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Relation Dynamic Shear Stress and Wake Boat Waves Energy

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***Abstract** Coastal area is the most populated throughout the world due to its business activities especially those involves commercial or recreational vessels to bring people or goods. Inadvertently, heavily vessels traffic will create effect on shoreline, riverbank or estuaries in which resulting an erosion problem. Overcoming the problem, a few local state authorities are enforcing a regulation for the vessels to cruise along the coastline to minimize the erosion impact. This research was conducted to study the relationship of dynamic shear stress generated from wake boat and tidal flow induced energy at Kemaman river estuary, which located at Kemaman province, East Coast of Peninsular Malaysia. Evidence shows that erosion occurred along the riverbank, and it was confirmed that the vessels contribute to the erosion problem due to negligence of vessels' speed. In addition, apart from the generated energy coming from the vessel, the dimension of the vessels also contributes to the erosion problem. The estimation of total energy created by each vessel is established by a formula through the relationship with wave energy under influenced of maximum wave height. The results indicate that increases in energy will increase the dynamic shear stress due to orbital wave velocity whereby it is a function of wave height generated by boat wave. Finally, the results also indicate addition minimum tidal flow rate and wake boat contributes higher dynamic shear stress as compared to mud bed shear stress. Therefore, it can be concluded that wake boat waves play a significant role in determining the riverbank erosion. The finding of this study serves some information as guidance to local state authority to impose regulation to community whom using the vessels to navigate through this estuary.*

***Keywords:** Boat Wave Wake, Erosion, Wave Energy.*

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I. INTRODUCTION

The high-energy induced by boat wakes has caused in damage of surrounding vegetation, habitat and shoreline erosion of estuarine environments [1]. On globally scale intensity of boat traffic in estuarine environment has increased because of risen economy activities thus the area has potential to redistribute large amount of sediments or contaminates [2]. Severely in environmental impacts due to boat wakes has increased many researchers involved in the study on site specific location [3],[6]. The study response to boat wakes has been conducted in Chesapeake Bay to review existing management and policy actions [7]. Previously research on estimation of critical bed shear stress was conducted through modelling simulation at same place with difference of seafloor roughness, current velocities and wave properties [8]. Sediment also contributes tendency for easily erosion depends on its characteristics such grain sizes, porosity, permeability and fractions such percentage of sand, gravel and mud [9],[10]. Regards on boat passes over the water surface, pressure differences are developed at the air-water interface and series of wave are then produced, as well as friction on the water surface by the hull boat, making the water goes into the Dynamics shear stress causes the growth of the waves and produced wave power [11].

As long as the waves propagate slower than the boat speed when across the water surface, there is an energy transfer from the boat speed to the wave's motion. The riverbank erosion happen when the boats navigate the estuary or channel a water surge ahead created by the boats will cause a wave motion in the direction of the passing boats. Damage may be caused by the effect of a single wave or the cumulative effect of several wave trains from many boats. Water wave is a very powerful erosion agent. The faster water wave moves onto streams surface, more sediment is picked up and transported. This is known as critical erosion velocity. The occurrence and amplitude of the drawdown are controlled by the width of the channel, the local water depth and some boat-related features, such as the shape of hull and the boat speed, e.g., the narrower the width, the larger the drawdown [12],[13]. Previous study at Ashfield Parade river, shoreline erosion was very likely as a result of vessel generated waves where a blanket speed limit of either 8 or 9 knots (or greater) was imposed as the energy and power of the maximum waves generated by all vessels far exceed that of the maximum wind waves over the entire range of lateral distances investigated.

It indicated that a reduction in vessel speed, down to 6 or 5 knots, should dramatically reduce the potential for erosion. Macfarlane [14] suggested that at a speed of 5 knots the energy and power of the maximum waves for all vessels are likely to be below that of the maximum wind waves, provided a minimum lateral distance of 20 metres is maintained between the vessel sailing line and the shore.

This study involved a site so called Kemaman River Estuary whereby the erosion are took placed since 1994 [15]. He focused in physical dimension and social problem regarded on this issue. However this study was focused on wave characteristics was generated by typical local boat which comprises of many classes usually passing over the surface of the Kemaman River Estuary. Therefore, the aim of the study was to investigate the relationship energy generated by boat and dynamics shear stress at mangrove area in Kemaman River Estuary. The following objectives were established such identifying boat wakes wave energy in the Kemaman River Estuary, examining the dynamics shear stress that related to the erosion occurs and investigating the relationship between energy of maximum wave, E_{max} with the energy of entire wave train, E_{total} induced by all boat types.

II. METHODOLOGY

A. Site Location

The study area was conducted at Pulau Sekepeng (Latitude: 04° 14.007' 60 N, Longitude: 103° 25.673' 0 E), Kuala Kemaman estuary. This area is under Kemaman Permanent Forest Reserve (KPFR). This site is about 3.1 km from the mouth of estuary and is located at the southern bank of Kemaman River, which is the main water transportation channel for local fishing boats. The distance from shoreline is about 0.44 km. The dominant mangrove species in this area are *Rhizophora sp.* with some minor species such as Avicennia sp., Sonneratia sp. and *Nypa Fruticans*. Sampling transect for this study site is located inside Rhizophora zone which consist pure stand of Rhizophora. Environmental conditions of this study area are typical of east coast of peninsular Malaysia which is wet equatorial climate with all year round high temperature and seasonal heavy rainfall during north – east monsoon. Fig. 1 shows the location of study area where the research and data was taken for this study.

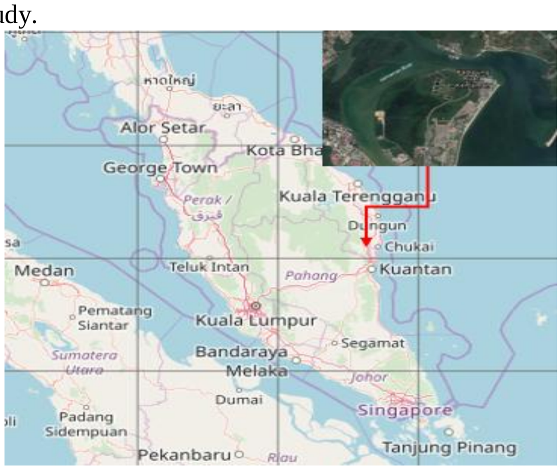

Fig. 1. Kemaman River Estuary (https://map.openseamap.org and http://maps.google.com.my/maps).

B. Boat Information

Data collection for this research the information of ship traffic, profile of boats and navigation channel were obtained from Marine Department. Ship traffic statistic data was collected to determine the type of vessel entering and leaving at Kemaman River Estuary. The profile of the boats was very important to verify the magnitude of ship waves such profiles as size of boats, type, length, breath, maximum speed design, and draft. Types of boats were picked out together with their profile form the observations during sampling throughout a year from Kemaman District Fisheries Department, Terengganu database.

C. Position of Water Level Logger

In this study a series of data collection obtain from water level logger were used to measure the parameter of wave characteristic. The three wave gauges were deployed at different water depth level in parallel position (Fig. 2) during low tide. The data of water height was recorded at one second intervals. The parameter recorded was wave height, pressure and water temperature over 24 hours.

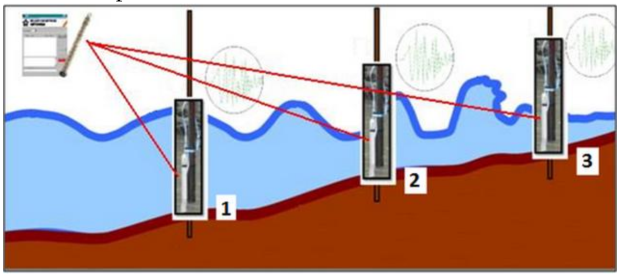

Fig. 2. Position of Gauge 1, 2 and 3 from middle of the river to the river bank.

D. Wave Energy

Wave energy from the wave train that induces by boat were divided with two categories, wave energy maximum and total wave energy in every wave cluster. Wave energy maximum is influenced with maximum wave height (H) and wave period peak (T_{peak}). The value total wave energy is depends on the successful crest at wave train at every wave number. Both of wave energy is calculated using the Equation 1;

$$E_{Hmax} = \frac{\rho g^2 {H_{max}}^2 T^2}{16\pi} \quad (1)$$

Whereas total Wave Energy Train E_{total} is calculated using equation 2.0 and as illustrated in Fig. 4.

$$E_{total} = \left(\frac{\rho g^2 H^2 T^2}{16\pi}\right)_{wave\ no.1} + \left(\frac{\rho g^2 H^2 T^2}{16\pi}\right)_{wave\ no.1} + \cdots \left(\frac{\rho g^2 H^2 T^2}{16\pi}\right)_{wave\ no.n} \quad (2)$$

E. Dynamics Shear Stress

The calculation of the bottom shear stress was using the following formula was used by [16] in his study in order to determine effective fetches and theoretical dynamics shear stress at the sediment from the previous study.

$$\tau_T = \tau_w + \tau_c \quad (3)$$

Where,

$$\tau_w = \frac{1}{2}\rho(f_{wr})U_w{}^2$$

$$\tau_c = \rho C_d U_c{}^2$$

where τ_T is dynamics shear stress for waves and currents, τ_w is the wave skin friction shear stress, τ_c is the current skin friction shear stress, f_{wr} is the rough bed wave friction factor, U_w is the depth averaged current speed and C_d is the drag coefficient by quadratic friction law. The results of Dynamics shear stress will be compared to erosion shear stress τ_e, from the previous study with the mud type sediment the erosion rate is 0.917 N/m² [17]. Current flow was measured and taken as an average of 0.04 m/s.

III. RESULTS AND DISCUSSIONS

Wave trains were generated by all type of boats across the Kemaman River in speed range between 7 – 28 knots. Refer to Table I where one days sampling of 23 boats were recorded whenever boats pass by the site at various speed.

Table I: Data sampling of boats at various speed

Boat type	Boat Plate	Boat speed	
		m/s	Knots
Speed boat	UNKNOWN	3.6	7.1
Passenger	TKM00035P	6.7	13.0
Speed boat	UNKNOWN	5.7	11.1
Type A	TRF981	3.3	6.5
Type C2	JHF90T	3.6	7.1
Speed boat	UNKNOWN	8.0	15.6
Type B	TRF1046	4.4	8.6
Passenger	TKM00035P	6.7	13.0
Type B	TRF1089	3.6	7.1
Passenger	TKM00029P & 35P	6.7	13.0
Type A	TFA332	3.6	7.1
Passenger	TKM00035P	5.7	11.1
Type A	TFA2646	3.6	7.1
Speed boat	UNKNOWN	10.0	19.4
Type A	TRF1092	2.9	5.6
Type A	TRF936	2.9	5.6
Passenger	TKM00026P	4.4	8.6
Type A	TRF1160	3.6	7.1
Speed boat	UNKNOWN	10.0	19.4
Speed boat	UNKNOWN	6.7	13.0
Speed boat	UNKNOWN	10.0	19.4
Type B	TFA2257	3.3	6.5
Type C	TRF1033	4.0	7.8

Fig. 3shows that gauge 3 has more average wave height than gauge 1 and 2. This imply that the depth water will have strong relationship to the wave energy induced by boat that not only depend on the speed, size and load of boat across the Kemaman River. Here the depth water will be more focused on the analysis of the wave energy and Dynamics shear stress on study area. Fig. 4 shows very low value of R^2 where 0.0035, 0.2332 and 0.227 at gauge 1, 2 and 3 respectively. That means, the data showed poor relationship to find the sustainability among speed (knots) and wave height (m). This due to the boat at high speed at some points creates the interference wave leads to turbulence water. In addition, dimension of boat is crucial affecting the wave height due to wake. This was found where difference dimensions with the same speed generates difference wave height.

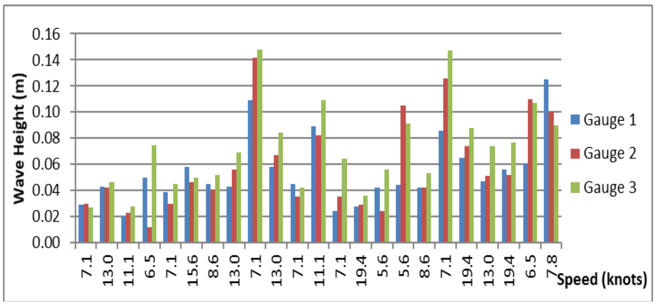

Fig. 3. Wave height and boat speed.

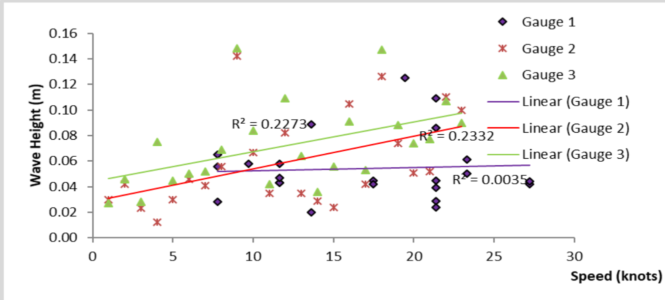

Fig. 4. Wave height and boat speed for three gauges.

Also when the crests and troughs of two sine waves of equal amplitude and frequency intersect or collide, while being in phase with each other, the result is called constructive interference and the magnitudes double. However when in anti-phase the result is destructive interference the resulting wave is the undisturbed line having zero amplitude [18]. The other factor is caused by superposition of waves whenever two Gaussian waves (or more) waves travelling through the same medium at the same time. The waves pass through each other without being disturbed. The net displacement of the medium at any point in certain time is simply the sum of the individual wave displacements [19].

Wave energy level induced by boat at Kemaman River is influenced by the wave height (H) and peak wave period (T_{peak}). Maximum energy level will be in high value when the wave in superposition or in constructive interference [18, 19]. The net displacement of medium at any point in certain time is simply the sum of the individual wave displacements. So, wave data wave height, H and wave period, T that captured by WLL is not so affected by the boat speed. Fig. 5 shows the high boat speed 16 knots not produce the maximum wave energy (J) but the speed at 8 knots can produces high energy.

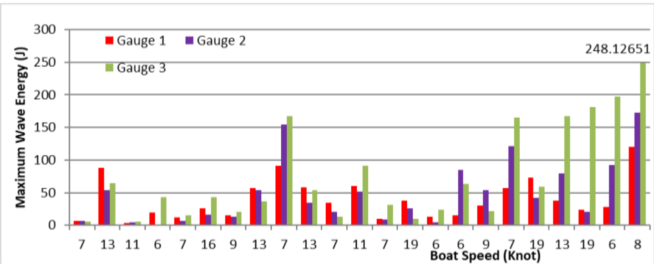

Fig. 5. Maximum wave energy and boat speed for three gauges.

Maximum energy produces increases with the distance from riverbank shore (see the difference values of maximum wave energy at gauge 1 and gauge 3). The response is variable when the shape of the offshore profile is less significant because of the depth of water become so relative to the energy produces.

According to [20] states that large vessel tend to generate large drawdown and small wave height, while small vessel, such as pleasure craft, generate small drawdown and large wave height. The size of boat doesn't determine the value of wave number. Even the small boat can produces the total of wave number more than the big boat. The wave number manipulates the total wave energy produce by boat when crossing the river. The wave train creates the repetition of wave oscillations that have many *H* and *T* value. Greater wave oscillation created will produces high value of energy total. Fig. 6 shows the relation of total wave energy and boat speed. The value of total wave energy produces in the one wave train per boat crossing at Kemaman River is not so affected by the boat speed. Difficult to state the speed wave at high throttle will get the total high energy.

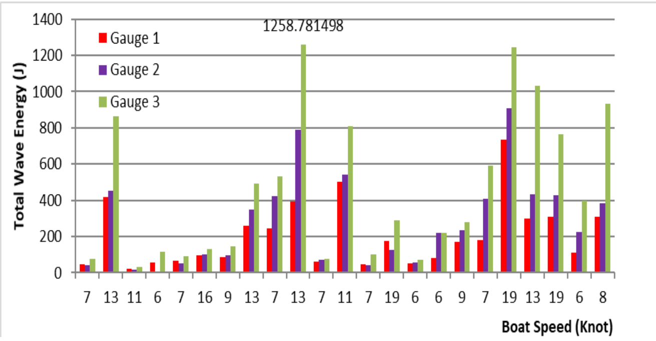

Fig. 6. Total wave train energy and boat speed for three gauges.

Fig. 7 shows a correlation (R^2 = 0.664) has been found between the total energy of the wave train and the energy of the maximum wave as calculated by equation below;

$$E_{total} = aE_{max}{}^{b} \quad (4)$$

Where a=9.3 and b=0.8

Using the equation, when energy of maximum in the wave train is finding from the boat wave wake, the value of total wave train energy will be easily obtain. This formula is valid only at Kemaman River for the depth water 0.1 meter until 1.8 meter and the boat speed is around 5- 30 knots for Fishing Boat and Passenger Boat.

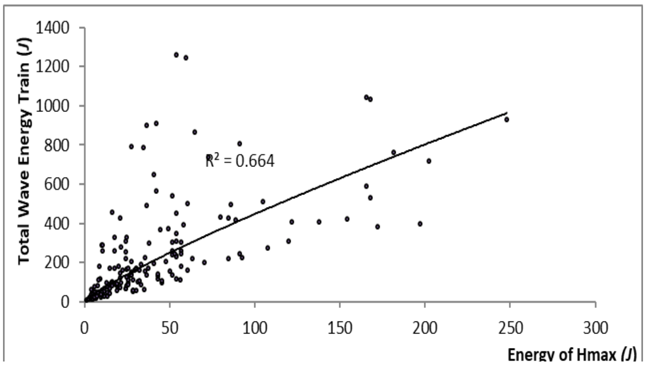

Fig. 7. Relationship between total wave energy train and maximum wave energy.

In analyzing boat wave wakes, the two parameters of maximum wave height and the corresponding wave period for the highest wave (often termed the maximum wave) have therefore been adopted as the primary measures. The relationship of total wave energy train and energy of maximum wave height give the information data to control the level of erosion occurs on the specific site. From the equation 4.0, when the wave height increase the total energy also will increase. That mean the wave height will be the determination of the level erosion. The importance of quantifying wave wakes with simple measures is critical when assessing small boat wave wake impacts. If the measures were complicated, statistically difficult to represent or costly to collect and collate, regulatory authorities may be reluctant to pursue a path of boating management through scientific understanding. So in this case, the wave wakes must be reducing to make sure the erosion can be lower.

Dynamics Shear Stress is the total of wave skin friction shear stress, τ_w and current skin friction shear stress, τ_c (refer equation 3.0). The erosion level will measure with Dynamics Shear Stress that induces by the wave boat and the current flow in the riverbed. Table II shows dynamics shear stress at sampling site. The Dynamics Shear Stress rate found from calculation is between 1.5 Nm^{-2} – 5.6 Nm^{-2}.

In geomorphic term it is the amount of wave energy and the rate at which this energy is transported towards the shore (i.e the ability of the wave to do the work) that is most important. Whether the wave energy is sufficient to overcome the resisting forces of the bank, causing erosion, depends on the wave period of wave and the energy in the wave relative to the resistance of the bank. Lake shore and river bank are sinks, dissipating oncoming wave energy. Where bank slope gently, the incident energy is dissipated, so that each unit area of bank receives only a small proportion of the total energy. Where the banks are steep the energy is focused over a much narrower surface area. Steep banks can also act like a wall interrupting the boat wave, so that even though critical break point conditions do not occur as they would in shallow water, the waves still break at the cliff face. The direct impact of the wave's i.e their normal force or pressure or the tangential shearing forces applied by the movement of the water i.e, from the waves breaking further from the cliff, may then be sufficient to erode a notch at the base of the cliff if the wave energy exceeds the resistance of the bank material [21].

Table II: Dynamics of shear stress, wave energy and boat speed

Type of boat	Boat plate	Speed (knots)	Wave Energy (h_{max}) Gauge 1(J)	Wave Energy (h_{max}) Gauge 2(J)	Wave Energy (h_{max}), Gauge 3(J)	Total dynamics shear stress, (Gauge 1) τ_{total} (Nm^{-2})	Total dynamics shear stress, τ_{total} (Gauge 2) (Nm^{-2})	Total dynamics shear stress, (Gauge 3) τ_{total} (Nm^{-2})
Speed boat	UNKNOWN	7.1	6.4	6.9	5.6	1.5	1.7	1.7
Passenger	TKM00035P	13.0	88.5	54.0	64.8	1.7	1.8	1.8
Speed boat	UNKNOWN	11.1	3.1	4.1	6.0	1.5	1.6	1.7
Type A	TRF981	6.5	19.1	1.1	43.1	1.7	1.6	2.2
Type C2	JHF90T	7.1	11.6	6.9	15.5	1.7	1.6	1.9
Speed boat	UNKNOWN	15.6	25.8	16.2	43.1	1.8	1.8	1.9
Type B	TRF1046	8.6	15.5	12.9	20.7	1.7	1.8	2.0
Passenger	TKM00035P	13.0	56.6	54.0	36.5	1.7	1.9	2.2
Cluster 9	TRF1089	7.1	91.0	154.4	167.7	2.4	3.2	4.0
Passenger	TKM00029P	13.0	58.0	34.4	54.0	2.1	2.1	2.6
Type A	TFA332	7.1	34.9	21.1	13.5	1.9	1.8	2.1
Passenger	TKM00035P	11.1	60.7	51.5	91.0	2.3	2.4	3.0
Type A	TFA2646	7.1	9.9	9.4	31.4	1.7	1.9	2.4
Speed boat	UNKNOWN	19.4	37.5	25.8	9.9	1.7	2.0	2.1
Type A	TRF1092	5.6	13.5	4.4	24.0	1.9	1.8	2.5
Type A	TRF936	5.6	14.8	84.4	63.4	1.9	3.3	3.1
Passenger	TKM00026P	8.6	30.4	54.0	21.5	1.9	2.0	2.5
Type A	TRF1160	7.1	56.6	121.6	165.5	2.5	3.3	4.7
Speed boat	UNKNOWN	19.4	72.8	41.9	59.3	2.4	3.0	4.7
Speed boat	UNKNOWN	13.0	38.1	79.7	167.7	2.2	2.6	4.1
Speed boat	UNKNOWN	19.4	24.0	20.7	181.6	2.4	2.7	4.7
Type B	TFA2257	6.5	28.5	92.7	197.3	2.9	4.7	5.5
Type C	TRF1033	7.8	119.7	172.3	248.1	5.9	5.5	7.0

The values of Dynamics Shear Stress are related to the energy level produce by the boat wave. Large energy level produces the high Dynamics Shear Stress. Refer to the Table II, the highest energy will produce the highest dynamics shear stress value. This relationship is depending on the wave parameter that influenced by wave height and wave period. High wave energy and wave period will produce the high energy event then effected to the dynamics shear stress value.

The total wave energy train is the combination of wave energy per oscillations in the cluster. The total energy train in cluster will produce more value of dynamics shear stress. The wave force will impact the bank surface in many times with the wave train repeated the oscillation of wave motion, that mean more wave number in the wave train more the energy will induce and contribute to erosion to river bank. This process not will effect in short period, but with the mostly boat passing the river in every day duty, the consequences will make the impact very high to the river bank, and last, the soil particle will move slowly. The soil particles have the strong flocculation (combination of silt, sand and clay) called mud. When boat across the river and create the wave, the water surface will construct the turbulence wave in form of energy. These phenomena will generate the kinetics energy and give impact of collision to the bank river that has the mud. With repeating impact due to the time, the flocculation bond among the soil particle will become not stronger because of water wave already separated combination of silt sand and clay. The silts and sand will easier to erode and bring this particle to the bottom river than clay that have median particle big than other. The research along the Kemaman River, wave heights and erosion potential will therefore be greater where the channel is confined. Although the results of the wave skin friction shear stress study are highly site specific, a number of general comments can be made regarding the potential for wake induce erosion. As already discussed, the pressure distribution and the resulting height of waves generated by a vessel passing, over a water surface depends on the clearance between the hull and the channel side bottom. According to [22], for a given vessel hull form and speed, pressure variations and wave heights increase as the water depth decrease. If water depth remains constant, wave height will increasing with the increasing speed assuming the vessel does not plane (i.e, skim the water surface).

Wave shear stress and maximum wave–current shear stress values were calculated with the wave–current skin friction shear stress which is based on the wave height (H), wave orbital velocities (U_w) and the wave period (T). In the fluvial part of the estuary, all boat across the river occurred unevenly during the surveys and were characterized by long waves ($T > 114$ s) induced by the drawdown effect and by short boat-waves ($T < 8$ s). Boat waves generated large dynamics shear stress values of 0.5 Nm^{-2} for 2–5 min periods and, in burst of several seconds, larger bottom shear stress values up to 1 Nm^{-2}.

The action of wave and the current may be sufficient to cause surface erosion, with material passing directly into suspension. From previous experiment by [17] with natural mud bed have shown that wave actions erode mud of a given dry density at about the same peak shear stress as that required with unidirectional flow. The erosion rate of a mud bed was found to the proportional excess shear stress relationship for current induce erosion by using Equation 3. The critical erosion shear stress (τ_{ce}) followed in the previous study by [17] for mud bed is 0.917 Nm^{-2}. The dynamics shear stress by total boat wave and current flow is between 1.5– 5.6 Nm^{-2}. So the critical value for the erosion rate is very high due to the boat wave and current that mean the erosion occurs on the bank river at the Kemaman River Estuary. The flocs on the surface of a cohesive sediment bed are bound together by inter-particle attractive forces. To remove flocs by flowing water requires a dynamics shear stress sufficient the attractive force. The critical erosion shear stress (τ_e) of a cohesive sediment surface is defined as the shear stress required to be exerted by the flowing water to cause erosion of flocs. Once the threshold has been exceeded then the rate at which sediment is eroded from the bed becomes the important factor determining how much erosion of the bed takes place in a particular time or by how much the sediment concentration will increase in the water column. Fig. 8 shows the rate of erosion and the Dynamics Shear Stress happen at study area.

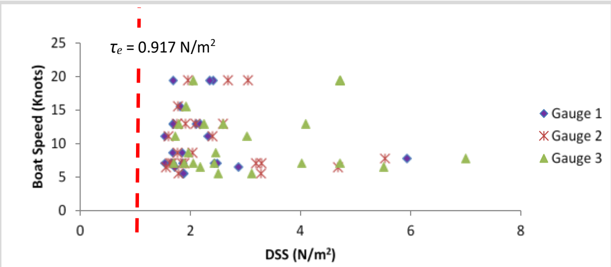

Fig. 8. Dynamic shear stress data for three gauges.

IV. CONCLUSION

The relationship between dynamic shear stress and wake boat waves energy with the erosion of riverbank has been studied. It was found that the maximum energy from wave train depends on wave height and wave period peak. Wave height is potentially greater where there are gently sloping profiles because the depths are less. So, the depth has general trend between producing the wave height and the influence the value wave energy.

Dynamics shear stress increases when the maximum wave energy is high. The value of dynamics shear stress induced by the boat also affected by the water depth. The decreasing of water depth will create a high value of shear stress. Riverbank will be affected more from the erosion during low tide. The data from the research is valid only in shallow water environment (water depth < 1.5 m).

With the mud type sediment, the erosion rate from the previous study is 0.917 Nm^{-2}. Using the field experiment data, the energy of the entire wave train (not just the individual wave) was calculated for each passing boat. A correlation (R^2 = 0.664) has been found between the total energy of the wave train and the energy of the maximum wave.

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