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Mathematical models for soil displacement under a rigid wheel

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Abstract

Soil–wheel interaction especially soil deformation caused by the wheel motion was investigated experimentally using a sophisticated soil bin test apparatus and an on-line measurement system for soil displacement. Based on these test results, characteristics of soil deformation were summarized focusing on the behavior and distribution of displacement increment vectors. Mathematical models were examined in order to describe the displacements of soil particles. Properties of the displacement loci are described. The magnitude of the displacement increment vector, its horizontal and vertical components are discussed, and characteristics of these distributions with respect to the relative horizontal distance from the vertical centerline of the wheel to the target point are clarified. Shapes of these distribution curves were closely similar to those of the derivatives of a Gaussian function. A distribution curve of the horizontal displacement increment had two peaks and that of the vertical one had three peaks. Based on the results, mathematical models for those displacement increments were proposed by employing a Gaussian function through multiplication of a linear function and a quadratic function. Predicted distributions and displacement loci of the models agreed with high

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accuracy to the measured values. The mathematical models were extended taking into consideration the wheel slip. The predicted distributions according to test conditions agreed very well to the measured results.

Keywords: Soil displacement; Rigid wheel; Displacement increment; Model; Gaussian function; Displacement locus; First derivative; Second derivative

1. Introduction

Traveling performances of a wheel are determined by the deformation state and the stress distribution in soil near the wheel. Therefore, in order to improve the prediction accuracy of the traveling performance, it is necessary to clarify quantitatively the characteristics and mutual relations among traveling performances, soil deformation and stress distribution. Especially, soil deformation is a key item to carry out these soil–wheel interactions. Modeling and analysis of the ground contact stress distribution have been advanced using various sensors in the previous studies [1]. Although the results are not sufficient, many applications based on those are developed. On the other hand, quantitative analyses of soil deformation have not been developed sufficiently due to difficulty of measurement and the complexity of soil properties. There are some reports concerned with soil deformation under a wheel, but these are limited qualitative analyses. Thus, the modeling of soil deformation has not been initiated, except through application of the theory of elasticity. Recently, numerical methods such as the finite element method have been developed remarkably, and are expected to be useful in analyses of traveling performance. Some problems restrict the development of numerical methods. One problem is that there are no experimental data to verify the analytical results.

Therefore, detailed analyses on the properties of soil deformation and its modeling were conducted in this study, based on the measurement of soil deformation near the wheel. An on-line measurement system for soil deformation was employed in the traveling tests. The locus of soil displacement was analyzed to clearly define its characteristics. The displacement increments of soil were separated into the horizontal and vertical components to allow the properties to be shown in detail. Modeling of these components was conducted using the Gaussian function and its derivatives.

2. Methods

2.1. Traveling test of a wheel

A series of wheel traveling test was executed to measure the soil deformation under the wheel. A sophisticated wheel test apparatus developed by the authors in