第 I 部門 **Study on Countermeasures for the Wind-induced Vehicle Accident**

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1. Introduction

In this study, analysis on threshold-exceeding duration of wind is conducted for purpose of duration prediction of strong wind. In addition, mean wind speed and maximum wind velocity are estimated. Moreover, as a safety index, the overturning probability is calculated by considering the vehicle type.

2. Analysis on threshold-exceeding duration

Firstly, average duration of threshold wind speed exceedance is calculated by,

$$\bar{t}(a) = \frac{t_1(a)+t_2(a)+\cdots+t(a)}{j} \quad (1)$$

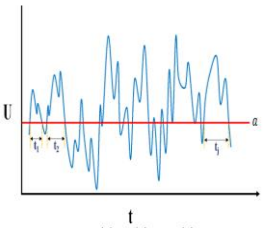

Fig. 1 The wind speed vs. time

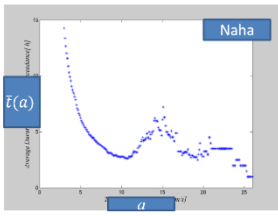

Fig. 2 $\bar{t}(a)$

In equation (1), a is threshold, t_i is threshold-exceeding duration, j is total number of threshold exceeding, $\bar{t}$ is average duration. Road administers can know how long on average a strong wind with speed larger than a continued in the history easily by analyzing Fig. 2.

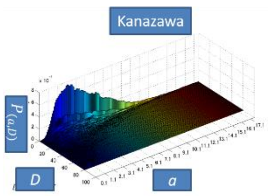

Fig. 3 $P_{(a,D)}$

Then, appearing probability distribution of the duration when threshold varies from the minimum wind speed to the maximum wind speed at interval of 0.1 m/s is analyzed. The distribution of probability is obtained by,

$$P_{(a,D)} = \frac{c_{(a,D)}}{\sum_{i=1}^{i=a_{max}}\sum_{j=1}^{j=D_{max}} c_{(i,j)}} \quad (2)$$

From the result in Fig. 3, administers of road could obtain the value of probability directly now. Based on this, prediction of duration will also become possible.

3. Wind speed prediction

Autoregressive Process (AR) model which is suitable for stationary process and Autoregressive integrated moving average Processes (ARIMA) model which is suitable for nonstationary process are firstly applied. AR model is represented as [1],

$$\tilde{z}_t = \phi_1\tilde{z}_{t-1} + \cdots + \phi_p\tilde{z}_{t-p} + a_t \quad (3)$$

where the symbols $\phi_1, \phi_2, \ldots, \phi_p$ is a finite set of autoregressive parameters of the time series $\tilde{z}_t$. ARIMA model is represented as,

$$\nabla^d\tilde{z}_t = \phi_1\nabla^d\tilde{z}_{t-1} + \cdots + \phi_p\nabla^d\tilde{z}_{t-p} + a_t - \theta_1 a_{t-1} - \cdots - \theta_q a_{t-q} \quad (4)$$

where ∇ is the differencing operator.

For Markov chain model, we assume the dynamic of the time series is full determined by the set of all transition probability $p(s_{k+1}|s_k,\ldots,s_{k-l+1})$. Delay vectors of dimension $m=l$ and unit time lag form the states onto which these transition probabilities are conditioned. Because of the smoothness of the transition probability, the future observations s_{k+1} of all delay vectors $\boldsymbol{s_k} \in \mathcal{U}_\varepsilon(\boldsymbol{s_n})$ which are neighbors of $\boldsymbol{s_n}$ in state space are subject to the same transition probability and form a finite sample of $p(s_{n+1}\,|\,\boldsymbol{s_n})$, Markov chain is written as[2],

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$$\hat{s}_{n+1} = \int s' p(s'|\boldsymbol{s_n}) ds' = \frac{1}{\|\mathcal{U}_{\varepsilon}(s_n)\|} \sum_{k:s_k \in \mathcal{U}_{\varepsilon}(s_n)} s_{k+1} \quad (5)$$

The prediction accuracy is measured by mean absolute error (MAE), mean square error (MSE), and correlation coefficient (R). Results for predicting one-step ahead 10-min mean wind speed at HeronIsland are shown in Table 1, with 15793 training data and 5264 testing data, ARIMA model showed the best prediction accuracy.

Table 1 Prediction accuracy

	AR	ARIMA	Markov chain
MAE	1.742	1.204	1.344
MSE	2.683	2.204	2.227
R	0.911	0.980	0.976

4. Evaluation of maximum instantaneous wind velocity

Based on the on-site data of wind, which was observed in the place close to Oomishima Bridge 10 minutes before the wind-induced track accident occurred in Oomishima Bridge on 2012, maximum instantaneous wind velocity is evaluated by,

$$\hat{U}_{\max} = U_a + g_d \sigma \quad (6)$$

where U_a is 10-min average wind velocity, g_d is peak factor and g_d=3, σ is the median of standard deviations, calculated by 3-s mean velocity for every 10-min duration, corresponding to U_a.

5. Safety assessment of overturning considering traffic

As the input vehicle weight and aerodynamic coefficients are determined randomly: for aerodynamic coefficients, factor of various vehicle types are firstly determined and factor of vehicles for a certain type is generated randomly according to uniform distribution, finally the aerodynamic coefficients are gained by multiplying the factors by the coefficients of a cuboid model, which simulates the overturned vehicle in Oomishima Bridge; the weight of vehicles is assumed to obey log-normal distribution. Based on the proportion (double lines) of vehicles belonging to different type for the Kobe-Awaji-Naruto Expressway and the assumption of a traffic flow with 10,000 vehicles, the probability of overturning is calculated 100 times and averaged for each case.

Results are shown in Fig.4 and Fig.5. The former corresponds to workday in February with 37.03 % total proportion of medium, large and oversize vehicle while the latter corresponds to holidays in May with 6.81% total proportion. The overturning probability is higher in Fig.4, which indicates that the safety countermeasure is more desired for road sections with high total proportion of medium, large and oversize vehicle.

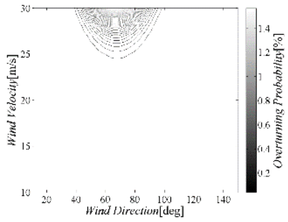

Fig.4 Workday in Feb.

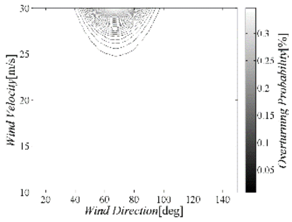

Fig.5 Holiday in May

6. Conclusion

1) $P_{(a,D)}$ is obtained by analyzing meteorological data, which will help road administers to provide more effective traffic regulation.

2) ARIMA model has the best prediction accuracy for the data from HeronIsland.

3) For the road section with high proportion of medium, large and oversize vehicles in the traffic, safety countermeasure is more desired.

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Reference:

[1] George E. P. Box, Gwilym M. Jenkins, Gregory C. Reinsel, “Time Series Analysis: Forecasting and Control, 4th Edition”, Chapter 3, 4, 6, June 2008

[2] Olle Häggström, “Finite Markov Chains and Algorithmic Applications”, Chapter2, 2002