## Development of Low-Cost and Precise Measurement Techniques for Distribution of Absolute Settlement of Ballasted Tracks

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The ballast layer is subject to both deformation and degradation because of frequent traffic running loads. It is therefore important to understand the mechanism of ballasted track deterioration and to predict track settlement for reducing track maintenance costs and designing new track structures. The author developed low-cost, high precision and non-contacting monitoring techniques to comprehend periodically, the multipoint distribution of the absolute settlement of the ballasted track over the long term. Using an electronic digital level with a bar code staff, artificial reading errors of measurement were abolished. A corrective calculation using three-dimensional least squares approximation was introduced based on four or more fixed stakes for reference, as arranged around the measuring points. The installation errors of the equipment, which was set on the tripod at an arbitrary point in the measurement zone, were backward calculated and removed. The proposed technique was applicable to a revenue-service railway line to grasp the settlement distribution of 100 continuous sleepers along the direction of the railway track, including welding joint positions. Results confirmed that the standard deviation of the error of measurement was highly precise: 0.2 mm or less. The measuring time was approximately 1 min per measuring point.