NETWORK OF MONITORED ROAD BRIDGES IN SPAIN

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ABSTRACT

The network presented here is a platform for structural monitoring of bridges managed at a national level under the ward of the Roads Directorate. A variety of monitoring systems are integrated in this network regardless of the data acquisition methodology. The network is formed by the bridges themselves and a Data Center, which automatically presents the recorded information real time via web, using general tools applied in common to all the structures integrated in the network.

1. INTRODUCTION

During the last three decades, the instrumentation of structures has become a usual task for the most complex bridges. In this process, computer science, as an inseparable partner of electronics, plays a role more and more important in all the involved items: data acquisition, data display, transmission, analysis, etc.

The technological improvements that have taken place in recent years have helped a lot to monitor the actual structural conditions of the bridges, considering both their static and dynamic behaviours. Nowadays, it is possible to measure accurately slow phenomena like thermal variations or very slow ones like creep or shrinkage and, at the same time, it is possible to measure quick phenomena like the response of the structure to traffic or to wind forces.

The use of this kind of testing gives a variety of results: movements (deflections or rotations), strains, stresses, accelerations, etc. from which it is possible to get knowledge applicable to fields which can be considered as complementary like technical regulations, design, construction and maintenance of the structures.

Once the first permanent monitoring systems were installed in bridges, a management system appeared necessary for the Roads Directorate of the Ministry of Public Works, to integrate all of them in the same network.

The use of the internet as a means to be connected to and to transmit data, and especially the use of M2M mobile technology, has allowed us to easily integrate into the network those bridges that are monitored for a short period of time only. This is the case, for example, of a maintenance operation like bearing substitution which in spite of being of short duration can be complicated and require detailed surveillance.

For the last years, the Roads Directorate is running a growing network of bridges with electronic instrumentation, which gives real time access from anywhere to the data recorded in each bridge. The purpose of this communication is to present this bridge network, called CELOSIA (www.celosia.es), describing how it is organized and its main characteristics.

2. GOALS OF THE STRUCTURAL MONITORING

The monitoring system of every bridge integrated in CELOSIA has at least one of the following objectives:

- *Construction aid tool*. It is applied to bridges with complex construction processes, either in an overall way or just monitoring a specific construction stage. Some decks have been launched, some arches have been rotated, others are segmental cantilever bridges, cable stay bridges, etc.

- *Serviceability behaviour surveillance*. It is used in some outstanding bridges to confirm the proper behaviour during their working life. It is used too as a surveillance tool for bridges in which some structural problem has appeared during construction or after open to traffic.

- *Improvement of technical regulations*. In some cases, the instrumentation provided for one of the previous reasons has been enhanced to obtain data that allow us to improve the knowledge of the structures and, as a consequence, the provisions of the technical regulations.

3. MAIN FEATURES OF THE NETWORK

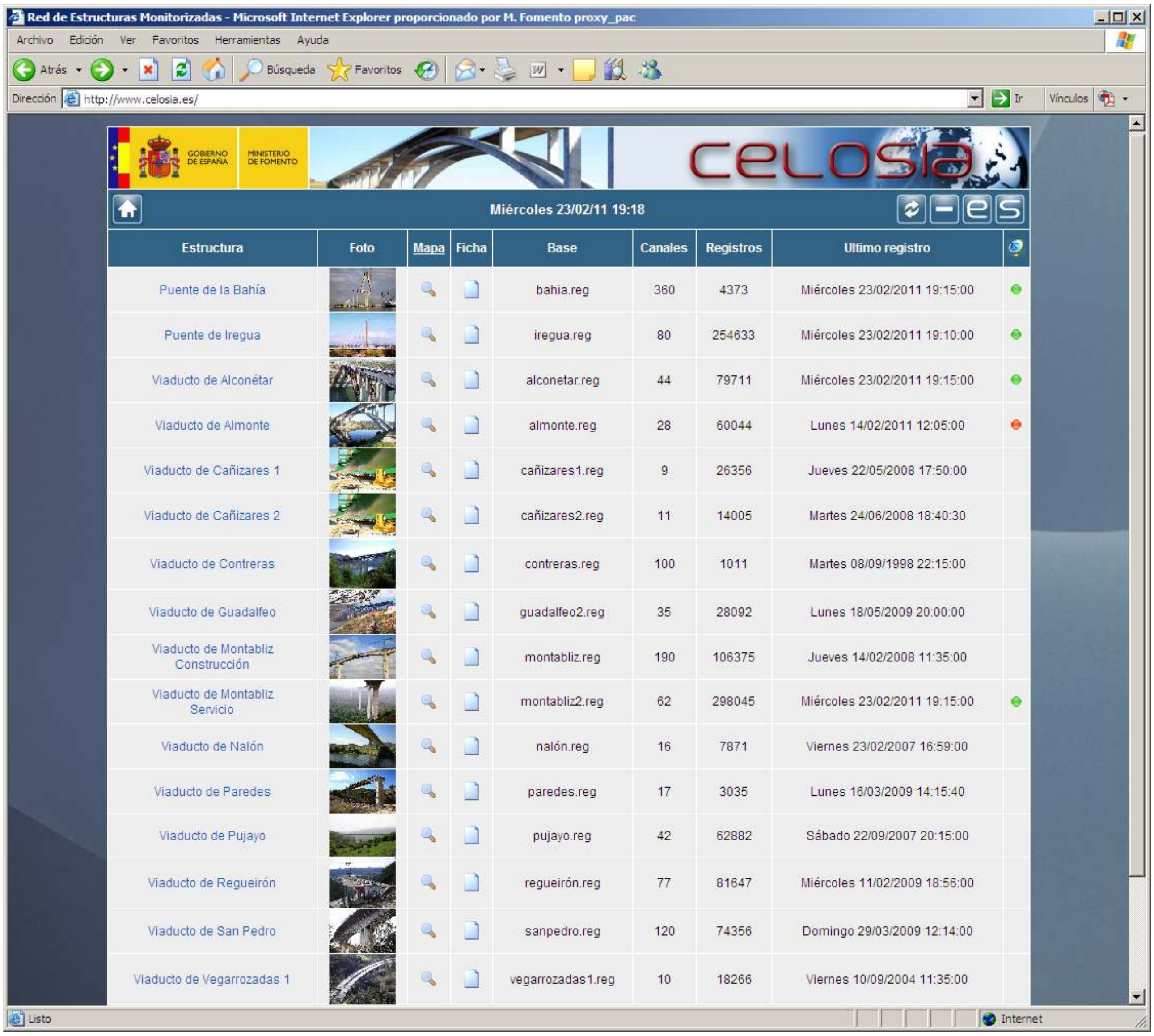
Ata present, the bridge network CELOSIA is made up of fifteen structures. The oldest monitoring system still in use is the one installed in the bridge over the Iregua river (Logroño, Spain) which is running since the year 2001. The youngest is the one in the Cadiz Bay bridge, working since the beginning of 2011.

The network is formed by the bridges themselves and a Data Center, which is the heart of the whole, where all the information is stored and made available. Among the main features of the system, the following can be included:

- Automatic data transmission between the bridges and the Data Center, that happens as fast as it is allowed by the used communication system (GPRS, UMTS, HSDPA, HSUPA…).

- Immediate display of the recorded information (Figure 1) through the web portal of the Data Center (www.celosia.es). The web browsing is identical for all the bridges of the network; the procedure to access the structural data is independent of the company and the methodology used for the data acquisition.

- Different levels of access to the web information: a public area (bridge location, bridge brochure, etc) and a private area with personal password (recorded data).



Estructura	Foto	Mapa	Ficha	Base	Canales	Registros	Ultimo registro
Puente de la Bahía				bahia.reg	360	4373	Miércoles 23/02/2011 19:15:00
Puente de Iregua				iregua.reg	80	254633	Miércoles 23/02/2011 19:10:00
Viaducto de Alconétar				alconetar.reg	44	79711	Miércoles 23/02/2011 19:15:00
Viaducto de Almonte				almonte.reg	28	60044	Lunes 14/02/2011 12:05:00
Viaducto de Cañizares 1				cañizares1.reg	9	26356	Jueves 22/05/2008 17:50:00
Viaducto de Cañizares 2				cañizares2.reg	11	14005	Martes 24/06/2008 18:40:30
Viaducto de Contreras				contreras.reg	100	1011	Martes 08/09/1998 22:15:00
Viaducto de Guadalfeo				guadalfeo2.reg	35	28092	Lunes 18/05/2009 20:00:00
Viaducto de Montabliz Construcción				montabliz.reg	190	106375	Jueves 14/02/2008 11:35:00
Viaducto de Montabliz Servicio				montabliz2.reg	62	298045	Miércoles 23/02/2011 19:15:00
Viaducto de Nalón				nalón.reg	16	7871	Viernes 23/02/2007 16:59:00
Viaducto de Paredes				paredes.reg	17	3035	Lunes 16/03/2009 14:15:40
Viaducto de Pujayo				pujayo.reg	42	62882	Sábado 22/09/2007 20:15:00
Viaducto de Regueirón				regueirón.reg	77	81647	Miércoles 11/02/2009 18:56:00
Viaducto de San Pedro				sanpedro.reg	120	74356	Domingo 29/03/2009 12:14:00
Viaducto de Vegarrozadas 1				vegarrozadas1.reg	10	18266	Viernes 10/09/2004 11:35:00

Figure 1 – Web portal of CELOSIA

Monitoring systems of different nature live together in the network, according to the following criteria:

- Static and dynamic measurements.
- Short-term (manoeuvring), medium-term (construction process) and long-term instrumentations (working life).
- Diverse technology of sensors and measurements (CELOSIA pursues the management of the information no matter how it has been obtained) which only have to follow a standard protocol for the data transmission.

From the Administration point of view, the network gives a solution to two important facets of the bridges monitoring:

- The set can be managed in a centralized way that allows, for example, to connect up a new structure or to remove an existing one, register new users, modify passwords, etc.

- The recorded data lie in a common center with a common format, avoiding the geographical as far as the technical scatter. At the same time it makes possible the backup task and ensures the data accessibility.

From the point of view of the final users of the information (who can play different roles and have different interests in relation with the bridges), the main aspects are:

- Permanent access to data. In this way, the user is not captive of the unavoidable stop intervals of the *in situ* systems (specially, in the bridges under construction). The information is always available through the Data Center.

- Universal format to the data presentation. As it has already been said, the information is served with the same format regardless of its origin or supplier.

- Simplicity of the software necessary to get the information: just a web browser.

From a functional point of view, CELOSIA, further than a simple data server, is a platform for structures surveillance and distribution of the information. The central engine of the network is continuously watching over the operational status of the instrumental systems. It sets a traffic light type indicator (see Figure 1) to the systems: green, to a structure active in the last day; yellow, to a structure active in the last week; and, red, to a structure active in the last month. In this way, it is possible to perceive at a glance through the web portal the proper performance of the monitoring and the transmission systems. Regarding data, CELOSIA, more than allowing the traditional file downloading, works out the information real time to show it in a manner directly understandable by the user: the behaviour of the structure or the construction stage can be followed through synoptic panels, evolution graphs, dial indicators, variable profiles, etc (see Section 5).

It is worth saying that the data served with the mentioned recourses are not just the measured values but can be the result of a postprocess: simple (gradients or envelopes), medium (uniform temperature of a cross-section) or complex (main stresses, cross-section curvatures, internal forces and moments). All that works without the participation of human resources, which gives to the system its main characteristic: its automatism.

Finally, two additional utilities enrich the suit:

- Ability to send alert messages (SMS, email) when certain conditions are exceeded (a specific wind speed, a high material stress, an excessive pier rotation, etc.).

- Ability to solve mathematical expressions without distortion when some of the variable values are missed (which is not unusual in a measuring process during construction). When this happens, the system automatically only uses the available values.

4. MONITORED BRIDGES

The bridges integrated in the network CELOSIA are located all over the country, as it is shown in Figure 2.

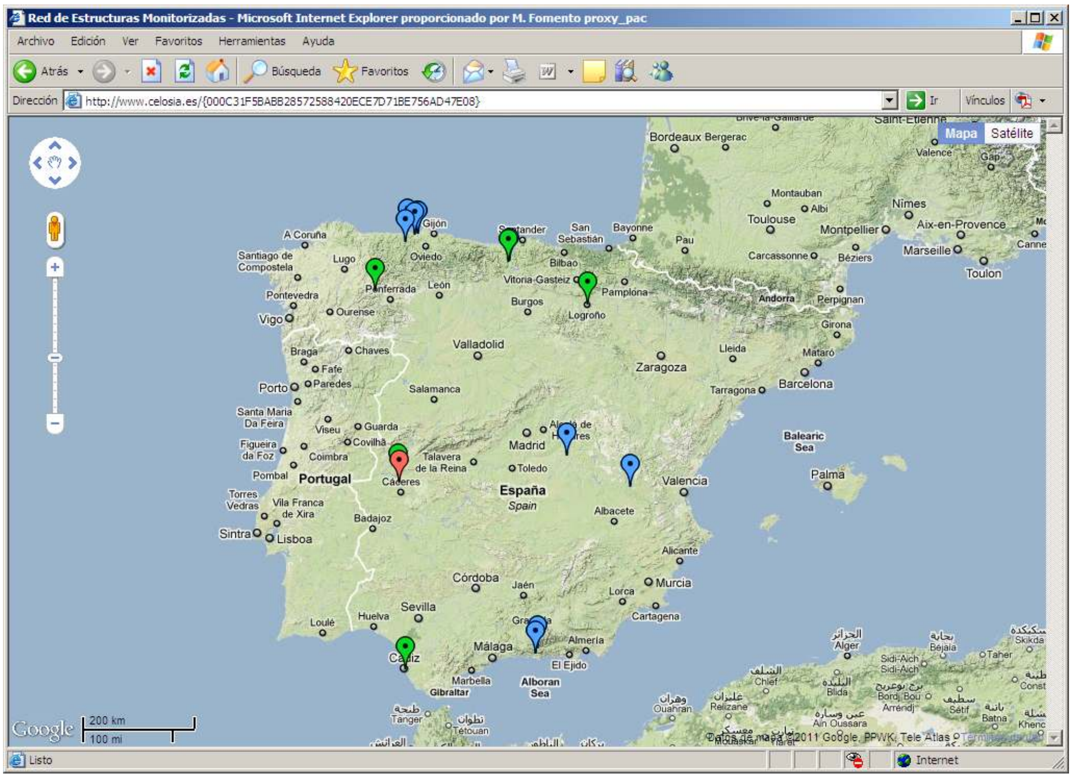
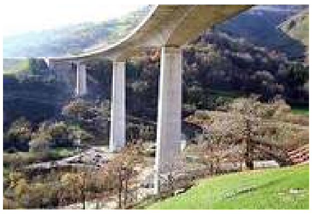


Figure 2 – Location of the bridges in the network CELOSIA

In Table 1, the main characteristics of the structures are collected, as well as the date of the corresponding measuring system implementation.

Table 1. Bridges integrated in the network CELOSIA

	***Viaduct of Contreras reservoir*** (Cuenca) Steel truss with concrete slab *Length*: 426 m *Maximum span*: 170 m *Starting point of data acquisition*: July 1998
	***Bridge over the Iregua river*** (Logroño) Cable stay bridge, prestressed concrete deck and composite pylon *Length*: 304 m *Maximum span*: 120 m *Starting point of data acquisition*: May 2001
	***Viaduct over the Almonte river*** (Cáceres) Concrete arch with prestressed concrete deck *Length*: 432 m *Maximum span*: 184 m *Starting point of data acquisition*: June 2003

	***Viaduct of Vegarrozadas*** (Asturias) Launched prestressed concrete deck *Length*: 397 m *Maximum span*: 48 m *Starting point of data acquisition*: June 2004
	***Viaduct over the Guadalfeo river*** (Granada) Launched tubular steel truss with concrete deck *Length*: 585 m *Maximum span*: 140 m *Starting point of data acquisition*: December 2005
	***Viaduct of Montabliz*** (Cantabria) Prestressed concrete girder 26 m de wide *Length*: 720 m *Maximum span*: 175 m *Pier height*: 130 m *Starting point of data acquisition*: December 2005
	***Viaduct of Pujayo*** (Cantabria) Prestressed concrete girder 26 m de wide *Length*: 420 m *Maximum span*: 100 m *Pier height*: 64 m *Starting point of data acquisition*: December 2005
	***Viaduct over the Tajo river*** (Cáceres) Steel arches with composite deck *Length*: 400 m *Maximum span*: 220 m *Starting point of data acquisition*: March 2006
	***Viaduct over the Nalón river*** (Asturias) Double composite action deck with external prestress tendons *Length*: 1.100 m *Maximum span*: 124 m *Starting point of data acquisition*: November 2006
	***Widening of the San Pedro Viaduct*** (Asturias) Widening up to 23 m with steel, composite and light concrete elements and external prestress tendons *Length*: 750 m *Maximum span*: 150 m *Starting point of data acquisition*: February 2008

	***Viaduct of Regueirón*** (Asturias) Launched composite deck 23 m wide and curved in plan *Length*: 560 m *Maximum span*: 92 m *Pier height*: 82 m *Starting point of data acquisition*: April 2008
	***Viaduct of Cañizares*** (Granada) Launched composite deck *Length*: 220 m *Maximum span*: 75 m *Starting point of data acquisition*: May 2008
	***Viaduct of Paredes*** (Cuenca) Launched double composite action deck *Length*: 380 m *Maximum span*: 104 m *Starting point of data acquisition*: February 2009
	***Slope of Trabadelo***[(1)] (León) Repair of a natural slope in road A-6 *Height*: 175 m *Surface*: 70.000 m^2 *Starting point of data acquisition*: November 2009
	***Bay Bridge*** (Cádiz) Cable stay bridge with steel, composite and concrete deck *Length*: 3.157 m *Maximum span*: 540 m *Starting point of data acquisition*: February 2011

(1) The *Slope of Trabadelo* is a singularity in the network: although it is not a bridge, this work has been included in CELOSIA because, due to the outstanding features of the action, the monitoring system provided there is similar the one of the other structures.

5. THE OUTCOME

In the following figures, a piece of the system outcome is presented. This is part of the material that can be accessed through the portal www.celosia.es and has been collected to illustrate the explanations given before.

— **Surveillance of a launching operation**

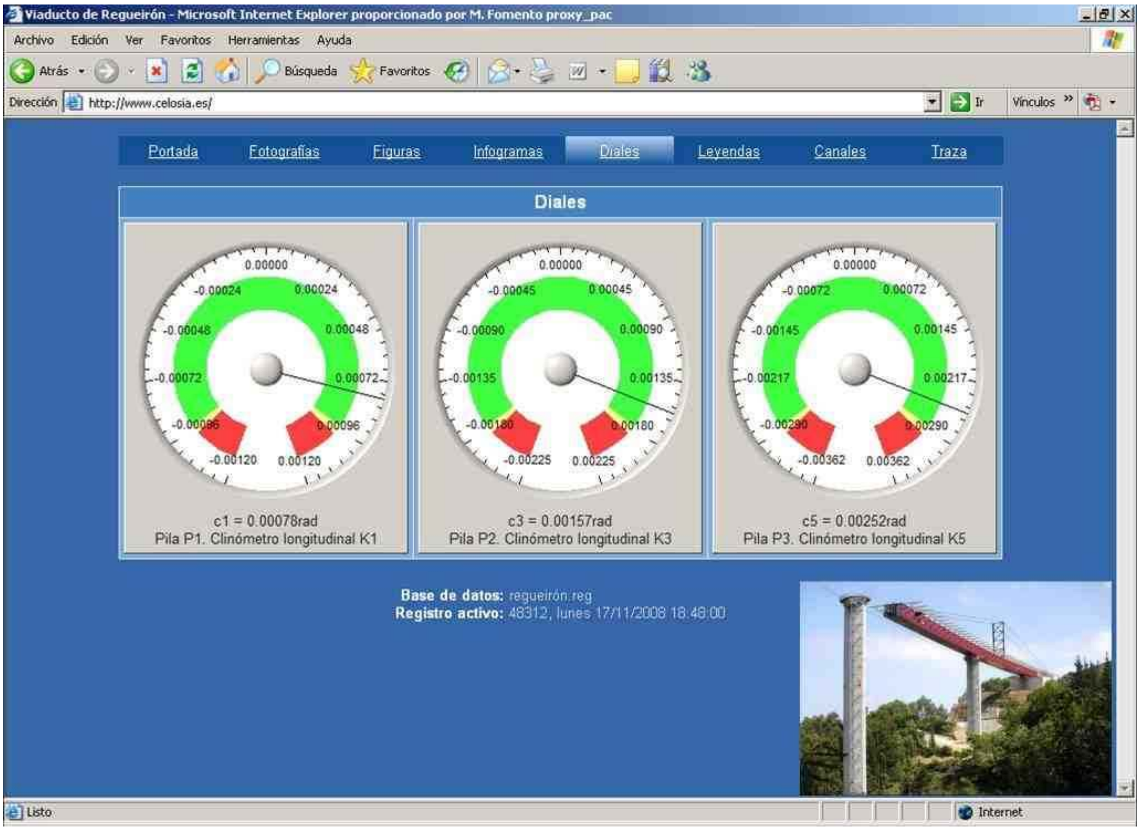
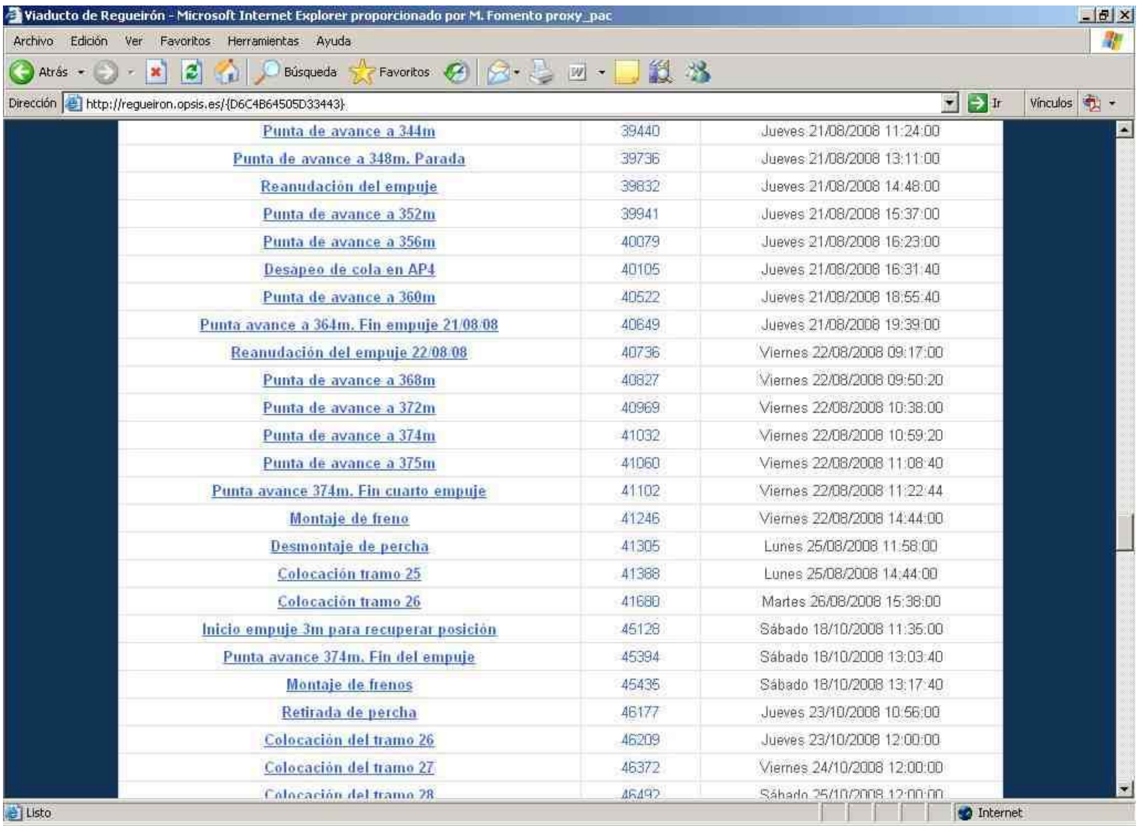


Figure 3 – Dial indicador to monitor the pier head rotation (Viaduct of Regueirón)



Punta de avance a 344m	39440	Jueves 21/08/2008 11:24:00
Punta de avance a 348m. Parada	39736	Jueves 21/08/2008 13:11:00
Reanudación del empuje	39832	Jueves 21/08/2008 14:48:00
Punta de avance a 352m	39941	Jueves 21/08/2008 15:37:00
Punta de avance a 356m	40079	Jueves 21/08/2008 16:23:00
Desapeo de cola en AP4	40105	Jueves 21/08/2008 16:31:40
Punta de avance a 360m	40522	Jueves 21/08/2008 18:55:40
Punta avance a 364m. Fin empuje 21/08/08	40649	Jueves 21/08/2008 19:39:00
Reanudación del empuje 22/08/08	40736	Viernes 22/08/2008 09:17:00
Punta de avance a 368m	40827	Viernes 22/08/2008 09:50:20
Punta de avance a 372m	40969	Viernes 22/08/2008 10:38:00
Punta de avance a 374m	41032	Viernes 22/08/2008 10:59:20
Punta de avance a 375m	41060	Viernes 22/08/2008 11:08:40
Punta avance 374m. Fin cuarto empuje	41102	Viernes 22/08/2008 11:22:44
Montaje de freno	41246	Viernes 22/08/2008 14:44:00
Desmontaje de percha	41305	Lunes 25/08/2008 11:58:00
Colocación tramo 25	41388	Lunes 25/08/2008 14:44:00
Colocación tramo 26	41680	Martes 26/08/2008 15:38:00
Inicio empuje 3m para recuperar posición	45128	Sábado 18/10/2008 11:35:00
Punta avance 374m. Fin del empuje	45394	Sábado 18/10/2008 13:03:40
Montaje de frenos	45435	Sábado 18/10/2008 13:17:40
Retirada de percha	46177	Jueves 23/10/2008 10:56:00
Colocación del tramo 26	46209	Jueves 23/10/2008 12:00:00
Colocación del tramo 27	46372	Viernes 24/10/2008 12:00:00
Colocación del tramo 28	46492	Sábado 25/10/2008 12:00:00

Figure 4 – Informative captions on-line (Viaduct of Regueirón)

— Continuous monitoring of construction processes

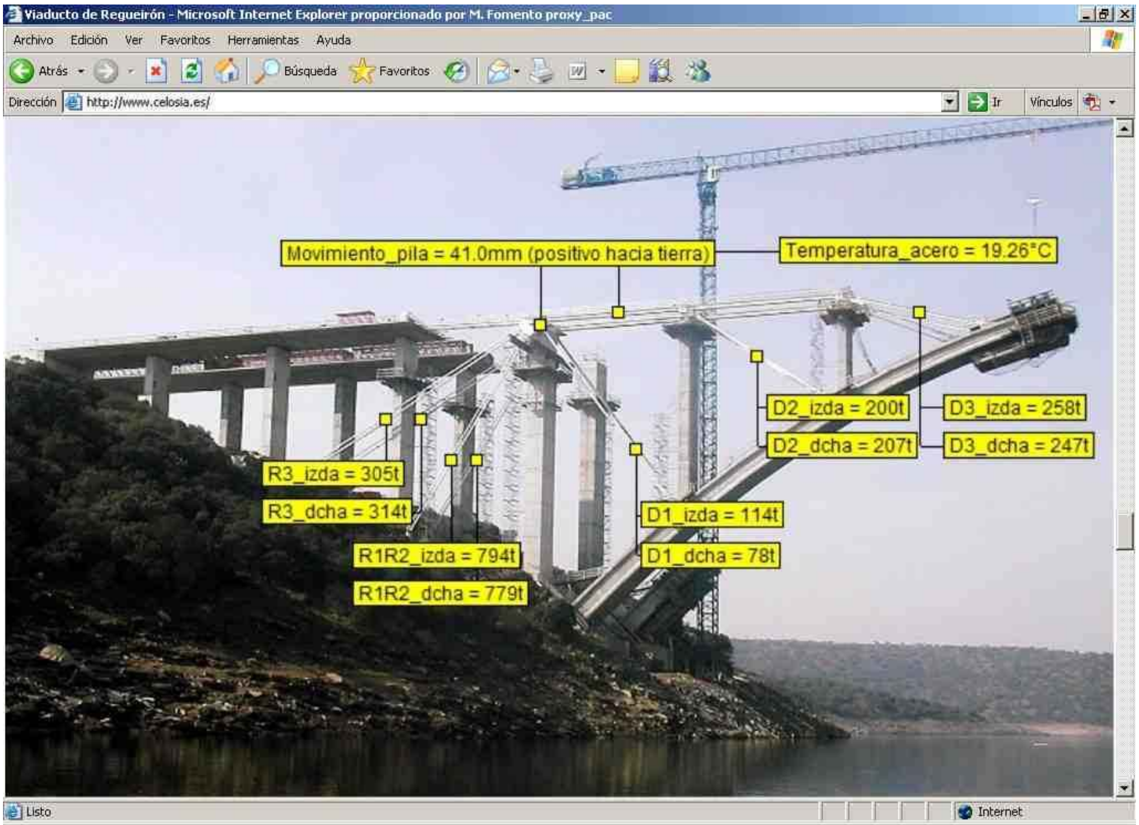


Figure 5 - Synoptic panel to monitor tie forces and pier movements (Viaduct of Almonte)

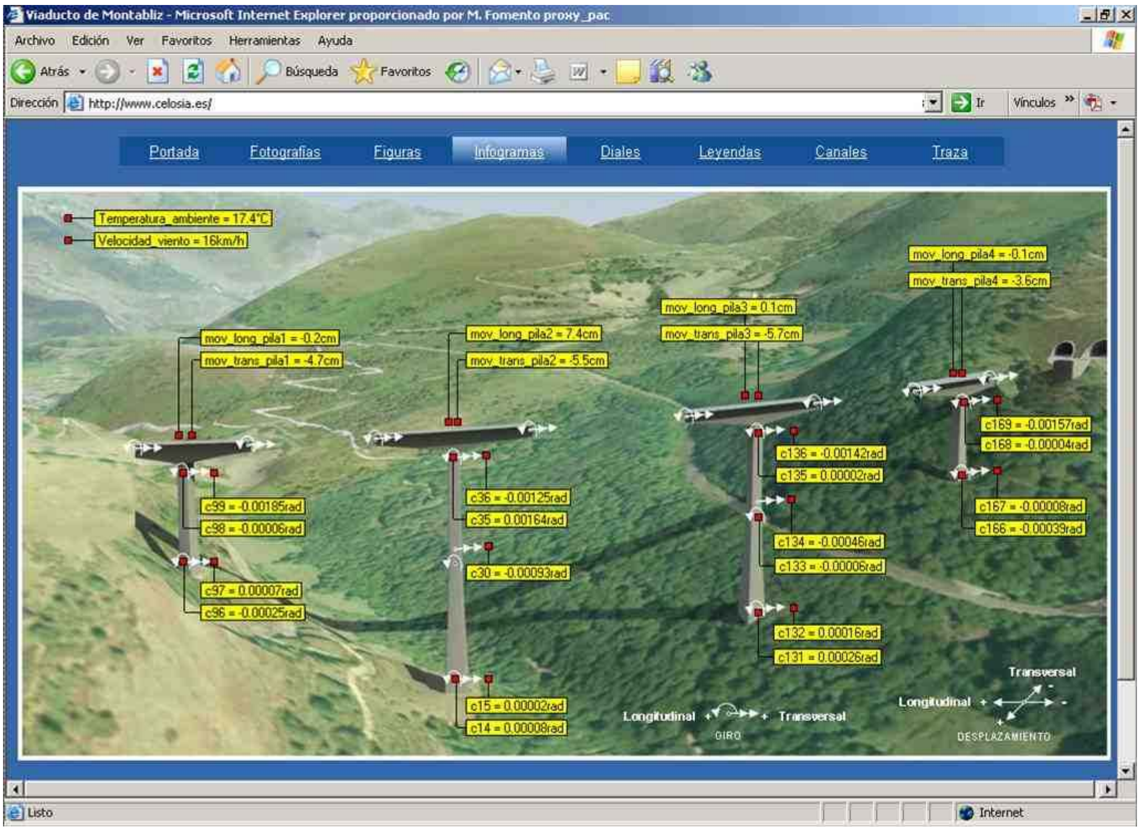


Figure 6- Synoptic panel to monitor pier rotation and displacements (Viaduct of Montabliz)

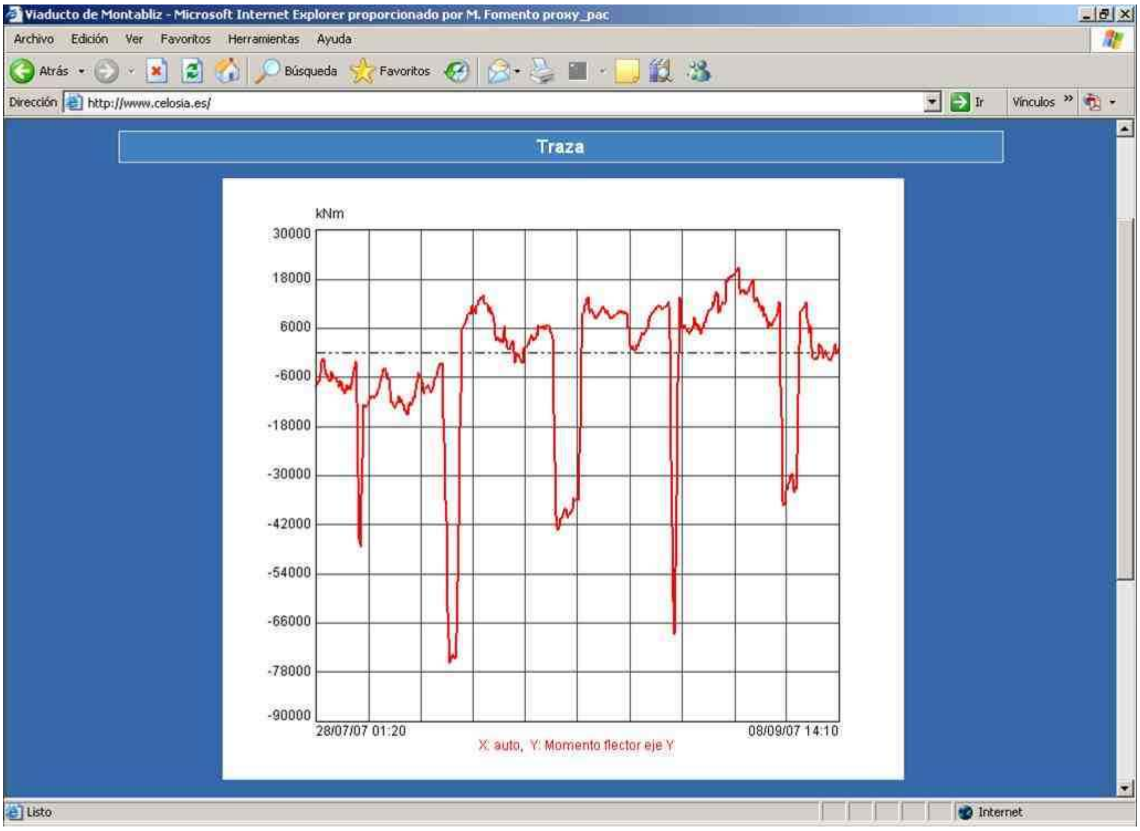


Figure 7 – Flexural moment variation at pier base, due to the concreting of five North cantilever deck segments and the five South counterbalanced ones (Viaduct of Montabliz)

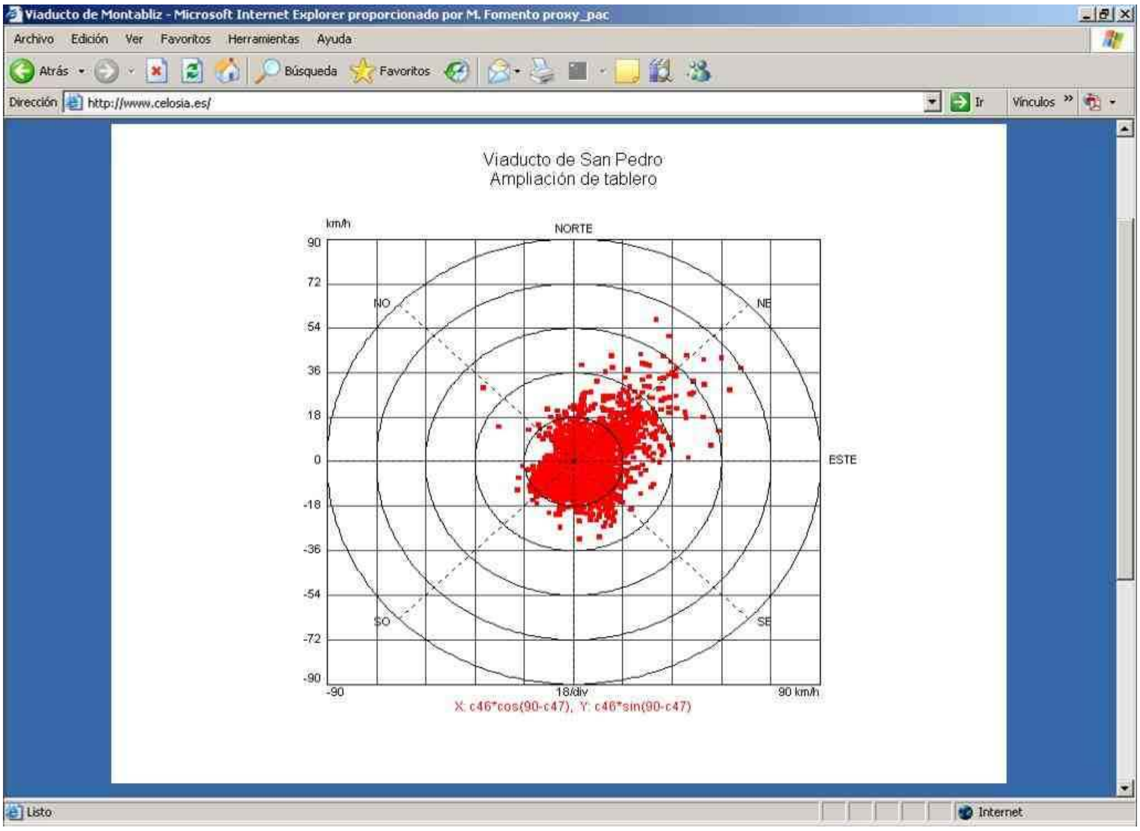


Figure 8 – Wind polar diagram to survey construction operation restrictions (San Pedro)

— Surveillance of bridges open to traffic

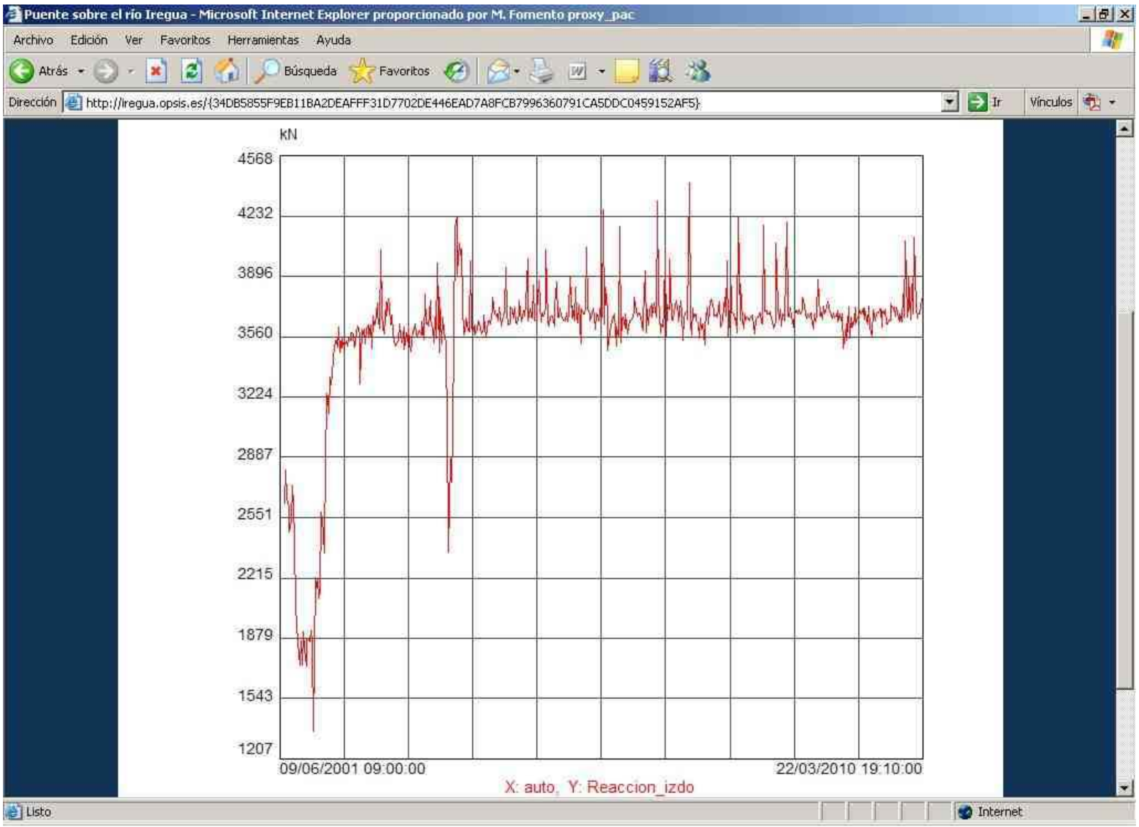


Figure 9 - Evolution of the abutment reaction between May 2001 and March 2010 (Bridge over the Iregua river: the first box of the graph belong to the construction stage, the oscillation of the third box is due to a repavement operation)

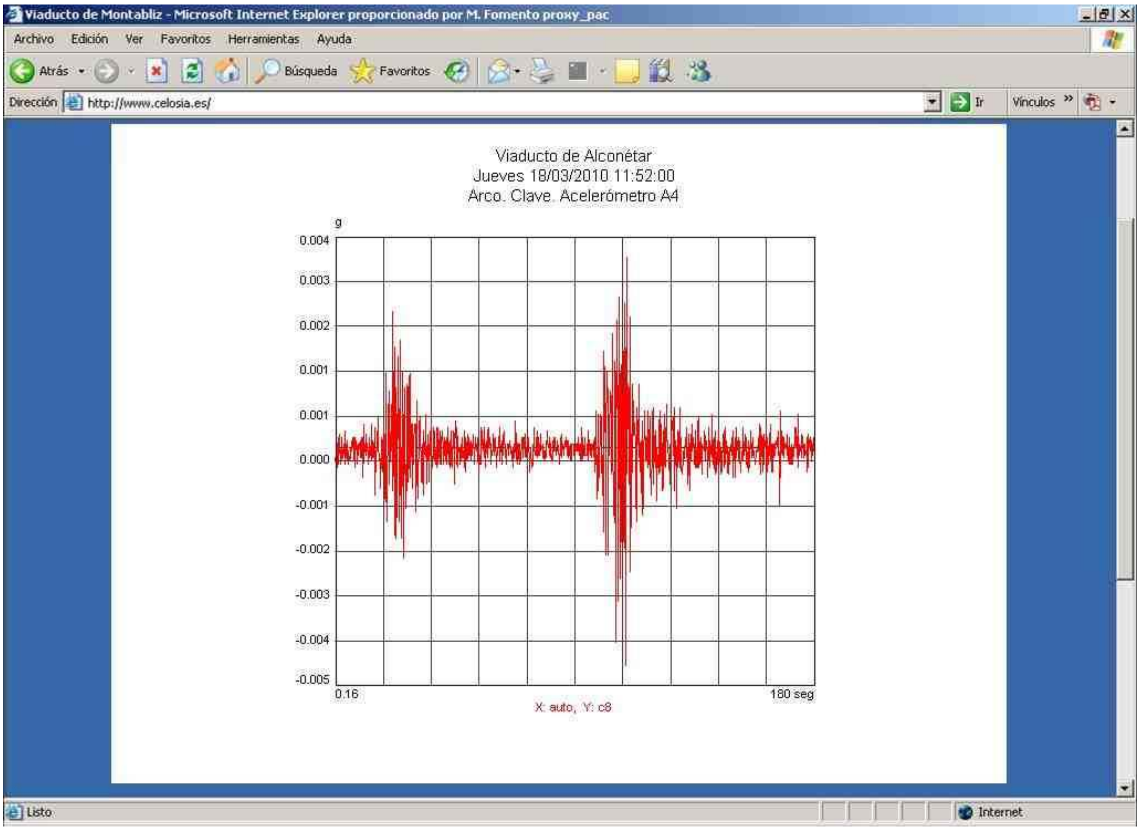


Figure 10 - Accelerogram induced by the traffic (Viaduct over the Tajo river)

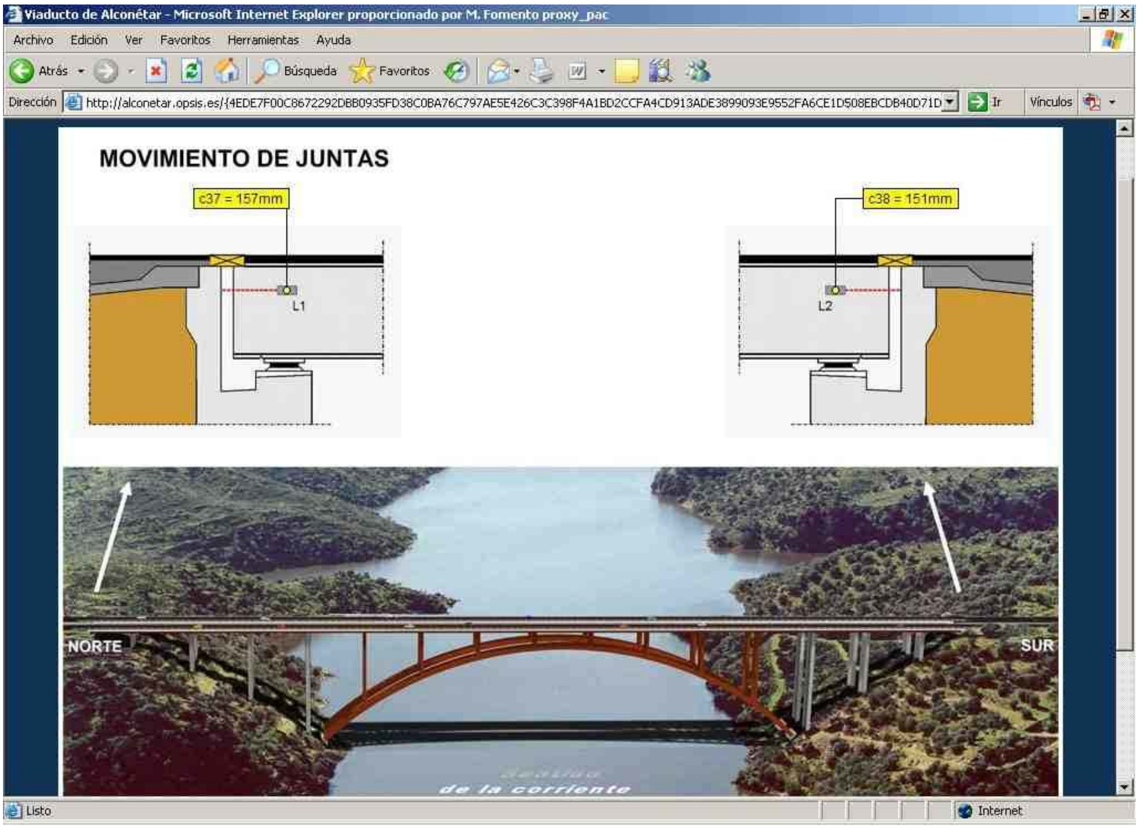


Figure 11 – Movement of the expansion joints (Viaduct over the Tajo river)

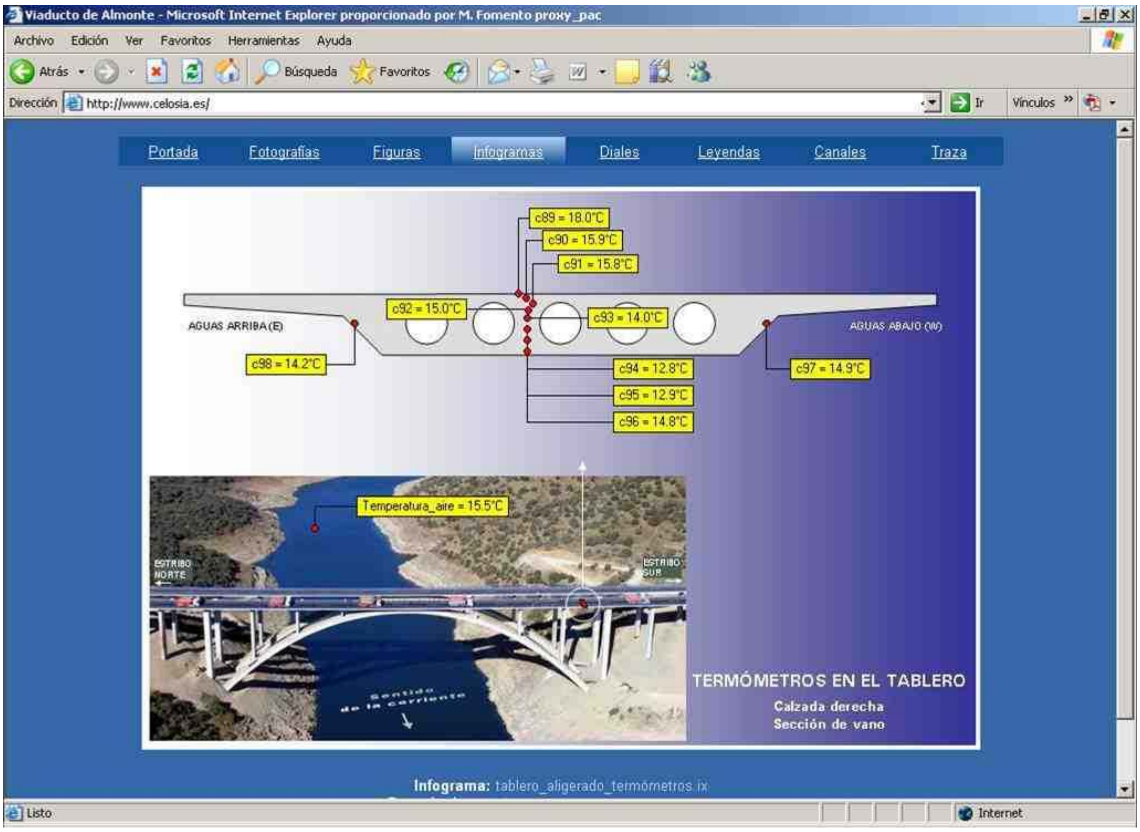


Figure 12 – Synoptic panel for the thermal analysis of the deck (Viaduct over the Almonte river)