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Equation Compliance of Tidal Range Calculation of Sama Tribe Method (MSS) on Ratio of Harmonic Constituent Amplitudes at Bitung Station

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Abstract

Measured tidal high water is the total number of developing tidal constituent harmonic amplitudes when the measurement takes place. In tidal range determination, the Sama tribe has a simple way to do so. Objective of this study was to prove the equation of tidal range calculation of Sama tribe method (MSS) on its harmonic constituent amplitudes. The verification was undertaken by the difference and ratio approach of six harmonic constituent amplitudes of Sya'ban over other Hijri months. The results showed that the ratio of amplitude difference of Sya'ban over other Hijri months on the total amplitudes were 33 % or equivalent with ΔLB/3 of the difference of high water in equation of MSS. Using the approach of amplitude ratio difference, the empirical equation of MSS could only be applied on the tidal range calculation in Sya'ban, and water range or Likkas Silapas (LS) calculation of MSS can be proved by using tidal harmonic constituent amplitude.

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***Keywords*:** tidal range; Sama tribe method; harmonic constituent amplitudes; Sya'ban; Hijri months.

1. Introduction

Sama tribe or Orang Bajo inhabiting eastern part of Indonesia (**Figure 3**) have their own way to set up the height of their house floor and fish trap construction [1], It is called Sama tribe method (MSS), and Gassala and Diegues called it Ethno-Oceanography [2]. Based on the MSS, the tidal measurement was performed at the day 15th of Sya'ban (nisfu Sya'ban). Tidal range or Likkas Silapas (LS in The Sama Language) was calculated using simple equation (Equation 1), utilizing the maximum high water or Likkas Boe Pasolon (LBp) and the minimum high water or Likkas Boe panggiri (LBn) in the second peak of tides (**Figure 1**). The Likkas Silapas (LS) was in range of the mean hightest water level (MHWL) value calculated using the equation of ICSM-PCTMS [3]. As shown below, the equation (1) showed that the LS calculation used the 1/3 (33%) of "Likkas Boe or the high water difference (ΔLB) of measured LBp and LBn values [1].

$$LS = LB_p + \frac{\Delta LB}{3} \qquad (1)$$

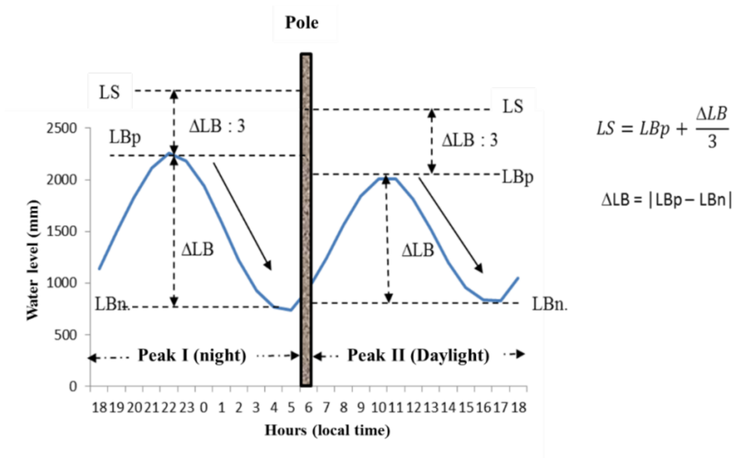

Figure 1: Illustration of tidal range with MSS

From the above cases there are two fundamentals in this study. *First*, the relatively similar number of LS and MHWL showed that the variation of high water (ΔLB/3) is a determinant of the measured tidal range of MSS in Sya'ban. This condition can be defined as the ratio of mean high water that represents the measured time, and it is possible to obtain new ratio measured in Hijri months. In this article, ΔLB/3 was further called ***Silapas Ratio*** (RS), and tidal range was the maximum amplitude resulted from subtraction of the maximum and minimum value of occurred tidal movement during a long term cycle (18.6 years).

Second, the new moon phase is always fixed in Hijri calendars, but variable in Gregorian calendars. Reference [4] calculated the amplitude of 10 main tidal harmonic constituents and reported that the deviation was small if the calculation was taken from the new moon phase (**Figure 2**). Specific cases were also observed if the data set of gregorian were started outside of the new moon phase that there was a positional change of harmonic constituent from high to small. It can be seen from the least mean square (**Table 1**) that the position of S_2 dan K_1

was changed if the data set was started from the full moon phase and quanter I (bold). If the starting data was started from the quanter II, then the position of constituent P_1 and K_2, and M_4 and MS_4 was changed.

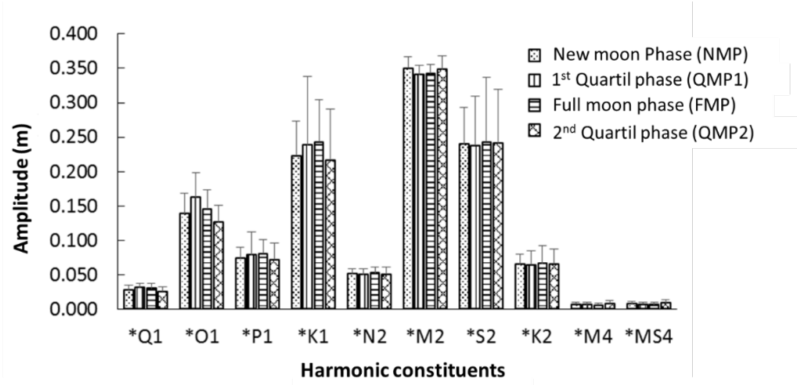

Figure 2: Mean amplitude of main harmonic constituent based on the starting tidal data of gregorian on the moon phase (second line)

Based on that two main case above, if the LS numbers are higher than the MHWL and harmonic constituent amplited values, there will be a possible relatioship of the two tidal calculation method ([1,4]). Objective of this study was to prove the equation of the sama tribe (MSS) in the tidal range calculation on its harmonic constituent amplitude. The equation 1 shall be explained by using the harmonic constituent amplitude where the LS is comprised of LBp dan ΔLB/3. LBp is the total accumulation of the tidal harmonic constituent amplitude of Sya'ban over other Hijri months, and ΔLB/3 is the silapas ratio which is the total variation of the harmonic constituent amplitude obtained out of Sya'ban.

Table 1: Least mean square of harmonic constituent amplitude variation on the starting data and moon phase based on Gregorian calendar.

Harmonic constituent	Moon Phase			
	NMP	QMP1	FMP	QMP2
$*M_2$	0.350	0.341	0.344	0.342
$*K_1$	0.221	**0.239**	**0.244**	0.216
$*S_2$	0.225	**0.238**	**0.234**	0.256
$*O_1$	0.140	0.162	0.145	0.128
$*P_1$	0.073	0.079	0.081	**0.071**
$*K_2$	0.061	0.065	0.064	**0.070**
$*N_2$	0.051	0.050	0.052	0.052
$*Q_1$	0.027	0.031	0.029	0.027
MS_4	0.008	0.007	0.006	**0.010**
$*M_4$	0.008	0.007	0.006	**0.009**

***=** Significant level, NMP = new moon phase; QMP 1 = first quarter of moon phase; FMP = full moon phase;

QMP2 = second quarter of moon phase.

2. Material and Methods

Tidal data was obtained from *University Hawaii Sea Level Center* (UHSLC) through downloading from website http://uhslc.soest.hawaii.edu/data/download/rq. The used data station was bitung station-Indonesia which is 01^o 26.4′ N and 125^o 11.6′ E (***Figure 2***). Main harmonic constituent was calculated using T-Tide [5], and it was also used to calculate the tidal range (6 constituents) based on the equation of ICSM-PCTMS (Intergovernmental Committee of Surveying and Mapping - Permanent Committee On Tides And Mean Sea Level) [3].

High Highest Water Level (HHWL) = MSL + (AM_2+AS_2+AK_2+AK_1+AO_1+AP_1) .... (2)

Mean Highest Water Level (MHWL) = MSL + (AM_2+AK_1+AO_1)... (3)

Where: MSL= mean sea level; AM_2= tidal amplitude influenced by the Moon's gravity to the orbit and alignment to the Earth's equator; AS_2= tidal amplitude due to solar gravitational effects to the orbit and alignment to the Earth's equator; AK_2= tidal amplitude influenced by the range change of Moon to Earth due to its elliptical orbit; AK_1= tidal amplitude influenced by the declination system of the Moon and Sun; AO_1= tidal amplitude influenced by Moon's declination and AP_1= tidal amplitude influenced by Sun's declination.

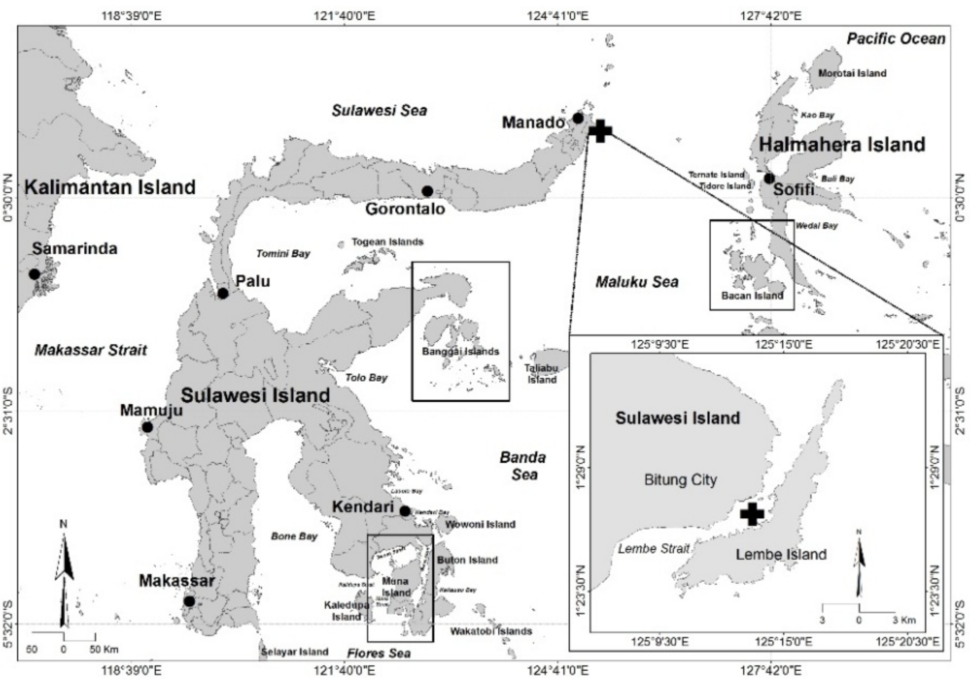

Figure 3: Map of data station and information sources about the Ethno Oceanography of the Sama Ethnic group in the eastrn Indonesia

Tidal range calcution of MSS referred to Hijri calendar system. In order to compare the values of amplitude ratio as verification, the equation (1) used the amplitudes of initial data set at full moon phase or corresponded to Hijri calendar. The variation can be found out as the following:

- Measured high water of MSS (LBp) is the sum of total main harmonic constituent amplitudes in Sya'ban (6 constituents)

$$\sum A_{Sya'} = AM_2+AS_2+AK_2+AK_1+AO_1+AP_1 \quad \text{.......} \quad (4)$$

- High water variation (ΔA) derived from out of Sya'ban (A_x)

$$\Delta A = A_{sya'} - A_x \quad \text{.......} \quad (5)$$

- Amplitude variation of each harmonic constituent (Ai) out of Sya'ban (A_x) is the difference of the same constituent amplitude on Sya'ban amplitude ($A_{sya'(i)}$).

$$\Delta A_{(i)} = A_{sya(i)'} - A_{x(i)} \quad \text{.......} \quad (6)$$

- The total of amplitude difference is the high water value (amplitude) which is influential to high water in Sya'ban

$$\sum \Delta A = \sum_{x=i}^{n} A_{(i)} \quad \text{.......} \quad (7)$$

- The ratio of high water is the total difference of high water out of Sya'ban over the the high water of Sya'ban (equation 7 and 4)

$$r\ (\%) = \frac{\Sigma \Delta A}{\Sigma A_{Sya'}}\ x\ 100 \quad \text{.......} \quad (8)$$

3. Results and Discussion

3.1. Harmonic Constituent Amplitude and Tidal Range Variation

Results of tidal harmonic constituent amplitude calculation from 83 Hijri month data are shown in **Table *2***. The lowest deviation was P_1, M_2, and K_2 (0.01m) and it was followed by O_1 dan K_1 (0.02 m). The maximum HHWL was 2.65 m indicating that the amplitude of equation 2 was in the maximum value. Harmonic constituents that contributed to the maximum HHWL were S_2 (0.30 m) and K_2 (0.08 m). It was greater deviation 2 times on the amplitude mean occurred in the Last Jumadil 1407 (February, 1987). Other constituents with greater number were M_2 (0.35 m), K_1 (0.22 m), P_1 (0.08 m), and O_1 (0.14 m).

Monthly mean amplitude with higher fluctuation was constituent S_2 and K_1, however, under the same number, it fluctuated greater compared to Hijri calendar (**Figure 4**). M_2 and O_1 which are the amplitude due to moon position effect, showed different pattern in both calendar systems. It was influenced by the effects of data set as all the data analyzed using T-Tide method in Hijri calendar was set under new moon phase [4]. The data set that was started at full moon phase generated that the least mean square of K_1 and S_2 was relatively similar. It also occurred at first quarter (QMP1). However, in second quarter (QMP2) the similar least mean square was found in the constituent P_1 dan K_2. Consequently, the amplitude variation was the tidal range variation that the HHWL and MHWL were 0.26 m and 0.13 m, respectively (**Table 2** and **Figure 4**).

Table 2: Maximum, minimum, mean and deviation of harmonic constituent amplitude and tidal range at bitung station.

Values (m)**	Harmonic Constituent Amplitude						Tidal Range***	
	*O_1	*P_1	*K_1	*M_2	*S_2	*K_2	HHWL	MHWL
Maximum	0.17	0.08	0.24	0.38	0.30	0.08	***2.65***	2.22
Minimum	0.09	0.05	0.16	0.33	0.17	0.05	2.39	2.09
Mean	0.12	0.07	0.20	0.35	0.24	0.06	2.53	2.16
Deviation	0.02	0.01	0.02	0.01	0.03	0.01	0.06	0.03

* = significant; ** data= 83 months; *** mean sea level (MSL) = 1.48 m

The data set of Harmonic constituent amplitude that was started at new moon phase was the most suitable with the Hijri calendar system [4]. The mean of M_2 in Sya'ban was the highest amplitude number (0.361 m) compared to other Hijri months (**Figure 4**A). The fluctuation of other amplitudes was far smaller compared to M_2. This was a common phenoma of tides in the equatorial as reported by [6,7,8].

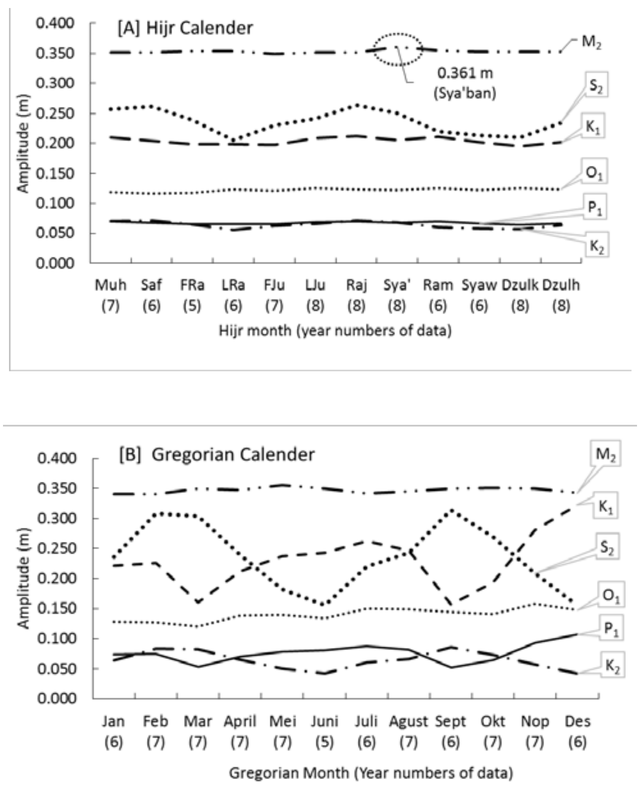

Figure 4: Distribution of mean amplitude of main harmonic constituent at bitung station for tidal range calculation based on Hijri calendar (A) and gregorian (B)

3.2. Variation of Measured High Water and Tidal Range of MSS

Number of month tidal data (92 data) obtained at day 15 of every Hijri month, it was found that the maximum high water (Hmax) ranged from 0.49 to 0.68 m and the minimum high water (Hmax) ranged from 49 to 0.68 m. The mean sea level (MSL) was 1.48 m, however, the mean high water of every Hijri month ranged from 1.46 to 1.50 m which was relatively similar to the MSL (±0.02 m).

The range of mean high water every month showed that the MSL can only be calculated with measured data for one Hijri month. The Hmax (LBp) were 2.32 m and the maximum tidal ranges were 2.65 m (**Table 2**). Consequently, the difference values of Hmax on HHWL were 0.32 m (**Figure 5**). This difference needed 0.32 m above of LBp, as, based on MMS, the number was derived from the silapas ratio (ΔLB/3) from equation (1).

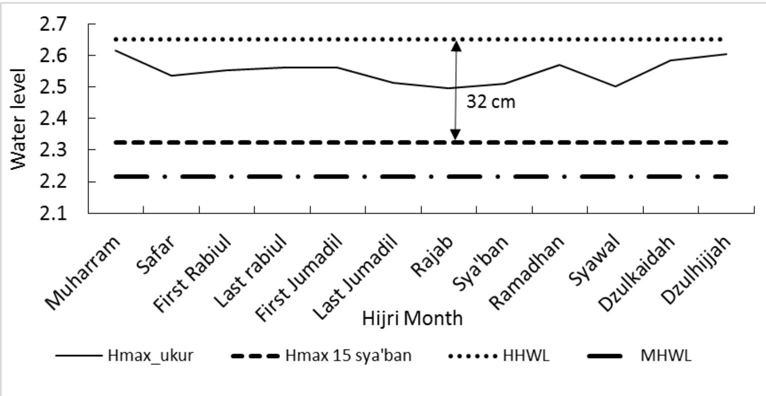

Figure 5: variation of high water on the tidal range in 15th Sya'ban

Principally the measured values of tidal movement are the total number of developing harmonic constituent amplitudes when the measurement takes place in which the harmonic analysis generate the amplitude values with the minimum number of data measurement are 15-29 days [9-11]. Therefore, the amplitude values resulted by each harmonic constituent are an optimum value to generate tidal range in the one period of monthly cycle.

Results of harmonic constituent amplitude calculation are shown in **Figure 4**A and **Table 3**. The highest total amplitude of six constituents occurred in Rajab (1.09 m).

The total amplitude in Sya'ban were 1.07 m, however, it was higher than the MSL. The mean of fluctuation of 6 harmonic constituent amplitudes in each Hijri month was relatively similar (0.01 m) except for S_2 (0.21 – 0.26 m). Based on the tidal calculation using Hijri calendar, this condition produced the tidal range which was greatly influenced by S_2, however, if the tidal range calculation (HHWL) used gregorian, the tidal range value were depended on K_1, S_2, P_1 and K_2. This indicated that variation of S_2 under Hijri calendar was high compared to other constituents.

In addition, variation of K_1, S_2, P_1 and K_2 in gregorian could be influenced by data structure which was variable in initial month [4].

Table 3: Mean and Difference of tidal harmonic constituent amplitude in each Hijri month at Bitung Station

Hijr month	Amplitude Constituent harmonic (meter unit)						Total
	$*O_1$	$*P_1$	$*K_1$	$*M_2$	$*S_2$	$*K_2$	
Muharram (7)	0.12	0.07	0.21	0.35	0.26	0.07	1.08
Safar (6)	0.12	0.07	0.20	0.35	0.26	0.07	1.07
First Rabiul (5)	0.12	0.07	0.20	0.35	0.24	0.06	1.04
Last Rabiul (6)	0.12	0.07	0.20	0.35	0.21	0.06	1.00
First Jumadil (7)	0.12	0.07	0.20	0.35	0.23	0.06	1.03
Last Jumadil (8)	0.12	0.07	0.21	0.35	0.24	0.07	1.06
Rajab (8)	0.12	0.07	0.21	0.35	0.26	0.07	1.09
Sya'ban (8)	0.12	0.07	0.21	0.36	0.25	0.07	**1.07**
Ramadhan (6)	0.13	0.07	0.21	0.35	0.22	0.06	1.04
Syawal (6)	0.12	0.07	0.20	0.35	0.21	0.06	1.01
Dzulkaidah (8)	0.13	0.06	0.20	0.35	0.21	0.06	1.00
Dzulhidjah (8)	0.12	0.07	0.20	0.35	0.23	0.06	1.04

*= significant level; parenthesis in Hijrih month is number of data year

Tidal range is a prediction of highest tide movement occurred during long term cycle that reach to 18.6 years [12-14]. This defined that there was one maximum tidal range value. As the amplitude variation was higher in georgion calendar, it was difficult to obtain maximum tidal range (**Figure 5**).

Table 4: Amplitude difference on the harmonic constituent in Sya'ban

Hijr moonth	Constituent harmonic (meter unit)						Total
	$*O_1$	$*P_1$	$*K_1$	$*M_2$	$*S_2$	$*K_2$	(absolut)
Muharram (7)	0.004	-0.001	-0.004	0.010	-0.006	-0.002	-0.001
Safar (6)	0.006	0.000	0.001	0.010	-0.011	-0.003	0.004
First Rabiul (5)	0.004	0.002	0.007	0.007	0.011	0.003	0.035
Last Rabiul (6)	-0.001	0.002	0.007	0.007	0.044	0.012	0.072
First Jumadil (7)	0.001	0.003	0.008	0.012	0.020	0.006	0.049
Last Jumadil (8)	-0.003	-0.001	-0.003	0.009	0.008	0.002	0.013
Rajab (8)	-0.001	-0.002	-0.006	0.010	-0.013	-0.004	-0.017
Sya'ban (8)*	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Ramadhan (6)	-0.003	-0.002	-0.006	0.006	0.030	0.008	0.034
Syawal (6)	0.000	0.001	0.003	0.008	0.037	0.010	0.060
Dzulkaidah (8)	-0.003	0.003	0.010	0.008	0.041	0.011	0.071
Dzulhijjah (8)	-0.001	0.001	0.004	0.008	0.015	0.004	0.032
Total (absolut)	**0.003**	**0.007**	**0.021**	**0.095**	**0.177**	**0.048**	**0.352**

* = amplitude reference (bold); (-) = amplitude values < amplitude values of Sya'ban amplitude; parenthesis in Hijrih month is number of data year

3.3. Amplitude Difference and Ratio

The amplitude difference of Sya'ban over other Hijri months from six constituents that determine the tidal range is shown in **Table 4**. The highest difference that is above Sya'ban was found in last Rabiul (0.072 m) and Dzulkaidah (0.071 m). Generally, the number of amplitude difference was positive, however, there were 2 negative-valued months found in Sya'ban that sum of the six constituent amplitudes was smaller than the total amplitude. Moreover, the S_2 (0.177 m) and M_2 (0.095 m) were the higher numbers than the other constituents. This described that the MSS application to measure the tidal range could only be applied in Sya'ban. The total amplitude differences out of Sya'ban were 0.351 m. This described that there 0.351 m amplitude needed to reach tidal range value. As the number of total amplitude and fluctuated harmonic constituent amplitude of Sya'ban were 1.07 m and 0.352 m, the needed percentage of high water to reach the tidal range was:

$$\frac{0.352}{1.07} x\ 100 = 32.893\ \% \Rightarrow 33\ \% = \frac{1}{3}$$

The tidal range calculation of MSS showed that there a conformity of percentage number with the denominator where the silapas ratio was of ∆LB/3. Total number of amplitude difference was 0.352 m (**Table 4**) which was almost close to the Hmax value (0.32 m) on **Figure 5** . It described that the silapas ratio was the high water representation out of measured time except for Sya'ban. 33 % of harmonic constituent amplitudes were the needed numbers of high water at day 15 of Sya'ban to reach the HHWL values in tidal range calculation using MSS. Likewise, the LB_P of the equation 1 was the total number of maximum amplitudes occurred in Sya'ban.

4. Conclusion

Based on the results found in this study, it can be concluded that: 1). There the same number use of 1/3 (33%) in tidal range calculation using the MSS and amplitude ratio difference. 2). Using the approach of amplitude ratio difference, the empirical equation of MSS could only be applied on the tidal range calculation in Sya'ban, and tidal range or Likkas Silapas (LS) calculation of MSS can be proved by using the tidal harmonic constituent amplitude.

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