PREDICTION OF STORM SURGE FOR RAKHINE COASTAL REGION

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Abstract— Rakhine coastal region, western coast of Myanmar, is prone to cyclone and storm surge flooding. The probability of cyclone in Rakhine coast is more than any other place of Myanmar coast. The observations show that large storm surges are caused by strong south westerly winds acting along a large section of the coast. This situation occurs when an intense low pressure center moves relatively close to the coast and in a direction nearly perpendicular to it. The maximum wind speed that causes rising storm surge in Rakhine coastal region can expediently be estimated for different return period probabilistic modeling of historical maximum wind speed data using an appropriate extreme value distribution. And also assessment of minimum central pressure of cyclones in Rakhine coastal region is carried out from the relationship of minimum central pressure versus maximum sustained wind speed. Prediction of storm surge due to wind stress and pressure deficit of Rakhine coastal region for different return period is carried out by empirical prediction method and results are present.

Index Terms— Rakhine coastal region, Maximum Wind Speed, Minimum Central Pressure, Storm Surge, Empirical Method.

I. INTRODUCTION

Increase in sea surface temperature is strongly evidence at all latitudes and in all oceans. Scientific evidence indicates that increased sea surface temperature will intensify cyclone activity and heighten storm surge. Surges will create more damaged flood conditions in coastal zones and adjoining low lying area. Destructive impact will generate greater when storm surge will be accompanied by storm wind and large on shore wave. Historical evidence highlights the danger associated with storm surge. Countries around the Bay of Bengal are threaten by the possibility of storm surge with severe tropical cyclonic storms. Destruction due to storm surge flooding is a serious concern along the coastal regions of Myanmar. As future storm surge prediction is needed to forecast for those regions, this study reveals the prediction of storm surge of Rakhine Coastal Region.

The physical mechanism responsible for storm surge formation is simply wind drag over a water surface that causes redistribution of water within a basin. Atmospheric pressure variation over the sea often leads to additional level changes (e.g. water level rise in low pressure system such as cyclones and hurricanes). Level variation generates long waves. The resulting motion tend to become complex one because it is the result of external long wave propagation, of local wind effect, which is particularly important for shallow waters, and of atmospheric pressure gradient, which is more significant over deep sea region.

The eleven cyclonic wind speed data that approach the Rakhine coast during the period of 1947 to 2008 are taken into consideration for frequency analysis and Gumbel extreme value distribution is applied after selecting of suitable method for determination of parameter of Gumbel distribution for estimation of maximum wind speeds for the region under study. Minimum sea level pressure that causes raising the sea surge needs to be considered because Rakhine coastal zone is deep sea region. Maximum wind speed versus minimum sea level pressure chart and table is developed by using empirical relation of wind and pressure. Length of continental shelf up to 200 m contour depth from shore line is measured by bathymetry contour map and coastal line developing ArcGis software by using digital data of Satellite ETOPO-2 altimetry data and coastline GEBCO data and then compared by Haversine programming result. In this paper, the surge height of Rakhine coastal region due to wind stress and pressure deficit for different return periods is presented using empirical surge prediction.

II. STUDY AREA

Rakhine State, a western coastal region of Myamar, lies between latitude from 17 36′ N and 21 00′ N to longitude from 92 E to 94 30′ E. Rakhine coastal zone is bounded by Bay of Bengal in the west and total land area is 367,780 km. The mountain ranges within the stretches from Bangladesh to Chin State slope downward north to south having elevations of about 900 meter. The northern valley area is narrower than southern valley; better known as the Sittwey valley considerably wide. The Rakhine coastal Region stretches 740km from Naff River to Mawdin point. The Upper part of the coastline is shallow and deltaic. The southern part is more or less rocky. Continental shelf down to 200-meter depth is narrow compared to other areas.

III. METHODOLOGY

A. Frequency Analysis of Cyclone Wind Speed

Data on maximum storm surge height during cyclone are very scare for the Rakhine Coastal Region. To find the maximum storm surge height for different return periods, maximum cyclonic wind speed data of cyclones in the Bay of Bengal that approached the coast of Rakhine State during the period of from 1967 to 2010 data were obtained from the Indian Metrological Department. The Gumbel distribution was then fitted to the data for the period (1967-2010) employing best suitable method, Method of Moment, and the wind speeds for different return periods are given in Table 1.

B. *Estimation of Cyclone Track and Measuring Length of Continental Shelf*

When Ideal tracks of cyclones is assumed based on the best track data of Joint Typhon Warning Centre and the results is shown in Figure 1. Length of continental shelf in kilometer up to 200 meter depth of contour is measured by constructing bathymetry contour map of Bay of Bengal (between latitude 89 E to 94 E and Longitude 15 N to 21 N) and coastal line by using ArcGis software. The coastal length of study area is divided 15 segments by 35 kilometer interval. The results measured length between two points (difference in latitude and longitude) by ArcGis software is compared with calculated distance given by Haversine Formula using Matlab software. The results are shown in Table 2 and Haversine formula is as follow;

$$a = \sin^2(\Delta\phi/2) + \cos\phi_1 \times \cos\phi_2 \times \sin 2(\Delta\lambda/2)$$

$$c = 2\tan a(\sqrt{a}, \sqrt{1-a})$$

$$d = R \times c \qquad (1)$$

Where, ϕ is latitude and λ is longitude and R is Earth's radius (mean radius is 6371 km).

C. Calculation of Central Pressure versus Maximum Sustained wind speed of cyclone

A Minimum mean sea level pressure for different return periods vs maximum cyclone wind speed is calculated from the maximum sustained wind speed vice versa minimum sea level pressure chart. The ambient or peripheral pressure of 1010 mb is fitted well in the Bay of Bengal according to the data got from Department of Metrology and Hydrology and the translational addition, V_{Transl}, was held at 5.0 ms^{-1} or 10 kt. Central pressure versus Maximum Sustained Wind for Bay of Bengal cyclones is computed using equation 2 and the operational chart and Table are developed as shown in figure 2 and Table 3.

$$V_{\max} = [(\frac{BRT}{P_{xw}e})(P_w - p_o)]^{1/2} + V_{Transl} \qquad (2)$$

Where, B is Holland's scale parameter, R is gas constant (287 kj t^{-1} deg^{-1}) , T is cyclone air temperature (298 K), P_{xw} is pressure at the maximum wind radius, P_o is central pressure in millibars and P_w is peripheral cyclone pressure in millibars and ***e*** is base of natural logarithms. [1]

From the figure I and figure II, it may be noted that the length of continental shelf up to 200 meter contour depth to coastal line in upper region is longer than the lower region of Rakhine coast since the upper region is shallow and deltaic due to sedimentation of Naff River, Kaladan River and Mayu River.

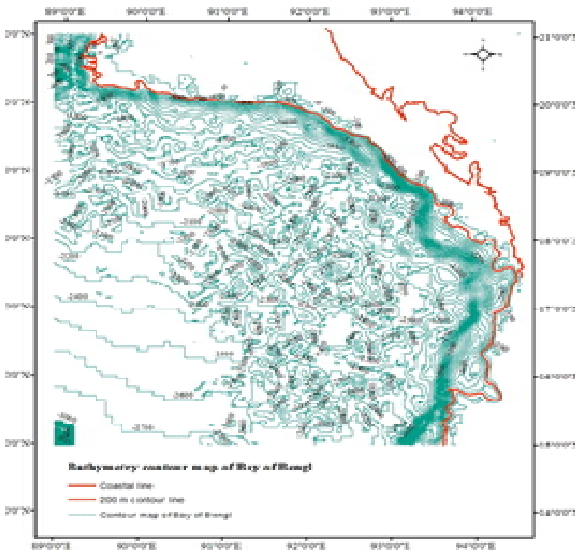

Fig. 1: Bathymetry contour map of Bay of Bengal

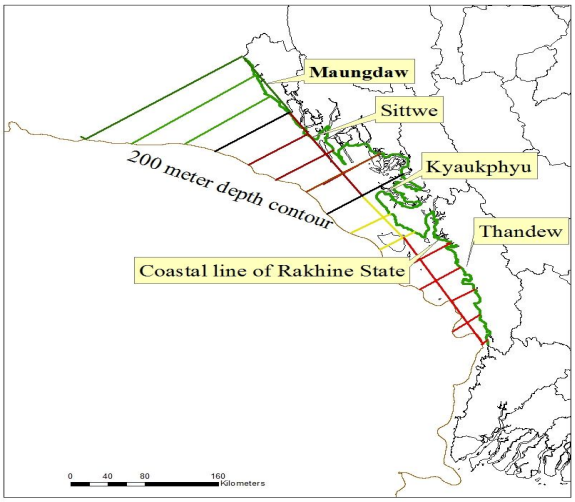

Fig. 2: Continental Shelf Length and ideal track

From the Table II, it can be seen that, by comparing the distance between measured length by ArcGis

software and program calculated length by Haversine Formula, both the two results are nearly the same and so these data can be applied in the calculation of storm surge due to wind stress.

From the figure 3 and Table III, it may be noted that, the greater the maximum wind speed the lower the sea level pressure. The estimated minimum central pressure with regarding to maximum wind speed for different return periods is taken from the operational chart of pressure wind relationship.

D. Storm Surge Forecasting

In this paper, Maximum wind speed and minimum sea level pressure relationship chart and Bretschneider's wind stress formulation (Reid 1956 and Bretschneider 1966) which is modified by Tareque @ Chowdhury (1992) is adopted to forecast the surge levels for Rakhine coastal region. As discussed in previous section, the two main

Table I: Cyclonic Wind Speed for Different Return Periods in Rakhine Coastal Region

Return Period(Year)	T=2	T=5	T=10	T=20	T=50	T=100
Cyclone wind Speed(kmh^{-1})	194	227	257	287	325	354

Table II. Comparison of length of continental shelf up to 200 meter contour depth

Point	Latitude (Degree)	Latitude (Degree)	Longitude (Degree)	Longitude (Degree)	ArcGis measured length(km)	Program calculated length(km)
1	21.196	20.125	92.175	90.629	200.066	200.136
2	20.922	20.066	92.306	91.093	158.172	158.183
3	20.625	20.054	92.437	91.592	109.292	108.596
4	20.446	19.970	92.627	91.926	90.317	90.290
5	20.161	19.780	92.806	92.223	74.158	74.210
6	19.959	19.602	93.056	92.497	70.673	70.689
7	19.923	19.435	93.520	92.782	94.330	94.419
8	19.649	19.150	93.722	92.996	94.183	94.216
9	19.161	18.900	93.627	93.246	49.454	49.4596
10	18.900	18.686	93.841	93.520	41.336	41.329
11	18.757	18.460	94.198	93.746	57.968	57.961
12	18.460	18.186	94.305	93.900	52.400	52.497
13	18.150	18.019	94.436	94.210	27.970	27.979
14	17.841	17.662	94.483	94.222	33.322	34.061
15	17.52	17.472	94.579	94.519	8.225	8.305

Table III: Central Pressure versus Maximum Sustained Wind Speed for the Bay of Bengal

P_o		B	P_{xw}	C	$(\Delta p)^{1/2}$	$C(\Delta p)^{1/2}$ (m/s)	V_{TRANSL} (m/s)	$V_{max}=C(\Delta p)^{1/2}+V_T$ (knot)	V_{max} (km/h)
mb	cb								
1010	101	0.95	101	-	-	-	-	-	-
1000	100	1.0	100.33	17.71	1.00	17.71	5	22.71	81.76
990	99	1.05	99.67	18.21	1.41	25.68	5	30.68	110.45
980	98	1.1	99.00	18.70	1.73	32.35	5	37.35	134.46
970	97	1.15	98.33	19.18	2.00	38.36	5	43.36	156.10
960	96	1.2	97.67	19.66	2.24	44.04	5	49.04	176.54
950	95	1.25	97.00	20.14	2.45	49.34	5	54.34	195.62
940	94	1.3	96.33	20.61	2.65	54.62	5	59.62	214.63
930	93	1.35	95.67	21.07	2.83	59.63	5	64.63	232.67
920	92	1.4	95.00	21.53	3.00	64.59	5	69.59	250.52
910	91	1.45	94.33	21.99	3.16	69.49	5	74.49	268.16
900	90	1.5	93.67	22.45	3.32	74.53	5	79.53	286.31
890	89	1.55	93.00	22.90	3.46	79.23	5	84.23	303.23
880	88	1.60	92.33	23.35	3.61	84.29	5	89.29	321.44
870	87	1.65	91.67	23.79	3.74	88.97	5	93.97	338.29
860	86	1.7	91.00	24.24	3.87	93.81	5	98.81	355.72
850	85	1.75	90.33	24.69	4.00	98.76	5	103.76	373.54
840	84	1.8	89.67	25.13	4.12	103.54	5	108.54	390.74

components of the surge are (a) air pressure variation effect and (b) onshore wind stress effects.

I. Inverted barometer effect

The inverted barometer effect is the tendency for the water surface to be sucked upwards in region of low atmospheric pressure. During the storm, the water surface rise is centered at the eye of the storm and depend directly on the central pressure relative to normal sea level pressure.

The surge height due to air pressure variation effect is

$$S_p = (1013 - P_c) \times 0.033 \quad (3)$$

Where, S_p is storm surge in feet of sea water and P_c is pressure of storm centre in millibars.

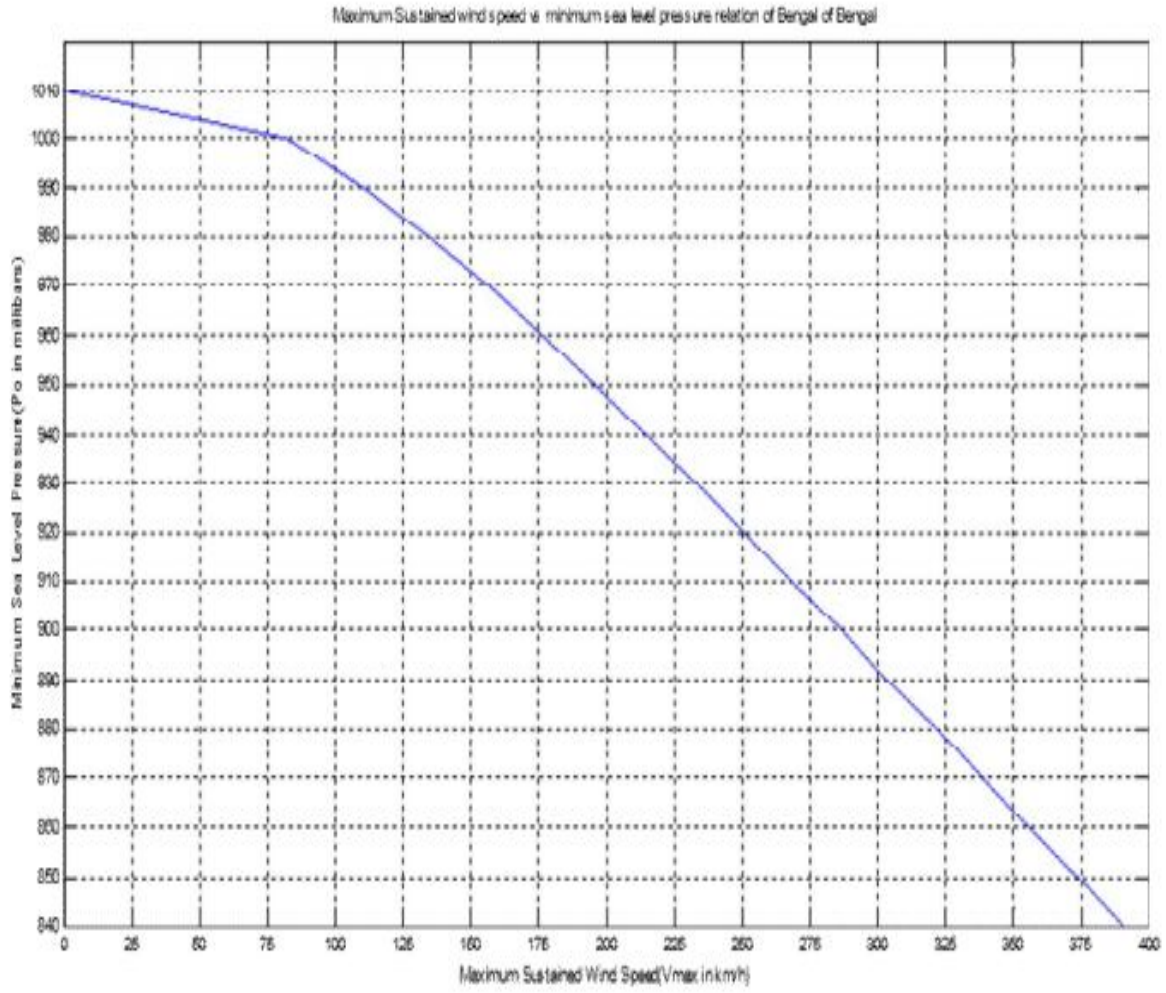

Fig. 3: Operational chart relating Maximum Sustained Wind Speed to given central Pressure values of tropical cyclone in the Bay of Bengal

II. Wind Stress Effect

Generally, the large component of storm surge is due to the wind stress on the water surface. The surge height due to wind stress effect is computed by equation (4) developed by Reid (1956) and Bretschneider (1966) and used with modification by Tareque & Chowdhury (1992):

$$S = \frac{13 \times 10^{-6} LV^2}{(5 \times 10^6 + LV^2)^{0.2}} \quad (4)$$

Where, S is the areal average surge height in m, L is the length of the continental shelf in kilometer up to 200 meter depth of contour, V is the cyclonic wind speed in km h^{-1}. [11]

The value of L is taken to be aerial average length of Rakhine coastal Region 139 km for Maungdaw district, 83km for Sittwe District, 45km for Kyaukphyu District, 36 km for Thandwe District and 76 km for the Rakhine Coastal Region. Applying the values of length L, the value of Wind Speed V and the values of minimum central pressure for various return period of different district, the surge is calculated and described in Table 4, 5, 6, 7 and 8. An average value of maximum tidal range (2.4 m) corresponding to spring tide was obtained on data from several tidal stations along the seaboard of Rakhine State. Accordingly, the computed maximum surge levels near the shoreline were super-imposed with a further rise in water level of 1.2 m to take into account the

worst-case tidal effect. Total surge height with respect to sea level can be found from the combination of surge height due to wind stress, surge height due to pressure deficit and mean tide height. [12]
From the Table 4, 5, 6, 7, 8, it can be found that amount of surge height for different return period mainly depend on the bathymetry of study area and intensity of storm. The shallower the continental shelf length and the higher the higher the wind speed, the greater the surge height and the more dangerous effect.

DISCUSSION

The Wind speed data from cyclone winds that hit the Rakhine coastal Region are analysed for different return periods and found to be 194, 227, 257,287, 325, 354 kmh^{-1}. The length of continental shelf up to 200m contour depth is measured by ArcGis software and examined with Haversine formula and taken as 139, 83, 45, 36, 76 km respectively for various district of Rakhine coast. Operational chart relating maximum sustained wind speed to given central pressure values of tropical cyclone in the Bay of Bengal is developed from the empirical relationship and estimated values of minimum central pressure for different return period is taken as 950, 933, 916, 900, 877, 860 millibars from the operational chart.

It is found that these minimum central pressure are within the range of Saffir-Simpson Scale. Surge height due to wind stress and pressure variation is calculated by respective empirical prediction surge height prediction formula and result are shown in table 4, 5, 6, 7, 8. From this study, it is also seen that the stronger the storm wind, the lower the sea level pressure and the higher the surge level.

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