NUMERICAL STUDY ON CORROSION PROFILE ESTIMATION OF A CORRODED STEEL PLATE USING EDDY CURRENT

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1. INTRODUCTION

Corrosion occurring in steel structures due to long-term exposure to harsh environment leads to thinning and deformation of load carrying members, adversely affecting structural strength, integrity, and safety of these structures. Corrosion can be judged by thickness loss, through visual inspection, and assessed in detail by using non-destructive evaluation methods such as eddy current testing. Akutsu et al. (2017) proposed a method using low frequency eddy current to measure the residual thickness of a corroded member, assuming the side accessible to the eddy current probe to be relatively smooth. However, the accessible side may not always be smooth, or there might be severe corrosion in both sides of a steel member. In such cases, the corrosion profile of the side accessible to the probe needs to be ascertained first, and the residual thickness can then be subsequently evaluated.

Hence, in the present study, a method has been proposed, where a higher frequency eddy current is used to estimate the corroded profile directly from the probe lift-offs. Reflection probes with different diameter and tilt angles are evaluated for their performance in approximating the profile of two simple geometries – a step and a triangular peak, and the best probe is selected for numerical estimation of the corrosion profile. The three-dimensional, numerical simulations were carried out in the general purpose, commercial FEM software, COMSOL Multiphysics 5.2a.

2. PROPOSED METHOD FOR CORROSION PROFILE ESTIMATION

Surface corrosion is considered, and the side accessible to the probe is taken to be corroded. Reflection probe comprising of an exciting coil and a detecting coil, has been used in the present study. An alternating current is supplied to the exciting coil and the voltage change due to the variations in lift-off and specimen thickness are picked up by the detecting coil. The lift-off is taken as the distance of probe to the point directly beneath the probe and change in the plate thickness as the variation in specimen thickness. Hence, the probe is calibrated for different lift-offs and plate thicknesses, whereby, at a particular frequency, a master curve depicting the relationship between detected voltage and lift-offs independent of the plate thickness is obtained (Fig. 1). The probe lift-offs thus obtained from the master curve are used to compute the corrosion profile regardless of the varying thickness of the corroded specimen.

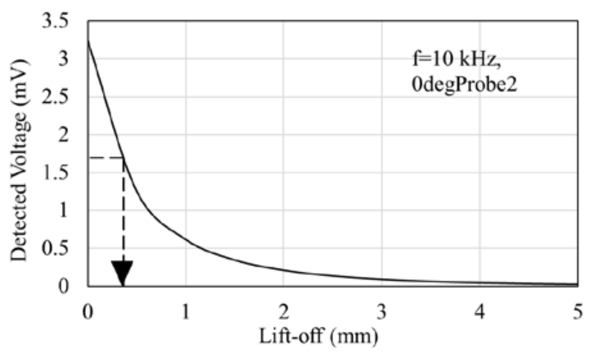

Fig. 1. Master curve at the desired frequency

3. FINITE ELEMENT MODELING AND PROBE SELECTION

The numerical analyses are carried out in the AC/DC module of the commercial software COMSOL Multiphysics 5.2a using three-dimensional, finite element models of the probe, steel plate (for calibration), simple geometries with a step and a triangular peak, and corroded specimen. The probes are modeled using two coils – one exciting coil and one detecting coil. An alternating current of 1A is supplied to the exciting coil. The steel plate and simple geometries are 200mm long and wide, the corroded specimen is 100mm long and 30mm wide (with a mesh of 100*30), and the computational domain (air) is 300mm*300mm*100mm. The boundary condition was imposed such that the tangential component of the magnetic vector potential is zero. The in-built materials namely, Air, Copper, and Steel (without losses) were assigned to air domain, coils, and steel plate, simple geometries and corroded specimen, respectively. The material properties are given in Table 1 below. A very small value of electrical conductivity has been assigned to air in view of the numerical stability of the three-dimensional problem.

Table 1. Material properties

Materials	Relative permeability	Electrical conductivity [S/m]
Air	1	0.1
Copper	1	$5.998*10^7$
Steel (without losses)	1	$4.032*10^6$

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Table 2. Probe Specifications

Probe Name	θ(°)	ϕ_{ex} (mm)	ϕ_{det} (mm)	CH_{ex} (mm)	CH_{det} (mm)
0degProbe1	0	10	6	10	10
0degProbe2		2	1	1	1
90degProbe2	90	2	1	1	1

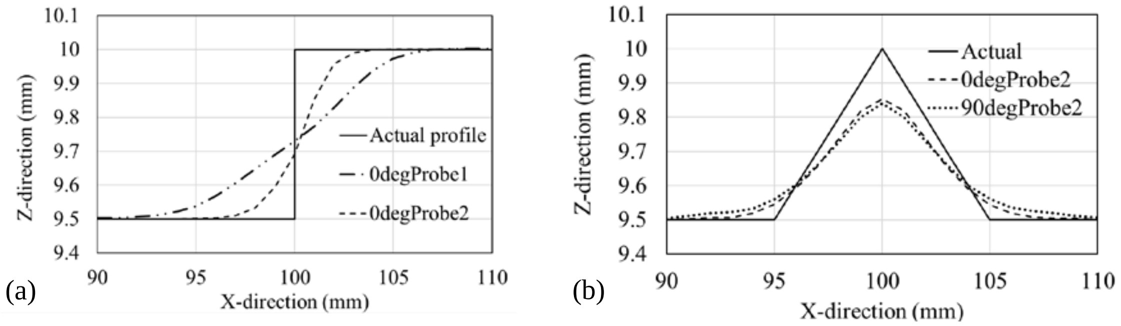

Fig. 2. Estimation of (a) step profile, and (b) triangular peak profile.

Three types of probe were considered, differing in diameter and tilt angle of the probe, as shown in Table 2, where θ, ϕ, and CH are the tilt angle, diameter and coil height of the probe. The subscripts 'ex' and 'det' denote the exciting and detecting coils, respectively. All the probes were calibrated for lift-offs of 0 to 5mm, with 0.5mm step and plate thicknesses of 5, 6, 7, 8, 9 and 10mm, at excitation frequencies of 1, 10, 100 and 1000 kHz. The master curves are obtained for the probes at an excitation frequency of 10 kHz, where the detected voltage versus lift-off relationships are independent of the plate thickness. Hence, all the numerical simulations henceforth are carried out at an excitation frequency of 10 kHz.

A step and a triangular peak were traced by the three probes, as shown in Fig. 2 (a) and (b), respectively. It is seen that 0degProbe2 with smaller diameter estimates the step profile significantly better than the larger diameter Probe F. Also, 0degProbe2 gives better shape and peak estimations than its θ = 90° counterpart, 90degProbe2. Therefore, 0degProbe2 was used to trace the corrosion profile of a corroded specimen.

4. ESTIMATION OF THE CORROSION PROFILE

The 0degProbe2 was moved over the corroded specimen along y=10mm, from x=0 to 100mm at 1mm step. The numerical model of the corroded specimen, the path of probe as it moves (dashed line), and the probe are shown in Fig 3 (a), and the actual and estimated profiles are presented in Fig. 3(b); the actual profile was measured by laser displacement meter. It can be seen that the corrosion profile estimated by the 0degProbe2 follows the actual profile very closely, except at the ends of the specimen, where the flow of eddy current is distorted due to the edge effect. Hence, the proposed method gives a good estimation of the corrosion profile.

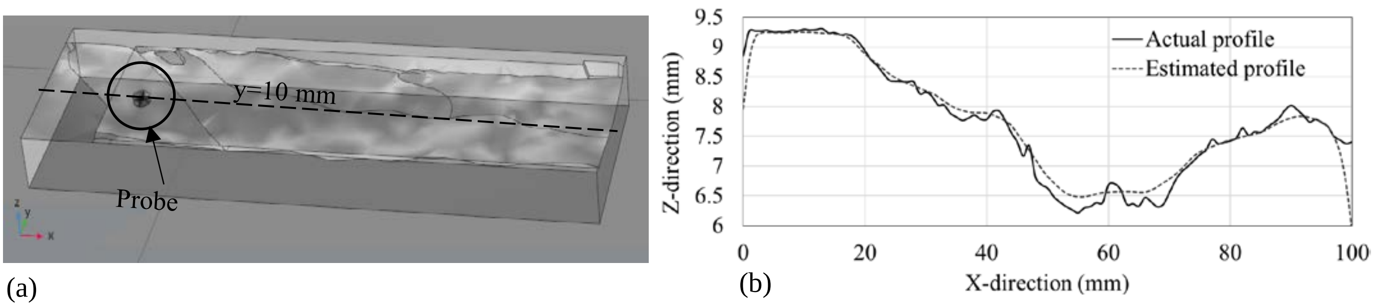

Fig. 3. (a) Numerical model and (b) Estimated corroded profile at y=10mm by 0degProbe2

5. CONCLUSIONS

In the present study, a method to estimate the corrosion profile of a steel specimen directly from the lift-offs, independent of the thickness variation of the specimen was proposed and verified through numerical simulations. The 0degProbe2 with the smallest diameter and zero tilt gave the best approximation of simple step and triangular peaked geometric profiles and hence, was employed to trace the corrosion profile. The estimated profile showed a good agreement with the actual profile of the corroded specimen, thus confirming the accuracy of the proposed method.

REFERENCES

Akutsu, A., Sasaki, E., Ebisawa, Y., and Tamura, H.: Analysis of Corrosion Damage Condition of Steel Members Using Low Frequency Eddy Current Testing (Japanese Title: 低周波渦電流による鋼部材の腐食損傷状態分析), Journal of Japan Society of Civil Engineers, Ser. A1 (Structural Engineering & Earthquake Engineering (SE/EE)), 73, 2017, pp. 387-398.