Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Object Information for InSAR Processing

An Annex to the Technical Requirements

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1 Introduction

Rijkswaterstaat employs the Interferometric Synthetic Aperture Radar (InSAR) processing to monitor the Dutch infrastructure. InSAR is a spaceborne differential measurement technique which produces repeated (near) millimeter-accurate displacement measurements over time. For Rijkswaterstaat, the objective lies with the detection of displacement anomalies of the national infrastructure for an informed prioritization of maintenance.

Anomalies can only be detected systematically if the baseline behavior is well understood. This document outlines several different object categories together with their expected behavior in the context of InSAR time series. This provides a *starting point* for the contractor to tailor and improve the processing to the project goal(s). For each object category, Rijkswaterstaat also imposes certain InSAR processing requirements. This document is therefore an annex to the technical requirements.

2 Object Information

The decomposition (and sometimes the deformation) directions are displayed in a figure for each object type. The blue arrows for the decomposition directions point in the positive direction. The opposite parallel direction is negative. The vertical axis is always perpendicular to the horizontal axis.

2.1 Roads

Road deformation can be very local (<1m) e.g. due to soil washing out from underneath. Widespread subsidence of soft soils also occurs, e.g. due to compaction after construction or due to oxidation of peat layers. An annual periodic cycle may be visible in the vertical direction due to the changing water table.

Roads with a foundation or anchoring show less variation throughout the year than roads without a foundation or anchoring. Individual lanes may have varying foundations by design or e.g. due to road expansion. Furthermore, road sections over culverts generally display different vertical deformation rates than the surrounding road sections without a culvert.

Roads are usually elevated above the ground level. The soil underneath is susceptible to shearing, which is visible as a displacement perpendicular to the road direction (Figure 1). The shearing interface at the surface shifts from the sloped side towards the middle of Figure 1 (and beyond) as the elevation above the ground level increases.

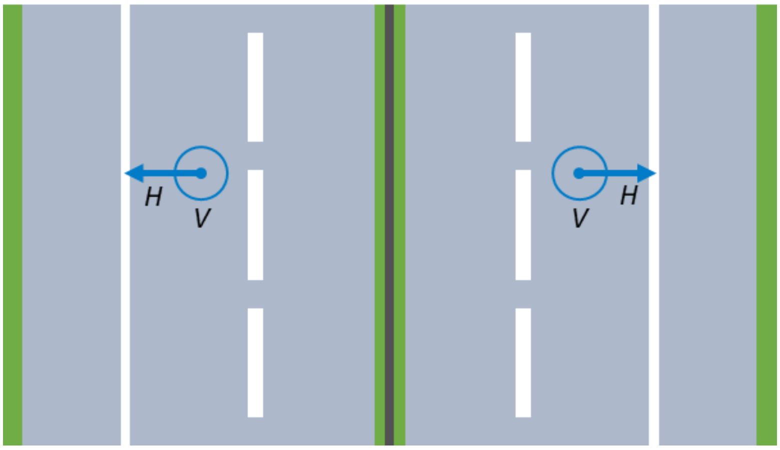

Figure 1 Schematic of the road 2D decomposition vectors. The center marking (black line) splits the two driving directions in two.

2.1.1 Data Processing Requirements

1. The road is divided into individual polygons. Each polygon envelops one road segment and does not cross any (expansion) joints. Polygons themselves may overlap.
2. Each DS(-like) point on a road section must be contained to the same respective road section.
3. Each decomposition must not cover multiple road sections simultaneously.

4. Unless specified otherwise, 1) the vertical direction is upward and perpendicular to the horizontal direction, 2) the horizontal direction is perpendicular to the driving direction, away from center marking (see Figure 1).

2.2 Tunnel Access Roads

Tunnels access roads are characterized by separate elements (see Figure 2). These elements experience displacements that may strongly vary in the longitudinal and upward direction of the tunnel. Figure 2 displays a tunnel with five tunnel elements and illustrates the groundwater and temperature induced deformation vectors. The temperature induced deformation is also visible in the vertical direction, albeit much smaller due to the dimensions of each element.

Debris may accumulate in the expansion joints between the tunnel elements. The accumulation primarily takes place during winter when the joints are the widest. Over the years, this results in an outward motion of the tunnel elements, which is largest during the summer because of thermal expansion.

Tunnel elements are often anchored vertically to counter the uplift induced by the (changing) water table. The vertical amplitude is positive during the winter when the buttressing effect from adjacent elements is minimal and the water table is highest. The vertical amplitude is generally much smaller than the horizontal amplitude. Additionally, the horizontal amplitude of elements increases from the center of the tunnel outwards.

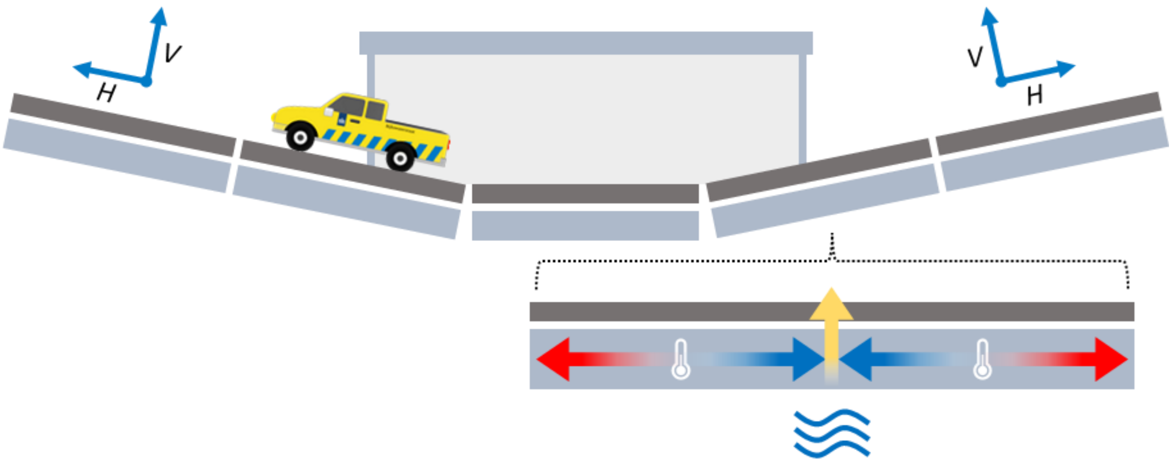

Figure 2 Schematic of the tunnel deformation vectors and the 2D decomposition vectors.

2.2.1 Data Processing Requirements

1. The tunnel infrastructure is divided into individual polygons. Each polygon envelops one tunnel element and does not cross any (expansion) joints. Polygons themselves may overlap.

2. Each DS(-like) point on a tunnel element must be contained to the same respective tunnel element.

3. Each decomposition must not cover multiple tunnel elements simultaneously.

4. Unless specified otherwise, 1) the vertical direction is upward and perpendicular to the horizontal direction, 2) the horizontal direction is parallel to the driving direction, away from the covered tunnel elements (see Figure 2). This means that the horizontal direction is (near) opposite at both ends. Each tunnel element has its own 2D decomposition vectors due to the varying road plane.

2.3 Bridges

Bridges experience displacements that may strongly vary in the longitudinal direction of the bridge. Figure 3 displays a bridge with two decks and three support points and illustrates loading and temperature induced displacements vectors. The temperature induced deformation is also present in the vertical direction, albeit much smaller due to the dimensions of each bridge deck.

The largest (vertical) deflections due to loading are expected at locations farthest from the bridge support points. Bridge support points are expected to be most stable. Thermal expansion with an annual periodicity is expected and is largest in the longitudinal direction and to a lesser degree in the vertical direction. Local references on the bridge are best positioned at the center of each bridge deck when significant deformation is present. In that case, the reference point may be noisy due to loading.

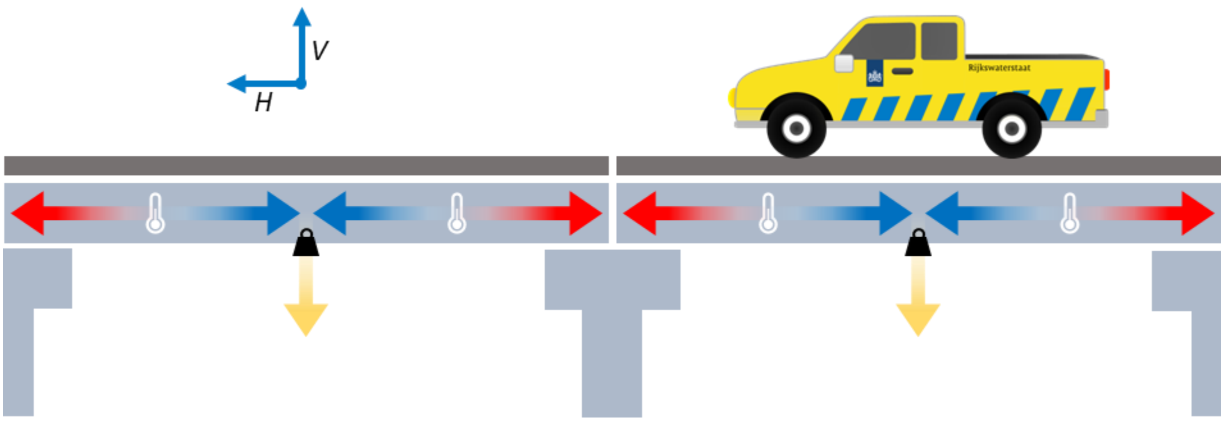

Figure 3 Schematic of the bridge deformation vectors and the 2D decomposition vectors. There are two halves (left and right) within a bridge deck and each requires their own grouping of measurement points.

2.3.1 Data Processing Requirements

1. The bridge is divided into individual polygons. Each polygon envelops one bridge deck and does not cross any (expansion) joints. Polygons themselves may overlap.

2. Each DS(-like) point on a bridge deck must be contained to the same respective bridge deck.

3. Each decomposition must not cover multiple bridge decks simultaneously.

4. Unless specified otherwise, 1) the vertical direction is upward and perpendicular to the horizontal direction, 2) the horizontal direction is parallel to the driving direction in one uniform direction (see Figure 3).

2.4 Viaducts

Viaducts (also referred to as an overpass) experience displacements that may strongly vary in the longitudinal direction of the viaduct. Figure 4 displays a viaduct with two sections and three support points and illustrates loading and temperature induced displacements vectors. The temperature induced deformation is also present in the vertical direction, albeit much smaller due to the dimensions of each section.

The largest (vertical) deflections due to loading are expected at locations farthest from the bridge support points. Viaduct support points are expected to be most stable. Thermal expansion with an annual periodicity is expected in the longitudinal direction and to a lesser degree in the vertical direction. Local references on the viaduct are best positioned at the center of each section when significant deformation is present. In that case, the reference point may be noisy due to loading.

Figure 4 Schematic of the viaduct deformation vectors and the 2D decomposition vectors.

2.4.1 Data Processing Requirements

1. The viaduct is divided into individual polygons. Each polygon envelops one viaduct segment and does not cross any (expansion) joints. Polygons themselves may overlap.
2. Each DS(-like) point on a viaduct segment must be contained to the same respective viaduct segment.
3. Each decomposition must not cover multiple viaduct segments simultaneously.
4. Unless specified otherwise, 1) the vertical direction is upward and perpendicular to the horizontal direction, 2) the horizontal direction is parallel to the driving direction in one uniform direction (see Figure 4). Each section has its own 2D decomposition vectors due to the varying road plane.

2.5 Sheet Piles

Sheet piles experience displacements induced by the horizontal pressure of the soil. Figure 5 displays the front view of a sheet pile segment and illustrates the displacements vectors.

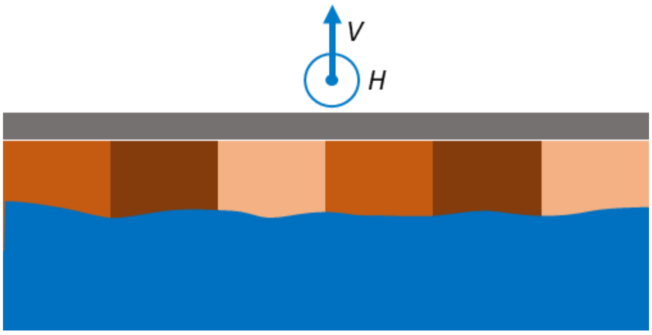

Figure 5 Schematic of the sheet pile 2D decomposition vectors.

2.5.1 Data Processing Requirements

1. Unless specified otherwise, 1) the vertical direction is upward and perpendicular to the horizontal direction, 2) the horizontal direction is perpendicular to the land water interface towards the water (see Figure 5).

2.6 Water Barriers

Water barriers (such as dikes and dams) experience displacements that are guided by gravity. Figure 6 displays a dike with two slopes and illustrates the displacements vectors.

Erosion and gravity combined can cause outer (left hand side) or inner (right hand side) slope instabilities (Figure 6). The most common (about two thirds) dike failure mechanism in the Netherlands is characterized by the failure of the inner slope caused by wave overflow and run-over[1].

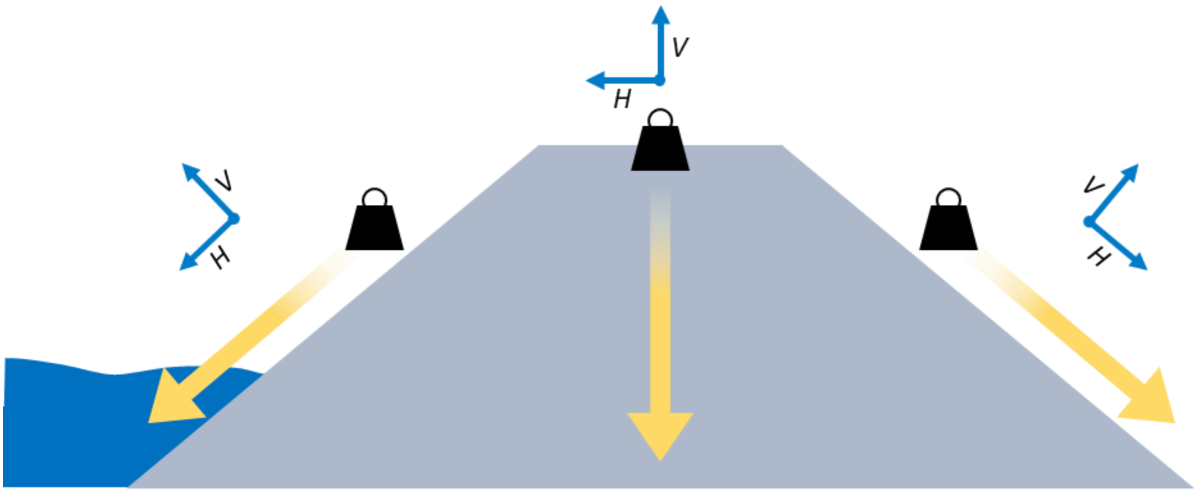

Figure 6 Schematic of the dike deformation vectors and the 2D decomposition vectors.

2.6.1 Data Processing Requirements

1. The water barrier is divided into individual polygons. Each polygon belongs to a planar segment of the water barrier. In the example of Figure 6 there are three planar segments: 1) the outer slope, the crest and the inner slope. Some water barriers may have more requiring more polygons in the cross direction. Polygons themselves may overlap. More and smaller segments may be used for dikes with a smoother transitions between planar segments.
2. Each DS(-like) point on a section must be contained to the same respective section.
3. Each decomposition must not cover multiple sections simultaneously.
4. Unless specified otherwise, 1) the vertical direction is upward and perpendicular to the horizontal direction, 2) the horizontal direction is parallel to the downward slope of the plane (see Figure 6Figure 4). For shallow planes (< 3 degrees), the horizontal direction is perpendicular to the interface of the water and the water barrier, towards the water (see Figure 6). Each section has its own 2D decomposition vectors due to the varying plane directions.

[1] S van Baars and I. M. van Kempen, "The Causes and Mechanisms of Historical Dike Failures in the Netherlands", European Water Association, 2009

2.7 Lock Complex

N/A.

3 Radar Sensitivity

The InSAR deformation data is directional, with its vector in the line of sight of the radar. The main directions are approximately Eastward or Westward, because standard radar satellites are side-looking in a near-polar orbit. As a consequence, the 3D motion is underdetermined when applying the decomposition. Horizontal motion perpendicular to the radar line of sight cannot be observed and near perpendicular horizontal motions are compressed to a fraction of the true horizontal motion. By supplying the decomposition vectors, the ambiguity is resolved mathematically, but the deformation cases with limited radar sensitivity remain. To that end, it is important to communicate, report and if necessary, propagate, the increased deformation uncertainty for such cases.

4 Visualization

The aforementioned objects may be long and difficult to visualize. Visualizations of objects are best displayed in the 2D side-view (equivalent to the view in Figure 2 to Figure 5), where the x-axis shows the distance along the longitudinal axis and the y-axis shows the deformation time series model parameter (e.g. mean velocity). Furthermore, parallel lanes could also be added to the same figure. This approach is preferred over a top-down view for simple object compositions. At least one top-down view is however required to relate the distance and/or labels along the x-axis to their spatial position.