Effect of Different Electrode Numbers on the Image Quality of Concrete Damage in Electrical Resistance Tomography

Shidong Sun¹, Lei Qin¹ and Hongwei Ren²
1. School of Civil Engineering and Architecture, University of Jinan, Jinan 250022, China
2. School of Electrical Engineering, University of Jinan, Jinan 250022, China
Correspondence: REN Hongwei, cse_renhw@ujn.edu.cn, Tel.: 18653172267

Abstract. Electrical resistance tomography (ERT) method [1] is proposed to visually investigated of the defect in concrete. It is an imaging modality in which the electrical permittivity distribution within an object is reconstructed based on measured resistance between electrodes attached on the object’s surface. It is assumed that the spatial resolution of the reconstructed images with an electrical resistance tomography system can be consummated by electrodes. In this paper, specimens with one precast defect are made with 0.5 water-cement (w/c) ratio and detected using the embedded electrodes. The results show that different electrode numbers is the significant factor influencing the image quality of concrete damage in electrical resistance tomography. For the multi-defect detecting, the influence of electrical soft field effect cannot be neglected. In addition, the experimental results also show that ERT technology has the potential of concrete defect detection and on-site monitoring.

Keywords: Electrical Resistance Tomography (ERT), image reconstruction, non-destructive testing, concrete, defect

1. Introduction
Monitoring of concrete is critical for assessing existing structures, since the aging of the concrete structures can result in performance degradation. It is estimated that more than 54% of the work in building sector is directed to evaluation and repairs of defect structures, and the percentage continues to increase. Concrete structure can be traced back to the mid-1900s which plays a vital role for the entire building. With the development of time, this infrastructure has deteriorated and damaged. In the early detection of the deterioration process, this can be carried out earlier to avoid the occurrence of disaster. Hence, it is essential to monitor the defects of the structures in time. The key is to search a fantastic non-destructive technique. The testing methods should be reliable, rapid and inexpensive. In recent, many kinds of techniques have been developed for monitoring concrete structures. The majority of these methods are based on electromagnetic radiation, including x-ray absorption, γ-rays, electrochemical impedance spectroscopy (EIS), neutron imaging, and nuclear magnetic resonance, nuclear magnetic resonance (NMR), spectroscopy, neutron imaging, gamma ray, scanning electron microscope, ultrasound imaging and other electrically-based methods [2-8]. However, the existing methods have their own advantages and limitations, for example, gamma-ray, X-ray, neutron imaging, scanning electron microscope and ultrasound imaging have high spatial resolution, but they are commonly limited to small specimens and laboratory environment due to large attenuation and their monitoring cost is expensive. On the contrary, electrically-based methods have a low spatial resolution, but electrically-based methods generally do not have such testing limitations and they are inexpensive,
easy and quick to perform, especially suitable for concrete structure. Based on these reasons, electrical resistance tomography was used to monitor the damage of the concrete in this paper.

2. Electrical Resistance Tomography
ERT is a tomographic measurement technique which was developed during the late 1980s [3]. The mathematical theory of electrical tomography technology is Radon transform and Radon inverse transformation for theoretical basis, the physical basis is based on the steady state electromagnetic field theory [9,14]. Since then it has been improved in many ways and applied in various areas of industrial processes for non-invasive monitoring and measurement. It is a class of diffuse tomography modalities which intent to estimate the interior distribution from boundary measurements [1]. Owning to the advantages of high speed, safety, non-invasiveness and low-cost, Electrical resistance tomography (ERT) is attracting more and more researches studying it to apply in structural health monitoring. As we all know, the compositions of the concrete is poor conductivity which lead to high resistance of concrete. Therefore, the application of ERT for concrete is still still a little bit difficult. In 2009, Hou and Lynch performed cracking of fiber-reinforced cementitious composites tests during tensile loading, which demonstrated that ERT can be as a powerful new nondestructive examination tool for health monitoring of cementitious structures. In 2010, the feasibility evaluations of ERT for imaging of the concrete was studied by Karhunen et al [10]. The results indicated that ERT could be a feasible technology for non-destructive evaluation of concrete. Crack and reinforcing bar sizes and their respective positions can be reliable estimated [11-13]. In 2015, Hallaji applied ERT to monitoring damage and unsaturated moisture flow in concrete. Crack and moisture distributions can be well characterized in cementitious materials. The principle of the ERT system, as shown in Figure 1.

![ERT system principle](image)

3. Experiments
3.1. General
In the experiments, three cylindrical specimens of w/c ratios: 0.5 were prepared. The experimental setups and electrodes are schematically illustrated in Figure 2. In this paper, the accuracy of the simulation experiment is verified by actual experiments. In order to reduce the workload of the experiment, the test specimens of 8 electrodes, 12 electrodes and 16 electrodes are fabricated. The image was constructed by the MATLAB image reconstruction algorithm [15,16]. The model of the sample is shown in Table 1.
3.2. Specimens-Sample Preparation
The materials of the test piece are Type I Ordinary Portland Cement (OPC), the fine aggregate standard sand and coarse aggregate. Three test specimens were cast into in cylindrical molds of 200mm in diameter and 50mm in thickness. Embedded electrodes were used, one of which is embedded in eight electrodes, one twelve electrodes, and other 16 electrodes. The test blocks after pouring were shown in Table 2. There is a 3cm diameter lesion at the same position on the upper left end of each test block.

3.3. Test System
The ERT system used in this paper is based on the National Instrument (NI PXLe-1062Q). Because it is an accurate and highly flexible modular instrument, it controls the instrument and equipment through a flexible and efficient graphical programming language. The ERT system is built by NI PXI platform and the test system is shown in Figure 3.
4. Result
The concrete damage test process in this paper is as follows. First, the data acquisition and image reconstruction are performed by the electrical resistance tomography system already constructed in this paper. The concrete test specimen and its image reconstruction results are shown in Table 3.

Table 3. image reconstruction results

|          | 8 electrodes | 12 electrodes | 16 electrodes |
|----------|--------------|---------------|---------------|
|          |              |               |               |

Owing to difference in conductivity between the damage and the matrix, obvious areas of relative high resistance and low resistance can be found. In other words, distinct color change are caused by different conductivity in concrete specimen. From the simulation tests, this phenomenon is very obvious. It can be seen from the imaging that the number of the three electrodes can roughly show the damage position of the concrete test block. However, in comparison, the 8 electrodes and the 12 electrodes have a certain improvement in damage location and size. This also shows that the number of different electrodes has a certain influence on the imaging of the damage.

5. Conclusion
In this paper, the influence of the number of electrodes on the quality of concrete damage imaging is discussed through experiments. Imaging quality generally refers to the accuracy of the location and size of the lesion. The image reconstruction algorithm of MATLAB is used to reconstruct the model of different electrode numbers. The number of electrodes directly affects the boundary data, which directly affects the sensitivity matrix and affects the quality of the reconstructed image.

As can be seen from the above three figures, the image quality of the 16 electrodes concrete test block is higher than that of the 8 electrodes and 12 electrodes. The main component of the concrete structure is the concrete material, and the concrete material itself is a multi-component mixture, which determines the non-uniformity of the internal resistivity distribution of the concrete structure, and the number of different electrodes affects the non-uniform resistivity distribution, which in turn affects the quality of the image. However, the increase in the number of electrodes will reduce the real-time performance of the data acquisition system. As the number of electrodes increases, the number of points collected by the data acquisition system increases, resulting in an increase in acquisition time.
At this time, in order to improve the real-time performance of the system, parallel processing circuits are generally used, but this will increase the cost of the hardware.

Through this experiment, it is proved that the number of electrodes has an impact on the accuracy of concrete damage. In comparison, the image quality of the 16 electrode number is the best. Although there is a slight increase in the acquisition time, it can be basically ignored. In the future, ERT might serve as a monitoring and visualizing tool for the damage of concrete materials, and in turn, provide information on the durability and condition of concrete structures.

Acknowledgements
The financial support is from Key R & D project of Shandong Province (2017GGX90107) and the National Natural Science Foundation of China (51678277). The third author would like to acknowledge the support provided by a Project of Shandong Province Higher Educational Science and Technology 2015 under Grant TJY1504 and Guangdong Provincial Key Laboratory of Durability for Marine Civil Engineering (GDDCE15-05).

References
[1] Song X, Xu Y, Dong F. A Hybrid regularization method combining Tikhonov with total variation for electrical resistance tomography [J]. Flow Measurement & Instrumentation, 2015.
[2] Biqin Dong, Guohao Fang, Yuqing Liu, Peng Dong, Jianchao Zhang, Feng Xing, Shuxian Hong. Monitoring reinforcement corrosion and corrosion-induced cracking by X-ray microcomputed tomography method. Cement and Concrete Research, 100 (2017) 311–321.
[3] Eichhorn, S. J., et al. (2006). "Analysis of interfacial micromechanics in microdroplet model composites using synchrotron microfocus X-ray diffraction." Composites Science and Technology 66(13): 2197-2205.
[4] Zhang P, Wittmann F H, Zhao T, et al. Neutron imaging of water penetration into cracked steel reinforced concrete [J]. Physica B Physics of Condensed Matter, 2010, 405 (7):1866-1871.
[5] Qin, L., Huang, S., Cheng, X., Lu, Y., Li, Z., The application of 1-3 cement-based piezoelectric transducers in active and passive health monitoring for concrete structures. Smart Materials & Structures 2009, 18, (9), 095018.
[6] Dong, B., Liu, Y., Qin, L., Wang, Y., Fang, Y., Xing, F., Chen, X., In-Situ Structural Health Monitoring of a Reinforced Concrete Frame Embedded with Cement-Based Piezoelectric Smart Composites. Research in Nondestructive Evaluation 2016, 27, (4), 216-229.
[7] Biqin Dong, Jianchao Zhang, Yanshui Wang, Guohao Fang, Yuqing Liu, Feng Xing*. Evolutionary trace for early hydration of cement paste using electrical resistivity method. Construction and Building Materials, 119 (2016) 16–20.
[8] Dierke C, Werban U. Relationships between gamma-ray data and soil properties at an agricultural test site [J]. Geoderma, 2013, 199:90-98.
[9] Alexandrov D V, Nizovtseva I G, Malygin A P, et al. Unidirectional solidification of binary melts from a cooled boundary: analytical solutions of a nonlinear diffusion-limited problem. [J]. J Phys Condens Matter, 2008, 20 (11):114105.
[10] Karhunen, K.; Seppänen, A.; Lehikoinen, A.; Monteiro, P. J. M.; Kaipio, J. P., Electrical Resistance Tomography imaging of concrete. Cement & Concrete Research 2010, 40, (1), 137-145.
[11] M. Pour-Ghaz, Detecting Damage in Concrete Using Electrical Methods and Assessing Moisture Movement in Cracked Concrete, Ph.D. Thesis. Purdue University, Indiana, 2011.
[12] Vlaev, D.; Wang, M.; Dyakowski, T.; Mann, R.; Grieve, B. D., Detecting filter-cake pathologies in solid–liquid filtration: semi-tech scale demonstrations using electrical resistance tomography (ERT). Chemical Engineering Journal 2000, 77, (1), 87-91.
[13] Loh, W. W.; Waterfall, R. C.; Cory, J.; Lucas, G. P., Using ERT for multi-phase flow monitoring. 1999, 47-53.
[14] A.P. Polyakova, I.E. Svetov, Numerical solution of the problem of reconstructing a potential...
vector field in the unit ball from its normal Radon transform, J. Appl. Ind. Math. 9 (4) (2015) 547–558.

[15] Buettner, M.; Ramirez, A.; Daily, W., Electrical resistance tomography for imaging the spatial distribution of moisture in pavement sections. Office of Scientific & Technical Information Technical Reports 1996.

[16] Song, X. H.; Lv, Y.; Xu, D. L.; Li, Z. Q., Experimental research of smart concrete ERT. Measurement & Control Technology. 2005, 24 (1), 11-13.

[17] Xu, D. L. Study on electrical resistance tomographic of carbon fiber reinforced concrete structure. Wuhan University of Technology, 2006.

[18] Hallaji, M.; Pour-Ghaz, M., A new sensing skin for qualitative defect detection in concrete elements: Rapid difference imaging with electrical resistance tomography. NDT & E International 2014, 68 (68), 13-21.