AERB SAFETY GUIDE NO. AERB/SG/S-6B

DESIGN BASIS FLOOD FOR NUCLEAR POWER PLANTS AT COASTAL SITES

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This document is subject to review, after a period of one year from the date of issue, based on the feedback received.

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FOREWORD

Safety of the public and occupational workers, and the protection of the environment should be assured while activities for economic and social progress are pursued. These activities include establishment and utilisation of nuclear facilities and the use of radioactive sources. They have to be carried out in accordance with relevant provisions in the Atomic Energy Act, 1962.

Assuring high safety standards has been of prime importance since the inception of the nuclear power programme in the country. Recognising this aspect, the Government of India constituted the Atomic Energy Regulatory Board (AERB) in November 1983 vide standing order No. 4772 notified in the Gazette of India dated 31.12.1983. The Board has been entrusted with the responsibility for laying down safety standards and framing rules and regulations in respect of regulatory and safety functions envisaged under the Atomic Energy Act, 1962. Under its programme of developing codes and safety guides, AERB has issued four codes of practice covering the following topics:

Safety in Nuclear Power Plant Siting,

Safety in Nuclear Power Plant Design,

Safety in Nuclear Power Plant Operation, and

Quality Assurance for Safety in Nuclear Power Plants.

Safety guides are issued to describe and make available methods of implementing specific parts of the relevant codes of practice as applicable to AERB. Methods and solutions other than those set out in the guides may be acceptable if they provide at least comparable assurance that nuclear power plants can be operated without undue risk to the health and safety of plant personnel, the general public and the environment.

Codes and safety guides may be revised as and when necessary, in the light of experience as well as relevant developments in the field. Appendices included in the document are considered an integral part of the document. Annexures, footnotes and references are not to be considered integral parts of the document. These are included to provide information that might be of help to the user.

The emphasis in the codes and guides is on the protection of site personnel and the public from undue radiological hazards. However, for aspects not covered in the codes and guides, applicable and acceptable national and international codes and standards shall be followed. Industrial safety shall be assured through good engineering practices and through compliance with the Factories Act, 1948 as amended in 1987 and the Atomic Energy (Factories) Rules, 1996.

This Safety Guide on Design Basis Flood for Nuclear Power Plants at Coastal Sites is one of a series of guides which have been issued or are under preparation as a follow-up to the Code of Practice on Safety in Nuclear Power Plant Siting. It outlines the methodology and procedures for carrying out analysis as applicable for implementing the relevant parts of the code of practice.

This Safety Guide has been prepared by the staff of AERB, BARC and NPCIL. The criteria followed by DAE for selection of a site and the relevant International Atomic Energy Agency (IAEA) documents under the Nuclear Safety Standards (NUSS) programme, especially the Safety Guide on Design Basis Floods for NPPs at Coastal Sites (50-SG-10B,1983) and similar documents from various leading countries, suitably adapted to Indian conditions have been utilised extensively in the preparation of this guide. It has been reviewed by experts and vetted by the AERB Advisory Committees before issue. AERB thanks all individuals and organisations involved in the preparation, review and finalisation of the Safety Guide. A list of persons who participated in the committee meetings along with their affiliation is included for information.

(Suhas P. Sukhatme)
Chairman, AERB

DEFINITIONS

Cyclone

A low pressure belt generated in the upper atmosphere, which has circular isobaric pattern and associated wind speed greater than 60 kmph.

Hurricane

A tropical storm in which wind speeds exceed 120 kmph.

Mean Sea Level (MSL)

The average height of the surface of the sea for all stages of the tide determined from hourly height readings over a long period.

Probable Maximum Water Level

A hypothetical water level (exclusive of wave run-up from normal wind-generated waves) that might result from the most severe combination of hydro, meteorological, geoseismic and other geophysical factors that is considered reasonably possible in the region involved with each of these factors considered as affecting the locality in a maximum manner.

Seiche

An oscillation of an enclosed water body in response to a disturbing force (seismic or atmospheric) having the same frequency as the natural frequency of water body.

Still Water Level

The elevation that the surface of the water would assume if all waves were absent.

Storm Surge

A rise above normal water level on the open coast due to the action of wind stress on the water surface and also the atmospheric pressure reduction caused by a cyclone.

Tidal Rise

The maximum height of tide above MSL.

Topography

The configuration of a surface giving general description of hills, valleys, water bodies and other man-made structures.

Tropical Storm

An intense tropical cyclone in which winds tend to spiral inward towards a core of low pressure, with maximum surface wind velocities that are less than 120 kmph for several minutes or longer at some points.

Tsunami

A wave train produced by impulsive disturbances of a body of water caused by displacements associated with submarine earthquakes, volcanic eruptions, submarine slumps or shoreline slides.

Wave Run-up

The rush of water up a structure or beach on the breaking of a wave, also called uprush. The amount of run-up is the vertical height above the still water level that the rush of water reaches.

SPECIAL DEFINITIONS

(Specific for the Present Guide)

Eye (of the cyclone)

In meteorology, the roughly circular area of comparatively light winds and fair weather at the centre of a severe tropical cyclone.

Extra Tropical Cyclone

A depression or low pressure area which is generated in mid or high latitudes 20° North or 20° South having the most severe combination of meteorological storm parameters.

Fetch

The area in which seas are generated by a wind having a rather constant direction and speed; sometimes used synonymously with fetch length.

Fetch Length

The distance in sea perpendicular to the coast over which wind having a constant direction and speed exit to generate a wave set-up.

Isovels

Contours showing lines of equal velocity.

Hurricane Path or Track

Line of movement (propagation) of the eye through an area.

Riprap Structure

A layer, facing or protective mound of stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment.

Shoaling

A process by which sediment particles churned up by waves are deposited beyond the region of wave turbulence to form shoal of deposited sediments.

Significant Wave

A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods. The average height of the one-third highest waves of a given wave group is called significant wave height. Significant wave period is an arbitrary period generally taken as the period of the one-third highest waves within a given group.

Surging Breaker

A wave breaking on a shore, over a reef, etc. Breakers may be classified into four types:

Spilling: Bubbles and turbulent water spill down front face of wave. The upper 25% of the front face may become vertical before breaking. Breaking is generally across over quite a distance.

Plunging: Crest curls over air pocket. Breaking is usually with a crash. Smooth splash-up usually follows.

Collapsing: Breaking occurs over lower half of wave. Minimal air pocket and usually no splash-up. Bubbles and foam are present.

Surging: Wave peaks up, but bottom rushes forward from under wave, and wave slides up beach with little or no bubble production. Water surface remains almost plane except where ripples may be produced on the beach face during runback.

Uplift

The upward water pressure on the base of a structure or pavement.

CONTENTS

1. INTRODUCTION

1.1 General

Nuclear Power Plants (NPPs) require water for cooling purposes and are, therefore, situated either at coastal sites or by the side of a reservoir or a river. It is therefore, imperative that safety of NPPs is assessed for flooding. Design basis flood (DBF) for NPPs on river sites has been covered in safety guide [1]. The present guide entitled 'Design Basis Flood for NPPs at Coastal Sites (SG/S-6B)' considers safety aspects of NPPs during design basis floods at coastal sites. This guide identifies various conditions stipulated by the code of practice [2] on siting of NPPs which can result in flooding relevant to Indian conditions and the methodologies for estimating water levels likely to be reached during the flooding incidence.

Though in the initial stages, flood was predicted using approximate methods, recently validated computer programs using hydrodynamic equations and actual field data have come to play a vital role in predicting flood water levels. These recent techniques are addressed in this guide.

1.2 Objectives

The aim of this guide is to give various methodologies for estimating Probable Maximum Tropical Cyclone (PMTC), the surge generated by this cyclone when it landfalls, the run-up generated at the site due to waves incidenting on the coast during this cyclone, and to identify methods that are more preferable for use.

The main objective is to evaluate the maximum water levels reached at the site due to the combined effect of astronomical tide, surge level and the wave run-up so as to arrive at a safe ground level elevation or suitable engineered safety features for NPPs. It is also necessary to identify different engineered barriers for keeping the site elevation for NPP at a reasonable value such that pumping costs can be kept to an affordable level without compromising the safety of NPP.

1.3 Assumptions

The probable causes of floods at coastal sites are:

i) Flood resulting from the Probable Maximum Storm Surge (PMSS);

ii) Flood resulting from Probable Maximum Tsunami (PMT), if applicable;

iii) Flood resulting from Probable Maximum Seiche (PMSE), if applicable; and

iv) Flood resulting from a reasonable combination of severe events of the type listed above.

Tsunami is a wave train produced by impulsive disturbances of a water body caused by displacements associated with submarine earthquakes, volcanic eruptions, submarine slumps or shoreline landslides. Seiche is an oscillation of an enclosed or semi-enclosed water body in response to an oceanographic or seismic disturbing force. Both these effects are thus related to the seismic activity at the sea bed. The available historical information shows that tsunamis in the east or west coast of India give a maximum wave height of around 2.5 meters [3]. Values of surge heights generated for design basis cyclonic storms at the coastal region are always higher than 2.5 meters. As the plant is designed for coastal surge heights generated by the cyclonic action, it will always be safe from the highest water levels reached due to the effect of tsunamis or seiches. Hence, these effects need not be considered. The cyclone and tsunami causing events are completely independent events and each of these events chosen for analysis has a low probability. As such, a combination of tsunami and cyclonic surge of design basis intensity will have extremely low probability.

1.4 Scope

This guide deals with flood resulting from cyclonic storm surge and gives a general description of the methods used along with critical factors involved in evaluating such floods.

Flood water level at coastal NPP site is a combined effect of the astronomical tide, surge height due to PMSS corresponding to PMTC landing in the area and the wave run-up.

The basic requirement in the identification of PMTC and various methods used for estimating PMTC together with the data needed for the same, are described in chapter 2.

Tide levels at any site vary during the day as well as over months. The procedure for choosing tide level for a site together with identification of agencies from where data could be available, is given in chapter 3.

Various methods for evaluating surge heights generated at coastal sites due to landfall of PMTC using methods described in chapter 2, are given in chapter 4 (along with the data requirement). The method to be used and the agencies equipped with the know-how are also identified in chapters 2 and 4 in the respective sections/paragraphs.

Wave run-up is an important parameter for evaluation of site elevation of NPP. The degree of wave run-up is a function of coastal topography and tidal characteristics.The run-up can be controlled by modifying coastal topography and characteristics. Chapter 5 describes different methods of computing wave run-up and also identifies the parameters of importance along with their influence on how they affect the wave run-up.

Chapter 6 gives methodologies to arrive at final flood water level for the site, while chapter 7 discusses flood protection aspects and monitoring and warning systems.

2. TROPICAL CYCLONE PARAMETERS

2.1 General

A tropical cyclone consists of a rotating warm humid air mass of hundreds of kilometers in diameter. Atmospheric pressure is lowest at the centre. In the northern hemisphere the winds of a cyclone spiral inwards towards the centre in an anticlockwise direction while in the southern hemisphere they spiral inwards in a clockwise direction. A well developed cyclone has widespread areas of thick cloud cover, extending to great heights (km), together with torrential rains and violent winds. The central region of the cyclone, also known as the eye of the cyclone, is normally devoid of clouds and wind. Wind increases rapidly near the eyewall and falls off as one moves out. Thus a well-defined region of high winds exists in the cyclone. The bodily movement of cyclone, however, is very slow, around a few meters per second. Typical cyclone isovels of cyclone camille are given in Fig. 2.1.

Tropical cyclones are warm core storms. The buoyant air gives rise to lower surface pressures and leads to circular isobaric pattern. Conditions for tropical storm to form and persist are:

(i) warm sea temperature > 26^{o}C,

(ii) air at low levels must converge inwards over a large area, and

(iii) air flow at high altitudes must be outwards.

2.2 Probable Maximum Tropical Cyclone (PMTC)

PMTC is a hypothetical steady state tropical cyclone having combination of values of meteorological parameters chosen to give the highest sustained wind speeds that can reasonably occur at a specified coastal location. For arriving at the maximum surge value it is essential to evaulate the probable maximum value of the parameter of interest. The parameters of interest will vary with the procedure for estimation of surge height, however invariably it is '? P', the pressure depression at the eye of the cyclone.

2.3 Parameters

PMTC data essential for studying thermal dynamic features of these cyclones are lacking. Some of the parameters which are useful for estimating PMTC and the resulting surge heights are:

- vertical temperature and humidity profile within the eye,
- characteristics of the tropopause over the eye,
- sea surface temperature profiles,
- shape and size of the cyclone eye,
- horizontal surface wind profile,
- maximum winds, and
- minimum central pressure in the eye of the cyclone.

Studies in this field indicate that estimation of tropical cyclone intensities using upper atmosphere temperature anomalies may lead to a more reliable method for assessing the maximum winds than based on surface temperature differences. However, it is difficult to estimate some of these parameters. Methods are therfore developed to assess surge heights in terms of those parameters that are easily measurable and which play a vital role in modifying surge heights near the coast. These parameters are listed below.

- radius of maximum wind wall, R (km),
- pressure difference between centre of cyclone and the periphery, ? P (millibars),
- translation speed of the cyclone, v (kmph)
- direction of cyclone movement vis-a-vis the coast (degrees),
- inflow angle i.e. angle between wind direction and tangent to the isobar lines of cyclone (degrees),
- bathymetry near the coast in shallow waters, and
- slope and type of surface on the coastal land.

2.4 Methodologies for Estimating PMTC

Methods for estimating PMTC can be divided into two categories; deterministic and probabilistic.

2.4.1 Deterministic Method

Conditions in the vertical air column over the eye of the cyclone that will produce the lowest pressures at sea surface are to be evaluated. Surface pressures can then be computed by hydrostatic approximations of the balance between pressure gradient force and force of gravity. The general structure of cyclone varies from region to region and it is therefore essential that regionwise analysis be carried out.

Pressure at the centre of the eye of the cyclone is an important parameter from the surge generation point of view. Estimation of this parameter requires an understanding of the following:

Height of the Tropopause: Tropical cyclone system requires the inflow of air mass at lower level and outflow of air mass at higher level. The limit of height is the tropopause.

Temperature of the Tropopause: Hydrostatic equations show that lower the sea surface pressure, higher the temperature of the tropopause. Some studies have shown a contrary behaviour and hence normally the mean value of tropopause temperature is used.

Sea Surface Temperature: Sea surface temperature varies inversely with pressure and can therefore be taken using the maximisation approach.

Moisture Distribution: This is an important parameter in deciding the strength of the cyclone. 100% humidity is expected to be at the sea surface and the decrease of humidity with height is to be adjusted for maximisation of the cyclone strength.

Though a mathematical approach is available, the regional dependence of the behaviour of cyclone makes it essential to conduct studies on regional basis and arrive at the best approach for generating the cyclone parameter. Normally the cyclones start forming at very long distances from sea coast and the values of the above mentioned parameters are not easily available. In view of this, as far as PMTC estimation is concerned, a deterministic approach is normally not followed.

2.4.2 Probabilistic Method

The probabilistic method for generating PMTC is based on using the extreme value approach to the historical cyclones which occurred in the area. It is important to note that the database needed for evaluation should be sufficient to generate meaningful results of probable maximum cyclone for the desired return period. Requirements of database to generate reliable estimates for a given return period using extreme value analysis are described in another safety guide [4]. A mean recurrence interval for having a return period of 1000 years is recommended, vide code of practice [2].

The parameters of interest for generating surge heights is the pressure difference (? P) at the eye of the cyclone. It is therefore essential that an extreme value analysis be carried out for this parameter.

2.5 Data Requirements

Data of historically observed cyclones to be used in the probabilistic method should preferably include cyclones landfalling within 250 km around the site [2]. However, in regions where cyclones, landfalling on the coast, have equal probability of falling anywhere along the coast, this restriction of distance is not to be considered (typically the east coast of India). The amount of data needed and the variance of the value generated will vary with the amount of data available and the Mean Recurrence Interval (MRI) looked for.

It is desirable to have atleast a 100-year database for arriving at meaningful and reliable value of a 1000-year MRI value. In case such a data set is not available for a region including the site, then data from other similar sites can also be used.

The maximum wind speed during the cyclone is generally dependent on pressure difference and as such the analysis is invariably carried out using only the data of pressure drop or pressure difference at the eye of the cyclone. The wind speed generated from the value of pressure difference using mathematical relation, is also used for generating the maximum wind speed for design basis cyclone.

V_{max} is related to the pressure drop ?P as [5,6] :

V_{max} = A · ?P

where V_{max} is the maximum wind speed in kmph.

?P is the pressure difference between the eye of the cyclone and the periphery in millibars,

and empirical constant A has a value between 7 and 9. A value of 8 is recommended.

It is difficult to obtain the data on temperature profiles and upper atmosphere (up to the topopause) needed for deterministic methods and, therefore, the probabilistic method is normally used. The data needed for this is the historically observed cyclones.

Data on the number of cyclones which have landed on Indian coast is given in Annexure I. This data includes cyclones during the period 1891 to 1972 and is in no way complete. However, this data does not include the values of various parameters of the cyclone. The pressure drop ?P at the centre of the cyclone, the cyclone eye, for all these cyclones is available from the India Meteorological Department. Though the restriction of 250 km on either side of the site of interest for choosing cyclones related to a site has been recommended in code of practice [2], the data will, by no means, be sufficient for statistical studies. However it is well known that a cyclone generated in deep sea, while moving to the coast, can land anywhere on the entire coast. Hence, as far as the parameter ? P is concerned, the data on all cyclones landing on east coast can be used for statistical analysis.

Data of cyclone tracks and all other parameters for the cyclone which have landed on the Indian coast are available with India Meteorological Department.

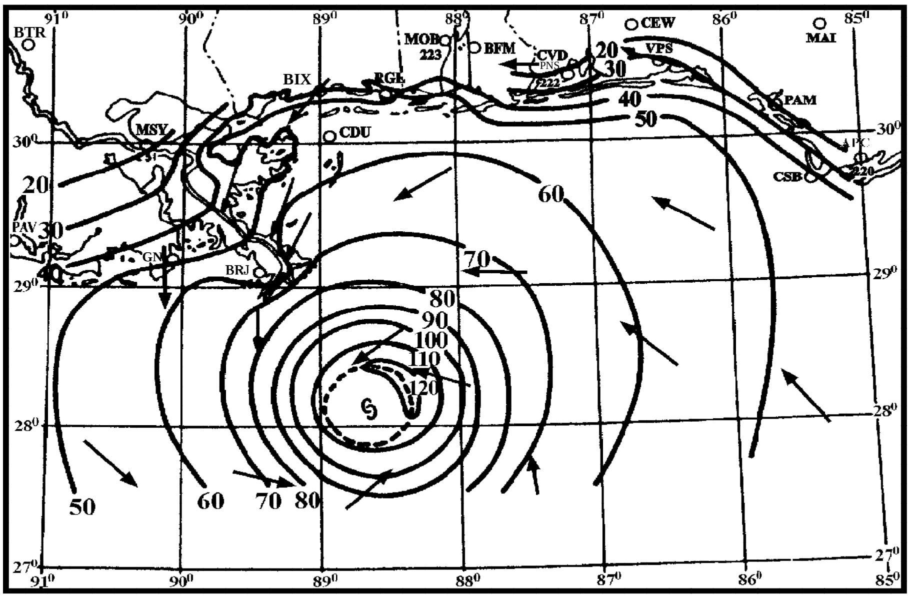

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Fig. 2.1 30 FOOT SURFACE ISOVELS (KNOTS), HURRICANE CAMILLE [14]

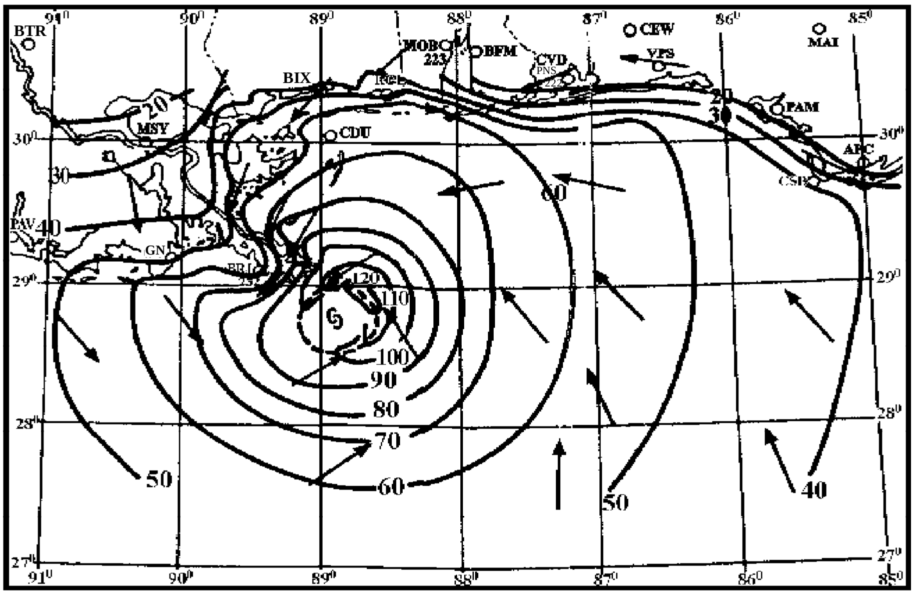

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Fig. 2.1 30 FOOT SURFACE ISOVELS (KNOTS), HURRICANE CAMILLE [14] (Contd.)

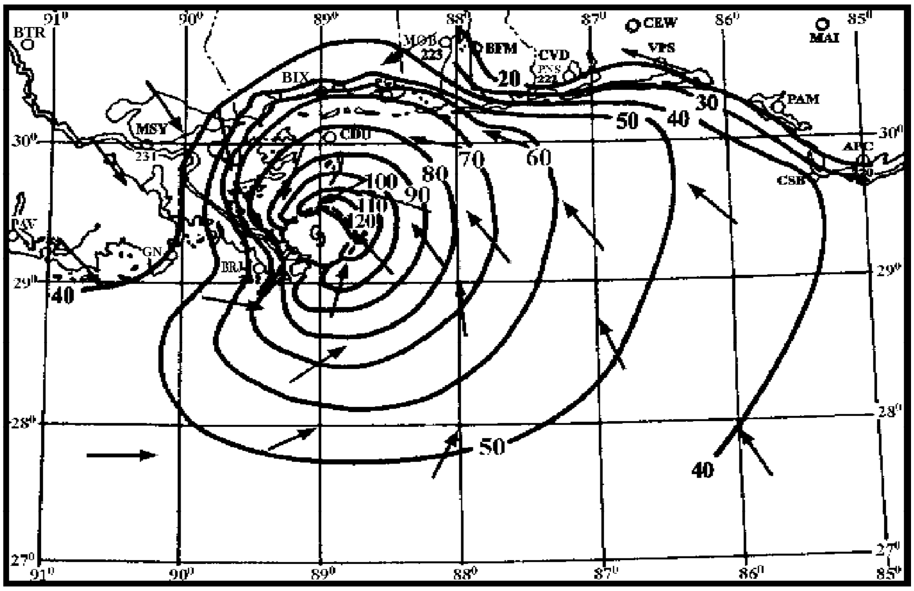

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Fig. 2.1 30 FOOT SURFACE ISOVELS (KNOTS), HURRICANE CAMILLE [14] (Contd.)

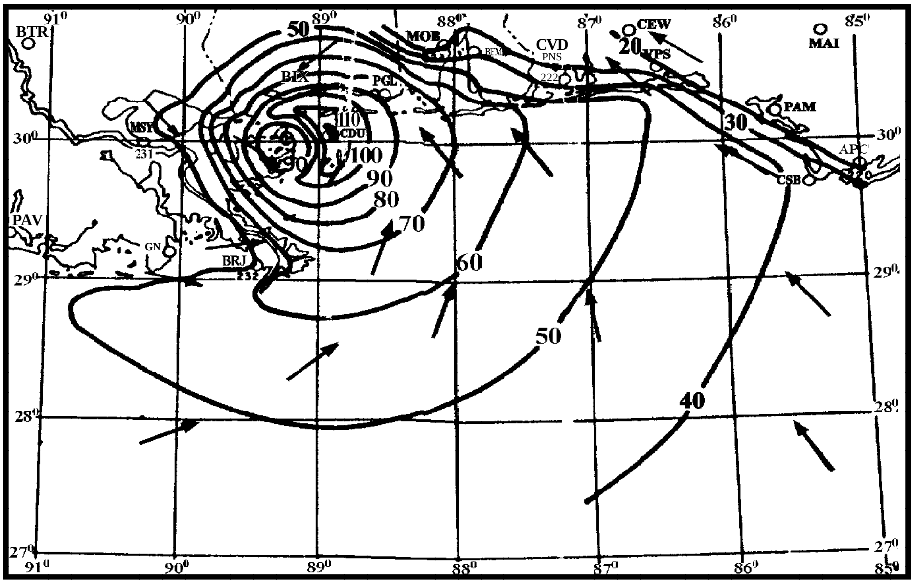

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Fig. 2.1 30 FOOT SURFACE ISOVELS (KNOTS), HURRICANE CAMILLE [14] (Contd.)

3. ESTIMATION OF ASTRONOMICAL TIDE VARIATION

3.1 Introduction

In order to generate the actual surge water level that has reached a site, it is essential to estimate the still water level value, which is the mean sea level plus the tide level. This is required as a reference level over which surge height is to be considered.

Sea water level in the absence of cyclonic conditions varies over an year. This variation follows both a daily as well as an annual cycle. The tide levels are controlled by the position of sun and moon vis-a-vis the earth, and to a very negligible extent, by the location of other celestial bodies. This parameter, therefore, will not change significantly over the years randomly and as such statistical treatment of return period may not be required. The maximum value can be obtained using the highest tide observed over the years. Use of this value will give the safe water level.

3.2 Data on Astronomical Tide

Tide value can be predicted by harmonic analysis. For this purpose, the constants to be used are for specific gauging stations nearest to the site. In general, tidal evaluation can also be done directly by referring to admirality tide tables or tide tables established by the port authorities. Where a site is not the standard port, correlation studies have to be carried out to establish the time difference and magnification factors for the site with respect to the nearest port.

To get a conservative estimate it is presumed that surge action will occur simultaneously with the highest tide level.

Sea level anomaly is the change in mean sea level over the years. This can be estimated by studying the historical records of the tides over the years. If a continuous decrease or increase is observed in the average tide values in the past, this trend should then be considered for determining possible

changes over the lifetime of NPP.
In computing PMSS on the open coast, a high tide with sufficiently low probability to be exceeded (e.g 10% exceedance high tide, namely the high tide equalled or exceeded by 10% of the maximum monthly astronomical tides over a continuous 21-year period [7]) is considered to occur coincidentally with the probable maxmimum flooding event. This can be determined from the recorded tides.

Data on tides, estuarial and sea level anomalies will normally be available from national meteorological and hydrographical services like IMD, NIO etc.

In case a systematic increase or decrease of the highest tide level is seen over the years, the best estimates of high tide levels can be used taking into consideration these systematic variations. If it can be proved that a cyclone occurs in the area of interest only during a particular period of the year, the highest tide value for the specific period need be used.

4. METHODOLOGY OF SURGE HEIGHT COMPUTATION

4.1 Problem Definition

Cyclonic depression is associated with areas of high wind field. The depression is the inverse barometric pressure that will generate a rise in water level locally and this will travel as a wave as the cyclone moves towards the coast. The associated winds will also generate waves in the deep sea due to frictional forces at the air-water interface. The combined effect of the above results in surge waves travelling towards the coast. These waves travelling towards the coast get modified in shallow waters near the coast and the modification depends on water depth as well as on near-shore bathymetry. The severity of the surge will also depend on the landfall of the cyclone and effects of the reflections and refractions which modify surge heights. This surge is superimposed on the sea water level existing at the time of occurrence, which will depend on the tidal cycle.

The best protection against flooding is to select a site for construction of NPP above the design basis water level which is the algebraic sum of astronomical tide level, the surge height and the wave run-up.

4.2 Methods of Analysis

Two basic methodologies are available for determining the Probable Maximum Surge Height (PMSH): deterministic and probabilistic.

4.2.1 Deterministic Methods

Deterministic methods use models that may be empirical or based on physical relationships which describe the system. For a set of initial and boundary conditions, the model can generate parameters of flood causing events.

Deterministic method involves solving basic hydrodynamic equations for generation of waves in deep ocean under the influence of cyclonic conditions and associated forcing fields of inverse barometric pressures and wind. Modifications of these deep ocean waves, as they approach shallow seas and coast, can be built-in in the formulation. This method needs the input design basis cyclone parameter viz. ? P, the pressure difference between normal pressure and pressure at the eye of the cyclone, arrived at using methodologies described in chapter 2.

In the deterministic method a set of maximised hypothetical storms is considered, selected and moved to the location critical for formation of a surge at the site. It is then used as input for an appropriate surge model. The procedure for maximisation, transposition and estimation requires a lot of expertise.

Surge height is generally evaluated using time dependent mathematical equations of conservation of mass and momentum for flow of an incompressible fluid (Appendix-I). These equations are integrated over the water depth using numerical techniques. Computer programs [8,9,10,11,12] for analysing surge height are available.

The computer program should be validated for the observed historical storm in the region of interest to evaluate the applicability of the program and thus validate the in-built parameters like roughness, porosity etc. for the region. In computing Probable Maximum Surge Height (PMSH) a reference level such as high tide or high water level with sufficiently low probability of being exceeded should be selected to be coincident with the storm surge (see section 3.2).

The analysis consists of selecting an appropriate cyclone and other relevant parameters (maximum wind velocity, atmospheric pressure differential, bottom friction and wind stress coefficients) to be used as input to one or two-dimensional storm surge models which maximises the storm surge potential. All parameters used should be conservatively evaluated and adequately substantiated. For surge analysis, one-dimensional model is adequate if the wind fields are symmetric. For handling large asymmetry in wind fields, two-dimensional models may be necessary. A combination of meteorological parameters, critical pathway of the cyclone and its rate of movement leading to most severe surge water level is essential.

A validated model for surge height estimations should be used. Validated models are now available with IIT, Delhi and IIT, Madras.

4.2.2 Probabilistic Method

Probabilistic method is based on statistical analysis of historical events to arrive at PMSH. Confidence on results obtained by this method depends on the adequacy of historical data available. It should be borne in mind that while handling historical data for analysis, it is essential to weed out time dependent component, outliers, and trends to remove the bias in data set. This data is normally handled using the extreme value statistical approach [4]. The analysis can generate PMSH value corresponding to MRI as envisaged for the analysis. A value of 1000 years as MRI is to be used [2].

A parameter to be used in this analysis is the surge height data observed during historical cyclonic events.

In case data set of 100 years is not available for a region which includes the site for evaluating the 1000-year MRI value, then data from other similar sites can also be used. Methodologies of extreme value analysis and handling data sets are described in another safety guide [4].

This method can be applied if reliable surge data are available over a sufficiently long period of time from an adequate number of surge gauge stations. When records cover sufficiently long periods and substantial data is available then different factors relating to intensity, path and duration of storms are implicitly incorporated. Some typical surge data for coastal site around Tamil Nadu is given in Annexure-I.

4.2.3 Semi-empirical Method

In earlier days when computers/computer programs were not freely available, semi-empirical methods were developed. Among these a method developed at India Meteorological Department is very useful and easy to use. This consists of solving approximate equations for an ideal coastline and generating a relation between pressure difference and surge level considering R, the radius of maximum wind speed region as a parameter.

As the landfalling direction affects the surge, a correction factor for the effect of this parameter on surge generated is also incorporated.

The most important part that needs to be considered is the effect of coastal bathymetry on the modification of surge. A detailed study of the east coast on regional basis has been conducted and a shoaling correction factor has been generated.

For more details and relevant graphs refer to Appendix II.

This method can generate quick and sufficiently accurate results.

4.3 Evaluation Approach

Deterministic methods normally do not evaluate the degree of protection in terms of return periods [2]. Probabilistic method, however, does give such an evaluation. The surge height calculation involves two stages: generation of design basis cyclone and then finding the effect of this cyclone on surge generation. What is therefore, followed is to generate the design basis cyclone parameters using probabilistic approach to give the desired degree of safety and the PMTC so generated is then used as input to deterministic method for generating PMSH.

The empirical methods of solving equations and using site data would involve detailed data acquisition at site for both PMTC and flood water levels. In situations where such data is not available, semi-empirical methods mentioned in Appendix-II can be used for flood estimation. Cyclones with maximum pressure depression on east coast and west coast respectively should be used as PMTC. In case more sophisticated methodologies are available in future, they can be used after proper validation.

4.4 Limitations

Both deterministic and probabilistic methods suffer from constraints which limit their applicability. For deterministic methods it is not possible to express quantitatively the level of safety. In the case of probabilistic method there is a lack of confidence in the results of extrapolation to low exceedance probability. This is because of paucity of data for predicting the 1000-year return period value.

Surges generated by tropical cyclones are usually evaluated by deterministic methods taking into account symmetrical characteristics of the generating cyclone.

Surges generated by extra-tropical cyclones are evaluated mainly by probabilistic methods since such storms are usually very extensive, asymmetrical, and difficult to model. Deterministic methods can be used for this, but the calculations are more complicated.

It is well known that the surge height for the same inverse barometric pressure varies depending on the coastal bathymetry. Therefore the data of surges observed over different bathymetry regions cannot be clubbed together for analysis. This aspect severely restricts the data available for statistical analysis.

It is important to mention here that as far as the eastern coast of India is concerned, a part of southern region is believed to be in shelter-zone of the Lankan land mass. As a result, any cyclone landfalling in this region will first landfall on the Lankan coast. The region of sea i.e. the water body between two land masses viz. Sri Lanka and India, subjected to the forces of winds, is small and the surge heights generated will be modified to a great extent. It has been observed that the path of cyclone sometimes takes a turn around the northern tip of Sri Lanka and moves in the channel. In such a case the use of numerical models and validation only gives the correct surge values. The formulations used in generating surges in the two methods viz. probabilistic and semi-empirical mentioned above in sections 4.2.2 and 4.2.3 assume open sea conditions. Hence the surge heights predicted using the above two methods for this region may be much higher than experienced. In view of this, while estimating surge heights, especially for this or similar regime, validated models should be used which consider all the physical parameters of the region (bathymetry) and the cyclone (path of the cyclone).

4.5 Data Base

Various mathematical formulations require site specific data as input for generating results pertaining to the site. Data needed for formulations involved in this guide can be grouped into 3 categories:

(i) meteorological data,

(ii) cyclone data, and

(iii) bathymetry data.

4.5.1 Meteorological Data

Meteorological data to be collected include historical data on wind speed and direction, air pressure and air temperature in the region. This data will mainly be restricted to the duration of cyclones which have occurred at and around the site.

Data is required on the type of cyclones, their frequency, magnitude, date of occurrence, location and duration of wind speed and pressure at different locations. In addition, data will be needed on storm tracks, aerial spread of the cyclone, extent and part of coastline affected by the cyclone and synoptic charts for the region around the site. A region of 250 km radius around the site is generally considered.

Meteorological data on land is available from the national meteorological agencies. Meteorological data of observation on high seas is not normally available but can be had through ships on high seas in the region during cyclone. Weather satellite data could also be used for this purpose. The Indian National Oceanographic Data Centre (INODC) of the National Institute of Oceanography (NIO) has meteorological data reported by research.

4.5.2 Cyclone Data

Two types of cyclones (tropical and extra-tropical) are generally observed in the world. However with reference to Indian conditions we need to consider only tropical cyclones.

Characteristics of PMTC to be used as input for the analysis of storm surges include:

- minimum central pressure and associated peripheral pressure, P (millibars),
- maximum sustained wind speed V_{max} (kmph),
- wind fetch, D,
- radius of the wall of maximum winds R (km),
- duration of storms and associated winds T (hours),
- direction and speed of movement of the storm i.e. the storm track and particularly the point at which storm track is closest to or crosses the coast,
- angle between translation velocity vector and primary radius of wind speed distribution (degrees),
- wind speed along a cross-section from the moving storm centre to the periphery of moving storm (kmph), and

- path of cyclone translation with respect to coastline.

Data on oceanography, meteorology, and hydrology needed for surge height calculations can be obtained from appropriate governmental agencies such as the IMD, the NIO and the local governmental bodies.

4.5.3 Bathymetry Data

Waves generated in deep sea are not affected by the bottom of the sea. But as the surge wave travels towards shallow waters, the sea bottom surface plays a vital role in modifying surge height. It is, therefore, essential to have data of sea bottom topography as well as characteristics of the sea bottom in terms of roughness. This data on the bathymetry, is normally available from the admirality charts or from NIO.

Bathymetry of coastal region fronting NPP is needed. Bathymetry maps are generally available for 1m intervals up to 6m depth and at 3m intervals up to about 50m depth. Bathymetric data for deeper seas is normally available from existing nautical navigation charts.

5. WAVE RUN-UP

5.1 Introduction

Waves generated in deep water will travel towards coast and get modified during its passage towards the coast, especially as they approach the shallow area near the coast. These waves after landing on the coast will travel over land and in so doing the land area which is above the high water level will get inundated. This is called the wave run-up.

5.2 Methodology of Estimation

The definition sketch for a wave run-up is given in Fig. 5.1. Wave of height H approaches the coast with slope ? and landfalls on the coast with slope ? ?R is the level to which the wave water will reach, where R is measured with respect to still water level (SWL) over which the wave travels. During cyclonic surge this will be the surge level superimposed over the astronomical tide level [14].

Run-up depends on beach shape (slope) and elevation, roughness of the coastal surface, water depth at the toe 'd_S'and incident wave characteristics viz. wave height H_0' and wave period T. A complete description of the wave run-up phenomena is lacking due to its dependance on many variables. Numerous laboratory investigations on smooth and impermeable slopes were conducted by Saville [15], while Dai and Kamel [16] investigated run-up on rubble backwaters and Savage [17] studied effects of structure roughness slope permeability on run-up. Saville [18] has generated curves using dimensionless parameters which can be used for estimating the relative run-up R/H_0' as a function of beach slope ? with ?, d_S/H_0' and H_0'/T as parameters. Typical curves with ? ?= 1/10 and d_S/H_0' values of 0, 0.45 and 0.8 are given in Fig. 5.2, Fig. 5.3 and Fig. 5.4. Knowing H_0'/T^2 (feet/sec^2) and slope of the beach one can find the relative run-up R/H_0' and hence R. As the roughness effect cannot be accurately reproduced in the laboratory models, a further correction factor has been suggested to adjust for scale effect. This can increase the run-up by about 10% .

Wave height H_0' which is to be used in the estimation of wave run-up is the significant wave height. Significant wave height is the average of one third of highest waves of a wave group. The composition of higher waves depends on the extent to which lower waves are considered. Experience indicates that a careful observer who attempts to establish the character of the higher waves will record values which approximately fit the definition of the significant wave height.

If a typical smooth faced shore with ? as 1/10 is subjected to a design wave having a period T=8 sec and an equivalent deep water wave height (significant wave height) H_0' = 5 ft. The depth at the structure toe is d_S = 4 ft, and the slope is 1:3 i.e.tan ? = 0.33 or cot ?? = 3. Then,

$d_S/H_0' = 4/5 = 0.8$,

$H_0'/(gT^2) = 0.00244$ where g is acceleration due to gravity.

From Fig. 5.4 which is a typical curve for $d_S/H_0' = 0.8$, it can be seen that R/H_0' corresponding to cot ?? = 3 and $H_0'/(gT^2) = 0.00244$ is 2.8. Correction for effect of scaling during laboratory experiments is given in Fig. 5.5 for various values of ?. The value of this factor corresponding to cot ?? = 3 from Fig. 5.5 is 1.11

The final value of the run-up R = (2.8)(1.11)(5)
= 15.2 ft.

It can be seen from Fig. 5.4 that the value of run-up can vary from

R = (4)(1.17)(5)
= 23.4 ft (for cot ? = 1.25),

to

R = (0.8)(1.03)(5)
= 4.12 (for cot ? = 10).

This indicates that wave run-up can be suitably modified by changing the value of ?. Similarly, if it is possible to change the value of the parameter d_S at the site, then also the wave run-up gets suitably modified. This is evident from Fig. 5.2, Fig. 5.3 and Fig. 5.4. It can be seen that for cot ? value of 3, the values of R/H_0', for $H_0'/(gT^2)$ value of 0.00244 corresponding to d_S/H_0' values of 0, 0.45 and 0.8 are 1.5, 2.1 and of 2.8.

Some work has been carried out using rough surfaces and nomograms for these are also available. However, these cover the range of $d_S/H < 3$.

To provide necessary design guidance Battjes [19], and Ahrens [20] have suggested use of roughness and porosity correction factor. This roughness and porosity correction factor r is the ratio of run-up on a rough permeable surface to run-up on a smooth impermeable slope. Values of this correction factor for some typical surfaces are given in the table below.

Table 5.1 Values of r for various slope surface characteristics [19]

Slope surface characteristics	**Placement**	**r**
Smooth, impermeable	-	1.00
Concrete blocks	Fitted	0.90
Basalt blocks	Fitted	0.85 to 0.90
Gobi blocks	Fitted	0.85 to 0.90
Grass	-	0.85 to 0.90
One layer of quarry stone (impermeable foundation)	Random	0.80
Quarrystone	Fitted	0.75 to 0.80
Rounded quarry stone	Random	0.60 to 0.65
Three layers of quarry stone (impermeable foundation)	Random	0.60 to 0.65
Quarry stone	Random	0.50 to 0.55

Concrete armor units	Random	0.45 to 0.50

5.3 Oceanographic and Hydrographic Data

In surge analysis, the wind-generated waves form a major part. Wind field will generate spectra of wave heights and periods. Maximum wave height and period will vary depending on wind speed, duration, direction and fetch over which it blows. In shallow waters the maximum wave height depends on the depth of water. These parameters keep constantly changing during movement of the storm towards the coast. In determining the wave effect, the following studies should be conducted:

- wind field generating the waves,
- offshore wave generation,
- offshore and near shore wave transformation, and
- near shore wave spectrum.

The wind field of cyclonic storm is identified and the deep ocean waves are computed. Transformation of deep water waves as they move to the shallow water due to bottom friction, shoaling, refraction, reflection, diffraction, breaking and regeneration is considered. Critical wind fields are established by studying the wind vectors along critical fetches for various time durations taking the movement of storm towards the site.

5.4 Coastal Data

When a wave comes to the coast it travels up the coast. The topography as well as roughness of the coast modify the wave features. The following data for coastal region is essential:

- a detailed contour map of the area in the vicinity of the site;
- land cover and the roughness factor of the coastal region;
- general slope of the coast; and
- changes in beach configuration.

This data is also needed for estimating wave run-up.

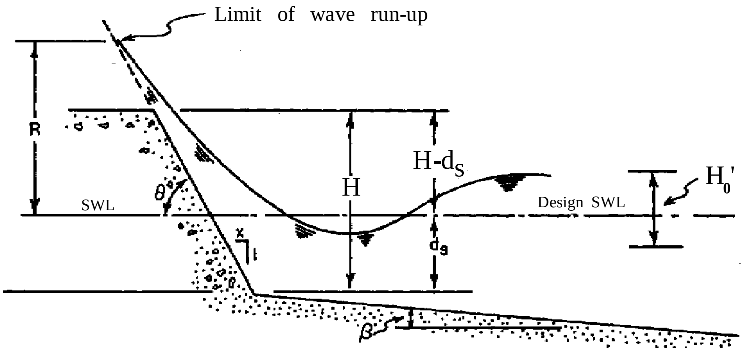


Fig. 5.1 WAVE RUN-UP [14]

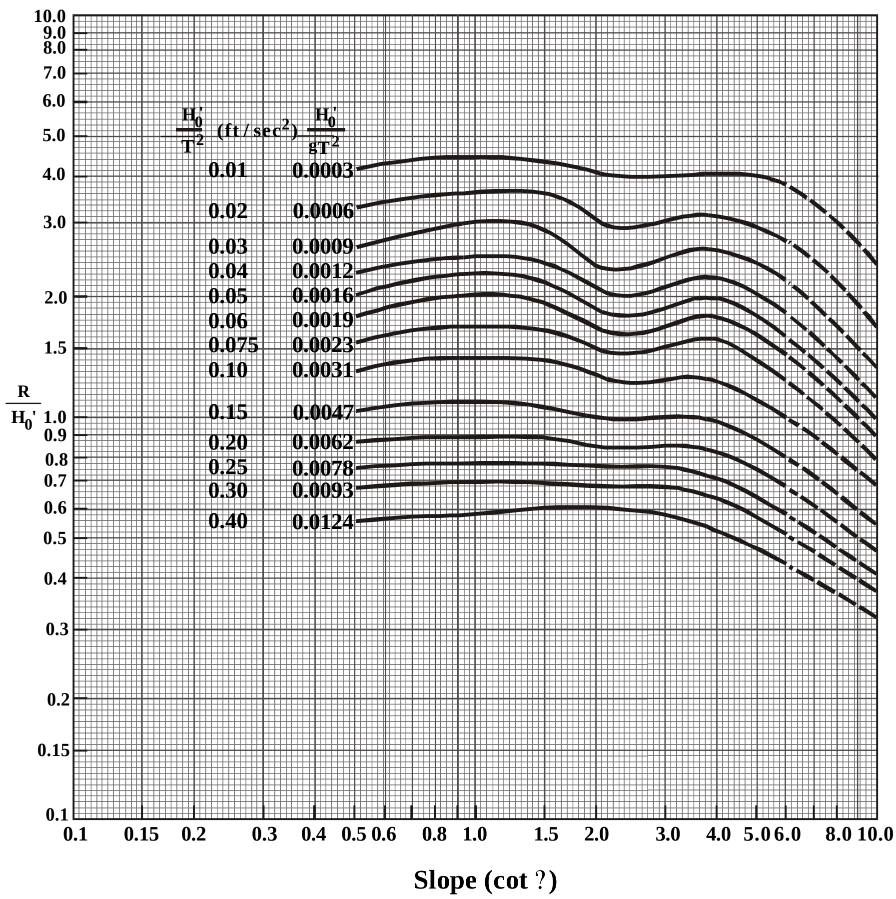


Fig. 5.2 WAVE RUN-UP ON SMOOTH IMPERMEABLE SLOPES $d_S/H_0' = 0$ (STRUCTURE FRONTED BY A 1:10 SLOPE) [14]

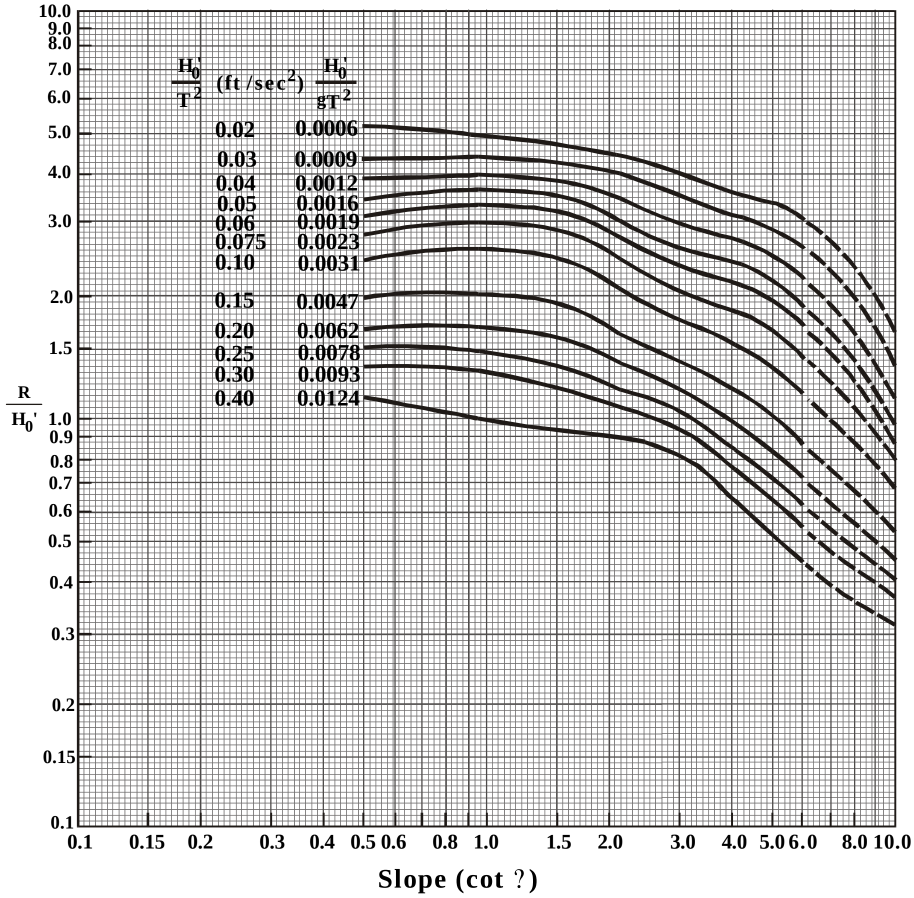


Fig. 5.3 WAVE RUN-UP ON SMOOTH IMPERMEABLE SLOPES d_S/H_0'= 0.45 (STRUCTURE FRONTED BY A 1:10 SLOPE)[14]

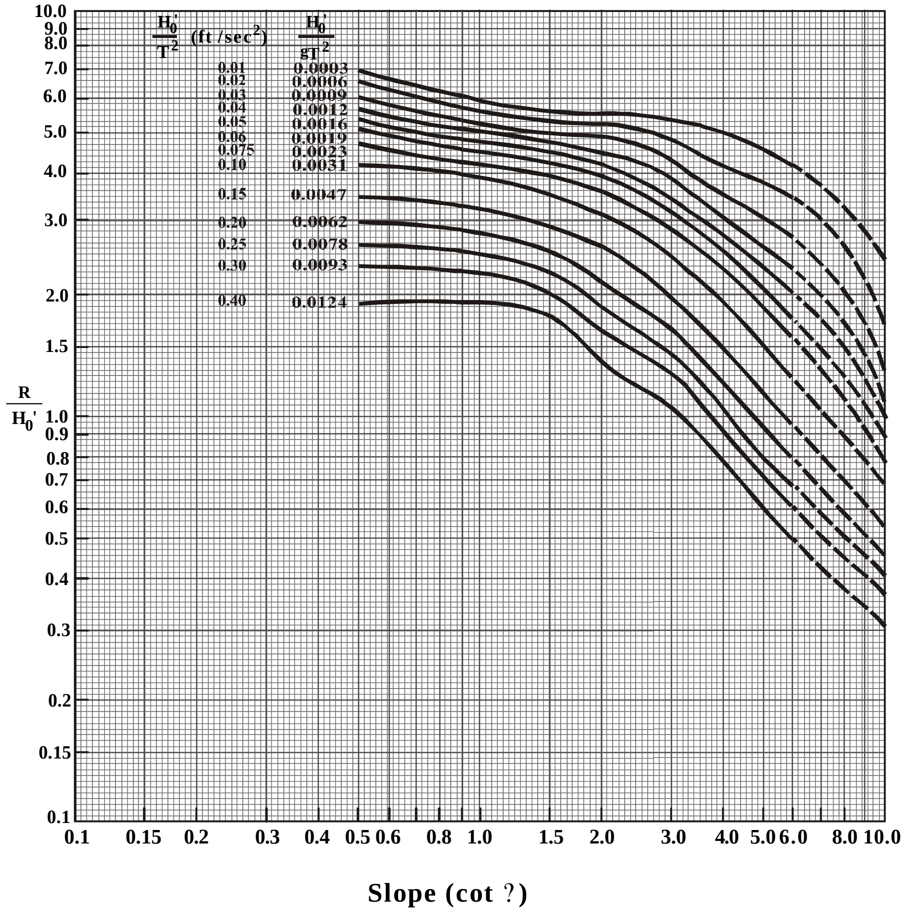


Fig. 5.4 WAVE RUN-UP ON SMOOTH IMPERMEABLE SLOPES d_S/H_0'= 0.80 (STRUCTURE FRONTED BY A 1:10 SLOPE)[14]

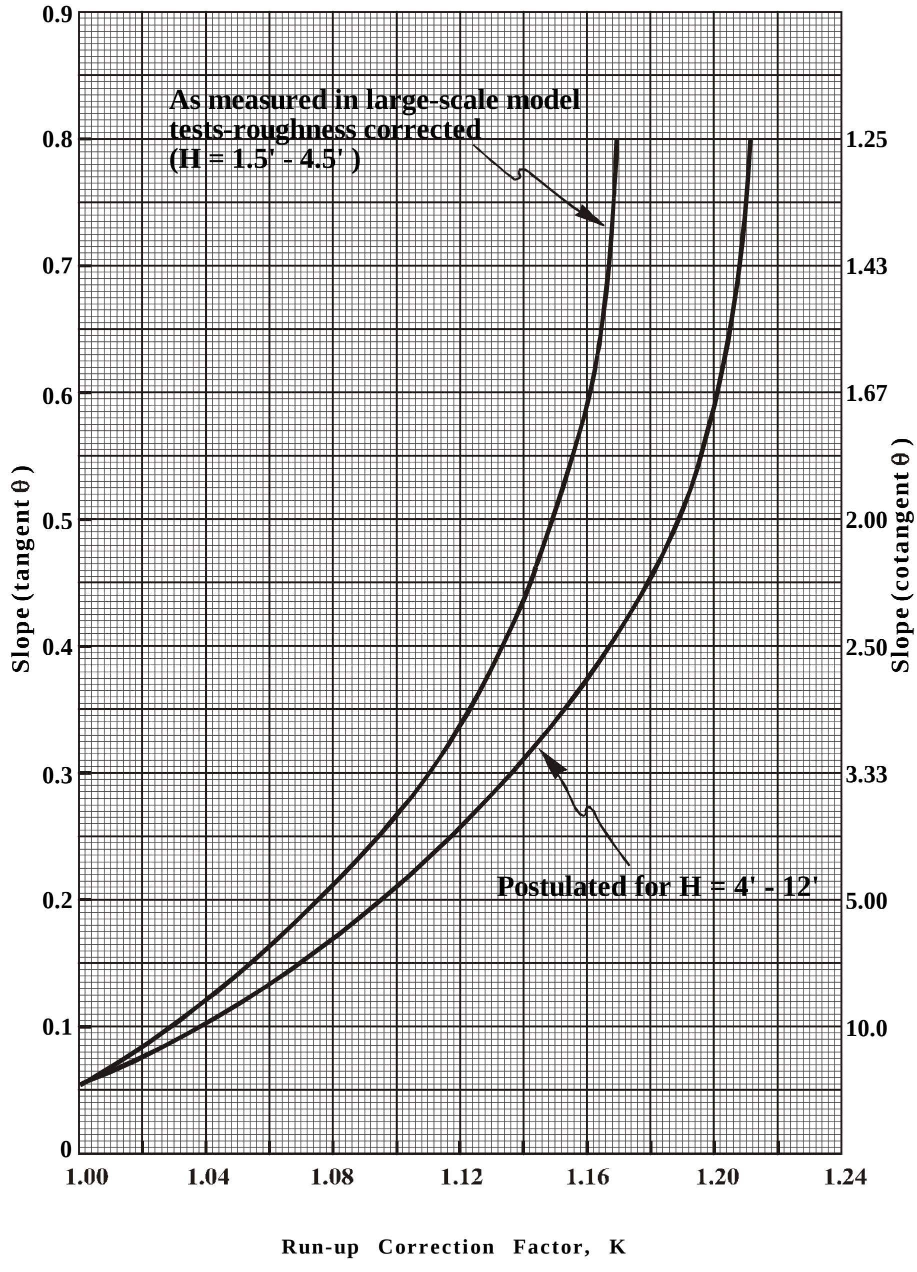


Fig. 5.5 RUN-UP CORRECTIONS FOR SCALE EFFECTS [14]

6. DESIGN BASIS FLOOD LEVEL

6.1 General

Computation of design basis flood water level (DBFL) needed for site selection and safety consideration consists of three parts:

(i) astronomical tide (H_1)

(ii) surge height (H_2)

(iii) wave run-up (H_3)

$$R = H_2 + H_3$$

6.2 Astronomical Tide

Tide level has a diurnal variation going through low tide and high tide water level. The highest and lowest tide levels vary during the year as well as on the general location of the site. For maximising purposes, the highest tide level corresponding to the site is selected and this value is increased by 10% to account for future variation.

6.3 Surge Height

Surge height calculations, arrived at following the procedures given in chapter 4, give the surge height over the mean sea level. This surge height will be superimposed over the tide level.

6.4 Wave Run-up

The effective water level of the flood reaching the coast will be the sum of surge height and tide level. This flood wave when it falls on land, will travel over the land (wave run-up) to a certain extent and the water level reached due to this will depend on the coastal topography, surface roughness etc.

Thus the final water level to be considered for safety considerations is the total sum of astronomical tide, surge height, and wave run-up, i.e.

$$DBFL = H_1 + H_2 + H_3.$$

7. FLOOD PROTECTION ASPECTS

7.1 General

The action of water on structures is static and/or dynamic. While considering flood protection aspects of structures, care must be taken to assess the stability of these structures against dynamic and static pressures generated as a result of the surge wave and the flood water level. Apart from this, these structures are likely to affect the reflection and refraction effects on the coast and thus may modify the erosion and depositional patterns along the coast. A detailed study of these effects on plant safety needs to be looked into. This has been described in detail in the Shore Protection Manual Vol. II [14].

Protection of a NPP from Probable Maximum Storm (PMS) may be achieved by the following methods:

(i) Construct all items important for safety above the level of PMS. This can be achieved by locating the plant at a sufficiently high elevation or by raising the ground with appropriate structures to hold up the raised levels.

(ii) Construct permanent barriers such as levees or dikes. While designing such structures care shall be taken to assure safety of such structures against static and dynamic pressures of the flood wave as well as the wind and seismic loading. Analysis shall be carried out to study the effects of such structures on depositional and erosional patterns and on the safety of site from these effects.

7.2 Monitoring and Warning for Plant Protection

It is necessary to collect data on various cyclones occurring in and around the region during the lifetime of the plant. Appropriate monitoring and warning systems and procedures should be laid down and adhered to during the lifetime of the plant. Tie up with Regional Meteorological

Centres and co-ordination with organisations like the India Meteorological Department (IMD) should be institutionalised.

Coastal features undergo changes due to beach erosion over a period, while general tide water levels may change due to reasons like global warming. It is therefore advisable to review the data used for arriving at the flood water levels once in ten years.

APPENDIX-I

MATHEMATICAL FORMULATION

Equations that describe the storm surge generation processes are the continuity equation expressing conservation of mass and equation of motion expressing Newton's second law of motion. The equations of motion and continuity given below represent a simplification [13]. See Fig.I.1

The following simplifications are assumed:

(a) vertical accelerations are negligible,

(b) curvature of the earth and effects of surface waves can be ignored,

(c) the fluid is inviscid and incompressible; and

(d) the bottom is rigid and impermeable.

The differential equations appropriate for tropical or extra-tropical storm surge problems on the open coast and in enclosed and semi-enclosed basins are as follows:

$$\frac{?U}{?t} + \underbrace{\frac{?M_{xx}}{?x} + \frac{?M_{xy}}{?y}}_{\text{Advection of Momentum}} = \underbrace{fV}_{\text{Coriolis}} \quad \underbrace{gD\frac{?S}{?x}}_{\text{Surface Slope}} + \underbrace{gD\frac{??}{?x}}_{\text{Inverse Barometer}} + \underbrace{gD\frac{??}{?x}}_{\text{Astronomical Tide Potential}} + \underbrace{\frac{?_{sx}}{?}}_{\text{Wind Stress}} \quad \underbrace{\frac{?_{bx}}{?}}_{\text{Bottom Stress}} + \underbrace{W_xP}_{\text{Rainfall Rate}} \quad \text{(I.1)}$$

$$\frac{?V}{?t} + \frac{?M_{yy}}{?y} + \frac{?M_{xy}}{?x} = fU \quad gD\frac{?S}{?y} + gD\frac{??}{?y} + gD\frac{??}{?y} + \frac{?_{sy}}{?} \quad \frac{?_{by}}{?} + W_yP \quad \text{(I.2)}$$

$$\frac{?S}{?t} + \frac{?U}{?x} + \frac{?V}{?y} = P \quad \text{(I.3)}$$

where

$$M_{xx} = {}^{S}_{d}\, u^2dz; \quad M_{yy} = {}^{S}_{d}\, v^2dz; \quad M_{xy} = {}^{S}_{d}\, uvdz; \quad U = {}^{S}_{d}\, udz; \quad V = {}^{S}_{d}\, vdz;$$

The symbols are defined as:

U, V = x and y components, respectively, of the volume transport per unit width:

t = time;

M_{xx}, M_{yy}, M_{xy} = momentum transport quantities;

f = 2? sin ??= Coriolis parameter;

? = angular velocity of earth (7.29 x 10^{-5} radians/second);

? = geographical latitude;

$?_{sx}$, $?_{sy}$, = x and y components of surface wind stress;

$?_{bx}$, $?_{by}$, = x and y components of surface wind stress;

? = mass density of water;

w_x, w_y, = x and y components of wind speed;

? = atmospheric pressure deficit in head of water;

? = astronomical tide potential in head of water;

u,v = x and y components, respectively, of current velocity;

p = precipitation rate (depth/time);

g = gravitational acceleration; and

? = angle of wind measured conter-clockwise from the x axis.

S = surge above still water level (SWL),

d = depth of SWL,

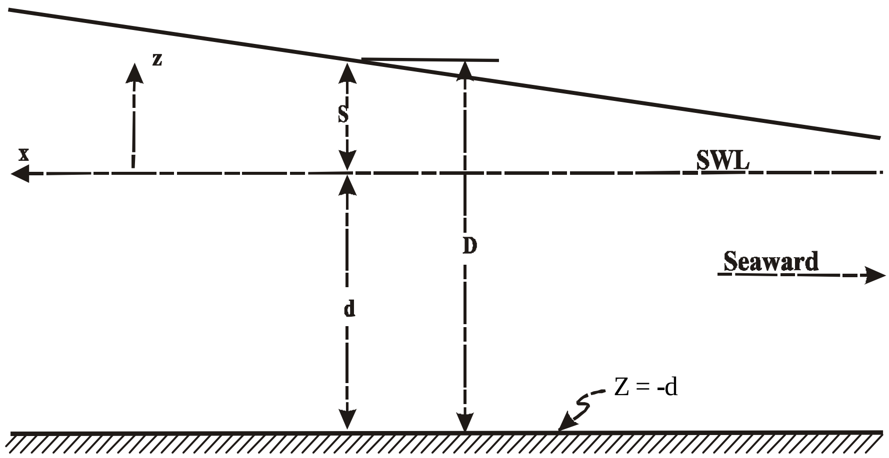
D = S+d.

S,d,D are as shown in Fig. I.1

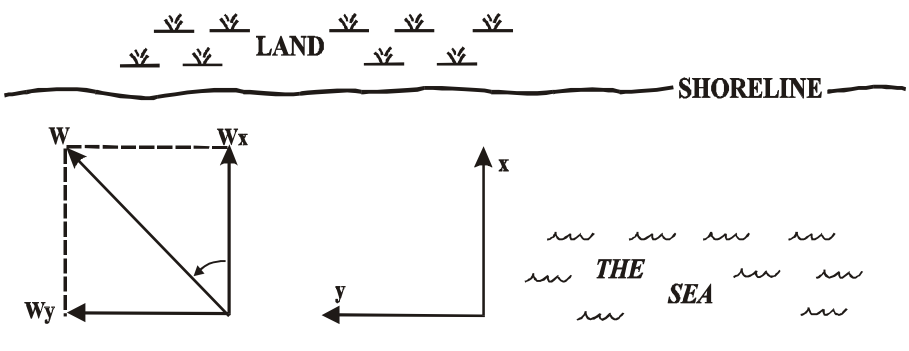
x,y,z are coordinates as shown in Fig. I.1

Equations (I.1) and (I.2) are approximate expressions for the equation of motion and equation (I.3) is the equation for continuity. These basic equations provide, for all practical purposes, a complete description of water motions associated with nearly horizontal flows such as storm surge problem.

A more simplified form is obtained by vertically integrating all governing equations and then expressing everything in terms of either mean horizontal current velocities or volume flow. These equations are generally preferred as the interest is in free surface motion and mean horizontal flow.



PROFILE



PLAN VIEW

FIG. I.1 PROFILE AND PLAN VIEW OF SHORELINE [14]

APPENDIX-II

NOMOGRAM METHOD

Peak surge depends predominantly on the central pressure of a cyclone, bathymetry and direction of cyclone land fall vis-a- vis the coastal line and to some extent on the radius of maximum wind and coriolis parameter. Actually it is the pressure drop at the centre of the storm that is the imporant parameter and not the actual pressure. The solution from a dynamic modelling described in earlier Appendix-I is complicated and time consuming.

IMD has carried out the exercise for solution of some standard storm scenario for various sections of the Indian coast and has generated nomograms which can be used for estimation of surge height for a typical input cyclone. Various approximations involved in generation of these nomograms can be seen from references [13, 25].

Nomograms in Fig. II.1a and II.1b give the relation of surge height as a function of pressure difference with radius of maximum winds as a parameter. With this nomogram knowing the pressure difference and radius of the maximum wind speed both of which are parameters of the cyclone, surge height can be estimated.

Nomogram in Fig. II.2a and II.2b give relation of wind speed and the angle of land falling vis-a-vis the coastal line and the correction factor (F_M) to be incorporated for the effects of these two parameters. When the shoaling-corrected surge heights are further corrected for this effect, one arrives at the final surge height for the typical storm for the specific site with specific land falling angle.

Initial work of IMD [13] gave the shoaling factor correction only for east coast north of 10°N. However, this has been extended to the entire east coast in a later publication [25] and is given in the nomogram in Fig. II.3a.

Nomogram in Fig. II.3b relates the correction factor for shoaling effect along the south-east coast. While generating this nomogram the average bathymetric data has been considered for the basin under consideration for various locations along the coast. Shoaling factor for the appropriate location for the specific site can be found out from this nomogram and the surge height arrived at using the first nomogram can be multiplied to get the shoaling-corrected surge height.

Typically if the pressure depression ?P in the cyclone at a site is 50 millibars, for a radius of maximum wind speed of 48 kms, the expected surge height observed from Fig. II.1a will work out to 5.3 meters. If the translation speed of the cyclone is 30 kmph and incidence angle is 90^o, the correction factor for this can be found out from Fig. II.2a to be 1.05. If this storm is landfalling somewhere on the coast around Kakinada the shoaling factor will be 0.9 (Fig. II.3b).

Thus the expected surge will be = (5.3)(1.05)(0.9) meters.
= 5.03 meters.

It can be seen that shoaling factor correction varies from place to place and variations could be by a factor of 2. It is therefore necessary to run the numerical model inputting the actual local bathymetry and topography data to get more reliable results.

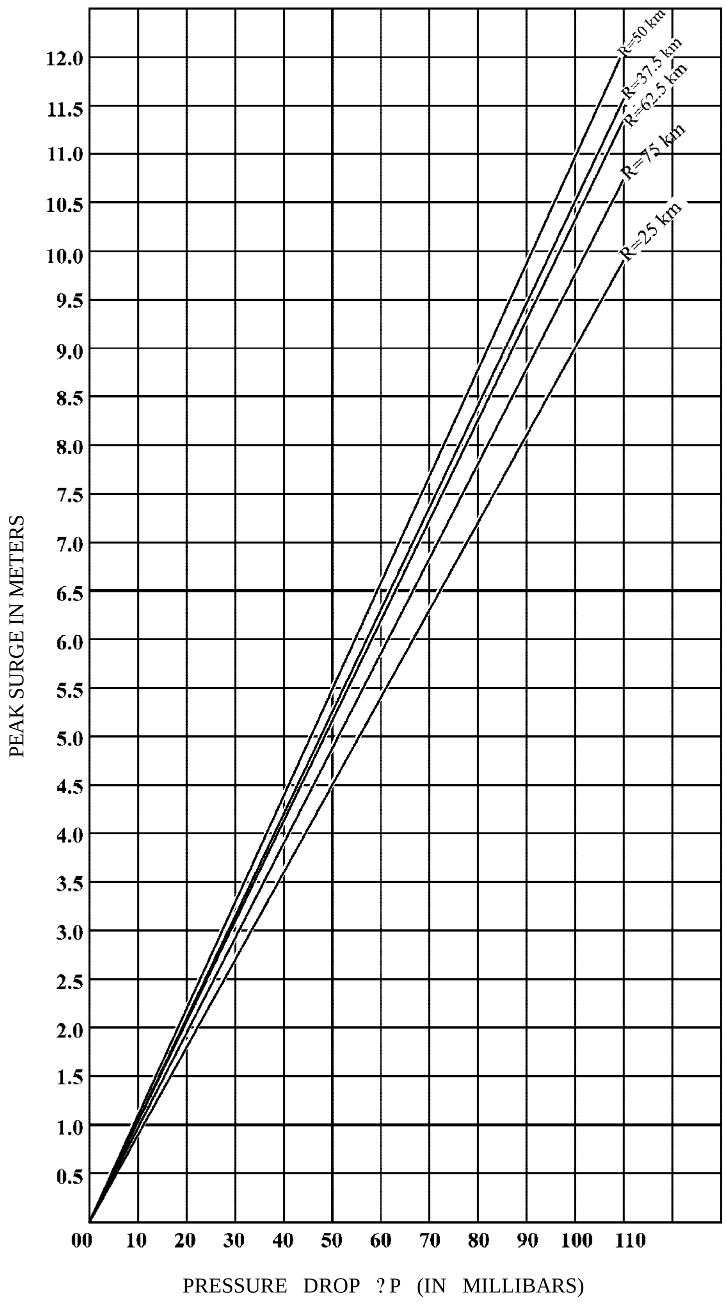


Fig. II.1a NOMOGRAM OF PEAK SURGE AS A FUNCTION OF PRESSURE DROP AND RADIUS OF MAXIMUM WINDS FOR THE NORTH-EAST COAST OF INDIA [13]

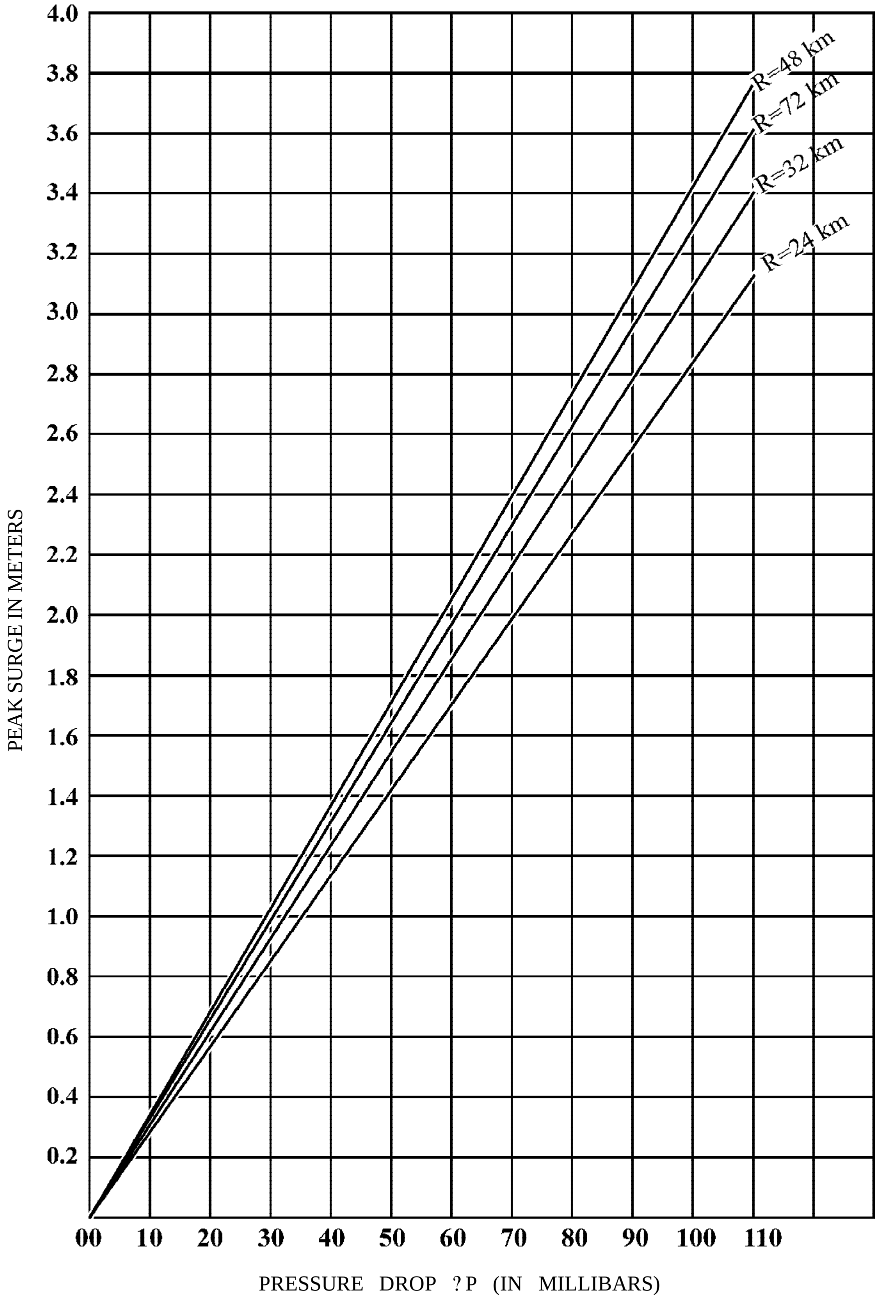
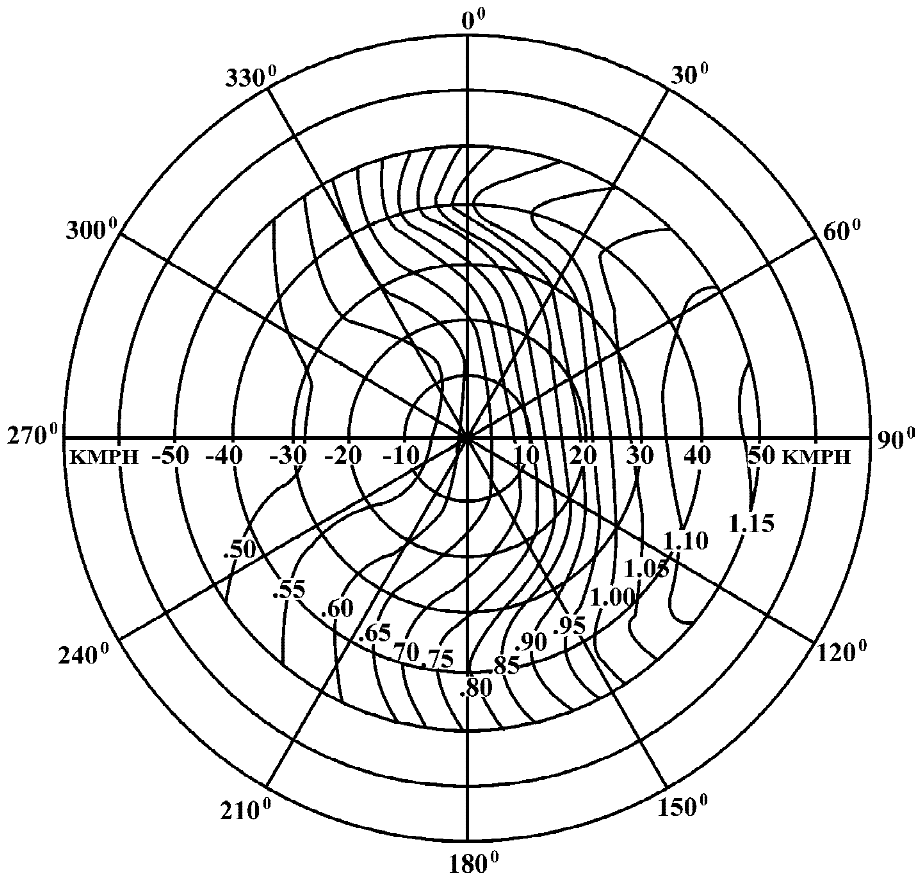


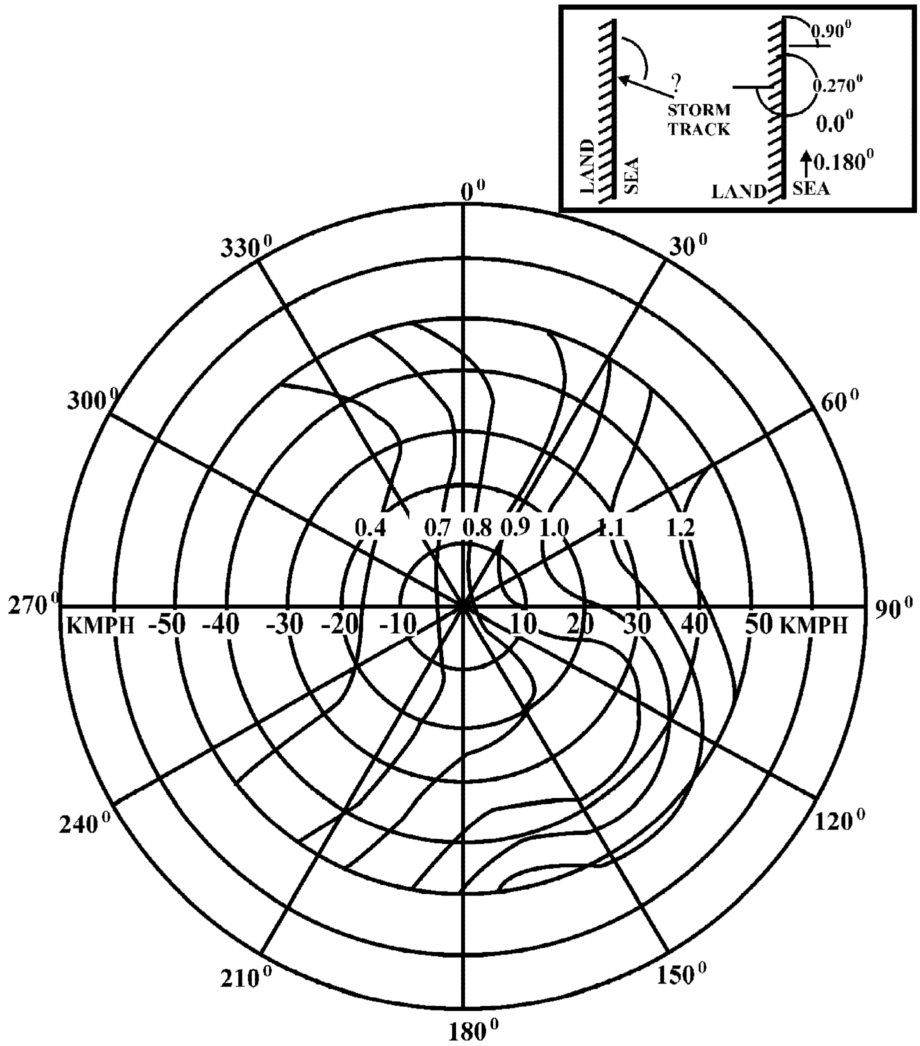
Fig. II.1b NOMOGRAM OF PEAK SURGE ON THE OPEN COAST AS A FUNCTION OF PRESSURE DROP AND RADIUS OF MAXIMUM WINDS FOR THE SOUTH-EAST COAST OF INDIA [25]



CORRECTION FACTOR, F_M'

Fig.II.2a NOMOGRAM OF CORRECTION FACTORS FOR VECTOR STORM MOTION FOR THE NORTH-EAST COAST OF INDIA [13]

Note: Radii are storm speeds and rays are crossing angles of storm track to the coast, ?, Radius of maximum wind, 50 km



CORRECTION FACTOR, F_M

Fig.II.2b NOMOGRAM OF CORRECTION FACTORS FOR VECTOR STORM MOTION FOR THE SOUTH-EAST COAST OF INDIA [25]

Note: Radii are storm speeds and rays are crossing angles of storm track to the coast, ?, Radius of maximum wind, 48 km

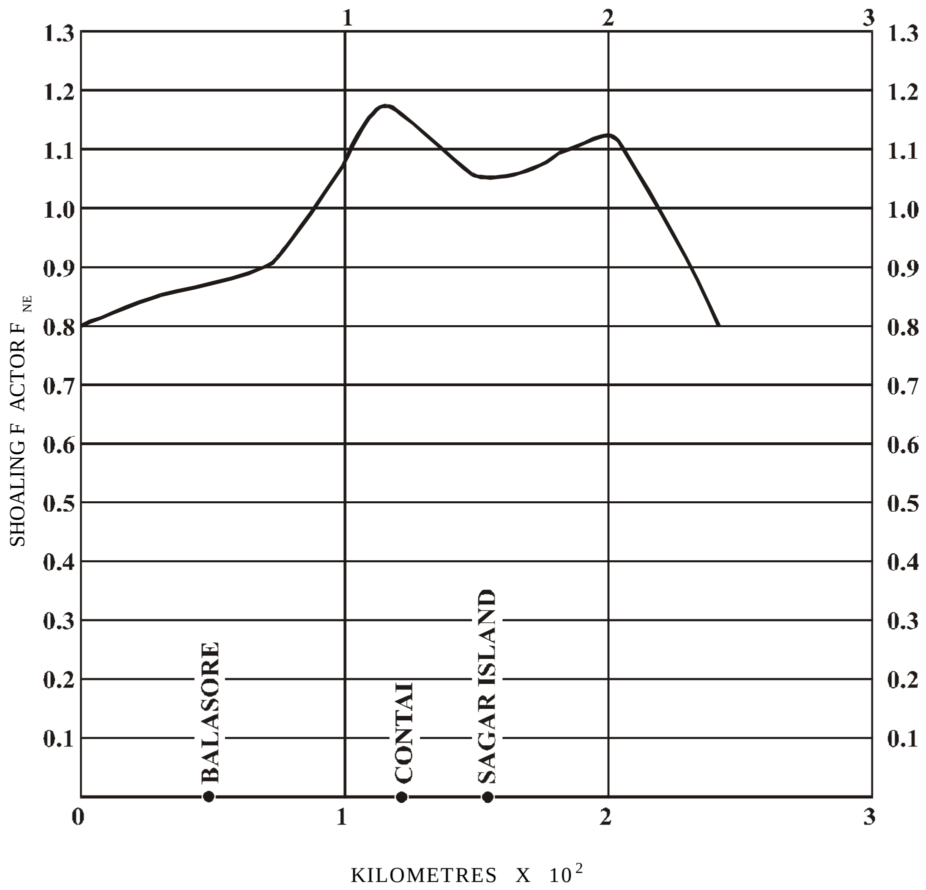


Fig.II.3a NOMOGRAM FOR SHOALING FACTORS FOR NORTH-EAST COAST OF INDIA [13]

Note : The actual bathymetry and shape of coast line changes the surge height values arrived at from nomograms given in Figs. II.1a and II.1b as the nomograms use only straight coastal boundaries.

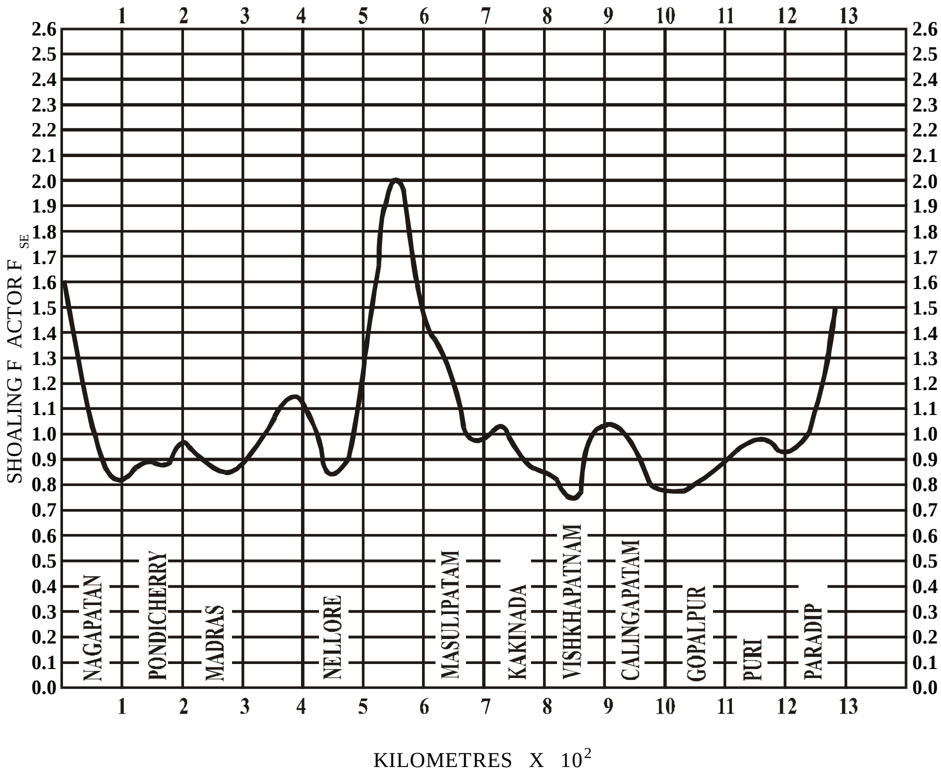


Fig.II.3b NOMOGRAM FOR SHOALING FACTORS FOR SOUTH-EAST COAST OF INDIA [25]

ANNEXURE-I

INDIAN CYCLONE DATA [21-26]

Tropical cyclones are large vortices in the atmosphere extending from 100 km to 1000 km in the horizontal direction with fierce winds spiralling around the central low pressure area.

Tropical cyclones have different names in different areas of the globe. They are known as “hurricanes” in North Atlantic, Carribean sea, Gulf of Mexico and Eastern Pacific, ‘typhoons’ in Western North Pacific and South Pacific, Willy-Willies in Australia, Baguio or Saruio in Philippines and ‘cyclones’ in India.

Intensity of cyclonic disturbance is measured either by central depression or by associated maximum wind speeds.

Tropical Disturbance		Wind speed in kmph
(i)	Depression	32-50
(ii)	Deep depression	51-60
(iii)	Cyclonic storm	61-89
(iv)	Severe cyclonic storm	90-119
(v)	Severe cyclonic storm with core of hurricane winds	> 119

In comparison with world data 13% storms occur in North Indian Ocean while 10% occur in South Indian Ocean. On an average, annually around 6 storms generate in the Bay of Bengal during April to June, around 2 storms in the Arabian sea during September to December and around 6 storms in South Indian seas. During the period of 100 years (1877-1976) around 447 cyclonic and 165 severe cyclonic storms occurred in the Bay of Bengal. Their month-wise break up is given below:

MONTH-WISE BREAK UP OF STORMS IN THE BAY OF BENGAL DURING 1877-1976

Month	Cyclonic Storms	Severe Cyclonic Storms
January	5	1
February	1	1
March	4	2
April	20	9
May	49	32
June	42	4
July	48	7
August	30	3
September	44	16
October	76	29
November	86	43
December	42	18
Total	447	165

Between 1891 and 1977 the Bay of Bengal generated about 400 cyclonic storms with different degrees of intensity. The effect of these storms are more pronounced in the states of West Bengal, Orissa, Andhra Pradesh and Tamil Nadu. Records indicate that Andhra Pradesh suffered the maximum. During this period the Andhra coast was subjected to 57 cyclonic storms. District-wise break up is given in the following table.

DISTRICT-WISE BREAK UP OF STORMS ON COASTAL ANDHRA PRADESH

District	Cyclonic Storms	Severe Cyclonic Storms
Nellore	10	5
Prakasam	4	2
Guntur	-	1
Krishna	7	7
West Godavari	1	-
East Godavari	7	1
Vizag	-	2
Srikakulam	5	5
Total	34	23

Note: The above data has been collected from references [21-24]

EXTREME VALUES OF TROPICAL CYCLONE PARAMETERS FOR DIFFERENT RETURN PERIODS OVER SELECT MARITIME STATES [21]

Maritime States	Parameters	Return period (years) (Probability given within brackets)				
		10 (.90)	25 (.96)	50 (.98)	100 (.99)	200 Y (.995)
1 Tamil Nadu	P(mb)	36	45	52	58	65
	V_{max}(Knots)	85	95	102	108	115
	Peak surge(m)					
	North of 10^0N	2.2	2.7	3.0	3.4	3.7
	South of 10^0N	4.8	5.9	6.6	7.5	8.1
2 Andhra Pradesh	P(mb)	54	64	70	76	83
	V_{max}(Knots)	104	113	119	125	129
	Peak surge(m)	3.8	4.2	4.8	5.2	5.6
3 Orissa	P(mb)	39	54	63	73	84
	V_{max}(Knots)	89	104	113	121	130
	Peak surge(m)					
	South of 20.5^0N	2.0	2.7	3.2	3.8	4.4
	North of 20.5^0N	5.1	6.4	6.9	8.8	10.4
4 West Bengal	P(mb)	40	55	67	78	90
	V_{max}(Knots)	90	105	116	125	135
	Peak surge(m)	4.5	6.3	7.8	9.2	10.9
5 Maharashtra	P(mb)	26	32	36	40	44
	V_{max}(Knots)	72	80	85	90	94
	Peak surge(m)	1.1	1.4	1.6	1.8	2.0
6 Gujarat	P(mb)	38	45	50	55	61
	V_{max}(Knots)	88	95	100	105	111
	Peak surge(m)	1.9	2.2	2.4	2.6	2.9

SURGES ALONG THE TAMIL NADU COAST [21 TO 25]

Year and Regions affected	Cyclone Description		Surge Parameters and Impact		
	Maximum wind (kmph)	Pressure drop	Surge (Height)	Inland Penetration	Damages, Loss of Human Life
1 November 1681 Nagapatnam				Seawater entered into port	14000 people died
2 December 1709 Coastal Ramnad					Thousands perished
3 December 1760 Pondicherry					1100 people perished
4 December 1807 Madras City				George Town inundated	Whole city was destroyed
5 May 1811 Very near Madras					
6 November 1871 Nagapatnam					40 people died
7 November 1952 South of Nagapatnam			3m	5miles	Several thousand died

SURGES ALONG THE TAMIL NADU COAST [21 TO 25] (contd.)

Year and Regions affected		Cyclone Description		Surge Parameters and Impact		
		Maxi-mum wind (kmph)	**Pressure drop**	**Surge (Height)**	**Inland Penetra-tion**	**Damages, Loss of Human Life**
8	December 1955 Rajamdam (Tanjore Dt.)	200	60 hpa	10-15'	2 to 5 miles	500 human loss
9	October 1963 Cuddalore	139	27 hpa	20'		
10	December 1964 Rameswaram Island	193	970 mb (20 hpa)	3 to 5 m		1000 people died
11	December 1967	130	988 mb (25hpa)		Tanjore district between 10^0 N and 11.3^0 N affected	
12	November 1978 Ramanathapuram	212	938 mb	3 to 5 m		10 deaths in India
13	November 1991 Near Karaikal	89	11		200-250 m	
14	December 1993 Near Karaikal	133	26 hpa	3 to 4 m	22 Km in land	

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LIST OF PARTICIPANTS

COMMITTEE TO PREPARE GUIDES AND MANUALS FOR SAFETY IN NUCLEAR POWER PLANT SITING (CPSGS)

Dates of meeting	:	September 22, 1993 January 30, 1995 February 17, 1995 May 29, 1997 September 22, 1997

Members and invitees participating in the meetings:

Shri S. Krishnan (Chairman)	:	NPCIL
Dr. V.N. Bapat*	:	BARC
Dr. A.K. Ghosh	:	BARC
Shri M.M. Tilak	:	NPCIL (Formerly)
Shri G.K. De (Member-Secretary till 16.12.1998)	:	AERB (Formerly)
Dr. T.M. Krishnamoorthy	:	BARC
Shri S.T. Swamy	:	AERB
Shri K. Srivasista (Member-Secretary)	:	AERB

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Date of meeting	:	July 31, 1999

Members and invitees participating in the meeting:

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Dr. V. Venkat Raj	:	BARC
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Shri S.T. Swamy	:	Invitee
Shri K. Srivasista (Member-Secretary)	:	AERB

PROVISIONAL LIST OF SAFETY GUIDES UNDER SITING

Safety Series No.	Title
SC/S	Code of Practice on Safety in Nuclear Power Plant Siting
SG/S-1	Meteorological Dispersion Modelling
SG/S-2	Hydrological Dispersion of Radioactive Materials in Relation to NPP Siting
SG/S-3	Extreme Values of Meteorological Parameters
SG/S-4	Hydrogeological Aspects of Siting of Nuclear Power Plants
SG/S-5	Models for Radiation Dose Computation Methodologies from Radioactivity Concentrations in Environment
SG/S-6A	Design Basis Flood Nuclear Power Plants on Inland Sites
SG/S-6B	Design Basis Flood for Nuclear Power Plants at Coastal Sites
SG/S-7	Man-Induced Events and Establishment of Design Basis Events
SG/S-8	Influence of Site Parameters on Emergency Preparedness
SG/S-9	Population Distribution and its Analysis in Relation to Siting of NPPs
SG/S-10	Quality Assurance in Siting
SG/S-11	Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites

NOTES