Japan Academy Prize to:

Akira Murakami
Executive Vice President, Kyoto University
Professor Emeritus, Kyoto University

for "Studies on Development of Inverse Analysis by the Kalman Filter and its Applications to Geotechnical Engineering"

Outline of the work:

Numerical simulations based on soil–pore water coupled finite element method (FEM) with an appropriate constitutive model for soil materials are commonly used in geotechnical engineering. Moreover, they help in predicting and evaluating the performance of soil structures and their foundations for their design under changing boundary conditions before the construction stage. However, observational programs are set up in the early stages of construction to evaluate design assumptions and current construction conditions and to accurately update such numerical predictions of behavior in future performances.

After the construction stage, discrepancies are often found between the numerical predictions and the corresponding field measurements in terms of deformation and pore pressure. This is due to the uncertainty of the initial and boundary conditions of the governing partial differential equations as well as the parameters of the constitutive model, which should be assessed during the design stage through site investigations and be based on the results of laboratory tests using collected soil samples from various depths. Inverse analyses have been used in performance observations in engineering practices to modify such uncertain conditions and parameters to bridge the gap between observations and predictions and to provide feedback on the re-evaluation of numerical simulations for subsequent construction sequences as a quantifiable observational method.

To address the aforementioned challenge, the Kalman filter is advantageous because it incorporates a regularization term for solving this type of inverse problem by conducting step-by-step observations and obtaining a full knowledge of the loading history. Dr. Akira Murakami developed an inverse analysis strategy using the Kalman filter in conjunction with FEM in 1987 and extended it using a nonlinear Kalman filter, such as the particle filter, to maximize the Bayesian likelihood and provide a "sequential Bayesian estimation" for strongly nonlinear problems as alternative so-called "data assimilation" strategies to the traditional Kalman filter. The developed strategies had a significant ripple effect on related research areas in various science and engineering fields.

Dr. Murakami focused on the fact that the previous records of ground deformation can be used to estimate multiple soil parameters. He then developed the world's first method for identifying soil parameters with high estimation accuracy using an inverse analysis method which combined the Kalman filter with the FEM model to simulate ground behavior. Before this type of research, soil parameters were treated as constant values, and the actual soil parameters were unknown and could only be assumed. However, his research has made it possible to predict ground deformation with dramatically high accuracy. Furthermore, this strategy solves the problem of predicting geohazards caused by ground deformation, enabling the long-term prediction of well-documented geotechnical construction projects, such as the long-term settlement of the Kobe airport island (Hyogo, Japan), neighboring work of earth retaining and excavation for pipelines and waterways, vacuum consolidation of the foundation for retention basin and rock-fill dam, adjustment of tunnel excavation speed due to increasing water pressure, and detection of the location and shape of multiple subsurface cavities using particle filters, as well as the parametric level set method for elastic wave propagation under the ground. These research results have been widely used to predict ground deformation and geohazards in various regions of Japan and have been highly evaluated.

In summary, (1) Dr. Murakami developed the Kalman filter in conjunction with the FEM for inverse analysis in the 1980s and has made progress on its scheme in parallel with the appearance of a nonlinear Kalman filter, such as particle filter, (2) nonlinear Kalman filter in conjunction with the FEM corresponds to a strategy for so-called “data assimilation” used for various types of practical problems in many research fields of natural science.

List of Main Publications

Books

1. Murakami, A. ed. (2000) *Introduction to Inverse Problems in Civil Engineering*, Maruzen, Tokyo (in Japanese).
2. Murakami, A., Tosaka, N., Hori, M. and Suzuki, M. (2002) *Inverse Analysis by Finite Element Method and Boundary Element Method—Application of Kalman Filter and Equivalent Inclusion Method*, Corona Publishing, Tokyo (in Japanese).

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1. Murakami, A. and Hasegawa, T. (1985) Observational prediction of settlement using Kalman filter theory, *Numerical Methods in Geomechanics* (Kawamoto, T. and Ichikawa, Y., eds.), **3**, 1637–1643.
2. Murakami, A. and Hasegawa, T. (1985) Observational prediction of settlement using Kalman filtering, *Irrigation, Drainage and Rural Engineering Journal*, **120**, 61–67 (in Japanese).
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11. Hamaguchi, T., Murakami, A. and Hasegawa, T. (1997) Groundwater model in consideration of moving boundaries in a two-dimensional analysis and its application to an inverse analysis, *Proceedings of JSCE*, **568**, 133–145 (in Japanese).
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14. Murakami, A. (1997) Application of inverse analyses to engineering problems, *Theoretical & Applied Mechanics*, **46**, 25–38.
15. Murakami, A. (2002) The role of Kalman filtering in an inverse analysis of elastoplastic material, *Proceedings of the Japan Academy, Series B,* **78**, 250–255.
16. Kobayashi, N., Murakami, A., Kikuchi, Y. and Yoshitake, Y. (2002) Identification of coefficient of subgrade reaction of multilayers based on *in-situ* horizontal loading test of piles, *Irrigation, Drainage and Riral Engineering Journal*, **222**, 55–62 (in Japanese).
17. Nishimura, S., Nishiyama, T. and Murakami, A. (2005) Inverse analysis of soft grounds considering non-linearity and anisotropy, *Soils and Foundations*, **45**, 87–96.
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