorded directly on the soil samples is up to 12cm when directly under the effect of waves for 72 hours. With the frequency of navigation in the study area, the erosion level corresponds to nearly 7 months. This result only takes into account the only impact factor is ship waves, when in fact the river bank of the earth can be less eroded by deposited sediment.

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Symbols and abbreviations

c:	wave celerity (m/s)
g:	Acceleration due to gravity (m/s^{-2})
h:	Water depth (m)
Ls:	Ship length (m)
L:	Wave length [m^{-1}]
MARD;	The General Department of Disaster Prevention
T:	Wave period [s]
v:	Ship velocity relative to water velocity (m/s)
θ	The angle of divergence wave (^{o})