AN ASSESSMENT OF WIND LOADING AND WIND ENERGY POTENTIAL FOR SRI LANKA

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(168004K)

Degree of Master of Philosophy

Department of Civil Engineering

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DECLARATION OF THE CANDIDATE & SUPERVISOR

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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DEDICATION

I will dedicate this dissertation to Dr. C. S. Lewangamage, my supervisor and mentor, as the person who always encouraged me to complete this study successfully.

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24.06.2019

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ABSTRACT

It was more than 40 years ago that Sri Lanka last established a wind loading map after the severe cyclone that struck the country in 1978. It is strongly believed that statistical methods had not been used in developing this wind loading map. Hence, the map can either overestimate or underestimate the wind speeds at least in some of the regions of the country. Therefore, an updated map which suits the changing climate patterns experienced in the country has become a necessity. In Sri Lanka, different wind codes are being used when structures are designed to withstand wind actions. Moreover, there is no suitable wind loading map that can be used with the Eurocode 1 or BS 6399-2.

The existing wind resource maps for Sri Lanka have been developed in macro scales with low resolutions which is not adequate for effective decision making in wind power generation. Moreover, most of them represents wind speed distributions except for wind power distribution. Therefore, the industry always uses expensive methods to identify the suitable regions for the establishment of wind turbines.

As the initial stage of this study a wind loading map for Sri Lanka was developed for different return periods (5, 10, 50, 100, 200, 500 and 1000 years) and for different averaging time periods (3-second gust, 10-minute average and hourly mean) using the wind data obtained from 24 weather stations. The data used were the monthly maximums of 3-minute average and instantaneous maximum wind speeds, recorded over a period of about 35 years. Extreme value distributions called Gringorten and Gumbel methods were tested to predict the extreme wind speeds. Finally, the Gringorten methods was adopted due to its unbiased nature. The generated wind contours for both 3-second gust and 10-minute average basic wind speeds were analyzed for defining the wind loading zones for Sri Lanka.

Altogether a new wind power distribution map was proposed for Jaffna Peninsula region in Sri Lanka which has been previously identified as a region with a higher wind energy potential. The required data was obtained from SLSEA (Sri Lanka Sustainable Energy Authority) and the Survey Department of Sri Lanka. Computational Fluid Dynamics based model has been used for the generation of wind power distribution map. The resolution of the map has been increased up to 150 m x 150 m (5” x 5”). Coastal regions such as Veravil, Pooneryn, Ampan, Punkudutivu, Kayts, Kankesanturai, Ponnalli Khadu, Karainagar, Mandaitivu and Alvai were identified as the regions which have the highest wind energy potential in Jaffna Peninsula.

Keywords: Wind loading map for Sri Lanka, Wind loading zones, Basic wind speed, Gringorten method, Wind energy forecasting, Wind power distribution, Siting of wind farms, Jaffna Peninsula

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LIST OF ABBREVIATIONS

Abbreviation	Description
AWS	Automatic Weather Station
CEB	Ceylon Electricity Board
CFD	Computational Fluid Dynamics
DEM	Digital Elevation Model
DMC	Disaster Management Center
GEV	Generalized Extreme Value
LA	Louisiana
LKR	Sri Lankan Rupees
MS	Mississippi
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NERDC	National Engineering Research and Development Center
NREL	National Renewable Energy Laboratory
NWP	Numerical Weather Prediction
RMSE	Root Mean Square Error
ROB	Rough Observation Books
SLSEA	Sri Lanka Sustainable Energy Authority
TX	Texas
USD	United States Dollars
WAsP	Wind Atlas Analysis and Application Program
WMO	World Meteorological Organization
WPD	Wind Power Density
WRF	Weather Research and Forecasting

LIST OF SYMBOLS

A	Scale parameter
A_H	Average horizontal area of the object
e	The exponential constant (2.718)
$F_U(U')$	Cumulative probability distribution function of the maximum wind speeds over a defined period, for an example one year
g	The acceleration of gravity (9.8 ms^{-2})
$G_k(\alpha)$	$1/k$ times the incomplete gamma function of the two arguments $1/k$ and α^k
h	Height of the object
k	Shape factor
m	Rank
n	Number of records in the averaging interval
N	Size of the data set
p	Exponent of the power law of wind profile
P	Air pressure
P_0	Atmospheric pressure at the standard sea level (101 325 Pa), or the actual sea level adjusted pressure reading from a local airport
p'	Probability of non-exceedance
$P(u)$	Power curve
P_i	Power at the i^{th} node
P_{i+1}	Power at the $(i+1)^{\text{th}}$ node
$Pr(u)$	Probability density function of u
R'	The specific gas constant of air (287 $Jkg^{-1}K^{-1}$)
R	Return period
y	Reduced variant
S	Cross sectional area of the object facing the wind direction
T	Air temperature in Kelvins
u	Wind speed at hub height
U	Unknown wind speed at height z above ground

U_0	Known wind speed at a reference height z_0
U'	Wind speed
$U_{(1-min)}$	1-Minute average wind speed
$U_{(3-sec)}$	3-Second gust wind speed
$U_{(max)}$	Instantaneous maximum wind speed
$U_{extreme}$	Predicted extreme wind speed for a return period of R
u_i	Wind speed at the i^{th} node
u_{i+1}	Wind speed at the $(i+1)^{\text{th}}$ node
v_i	Wind speed
WPD	Unknown wind power density at height z above ground
WPD_0	Known wind power density at a reference height z_0
z	Site elevation above sea level
z	Height of wind measurement
z_0	Roughness length
Z_0	Aerodynamic roughness length
α	Power law exponent (For well exposed areas with low surface Roughness a value of 0.143 can be used)
ρ	Air density

LIST OF APPENDICES