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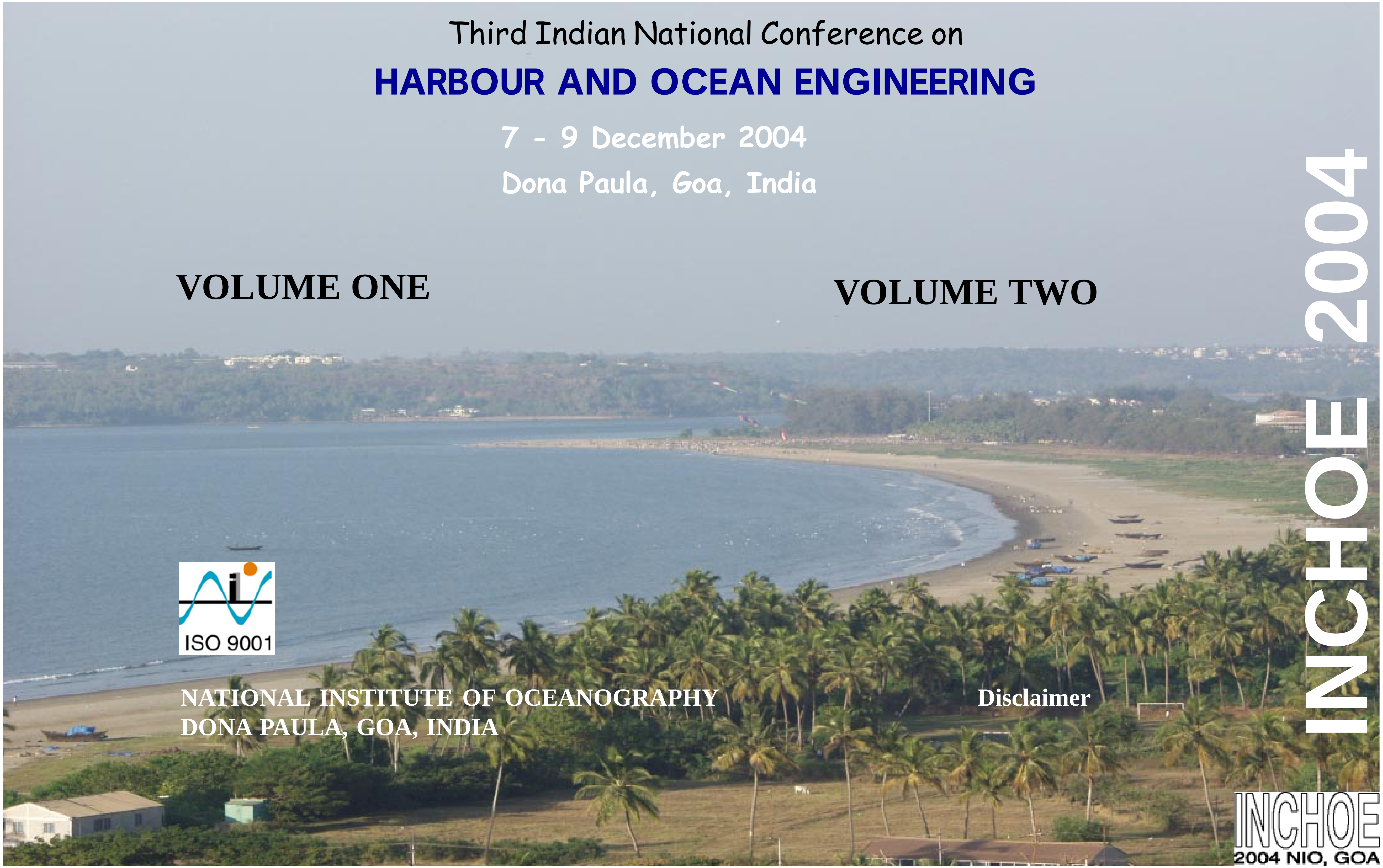

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Editors	Dr. S. Mandal,	Scientist, NIO, Goa
	Dr. V. Sanil Kumar,	Scientist, NIO, Goa
	Mr. S. Jaya Kumar,	Scientist, NIO, Goa

Editorial Assistance Mr. S.P. Sharma, Mr. Arun Y Mahale

Production Ms. Smita G Bhandari, Mr. Shankar Subhedar, Ms. Kirti A Naik

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FOREWORD

The last 25 years have seen a dramatic increase in development of coastal waters of India: enlargement of harbours and building of new ones; erection of offshore platforms; construction of pipelines; etc. A major jump in these activities occurred with growth in exploration for oil and gas in deep waters. During this time of increase in application of ocean engineering tools to the Indian coastal region, the series of Indian National Conferences on Ocean Engineering (INCOE) served as a place for the engineers interested in this field to meet, discuss current issues, and plan for the future. The first INCOE was held at the Indian Institute of Technology (IIT), Madras, in February 1981, the second at Central Water and Power Research Station (CWPRS), Pune, in 1983, the third at IIT Bombay in 1986, and the fourth at the National Institute of Oceanography, Goa in 1991.

Another platform that served a purpose similar to that of INCOE was the National Conferences on Dock and Harbour Engineering. These were held at IIT Bombay in 1985, at IIT Madras in 1987, and at KREC, Surathkal, in 1989.

In 1994, the two conferences were brought together to form the Indian National Conferences on Harbour and Ocean Engineering (INCHOE). The first of these was held at CWPRS, Pune, and the second at Centre for Earth Science Studies, Thiruvanathapuram, in 1997. The third, INCHOE2004, is being held at National Institute of Oceanography, Goa during 7-9 December 2004.

The proceedings of INCOE2004, with 103 papers, have been brought out in two volumes. They bring into focus India's contributions in the field of harbour and ocean engineering. Participation of international experts in INCOE2004 brings to the conference a wider perspective. It is hoped that the proceedings will serve as a document useful to scientists, engineers, academicians and planners interested in coastal development in general, and in activities along the Indian coastline in particular.

Dr S R Shetye
Director, NIO, GOA

3rd Indian National Conference on Harbour & Ocean Engineering,
NIO, Goa, December 7-9, 2004

MATHEMATICAL MODELING STUDY OF DESIGN PARAMETERS FOR SUBMARINE PIPELINE AT GULF OF KACHCHH

P. Chandramohan*, D.P. Rao and P. Senthil Pandi

Indomer Coastal Hydraulics (P) Ltd., Chennai.

Abstract

A study was undertaken to estimate the design waves along the proposed submarine pipeline corridor in Gulf of Kachchh. The software CEDAS was used for wave hindcast and design wave analysis. The synoptic information on past cyclones were derived from IMD reports. From the deep water waves, the design waves along the pipeline corridor were estimated using numerical wave refraction study.

1.0 INTRODUCTION

A submarine pipeline is being laid into the Gulf of Kachchh for receiving the crude oil from the offshore facility. The synoptic information during past cyclonic history were collected from India Meteorological Department and wave hindcast was done using the software CEDAS (Coastal Engineering Design and Analysis System, CERC, U.S. Army). The numerical wave refraction model was carried out for the wave propagation inside the Gulf of Kachchh and the design extreme waves were estimated along the pipeline corridor (Fig. 1).

Fig. 1. Study Area.

*Corresponding author, e-mail: ponpcm@yahoo.com

2.0 METHODS

2.1 Wind

The synoptic information corresponding to the occurrences of meteorological depressions, storms and severe storm during the period 1891-1998 were extracted from India Meteorological Department and the wave characteristics corresponding to above storm conditions were estimated. The characteristics of the wind field needed for the simplified wave prediction model are described in Weigel (1964). Using the pattern of isobars and spacing between isobars, the geostrophic wind characteristics were estimated using the meteorological dynamic equation *(Byer, 1959)*.

$$u_g = \frac{\alpha}{2\Omega \sin\phi} \frac{\delta\rho}{\delta z} \tag{1}$$

where, α = specific volume of air in m^3/kg; Ω = angular velocity of the earth in radian/s; ϕ = latitude in degrees; δp = pressure gradient of the isobar; u_g = geostrophic wind speed in m/s.

Fetch: The fetch has been defined subjectively as a region in which the wind speed and direction are reasonably constant. A coastline upwind from the point of interest always limits a fetch. Frequently the discontinuity at a weather front will limit a fetch.

Duration: Estimates of the duration of the wind are important for wave prediction. Computed results, especially for short duration and high wind speeds may be sensitive to differences of only a few minutes in the duration. In the present study, 12 hours wind duration was considered in the offshore region.

2.2 Model

The coastal engineering application model CEDAS developed by Coastal Engineering Research Centre, US Army Corps of Engineers, USA was used for hindcasting of waves. Sverdrup, Munk and Breitschneider proposed following equations in order to estimate the wave characteristics.

$$\frac{gH}{U^s} = 0.283 \tanh(0.0125\beta^{0.42}) \tag{2}$$

$$\frac{gT}{2\pi U} = 1.20 \tanh(0.077\beta^{0.25}) \tag{3}$$

and,

$$\frac{gt}{U} = 6.5882\exp\ [0.0161(1n(\beta))^2 - 0.3692\ 1n(\beta) + (2.2024)]^{1/2} + 0.8798\ 1n(\beta) \quad (4)$$

where, β = $\frac{gF}{U^2}$; H = significant wave height in m; U = wind speed in m/s; T = zero crossing wave period in s; t = wind duration in s; F = fetch in m; g = acceleration due to gravity in m/s^2.

The model CEDAS primarily solves the equations (2), (3) and (4) to obtain the significant wave height, zero crossing wave period and wave direction. The input for the model comprises of fetch length, gradient wind speed and wind direction. Based on the various synoptic information, a fetch length of 300 km was considered for wave generation. The output comprises of significant wave height, zero wave crossing period and wave direction.

2.3 Numerical wave refraction

The waves propagating in shallow water undergo changes in wave height, length, celerity and direction of propagation primarily due to wave shoaling, refraction and bottom friction. The numerical wave transformation model TARANGAM was used to carry out the study . For the calculation of wave height and direction due to wave refraction, Munk and Arthur (1952) have derived a second order homogeneous ordinary differential equation for the orthogonal separation factor (b) as,

$$\frac{d^2\beta}{dt^2} + p(t)(\frac{d\beta}{dt}) + q(t)\beta = 0 \quad (5)$$

where, p(t) = -2(cos q $\frac{dc}{dx} - \sin\theta \frac{dc}{dy}$) (6)

$$q(t) = c((\sin^2\theta \frac{d^2c}{dx^2}) - (\sin 2\theta \frac{d^2c}{dxdy} + (\cos^2\theta \frac{d^2c}{dy^2}) \quad (7)$$

ß = K_r^{-2} (8)

where, ß = wave orthogonal separation factor; K_r = refraction coefficient; t = time period in s; θ = wave direction in deg; x = distance along the coastline in m; y = distance perpendicular to coastline in m.

The refraction study was carried out for 4, 6, 8 and 10 s wave periods to represent three seasons, viz. southwest monsoon, northeast monsoon and fair weather periods. Based on the refraction study, the attenuated wave height and wave direction along the pipeline corridor were estimated.

2.4 Design waves

Based on the hindcast annual wave characteristics and storm waves, the design waves for various return periods were estimated using the model CEDAS. The extreme value analysis is done using Weibull statistical distribution as described in Ochi, 1982. Based on the distribution, the design waves were obtained for the return periods of 2, 5, 10, 25, 50 and 100 years.

3.0 RESULTS

3.1 Wind

The estimated wind speed shows that it prevails around 40 km/hour during southwest monsoon (April to August), 20 km/hour during northeast monsoon (December to March) and less than 10 km/hour in October and March. Strong wind prevails during southwest monsoon and it remains relatively calm during the rest of the year. The wind direction predominantly varies between 250° - 260° during May to October, 300° – 310° during November to February and 270° - 290° during March and April.

3.2 Hindcast waves in deepwater

The typical input for the wave hindcast model CEDAS *are:*

Table 1

Year	Month	date	Fetch (km)	Spacing between isobars (deg.)	Direction (deg.)
2000	01	01	300	4.5	310
2000	01	02	300	4.5	300
2000	01	03	300	5.0	300
…	…	…	…	…	…

Table 2

Year	Month	Date	Fetch (km)	Surface wind (kmph)	Significant wave height (m)	Zero crossing wave period (s)	Wave direction (deg)
2000	01	01	300	20.3	0.8	4	310
2000	01	02	300	20.3	0.8	4	300
2000	01	03	300	18.2	0.7	3	300
…	…	…	…	…	…	…	…

3.3 Annual wave climate

The estimation shows that the significant wave heights in deepwater predominantly prevail about 0.5 – 1.0 m from January to May and September, 0.5 m from October to December and

2 – 3 m from June to August. The zero crossing wave period varies around 4 s from November to March, 6 – 8 s from June to September and 5 s during the rest of the year. The wave direction predominantly prevails between 250° - 260° during May to October, 300° – 310° during November to February and 270° - 290°during March and April.

3.4 Storm generated waves

The occurrences of severe storms, storms and depressions in the vicinity of Gulf of Kachchh during 1891 to 1998 indicate that totally 111 events had occurred with 24 severe storms , 26 storms and 61 depressions. The extreme waves estimated using the model CEDAS for the reported storms are shown in Table 3. The estimation shows that the significant wave height up to 12.7 m can be generated during severe cyclonic storm. The most probable direction of waves during the cyclonic storm approaching the Gulf region will be between 260° and 270°.

3.5 Wave transformation

Based on the numerical wave refraction study, the distribution of attenuated wave height after refraction, shoaling and bottom friction for this 6 s wave period in southwest monsoon and northeast monsoon are shown in Figs. 2 and 3.

SW monsoon*:* The incoming waves having periods more than 6 s break before crossing the Mandvi region. The transmitted waves near the pipeline corridor exist around the same height of open sea waves for 4 and 6 s wave periods and around 0.5 times for 8 and 10 s wave periods. ***NE monsoon****:* During the northeast monsoon (October to January), the propagation of waves without significant attenuation was observed till the pipeline corridor. The wave heights near the pipeline corridor remain the same as incoming wave heights for 4 and 6 s wave periods ***FW period***: During fair weather (February to May), waves approach the pipeline corridor without significant reduction in height for 4 and 6 s wave periods. The wave height near the pipeline location remains as that of the open sea for 4 and 6 s wave periods. The divergence of wave orthogonals was observed for 8 and 10 s wave periods. The wave height at SPM location reduce to 0.5 times of the deepwater wave height for the waves more than 6 s wave period.

Storm period: During the storm condition the waves will arrive from the direction between 260° and 270° which will be similar to the wave direction during southwest monsoon. It was observed that in all seasons the wave heights at pipeline corridor remain as the same order of the open sea, for waves having period less than 6 s and get attenuated to 0.5 times for the waves exceeding 6 s. However, at 3 km west of the pipeline corridor, there appears to be a zone with high concentration of wave energy, wherein the wave heights increase higher than the deepwater wave heights during southwest monsoon and fair weather period. The waves propagating from open sea into Gulf get attenuated first at Lushington Shoal at mouth, then at

Gurur shoal opposite to Okha, again at Ranwar shoal off Mandvi and Chandri reef and finally at Nora Tapu. Except a part of the waves propagating through the deeper channel at the middle of the Gulf, the entire waves having period more than 6 s period are totally attenuated before approaching Mudwah Point.

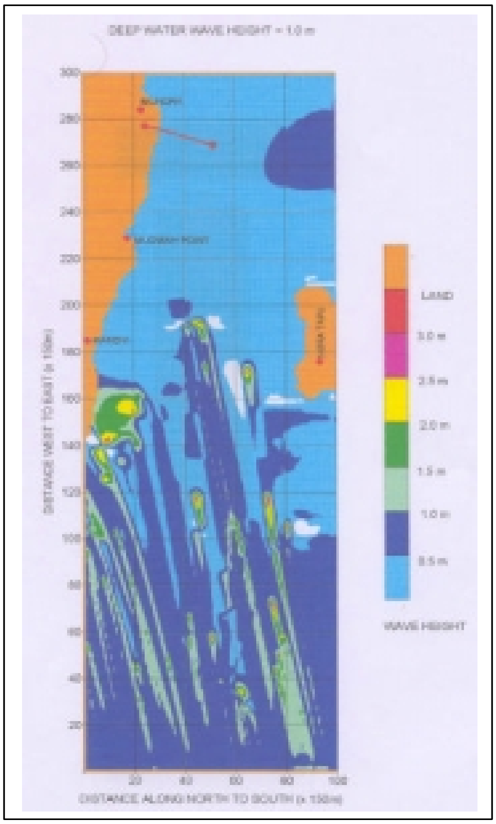

Fig. 2. Wave transformation during SW Monsoon for T=6 s.

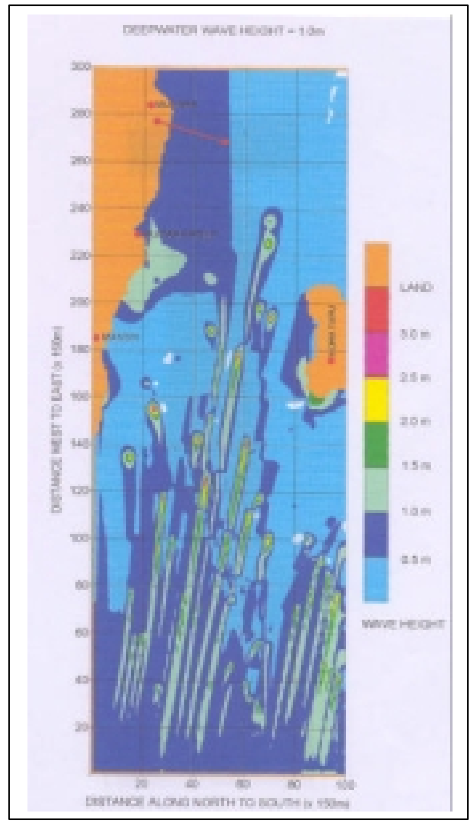

Fig. 3. Wave transformation during NW Monsoon for T=6 s.

3.6 DESIGN WAVES

Deepwater

The extreme wind and wave statistics using Weibull statistical distribution was carried out for the storm waves. The estimated design extreme wind speed and significant wave heights for various return periods arrived using the model CEDAS are given below:

Table 3.

Return period (years)	Extreme wind speed (km/h)	Design significant wave height based on storm waves (m)	Design maximum wave height based on storm waves (m)	Wave period (s)
2	75	7.12	12.82	11.11
5	100	10.19	18.34	12.62
10	114	11.98	21.56	13.50
25	130	13.98	25.16	14.48
50	140	15.31	27.56	15.13
100	150	16.53	29.75	15.73

Pipeline corridor

The extreme significant wave heights and extreme maximum wave heights along the pipeline corridor at water depths 32, 30, 25, 20, 15, 10 and 7.5 m for different return periods are shown below:

Table 4.

Return period (years)		Deepwater	Water depth (m)						
			32	30	25	20	15	10	7.5
2	H_s	7.12	2.1	2.13	2.12	2.0	2.0	2.0	2.1
	H_{max}	12.82	3.8	3.83	3.82	3.6	3.6	3.7	3.8
	θ	260°	260	260	259°	259	258	257	256
5	H_s	10.19	3.0	3.03	2.98	2.9	2.9	2.9	3.0
	H_{max}	18.34	5.5	5.45	5.36	5.2	5.2	5.3	5.5
	θ	260°	260	260	260°	259	258	257	256
10	H_s	11.98	3.5	3.56	3.50	3.4	3.4	3.4	3.6
	H_{max}	21.56	6.4	6.41	6.30	6.1	6.1	6.2	6.6
	θ	260°	260	260	260°	259	258	257	257
25	H_s	13.98	4.1	3.97	3.90	3.8	3.8	3.9	4.0
	H_{max}	25.16	7.5	7.15	7.02	6.9	6.8	7.0	7.2
	θ	260°	260	260	259°	259	258	257	256
50	H_s	15.31	4.5	4.36	4.28	4.2	4.1	4.2	4.3
	H_{max}	27.56	8.2	7.85	7.70	7.5	7.5	7.6	7.9
	θ	260°	260	260	259°	259	258	257	256
100	H_s	16.53	4.9	4.70	4.62	4.5	4.5	4.6	4.7
	H_{max}	29.75	8.9	8.46	8.32	8.1	8.1	8.2	8.5
	θ	260°	260	260	259°	258	258	257	256

H_s - Design extreme significant wave height; H_{max}- Extreme maximum wave height; θ - Wave direction

4.0 CONCLUSIONS

The wave climate in deep water was evaluated using hind cast model. The hind cast shows that strong wind prevails during southwest monsoon and the wave height prevails around 2 to 3 m. The wind speed remains relatively low during the rest of the year and correspondingly the wave height remains less than 1 m. The severe cyclonic storm can generate waves up to 12.7 m height in open sea. The extreme significant wave height along the pipeline corridor is expected to occur around 3.59, 4.19 and 4.59 m for the return periods of 10, 25 and 50 years respectively.

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