TECHNICAL REPORT ON THE DEVELOPMENT OF PATTERN-CONSTRAINED INVERSION

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Noise contamination is a common issue in electrical resistivity surveys, and it can substantially reduce the reliability of resistivity models derived from inversion. To obtain more dependable models, data correction is often required. A previous technical report on automated data correction indicated that the automated approach could produce a lower RMS misfit than conventional correction procedures, while yielding models consistent with borehole information. Automated correction can produce many data points with about 10% relative error, making standard data-misfit metrics unreliable. The standard metric (RMS misfit) is computed as follows:

$$RMS = 100 * \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{r_i - d_i}{\epsilon_i}\right)^2}{N}},$$

where denotes the observed data, denotes the model-predicted data, denotes the data uncertainty, and is the number of data points. This conventional metric performs well when most data points have small errors (Fig. 1a), such that the model-predicted data (green line) closely follow the observations (black dots). It can also perform adequately when a limited subset of data points exhibit large errors (Fig. 1b), because the inversion remains constrained to reproduce the overall trend of the observations. However, the conventional metric can fail when a majority of data points have large errors (Fig. 1c). In this situation, the metric does not explicitly account for the pattern or shape of the data; instead, it primarily penalizes pointwise differences relative to the assumed uncertainty. Consequently, both the green and orange curves in Fig. 1c may be judged acceptable under the conventional RMS criterion. This motivates the development of a new metric that can evaluate data patterns while still incorporating uncertainty to guide inversion, as conceptually illustrated by the red curve in Fig. 1c.

Accordingly, the team developed a new misfit metric, termed *Pattern-Constrained Inversion*. The mathematical formulation is not disclosed in detail in this report; nevertheless, the company presents validation results using (i) synthetic models designed to test the proposed metric and (ii) field data. In both cases, the results are compared against those obtained using the conventional metric and are evaluated with reference to borehole information.

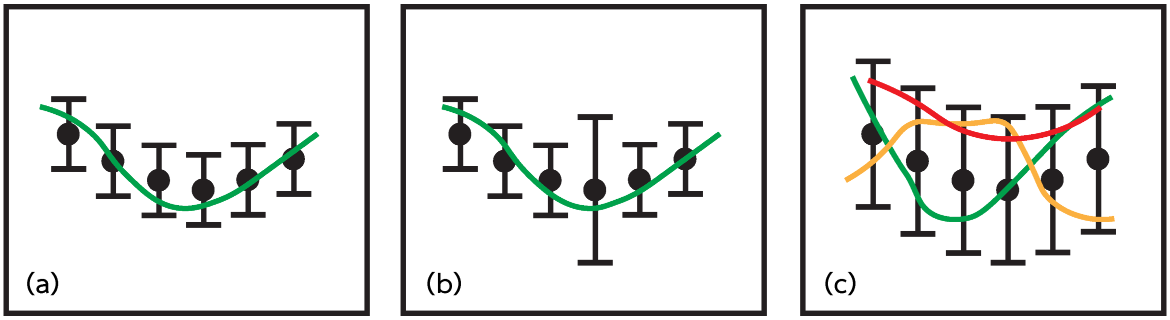

Figure 1. Schematic illustration of observed data (black dots) and model-predicted data (green, orange, and red curves) for: (a) high-quality data, (b) moderate-quality data with a limited number of high-error points, and (c) low-quality data in which most points exhibit large errors.

1.11.1 SYNTHETIC MODEL 1

Synthetic Model 1 is a simple benchmark model consisting of a 10 Ohm·m body with dimensions of 15 × 10 m, embedded in a homogeneous background of 100 Ohm·m. The low-resistivity body is located at a depth of 5 m (Fig. 2a).

For the synthetic data, a uniform data uncertainty of 1% was assigned to all measurements. The data were then inverted using an identical parameter set for both the conventional metric (Fig. 2b) and the proposed metric (Fig. 2c).

The models recovered using the two metrics are broadly similar. Both successfully reconstruct the low-resistivity body at the correct location, with lateral boundaries close to the white dashed line (the true boundary), except for the lower boundary, which is elongated significantly below the true extent. This behavior is commonly observed due to the inherent limitation that the survey samples data only from the ground surface.

Although the overall geometries are comparable, the inversion based on the proposed metric yields a resistivity value for the low-resistivity body that is closer to the true value than that obtained using the conventional metric.

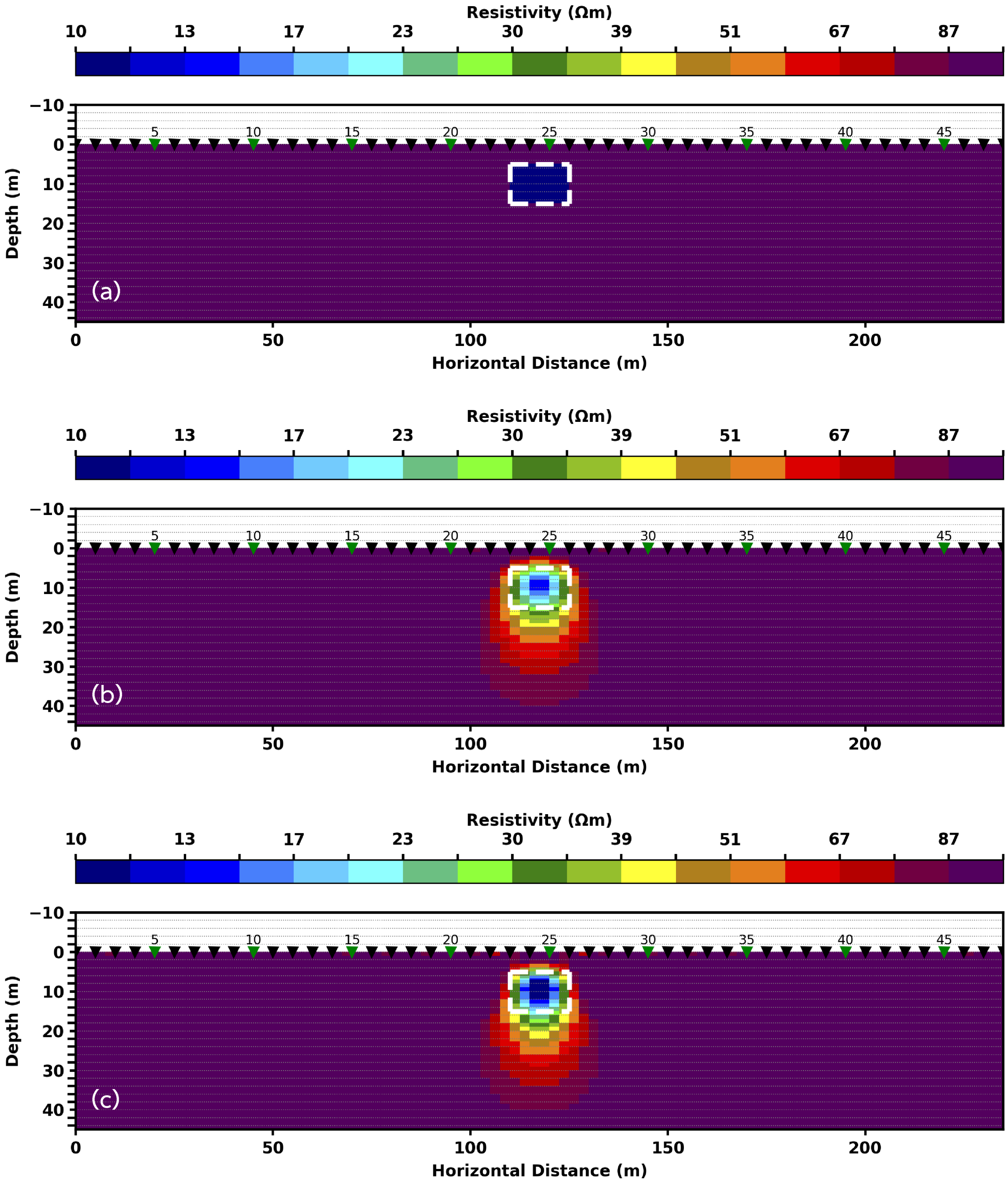

Figure 2. Synthetic Model 1 used to evaluate the proposed metric. The white dashed line indicates the boundary of the 10 Ohm·m body: (a) true synthetic model, (b) inversion result using the conventional metric, and (c) inversion result using the proposed metric.

1.21.2 SYNTHETIC MODEL 2

Synthetic Model 2 (Fig. 3a) was constructed from a model derived from a field survey conducted at a bank-protection dike along the Ping River (Villages 3, 1, and 2), Wang Khaem Subdistrict, Khlong Khlung District, Kamphaeng Phet Province. This site exhibited pronounced noise contamination, necessitating automated data correction. The corrected dataset differs from the pre-correction dataset by 34.89%.

The synthetic data were assigned uncertainties based on the error characteristics inferred from the field survey. The dataset was inverted using the same parameter set for both metrics. The inversion using the conventional metric produced an RMS misfit of 0.98, whereas the inversion using the proposed metric produced an RMS misfit of 0.07.

The inversion using the conventional metric recovers a structure with a pattern broadly similar to the synthetic model; however, the recovered resistivity values deviate from the true values. The inferred interfaces are displaced relative to the correct model, and the structure below approximately 20 m depth is substantially erroneous.

In contrast, the inversion using the proposed metric closely reproduces the synthetic model, with only minor discrepancies. While such agreement might be attributed to potential overfitting associated with an extremely low RMS misfit, it should be noted that the proposed inversion procedure does not use RMS misfit to determine the model-update direction. The reported RMS misfit is computed after the inversion has terminated. Therefore, the low RMS misfit obtained with the proposed metric should not be interpreted as evidence of overfitting.

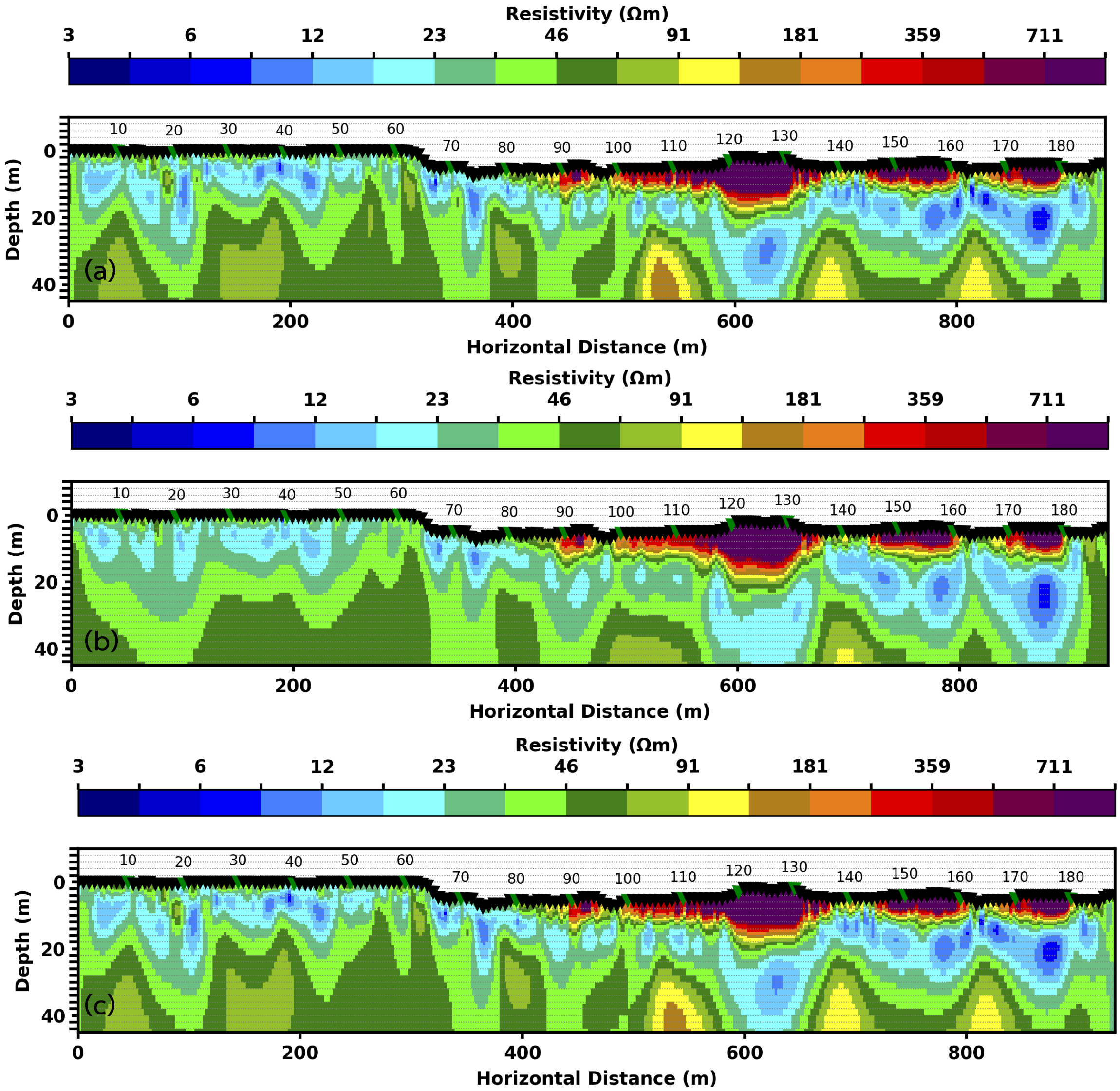

Figure 3. Synthetic Model 2 derived from field data acquired at a bank-protection dike along the Ping River (Villages 3, 1, and 2), Wang Khaem Subdistrict, Khlong Khlung District, Kamphaeng Phet Province: (a) true synthetic model, (b) inversion result using the conventional metric, and (c) inversion result using the proposed metric.

1.31.3 FIELD-DATA VALIDATION

The field dataset used for validation was acquired at a bank-protection and landscape-improvement project along Khlong Prem Prachakorn, Suan Prik Thai Subdistrict, Mueang Pathum Thani District, Pathum Thani Province. The raw data were processed using the automated data-correction procedure; the corrected dataset differs from the original dataset by 161%. The corrected data were then inverted using both the conventional and proposed metrics with identical inversion parameters. The conventional metric yielded an RMS misfit of 4.4, whereas the proposed metric yielded an RMS misfit of 4.2.

The model obtained using the proposed metric differs markedly from that obtained using the conventional metric. Specifically, the proposed metric produces higher resistivity values within high-resistivity units and lower resistivity values within low-resistivity units, consistent with the synthetic tests indicating improved resistivity recovery. When considering structure alone (i.e., ignoring absolute resistivity values), both models exhibit similar structural characteristics, including four high-resistivity bodies between 0 and 150 m along the profile. Near borehole BH-1R, a low-resistivity feature occurs adjacent to a high-resistivity feature.

The model derived using the conventional metric agrees with borehole information primarily at BH-4 only. In contrast, the model derived using the proposed metric shows consistency with borehole information at all boreholes. At BH-4, resistivity increases when transitioning from soft clay to very stiff clay. At BH-3, resistivity decreases upon entering very stiff clay—a behavior not reproduced by the conventional-metric result. At BH-1R, resistivity decreases to below 0.8 Ohm·m upon entering very stiff clay and increases again upon entering the silty sand unit.

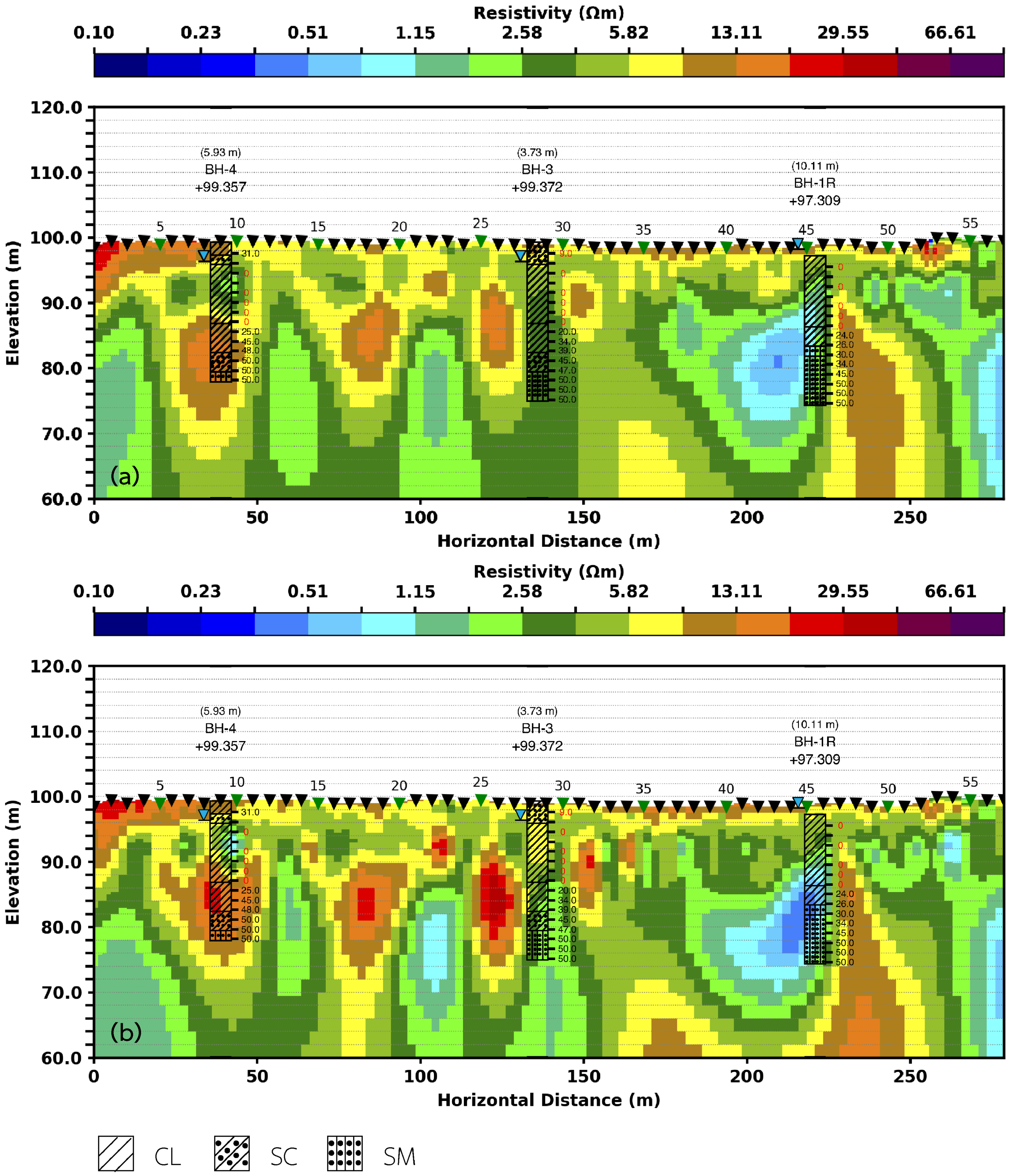

Figure 4. Field-data validation results from the bank-protection and landscape-improvement site along Khlong Prem Prachakorn, Suan Prik Thai Subdistrict, Mueang Pathum Thani District, Pathum Thani Province: (a) conventional metric and (b) proposed metric.

1.41.4 SUMMARY OF RESULTS

When noise substantially degrades data quality and extensive correction is required, inversion based on the conventional misfit metric may yield biased results. The tests demonstrate that, under substantial data modification, the conventional metric tends to produce accurate results only at shallow depths, while exhibiting significant errors at greater depths. In contrast, the proposed metric yields more accurate resistivity estimates and remains capable of recovering reliable models even when the dataset has been heavily corrected. Moreover, the proposed metric produces resistivity distributions that are consistent with lithological changes observed in all boreholes, whereas such relationships are not reliably identified using the conventional metric.