Eddy Current Analysis of Large-scale Constructions in Railway System by Infinite Edge Elements

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***Abstract*—This paper deals with a large-scale eddy current analysis of the constructions in railway system from the view point of electromagnetic noise assessment. To reduce computational costs with the calculation accuracy kept, we develop some numerical methods and demonstrate their effectiveness by the practical large-scale model.**

I. INTRODUCTION

The train service in recent years becomes more complicated and is supported by safety signal systems, in which the stable information trading between the vehicle and ground system is important. The information trading is performed on the basis of electromagnetic induction phenomena between the receiver on vehicle and the magnetic field made by the alternating signal current in the rail [1].

On the other hand, there are many constructions made of the magnetic materials which has also conductivity around the rail, e.g., a railroad bridge. The magnetic field made by the rail current may be affected by the eddy current in the structure, which results in the degradation of signal systems. So, it is important to investigate the influence in advance by using numerical analysis. However, the model in the railway system to be analyzed is generally huge, which leads to extremely large scale computation.

With this background, in this paper, we propose some numerical methods, e.g., infinite edge element with configuration radiated from reference line, to reduce the computational load with the calculation accuracy kept. Some numerical examples of real scale model, which demonstrate the effectiveness of the proposal methods, are also presented.

II. ANALYSIS MODEL

We analyze the construction model shown in Fig.1. The model consists of rail currents and magnetic materials with conductivity. Fig.1 (a), (b) illustrate one unit of the constructions and an enlarged view of its periodic parts, respectively. The analysis conditions are shown in Table I. Since the configuration of a periodic part is fine compared with the whole unit scale, vast amounts of finite elements are required for an accurate analysis. Furthermore, when a number of units shown in Fig.1 are placed along with the rail over a long distance, it becomes impossible to carry out the analysis by the conventional finite element method.

III. NUMERICAL METHODS AND RESULTS

In this paper, to reduce the computational costs efficiently, we apply the following numerical techniques to the eddy current analysis of the model.

A. Transformation of rail current to equivalent line current

When a signal current flows in a rail, it flows intensively near the surface of a rail because of the skin effect. If we carry out the analysis under the condition of original rail shape, the computational load increases because extremely fine mesh division in consideration of the skin effect leads to the huge number of elements in the whole model.

So, first, we analyze the signal current distribution in a rail with sufficiently fine meshes under voltage source condition. Next, we calculate the current's center of gravity as shown in (1), where i is the element number of finite elements, S_i is the cross-sectional area of the i_{th} element on x-y plane, J_{zi} is the z component of current density which flows into the i_{th} element, y_i is the y coordinate of the element center of gravity, and I_{total} is the total current which flows into a rail section. Finally, we transform the distributed rail current to the equivalent line current at the current's center of gravity. The transform technique enables us to avoid the increase in the number of elements. Table II shows the estimated position of current's gravity of the rail model in Fig.2. The current's gravity shifts in location according to the current frequency.

$$y_{current's\ center of\ gravity} = \sum_i \left(S_i \times J_{zi}\right) \times y_i \Big/ I_{total} \qquad (1)$$

B. Computational load reduction by infinite edge element method

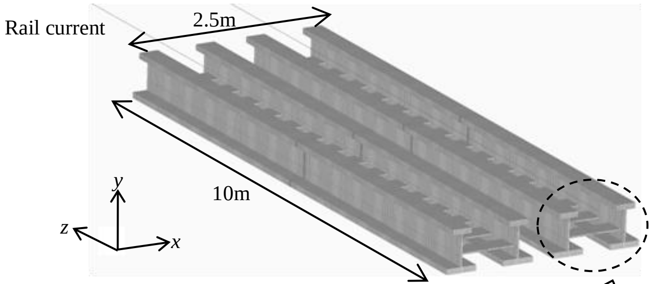
The electromagnetic phenomena intrinsically spread over the infinite space. To precisely analyze the magnetic field in an extensive air domain without increasing calculation load, we apply the orthogonalized infinite edge element method (IEEM) [2] to the mesh division of an air domain. Previously, we have developed the infinite edge element (IEE) with configuration radiated from reference point [3]. In this paper, considering the characteristic of the shape of the model shown in Fig.1, we propose the IEE with configuration radiated from reference line. The conceptual figure of the proposed IEE is shown in Fig.3 [2-4]. We can dramatically reduce the number of meshes by using the proposed method, which enables us to prepare the sufficiently fine meshes for the construction region without increasing computational load in total. A numerical result of eddy current distribution in a part of constructions is shown in Fig.4.

C. Transformation of distributed eddy current to equivalent loop line current

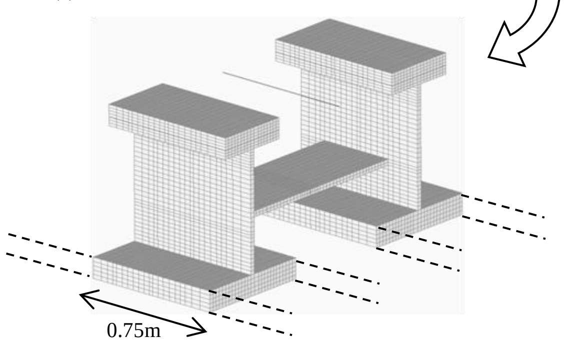
To evaluate the magnetic field made by the eddy currents in a number of construction units placed along with the rail over a long distance, we combine a theoretical method with the numerical analysis. After analyzing eddy current distribution in one construction unit in detail, we transform it to some equivalent loop line currents. Finally, we estimate the magnetic field at an arbitrary investigated point based on an analytical integration of the magnetic field made by the equivalent loop currents.

Fig.4 shows the eddy current distribution in a part of construction unit, which indicates the eddy currents in a half of construction unit roughly form two kinds of loops as shown in Fig.5. Theoretically integrating the magnetic fields owing to the equivalent loop currents along with a rail, we can estimate the influence of electromagnetic noise at the investigated point in the air region.

The detail of the formulation and the comparison between measured and computational results will be included in the full paper.



(a) Overall view of one unit of constructions



(b) Enlarged view of periodic part

Fig. 1. Analysis model

TABLE I Analysis conditions

Frequency and current value of the rail	1kHz, 1A
Conductivity of the rail	4.56×10^6 S/m
Relative permeability of the rail	70
Conductivity of the magnetic materials	2.50×10^6 S/m
Relative permeability of the magnetic materials	300

TABLE II

	Section area of Rail [m^2]	Gravity of the rail [mm]	Gravity of current [mm]
Real model	8.332×10^{-3}	72.8	67.6

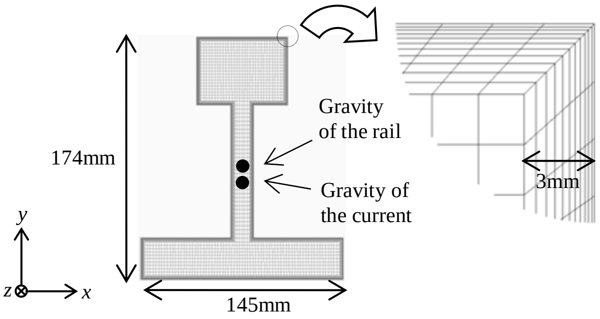


Fig. 2. Rail model

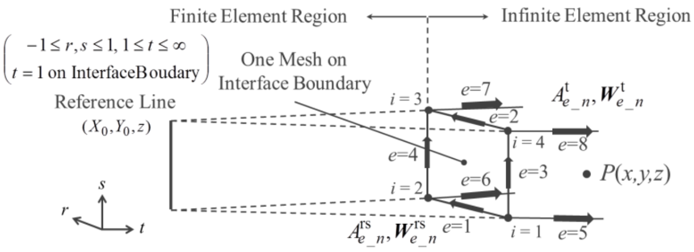


Fig. 3. Infinite edge element with configuration radiated from reference line (A-ϕ method) [2][3].

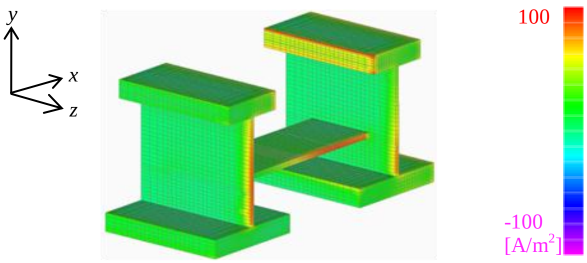


Fig. 4. Eddy current distribution in an end part of construction unit

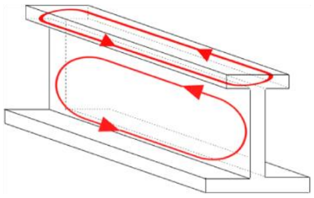


Fig. 5. Connectional figure of equivalent loop currents

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