Alexandria Engineering Journal (2022) 61, 3165–3174

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Alexandria Engineering Journal

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Speed limit determination of fishing boats in confined water based on ship generated waves

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Received 12 March 2021; revised 28 June 2021; accepted 13 August 2021
Available online 03 September 2021

KEYWORDS

Ship generated wave;
Allowable energy;
Speed limit

Abstract Ship generated waves (SGW) can cause bank erosion, disturbance to moored boats and bad impact on the environment especially in confined water. One of the important vessel parameters that will affect the SGW is the speed of the boat. The speed limit determination for fishing boats in confined water will be discussed which can be used as a reference to decide the maximum boat or ship speed. The confined water of Mersing River has been chosen for the current study. This river is a busy river located in Johor in the southeast area of Peninsular Malaysia. The limited speed is needed in this river because the river is restricted to many boat activities. The typical boat particulars in Mersing River are 14.05 m in length, 4.35 m in breadth and 1 m in draft. The field experiment has been conducted with several scenarios considering the speed and tidal conditions. The results of the experiment were used to determine the maximum energy of SGW in this area. By using trendline characteristics, the formula of maximum energy was generated by considering the speed of the boat. The Brisbane River Criteria in Australian River has been selected due to the same characteristic with Mersing River. Hence, the reference for allowable energy was defined in this study. By using this river criteria, the limit of the boat speed was provided for all tidal conditions (ebbing, slack and flooding), and it was found that the allowable speed as the speed limit in the Mersing River is 5 knots. This will reduce bank erosion, disturbance to moored boats, environmental impacts and energy consumption. Moreover, the generating process of the formula can be a refer-

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

https://doi.org/10.1016/j.aej.2021.08.045
1110-0168

ence to get the speed limit at particular area as the river in other areas.

1. Introduction

In recent decades, research on Ship Generated Waves (SGW) has focused on the study of wake wash. It has become significant in the ship design industry criteria due to its impact on the environment in terms of erosion of natural shoreline wetlands in addition to the particular dimensions, speed, dead weight capacity, number of passengers and manoeuvrability of the ship [23,10]. Naval architects and shipbuilders also considered that the wake wash is an important issue, especially to make environmental-friendly design because of slow steaming reduced all shipping emissions [23,12].

Some countries had detailed regulations to manage the maximum wave height at particular distance from sailing line. One of the important parameters that contribute the SGW is the speed of ships or boat. Thus, managing the speed of the boat or ship at critical area is important to minimize the SGW at this area as the river. The study of ship-generated waves in the river area is important because of its shallow and narrow water. Stumbo et al. [19] found that the energy of ship's wake wash in shallow water is higher than deep water. Therefore, the river can acquire higher energy from ship waves than open sea, which later makes it more vulnerable to erosion than coastal areas.

Macfarlane et al. [13] discussed seven vessel parameters that can be considered while investigating boat-generated waves. Those parameters are speed, trim, hull form, direction, draft, loading and propulsion. The speed parameter is the most important parameter. Almost all researchers in ship generated waves considered this parameter. In the river, some researcher has conducted investigations with the speed parameter. Gourlay [9] conducted experiments in river using small boat, Haines Hunter 680 with 8.4 knot service speed. Dam et al. [7] investigated waterbus waves in the river with water depth around 4 m.

Most busy fishing boat port is located at the estuary area near with the sea, which has high tidal conditions. The tidal effect is relevant to the sea, because it happens every day. Dam et al. [7] tried simulating the tide situation by providing the current speed based on river-net program, by assuming that the current speed is strongly influenced by tides. Moreover, Macfarlane [15] argued that tides are cyclical, not incidental. The tidal have energy relatively, but the shorelines have features to resist the tidal impacts. In a recent study, Mao et al. [16] and Thuy et al. [22] indicated the tides that can generate a current and different water depths. Mao et al. [16] showed that the tidal made the current condition is hardly influenced at Xin xiagang River (observation river). Unfortunately, in recent study did not show the effect of tidal with SGW. Therefore, the tidal effect on SGW needs to be further investigated because this factor occurs cyclical daily, especially in estuary area of the river.

Most SGW studies in river areas showed that SGW increase erosion potential in rivers considering the speed parameter Bradbury [4]; Dam et al. [7]; Ahmad et al. [1]; Macfarlane [15]; Goranson et al. [8]; Thuy et al. [22]. The studies describe about the wave height or wave energy at several speeds in the area. Unfortunately, the study on the speed limitation still not found clearly in the river area. No specific ways from the studies are provided to generate the limitation. Thus, the objectives of the current study are to get similarity characteristics with the river that has rules of allowable SGW, then the rule or criteria of allowable SGW in the Mersing River is defined. The energy with allowable maximum wave height of the referenced river is also obtained. Finally, the limit of speed (relative and boat speed) with considering the allowable energy maximum wave height is defined.

2. Consideration of allowable SGW in rivers

Some rules have been developed to consider the SGW of the ship. The rules are intended to impose the acceptance criteria as speed classification, wave height criteria, and wave energy limit. Most criteria are built based on field measurements by using several types of ships. Some countries, such as Australia, Denmark and US have standard for maximum SGW in certain areas. The wash rule is essentially a formula that gives wave height (H) for any period (T) so that power remains constant [5,4] as below formula. H_b and T_b represent reference of wave height and period.

$$\left(\frac{H}{H_b}\right)^2 = \frac{T_b}{T} \tag{1}$$

2.1. Denmark – Danish Maritime authority (DMA)

In calm water conditions with 3 m water depth, maximum wake-wash height (H_h) criteria is devised as below [6,17,15]:

$$H_h \leq 0.5\sqrt{\frac{4.5}{T_h}} \tag{2}$$

where T_h is the average generated wave period of the long periodic waves measured in seconds. As a rule, the height of the long wave with an average wave frequency of 9 s may therefore not exceed 0.35 m when measured in water 3 m deep and in calm water.

2.2. United States – Washington state ferries (WSF)

The maximum wake-wash height H_{max} authorized by WSF is [2,3]:

$$H_{max} \leq 0.28 \text{ m} \tag{3}$$

with the wave mean period T_{ww} connected to the energy density E = 2450 J/m, by the following formula:

$$E = \frac{\rho.g^2.H_{300}^2.T_{ww}^2}{16\pi} \tag{4}$$

where H_{300} is the measured wake-wash height. The seawater water density (ρ), and the gravitational acceleration (g) can be combined with the constant 16π to form one constant value, which is 1961. The meaning of "300" is the distance between measuring point and sailing line/navigation track is 300 m. So, WSF rules applied at deep water or coastal area.

2.3. Australian river

In Australia, some studies of SGW in the river have been conducted, subsequently, three criteria were considered, which they are energy criterion, period-based waterline criterion and blanket speed limit criterion [14]. The first and second criteria are jointly applied while the third criterion is used as more traditional option that was introduced by the authority without any detailed study. The developed criteria at different rivers in Australia are illustrated in the subsequent sections.

2.3.1. Noosa River criteria

Energy criterion: the energy per metre crest length of the maximum wave (H_m) that also considering the period (T_m) must be less than 60 J/m.

$$\frac{\rho . g^2 . H_m^2 . T_m^2}{16\pi} \leq 60 \quad J/m \tag{5}$$

Furthermore, it is measured approximately 23 m from sailing line. Macfarlane and Cox [14] considered that the fixed value of Eq. (5) is similar to WSF standard which is 1961. Therefore, the density has been considered as a seawater which the location of the measurement is nearest from the sea.

Based on Macfarlane and Cox [14], explained that if a vessel has waterline length less than 5.2 m then the speed can be $> 3.04\sqrt{L}$ to get satisfying energy criterion. Meanwhile, the vessel longer than 5.2 m waterline length should be restricted to speed less than $3.04\sqrt{L}$ that satisfy the energy criterion. This criterion was developed by using relation between the period of the waves and vessel's water line. A speed of 5 knots is recommended in case of Blanket speed limit to apply along the entire river that would limit boat wash energy to the levels present before the introduction of high speed craft. Additionally, the shoreline type of Noosa River was compacted soil banks supported by riparian vegetation.

2.3.2. Brisbane River criteria

For Brisbane River, the energy per metre crest length of the maximum wave must be less than 180 J/m, i.e.,

$$1961 H_m^2 . T_m^2 \leq 180 \quad J/m \tag{6}$$

where H_m = height of the maximum wave in metres, T_m = period of the maximum wave in seconds

The experiment was measured approximately 23 m from sailing line. The characteristic of shoreline type of Brisbane River was muddy sand with a beach-like profile. As Macfarlane and Cox [14], the constant/fixed value in Eq. (6) is 1961. Therefore, the density can also be considered as sea water that the location of the measurement is close to the sea.

2.3.3. Gordon River criteria

Gordon River is one of the rivers in Tasmania, Australia. This river also has SGW criteria based on maximum wave height. For normal operations in management zone one, it is recommended that the maximum wave height is simply 75 mm that based on study with reference using Danish wash rule (DMA). Meanwhile, this river also has the equation to express an elegant concept of the wash rule corresponding with the period, as follows,

$$H_{max} \leq 70\sqrt{\frac{1}{T_{Hmax}}} \tag{7}$$

A rule is also present for a small proportion of high sensitivity sites that are particularly vulnerable if water level is lower than about 0.4 m by the Heritage Landing gauge board. Appropriate values are maximum wave height = 30 mm and T = 1.2 sec [5,4].

2.4. Discussion on the several rules and criteria

According to Danish Maritime Authority - DMA [6] and Parnell and Kofoed-Hansen [17], the limitation of the wave height is needed to make the effect of SGW more restrained for safety. DMA gave the maximum wave height of 0.35 m. Wave height criteria were also developed by Sørensen et al. [18], which described a wide variety of wave height prediction methods. Begovic et al. [2] also suggested that WSF uses wave height not exceeding 0.28 m in the regulation. In addition, WSF projected energy density criteria should not exceed 2450 J/m. Macfarlane and Cox [14] reported that the criteria of SGW in the river must not only consider the energy, but criteria such as wave period and speed limit need to be considered as well. The proposed maximum energy in Nossa River was 60 J/m and for Brisbane River was 180 J/m, based on the length of the waterline as shown in Eqs. (5) and (6). Meanwhile the speed limit was determined using traditional option as use the blanket speed limit that the speed is provided based on the experience of fisherfolk or the authority without any detailed study.

In terms of energy criteria, Benasai et al. (2013) showed that the energy density of Washington States Ferries (WSF) rule is 2450 J/m, while Macfarlane and Cox [14] reported that energy density for Nossa river is 60 J/m and Brisbane River is 180 J/m. Thus, WSF rule has higher energy density than Noosa and Bribane River. Begovic et al. [2] used WSF rule to apply for the beach area. Benassai et al. [3] also referred to WSF rule because the experiment focused on coastal management. WSF obtained the criteria with field measurement, where the distance between measurement point and navigation track was 300 m. Thus, WSF rule cannot be applied in the river due to its considerably shorter distance. The summary of all criteria is shown in Table 1.

Nossa River criteria have less energy density than Brisbane River. The Noosa River characteristic has more pristine condition than Brisbane River. Nossa River has riparian vegetation in the form of Melaleuca forests. Meanwhile, Brisbane River near the Brisbane city is open into Moreton Bay at Port of Brisbane, which has anthropogenic activities such as removal of riparian vegetation, cattle grazing, bank armoring, etc. Tidal condition also occurs in Brisbane River.

Based on the above discussion, it was concluded that the speed of boats along river area is mainly based on the experience of fisherman, thus there is no standard of allowable speed during the navigation in the river. Therefore, it is important to indicate the allowable speed along the river.

Table 1 International rules of ship generated wave.

No	Description of criteria comparison	DMA	WSF	Gordon River	Noosa River	Brisbane River
1	Factor to limit	Hmax	Hmax; E	Hmax	E (J/m), Speed (knot)	E (J/m), Speed (knot)
2	Maximum limit	Hmax < 0.35 m	Hmax < 0.28 m E < 2450 J/m	Hmax < 0.075 m If water depth < 0.4 m, Hmax = 30 mm	1. E $\leq$ 60 J/m 2. If waterline < 5.2 m, Vs $\geq 3.04 < \sqrt{L}$; If waterline > 5.2 m, Vs $\leq 3.04\sqrt{L}$ 3. Blanket speed, Vs = 5 knot	1. E $\leq$ 180 J/m 2. If waterline < 9 m, Vs $\geq 3.04\ \sqrt{L}$; If waterline > 9 m, Vs $\leq 3.04\sqrt{L}$ 3. Blanket speed, Vs = 6 knot
3	Factor to be considered	Water depth, Tmax	Distance of sailing line	Distance of sailing line	Wave height max, Period Hmax, Speed	Wave height max, Period Hmax, Speed
4	Formula a. Hm for DMA and Gordon River b. E for WSF, Noosa and Brisbane River	$0.5.\sqrt{\frac{4.5}{T_h}}$	$1961.H^2.T^2$	$70.\sqrt{\frac{1}{T_{Hm}}}$	$1961.\ H_m^2.\ T_m^2 \leq 60$ J/m	$1961.\ H_m^2.\ T_m^2 \leq 180$ J/m

3. Location selection (Mersing River)

Mersing River was selected because it is the busiest and the largest river in the state of Johor in Malaysia. The location of the research is at estuary of the River and South China Sea. Table 2 shows the number of total licenced fishing boat at different inboard engines in Johor, Malaysia. The table also illustrates that Mersing area has the highest number of fishing boats. Therefore, this have been made the busy traffic of the boats in the river. In addition, the ferry terminal also located near the mouth of Mersing River that has been created the high traffic movement of the fishing boat, ferries and patrol boat, especially during flooding time.

The research location was at LKIM (Lembaga Kemajuan Ikan Malaysia – Fisheries Development Authorities of Malaysia) port area at Mersing River that has water depth of 4.5 m at sailing area, width of 60 m during high tide and 40 m at low tide. The location map is shown in Fig. 1(a) and Fig. 1(b) describes the river conditions at high tide at fishing port area.

Mersing River has unique characteristics such as a narrow river and close to the sea (estuary). Fig. 1(c) shows that three finishing boats were navigating beside the unloading fishing and parking boat. The bathymetry of the river is located in deep water on one side (fishing port) and in shallow water on the other side. Therefore, this conditions tends to highly restricted river. Meanwhile, most fishing boats are parked at the side of the river as shown in Fig. 1(d), thus the possibility of collision between parked boats is high when moving boats generated waves. This condition makes this River as the confined area. Thus, the determination speed of the boat is critical at the River, which have confined area characteristic to minimise SGW. Furthermore, in Mersing River, especially in estuary area, the shoreline type is muddy sand. This area also has anthropogenic activities such as bank armouring, development of recreation place and port. No riparian vegetation lives in good condition at this location. The tidal conditions also influence the water depth. Thus, the characteristics of Mersing River, especially in estuary area are similar to Brisbane River. Therefore, Brisbane River criteria are deemed appropriate for Mersing River to give the limit of ship or boat-generated waves in this area and the allowable criterion of Mersing location can be based on Brisbane River criteria. The specific characteristics (e.g. width, length, depth of river) can be vary between Mersing and Brisbane River, however, what is important is that the wave energy at the pole which will be considered at the river bank. The wave wash energy should be less than 180 J/m as Brisbane River Criteria. Therefore, the information regarding to the specific characteristic Brisbane River (width, depth, length and water basin) are not required.

Table 2 The number of licensed fishing boat [11].

No	Districts	Total Number
1	Muar	191
2	Batu Pahat	127
3	Pontian	131
4	Kota Tinggi	195
5	Mersing	519

4. Field experiment methods and procedures

4.1. Selected fishing boat

The field experiment was conducted using fishing boat at Mersing River [20]. There are two types of fishing boats, boat type A (40 to 69.9 GRT) and type B (25 to 39.9 GRT), both of which are of displacement type with engine inboard. This boat can operate 3 to 5 days at sea. For the field experiment, this research used the fishing boat type B as it is easier to manoeuvre during experiment. Moreover, boat type B has higher movement in this river because the duration of operation of this boat in the sea is shorter than boat type A, therefore Type

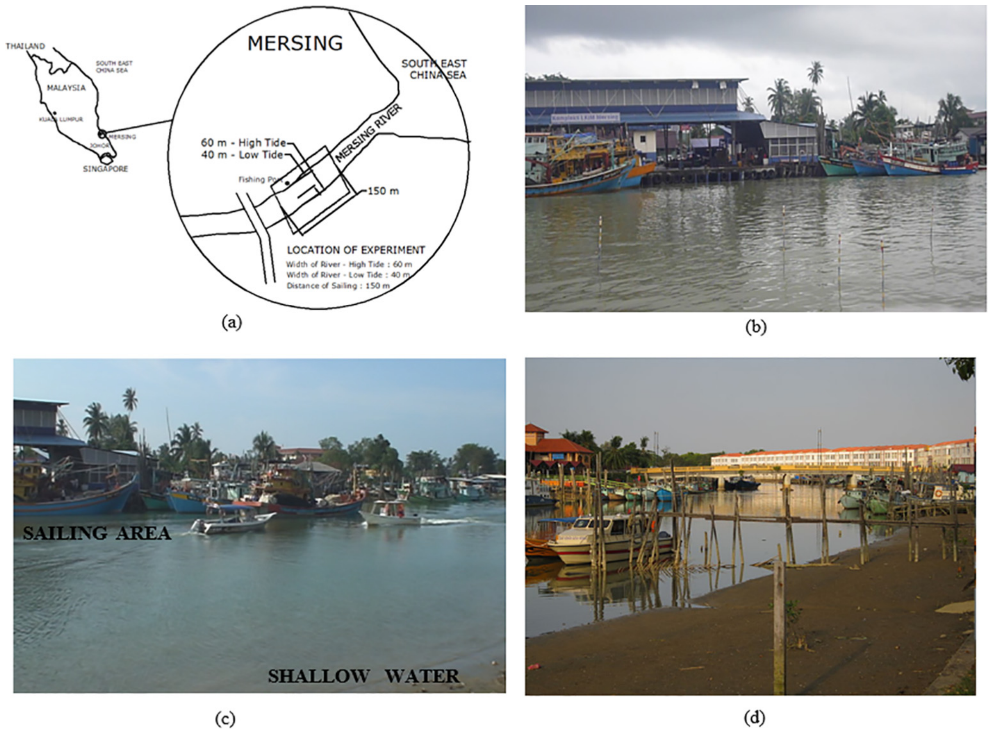


Fig. 1 (a) Map of Field Measurement Location; (b) Mersing River Condition at High Tide ; (c) Fishing boats sailing next to the parking boats; (d) Fishing boats parked at Low Tide.

B goes to the port in the river more often than boat type A. The boat type B is also the preferred choice for other purposes such as fishing activity hobbies. The fishing boat for experiment is shown in Fig. 2, while the boat details are elaborated in Table 3.

Fig. 2 Displacement fishing boat used in the experiment.

4.2. Experimental methodology

As discussed above, the allowable criterion is based on Brisbane River criteria. Thus, the energy criterion was used to determine the total energy by comparing the limit of the river according to Eq. (6). The objective of the experiment will also give the speed limit for displacement-fishing boat on three current types as flooding, slack and ebbing conditions. Thus, this speed can give alert to the displacement-fishing boats when navigating in the Mersing River. For that purpose, the maximum wave height at several speeds, i.e., 6, 9 and 12 knots for displacement-fishing boat must be identified. Suprayogi et al. [20] show the method of field experiment that will use video recording of the SGW to get the maximum wave height includes the period.

4.3. Equipment of the experiment

The equipment for this field measurement are listed as follows:

a) Digital video cameras complete with tripods: 6 units (minimum optical zoom is 25 x). In this experiment, the cameras used were JVC Evario (2 units), Samsung VP-DC161 (1 unit) and Sony HDR series (3 units).
b) Poles with scale: 5 pieces. The length of the pole was 3 m each.

Table 3 Particular dimension of displacement fishing boat.

No	Description	Value
1	Length overall (L_{oa})	14.05 m
2	Length waterline (L_{wl})	10.25 m
3	Breath (B)	4.35 m
4	Depth (D)	1.09 m
5	Draft (T)	1 m at AP and 0.5 m at FP
6	GRT	26

c) Measuring tape.
d) Laser distance measurement with model of Makita LD series.
e) Furuno FCV 620 for measuring the water depth.
f) Garmin GPS 128 for detecting the location of the boat.

4.4. Experimental set up and procedures

The set-up of the field measurement is shown in Fig. 3. The targets of the digital video cameras were scaled poles and those were placed in the river at points A, B, C, D and E. The video cameras were placed on the top of the vertical wall along the river bank at point A', B', C', D' and E' that the cameras taken video movement of SGW at poles A until E as one camera record one pole. Another video camera was placed on a high position (point F') to record the overall scene of the experiment, such as poles, boat movement and wave propagation. In this research, the results were obtained from point A, and the other points (B, C, D, and E) were used as references. The boats were run with constant speed between point P and Q. Distance between measuring pole (Pole A) and sailing line is 13 m. Several scenarios were also generated in the experiment (Table 4).

Movements of wave heights were recorded by video cameras for a certain duration and the resulting video footage were extracted frame by frame images with 5 frames per second. One example of the simultaneous image capture from the six digital video cameras for recording the wave heights is described in Fig. 4. Video footage and the images were processed to obtain wave heights and directions. In this field measurement five scaled poles were used as targets, while five digital video cameras were used to record the movement of waves on every pole. The recorded video footage was then processed by the imaging method to find the wave height time series. Suprayogi et al. [20] described the derivation of wave height from extracted images. In this work, several processes must be implemented to obtain the wave height data using image processing program based on Matlab. Several steps had to be done for the program. By repeating the process for the whole sequence, a compilation of wave heights for every image associated with a discrete time step could be obtained, thus creating a time series.

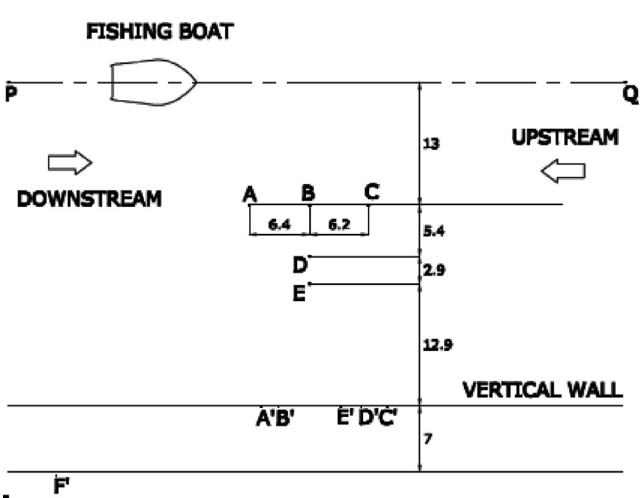


Fig. 3 Arrangement of field measurement, the dimensions are shown in *m*.

5. Results and discussions

Suprayogi et al. [20] showed a method to derive the extracted image to be wave height in the time domain (time series). The wave height in time series results was obtained based on measurement of speed, tidal conditions (upstream and downstream) and direction of the boat. Fig. 5 show the results of flooding, slack and ebbing tidal conditions based on the conditions or scenarios for displacement-fishing boat experiment from B1 to B15 which are shown in Table 4.

The field experiment in the flooding condition that means the current moving from sea into the river (upstream direction) is shown in Fig. 5(a), (b), and (c), where Fig. 5(d) illustrates the river in slack condition (consider no current). Then, The graph of ebbing condition is shown in Fig. 5(e), (f) and (g). The same direction between boat and current has the same orientation. Consequently, as a sample, in flooding condition, the direction between boat and current is the same when the boat navigates in upstream direction (from sea to upstream of the river) while the direction is contrary when the boat moves downstream (from upstream of river to the sea). The boat moves with speed 6, 9 and 12 knots in all conditions (flooding, slack and ebbing) and the duration was approximately 15 *s* for wave recording. All maximum wave height (H_{max}) and period at H_{max} (T_{max}) every experiment (B1-B15), the direction of current-boat are compiled in Table 5.

5.1. Determination of tide effect on allowable speed

According to the discussion in Sections 2, the allowable energy based on Brisbane River criteria should be less than 180 J/m [14]. Table 5 presents the boat speed (V_B), current speed (V_C), relative speed (V_R), the result of the maximum wave height in field experiment of SGW of displacement-fishing boat is also provided. The relative speed (V_R) is provided by adding or reduced the boat speed (V_B) with current speed (V_C). The current speed is positive if the direction is opposite to the vessel direction, but it will be negative if the direction is the same as the vessel. Moreover, the energy is taken from calculations of maximum wave height and the period that are included in Eq. (10) at the poles (13 m off sailing line) ; see Table 5.

$$E = \frac{\rho . g^2 . H^2 . T^2}{16\pi} \tag{8}$$

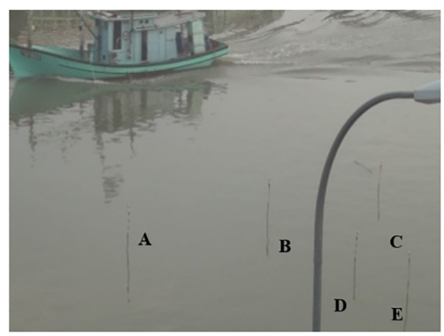
The maximum wave height is obtained from experiments B1 to B15 on wave height. T_{max} is the period of wave at maximum wave height. Based on maximum wave height and period, and the calculation of energy can be provided using Eq. (8).

Based on the results on the field experiment scenarios that are illustrated in Table 5, the energy recorded values above 180 J/m for all cases except B1, B7 and B11. By employing energy criterion of Brisbane River Criteria, it is found that the acceptable speed for displacement-fishing boat for slack condition is 6 knot because the created energy is 147.45 J/m. The fishing boat with speed 9 and 12 knots are not permitted when the distance between the river bank and sailing line is

Table 4 Experimental condition for displacement fishing boat.

No	Exp	Speed (knot)	River/Current Condition	Boat Direction	Current Vs Boat Direction	Depth water (m)
1	B1	6	flooding	upstream	same	3.9
2	B2	6	flooding	downstream	opposite	3.9
3	B3	9	flooding	upstream	same	3.9
4	B4	9	flooding	downstream	opposite	3.9
5	B5	12	flooding	upstream	same	3.9
6	B6	12	flooding	downstream	opposite	3.9
7	B7	6	slack	downstream	–	4
8	B8	9	slack	upstream	–	4
9	B9	12	slack	downstream	–	4
10	B10	6	ebbing	upstream	opposite	3.6
11	B11	6	ebbing	downstream	same	3.6
12	B12	9	ebbing	upstream	opposite	3.6
13	B13	9	ebbing	downstream	same	3.6
14	B14	12	ebbing	upstream	opposite	3.6
15	B15	12	ebbing	downstream	same	3.6


(a)



(b)

Fig. 4 Example of images from the video cameras, (a). video at pole A, (b). video from high place (point F′).

13 m because the generated energy is higher than the maximum energy based on the applied criteria (see the corresponding energy level in Table 5).

The tide conditions (flooding and ebbing) affect significantly on the energy of SGW. Based on Table 5, two energy are generated from a speed of 6 knots, which are 225 J/m (B2) and 226 J/m (B10), moreover, they are higher than the maximum limit of Brisbane River Criteria. This condition tends to a different direction between the boat and river current direction. For B2, the direction of the boat is downstream and the current is flooding condition while the direction of displacement-fishing boat is upstream with current direction is ebbing condition in case of B10.

Fig. 6 shows the energy of ship-generated wave in several conditions with the limit of energy criterion of Brisbane River Criteria. It is revealed that ebbing condition has higher energy than flooding condition. Moreover, the maximum energy in ebbing condition with the downstream direction for the boat at 12 knot is 956 J/m. However, the lowest energy is 53.8 J/m in flooding condition with upstream boat direction at 6 knots of speed. Comparing between flooding – upstream and ebbing– downstream, and the energy is increased gradually with an increase in boat speed. The maximum allowable energy with maximum wave height based on the Brisbane River Criteria is 180 J/m as shown in Fig. 6.

The relation between Energy of maximum wave height and Relative speed considering to the boat speed and current speed are described in Fig. 7, which clearly shows the maximum limit of SGW's energy based on Brisbane River Criteria as maximum 180 J/m. It can be seen that the generated energy at most 6 knots speed is acceptably based on the data of this field experiment, except for the cases in the opposite direction at flooding and ebbing conditions as shown in Table 5. It can also be noted that the maximum energy at speeds 9 and 12 knots exceeds the limit of the criteria.

Fig. 7 defines the relationship between the energy of maximum wave height and relative speed. The experiment was run with F_{nd} between 0.49 and 0.87 (Sub and Trans-Critical area). The characteristic result of the experiment shows increasing in the energy with a certain rate and the quantity of data also are not large. Therefore, the appropriate trendline can be applied for the result is power type. The trendline curve is expressed below with the coefficient of determination $R^2 = 0.8981$.

The F_{nd} for displacement-fishing boat running at 6 knot is approximately 0.5 (sub-critical area). The wave height will be reduced if the F_{nd} is less than 0.5. Based on Depth Froude

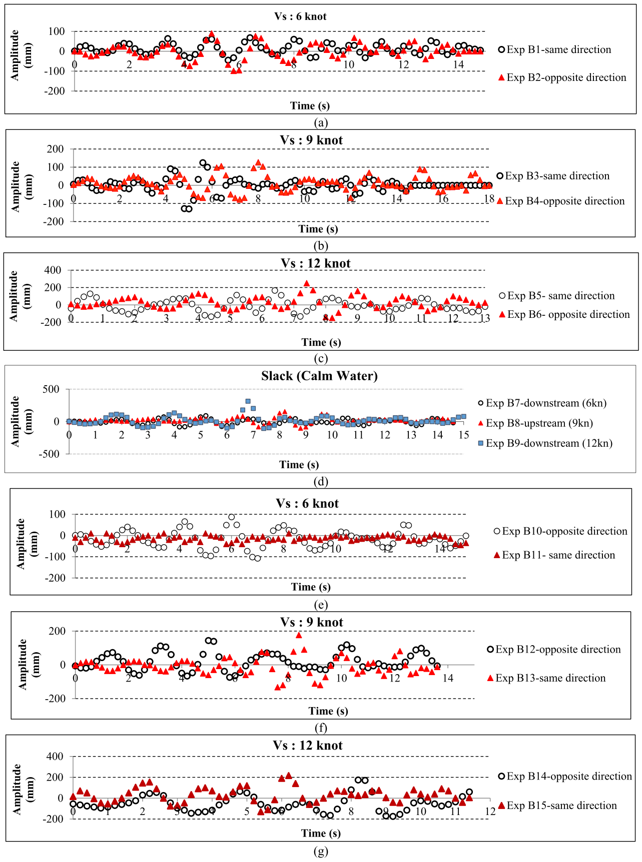


Fig. 5 Wave height in time series domain, (boat moving from upstream and downstream in 6, 9 and 12 knot with flooding ebbing condition.

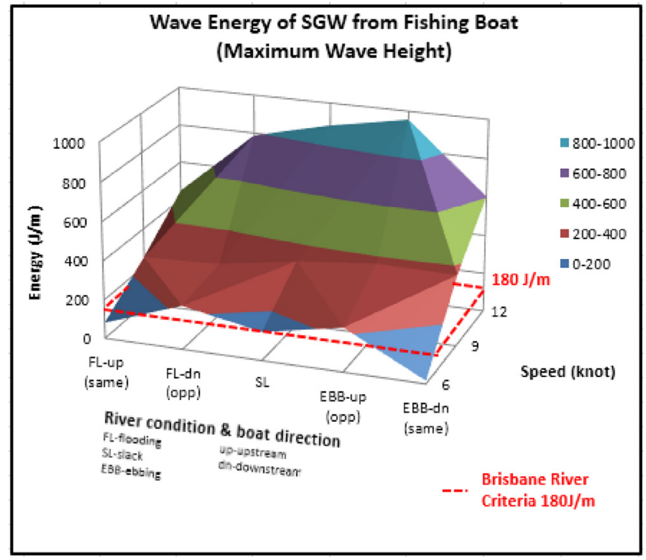


Fig. 6 Wave energy of SGW from fishing boat based on maximum wave height.

Number formula, the reduction Froude number will decrease speed if the water depth is the same. From here, the way to get acceptable speed during flooding and ebbing in the opposite direction with the boat can be found. In Fig. 7, a trendline curve formula can be found as shown in Eq. (9) that change "y" as the energy of the maximum wave height "E" and "x" as relative speed (V_r).

$$E = 1.2747.V_R^{2.5414} \tag{9}$$

The modified trendline formula must be generated using Eq. (9), considering the tidal conditions as flooding, slack and ebbing. The generation of the formula used the nearest speed with allowable limit line that shows in Fig. 7, the limit is 180 J/m as the allowable line (Brisbane River Criteria). From Fig. 7, speed of 6 knot is the closest in all tidal conditions. Therefore, the formula used minimum speed (6 knots) that has the highest energy as reference point, which will provide the lowest speed. Higher energy is also generated from the lower water depth as ebbing condition. Thus, it is concluded that the reference point will be highest energy at the lowest speed (6 knot), then the speed limit will apply to other tidal conditions. Here, Experiment B10 is the reference point to get the speed that have highest energy at the lowest speed (6 knots) in ebbing conditions. The modified trendline curve use main formula at Eq. (9) and put additional constant that need

Table 5 Criteria status of energy maximum wave height of displacement fishing boat.

No	Exp	Boat Speed V_B (knot)	Current Speed V_C (knot)	Current and Vessel Direction	Relative Speed-V_R (knot)	F_{nd}	H_{max} (m)	T_{max} (s)	Energy E (J/m)
1	B1	6	0.8	same	5,2	0.39	**0.11**	**1.80**	**81.21**
2	B2	6	0.8	opposite	6,8	0.51	**0.19**	**1.80**	**225.02**
3	B3	9	0.8	same	8,2	0.61	**0.26**	**1.40**	**250.05**
4	B4	9	0.8	opposite	9,8	0.73	**0.20**	**1.80**	**265.92**
5	B5	12	0.8	same	11,2	0.85	**0.30**	**1.60**	**447.67**
6	B6	12	0.8	opposite	12,8	0.96	**0.35**	**1.80**	**788.85**
7	B7	6	–	–	6,0	0.44	**0.17**	**1.60**	**147.45**
8	B8	9	–	–	9,0	0.66	**0.26**	**1.60**	**333.00**
9	B9	12	–	–	12,0	0.89	**0.42**	**1.60**	**884.02**
10	B10	6	0.7	opposite	6,7	0.53	**0.19**	**1.80**	**226.18**
11	B11	6	0.7	same	5,3	0.42	**0.05**	**1.80**	**53.8**
12	B12	9	0.7	opposite	9,7	0.75	**0.22**	**2.00**	**371.82**
13	B13	9	0.7	same	8,3	0.65	**0.31**	**1.40**	**366.42**
14	B14	12	0.7	opposite	12,7	1.00	**0.35**	**2.00**	**955.89**
15	B15	12	0.7	same	11,3	0.89	**0.35**	**1.60**	**604.78**

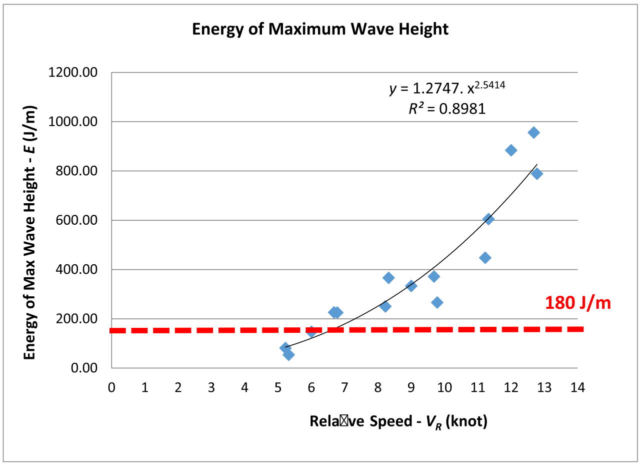


Fig. 7 Maximum wave height of SGW from displacement fishing boat with allowable energy of Brisbane River Criteria.

to connect with reference point (B10) which new formula in Eq. (10) below. The below shows the step of constant generation.

$$E = 1.2747.V_r^{2.5414}$$

Put a constanta ("c") to get modified trendline, so the formula will be as below

$$E = 1.2747.V_r^{2.5414} + c$$

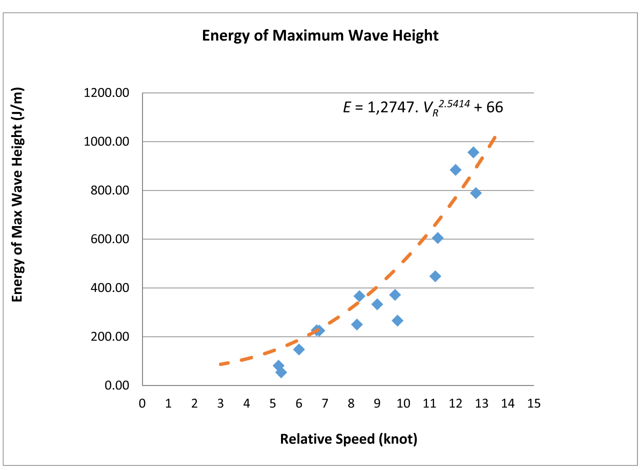


Fig. 8 The energy maximum wave height with Brisbane River Criteria for displacement fishing boat with modified trendline.

The trendline need to connect with reference point, in this case V_r is 6.7 knot and 226 J/m (B10), then plot in the formula as below

$$226 = 1.2747(6.7)^{2.5434} + c, \quad \text{then}$$

$$c = 66.$$

Then, modified trendline formula will be shown as below

$$E = 1.2747.V_R^{2.5414} + 66 \tag{10}$$

Based on modified formula in Eq. (10), the ploting can also be provided, as shown in Fig. 8 that describes the relation of energy maximum wave height and the relative speed. By using Eq. (10), the speed limit can be found in the Mersing River.

Based on Fig. 8 and Eq. (10), the maximum speed that has energy 180 J/m can be found and the speed is considered the relative speed. Energy is provided using Eq. (10) with make estimate relative speed and found the Relative Speed that has allowable limit the Energy which in the case is 180 J/m (Brisbane River Criteria). From Eq. (10), the limit of relative speed that can create maximum energy (180 J/m) is 5.8 knot.

After generating the limit of relative speed, the boat speed (V_B) can be provided by considering the current speed (V_C) and direction of boat and current. Based on Table 6, during flooding V_C is 0.8 knot and in ebbing condition V_C is 0.7 knot. For the direction, there is the same and the opposite direction. From all conditions, V_B for Mersing river is concluded in Table 6. The boat speed limit is generated using the limit of relative speed and current speed at the same direction. Furthermore, the V_R is added with V_C and during the opposite direction in addition to the V_R is deducted with V_C. The lowest boat speed from the condition is 5 knots, this speed can be used as a recommendation of the boat speed limit for tidal in all conditions (flooding, slack and ebbing).

6. Conclusion

The field experiment of boat-generated waves was conducted at Mersing River, which is defined as the busiest River in the East of Johor, Malaysia. The allowable speed was provided in the experiment that was based on SGW's energy and the tidal condition. The calculations were conducted using the maximum wave height. The correlation between the energy (E) of boat-generated waves and relative speed (V_r) was obtained in this study.

Consequently, a modified trendline formula is generated. It is concluded that some parameters should be considered for determining the modified trendline formula. First, a location that is a reference for the Boat Wave Criteria must be determined, which be used as a guidance for providing the limit of the allowable energy (J/m) of SGW. As mentioned before,

Table 6 Determination of boat speed (V_B) as the limit considering the tidal condition at Mersing River.

No	V_R (knot)	Current condition	V_C (knot)	Boat direction	Boat and current direction	V_B (knot)
1	5.8	Flooding	0.8	Upstream	Same	6.6
2	5.8	Flooding	0.8	Downstream	Opposite	5
3	5.8	Slack	–	–	–	5.8
3	5.8	Ebbing	0.7	Upstream	Opposite	5.1
4	5.8	Ebbing	0.7	Downstream	Same	6.5

Brisbane River has been chosen as the reference for the wave wash energy criteria due to the similarity with Mersing River. In the Brisbane River criteria, the allowable energy is below 180 J/m. Secondly, provide a reference point that also should be defined for the exact value of speed limit. Finally, the modified trendline can be determined.

$$E = 1.2747.V_r^{2.5414} + 66$$

From the previous formula, the boat speed limit can be provided by using the allowable energy of Brisbane River Criteria, which result in maximum speed of 5 knots. The speed of the boat must be below 5 knots and this speed can be used during all tidal conditions such as flooding, slack and ebbing. Finally, the proposed speed tends to reduce bank erosion, disturbance to moored boats and all shipping emissions in addition to energy saving.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to express sincere gratitude to Universiti Teknologi Malaysia (UTM) for providing assistance, access to data and experimental apparatus for this publication. This research project [21] was supported by Institutional Grant No. Vot 77235 from Universiti Teknologi Malaysia Johor - Bahru (UTM - JB).

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