REAL TIME BRIDGE DECK GUIDANCE USING GNSS SYSTEMS

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SUMMARY

Arbizelai´s bridge, 400 meters long, 6 spans, 5 pillars and 25 meters wide is part of the AP-1 Vitoria - Eibar Motorway and is located near the city of Mondragón (Gipúzkoa). A very advance positioning solution made it possible to successfully complete – and on time - the manoeuvre of incremental launching of the bridge's deck over pillars with an error of less than 3 centimetres. Technicians responsible for the launching were able to better adjust their hydraulic system while the deck was moving so there was no need to periodically stop and check the structure.

This system has proven to be perfectly suitable for other various engineering projects where large moving structures need to be accurately guided and monitored.

RESUMEN

El viaducto de Arbizelai, de 400 metros de longitud, 6 vanos, 5 pilas y 25 metros de ancho, forma parte de la Autopista Vitoria – Eibar y se encuentra próximo a la localidad guipuzcoana de Mondragón. Gracias a la tecnología GNSS de Leica Geosystems, se consiguió completar a tiempo la maniobra de empuje del tablero sobre las pilas con errores inferiores a 3 centímetros. Los técnicos responsables del empuje pudieron ajustar y corregir el sistema hidráulico en tiempo real al mismo tiempo que el tablero se desplazaba, con lo que se eliminaba la necesidad de hacer paradas para comprobar y corregir.

El sistema demostró ser perfectamente adaptable a otros tipos de proyectos de ingeniería donde exista la necesidad de guiar y monitorizar con precisión estructuras de gran tamaño.

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1. INTRODUCTION

.1 Construction of the 'Autopista del Norte (AP-1)' (North Motorway)

North Motorway or AP-1 is a Spanish motorway that starts in Castañares (near Burgos – Castilla y León) and ends in Eibar (Gipúzkoa – Basque Country), passing across the region of 'Alto Deva'. The motorway was originally designed to be located between Burgos and Eibar, but finally the concessionaire only built up to the city of Armiñón (near Vitoria). During the 90´s, local governments of Álava and Gipúzkoa agreed to build the remaining section of the motorway.

This section, linking Vitoria and Eibar (47 kilometres) has a 6.4 kilometres subsection between Escoriaza and Arrasate to cross the valley of the Deva river requiring to build a 400 meters long structure: namely the Arbizelai´s bridge.

Plan view of Arbizelai´s bridge crossing the Valley of Deva´s river

.2 Technical data of Arbizelai´s bridge

Arbizelai´s bridge, 408.72 meters long, is the most spectacular ouvrage of North Motorway´s AP-1 section between Escoriaza and Arrasate (Gipúzkoa). It is distributed in six spans of 37.44+53.04+59.28+59.28+140.4+59.28 meters long. Its height over the valley is 25 meters.

The deck is a continuous beam of 2.65 meters edge. Deck's widths vary between 25.20 meters in abutment #2 and 27.37 meters in abutment #1. This platform is formed by two sidewalks of 1 meter wide where the defences are placed, 2 exterior verges 2.5 meters wide, 2 interior verges 2.5 meters wide, 2 lanes 3.5 meters wide per side and a central reservation of variable width. With this width, lateral cantilever of the slab is more than 7 meters long. The continuous beam is cable-stayed in its main gap and counterbalanced by means of series of suspenders placed in the axis of the bridge, with two towers formed by one single vertical pillar in the central reservation. These towers are metallic, filled with auto-compactable concrete. Pillars are made of concrete with a central shaft that opens on top by means of two lateral wings that support the edges of the box-girder.

Theoretical path to be followed by the deck

Lateral view of Arbizelai´s bridge

.3 Bridge deck launching

The most suitable construction method for this kind of bridge is by means of the incremental launching of the steel structure from both sides, up to closing in the keystone of the 140 meters span. Horizontal Alignment is a circular curve of radius 1078 meters, except for the abutments (80 meters for abutment #1 and 56 meters for abutment #2).


Rear view of the deck during the launching (left) and detailed view of the hydraulic jacks (right)

Incremental launching means the full construction of the bridge deck steel structure in one (or both, in this case) of the abutments. Later, once the full deck structure is built, it is attached to a hydraulic system that slowly drags it over the pillars. Hydraulic jacks placed on both sides of the structure pull the steel cables that centimetre to centimetre drag the deck forward towards the first of the pillars.

On top of each pillar, there is a pair of 'rails' that need to exactly fit with the bottom of the deck surface in order to continue with the launch towards the following pillar.

.4 Traditional surveying methods to monitor bridge deck launching

For those in charge of the launching manoeuvres, it is extremely important to have accurate information regarding the position of the structure with regards to the theoretical position it should have in a moment in time. Longitudinal, transversal and height displacements of representative points along the deck and relative to the horizontal and vertical alignment are crucial for structural engineers.

Traditionally, surveyors are using single or multiple total stations located on known coordinates points to measure periodically reflectors attached to the deck structure while it moves. In order to meet a compromise between speed (and latency in consecutive measurements to the same point) and the number of different reflectors to be measured, no more than 3-5 points per total station can be assigned in a measurement cycle.

2. OBJECTIVES

When the author working in Leica Geosystems Spain was contacted by the surveying department of the construction company responsible for the bridge (DRAGADOS), they asked to develop an innovative method for the guidance of the bridge deck during the launching process. Features required were:

- Continuous real time positioning of, at least, 5 selected points distributed along the bridge deck while the launching process takes place.

- The 3D positioning error threshold on every point must be below 3 centimetres.

- To make use of wireless communications as wires based communication media along the structure to link up different devices will be impossible.

- Full remote control of the system: no need to stay next to the construction site.

- Easy installation and removal: system must be installed on both sides of the bridge alternatively.

- Continuous operations over 24 hours allowable.

- Scalable: user must be able to easily increase or reduce the number of points involved in the system.

- Traceability: results from the launching process must be logged into a file for analysis and examination.

With these requirements it was obvious that the new system would make use of GNSS receivers instead of Total Stations. However, it was required to develop a new software that, combined with the Leica GNSS Spider positioning RTK engine (which already computed baselines), could easily display on screen the displacements of each of the points.

This new software (later named as 'Leica Alignment Monitoring') should have the following features:

- Coordinate transformation between WGS84 and the local coordinate system of the construction site

- Interpret horizontal and vertical alignments exported directly from the Leica Geo Office software.

- Input of individual points offsets (GNSS Antenna can not be directly attached to the point being measured on the structure)

- Filtering of the coordinates provided by Leica GNSS Spider by analysing the 3D coordinate quality factor. Use of colours on screen to easily identify points out of tolerance

3. DEVELOPMENT

3.1 Previous works

Before beginning with the installation of the system, some checks had to be made to ensure that all components will work as expected. These checks were:

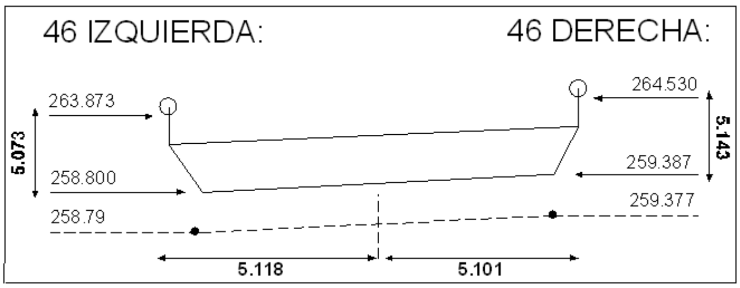
- Full quality control of 24 hour RINEX observations made of both sides of the bridge, near the abutments. This was to be sure that steep hills on both sides of the valley didn't critically affect the quality of the GNSS observations (obstructions, multipath, and number of satellites...)

- Coordinate System calculation: 7 reference points with local and WGS84 known coordinates surrounding the construction site were measured using GNSS receivers in static mode.

- Communications checks: at first three different communication solutions were considered to transmit data from the GNSS Receivers (2.4Ghz line-of-sight wireless, GPRS/3G and 406.425Khz radio-modems). It was finally decided to go ahead with the radio-modems solution.

- Point's offset calculation: horizontal and vertical alignment data was referred to points on the bridge deck where it was impossible to set up a GNSS antenna. For this reasons, it was needed to set the antennas as near as possible to those points and then precisely measure easting, northing and height offsets.

- Selection of the stable point where the 'base' GNSS receiver (the one from which all baselines are computed) would be installed.



Cross-section of the bridge deck displaying 2 of the GNSS receivers installed in both corners on top of the deck

3.2 Hardware

3.2.1 GNSS Receivers

In total, 6 GNSS Leica GX1230GG were used on this project.

Leica GX1230GG receiver with Satel 3AS radio modem fitted

4 of them were placed on the bridge deck structure, one on each of the 4 corners. Additionally, a fifth receiver was placed on top of the tower to monitor its movement. The sixth one was the one placed on the stable known point acting as Reference Station.

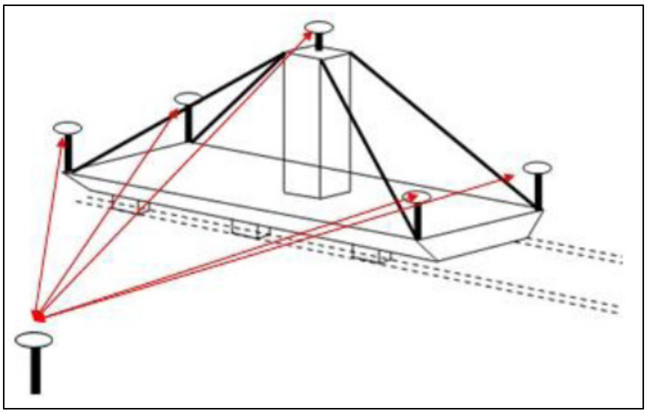
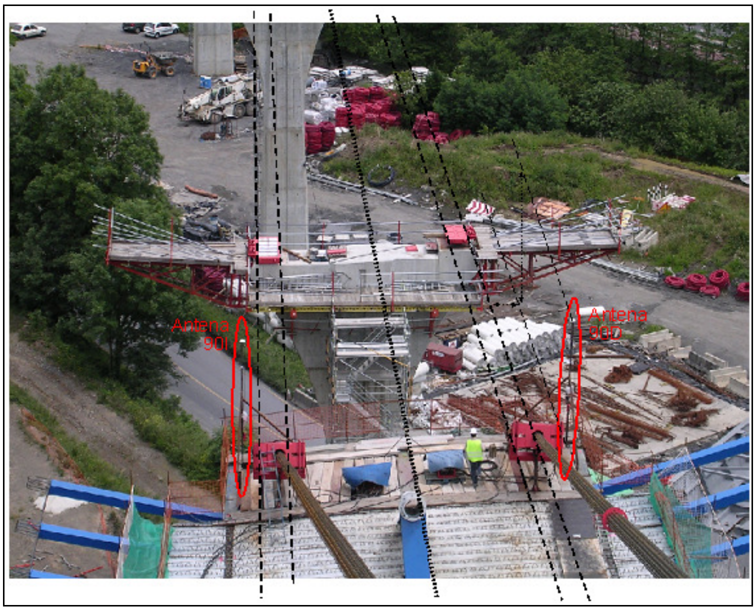


Diagram showing the system layout

A special steel structure was erected on the deck to accommodate the receivers, their antennas and batteries.

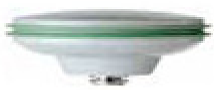
Leica GX1230GG receiver installed on the deck



Deck's front section view halfway between abutment #1 and the first pillar.
Highlighted in red, 2 GNSS receivers can be seen.

3.2.2 GNSS Antennas

Antennas attached to the 6 receivers were Leica AX1202GG (GPS and Glonass tracking). Approximate height of the antennas over the deck was 2 meters.



Leica AX1202GG Antenna

3.2.3 Radio-Modems

Each receiver was fitted with a 406.425 KHz radio-modem to transmit raw data observations to the site offices 300 meters away from the bridge. They were configured using a different frequency for each pair of radios. Prior frequency checks were crucial to the success of the project because it was discovered that some radio-channels were useless due to antiterrorist's counter-measures in the surroundings.

3.2.4 Computers

Two computers were used. The first one (desktop PC inside site offices) was affected to receiving raw data from the 6 GNSS receivers, processing this data in real time using Leica GNSS Spider measurement engine and feeding the other 2 software with the results (Leica GeoMoS and Leica Alignment Monitoring).

Second computer (laptop) was equipped with a 3G Internet connection and made use of remote control software to have access to the PC inside site offices. This remote access could be done anywhere around the construction site, allowing the technicians to freely move.

3.3 Software

3.3.1 Leica GNSS Spider

Although Leica GNSS Spider is well known as a GNSS Network RTK software (being used in major GNSS Network worldwide), it includes some unique features for accurate baseline processing in real time as well as post-processing. These two features are called ‘RT Positioning’ and ‘Post-Processing’.

Site name	Site code	Comm activity	Data received
BASE	BASE	receive data	93.6

Screenshot of Leica GNSS Spider Communication Status Module

Raw data observation streams coming via radio-modem from the 6 receivers are processed together in real time with the settings defined by the user (for each baseline: reference receiver, rover receiver, initialization mode, satellite system, frequency)

		CQ ...	GDOP	Sats	Last Change	Product Name
yes		0.020	2.2	12	21.11.2008 13:14:18	Antena 90D
yes		0.020	2.2	12	21.11.2008 13:14:18	Antena Pilono

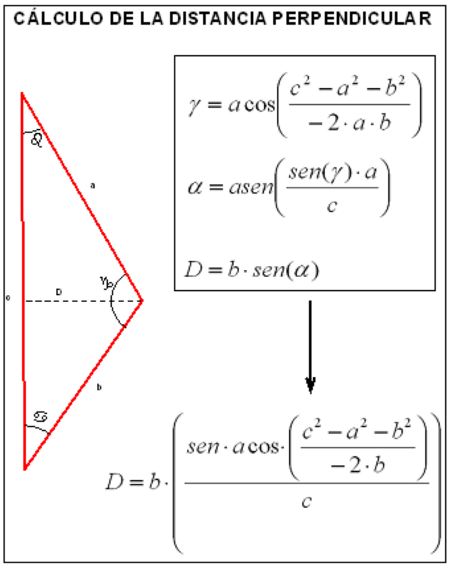
Screenshot of Leica GNSS Spider Real Time Positioning Module

Results (precise WGS84 rover coordinates in NMEA format) from RT positioning can be sent to third party software using serial or TCP/IP protocols. In this project, it was used a different TCP port per ‘rover’ calculated position.

3.3.2 Leica GeoMoS

The purpose of using Leica´s monitoring software ‘GeoMoS’ in this particular guidance system was to provide engineers with data regarding the geometric behaviour of the central deck’s steel pylon. Particularly, engineers were interested in knowing in every moment the perpendicular distance of the pylon with respect to the side of the bridge deck.

GeoMoS´ unique ‘Virtual Sensor’ feature allowed this calculation to be constantly made combining the precise WGS84 coordinates of each point coming from Spider.



Formula to compute perpendicular distance of the pylon with respect to the side of the bridge deck

Results were displayed on screen together with the information from Alignment Monitoring.

GeoMoS could as well trigger different alarms (form example, send SMS messages) in case results exceeded the tolerances.

3.3.3 <u>Leica Alignment Monitoring</u>

This software was specially designed to meet the specific requirements of this project. Its task was to display live on screen easting, northing and height deviations of each point with respect to the theoretical horizontal and vertical alignment of the bridge deck. This way, technicians operating the hydraulic jacks could check in real time how the bridge was behaving to their inputs.

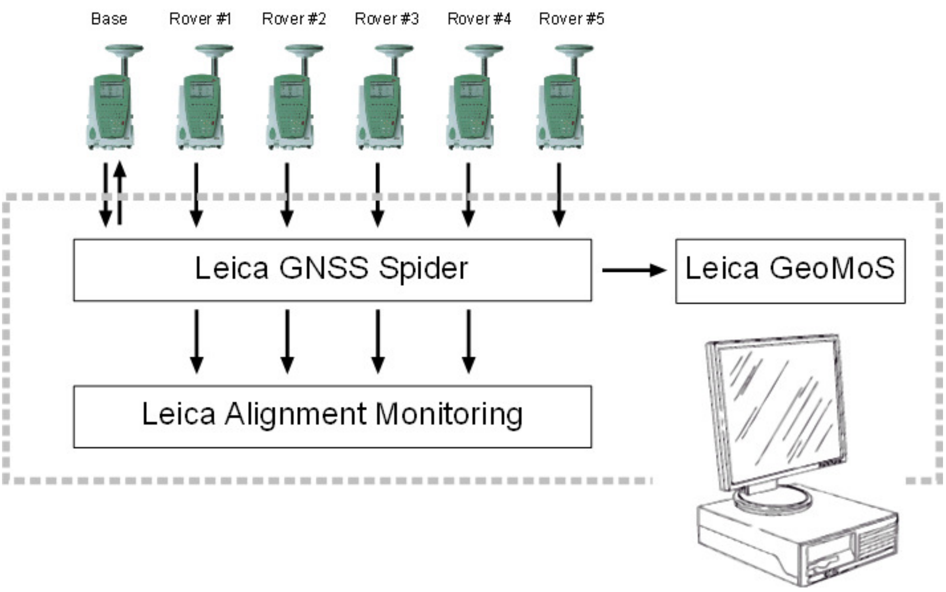
For this task, it was needed to provide it with the results coming from Spider RT Positioning module using NMEA Protocol. This was achieved by allocating individual TCP ports for each point precise coordinate.

Screenshot of Leica Alignment Monitoring guidance screen

For each point it had to be defined the offset (easting, northing and height) relative to the 'real' point on the bridge deck being compared to the alignments, as well as its name, decimal places and 3D CQ tolerance value.

3.4 Software Integration

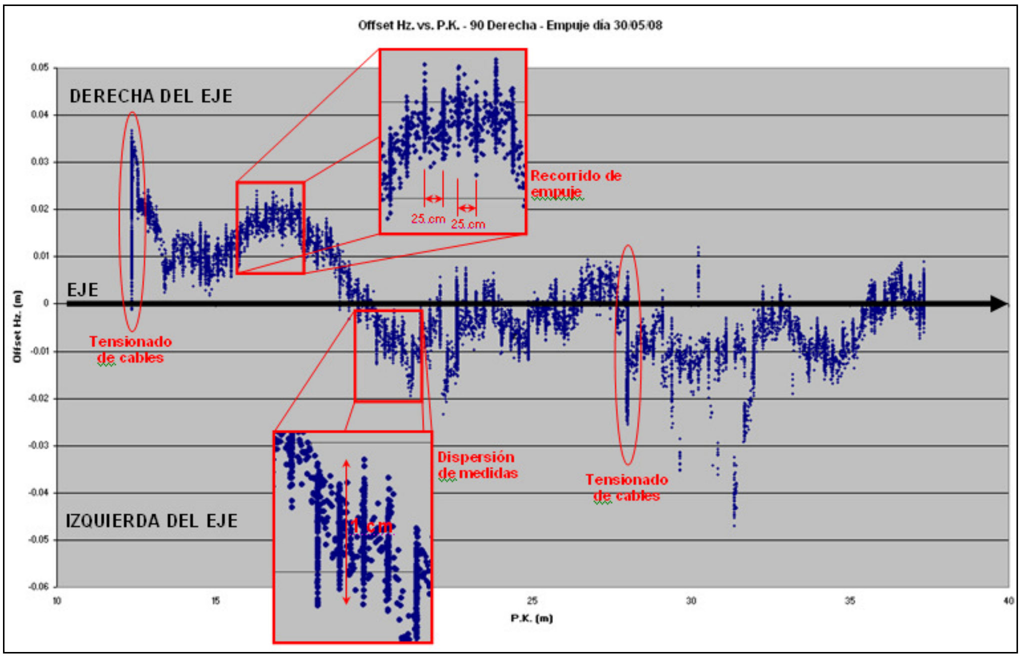
All 3 programs involved in the guidance of the bridge deck (Spider, GeoMoS and Alignment Monitoring) were running simultaneously on the same desktop PC, communicating each other using TCP/IP local ports. Spider and GeoMoS could be minimized in order to let Alignment Monitoring display all relevant information to engineers and technicians.



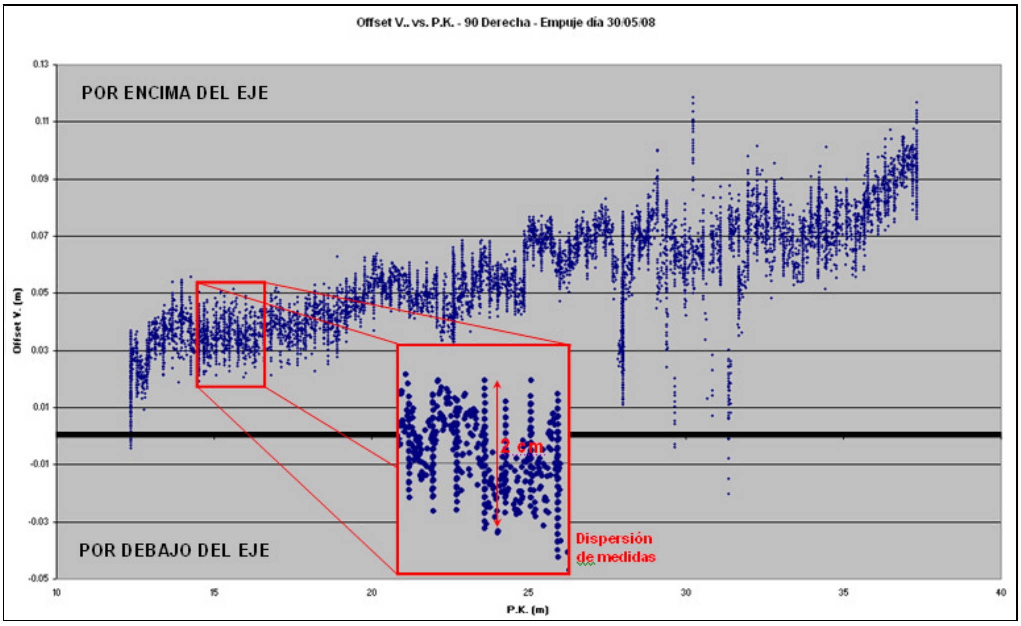
Data flow diagram

4. RESULTS

Examination of data obtained from the system during the launching process showed that the standard deviations obtained met the initial customer requirements of 1 centimetre (2 sigma) in East-North and 2 centimetres in Height (2 sigma), as shown in the following graphics:



East-North Deviation of point 90 Right with respect to the theoretical horizontal alignment during the launching of 40 meters of deck



Height Deviation of point 90 Right with respect to the theoretical vertical alignment during the launching of 40 meters of deck

5. FUTURE IMPROVEMENTS

5.1 Alignment Monitoring new features

Future versions of this software should include a CAD graphical output displaying the plan view of the structure and dynamically updating the position of the points being monitored. It also should support not only GNSS data, but Total Station measurements, allowing combination of both sets of data on the same project.

5.2 Kalman filtering

Implementation of a Kalman filtering algorithm to smooth results is the logic improvement when large sets of dynamic GNSS data is to be analysed.

Although the software includes a CQ3D filter, this alone is not enough to prevent blunders from affecting the measurements.

5.3 Use of monitoring GNSS Receivers

Instead of using typical survey GNSS receivers such as the GX1230GG (chosen by the customer), specific Monitoring receivers such as the GMX901 or GMX902GG could be used to benefit from their small size, rugged design, ease of installation and low power consumption.

Leica Monitoring GNSS receivers: GMX901 & GMX902GG

6. CONCLUSIONS

Although tailored for the specific task of guidance in real time of this particular bridge deck (Arbizelai´s bridge), this system proved to be perfectly suitable for its use in any kind of moving structure where engineers need to know as fast as possible how the structure is behaving. In the near future, more and more projects will require flexible and scalable monitoring solutions such as the one presented in the paper.

Possible applications include:

- Incrementally launched bridges
- Barge guidance for pile's embedding
- Jump forms
- Cantilever bridges

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