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Freak waves off Ratnagiri, west coast of India

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Freak waves are relatively large and spontaneous ocean surface gravity waves whose heights are larger than the expected maximum wave height for a given sea state. Wave data collected off Ratnagiri, along the west coast of India during 1 January to 31 December 2011 using directional wave rider buoy at 13 m water depth is used to study the freak waves. Abnormality Index (AI), the ratio between maximum wave height and significant wave height, is used to identify and study the variation of the freak wave events off Ratnagiri. From the half hourly wave data covering one year period, 89 freak wave events are observed. The statistics built on these selected events suggests that maximum freak events (29 events) are during the rough SW monsoon and 20 events during the calm pre-monsoon season. Highest freak wave (wave height=6.9 m) is observed in July 2011. The Abnormality Index varied from 2 to 2.5 during the study period. Daily variations in number of freak wave events are associated with the interaction between sea-breeze generated random wind sea and swells propagating towards the study area.

[Keywords: Abnormality Index, Arabian Sea, Extreme wave, Rouge waves]

Introduction

Extreme wave conditions are one of the major factors affecting naval and civilian shipping and can damage the offshore oil platforms and coastal structures. Extreme wave condition can occur either by atmospheric (cyclones) or oceanic (wave-wave interation and wave-current interaction) conditions. One type of extreme wave condition produced in random oceanic water surface responsible for numerous marine disaster is the oceanic rogue or freak waves. Freak waves are relatively rare, large and spontaneous ocean surface waves whose heights are larger than maximum wave height expected for a given sea state. Freak waves have been observed all over the world ocean and their characteristics are studied in the Mediterranean sea, the Pacific, the Atlantic, and some parts of Indian Ocean. The rarity in the freak wave events and its high wave height can even lead to failure of offshore structures or ship accidents[1,2].

The generation of freak waves is not only restricted to open ocean, but also observed in the near-shore area, where these sudden waves cause damage to coastal structures and danger for small fishing boats. Such near-shore freak events are reported in the coastal zone of Taiwan[3]. Earlier studies were carried out on visually observed freak wave events in the near-shore regions[1] and on the development of freakish sea state due to the interaction between swell and wind sea[4]. Such high wave events in the Indian ocean are also reported[1]. Venkatesh[5] reported about freak waves hitting few boats at sea near Andhra Pradesh besides extreme waves such as Tsunamis and storm surges. The New Indian Express[6] reported from Sub Divisional Officer of Amini Island, as sudden huge waves at the accident location on 18 May 2013, which cause the boat mishap and kills 5. But the characteristics of freak waves in the near-shore regions of Indian subcontinent in the Arabian sea and Bay of Bengal is not studied. Hence, a study is carried out on the seasonal and annual variation of freak wave events at Ratnagiri located along the west coast of India.

Materials and Methods

The wave data collected from the near-shore region off Ratnagiri in the eastern Arabian Sea (Fig. 1) was used in this study. The study area lies along the west coast of the Indian subcontinent. North eastern boundary of the study area is covered by the Arabian Peninsula and the Persian Gulf. The gravity waves along the west coast of India depends mainly on the wind conditions prevailing over three different seasons; viz. South West (SW) monsoon or summer

monsoon (June-September), North East (NE) monsoon or post monsoon (October-January) and pre-monsoon or fair weather period (February-May)[7,8]. The wave climate is observed with high wave activity during the SW monsoon and relatively calm condition with long period waves prevails during the rest of the year[9]. The predominant direction of waves are W and W-SW during the SW monsoon, W and W-NW during the NE monsoon and SW during the fair weather period[10], with increasing trend in swell height towards the north[11]. The local wave climate at the near-shore region of Ratnagiri is influenced by the sea/land breeze system prevailing in the region during the pre[12] and post-monsoon season because of the weak seasonal winds[9].

Wave climate over the Arabian Sea in an annual cycle also depend on the swells arriving from far North-West Arabian Sea because of the north westerly Shamal winds during pre- and post-monsoon[13]and SW monsoon period[14].

Wave data collected using Directional wave rider buoy DWR-MK III[15] at 13 m water depth off Ratnagiri (16° 58' 48.3" N and 73° 15' 30.3" E) along the west coast of India during 2011, was used for the study. The wave rider buoy measures heaves in the range of -20 to +20 m and periods from 1.6 to 30 s, with a resolution of 1 cm in heave and cross sensitivity of less than 3%. The measurement of the wave direction using DWR-MK III is in the range of 0-360° and a resolution of 1.5°, and an accuracy of 0.5° reference to the magnetic north. Data were measured and recorded continuously at a frequency of 1.28 Hz for every half an hour from January 1 to December 31 in 2011. The collected time series were subjected to standard error checks for spikes, steepness and constant signals[16]. Wave spectra were obtained through Fast Fourier Transform (FFT) analysis. A FFT of 8 series, each consisting of 256 measured vertical elevations of the buoy data, were added to obtain spectra with a high-frequency cutoff at 0.58 Hz and a resolution of 0.005 Hz. The significant wave height (Hs), or $4\sqrt{m_0}$ was obtained from the wave spectrum. Where m_n is the n[th] order spectral moment and is given by $m_n = \int_0^\infty f^n S(f)df, n=0, S(f)$ is the spectral energy density at frequency f. The period corresponding to the maximum spectral energy (i.e., spectral peak period, Tp) was estimated from the wave spectrum. Zero-crossing analysis of the surface elevation time series was used to estimate maximum wave height (Hmax). We used Abnormality Index (AI), the ratio between maximum wave height and significant wave height[17], to identify and study the variation of the freak wave events off Ratnagiri.

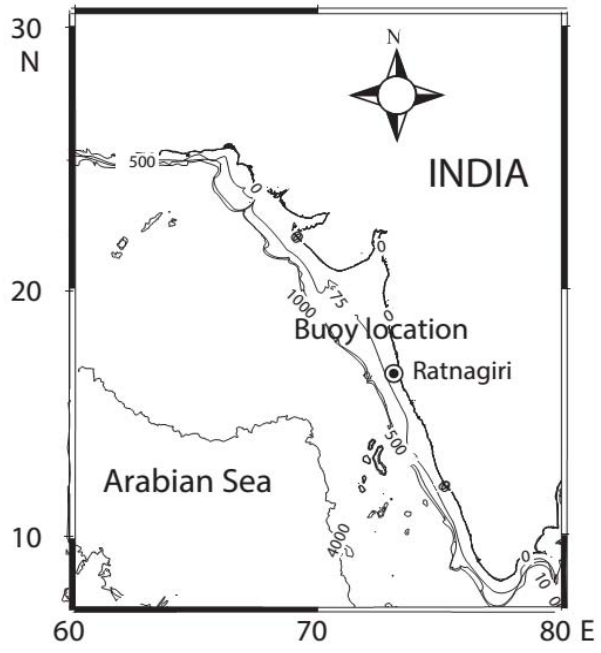

Fig. 1— Study region and wave buoy location off Ratnagiri. Depth contours are in meters.

Results and Discussion

Seasonal variability

Abnormality Index (AI) higher than two was used to identify the freak wave events off Ratnagiri. A total of 89 freak events (Table 1) were identified from a total of 16464 datasets of 30 minutes interval during

Table 1— Freak wave events during different seasons and annual variation in freak wave parameters

Seasonal and annual freak events			
Pre monsoon	SW monsoon	Post Monsoon	Annual
20	29	27	89
Annual maximum of freak waves			
Maximum significant wave height (Hs) in (m)	Maximum wave height (Hmax) in (m)	Maximum of Abnormality Index (AI)	Freak event (percentage)
3.2	6.9	2.5	0.46

the year. Number of freak events was observed throughout the year from January to December with a maximum of 14 events during the month of June and a minimum during April (2 events). Freak wave height (maximum wave height corresponding to freak events) varied between 0.6 and 6.9 m during the study period.

During the study period, five different types of freak wave events were observed (Fig. 2). In these freak wave types, most number (38) of the freak wave events (Table 2) observed were Type 3 (Table 2) and minimum number of freak wave events (3 events) are of type 2 (Table 2). Type 3 freak waves were the dominant freak waves in the coastal waters[18].

Freak wave events observed during the year was 0.46% of total wave events at the location. Maximum and minimum numbers of freak wave events were observed during the SW monsoon period and Post monsoon period (Table 1). The most dominant freak wave event was observed on 6 June 2011 with a freak wave height of 6.9 m (Table 1). During the period, significant wave height and the peak period corresponding to freak wave event was about 3.2 m and 11 s respectively. Maximum of Abnormality Index of 2.5 was observed on 12 July 2011 corresponding to a significant wave height and freak wave height during the period of 2.2 and 5.6 m, respectively. The Abnormality Index varied from 2 to 2.5 during the period. Most of high freak waves (45%) with maximum wave height more than 2.5 m occurred during the SW monsoon period and relatively small height during the rest of the season.

Diurnal variation of freak events

Hourly variation of freak wave events is discussed in this section. Analysis of hourly variation was studied in seasonal and in annual scale (Fig. 3). We used time scale in GMT/UTC (Universal Time Coordinates) to analyze these results. In daily cycle, maximum number of freak wave events was observed during the late hours of the day. Minimum number of freak events was observed during the early hours of the day in between 0600 and 1200 hrs. The number shows an increasing trend in freak wave events as time progresses and reaches its maximum at 1900 hrs. This trend was observed during the pre monsoon and post monsoon due to the interaction between sea

Table 2— Percentage occurrence of different types of freak wave events at Ratnagiri

Type of freak wave	Occurrence (%)
Type 1	26
Type 2	3
Type 3	38
Type 4	17
Type 5	5

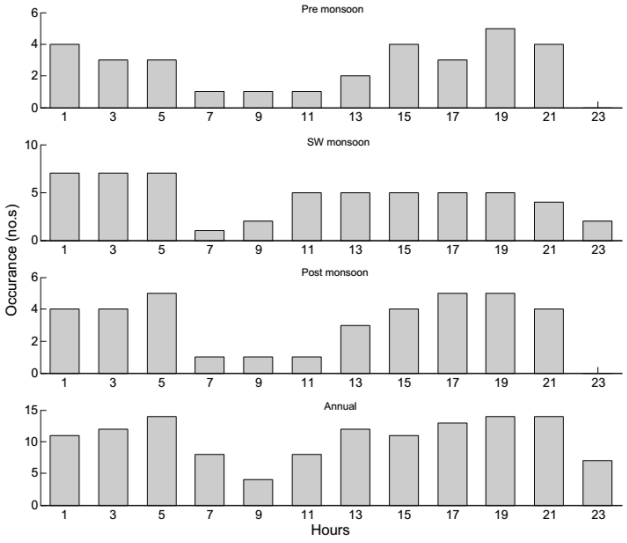

Fig. 3— Diurnal variation of freak waves in seasonal and annual scale at Ratnagiri. Time scale is in GMT

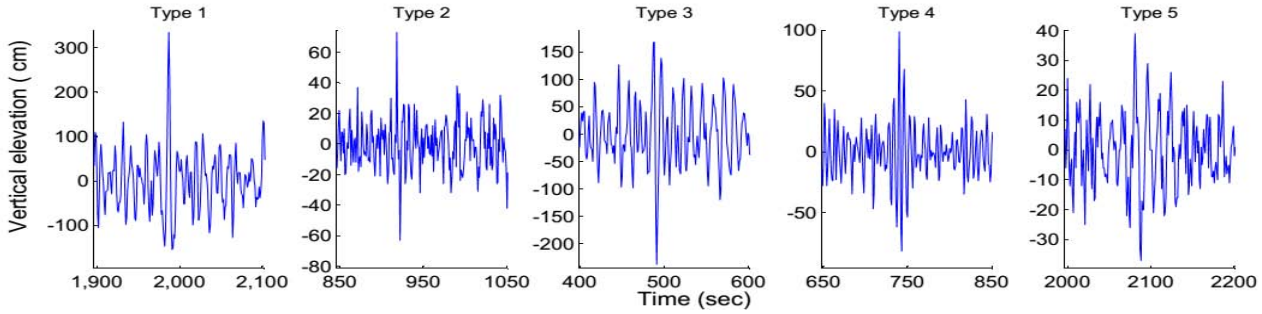

Fig. 2— Different types of freak waves occurred off Ratnagiri during 2011

breeze induced wind sea[9] at the location and swells propagating[9,13] towards the rough wave climate over the region[19]. During the SW monsoon season, variation in number of freak events were independent of the time because of the absence of locally prevailing sea breeze/land breeze system over the region[9] and depends on the rough wave climate produced by the strong SW monsoonal winds.

Conclusions

This paper provides the seasonal and annual variation of freak wave events and analysis of different types of freak waves in the near-shore region of Ratnagiri based on the wave elevations measured using Directional wave rider buoy at water depth of 13 m during 2011. The dataset contains 89 freak waves out of 16464 data sets which occur throughout the year during calm and rough conditions. Freak wave events were observed in five different types and maximum number observed was Type 3. The most extreme freak wave event was observed on 6 June 2011 with a freak wave height of 6.9 m. The Abnormality Index varied from 2-2.5 during the period. 45% of the freak events with maximum wave height more than 2.5 m were observed during the SW monsoon season. Daily variation in number of freak wave events were associated with the rough condition, which were produced by the sea-breeze generated random wave climate in the area.

Present study describes the seasonal and annual variability of freak waves events and its dependence on the rough condition and the sea-breeze at the study location. A detailed analysis is required to study the mechanism related to generation of freak wave events over the near-shore region of Indian subcontinent.

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