PRE- AND POST-EARTHQUAKE DISPLACEMENT MONITORING OF HIGH-RISE BUILDINGS IN BANGKOK USING SATELLITE TIME-SERIES INSAR ANALYSIS

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1. INTRODUCTION

The major earthquake that struck central Myanmar on March 28, 2025, caused significant shaking in high-rise buildings in Bangkok, Thai-land, located more than 1,000 km from the epi-center. Several buildings, including those under construction, sustained damage. Structural health monitoring techniques are effective for evaluating earthquake-induced building dam-age; however, they are costly due to sensor installation and maintenance costs. This impact is particularly significant when monitoring a large number of buildings. On the other hand, while satellite-based monitoring involves measuring static (permanent) displacement, it can observe multiple structures over a wide area, and some satellite data is available free of charge. If this data can be utilized to detect structural deformation (abnormalities), significant cost reductions in damage estimation are expected.

Time-series InSAR analysis, such as PSI (Persistent Scatterer Interferometry) and SBAS (Small BAseline Subset), is used for displacement measurement by satellite-mounted synthetic aperture radar (SAR) [1, 2]. The authors have also used SBAS to determine the subsidence of a road bridge over a lake in Iran [3]. SBAS has relatively low spatial resolution and requires phase unwrapping, making it unsuitable for monitoring densely populated urban are-as or small-scale infrastructure facilities. On the other hand, conventional PSI could not handle large displacements accompanied by nonlinear trend and 2π ambiguity, but the authors have recently developed NN-PSI [4, 5] that over-comes these drawbacks.

In order to investigate the feasibility of using Sentinel-1 satellite images, which are available free of charge but have relatively coarse spatial resolution, for estimating building damage after an earthquake by applying the newly developed NN-PSI, this study focuses on the displacement estimation of high-rise buildings in Bangkok, Thailand, following the central Myanmar earthquake.

2. NN-PSI (NON-LINEAR NON-PARAMETRIC PERSISTENT SCATTERER INTERFEROMETRY)

PSI is one of the time-series InSAR analysis methods, which measures the time-series dis-placement in the line-of-sight direction (range direction) of pixels (PS: Persistent Scatter) where microwaves are strongly scattered continuously. Therefore, it is necessary to prepare SAR images from multiple periods. A conceptual diagram of the observation is shown in Figure 1. The accuracy of displacement measurement depends on the wavelength of microwaves. The Sentinel-1 satellite of the European Space Agency used in this study is equipped with a C-band (wavelength: approximately 5.7 cm) SAR sensor and observes the entire globe at 12-day intervals. The data is available for free. The spatial resolution of the Sentinel-1 satellite is approximately 2 m in the range direction and approximately 15 m in the azimuth direction.

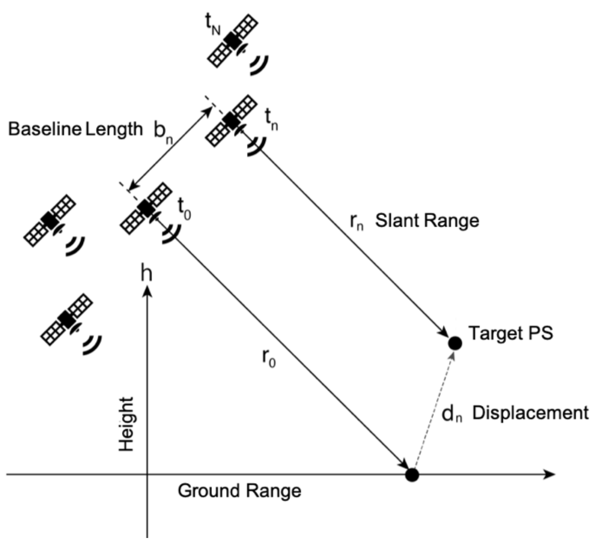

Figure 1. Schematic diagram of time-series InSAR

Displacement measurement using PSI is performed on individual pixels, which is advantageous because it preserves the spatial resolution of the image. Furthermore, since it is similar to stereoscopic vision, it is possible to estimate not only displacement but also the height of locations where microwaves are backscattered. When the measurement target is predetermined, the height values estimated by PSI can be used as a reference; however, the estimation accuracy of height is not as high as that of displacement.

The specific calculation procedure for NN-PSI [4, 5] based on PSI, is shown below.

1. As shown in Figure 1, when a satellite observes a target point n+1 during the period t_0 to t_n, the phase difference of the observed microwaves is determined by the height and displacement velocity of the tar-get point. The displacement velocity is the displacement in the slant range direction ($r_n - r_0$) caused by the variation of the target object, divided by the observation interval ($t_n - t_0$), expressed in mm/yr.
2. Considering the observation conditions (observation period, observation interval, baseline length, and microwave wavelength) of the satellite, calculate the time-series coherence within the range of possible heights and displacement velocities, and determine the height value where the cumulative value of the time-series coherence with respect to the displacement velocity is the smallest as the height of the target object.
3. At the determined height, calculate the time-series displacement for all possible displacement velocities, and sum these displacements while weighting them by the time-series coherence values to obtain the final displacement.
4. Since NN-PSI is calculating continuous displacement over time, if a 2π offset appears, correct the displacement in the direction of the offset (unwrap) to estimate large displacements.

In the following sections, we introduce the time-series displacements estimated by NN-PSI for high-rise buildings in Bangkok, Thailand, before and after the earthquake.

3. TIME-SERIES DISPLACEMENTS ESTIMATED USING NN-PSI

3.1 Data Used and Target Buildings

The study covers the period from January 2023 (pre-earthquake) to April 2025 (immediately post-earthquake). For the ascending orbit, 65 scenes (63 pre-earthquake and 2 post-earthquake) were used, and for the descending orbit, 66 scenes (64 pre-earthquake and 2 post-earthquake) were used. The polarization is VV. Figure 2 shows the distribution of the targeted high-rise buildings.

Displacement measurements are limited to the line of sight from the satellite. Figure 3 shows the direction of displacement measurements for each orbit. For example, in the ascending orbit, microwaves are emitted from the southwest, so measurements are taken in the southwest-northeast direction, and due to the 34-degree incidence angle, displacement in the diagonal up and down directions is measured. Note that the measured microwave components may include not only single scattering from buildings but also double scattering from buildings and the ground, so the estimated displacement may not be solely due to buildings.

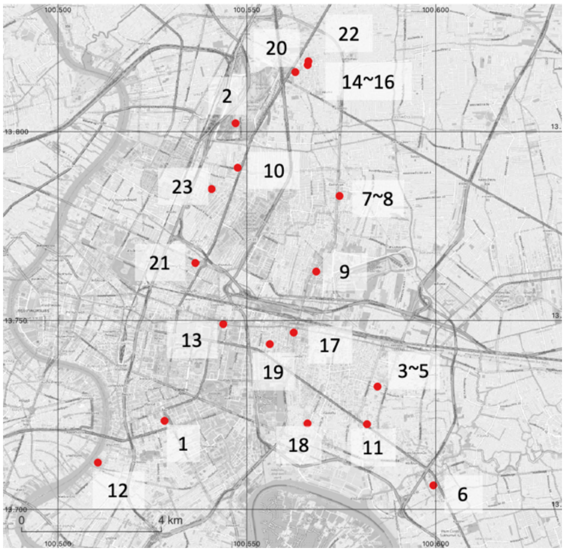

Figure 2. Distribution of target high-rise buildings in Bangkok, Thailand (The numbers and building names are shown in Table 1.)

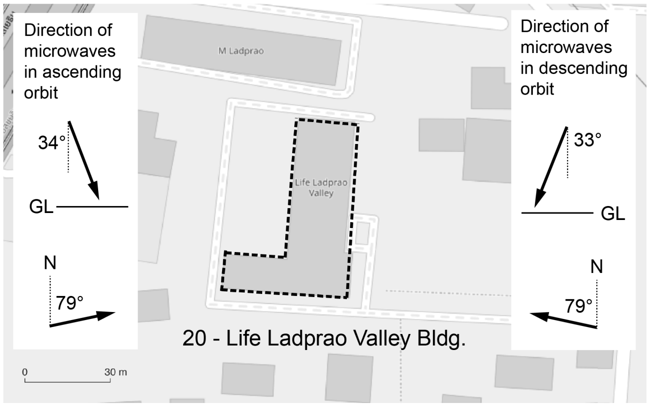

Figure 3. Relationship between buildings and microwave direction from two different orbits

3.2 Time-series Displacement and Anomaly Detection

NN-PSI can be applied to all pixels in the target buildings. However, pixels (PS) where microwaves are strongly scattered continuously are subject to various noise influences, making dis-placement values unreliable. Here, we selected PS following the procedure below to extract anomaly displacement behavior after the earthquake.

1. Screening
   1.1 Calculate the average and standard deviation of the microwave backscatter intensity from the time-series data, and select pixels where the average divided by the standard deviation exceeds the threshold (set to 2 in this study).
   1.2 From the time-series displacement data before the earthquake, we estimated a linear regression equation. We selected pixels where the Root Mean Square Error (RMSE, σ) between the predicted values from the regression equation and the observed displacements

Table 1. Target buildings and anomaly detection result

Building No.	Name	Anormaly	
		Ascending orbit	Descending orbit
1	Mahanakhon	–	–
2	State Audit Office Building	NA	NA
3~5	Park Origin Thonglor Tower A~C	–	NA
6	Rhythm Sukhumvit 50	–	✓
7~8	Life Ratchadapisek Tower A~B	–	–
9	Ivy Ampio	✓	NA
10	The Reserve Phahol-Pradipat	–	NA
11	Intercontinental Sukhumvit	–	–
12	Four Seasons Private Residences	–	–
13	Q Child Lom-Phetchaburi	NA	–
14~16	The Line Phahonyothin Park Tower A~C	–	✓
17	The Loftd Asoke	–	–
18	Lumpini Sukhumvit 24	–	–
19	Hyde Sukhumvit 11	–	–
20	Life Ladprao Valley Bldg.	✓	✓
21	Rajavithi Hospital	–	–
22	Immigration Bureau	–	–
23	The Revenue Department	–	–

was smaller than the threshold (set to 3 mm in this study).

2. Anomaly detection

   Pixels where the displacement measured in two observations after the earthquake exceeded the regression equation prediction value ±4σ (range covering approximately 99.99% when assuming a normal distribution) were classified as anomalies.

Table 1 indicates the presence or absence of anormal PS in the target buildings. "NA" indicates that PS could not be obtained, a hyphen "-" indicates that no anormal PS was detected, and a check mark "✓" indicates that anormal PS was detected.

Anormal displacements are not detected in most buildings; however, in the 20-Life Ladprao Valley Building, which sustained severe damage to the first-floor columns, anormalities were detected in both the ascending and descending orbits (see Figure 4). Additionally, in the 6-Rhythm Sukhumvit 50, anormalities were detected in the descending orbit (see Figure 5). In the figures, displacement toward the satellite is positive, and displacement away from the satellite is negative. Looking at the direction of displacement after the earthquake, it can be seen that the displacement of the 20-Life Ladprao Valley Building is complex depending on the location of the building, but the displacement of the 6-Rhythm Sukhumvit 50 shows PS in the descending orbit in the direction away from the satellite, suggesting that part of the building may have shifted northwest or subsided. Anormal dis-placements were also detected in the 9-Ivy Ampio and 14~16-The Line Phahonyothin Park Tower A~C. Field investigations of these buildings are required to verify the results.

4. CONCLUSIONS

NN-PSI was applied to Sentinel-1 SAR images of high-rise buildings in Bangkok, Thailand, observed before and after the earthquake in central Myanmar on March 28, 2025, and buildings with anormal displacement were detected after the earthquake. The anomalies detected in this analysis may not necessarily be directly caused by displacement of the building's main structure, but could be influenced by deformation of exterior walls, damage to ancillary facilities, and ground deformation reflected in the second scattering of microwaves. Field surveys are required for verification.

5. REFERENCE

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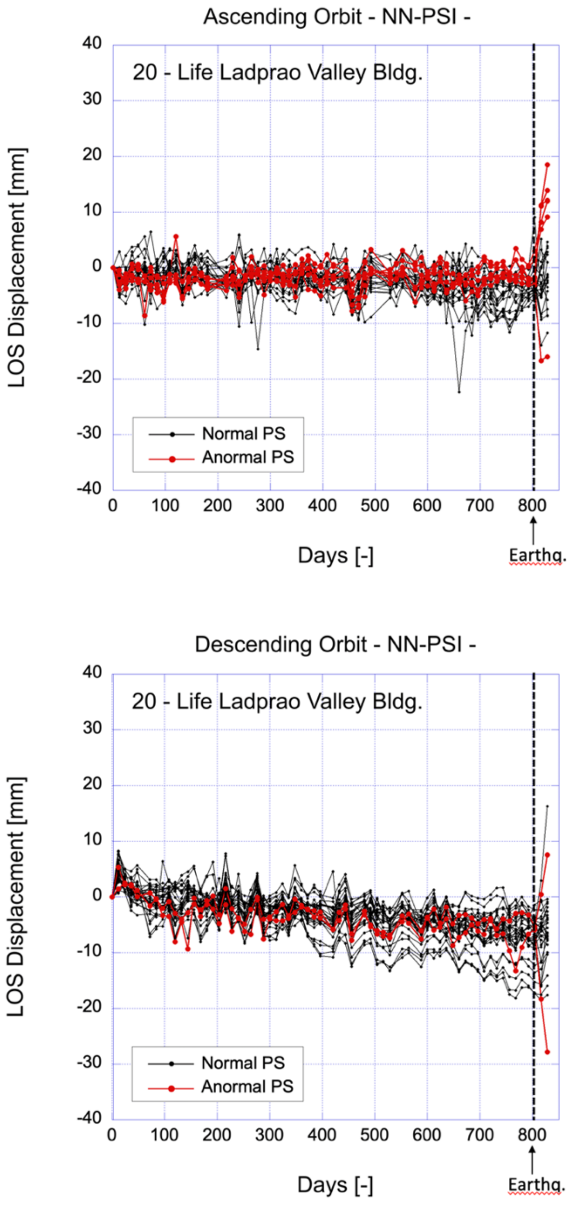

Figure 4. Time-series displacement of 20- Life Ladprao Valley Building. The upper figure shows the result of the ascending orbit data, and the lower figure shows the descending orbit data. (black and red lines indicate normal and anormal PS, respectively)

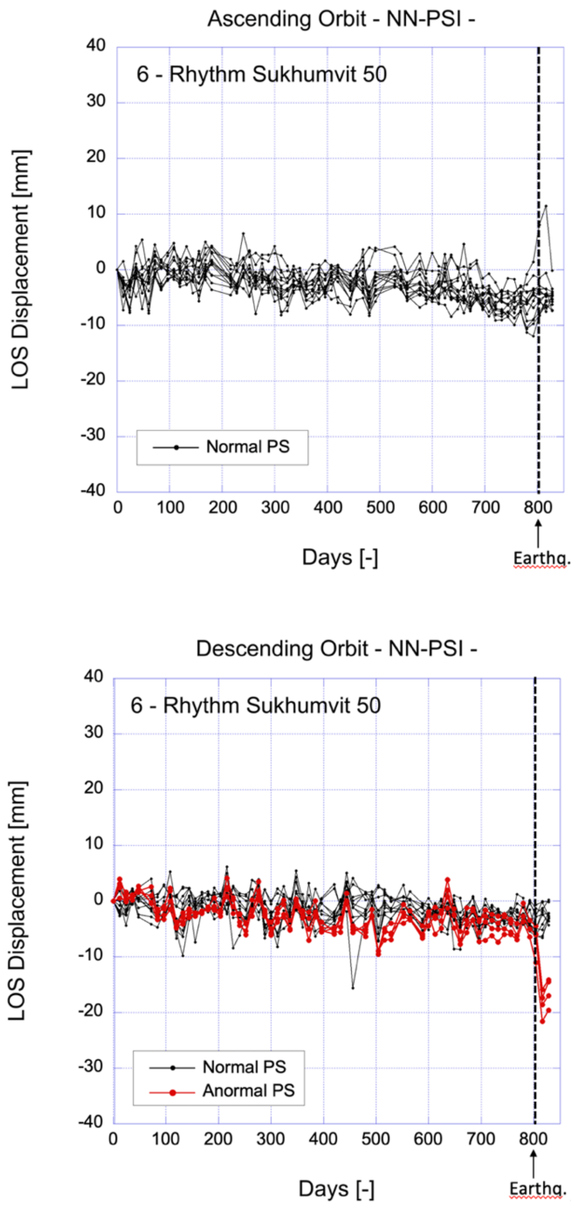

Figure 5. Time-series displacement of 6- Rhythm Sukhumvit 50. The upper figure shows the result of the ascending orbit data, and the lower figure shows the descending orbit data. (black and red lines indicate normal and anormal PS, respectively)