Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Project Description: Developing and applying InSAR to bridges and viaducts (EU tender, lot 2)

InSAR based deformation for the Dutch built environment

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Content

1 Project Description Lot 2: Developing and applying InSAR to bridges and viaducts

1.1 General introduction: satellite data at Rijkswaterstaat

Rijkswaterstaat manages the Dutch national roads, part of the primary dikes, locks and storm surge barriers. A significant part of that infrastructure was built in the 1950's to 1980's. The focus of Rijkswaterstaat in the coming decades will be on maintenance, renovation and replacement of aging infrastructural assets.
Satellite radar observations based on interferometric synthetic aperture radar (InSAR) can be used to accurately monitor subsidence and rise of critical infrastructure, such as dikes, freeways and tunnels. As such, InSAR data can support Rijkswaterstaat's renovation and replacement task in two ways: firstly, to analyze historical behavior of structures and/or subsurface to inform (re)designing renovation or replacement. Secondly, to monitor object deformation behavior for anomalies which can indicate processes related to structural failure to enable threat response and project prioritization.

This project is set up to advance InSAR use to enable large scale infrastructural monitoring at Rijkswaterstaat. The project consist of two parts, called lots.

Lot 1: Monitoring of tunnels and historical analysis of other objects
This lot is composed of call-off-contracts under framework agreement for operational InSAR monitoring and one-off analyses for objects with established measurement feasibility (e.g., dikes, freeways and tunnels).
Lot 2: Developing and applying InSAR analysis to bridges and viaducts
This lot is an applied research on applying InSAR to bridges and viaducts.

This document contains the description for **Lot 2.**

1.2 Background and objectives Lot 2, developing and applying InSAR to bridges and viaducts

1.2.1 Background

To assure stability and safety of objects, Rijkswaterstaat performs regular in-situ deformation measurements for around 2600 objects, mainly viaducts (1300) and bridges (500). Other object types include culverts, aqueducts, ecoducts, locks, tunnels and quays. Each year approximately 200 objects are measured. These are prioritized based on risk profiles and results of earlier measurements. Monitoring of all objects is not seen as feasible due to limited resources (e.g., time, money and manpower).

Additionally, in-situ measurements require roads to be partly or completely closed for traffic to ensure the safety of the survey personnel. This is not always possible. InSAR does not require any on-site personnel as satellite imagery is used, thus preventing costly traffic measures and safety risks.

As a number of bridges and viaducts in Western Europe incurred damages, there is need for more information than is available from historic in-situ measurements to do detailed risk assessment. InSAR can provide such historical deformation information.

However, while InSAR processing and analysis has become more and more commonplace on infrastructure, challenges remain when applied to bridges and viaducts. Earlier projects instigated by Rijkswaterstaat proved the potential of InSAR for these object types, but the level of detail and accuracy were not on par with the required accuracies. The most recent research conducted on InSAR deformation measurements for two bridges (Houtensebrug 2023, Hagesteinsebrug 2024) brought forward several challenges with regards to InSAR deformation measurements:

- Differences in loading and vibrations of bridges per satellite overpass causes variations in time series which complicates finding a good InSAR solution
- Complex and non-uniform movement due to bridge structure can cause problems in InSAR data processing
    - Due to expansion joints between bridge decks, jumps in (mostly) horizontal movement are present which can cause problems in InSAR data processing
    - Opposing movements around expansion joints complicate the decomposition in horizontal and vertical displacement
    - Movement varies mostly in longitudinal direction of the bridge deck, requiring tailored segmentation per bridge section for correct InSAR decomposition

- Differential movement between different structural elements (e.g., pylons, decks, cables, …)

Many of these challenges originate from the type of construction and material of the bridge, thus making it essential that this information is used for InSAR data processing to ensure meaningful results.

Beyond technical challenges, there is an organizational issue: Rijkswaterstaat currently cannot assess InSAR suitability for objects until after processing and analysis is complete. Pre-analysis evaluation of InSAR suitability would improve resource allocation, time management and prioritization effectiveness. Therefore, this assignment includes developing methods to estimate expected InSAR uncertainties (i.e. suitability) based on object characteristics before full analysis.

1.2.2 Objectives

The main objectives of this assignment are as follows:

i) Develop and validate InSAR data processing methodologies for bridges and viaducts by finding technical solutions for the aforementioned and emerging challenges to enable upscaling

ii) Explore and quantify the differences in uncertainty between medium- and high-resolution InSAR measurements for bridges and viaducts and its implications for object suitability

iii) Develop and validate a methodology to assess and predict suitability and expected uncertainty of InSAR analyses based on object properties. Suggested object properties include, but are not limited to construction type, material, span, deck width and/or orientation of the object

1.3 Assignment description

The research assignment is composed of three distinct phases.

Phase 1 (*research phase*): Research and develop a technical solution for operational InSAR monitoring by testing on 5 objects to overcome current implementation barriers.

Phase 2 (*generalization phase*): Generalize the developed technical solutions to allow for robust scaling. Robust is understood as applicable and reliable on multiple object types without additional actions. Also, explore how object properties dictate suitability and expected uncertainty of InSAR analysis and develop this into a methodology.

Phase 3 (*production and testing phase*): Apply the developed technical solution to multiple objects for validation testing.

More details on the 3 phases are given in the next chapters

1.4 Datasets to be processed

SAR images will be provided by Rijkswaterstaat at the beginning of the project. All provided SAR images (medium- and high-resolution) must be processed. RadarSat-2 is classified as medium-resolution, TerraSAR-X and Cosmo-SkyMed are classified as high-resolution.

The contractor must sign the end user license (EULA) of the corresponding provider (TerraSAR-X: Airbus, Cosmo-SkyMed: e-GEOS, RadarSat-2: MDA) before use. Furthermore, the contractor must adhere to the following:

1. The contractor must comply with the EULA's for both satellite datasets in the way they store, process and distribute the data.
2. The use of the datasets provided by Rijkswaterstaat is strictly limited to this project.
3. At the end of the contract term, all provided datasets must be destroyed by the contractor. This must be confirmed by the contractor in writing.

1.5 Data delivery by Rijkswaterstaat

The contractor must provide an SFTP server on which Rijkswaterstaat can upload the datasets. The SFTP details must be provided by the contractor after which the data will be uploaded by Rijkswaterstaat.

1.6 Maintenance history of objects of interest

Because maintenance activities, partial replacements and other structural modifications can disrupt InSAR time-series, available maintenance history for the study period will be provided to the contractor. However, maintenance records may be incomplete or lack sufficient detail, requiring the contractor to identify and account for additional coherence disruptions. This information can be used by the contractor to adapt and optimize the data processing accordingly.

1.7 Technical requirements

Initially (in phase 1), processing must take place according to the requirements as included in the Technical Requirements (TR).
Due to the nature of this assignment, alterations will be made to the TR based on progressive insight and implemented in phase 3. This can be instigated by either Rijkswaterstaat or the contractor, and decided in mutual agreement.

1.8 Delivery and assessment terms

The table below applies to the delivery terms of the contractor and the assessment terms of the client.

Phase 1 and 2 (2026)

For phase 1 and 2, three deliveries are defined.

Delivery	Data	Delivery date
Phase 1 delivery 1 Deliverables for first three objects	Level-2, level-3 and InSAR analysis report (see deliverables 2.3)	1 July 2026
Assessment of 1st delivery		Within 10 working days after delivery
Phase 1 delivery 2 Deliverables for last two objects + research report	Level-2, level-3, InSAR analysis report and research report (see deliverables 2.3)	1 November 2026
Assessment of 2nd delivery		Within 10 working days after delivery
Phase 2 delivery 1 Deliverables for phase 2	Complemented list of objects and inventory report (see deliverables 3.3)	16 November 2026
Assessment of 3rd delivery		Within 10 working days after delivery

Phase 3 (2027)

Delivery	Data	Delivery date
Phase 3 delivery 1 Deliverables for first 50% of objects	Level-2, level-3, InSAR analysis reports and validation report (see deliverables 3.4)	1 July 2027
Assessment of 1st delivery		Within 10 working days after delivery
Phase 3 delivery 2 Deliverables for second 50% of objects	Level-2, level-3, InSAR analysis reports and validation report (see deliverables 3.4)	1 November 2027
Assessment of 2nd delivery		Within 10 working days after delivery

Although for phase 3 delivery and payment milestones are structured around two deliveries to minimize administrative overhead (first and second half of objects), we require more frequent deliveries to facilitate adequate assessment times.

1.9 Payment after acceptance

Payment takes place after acceptance of the results of the services in accordance with the table below.

Phase 1 and 2 (2026)

Delivery Acceptance	Percentage of the total price
Phase 1 delivery 1	40%
Phase 1 delivery 2	40%
Phase 2 delivery 1	20%

Phase 3 (2027)

Delivery Acceptance	Percentage of the total price
Phase 3 delivery 1	50%
Phase 3 delivery 2	50%

Although for phase 3 delivery and payment milestones are structured around two deliveries to minimize administrative overhead (first and second half of objects), we require more frequent deliveries to facilitate adequate assessment times.

2 Phase 1 – Research on five objects

2.1 Objectives

The objective of phase 1 is to research and develop a technical solution for challenges that currently hinder operational implementation of InSAR for monitoring bridges and viaducts through applied research on five objects.

We have selected the following objects of different types for InSAR data processing:

1. Concrete cantilever bridge (bridges built using structures that project horizontally into space). **Rooyensteinse brug**
2. Bridge with steel decks. **Hagesteinse brug**
3. Newly constructed bridge (<10yr) with concrete beams/girders. Best option: **Betlembrug**
4. Arch bridge. **Van Brienenoordbrug**
5. Multiple fly-overs at one location. **Knooppunt Prins Clausplein**

For all these objects we request data processing for both medium- (RadarSat-2) and high-resolution (TerraSAR-X and Cosmo-SkyMed) data that Rijkswaterstaat has acquired.

Developed strategies for mitigating the following challenges must be shared in a **public report** with Rijkswaterstaat to enable knowledge transfer (deliverable D), though only general methodological approaches and principles need be disclosed rather than proprietary technical details or specific implementations.

- Development of method(s) where phase differences between bridge decks will not cause problems
- Development of method(s) that utilize a priori information on objects for improved data processing. For example, to separate bridges into (expected) uniformly moving segments before data processing to allow for better point selection for DS-planes
- Development of method(s) where temporary displacement or vibrations due to loading (e.g., moving freight traffic on bridge) will not cause unwrapping issues
- Development of method(s) to distinguish between movement of different parts of the bridge (e.g., pylons, pillars, decks, cables)

2.2 Principles

1. The data processing is done based on a base set of technical requirements that also apply to other InSAR projects
2. Based on the results, additional technical requirements will be added to the existing technical requirements which shall be used for future InSAR data processing assignments (including phase 3).

3. The contractor must identify uniformly moving segments prior to level-3 processing. This segmentation must be based on provided and/or public data (e.g., AHN, DTB) and InSAR-derived deformation patterns and requires Rijkswaterstaat approval before level-3 processing. This approval process is designed as a single review cycle (initial submission plus one possible revision) based on technical justification.

2.3 Deliverables

The required deliverables are as follows.

For each object complex:

A. The delivery of point data sets with displacement time-series (level-2) in line of sight for each satellite track.
B. The delivery of the line of sight, horizontal and vertical displacement time-series of the object in (if applicable) uniformly moving segments (e.g., bridge decks) (level-3)
C. InSAR analysis reports which describe the InSAR processing and quality of the level-2 and level-3 products according to the Technical Requirements consisting of:
    a. Project report
    b. Quality report

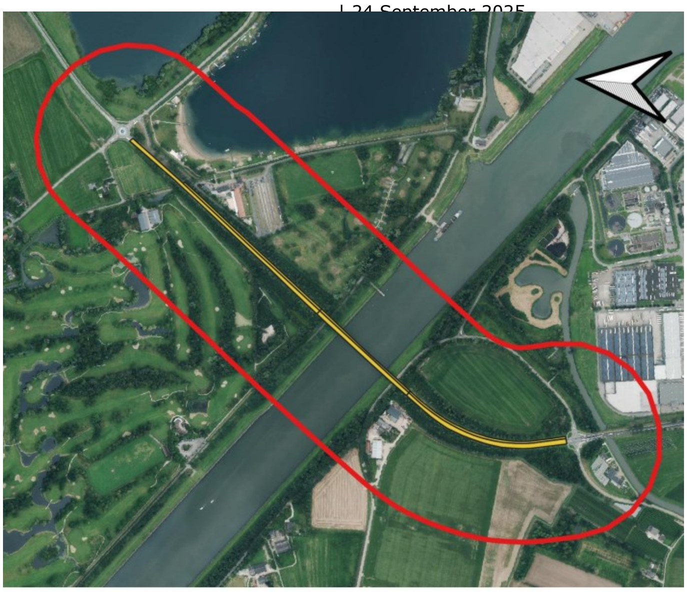
Overall phase 1:

D. Research report summarizing developed and recommended processing strategies for mitigating the challenges that have been summed up in section 2.1. This research report must contain transferable recommendations regarding methodology and must supplement the Technical Requirements, though only general methodological approaches and principles need be disclosed rather than proprietary technical details or specific implementations. This report is **not confidential**, meaning **it may be shared externally** (non-Rijkswaterstaat).

2.4 Area description

The area of interest (AOI) are the relevant objects at five locations in the Netherlands. Those are:

- Rooyensteinse brug, concrete cantilever bridge – *(lat 51.923, lon 5.426)*
- Hagesteinsebrug, bridge with steel decks – *(lat 52.025, lon 5.130)*
- Betlembrug, bridge with concrete beams/girders – *(lat 52.331, lon 5.016)*
- Van Brienenoordbrug, arch bridge – *(lat 51.904, lon 4.543)*
- Knooppunt Prins Clausplein, challenging traffic junction with several fly-overs – *(lat 52.062, lon 4.376)*

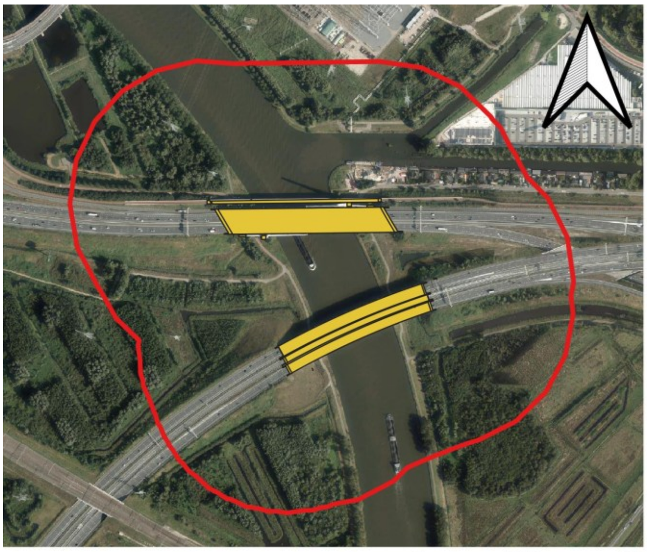


Rooyensteinse brug

0 200 400 m

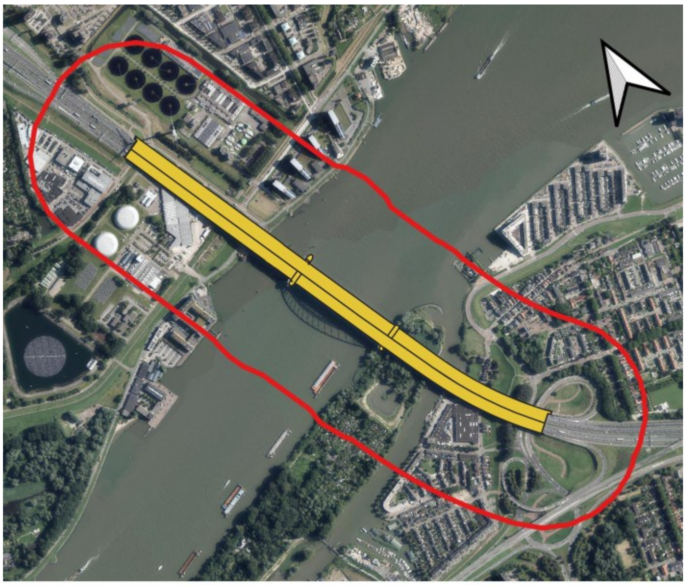
Hagesteinsebrug

0 200 400 m



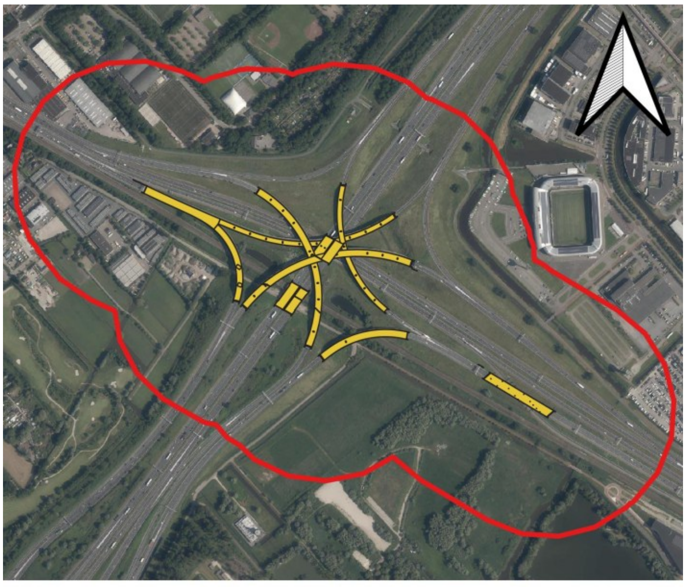
Betlembrug

0 200 400 m



Van Brienenoordbrug

0 200 400 m



Prins Clausplein

0 200 400 m

3 Phase 2 – Generalization

3.1 Objectives

The objective of phase 2 is to generalize the developed technical solution of phase 1 to allow for robust scaling, in which robust is understood as applicable and reliable on multiple object types without additional manual intervention. This generalization will serve as the basis for developing a predictive tool for uncertainty estimation. Rijkswaterstaat aims to obtain a methodology to estimate expected uncertainties of InSAR deformation measurements for any bridge/viaduct in the Netherlands based on satellite data properties, specific object properties (construction type, material, span, deck width and orientation of the object) and object surroundings following from generalized experiences of phase 1. This methodology for pre-analysis evaluation of InSAR suitability will improve resource allocation, time management and prioritization effectiveness.

The contractor will receive a list of objects (Appendix: Lot2Phase2-3_object-list) and must complement this list with expected uncertainties for medium- and high-resolution InSAR. These uncertainties must be supported with an inventory report that analyzes how object properties and environmental factors influence InSAR suitability for each object.

3.2 Principles

Conditions for the system to be developed are:

1. Processing must follow the adapted Technical Requirement developed in Phase 1. Report expected uncertainties that result from processing in accordance to the TR.
2. In consultation with Rijkswaterstaat, the contractor must define parameters/measures that can characterize the suitability of InSAR for an object.
3. Analysis must be based on publicly available data (e.g., BGT, AHN, DTB) and data provided by Rijkswaterstaat.

3.3 Deliverables

A. **List of objects** (Appendix: Lot2Phase2-3_object-list) complemented with expected uncertainties for medium- and high-resolution InSAR analyses. In consultation with Rijkswaterstaat, the contractor must construct reasonable and reliable measures of uncertainty.

B. Expected uncertainties must be supported with an **inventory report.** This report (1-pager) expands on the expected uncertainties of InSAR deformation measurements by analyzing contributing factors, both advantageous and disadvantageous, based on its properties such as construction type, material, span, deck width and/or orientation of the object. Furthermore this report contains a paragraph/page describing the expected uncertainties for each object split out by the contributing factors.

C. The developed methodology for estimating uncertainty of InSAR deformation measurements for bridges and viaducts. This must be presented as rule of thumb, (set of) formula(s) or tool.

D. Research report containing developed and/or recommended strategies for the objectives of 3.1. This research report must contain transferable recommendations regarding methodology and must supplement the Technical Requirements. This report is **not confidential**, meaning **it may be shared externally** (non-Rijkswaterstaat).

4 Phase 3 – Production and testing

4.1 Objectives

The objective of phase 3 is to test the generalized technical solution of phase 2 via applied research on a predetermined number of objects based on the budget of 50K€. This involves the development of test(s) based on InSAR data that can be used to determine the quality of the uncertainty assessment and segmentation. Essentially, this is designed as a method to test the robustness and quality of the developed system by performing InSAR analyses. The contractor must create and develop a test plan and apply this to a predetermined number of objects from the total list of (prioritized) objects. The exact number of objects to process is part of the tender and selection process. Each contractor must indicate the number of object complexes (in order of priority) they can process within the budget constraints of 50K€. Note that object complexes can contain multiple individual objects (e.g., separate viaducts within a traffic interchange) and must be completed in their entirety.

4.2 Principles

Conditions for the system to be developed are:

1. Produced level-2 and level-3 measurements are delivered to Rijkswaterstaat using a fixed format together with the (standard) InSAR analysis report, and are in ownership of Rijkswaterstaat.
2. Processing must follow the adapted Technical Requirement developed in phase 1 and 2.
3. The contractor must identify uniformly moving segments prior to level-3 processing. This segmentation must be based on provided and/or public data (e.g., AHN, DTB) and InSAR-derived deformation patterns and requires Rijkswaterstaat approval before level-3 processing. This approval process is designed as a single review cycle (initial submission plus one possible revision) based on technical justification.

4.3 Deliverables

For each object complex we require:

A. The delivery of point data sets with displacement time-series (level-2) in line of sight for each satellite track
B. The delivery of the line of sight, horizontal and vertical displacement time-series of the object in (if applicable) uniformly moving segments (e.g., bridge decks) (level-3).

C. InSAR analysis reports which describe the InSAR processing and quality of the level-2 and level-3 products according to the Technical Requirements consisting of:
    a. Project report
    b. Quality report
D. Validation Report with a comparison of actual uncertainty with expected uncertainty as presented in the Inventory Report.