

## Validation of Tsunameter in laboratory environment

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Received 12 September 2016 ; revised 15 February 2017

In this work authors reports simulation of tsunami detection algorithm in MATLAB software, validation of tsunami detection system in a tank, qualification of tsunami detection algorithm in an automated test rig in the laboratory. It also discuss the results from tsunami detection systems on a tsunami event (12 September 2007) deployed in the Bay of Bengal.

**[Keywords:** Tsunami, DOPR, DART, automated test rig, detection algorithm.]

### Introduction

The word tsunami is of Japanese origin and means "harbour wave"<sup>1</sup>. The earthquakes, landslides, volcanic eruptions and explosions are some of the known causes of tsunami. The resultant tsunami surface waves can cause widespread damage to property. On December 26, 2004, a massive earthquake occurred under the Indian Ocean off the coast of Indonesia. The earth quake created a series of tsunami waves that caused great destruction and loss of life throughout the Indian Ocean basin.

The National Early Warning System for tsunami, storm and surges for Indian Ocean is established by Ministry of Earth Sciences (MoES), Government of India at Indian National Centre for Ocean Information Services (INCOIS), Hyderabad with active contributions from National Institute of Ocean Technology (NIOT), Project Directorate of Integrated Coastal and Marine Area Management (ICMAM), India Meteorology Department (IMD) and Indian Space Research Organization (ISRO)<sup>2</sup>. The Objective of this new establishment is to institute a mechanism to issue 'warning' and 'watch' advisories on a 24 X 7 basis for tsunami and storm surges.

In order to meet the above objective, systematic observations are planned with Deep Ocean pressure recorders (DOPR), tide gauges, seismic network and coastal high frequency radars. The schematic of the warning system is

described in the Fig. 1. NIOT has taken up the task of establishing the DOPR in 2005 as one of the project under national data buoy programme which presently operates data buoy network for time series measurements of metrological and oceanographic parameters. The development of DOPR involves integration of the three major instrumentations. In addition, the present work explains the validation carried out on these systems to qualify for sea deployment and operationalization.

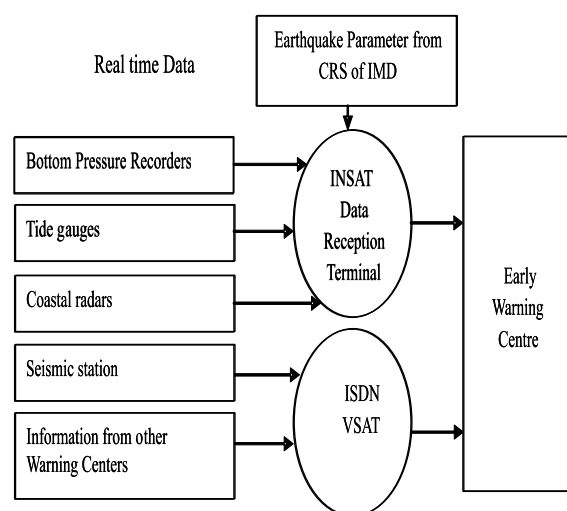
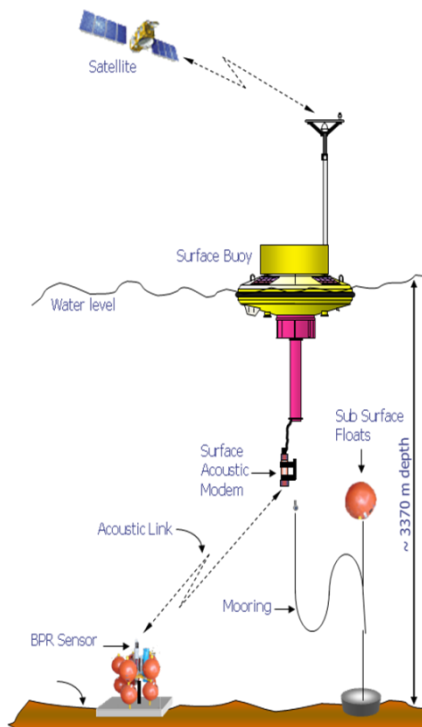


Fig.1. Tsunami early warning system schematic, India Meteorological Department (IMD), Common reporting standard (CRS), Integrated Services Digital Network (ISDN), very small aperture terminal (VSAT).

**Material and Methods**

*DOPR System*

The DOPR system is a standalone module located on the deep seabed making pressure measurements for tsunami wave detection<sup>3</sup>. When a likely tsunami event is detected, it starts transmitting the pressure values more frequently to a surface buoy, which in turn sends the data to the processing centre for experts to assess the data. The typical system is shown in the Fig. 2. DOPR consists of a high-resolution pressure sensor interfaced to a processor, which in turn is interfaced to an acoustic modem and release. Processor reads the hydrostatic pressure from the sensor and transmits it to the surface buoy through acoustic modem. Power is supplied from internal lithium batteries. An appropriate weight is attached below the frame to keep it anchored at the desired depth and position. Equipment and buoyancy floatation spheres are also mounted on the frame making it possible to retrieve the unit by issuing a release command to the acoustic modem and release. The weight is designed to be left out on the seabed on activation of the release. The pressure is measured periodically and an in-built algorithm searches for a tsunami event. If an event is detected, the DOPR starts transmitting pressure data to the surface in real time.



**Fig.2.** Typical tsunami detection system

*Indian DOPR systems*

The Project was initiated after the Indian Ocean Tsunami in 2004 and India took approach of procuring deep ocean pressure recorder from reputed manufactures (Sonardyne (UK), Envitech (Italy) and Oceanor (Norway)) and interface to the surface buoy system which is available with NIOT. All the three systems are identical in sensing element (Paroscientific pressure sensor, model 410E)<sup>4</sup>, sampling interval (one sample in every 15sec) and tsunami detection algorithm (NOAA’s DART algorithm) which is similar to the DART buoys<sup>5,6</sup>. The DOPR system measures water level at 1 mm resolution. During the normal mode the systems are programmed to transmit four pressure measurements which are averaged for 15 min interval to surface buoy and during event (tsunami) mode the data is update every 5 min for 180 minutes after the detection of the event. All the three systems are functionally same and are different is using their own acoustic communication equipment, internal hardware and mooring methods.

The DOPR developed for NIOT is deployed on the seabed has an in-built programme developed based on the algorithm developed by National Oceanic and Atmospheric Administration (NOAA)<sup>7</sup>. The pressure measurements are integrated over 15 seconds by the processing unit. A moving window average of consecutive 40 pressure values gives the 10 minute average of water level. Thus the first measurement occurs 5 minutes after the DOPR settles down on the seabed. The processor updates the average water level at every 15 seconds. The water level is predicted based on previous 760 water levels. Details of algorithm for prediction is given below in Equation (1)<sup>8</sup> (Fig. 3).

$$H_p(t') = \sum_{i=0}^3 w(i) H^*(t - i dt) \quad (1)$$

where  $H^*$  denotes 10 min averages and  $dt = 1$  hr. The prediction ( $H_p(t')$ ) time  $t'$  is set to 5.25 minutes, which is half the 10 minute averaging interval and the next pressure sampling interval (15 seconds). The  $w(i)$  is the coefficients from Newton's formula (II) for forward extrapolation. The  $w(i)$  is the coefficients for the above temporal parameters are:

$$w(0) = 1.16818457031250 \quad (2)$$

$$w(1) = -0.28197558593750 \quad (3)$$

$$w(2) = 0.14689746093750 \quad (4)$$

$$w(3) = -0.03310644531250 \quad (5)$$

A tsunami is detected if the difference between the observed pressure and the prediction  $H_p$  exceeds the prescribed threshold in magnitude (0.03 m).

The DOPR transmits pressure data at 5 min interval to the surface buoy through acoustic telemetry after detecting a tsunami event.

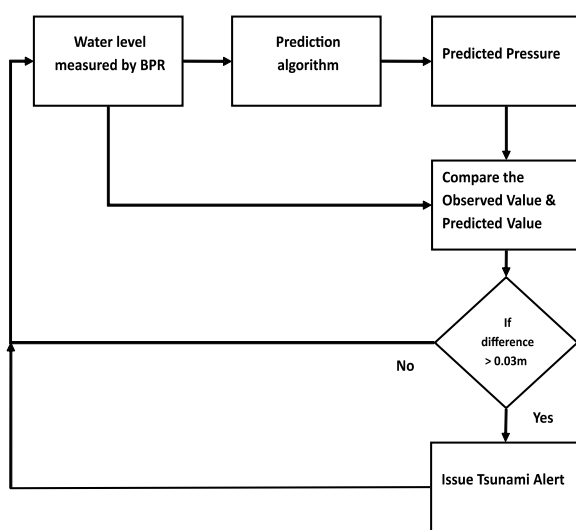


Fig. 3. Flow chart of tsunami detection algorithm

#### Laboratory scale validation technique

Tsunami meter, specially developed tsunami systems for NIOT are procured from three different vendors. Tsunami is an unpredicted disaster event. Hence, it is essential to validate these systems before deploying in the sea. The system needs to be checked for stability of the measurement and for the response to the detection algorithm. Following tests are carried out on the developed systems.

1. The stability and resolution determination test.
2. Response of the system to a sudden change in pressure.
3. Response of the system to a simulated tsunami wave.

The experiments are carried out at NIOT Acoustic Test Facility (ATF) tank which is about 8 m length, 6 m width and 7 m depth.

Laboratory testing of the tsunami detection system in deployed condition is a cumbersome task. A static pressure of 400 bar and 0.1 bar dynamic pressure variation about 0.1 bar with better than 0.01 mbar accuracy is required to test the system. In order to test the dynamic performance of the tsunami detection systems, an automated tsunami test rig is developed at NIOT and applied for patent<sup>9</sup>.

The test rig (Figures 4) is capable of simulating tsunami wave superimposed on 1000 mm tide. A few days of high resolution tsunami event recorded by tsunami detection system deployed by NIOT is the input to the test rig. The system calculates minimum value of the time series and removes static pressure from it. Modified time series is fed to an embedded controller that moves an underwater fixture with help of a stepper motor. Tsunami detection system is fixed on the underwater fixture and subjected to water column pressure.

The embedded controller takes feedback from an encoder to control motion of the underwater fixture. Test underwater ring can simulate sine and triangle type of long period waves. Graphical User Interface helps to load user files and control the test rig. A data logger records input to the test ring, its motion and an external RS232 input at every one second interval. Motion of the ring is monitored and controlled in real time. Test rig is power efficient to run for more than 5 hrs with a sealed maintenance free battery (47Ah/12V).



Fig.4. Tsunami test rig

*Testing of Tsunameter in the Ocean*

Tsunami detection systems are qualified at the laboratory before deploying in the sea. The laboratory qualified systems are deployed in the Bay of Bengal. Sea trials of these systems are started in 2006 and NIOT could install four working system (2 nos made by Sonardyne and 2 nos made by Envirtech systems) by October 2007 in (Fig. 5). Sonardyne systems are in TB10 & TB3 and Envirtech systems are at TB8 & TB5. Since October 2007 the DOPR systems along with other tsunami warning sub systems are operational. Performances of the systems are tested during tsunami event on 12 September 2007 due to an earthquake (magnitude 8.4 richer scales) in the Sumatran coast. The earthquake generated a tsunami wave of 30 – 40 mm magnitude.

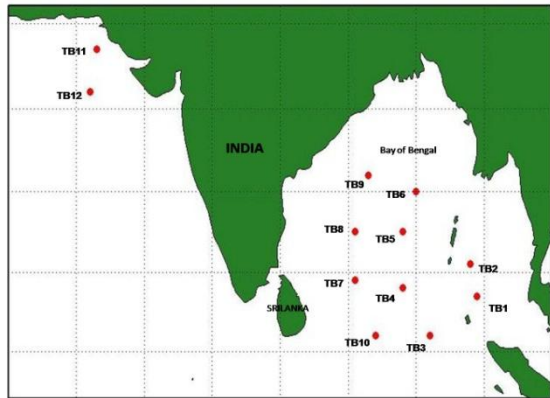


Fig.5. Position of DOPR installed stations, tsunami buoys (TB1-TB12).

**Results and Discussion**

The tsunami detection algorithm is simulated in MATLAB software. A sinusoidal of 1 m amplitude for about 12 hrs duration is generated in the software and a tsunami like pulse with 5 minutes duration is superimposed on the simulated tidal signal. The data is sampled at 15 seconds and above described algorithm is applied. Figure 6 shows the simulated studies carried out using MATLAB software. The residual as a function time is shown in the (Fig. 7) where a threshold of 30 mm is applied to detect on the tsunami event. Algorithm detected the tsunami event. This graph shows the tide with tsunami wave and the difference between the measured water level and predicted water level.

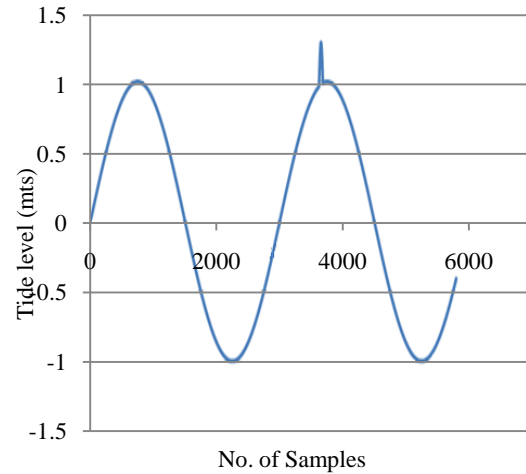


Fig.6 Simulation of tsunami wave on the tide

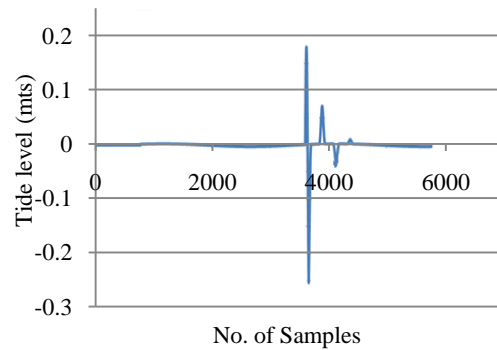


Fig. 7. The difference between predicted & simulated data.

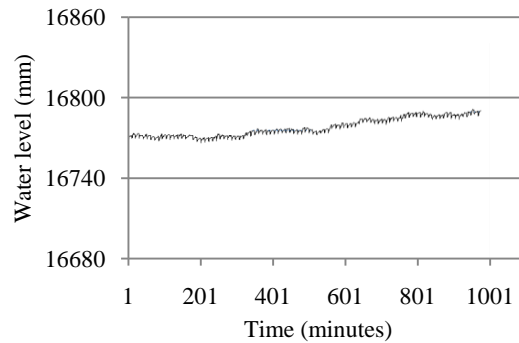


Fig.8. The pressure data during the stability test

The developed tsunami detection system is tested in the ATF tank. Figure 8 shows the variation in the pressure value when the system is deployed in the tank. The variation in the pressure is due to diurnal variation of air pressure. Pressure data from DOPR is recovered every one hour and the pressure value are corrected with air pressure data and found that data was stable. The stability and resolution

verification tests show that the system responds to small variation of pressure.

In order to check response of the system to an impulsive pressure level difference more than the threshold value, water level of the tank was reduced by pumping out a known quantity of water<sup>10</sup>. It is found that the system responded to the impulsive pressure level difference and state changed to tsunami mode. The response of the system is shown in Figure 9.

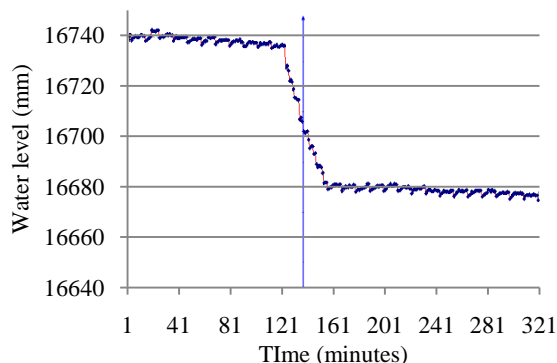


Fig.9. System response to the sudden change in pressure

The system response to slow variation in the pressure value is tested by creating an artificial wave slope equal slope of ocean tide. DOPR is attached to the crane in the tank and the DOPR is lowered and heaved with steps of 1 minute to create an artificial wave (Fig. 10).

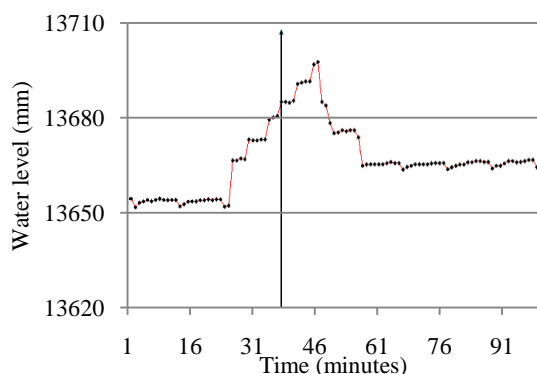


Fig.10. Response of the system to the simulated wave, tsunami event (blue line)

The tsunami detection System is tested in the automated tsunami test rig. A low frequency wave (1m peak to peak amplitude and 12 hr time period) is simulated in the test ring and validated the prediction algorithm. A pre-recorded tsunami event data is fed to the test ring after removing static values. It is found that the system detected the tsunami event.

The response of the designed system is recorded during 12th September 2007 tsunami in the Bay of Bengal. All the four systems states is changed into tsunami mode due to the Raleigh wave and three of the four systems TB10, TB8& TB3 have recorded tsunami wave (Fig. 11).

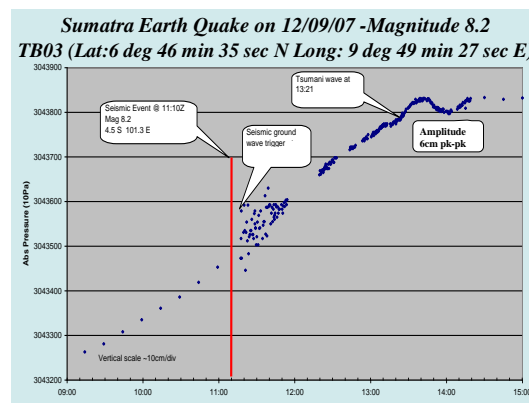


Fig.11. Tsunami detected by Indian network on 12<sup>th</sup> September 2007.

## Conclusion

The Tsunami detection algorithm simulated in MATLAB software for sinusoidal and step signals. The DOPR systems jointly developed NIOT and Sonardyne (UK), Envirtech (Italy) and Oceanor (Norway) is tested in ATF tank. The stability and resolution verification test show that the systems respond to small variation of pressure. We also demonstrated the usefulness of an automated tsunami test rig for qualifying the tsunami detection system in laboratory environment. The developed systems are installed in the field and detected tsunami event on 12 September 2007.

## Acknowledgements

The authors wish to thank Ministry of Earth Science for funding the work and staff of National data buoy programme for support.

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