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Conceptual weather environmental forecasting system for identifying potential failure of under-construction structures during typhoons

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ABSTRACT

In this study, we developed a conceptual weather environmental forecasting system (CWEFS) for predicting the failure of under-construction structures during typhoons. Major functions of the developed system include 1) forecasting hourly typhoon wind velocity, 2) analyzing structure reference load during the construction stage, 3) identifying potential failure of under-construction structures, and 4) evaluating the weather in future hours to determine whether the conditions are suitable for work. Data-driven models, namely support vector machines for regression (SVRs), regression, and two decision trees (namely C5.0 and CART) were employed in this study as forecasting techniques to predict the wind velocity on Orchid Island, Taiwan, the study site. Structure reference load analysis was performed using a finite element model to evaluate the reference load on an experimental tank under construction. Typhoons Nanmadol (2011) and Saola (2012) were selected for real-time simulation by using the proposed CWEFS. This study identified potential collapses by using 1- to 6-h-ahead wind speed predictions. However, prediction errors inevitably occur. The results showed that the SVRs provided excellent prediction accuracy compared with regression, C5.0, and CART regarding the average time error between the observed and predicted values in all structure scenarios. A high forecast time error might result in increased construction costs and delays in construction schedules. Thus, we suggest that shorter prediction windows (e.g., 1 and 2 h) and models with higher prediction accuracy (e.g., SVR and C5.0) be employed to create a reasonable warning system.

1. Introduction

The construction industry is statistically one of the most hazardous industries (Wang et al., 2006). Numerous structures fail during construction because calculations are based on the requirements of the complete structure, and sufficient provisions are not made to enable structures to withstand loads before completion (Jaca and Godoy, 2010). Extreme weather such as typhoons can generate violent winds and cause serious destruction on incomplete structures.

Generally, most typhoons are formed in warm, humid air between 10 and 25° latitude in both hemispheres; then, they move westward and pole-ward at a speed of 5–40 km/h. Strong winds inside a typhoon are clearly crucial for wind wave development (Chang and Chien, 2006). In Taiwan, typhoons are one of the most destructive types of natural disasters, because the island is located in the main path of western North Pacific typhoons. On average, 3.5 typhoons pass near or over Taiwan annually (Tsai et al., 2012; Wei, 2015a). The powerful winds and torrential rain accompanying these severe typhoons drastically affect Taiwan and its offshore islands. In Taiwan, the Central Weather Bureau (CWB) issues a typhoon warning when a typhoon might land or affect the region within 18 h. Local governments can cancel school and work according to their judgment and the status of wind speed, rain, and debris flows. Thus, when a local government announces that work is not cancelled despite an approaching typhoon, the under-construction structures cannot shut down and are expected to continue working. This creates a situation in which a strong gust could blow down under-construction structures when a typhoon strikes.

A useful scheme for wind speed forecasts during typhoons is highly desirable for Taiwan's construction industry because timely and reliable information on recent, current, and future wind speeds is vital for making accurate and timely forecasts. The purpose of this study was to develop a conceptual weather environmental forecasting system (CWEFS) that can be used to identify potential failure of under-construction structures. The major functions of the CWEFS include 1) forecasting hourly typhoon wind velocity, 2) analyzing structure reference load during construction, 3) identifying potential failure of under-construction structures, and 4) evaluating the weather to determine whether future hours are suitable for work.

Forecasting the behavior of complex systems has been a broad application domain for machine learning. To solve the wind speed

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prediction problem, data-driven models are widely accepted as a feasible approach for typhoon wind hazard analysis (Croonenbroeck and Ambach, 2015; D'Amico et al., 2015; Liu et al., 2015; Vernay et al., 2015). For example, Matsui et al. (2002) developed a Monte-Carlo simulation of a typhoon model that considers fluctuations in both wind direction and wind speed. Yoshida et al. (2008) proposed a model for predicting the wind speed and direction of typhoon winds according to the Monte-Carlo method. Xiao et al. (2011) adopted the Monte-Carlo simulation approach for typhoon wind hazard analysis in the coastal regions of southeast China by integrating the numerical typhoon wind field model. Li et al. (2012) proposed a data-driven model for determining a typhoon's wind power spectrum according to analytical considerations and field measurements of typhoons in the South China Sea. Moreover, Wei (2015a) developed a highly reliable surface-wind-speed prediction technique, namely a four-kernel-based support vector machine for regression (SVR) model, comprising the radial basis function and linear, polynomial, and Pearson VII universal kernels. The feasibility of various SVRs was examined through comparison with traditional regression models and some parametric typhoon models, namely the modified Rankine vortex profile (Depperman, 1947), DeMaria wind profile (DeMaria, 1987), and Holland wind profile (Holland, 1980). The aforementioned studies have examined the usability of statistical approaches in predicting typhoon winds.

In this study, we focused on building CWEFS to assess potential failure of under-construction structures. The study site was Orchid Island (also called Lanyu), an offshore island of Taiwan. To predict typhoon wind efficiently, we employed the SVR-based data-driven models developed by Wei (2015a). Additionally, two decision trees, namely C5.0 (Quinlan, 1993) and CART (Breiman et al., 1984), were investigated in this study (Section 2.1). In addition, this study compared the aforementioned data-driven statistical models with the Holland wind profile, and empirical parametric typhoon model (Holland, 1980). The structure reference load evaluation model was employed to evaluate the reference load on under-construction buildings. An experimental tank under-

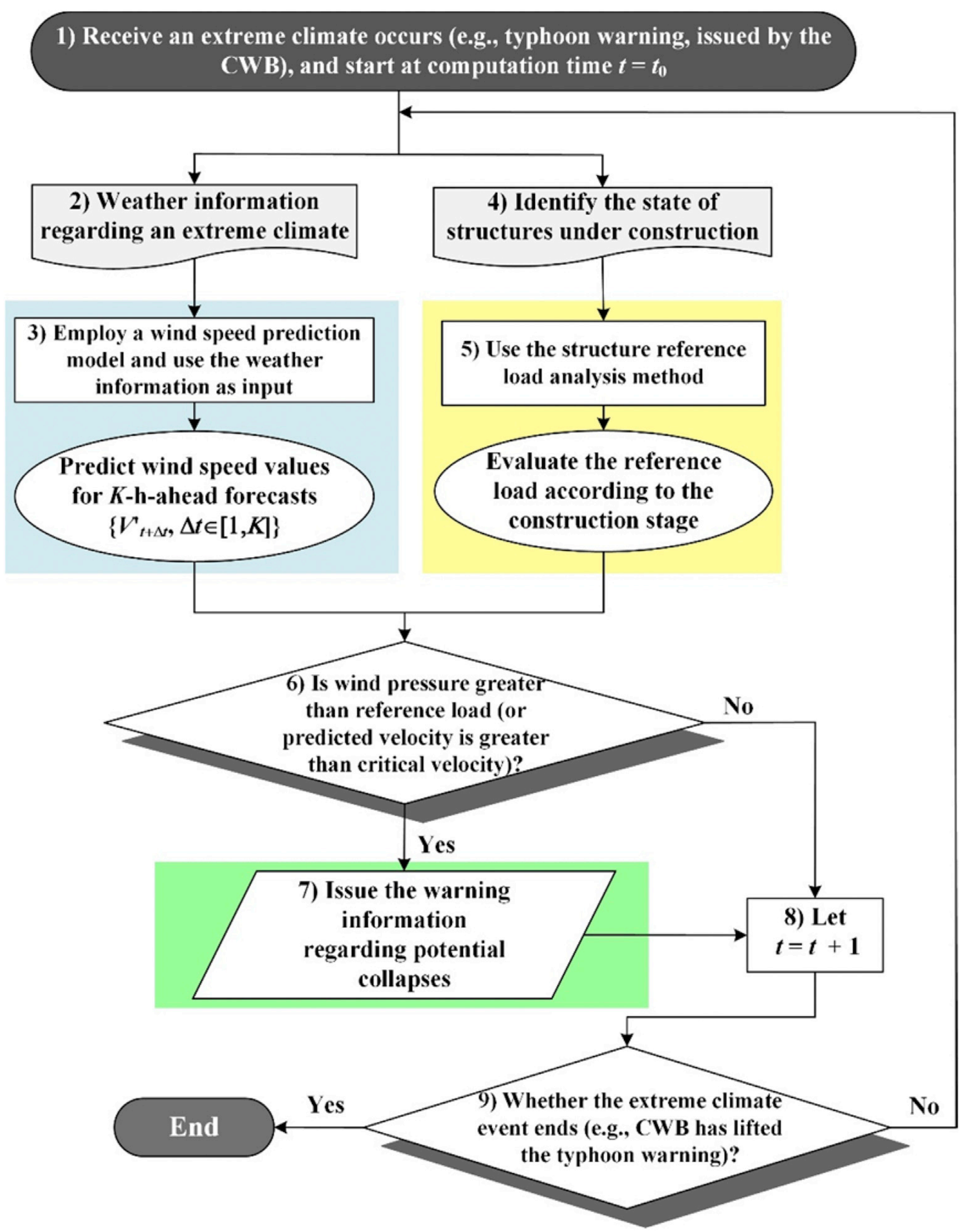

Fig. 1. Conceptual weather environmental forecasting system (CWEFS) for identifying potential failure of under-construction structures.