Proceedings of the 8th International Conference on Civil Structural and Transportation Engineering (ICCSTE'23)
Ottawa, Canada – June 04-06, 2023
Paper No. 198
DOI: 10.11159/iccste23.198

Damages Identification Methodology of Unseen Reinforced Concrete Foundations Using Error Analysis of Transfer Resistance

Ronald Alvarez and Shigeki Unjoh
Department of Civil and Environmental Engineering, Tohoku University
6-6-06 Aramaki Aoba, Aoba-ku, Sendai-shi, Miyagi-ken 980-8579, Sendai, Japan
ronald.alvarez@dc.tohoku.ac.jp; shigeki.unjoh.c7@tohoku.ac.jp

Abstract – Natural disasters such as earthquakes and tsunamis have constantly proved the fragility of infrastructures and shown the complexity of strong ground motion generation. To reduce the vulnerability of infrastructures, numerous methodologies have been developed to extract detailed information from the earthquake source mechanism to provide rational earthquake hazard information and use it as input for structural vulnerability assessment. A common practice after a destructive earthquake occurs is to observe and analyse the damage mechanisms on the structures distributed in the damage zones, aiming to comprehend and infer the process and reasons for such destructive damages. To later upgrade the seismic standards for structural analysis and engineering design practices from the outcomes of the lesson learned from this devastating experience, to level up decision-making associated with diagnosis and strengthening of vulnerable infrastructures, and to contribute to decision-making related to strengthening of infrastructures, susceptible to earthquake damages, we proposed an earthquake damages detection methodology for unseen underground bridge infrastructures based on transfer resistance as essential measurement, and combined along with seasonal external effects, and error analysis; to consider the dispersive and propagation nature of uncertainty, and account for correction factors, respectively. To unravel the dimensional and intrinsic error associated with the fracturing area within the foundation and observed over the residual power spectrum. In general, we detected the earthquake damage zone when the reinforcement mesh was exposed and surpassed by the rupture zone.

Keywords**:** transfer resistance measurement, bridge foundation, earthquake damage, error analysis, residual power spectrum of resistance

1. Introduction

Bridge structures have been enhancing primarily infrastructural function and connection between urban areas, mainly for transportation activities of different means, and which play a crucial role in the urban development. Initially, bridges were built of stone and masonry materials. However, with industrialisation, new materials and techniques became available to improve their structural performance. Nevertheless, several disasters such as earthquakes and tsunamis have taught engineers the importance of bridge in emergency, rescue, and supplies transportation response as aid after a disaster strikes. Highlighting the critical role these structures have as part of the principal transport artery in earthquake-prone countries.

Throughout history, seismic guidelines have been evolving according with the earthquake damage experienced and observed. In Japan, particularly, seismic provisions for structural design and assessment have been under constant scrutiny due to the seismic nature of the region, which is characterised by subduction and active fault earthquakes, resulting from the interaction of the continental and oceanic crusts, and geological faults within the continental plate, respectively. The Hyogo-ken Nanbu earthquake on 17 January 1995, provided one of the most valuable lessons experienced in the seismic history of urban areas that led to the upgrading of seismic standards for highway bridges in Japan [1]. Therefore, in the aftermath of a destructive disaster, researchers and engineers make a concerted efforts to facilitate reliable information for disaster mitigation practices through the development of analytical and empirical activities. Most studies have been spotlighted by earthquake engineers in the field to investigate visual damages, and frequently ignoring the evaluation of underground foundations, which are imperceptible at first sight. Accordingly, we proposed a methodology to identify earthquake damage over underground bridge foundation based on the residual power spectrum of transfer resistances calculated from normalised error analysis of 2D modelling to unravel the dimensional and inherent error related with the rupture zone within the foundation.

2. Methodology for damages detection

The methodology for damages detection was built based on the measurement of resistance across the foundation, which provides the voltage error structure shown in Figure 1 with (1) the systematic error component and (2) the random and uncorrelated error component [2]. In this study, we did not contemplate the systematic error component because its numerical nature may not follow a normal distribution [3]. Therefore, we considered the random and uncorrelated error associated with the seasonal effect, grid structure, and spatial geometry variation within the modelling. We used normal and reciprocal measurements to determine the error and polarity associated with the temporal effect in the dataset [4], and statistical analyses to quantify the correction factors. We estimated the correction parameters by calculating the normalised histogram distribution associated with the standard deviation and mean transfer resistance of the bins. We removed the outliers that spread the error due to their dispersive nature. Later, we fitted a power model to determine the correction values. We ignored the mesh discretisation error component by reducing its impact in the modelling. Next, we constructed a normalised residual wave within the model by combining the error resistance response of each discretised element or group of cells across the modelling. Then, we calculated the residual power spectrum of the error wave to study the dimensional error component associated with the fracture regions within the foundation.

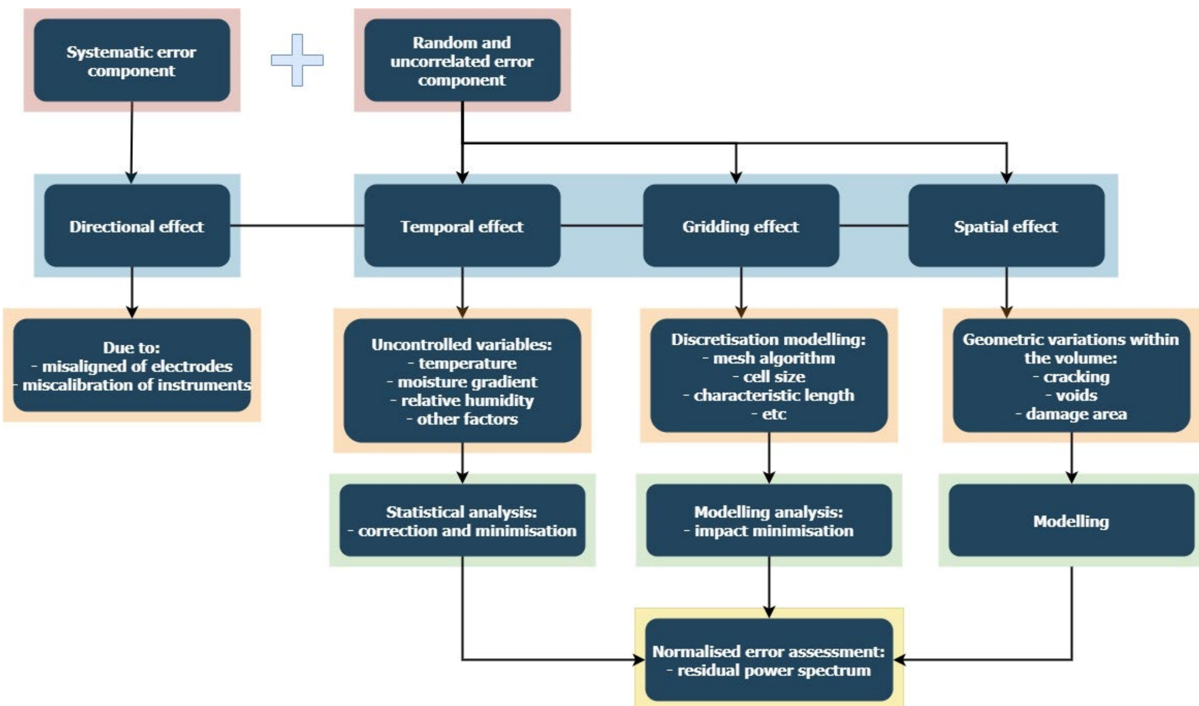
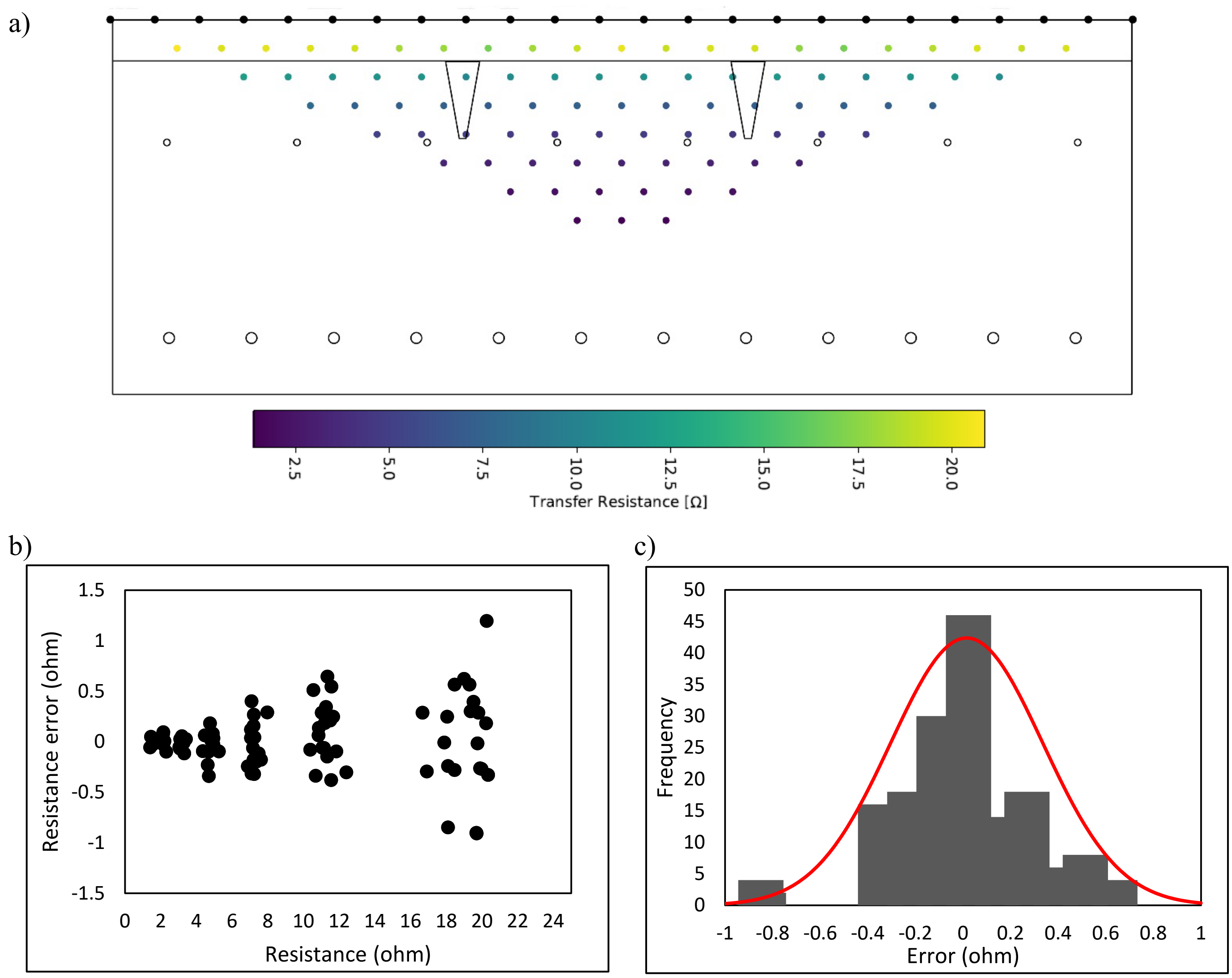


Fig. 1: Methodology for damages assessment based on the analysis of resistance error structure.

3. Modelling results

Figure 2 shows the results of the data processing of the reinforced concrete foundation. a) Illustrates the resistance measurements obtained from normal and reciprocal readings within the foundation. The synthetic model was made of reinforced concrete with the size of 1500 mm x 960 mm x 450 mm, and had a surface soil layer of about 5 cm and two fracture regions of 5 cm above and 1 cm below with an extended depth of about 7.5 cm. b) Displays the resistance error computed by the mean difference between normal and reciprocal readings. c) Demonstrates the histogram and normal distribution of resistance error of b). d) Shows the absolute values of the standard deviation of resistance error calculated from the dataset within each bin of the histogram and associated with the mean transfer resistance of the bin. We filtered out the outliers and fitted a power model to the dataset to correct and minimise the error associated with temporal changes. e) Refers to the error wave calculated by the normalised residual analysis, which represents the response of a group of elements within the foundation. f) Shows the power spectrum of the error wave to identify the variation of the residual resistance due to the fracture areas within the model. In f) we ran two models associated with reinforced concrete as a black curve and a reinforced concrete model with two fracture zones and a superficial soil layer above the foundation as a red curve. In general, the black curve illustrates two peaks associated with the dimensional changes of concrete and reinforcement. The red curve shows one fundamental and two secondary peaks related to the reinforcement, concrete, and and fractured zones, respectively. We found that (1) the fracture zones increase the spatial component error and allow the reinforcement response to impact the concrete cover and characterised the residual power spectrum by a fundamental peak and (2) the surface soil layer attenuated the power spectrum for this modelling.



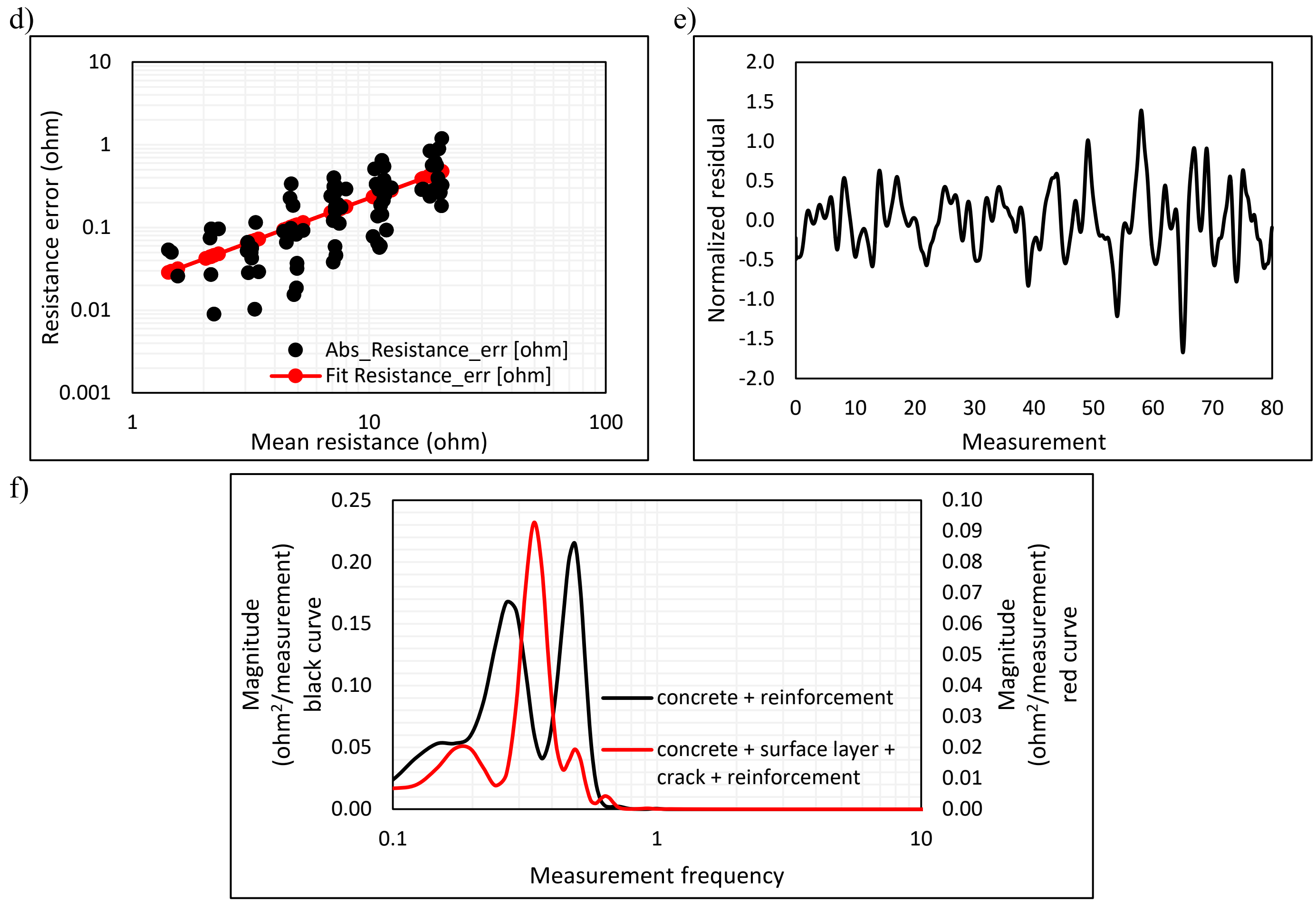


Fig. 2: Data processing for bridge foundation damages detection. a) Normal and reciprocal readings within the reinforced concrete foundation, b) resistance measurement error, c) histogram and normal distribution of error, d) absolute values of the standard deviation of resistance error in log-log chart, e) error wave calculated by normalised residual analysis, f) power spectrum of residual resistances.

4. Conclusion

In this study, we developed a methodology to identify earthquake damage in underground bridge foundations. The methodology was characterised by the seasonal effect, minimisation of mesh error, and normalised error assessment to synthetise and correct the dataset as in field and laboratory studies, neglect the impact of modelling discretisation, and compute the residual power spectrum to detect the rupture patterns.

References

[1] K. Kawashima and S. Unjoh, "The damage of highway bridges in the 1995 Hyogo-ken Nanbu earthauqke and its impact on Japanese seismic design," *Journal of Earthquake Engineering,* vol. 1, no. 3, pp. 505-541, 1997.

[2] J. Taylor, Error Analysis, Sausalito, C. A: University Science Books, 1997.

[3] G. Oldenborger, P. S. Routh and M. Knoll, "Sensitivity of electrical resistivity tomography data to electrode position errors," *Geophysical Journal International,* vol. 163, no. 1, pp. 1-9, 2005.

[4] A. Binley and L. Slater, Resistivity and Induce Polarization, UK: Cambridge University Press, 2020.