Tsunami Early Warning System through Bottom Pressure Recorder and Data Transmission through Satellite Communication Network

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Abstract-

The Tsunami strike without warning and can damage life and property. The resulting damage can be minimized and lives can be saved if the people living near the coastal areas are already prepared to survive the strike. This can be done by employing a warning system wherein warning signal can be transmitted to different places using Satellite Communication Link. The Bottom Pressure Recorder detects greater water pressure when a passing tsunami increases the level of water above it. The surface buoy receives the transmitted information from the BPR via an acoustic link and then transmits the data through satellite link to Tsunami warning Station. The system doesn't try to find out the origin of the tsunami waves inside the sea but it generates an alert signal when the pressure level of sea water crosses a threshold.

Keywords-Tsunami, Tsunamigenic Source Region, Bottom Pressure Recorder, Real Time Data, DART, Satellite Communication Link, Tsunami Response Mode

I. INTRODUCTION

A tsunami is, along with strong motion, one of the two major disasters caused by earthquake [5]. A large tsunami may cause disasters along densely populated or built-up coasts and sometimes also by the inundation of low land areas, up to several km in land. Most tsunamis are generated by large earthquakes occurring in oceanic areas, and it is possible to estimate tsunami generation to a certain extent from seismic wave analysis. By taking advantage of the propagation velocity difference between the much faster seismic and the slower tsunami waves, it is possible to mitigate tsunami disasters by issuing tsunami forecast before the tsunami arrives at the coast, thus enabling evacuation and other countermeasures [7]. For other origins of tsunami, it is still difficult to quantitatively forecast tsunami generation until it is observed actually by the sea level change sensors.

II. COMPONENTS OF TSUNAMI EARLY WARNING SYSTEM (TEWS)

In general, a tsunami early warning system consists of the following constituents:

1. Seismic network (seismometers and real-time data transmission link)
2. Real-time seismic data processing system for hypocenter and magnitude determination
3. Tsunami forecast system (including warning criteria, assembling of the text, and dissemination)
4. Sea level data monitoring system (tide gauge /tsunamimeter and real-time/near real-time data transmission link)

Moreover the Tsunami warnings and schedule are clearly depicted in figure 1.

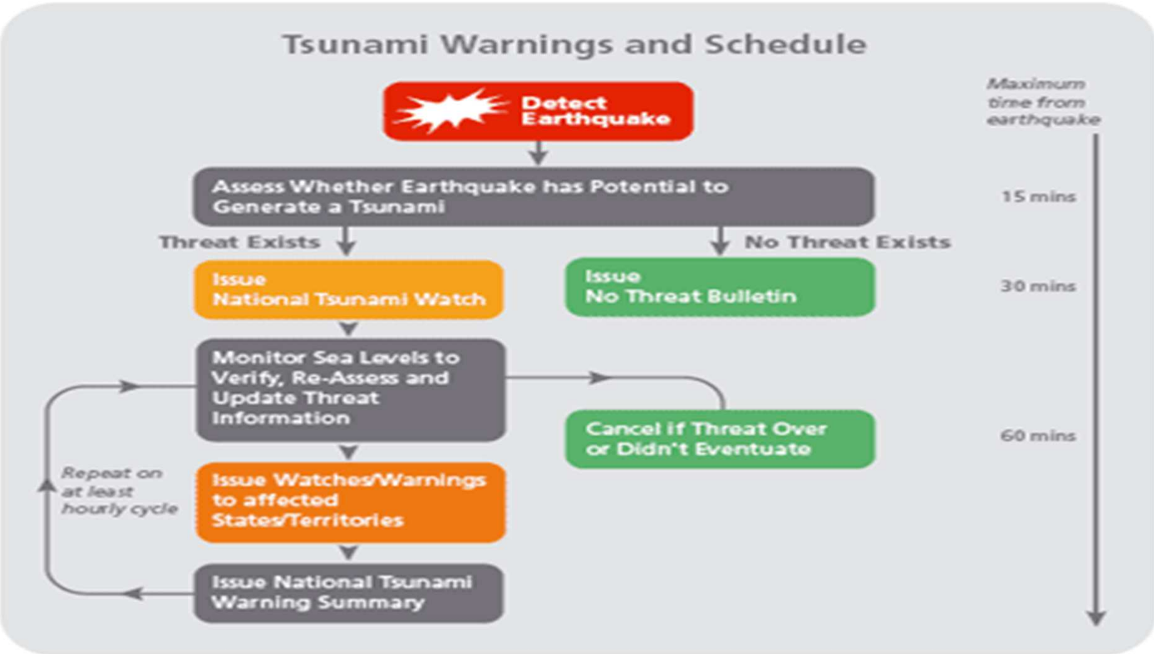

Figure: 1 Tsunami Warnings and schedule

III. BOTTOM PRESSURE RECORDER

The Bottom Pressure Recording (BPR) detects greater water pressure when a passing tsunami increases the height of water above it [9]. The surface buoy receives transmitted information from the BPR via an acoustic link and then transmits data through a satellite link to central stations.

Importance of BPR

From historical studies, it is clear that all earthquakes in tsunamigenic source regions cannot trigger tsunamis. In order to confirm whether the earthquake has actually triggered a Tsunami or not, it is essential to measure the change in water level in the open ocean with high accuracy in real time [2]. Bottom pressure recorders are used to detect the sea level changes near to tsunamigenic source regions and consequent propagation of Tsunami waves in the Open Ocean.

BPR Network setup

As part of the Indian Tsunami Early Warning System, a real time network of Deep Ocean Assessment and Reporting System has been established by National Institute of Ocean Technology (NIOT) [1]. The network is designed to detect measure and monitor tsunamis. The network comprises of 12 BPRs transmitting real time data through satellite communication to NIOT at Chennai and INCOIS at Hyderabad simultaneously for processing and interpretation. Each BPR is strategically placed at 30 minute and 60 minute tsunami wave arrival times (from hypothetical tsunami sources), so that they offer sufficient warning time and redundancy [3]. At the same time, they are far enough from the earthquake zone so that the tsunami wave signal can be clearly distinguished from the seismic Rayleigh wave. In addition to Indian BPR network, INCOIS is also receiving real time data from internationally coordinated networks like DART (Deep Ocean Assessment and Reporting Tsunamis) in Indian Ocean via Internet [6]. Currently, NIOT has deployed four BPRs out in Bay of Bengal and two BPRs in the Arabian Sea (Refer Figure 2).

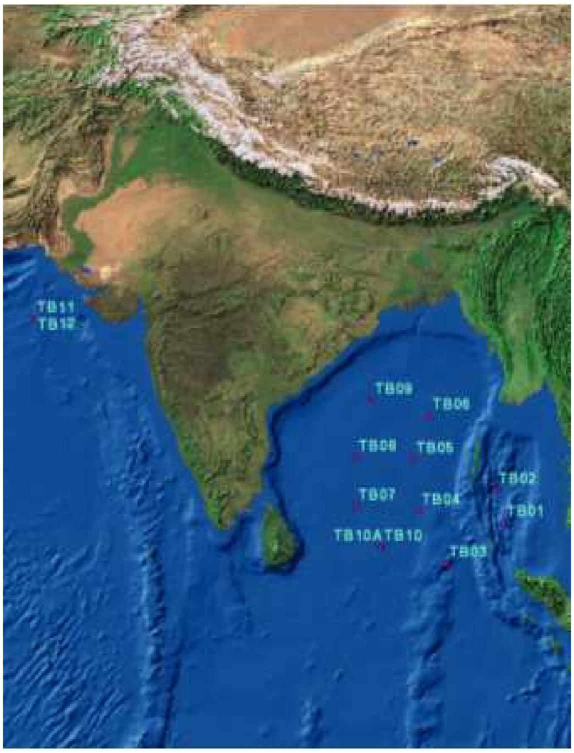

Figure: 2 BPRs in oceans surrounding India

BPR Configuration

Each BPR system consists of an anchored sea floor Bottom Pressure Recorder with acoustic link to a companion Moored Surface Buoy for real time communications and is designed to detect and report tsunamis if the pressure fluctuations are above a preset threshold. The BPR operates in one of two data reporting modes: a low power, scheduled transmission mode Normal mode, samples for every 15 min and transmits for every 1 hour and a triggered event mode called as Tsunami Response Mode, samples for every 15 seconds and transmits for every 5 minutes [4]. The BPR uses a piezoelectric

Pressure transducer to make 15 seconds-averaged measurements of the pressure exerted on it by the overlying water column. The Tsunami detection algorithm running in the BPR generates predicted water height values with in the tsunami frequency band and compares all new observed samples with these predicted values. If two 15-second water level values exceed the predicted values greater than the threshold (30 mm), the system will go into the Tsunami Response Mode [10] [8]. An acoustic link transmits data from the BPR on the sea floor to the surface buoy. The data are then relayed via a satellite (e.g. INSAT) communication finally to the Tsunami Warning Centre. Each BPR system has two-way communication link and thus able to send and receive data from Tsunami Warning Centre. The data center at INCOIS is equipped with state-of-the-art computing hardware for data reception, INSAT two-way communication hub, data processing & visualization and dissemination facilities [8]. The BPR can be accessed from warning center remotely at any point of time and perform the functions like trigger the BPR into tsunami response mode, inspecting the state of health, requesting the tsunami response mode data from BPR etc. The figure 3 demonstrates the schematic of TEWS.

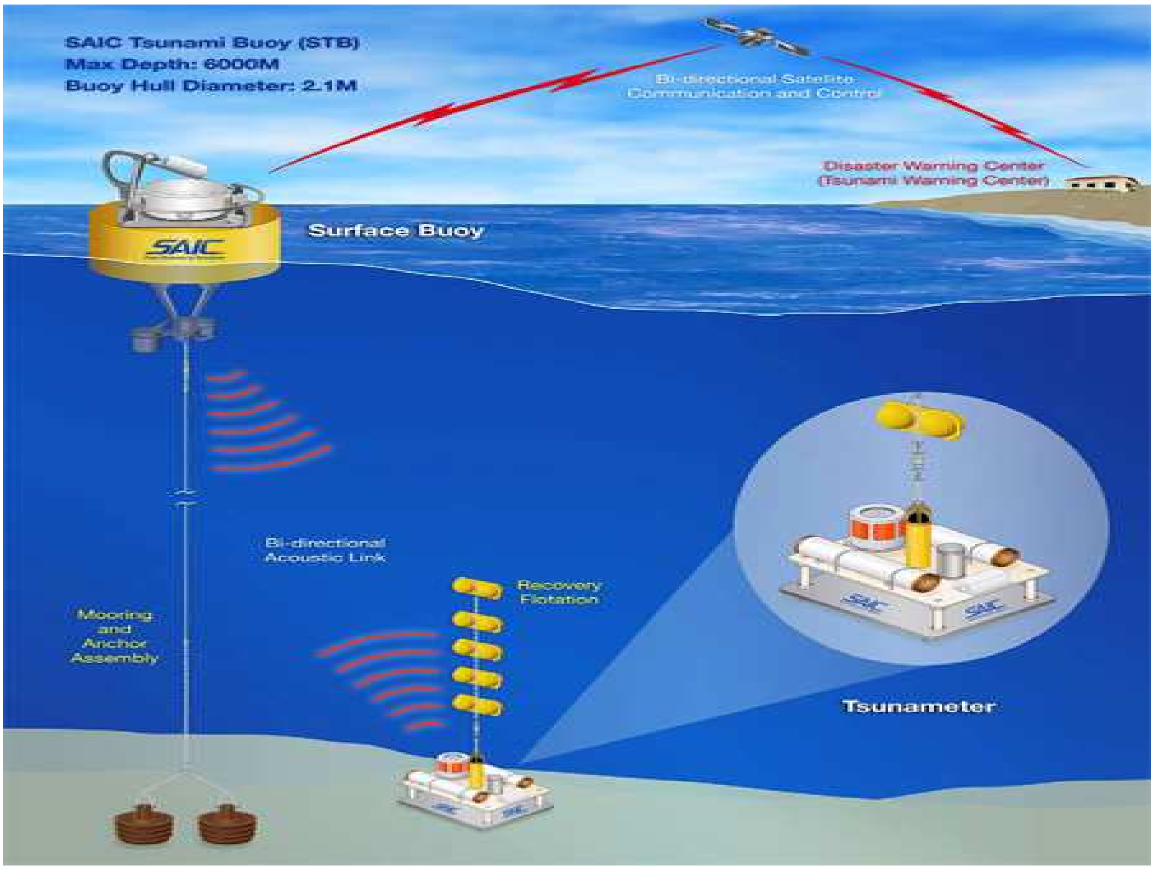

Figure: 3 Schematic Diagram of TEWS

IV. NUMERICAL SIMULATION OF TSUNAMI PROPAGATION

Non-linear long-wave approximation equation with advection term and ocean-bottom friction term is adopted as the equation of motion, and solved together with the equation of continuity as shown below by finite difference method with staggered leap frog scheme.

$$\frac{\partial Vx}{\partial t} + Vx\frac{\partial Vx}{\partial x} + Vy\frac{\partial Vx}{\partial y} = -fVy - g\frac{\partial h}{\partial x} - C_f\frac{Vx\sqrt{Vx^2+Vy^2}}{d+h}$$

$$\frac{\partial Vy}{\partial t} + Vx\frac{\partial Vy}{\partial x} + Vy\frac{\partial Vy}{\partial y} = fVx - g\frac{\partial h}{\partial y} - C_f\frac{Vy\sqrt{Vx^2+Vy^2}}{d+h}$$

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}\{Vx(h+d)\} + \frac{\partial}{\partial y}\{Vy(h+d)\} = 0\,,$$

where V_x and V_y are the x (east) and y (south) components of the average water particle motion velocity in the depth direction, and h and d are sea surface displacement and sea depth, respectively. f is the Coriolis parameter (= 2Ωcos θ, Ω is the angular frequency of Earth's self-rotation, θ is the co-latitude), and C_f is the sea bottom friction coefficient.

FUTURE OUTLOOK

In tsunami forecasting, trade-off exists between promptness and accuracy/reliance. It assure promptness of the first issuance of tsunami forecast, based on preliminary seismological results including that of EEW (Earthquake Early Warning), and its subsequent revision, if required, as soon as more accurate and reliable data such as sea level change, and the results of a more detailed complex data analysis have become available. And as for accuracy/reliability there are two ways to be taken. One is quicken the process of reducing the uncertainty of initial tsunami wave distribution assessments. Quick focal process inversion technique, new magnitude definitions applicable for gigantic or tsunami earthquakes and tsunami source inversion techniques using sea level data (also from satellite altimetry) will become effective for this purpose soon. The other way is very detailed numerical simulation, after reduction of uncertainties in the initial tsunami wave distribution, using fine bathymetry mesh data. Along with the development of integrated calculation algorithms, the improvement of the computer performance might solve this problem in future. But even then, due to the stochastic nature of tsunami behavior near the coast, one has carefully to examine on what statistical quantity of simulated results the tsunami forecast criterion has to be based.

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