ISSN 8755-6839

SCIENCE OF TSUNAMI HAZARDS

Journal of Tsunami Society International

Volume 33 Number 2 2014

IMPROVING EXPERIMENT DESIGN SKILLS: USING THE JOKO TINGKIR PROGRAM AS A LEARNING TOOL OF TSUNAMI TOPIC

Madlazim and Supriyono

Physics Department, Faculty of Mathematics and Science, Universitas Negeri Surabaya (UNESA), INDONESIA
e-mail: madlazim@fmipa.unesa.ac.id

ABSTRACT

Students are rarely given an opportunity to think deeply about experimental design or asked to develop experimental skills on their own. Without participating in these endeavors, they are often unaware of the many decisions necessary to construct a precise methodology. This article describes the Joko Tingkir Program as an Early Warning Tsunami, and how we have used this program as a learning tool for physics teacher candidates to improve their experimental design skills. The Joko Tingkir computer program has implemented a Tsunami Faulting Model (TFM). The TFM uses the principle that the tsunami is affected by the length and width of earthquake rupture. Both can be represented by the duration of rupture (Tdur) or Exceed 50 second duration (T50Ex) and the dominant period (Td). The TFM has been implemented by the Joko Tingkir computer program. When students are given a simple method using the Joko Tingkir program - such as the tutorial, observation of seismic station distribution, seismograms of the earthquake, equipment and software for this experiment, measurement of P time onset and determination of Tdur, Td and T50Ex - it allows them to focus exclusively on improving experiment design skills as indicated by significantly improved gain scores. Based on the gain analysis it can be inferred that the experiment design skills can be improved by implementation of Joko Tingkir Program as a Learning Tool of Tsunami Warning in the learning process

Key word: *Experiment design skills, rupture duration, exceed duration 50 second, dominant period, Joko Tingkir program.*

1. INTRODUCTION

Scientific inquiry is fundamental in conducting experimental science. Exposing undergraduate students to this process of inquiry can be challenging, especially when teaching courses that do not have an associated laboratory section. Many students are not familiar with how to develop a testable hypothesis or they may believe that they do not know enough about scientific methods to design an experiment. Indeed, student misconceptions and inaccuracies regarding randomization, sample size, and proper controls have been described at the college-level (Anderson-Cook and Dorai-Raj, 2001; Hiebert, 2007), at the graduate-level (Zolman, 1999), as well as in professional publishing in life sciences (Festing, 2003). However, by using a simple experimental measure, students can become engaged in the process of scientific inquiry and, in turn begin to think deeply about experimental design. As an example of the power of this approach, this paper describes how we have used the Joko Tingkir program for physics teacher candidates as a means to have them improve issues related to experimental design.

For pedagogical purposes, Etkina et al (2006) have classified experimental investigations that students perform in introductory courses into three broad categories: observational experiments, testing experiments and application experiments. When conducting an observational experiment, a student focuses on investigating a physical phenomenon without having expectations of its outcomes. When conducting a testing experiment, a student has an expectation of its outcome based on concepts constructed from prior experiences. In an application experiment, a student uses established concepts or relationships to address practical problems. In the process of scientific research the same experiment can fall into more than one of these categories. Etkina et al (2006) have identified the following steps that students need to take to design, execute and make sense out of a particular experimental investigation.

Some methods and applications are available and have been proposed and has been applied to determine the source parameters of earthquakes for a tsunami early warning system. Along with other parameters, seismic moment magnitude (*M*w) is found to be a good discriminant for many, past, tsunamigenic earthquakes but not for all them – particularly for the so-called 'tsunami earthquakes' which, by definition, cause larger tsunami waves than would be expected from calculated moment magnitudes, *M*w (e.g. Satake, 2002; Polet & Kanamori, 2009; Lomax & Michelini, 2011). The discrepancy for these earthquakes can be related to rupture at shallow depth where the parameter designated as "μ" can be a very low, anelastic deformation occurring by compression and uplift of sediments, or when the fault surface may be non-planar with splay faulting into the accretionary wedge (e.g. Lay & Bilek 2007) and as postulated for the great 2011 Tohoku-Oki tsunamigenic event Pararas-Carayannis (2013). One or more of these effects can result in an underestimate by *M*w of an effective *LWD* value by a factor of four or more, relative to the value needed to explain the observed tsunami waves (Okal 1988; Satake 1994; Geist & Bilek 2001; Lay & Bilek 2007; Polet & Kanamori 2009; Lomax & Michelini, 2011).

Several analyses of teleseismic, *P*-wave seismograms (30◦–90◦ great-circle distance; GCD), (Lomax & Michelini, 2009) have shown that a high frequency, apparent rupture-duration, "*T*0", greater than about 50 seconds forms a reliable discriminant for tsunamigenic earthquakes (Fig. 1). Lomax & Michelini (2009) exploit this result through a direct, duration-exceedance (DE) procedure applied to seismograms at 10°–30° GCD, to rapidly determine if the rupture duration "*T*0" of an earthquake is likely to exceed 50–55 seconds and thus be potentially tsunamigenic, and based on the analysis of seismic parameters Madlazim (2013) and with the present study, help explain why one earthquake event generates a tsunami, while another one does not.

In this study, we present improved experimental design skills by using the Joko Tingkir program as a Learning Tool of Tsunami Faulting Model (TFM) and by implementing a direct procedure for assessing potential tsunami generation (Lomax & Michelini, 2009; 2011; 2012, Madlazim, 2011; 2012; 2013). The method is based on combining rupture duration (Tdur) with a measure of the dominant period (Td) and a duration exceedance 50 seconds (T50Ex) as determined simultaneously by local velocity records of stations of the real-time early, tsunami warning system. Tdur, *T*d and *T50Ex* are simple to measure on observed, *P*-wave seismograms and can be related to the critical parameters rupture of length (*L*), width (*W*), slip (*D*) and depth, such parameters needed for assessing tsunami generation potential (Lomax and Michelini, 2011).

2. THE JOKO TINGKIR PROGRAM

Briefly, Joko Tingkir is a script program which calculates three parameters as indicators of a potentially tsunamigenic earthquake. These parameters are Tdur (Rupture duration), Td (Dominant Period), T50Ex, and the Products (Tdur*Td, T50Ex*Td), simultaneously. Tdur is associate/equivalent with the length of the rupture zone, Td is associated/equivalent with the width of the rupture zone and T50Ex is associate/equivalent with the length of the rupture zone (a better estimate than Tdur). The products are related with the area of the rupture zone and the Strength Scale of the earthquake source.

The Joko Tingkir Program can directly read the data from seismograms in mini-seed format by using the SeisGram2K software (http://alomax.free.fr/software.html), which is faster than reading seismograms in real time, without the need to first convert into other formats or SAC. The computational speed of determining the earthquake parameters is dependent on the amount of data processed. For example, if the amount of data that is being processed is related to the vertical components of 20 recorded seismograms by 20 stations, and then the time required by the Joko Tingkir Program to compute these parameters is approximately 18 seconds.

The output of the Joko Tingkir Program - in addition to mean values of Tdur, Td, T50Ex, Td * T50Ex - also provides values of Tdur, Td and T50Ex for each station, so that the user can evaluate whether Tdur, Td and T50Ex at each of the stations is valid and homogeneous when compared with the value Tdur, Td and T50Ex on most other stations. If the value Tdur, Td, T50Ex and Td * T50Ex are more than a critical value, then it can be implied that an earthquake is potentially tsunamigenic. Thus, by using the Joko Tingkir Program, an early tsunami warning could be announced in less than 5 minutes after earthquake occurrence, so that the public and the relevant civil defense agencies will have more time to prepare for evacuation of the coastal areas at risk. The last step is the plotting of the Joko Tingkir Program results, particularly the Tdur, Td, T50Ex, T50Ex*Td and Tdur*Td solutions and the decision making on whether a tsunami was generated or not can be obtained about 4 minutes after the earthquake occurrence (Fig. 1).

2a. The Joko Tingkir Program as a Learning Tool In Improving Experiment Design Skills

We used the above-described Joko Tingkir program as a Learning Tool for improving students' experimental design skills by enabling them to measure an earthquake's length of rupture and in developing a strategy to incorporate the findings into an experimental design. To accomplish this goal we implemented the Four Question Strategy (FQS), as described in the literature (Cothron et al, 1989; Science Pioneer), by applying it to the tsunami-warning problem. With this method, we can have the students explore the possible variations of a research topic before attempting to state a problem, write a hypothesis, and identify variable, constants and in setting control parameters. Students need a method that is tried and proven and then practice it to measure tsunami parameters several times before designing an original experiment of their own. The FQS is a skill that is guaranteed to strengthen with practice but is not likely to be mastered in any one session. Students can even apply the approach, but must be given simple materials with few variations

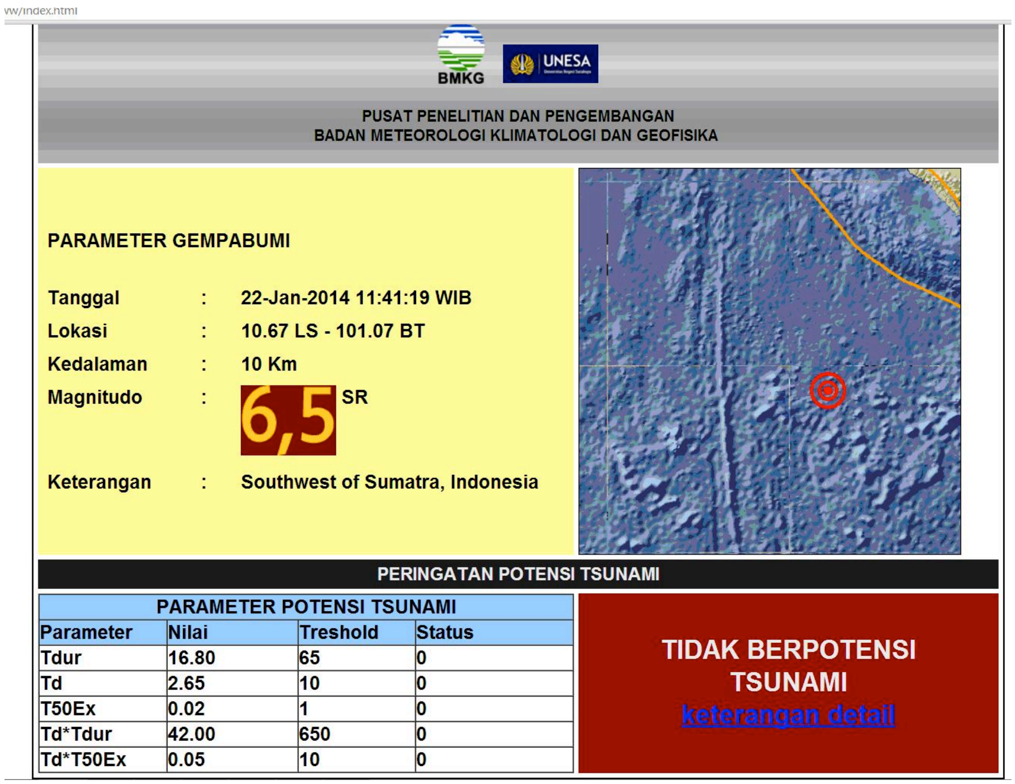

Figure 1. The Joko Tingkir real time system plotting result (Madlazim et al, 2014; Masturyono et al.; 2013).

.

The use and implementation of the FQS learning process requires four steps (Cothron et al, 19890:

Step one - the relevant question is: What materials are readily available for conducting experiments on the earthquake topic (e.g. tsunami) and then listing them in writing.

Step two - requires asking the question: How does an earthquake relate to a tsunami? One response is: an earthquake can generate A Tsunami. This step is the most difficult because children typically think actions are behaviors and in a sense, here we can say, "How does a tsunami behave?" However, with other physical or earth science topics, it may be more difficult to identify how relevant is a resulting disaster. For example, "How does a tsunami impact a coastline?" The point of this question is to focus on what tsunami actions/effects can be measured.

Step Three - In *Step Three* the question to be answered is: How can one measure, describe or evaluate the potential action of the tsunami or of the needed response? Some responses may include: *Measure the length of the longest earthquake rupture.* If students had difficulty with *Step Two*, going on to *Step Three* may make *Step Two* easier to understand. This is the data collection phase of experimental design. An important part of the question is: What can you measure? Linear measurement comes quickly to students. However, counting objects, frequency, time, volume, mass, etc. are other measurement options that might be more appropriate than linear measurements in an experiment. Another important point is that an experiment is not always contingent on actual measurements. Written descriptions are very acceptable. If a written description is the method of data collection, then time must be spent in teaching the students to be precise about the words they use. This part of the experiment is call the Dependent Variable, or how you can document change.

Step four - is the final step where brainstorming and creativity begin to evolve. It is here that students will identify the variables they will be testing in the experiment. Each tested variable becomes a different experiment. *Step Four* may be introduced by going back to *Step One*, which was to identify the materials needed to experiment with the topic. The question that needs to be answered is: How can you change the set of tsunami topic materials to affect the action or the impact behavior? It must be remembered that it is the action or the impact/behavior, which needs to be measured. At this point one must refer to the list of materials in *Step One*. If these are listed in a vertical column, they need to be placed as horizontal "column headlines". Exploring one material item at a time (i.e. length of rupture) - rather than skipping around - is better because the students remain focused.

After the students have exhausted the way they could vary this item, then they must move on to the next variable. The variable that will be deliberately changed or altered becomes the Independent Variable. All other listed variables (materials) must remain constant, because if more than one is altered; it will be too difficult to know which caused the change. As students increase their skills and sophistication, they can alter more than one variable or study different correlations. The control is the "set-up" that is not affected by the independent variable. It will not receive the same treatment. This set-up is the one that the others will be compared to. Having completed these tasks, the students are now ready to write their experimental question, purpose and hypothesis. The question contains two items: material (variable in *Step Four*) and how the change will be measured (*Step Three*). For example, if the independent variable is the length of earthquake rupture and the dependent variable is how the change in tsunami generation will be measured, the resulting question is: *Does the length ofrupture* affect *tsunami generation*? The hypothesis can simply answer the question: Indeed, the length of rupture affects tsunami generation. In the scientific method, the purpose is an expansion of the explanation (more explanation) of the hypothesis. What does one want to find out or what knowledge does one want to support? The procedure should be a sequence of steps the student will follow to find the answer to the question in order of fulfilling the purpose of his/her inquiry. Data collection strategies must be included in this part. Students must be discouraged from using transitional words for sequence. Having the students write the steps in sequence and by beginning each step with a verb will help them make the directions become more precise and clear. The material is a thorough list of items needed to complete the experiment. Thus, students must be encouraged to be very specific. The results must include data displays (i.e. charts, graphs, tables), and an explanation of what the data represents. It is also a good opportunity to have the students take notes that might explain along the way the effect of the outcomes. The final conclusion is an explanation of why the student researcher thinks he or she arrived at their results. This is the point when the researcher is better prepared to do further research on the question. In conclusion, the student should reflect on why the data did or did not support the hypothesis. This is also a good place to suggest the next steps the researcher might take to further explore the topic.

As stated earlier, further sessions in designing experiments are a skill that needs to be introduced in a simple manner and practiced frequently. The instructor may want to spend a session on one step at a time but if the students are familiar with the experimental design, one session of the four-step strategy may be enough to get them going. For a follow-up session, students as a group may be given a topic, which may be run through the described steps in order to reach a research question and a hypothesis.

3. METHOD

Students' performance was assessed by the administration of a diagnostic test for experiment design skills on the first and last day of control and experiment class; only students who took both pre-test and post-tests are part of the sample. The diagnostic instrument was the experiment design skills. This is the 13-item Liker-scale related to experiment design ability evaluation. The experiment design skills evaluation is almost entirely on a qualitative scale. The evaluation was adapted from Karelina and Etkina(2007) and Science Pioneers

(http://www.sciencepioneers.org/sites/default/files/documents/ Experimental Design vs ScientificMethod_0.pdf)
and modified to measure the students' performance. The test contained thirteen indicators with a maximum score of 52. The instrument was given for validation to four experts in physics education. The reliability of test was ascertained by control-testing it using a class of physics education students at Universitas Negeri Surabaya, Indonesia, which was not been included in the study but had similar characteristics as the sample classes. The reliability coefficient was calculated using that described in Kolen et al. (1996). This method is suitable when a performance scale can be scored. The reliability coefficient of the performance assessments instrument was 0.84 which rounds of to α=0.76.

According to Fraenkel and Wallen (2000), an alpha value of 0.7 and above is considered suitable to make group inferences that are accurate enough. On the pretest, students were given enough time to demonstrate their experiment design skills on a format that consisted of the 13 indicators. On the last day of class, the same evaluation was administered as a pos-test to assess experiment design skills after training by use of Joko Tingkir, as a Tsunami Warning Program treatment for both the control and the experiment class. The content used in class instruction was developed based on the revised 2011/2012 physics syllabus of the Physics Department, Mathematics and Science Faculty, of UNESA. A guiding manual was compiled for the lecturers in administering learning using Joko Tingkir as a Tsunami Warning Program for the purpose of improving the student's experiment design, used throughout the treatment period.

4. RESULTS AND DISCUSSION

The results of the pre-test scores on experiment design skills evaluation for both control and experiment classes showed statistically with significance 0.746 and > 0,05, respectively. The difference between the samples is regarded as not significant. This indicated that the two classes used in the study exhibited comparable characteristics as shown by Table 1 and Table 2. Therefore, the classes were suitable for the conduct of the study when comparing the results of learning using the Joko Tingkir Program as a learning Tool of Tsunami Warning and as a regular learning method on experiment design skills.

Table 1. Result of the Mann-Whitney Test

Ranks

	Class	N	Mean Rank	Sum of Ranks
pretest	Experiment Class	40	41,34	1653,50
	Traditional Class	40	39,66	1586,50
	Total	80		

Table 2. Result of the Mann-Whitney Test

Test Statistics[a]

	pretest
Mann-Whitney U	766,500
Wilcoxon W	1586,500
Z	-,324
Asymp. Sig. (2-tailed)	,746

Figure 2 shows that the average gain (gr) is smaller than the student individual gain (g) and that the students with low pre-test scores tend to have larger score improvements than the students of the experiment class, with high pretest scores. While the control class shows that the average gain (gr) is the greater than student individual gain (g), students with low pre-test scores tend to have either smaller or similar score improvement than students with high pre-test scores. Bao (2006) interpreted that he made inferences about how the experiment class of students has changed. For the traditional class, gr is greater than g; so that we can infer that students with low pre-test scores tend to have either smaller or similar score improvement than students with high pre-test scores. For the Joko Tingkir Program with FQS class, gr is smaller than g, so that students with low pre-test scores tend to have larger score improvements than students with high pretest scores.

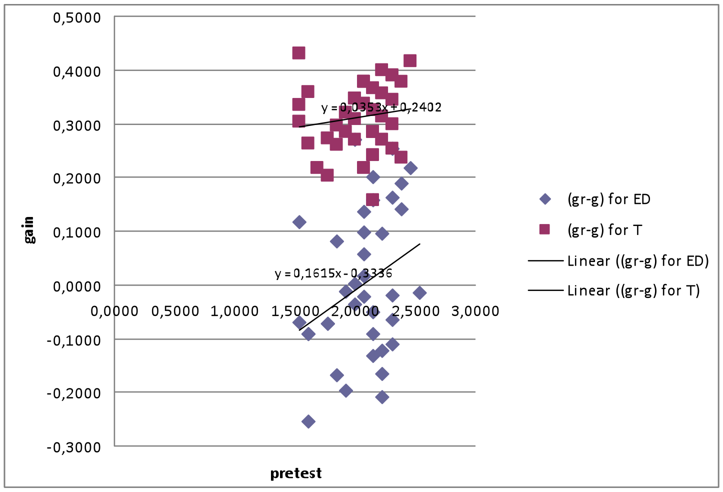

Figure 2. Y axis = (gr-g) versus pre-test (x) of control class (T) and experiment class (ED)

To analyze differences of the two means of the experiment and control class, post-test scores used the Wilcoxon W Test as shown in Tables 3 and 4 which show significance of (0.000) - less than 0.05. This indicates that there are significant differences in mean post-test scores between the experimental class and traditional class. Based on the mean (average), the average grade post-test experimental scores are greater than the average post-test scores of a traditional class. The results indicate that the students' experimental design skills are better than the students' traditional class.

Table 3. Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
posttest_ED - pretest_ED	Negative Ranks	9[a]	5,67	51,00
	Positive Ranks	1[b]	4,00	4,00
	Ties	30[c]		
	Total	40		
posttest_T - pretest_T	Negative Ranks	40[d]	20,50	820,00
	Positive Ranks	0[e]	,00	,00
	Ties	0[f]		
	Total	40		

Table 4. Test Statistics[b]

	posttest_ED - pretest_ED	posttest_T - pretest_T
Z	-2,489[a]	-5,515[a]
Asymp. Sig. (2-tailed)	,013	,000

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

The Joko Tingkir Program, when used as a Learning Tool for Tsunami Warning implementation, can improve experiment design skills for students, because it encourages them to demonstrate their ability with an expectation of an outcome. Students, who focus on investigating a tsunami phenomenon without having expectations of its outcomes, do not fare as well as the students who have such expectations based on established tsunami concepts or relationships – the latter being able to better address practical problems.

Furthermore, the use of the Joko Tingkir Program with FQS can encourage students to explore the possible variations of a research topic before attempting to state a problem, write a hypothesis, identify variables, constants and the needed control. Students need a method that is tried and used several times before using measures of tsunami parameters in designing an original experiment of their own. This finding is in good agreement with what is supported by the Cothron et al. (1989) reference.

A plot of average gain (gr) and individual gain (g) difference (gr-g) versus pre-test scores of the experiment class that using the Joko Tingkir Program with the FQS shows a strong positive correlation with regression (gr-g) = 0.1615 (pre-test scores) - 0.3336. A plot of average gain (gr) and individual gain (g) difference (gr-g) versus pre-test scores of the control class that uses traditional method (laboratory activity, using receipt laboratory and passive student), shows a positive correlation with regression (gr-g) = 0.0353 (pre-test scores) + 0.2402.

5. CONCLUSIONS

Based on the gain analysis it can be inferred that the experiment design skills can be improved by implementation of the Joko Tingkir Program as a Learning Tool for Tsunami Warning understanding.

ACKNOWLEDGMENTS

This work was supported by Unggulan Perguruan Tinggi (UNESA) Grants No.: 024.3/UN38.11-p/LT/2014, funded by the Islamic Development Bank (IDB). We thank Dr. George Pararas-Carayannis, of Tsunami Society International for editing sections of this paper to improve on clarity.

REFERENCES

Anderson-Cook CM, Dorai-Raj S (2001) An active learning in-class demonstration of good experimental design. J Stat Educ 9. http://www.amstat.org/publications/jse/v9n1/anderson-cook.html

Bao, L., (2006). Theoretical comparisons of average normalized gain calculations. Am. J. Phys., Vol. 74, No. 10, October 2006

Bilek, S. L. and Lay, T., 1999. Rigidity variations with depth along megathrust faults in subduction zones, NATURE, Vol. 400, 29 July 1999, www.nature.com

Cothron, J. H., Giese, R. N., & Rezba, R. J. (1989). Students and research: Practical strategies for science classrooms and competitions (2nded.). Dubuque, IA: Kendall/Hunt.

Etkina, E., Alan Van Heuvelen, Suzanne White-Brahmia, David T. Brookes, Michael Gentile, Sahana Murthy.

David Rosengrant, and Aaron Warren. 2006. Scientific abilities and their assessment. PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH **2**, 020103.

Festing MFW (2003) Principles: the need for better experimental design. Trends Pharmacol Sci 24:341-345.

Geist, E. and Yoshioka, S., 1996. Source Parameters Controlling the Generation and Propagation of Potential Local Tsunamis, NaturalHazards 13: 151-177.

Geist, E. L. & Bilek, S. L., 2001. Effect of depth-dependent shear modulus on tsunami generation along subduction zones, Geophys. Res. Lett., 28, 1315–1318, doi:10.1029/2000GL012385.

Hiebert SM (2007) Teaching simple experimental design to undergraduates: do your students understand the basics? Adv Physiol Educ 31:82-92.

Karelina, A. and Etkina, E. (2007). Acting like a physicist: Student approach study to experimental design. PHYSICAL REVIEW SPECIAL TOPICS - PHYSICS EDUCATION RESEARCH **3**, 020106.

Kolen, M. J., Zeng, L., & Hanson, B. A. (1996). Conditional standard errors of measurement forscale scores using IRT. Journal of Educational Measurement, 33, 129-140.

Lay, T., Kanamori, H., Ammon, C. J., Nettles, M., Ward, S. N., Aster, R. C., Beck, S. L., Bilek, S. L., Brudzinski, M. R., Butler, R., DeShon, H. R., Ekstrom, G., Satake, K. and Sipkin, S., 2005. The great Sumatra- Andaman earthquake of 26 December 2004, Science, 308, 1127–1133.

Lomax, A. & Michelini, A., 2009a. Mwpd: a duration-amplitude procedure for rapid determination of earthquake magnitude and tsunamigenic potential from P waveforms, Geophys. J. Int., 176, 200–214, doi :10.1111/j.1365-246X.2008.03974.x.

Lomax, A. & Michelini, A., 2009b. Tsunami early warning using earthquake rupture duration, Geophys. Res. Lett., 36, L09306, doi :10.1029/2009GL037223.

Lomax, A. And A. Michelini, 2011. Tsunami early warning using earthquake rupture duration and P-wve dominant period: the importance of length and depth of faulting, Geophys. J. Int. 185, 283-291, doi: 10.1111/j.1365-246X.2010.04916.x.

Madlazim (2013), Assessment of Tsunami Generation Potential through Rapid Analysis of Seismic Parameters Case study: Comparison of the Earthquakes of 6 April and of 25 October 2010 of Sumatra, science of tsunami hazards 1 (32),

Madlazim (2012a), Toward tsunami early warning system in Indonesia by using rapid rupture durations estimation, AIP Conf. Proc. 1454, pp. 142-145; doi:http://dx.doi.org/10.1063/1.4730707 (4 pages) INTERNATIONAL CONFERENCE ON PHYSICS AND ITS APPLICATIONS: (ICPAP 2011).

Madlazim, 2011a. CMT, Fault Plane and Rupture Duration for Earthquakes in Sumatra and Possibility of its Implementation for Tsunami Early Warning System, PhD Program of Technology Sepuluh Nopember Institute (ITS) Surabaya. Dissertation.

Madlazim, 2011b. Toward Indonesian Tsunami Early Warning System by Using Rapid Rupture Durations Calculation, Science of tsunami hazards, 4(30).

Madlazim, Bagus Jaya Santosa, Jonathan M. Lees and Widya Utama, 2010. Earthquake Source Parameters at Sumatran Fault Zone: Identification of the Activated Fault Plane, Cent. Eur. J. Geosci. 2(4), 2010. DOI:10.2478/v10085-010-0016-5.

Masturyono, Madlazim, Thomas Hardy, and Karyono. In the 3rd International Symposium on Earthquake and Disaster Mitigation (ISEDM), Yogyakarta, 17-18 December 2013.

Okal, E.A., 1988. Seismic parameters controlling far-field tsunami amplitudes: a review, Nat. Hazards, 1, 67–96.

Pararas-Carayannis, G., 2013. “The Great Tohoku-Oki Earthquake and Tsunami of March 11, 2011 in Japan: A Critical Review and Evaluation of the Tsunami Source Mechanism,” Pure and Applied Geophysics, pp. 1-22, 2013.

Polet, J. & Kanamori, H., 2009. Tsunami Earthquakes, in *Encyclopedia of Complexity and Systems Science,* p. 10370, ed.Meyers, A., Springer, New York, doi:10.1007/978-0-387-30440-3_567.

Satake, K., 1994. Mechanism of the 1992 Nicaragua tsunami earthquake, *Geophys. Res. Lett.,* **21**(23), 2519–2522

Satake, K., 2002. Tsunamis, in *International Handbook of Earthquake and Engineering Seismology,* pp. 437–451, eds Lee, W.H.K., Kanamori, H., Jennings, P.C. & Kisslinger, C., Academic Press, Amsterdam.