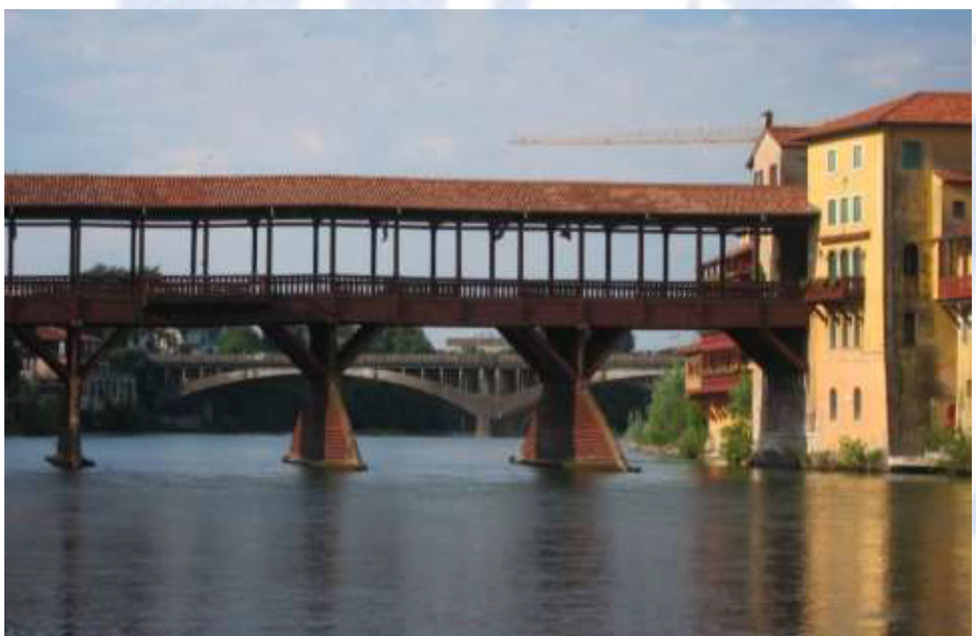
INCONTRIAMOCI ON LINE
Programma Webinar 2020

Diagnostica per la Valutazione della Vulnerabilità di Ponti in Cemento Armato



Dario Foppoli
Foppoli Moretta e Associati
Tirano (SO) – ITALY
posta@foppolimoretta.it
www.foppolimoretta.it

Foppoli Moretta e Associati consulting engineers

FMeA is an Italian SME settled in 1995

The company is divided into three areas:

- NDT Lab for Existing Building and Structures;
- Building, Structures & Restoration
- Environment, Territory & Infrastructure

On the field of cultural heritage FMeA has worked for the restoration and structural enhancement of public buildings, archaeological sites, castles, palaces and mansions, churches.

On the field of surveys, diagnostic analysis and monitoring FMeA have performed testing on masonry and wooden structures, structural monitoring, modeling and static and seismic assessment of several ancient buildings all over the Italy.

FOPPOLI MORETTA e ASSOCIATI

società di ingegneria


Giotto Bell Tower - Firenze


Bramante Tower – Vigevano (PV)


S. Biagio Church – Montepulciano (SI)


Fenice Theatre - Venezia


Sindone Chapel - Torino


2012 earthquake


Montecitorio Palace - Roma


Farnese Palace - Roma

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R.C. Ponte della Vittoria – Bassano (VI)


R.C. Viadotto Valdone – Sondrio


R.C. Ponte sull'Adda – Stazzona (SO)


Mas. Ponte di Ganda – Morbegno (SO)


Mas. Ponte medievale – S.Lorenzo (TN)

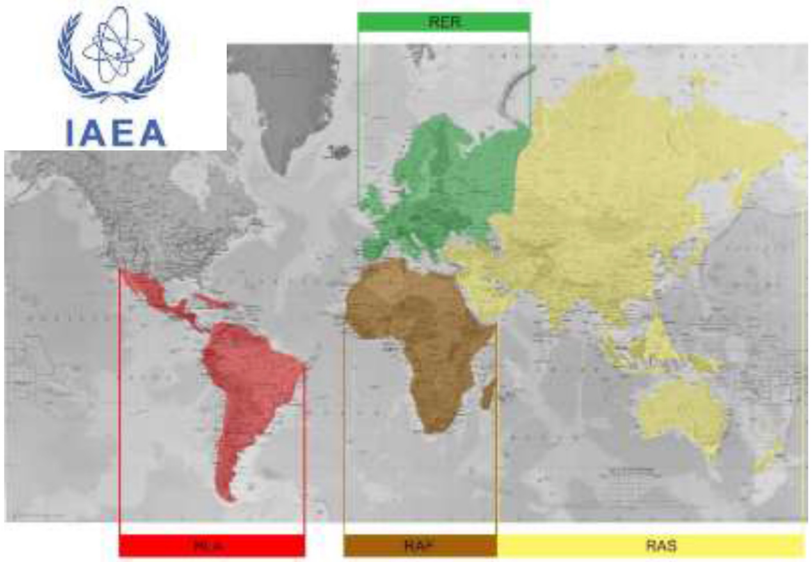

Mas. Ponte d. Cittadella – Alessandri


Wood Ponte degli Alpini – Bassano (VI)


Mas. Ponte del Castello – Vigevano (PV)


L.W. Passerelle - Verbaina

International Atomic Energy Agency (IAEA)



ARCAL RLA 1014 "Promocion de tecnologia de Ensayos No Destructivo para la Ispeccion de Estructuras Civiles e Industriales"

RCA RAS 1022 "Strengthening Regional Capacity in Non-Destructive Testing and Examination … for Safer, Reliable, More Efficient and Sustainable Industries Including Civil Engineering"

RER 1018 "Harmonizing Non-Destructive Testing, Training and Certification for Civil Engineering and Cultural Heritage"

Expert missions for:

a) drafting of training programs (syllabi);

b) carrying out training activities;

c) drafting of e-learning supports;

d) personnel certification;

e) field activities during seismic events.

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Outline

1. *Introduction*
2. *Inspection Matched with NDT*
3. *Analysis of the Effectiveness of NDT Techniques*
4. *Mechanical Characterization of the Materials*
5. *Occasional Static Monitoring*
6. *Survey of the Dynamic Reaction*

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Le Linee Guida Approvate il 17 aprile 2020

Linee Guida per la Classificazione e Gestione del Rischio, la Valutazione della Sicurezza ed il Monitoraggio dei Ponti Esistenti, Allegate al parere del Consiglio Superiore dei Lavori Pubblici n.88/2019, espresso in modalità “agile” a distanza dall’Assemblea Generale in data 17.04.2020

Sono articolare in 3 parti:

- Censimento e classificazione del rischio
- Verifica della sicurezza
- Sorveglianza e monitoraggio

Cap. 1.3 APPROCCIO MULTILIVELLO:

- Livello 0 - censimento di tutte le opere e delle loro caratteristiche principali;
- Livello 1 - ispezioni visive dirette e rilievo speditivo della struttura;
- Livello 2 - definizione della classe di attenzione (CdA);
- Livello 3 – Valutazioni preliminari atte a comprendere se sia comunque necessario procedere ad approfondimento mediante verifiche di Livello 4;
- Livello 4 – Valutazioni accurate sulla base delle Norme Tecniche per le Costruzioni vigenti;
- Livello 5 – Analisi più sofisticate applicate ai ponti di significativa importanza all’interno della rete;

Le Linee Guida Approvate il 17 aprile 2020

Il fulcro dell'approccio multilivello è il Livello 2, ossia la definizione della Classe di Attenzione: ad ogni CdA corrispondono determinate conseguenti azioni in termini di indagini/ monitoraggio/ verifiche (➔ cap. 1.3)

In relazione all'argomento oggetto della presentazione risultano particolarmente rilevanti i seguenti capitoli:

Cap. 6.2 LA CONOSCENZA DEL PONTE:

a. analisi storico-critica;
b. analisi del progetto originario;
c. rilievo (geometrico-strutturale, dei dettagli costruttivi, del quadro fessurativo e dei dissesti);
d. caratterizzazione geologico-geotecnica del sito;
e. indagini finalizzate alla caratterizzazione dei dettagli costruttivi e dei materiali;
f. inquadramento dell'ambito idraulico …;
g. inquadramento dell'assetto geo-morfologico …;

NOTA: (f. e g. si applicano nei casi specificati dalle linee guida)

Cap. 7.6 MONITORAGGIO STRUMENTALE

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2014 – 2017: a significant collapse every year…

2015 April 10th , A19 Highway HIMERA VIADUCT between Palermo and Catania

2014 July 7th, SS626 PETRULLA VIADUCT between Ravanusa e Licata (AG)

2017 April 18th , Fossano RingRoad (CN)

2016 October 28th , SS36 Overpass, Cesana Brianza (LC) -1 victim

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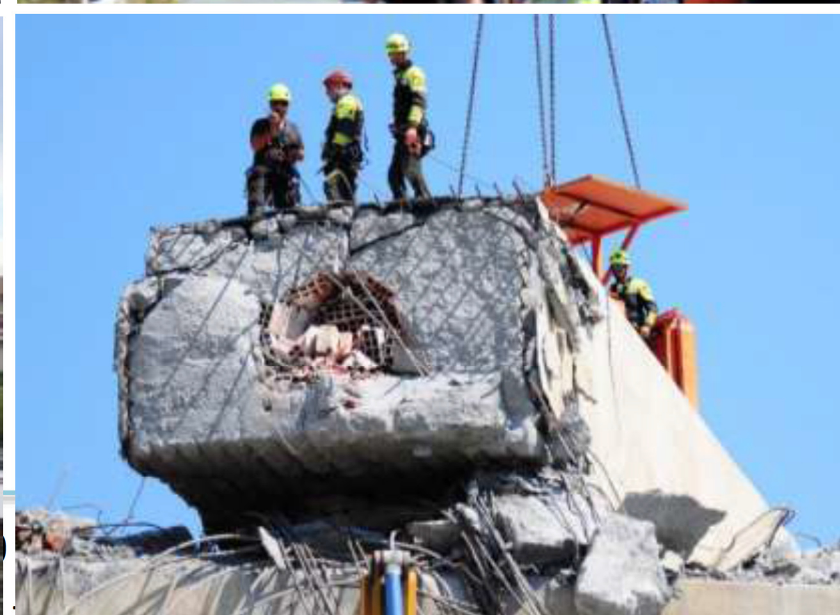
2018 August 14th - Genova - 43 victims; 600 evacuees



Introduction

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società di ingegneria

2019-2020 Other Collapses

2019 November 24th – A6 Highway MADONNA DEL MONTE VIADUCT close to Savona

2020 April 8th – Bridge across Magra river between Caprigliola and Albiano (MC) – it happened during COVID lock-down

Baodai Bridge in Suzhou (near Shangai)

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Baodai Bridge in Suzhou was built in 618 and altered several times until 1442. It has unusually thin piers: each arch is counter-balanced by the neighboring arches on either side.

In 1863 the English major-general Charles Gordon sailed his steamship to Suzhou to help the emperor to quell a rebellion. The Baodai Bridge blocked his way to the dock at the riverside.

He simple tore down the 9th arch on one end to allow his boat to pass through, and 25 of the 53 arches, half the bridge collapsed. It was only the one wider pier in the middle of the bridge (brake pier), between arches 26 and 27 that saved the rest.

Introduction

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Collapse of the Bridge across the Magra River

1905-1908 The bridge was built on the basis of the project of Eng. Muggia (concessionaire of the Hennebique patent for central Italy)

1945 Mined during the retreat of German troops (WW2) - decks destroyed and piles and shoulders not damaged

1945-1949 Rebuilt on the basis of a new project (Carè and Giannelli) that maintains its overall shape but:

- It reduces the section of the arches close to the pier
- It Reduces the number of pilasters
- It removes the central abutment

https://it.wikipedia.org/wiki/Ponte_di_Caprigliola

Introduction

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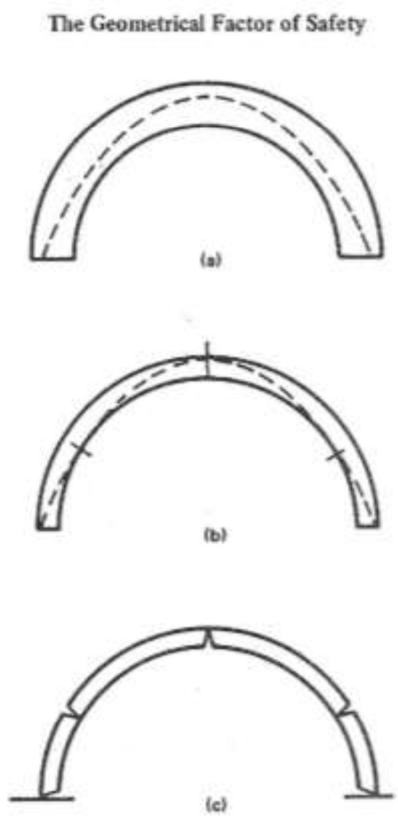
Collapse of the Bridge across the Magra River



a) The funicular polygon is contained within the masonry ➔ safe

b) The thinnest arch that could carry safety the same load ➔ Factor of Safety

c) Five hinges (symmetrical arch) create a cynematism ➔ unsafe

Heyman J., The masonry arch, Ellis Horwood Ltd, Chichester, 1982

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Introduction

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The “New” Bridge at Bassano del Grappa

The “new” R.C. bridge “Victory bridge” at Bassano del Grappa (VI)

The “New” Bridge at Bassano del Grappa

- 1915 work began to ease traffic due to the war on the old wooden bridge
- 1944-1945 the bridge was destroyed during three successive Allied bombings
- 1947 the reconstructed bridge was tested and inaugurated

Survey and Diagnostic

- visual inspection (VT) of conservation structural status;
- electromagnetic covermeter (EL) analysis;
- determination of carbonation depth (PC);
- determination of rebound number (SC);
- determination of ultrasonic pulse velocity (UT)
- sonic pulse velocity measurements processed with tomographic methods
- identification of positions suitable for the sampling of concrete to correlate the previous values

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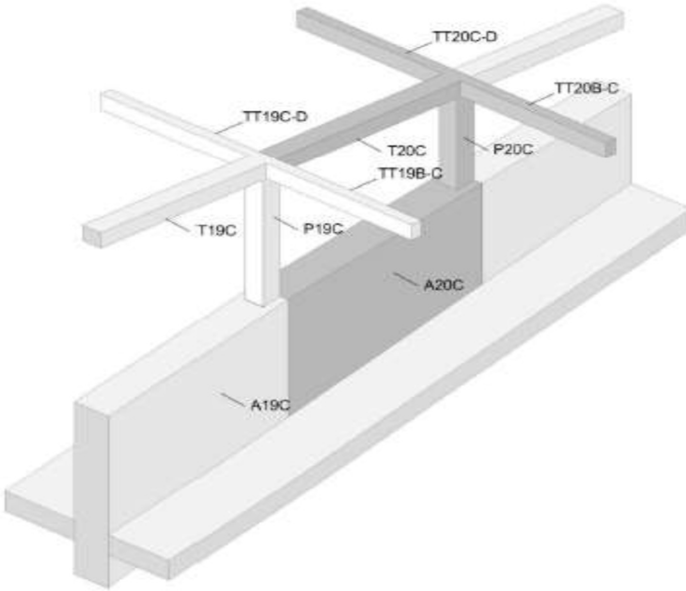
Construction Details



AIPnD

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Conservation Status

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Spalling of the concrete cover of an arch

Spalling on the brackets and longitudinal bars

Steel oxidation resulting in the rupture of the concrete cover - arch

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Conservation Status

Degradation of the shelves close to the position of the joint

Degradation due to the expansion joint

Oxidation of the bars of a pillar and spalling close to the position of the expansion joint

Deterioration of the section at the basis of a pillar: bar almost completely oxidized

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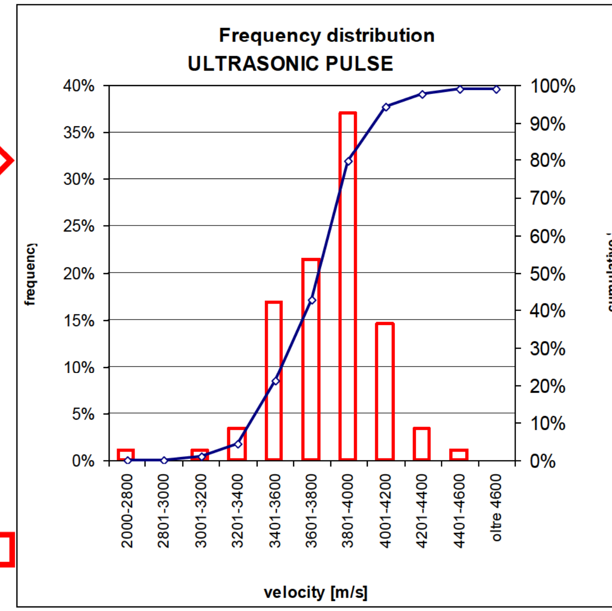
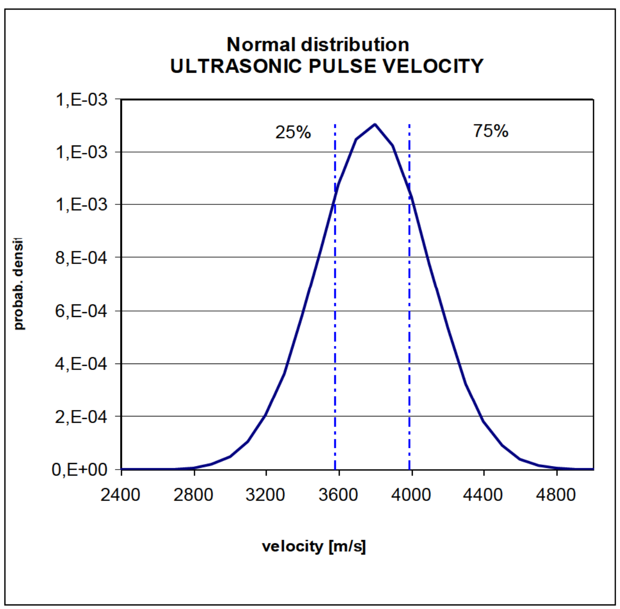
Instrumental Analysis

	Elemento	EL	PC	SC	UT	TS
Arcata sinistra	Arcone [A]	8	10	-	9	2
	Pilastro [P]	12	14	-	12	
	Trave [T]	4	4	-	4	
	Travetto [TT]	4	4	-	4	
Arcata destra	Arcone [A]	9	16	-	16	
	Pilastro [P]	32	32	15	32	
	Trave [T]	6	6	-	6	
	Travetto [TT]	6	6	-	6	
sommano		**81**	**92**	**15**	**89**	**2**

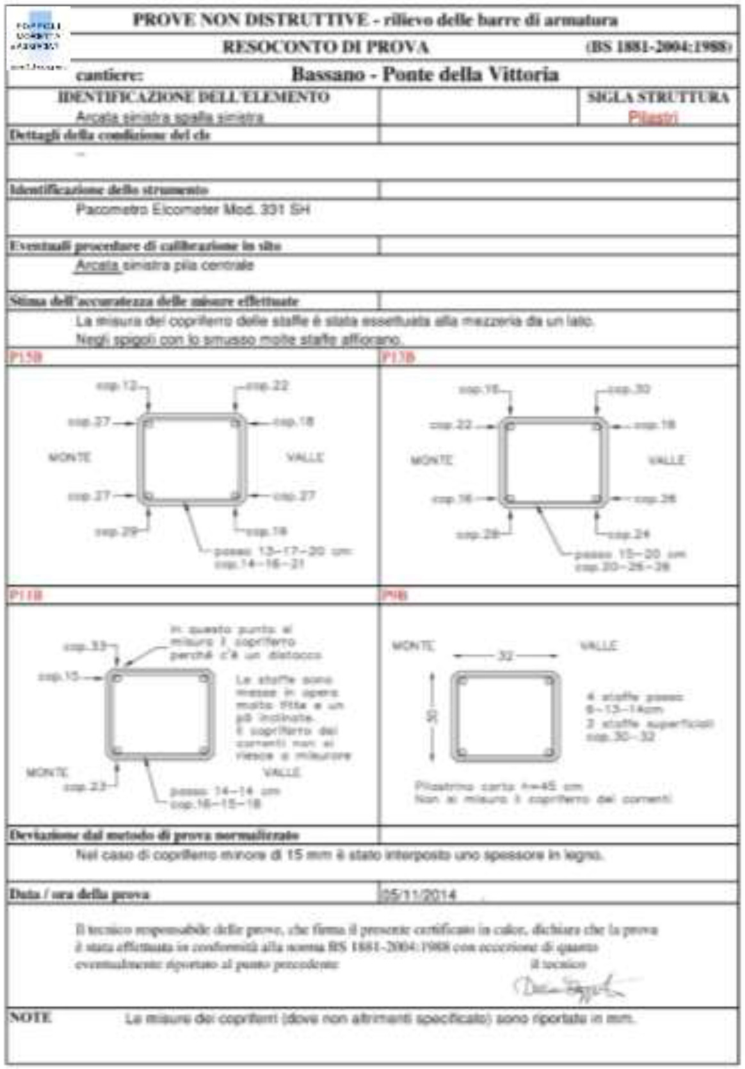




s.d.a. bassa	s.d.a. media	s.d.a. alta
>3996	3584≤x≥3996	<3584

Due to the high number of tests carried out, they can be interpreted as a statistical sample

Electromagnetic Covermeter Analysis



PROVE NON DISTRUTTIVE - rilievo delle barre di armatura

RESOCONTO DI PROVA (BS 1881-2004:1988)

cantiere: **Bassano - Ponte della Vittoria**

IDENTIFICAZIONE DELL'ELEMENTO		SIGLA STRUTTURA
Arcata sinistra spalla sinistra		Pilastri

Dettagli della condizione del cls

–

Identificazione dello strumento

Pacometro Elcometer Mod. 331 SH

Eventuali procedure di calibrazione in sito

Arcata sinistra pila centrale

Stima dell'accuratezza delle misure effettuate

La misura del copriferro delle staffe è stata essettuata alla mezzeria da un lato.
Negli spigoli con lo smusso molte staffe affiorano.

P15B | P13B | P11B | P9B

MONTE | VALLE

Deviazione dal metodo di prova normalizzato

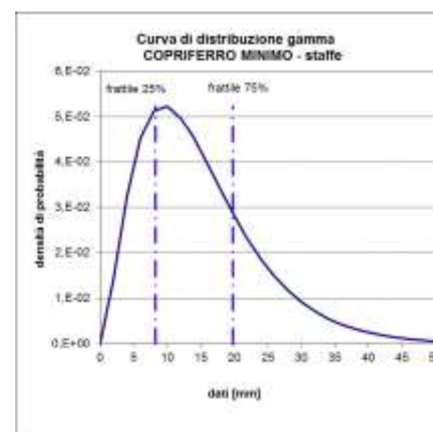
Nel caso di copriferro minore di 15 mm è stato interposto uno spessore in legno.

Data / ora della prova 05/11/2014

Il tecnico responsabile delle prove, che firma il presente certificato in calce, dichiara che la prova è stata effettuata in conformità alla norma BS 1881-2004:1988 con eccezione di quanto eventualmente riportato al punto precedente

Il tecnico

NOTE La misure dei copriferri (dove non altrimenti specificato) sono riportate in mm.



Ref. **BS 1881-2004 1988**

indagine	grandezza analizzata	U.M.	s.d.a. bassa	s.d.a. media	s.d.a. alta
EL	coprif. minimo	[mm]	>20	9 ≤ x ≤ 20	< 9

Determination of Carbonation Depth

PROVE NON DISTRUTTIVE - determinazione della profondità di carbonatazione

RESOCONTO DI PROVA (UNI 9944)

cantiere: **Bassano - Ponte della Vittoria**

IDENTIFICAZIONE DELL'ELEMENTO		SIGLA STRUTTURA
Pilastro		P2A

Rappresentazione fotografica

Profondità del foro	Quantità polvere in provetta	Carbonataz. misurata	Profondità della carbonatazione
70 mm	137 mm	20 mm	**10 mm**

Orientamento superficie esposta e tipo di esposizione

Destra orografica

Dettagli della condizione del cls

IDENTIFICAZIONE DELL'ELEMENTO		SIGLA STRUTTURA
Pilastro		P2E

Rappresentazione fotografica

Profondità del foro	Quantità polvere in provetta	Carbonataz. misurata	Profondità della carbonatazione
70 mm	145 mm	92 mm	**44 mm**

Orientamento superficie esposta e tipo di esposizione

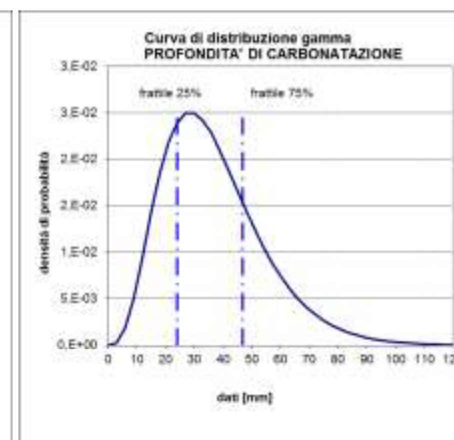
Destra orografica

Dettagli della condizione del cls

Data / ora della prova 06/11/2014

il tecnico

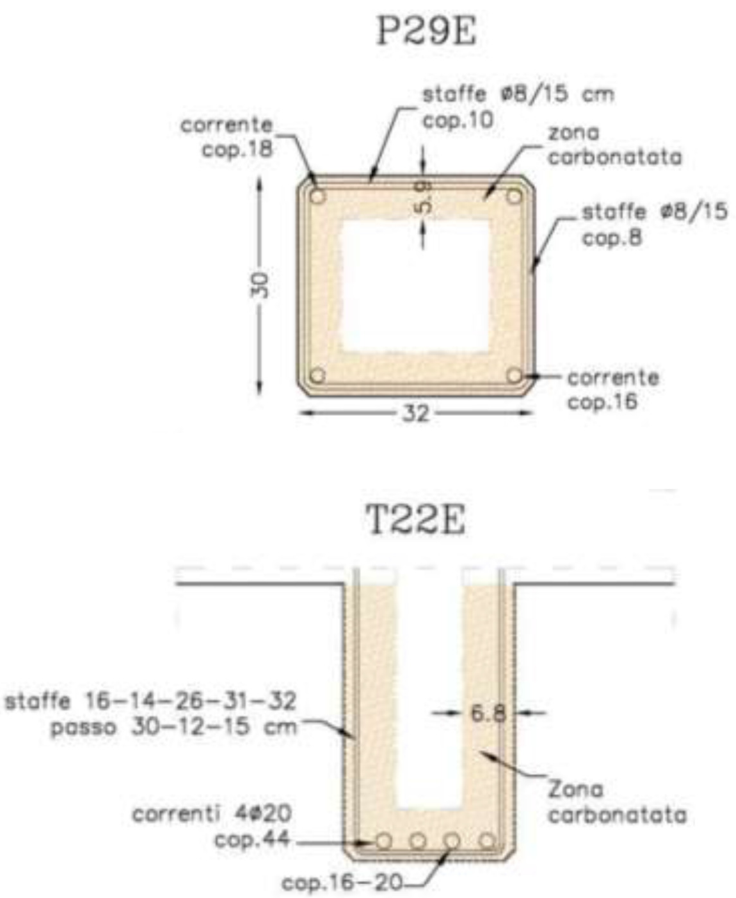
NOTE

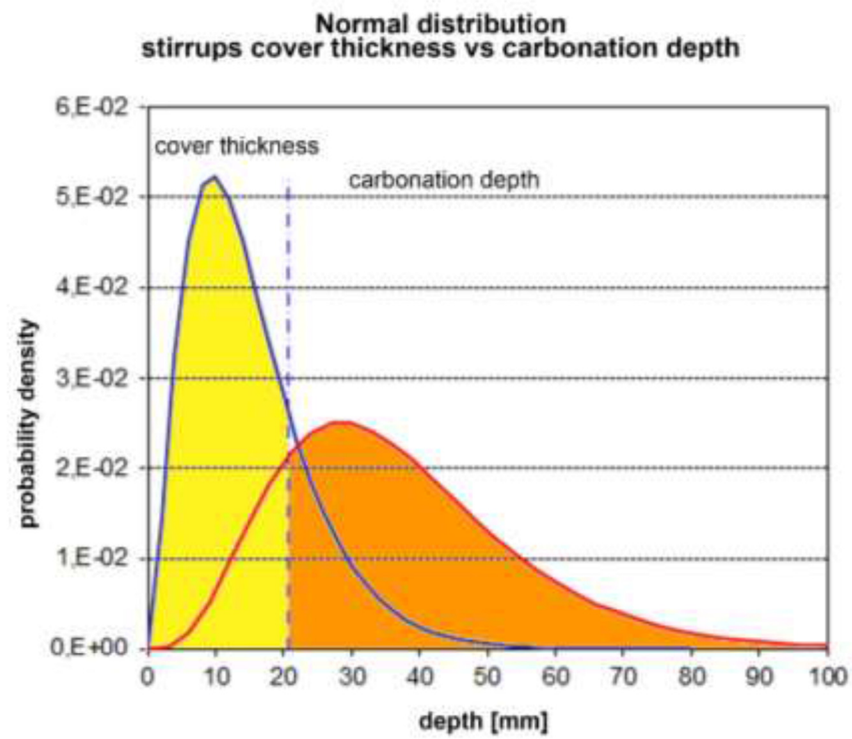


Ref. **UNI 9944**

indagine	grandezza analizzata	U.M.	s.d.a. bassa	s.d.a. media	s.d.a. alta
PC	prof.carbonataz.	[mm]	≤ 24	24 < x < 47	≥ 47

Bar Cover vs. Carbonation Depth





Because of carbonation, rebar lies in an environment which allows their corrosion

Determination of Rebound Number

PROVE NON DISTRUTTIVE - determinazione dell'indice sclerometrico

RESOCONTO DI PROVA

Bassano - Ponte della Vittoria

Elemento: Pilastro — Sigla: P27E

Data: 03/11/2014 — Ora: 11:00

Preparazione dell'area di prova: Rettifica della superficie con pietra abrasiva

Dettagli della condizione del cls: Carbonatazione = 47mm

Schema della prova effettuata

+ α

area di prova 30x30

52	48	46
46	38	39
40	42	40

7 7 7

Interasse punti: 7 cm

Identificazione dello sclerometro: Schmidt N-9 matr.22584

Media: 43,44

α: 0°

Correlazione: □ Strumentale □

Rck: ((47))

Limiti di accettazione media ±6 unità

n° misure: 9

n° Fuori Limite: 1

% Fuori Limite: 11%

Per % Fuori Limite > 20% si scarta l'intera serie di misure

Deviazione dal metodo normalizzato

La prova è stata effettuata in conformità alla norma UNI EN 12504 - 2 dic. 2001.

Il tecnico

Note: Prova effettuata sul lato sinistro del pilastro all'altezza di 150 cm a partire dall'estradosso dell'arcone. Il calcolo Rck risulta non attendibile a causa dell'elevata carbonatazione.

PROVE NON DISTRUTTIVE - determinazione dell'indice sclerometrico

RESOCONTO DI PROVA

cantiere: **Bassano - Ponte della Vittoria**

Elemento: Pilastro — Sigla: P27F

Data: 03/11/2014 — Ora: 11:05

Preparazione dell'area di prova: Rettifica della superficie con pietra abrasiva

Dettagli della condizione del cls: Carbonatazione = 47mm

Schema della prova effettuata

+ α

area di prova 30x30

50	40	42
50	38	48
49	36	44

7 7 7

Interasse punti: 7 cm

Identificazione dello sclerometro: Schmidt N-9 matr.22584

Media: 44,11

α: 0°

Correlazione: □ Strumentale □

Rck: ((49))

Limiti di accettazione media ±6 unità

n° misure: 9

n° Fuori Limite: 1

% Fuori Limite: 11%

Per % Fuori Limite > 20% si scarta l'intera serie di misure

Deviazione dal metodo normalizzato

La prova è stata effettuata in conformità alla norma UNI EN 12504 - 2 dic. 2001.

Il tecnico

Note: Prova effettuata sul lato sinistro del pilastro all'altezza di 150 cm a partire dall'estradosso dell'arcone. Il calcolo Rck risulta non attendibile a causa dell'elevata carbonatazione.

Ref. **UNI EN 12405-2**

Determination of Ultrasonic Pulse Velocity

PROVE NON DISTRUTTIVE

determinazione della velocità di propagazione degli impulsi sonici-ultrasonici

RESOCONTO DI PROVA (UNI EN 12504-4)

cantiere: **Bassano - Ponte della Vittoria**

IDENTIFICAZIONE DELL'ELEMENTO: Pilastro — **SIGLA STRUTTURA**: P4A

RISULTATI DELLA PROVA

	1	2	3	4	5	6	media
L [m]	0,32	0,32	0,32	0,32	0,32	0,32	
T [μs]	82	83	84	86	86	86	
v [m/s]	3926	3846	3814	3717	3708	3734	3791 [m/s]

IDENTIFICAZIONE DELL'ELEMENTO: Pilastro — **SIGLA STRUTTURA**: P4E

RISULTATI DELLA PROVA

	1	2	3	4	5	6	media
L [m]	0,32	0,32	0,32	0,32	0,32	0,32	
T [μs]	76	76	78	77	76	77	
v [m/s]	4194	4211	4103	4172	4205	4156	4173 [m/s]

Dettagli della condizione del cls / muratura — Età del cls / muratura

Identificazione dello strumento — Appar. ad ultrasuoni System CMS V3HLF-P N.serie SG02.0113

dim. area contatto trasdutt. — Trasmettitore ∅ 6cm — Ricevitore ∅ 6cm

frequenza dei trasd.

accoppiamento — ☐ Gel — ■ Plastilina

metodo di trasmissione — ■ per Trasparenza — ☐ per Rifrazione

Indagine magnetometrica — ■ SI — ☐ NO — ☐ NON Necessaria

Presenza di armature o altri elementi

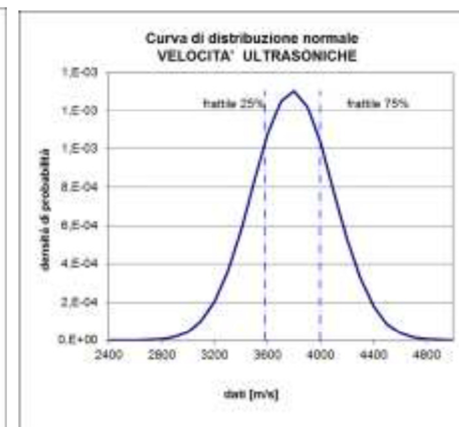
Preparazione della superficie — ☐ SI — ■ NO — ☐

Misura della distanza del percorso

Data / ora della prova — 06/11/2014

Il tecnico responsabile delle prove, che firma il presente certificato in calce, dichiara che la prova è stata effettuata in conformità alla norma UNI EN 12504-4 gen 2005 con eccezione di quanto eventualmente riportato al punto precedente — il tecnico

NOTE

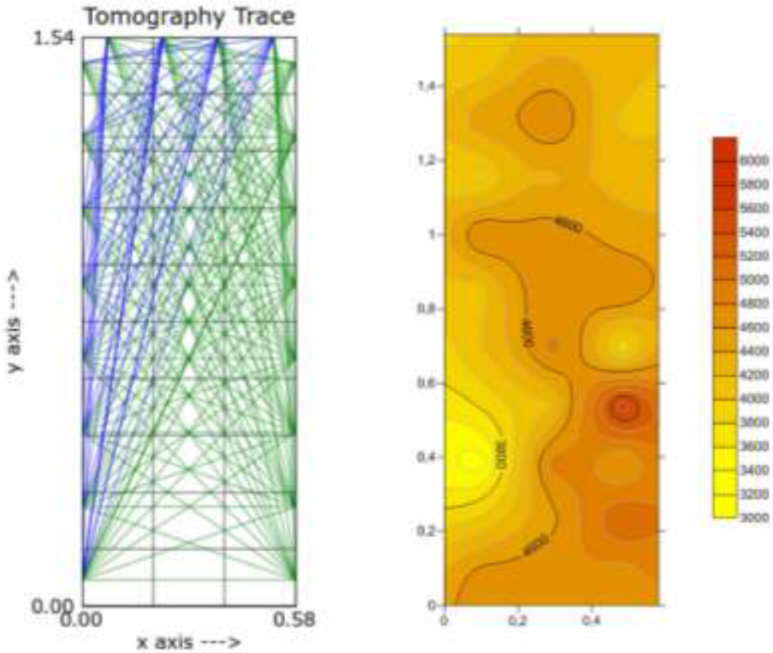


Ref. **UNI EN 12504-4**

indagine	grandezza analizzata	U.M.	s.d.a. bassa	s.d.a. media	s.d.a. alta
UT	velocità	[m/s]	>3996	3584≤x≥3996	<3584

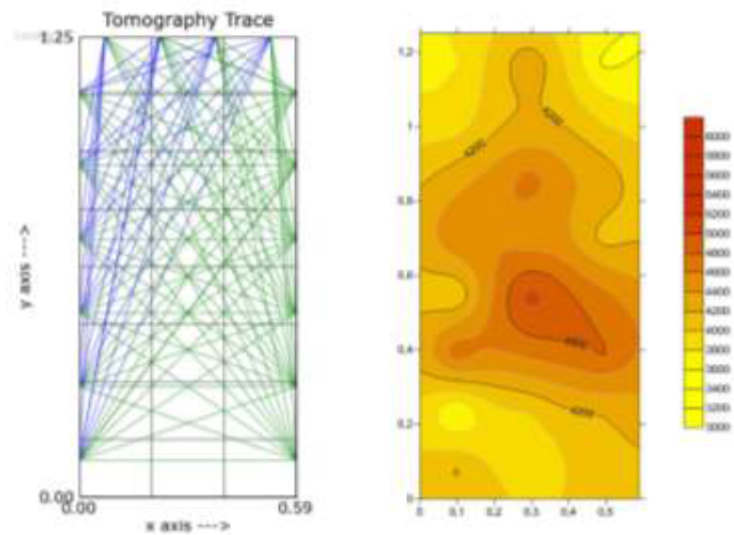
Determination of Sonic Pulse Velocity

Arcone A4C



Maximum speed: 5739.0 m/s
Minimum speed: 3275.0 m/s
Average speed: 4462.0 m/s

Arcone A5C

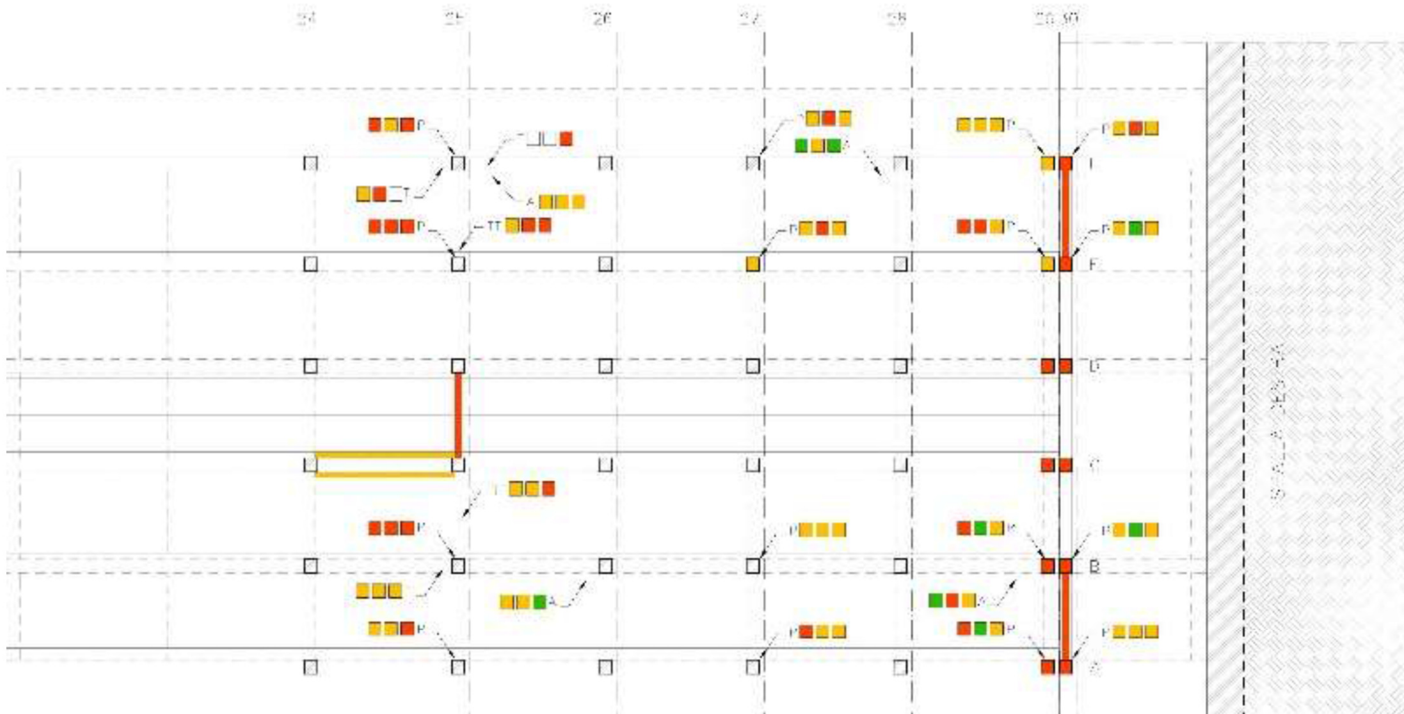


Maximum speed: 5084.0 m/s
Minimum speed: 3565.0 m/s
Average speed: 4261.0 m/s

The sonic pulse velocity measurements were processed with tomographic methods to assess the dishomogeneity on cross structural section

Acquired Data – Synoptic Tables

ARCONE DESTRO SPALLA DESTRA



	Ispezione (VT)	Copriferro (EL)	Carbonatazione (PC)	Velocità ultrasonica (UT)
	Degrado	Basso	Alto	Basso
	Innesco	Medio	Medio	Medio
		Alto	Basso	Alto

Synoptic tables showing the R.C. structures degradation status

Stazzona Bridge on Adda River

In collaboration with universities and private companies of its partnership, in 2018 AIPnD organized an on-site experimental activity aimed at the "**Analysis of the effectiveness of NDT techniques on RC bridges**", with the aim of comparing different operative techniques applied to a specific case of study.

The tests were carried out on an old R.C. bridge: some sections of the bearing beams of the deck were subjected to test. The “blind” analyses were carried out independently by different operators and with different techniques (VT, UT, GPR e Pulse-echo).

Results were then compared with regard to the applicability of the specific test techniques and to the effectiveness of their results.

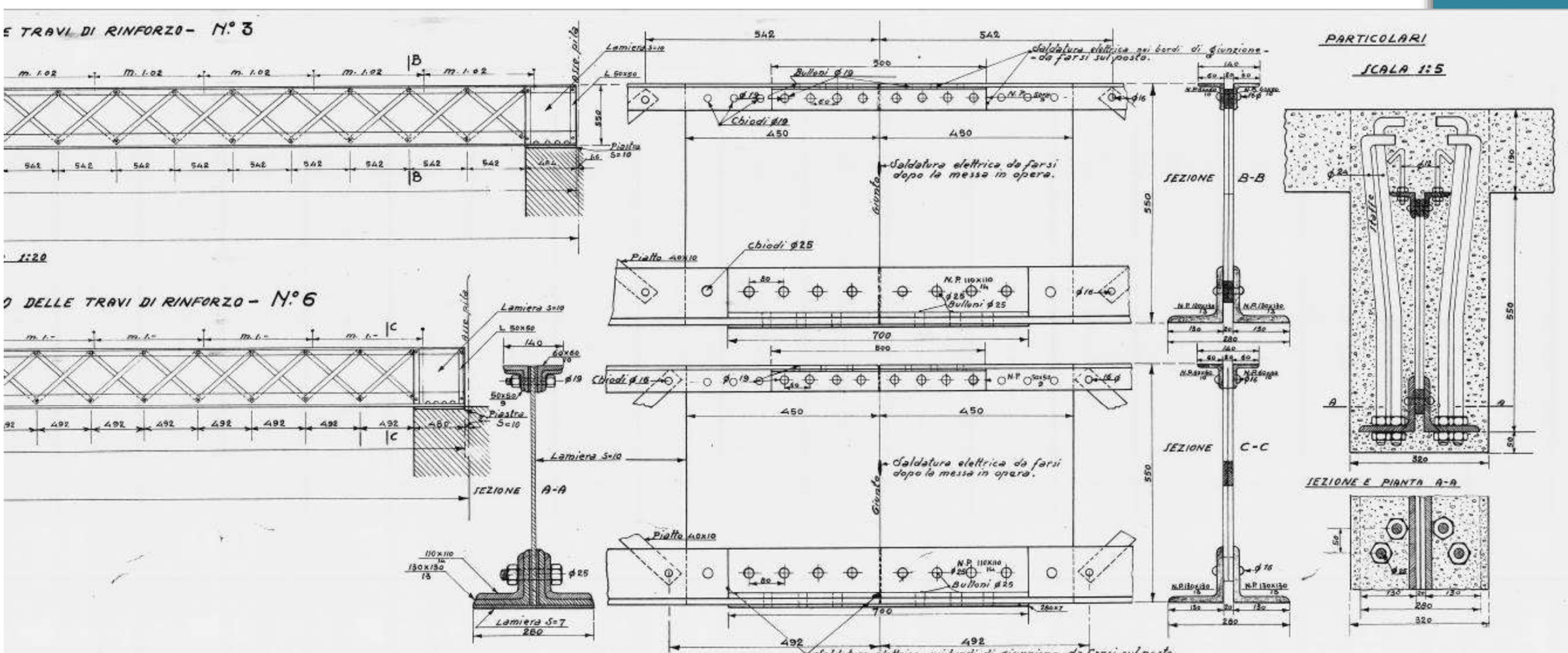
Analysis of the effectiveness of NDT techniques on RC bridges

The operators that worked on site are certified from a Certification Body accredited by ACCREDIA provided with a framework governing the "**Qualification and certification of the technical staff involved in non-destructive tests in the field of civil engineering**" drawn up with reference to standard UNI EN ISO 9712:2012.

sigla	livello	certificazione	operatore
VT	2	VT/INF ISO9712 – cert. BUREAU VERITAS n. CIV-18-00166-C	Gianluca Dal Bianco
UT	3	cert. CICPND n. 371/CAP/C	Alessio Caligari
VT	3	cert. CICPND n. 425/CAP/C	Dario Foppoli (coordinatore)
VT	3	"Ispezione e Monitoraggio di Ponti, Viadotti, Cavalcavia e Passerelle" - cert. KIWA PnD-CIV-0405	
SC	3	cert. CICPND n. 353/CAP/C	
EL	3	cert. CICPND n. 353/CAP/C	
MP	3	cert. CICPND n.301/CAP/C	
MS	3	cert. CICPND n.239/CAP/C	
VT	2	"Ispezione e Monitoraggio di Ponti, Viadotti, Cavalcavia e Passerelle" – cert. QAID QA/ISP/244/18	Emanuele Moretta (coordinatore)

Historic Outline

- 1913 construction of the bridge with three spans and four bearing beams
- 1936 reinforcement of the bridge to allow the transit of exceptional loads foreseen for the construction of the nearby Stazzona hydroelectric plant: three additional R.C. beams were interposed among the existing ones



It was possible to find out two drawings dated 1936 from which it is evident the particular conformation of the steel reinforcement frame provided for the new beams. **For this experimental activity they were not made available to the on site operators**

Experimental Campaign

The experimental preliminary diagnostic campaign was developed by applying the following methods:

- **Visual Inspection (VT)** through DRONE device (SAPR)
- **Ultrasonic Test (UT)** processed by tomographic methods
- **Pulse-echo (UT-pe)** ultrasonic tomography
- **Ground Penetration Radar (GR)** inspection

1 – 3 – 5 - 7: 1st phase beams built in 1913
2 – 4 – 6: 2nd phase beams built in 1936

Blind tests were carried out: no information was provided to the on site operators about the drawing drafted in 1936.

Visual Inspection through DRONE device (SAPR)

Visual Inspection **(VT)** allowed to detect a bad general maintenance and conservation status. The major degradation phenomena observed are exfoliation of the superficial layers of the concrete on the shoulders and spalling of the concrete cover on the beams of the deck, due to percolation and high humidity. Spalling phenomena are progressive and require to restore the section as soon as possible.

Execution of visual inspection through Tramite Remote Piloting System (SAPR)

Visual Inspection through DRONE device (SAPR)

Execution of visual inspection through Tramite Remote Piloting System (SAPR)

Visual Inspection through DRONE device (SAPR)

Italsabi 45 Years

Certificato n°	18/VI/084/001
Località:	Tirano (SO)
Data Esec: 8/11/18	Data Emissione: 4/12/18

Cliente:	AIPnD Associazione Italiana Prove non Distruttive – Studio Foppoli e Moretta
Oggetto	VIDEO ISPEZIONE TRAMITE SISTEMA **SAPR** CON TECNICO QUALIFICATO PER CONTROLLO VT/INF LIV. II ISO9712
Tecnico Qual.	Gianluca Dal Bianco cert. ACCREDIA n° CIV-18-00165-C
Pilota APR	Riccardo Savio
Operatore ENAC	ITALSABI N° 19798
Normative di Riferimento	IT-IND-REG-02_NDT.CIV, Circolare 19/07/1967 n. 6736/61A1

Foto 5 – Arcata 1, Lato valle

Descrizione: Espulsione dei ferri, dettaglio.

Suggerimenti: Si raccomandano incisivi interventi di ripristino nelle aree soggette a percolazione tramite sabbiatura delle parti delle armature esposte e protezione delle stesse con l'uso di un passivante ed il ripristino dell'elemento portante.

Italsabi 45 Years

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Pilota APR	Riccardo Savio
Operatore ENAC	ITALSABI N° 19798
Normative di Riferimento	IT-IND-REG-02_NDT.CIV, Circolare 19/07/1967 n. 6736/61A1

Foto 9 – Arcata 2, impalcato

Descrizione: Espulsione del ferro ed erosione dell'impalcato.

Suggerimenti: Si raccomandano incisivi interventi di ripristino nelle aree soggette a percolazione tramite sabbiatura delle parti delle armature esposte e protezione delle stesse con l'uso di un passivante ed il ripristino dell'elemento portante.

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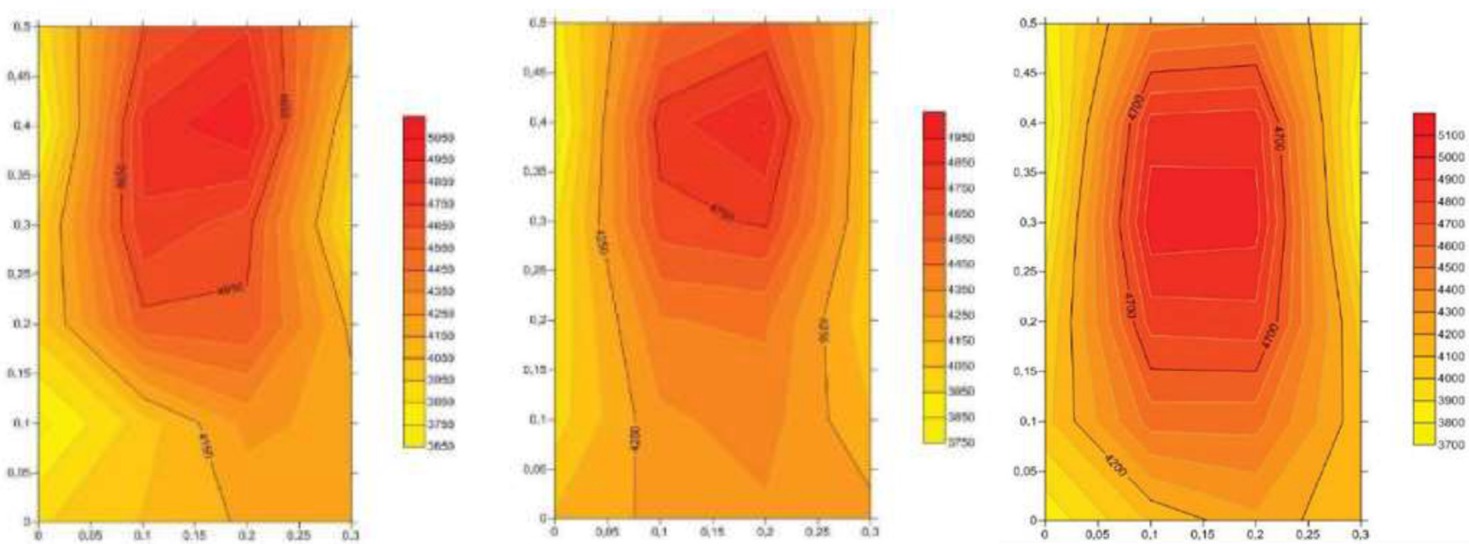
Italsabi

Ultrasonic Tests Processed with Tomographic Methods

For the **first phase** beams three vertical Ultrasonic (UT) tomographies have been performed in order to evaluate the homogeneity of the concrete.

UT velocities are lower in the cortical part of the beam: this distribution highlights the lower density of the cortical concrete (if compared to the nucleus). This could be correlated to the constructive technologies of the time (beginning of the 20th century), for example to a poor attention to the vibration during the casting or to the environmental conditions during the curing.

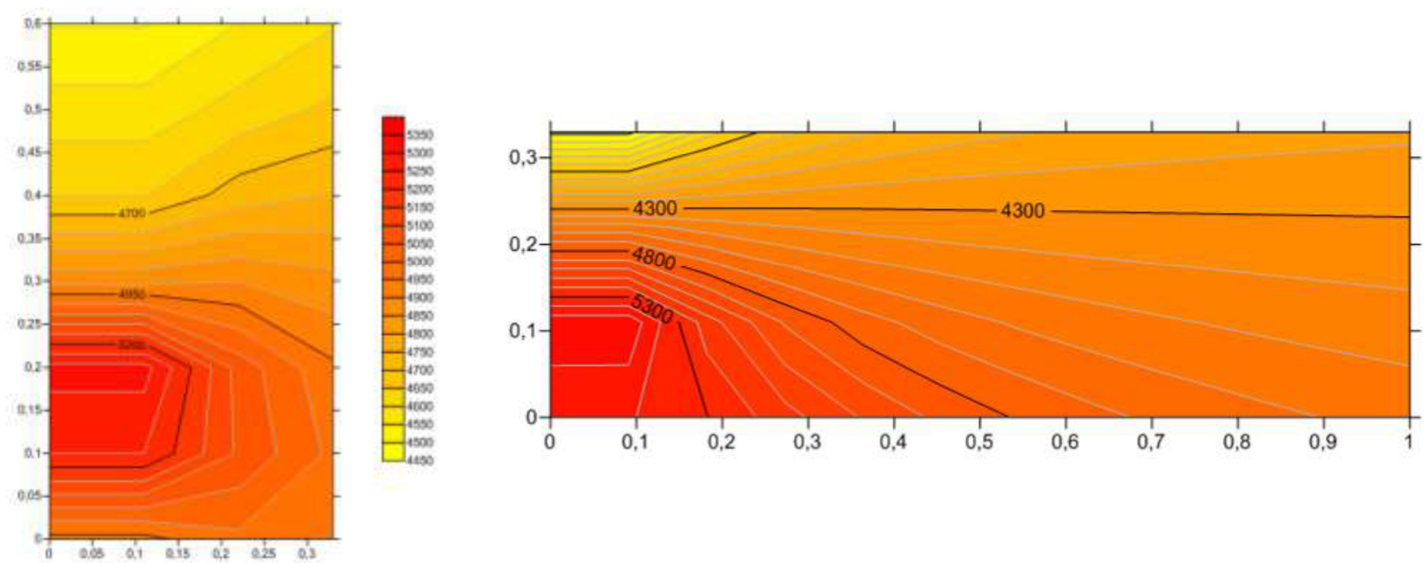


Tomographic sketch of the 1st phase beams (cross section)

Ultrasonic Tests Processed with Tomographic Methods

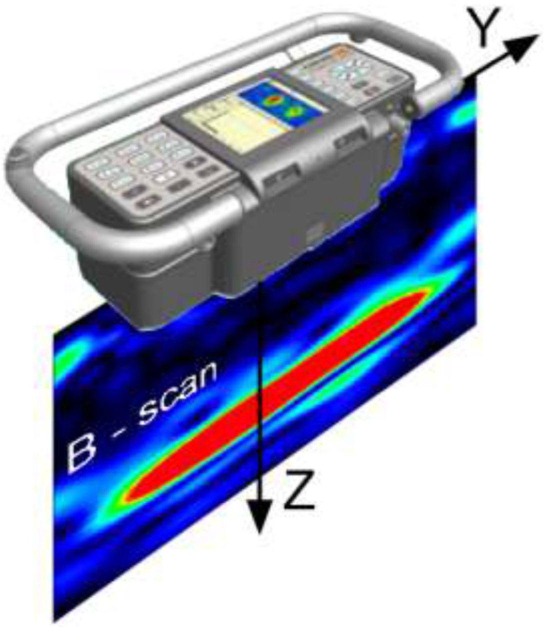
For the **second phase** beams two ultrasonic tomographies have also been carried out along a vertical cross section and along a horizontal longitudinal section placed at mid-height of the beam.

UT velocities are higher in the lower part than in the upper part of the beam: in this case this can be related to the presence within the core of concrete of metal elements, which geometry, however, was not possible to determine with this methodology.



Tomographic sketch of 2nd phase beams (cross section and horizontal)

Pulse-echo Ultrasonic Tomographies and Georadar Analysis



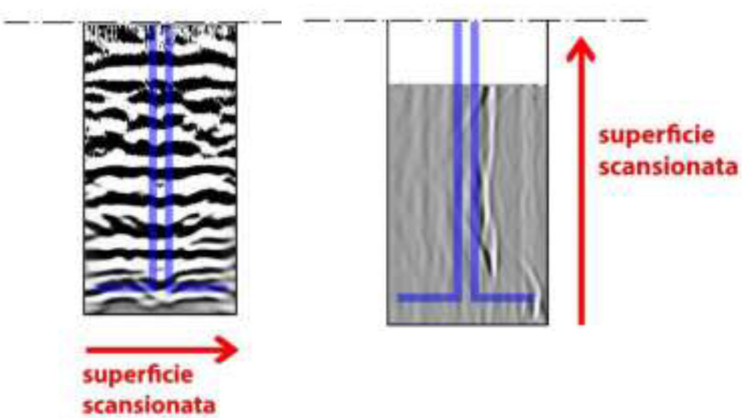
Pulse-echo sonic tomographies

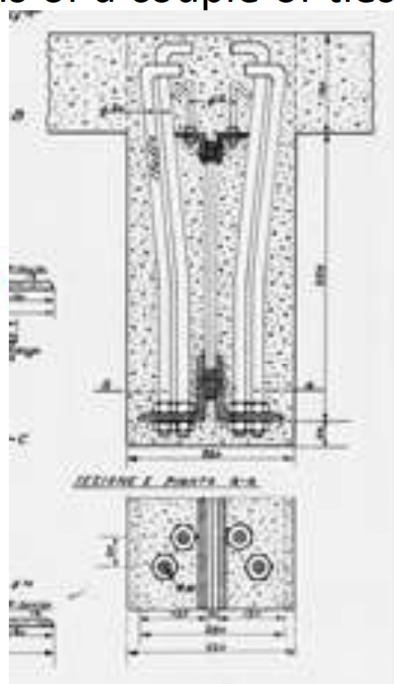
GPR surveys

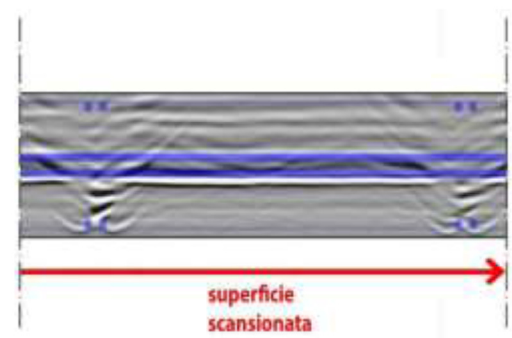
Pulse-echo Ultrasonic Tomographies and Georadar Analysis

Matching the results of Pulse-echo ultrasonic tomographies (**UT-pe**) and georadar (**GR**) we can do some consistent hypothesis dealing with the reinforcement system of the 2nd phases beams.

It is possible to suppose the existence of steel elements L or C shaped within the core of the concrete beam . It was detected the lower lintel and the vertical core; in some survey the core seem not to be continuous. The lower lintel is also connected to the upper concrete slab by means of a couple of ties placed at a distance of 100 cm from each other.

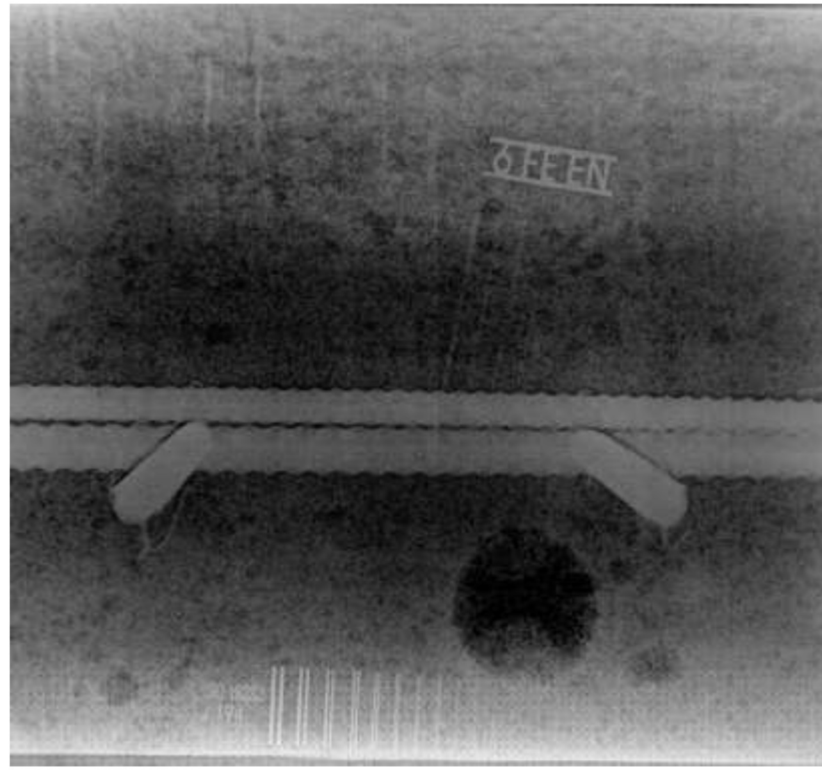






Cross section – hypothesis vs original design sketch – Longitudinal section

Radiographic Test



- it is necessary to use gamma-emitting radioactive sources with high energy and high activity, such as Cobalt-60;
- exposures with long times are expected related to the thicknesses to be inspected;
- the need to have a radioactive source on display cause a relevant difficulty connected to traffic and therefore to safety

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NDT Experimental Activities - Considerations

- The preliminary Visual Inspection (VT) allowed to perform a **first rough evaluation** of structural degradation and its reporting on standard forms.
- Ultrasonic Test (UT) were processed with tomographic methods so allowing to evaluate the homogeneity of the beams in their cross and longitudinal sections. These tests did **not allow to detect the steel reinforcements** within the beam.
- Steel reinforcements were detected through pulse-echo ultrasonic tomographies (UT-pe) matched with georadar survey (GR). Results coming from these methodologies were then compared with the original project drawings and it was possible to observe a good correspondence; anyway it was **not possible to identify the details of steel reinforcements** (geometry, number and diameter of the elements, deterioration status) despite these elements are effective to evaluate the static and seismic vulnerability of the structure.
- A possibility to obtain a better resolution and to recognize the geometry of the steel reinforcement frame could be the execution on the R.C. beams of 3D tomographies both with the pulse-echo ultrasonic device and with the radar.

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Promotion and Educational Activities

The preliminary results of the tests carried out were presented during the workshop "**Effectiveness of non-destructive testing techniques for assessing the safety of bridges**" which was a good success event.

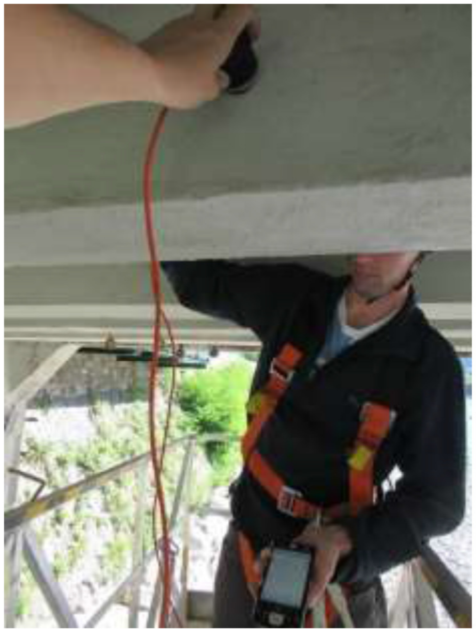
The standard frontal classroom training was matched with a practical session that took place in the afternoon on site to attend the execution of the tests.

Investigation for the Definition of Mechanical Properties

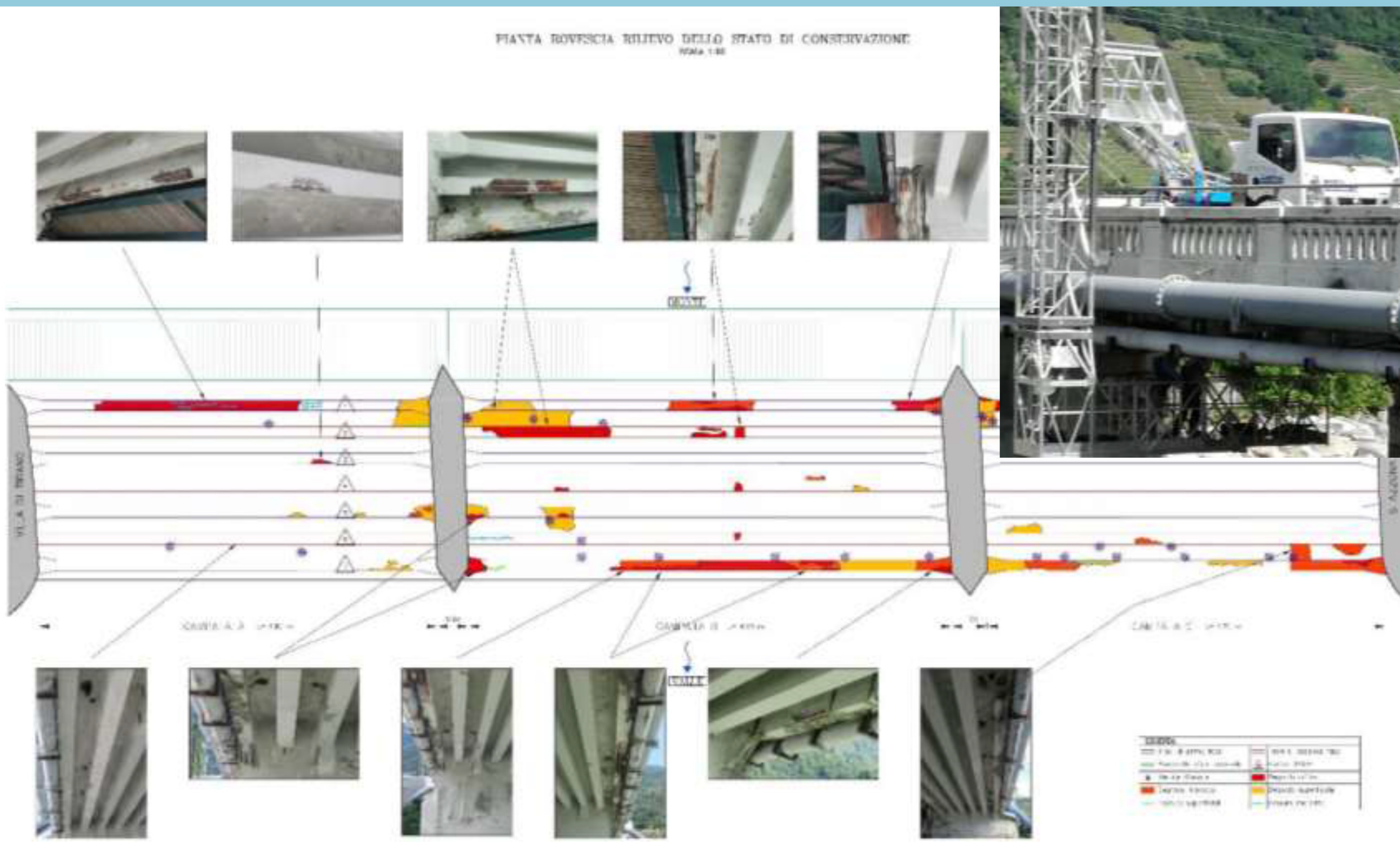
- The investigations carried out in the context of the experimental campaign were **non-destructive** and of **extensive** type, that means they were applicable to large areas allowing to obtain general **QUALITATIVE** indications on the state of conservation of the artefact.
- However, to carry out the structural vulnerability assessment, it was also necessary to define **QUANTITATIVE** geometric and mechanical parameters; for this purpose it was essential to match further NDT with the execution of **partially destructive tests** of an **intensive** and punctual nature.

DEEPENEING OF THE INVESTIGATION FOR THE DEFINITION OF MECHANICAL PARAMETERS

- Close Visual Inspection (**VT**)
- Electromagnetic survey (**EL**)
- Corings
- Carbonatation tests (**CH**)
- Compressive tests on concrete
- Ultrasonic tests (**UT**)
- Pull-out tests (**ES**)
- Traction tests on steel bars
- Durometric tests

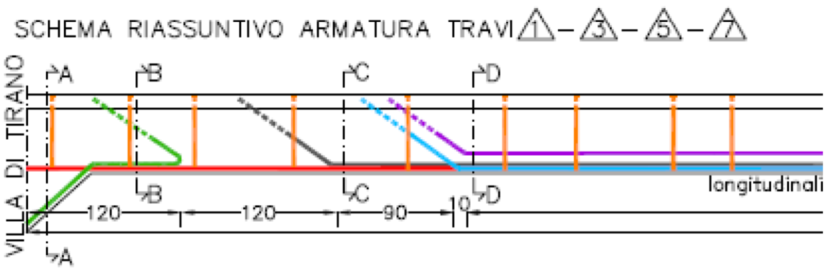


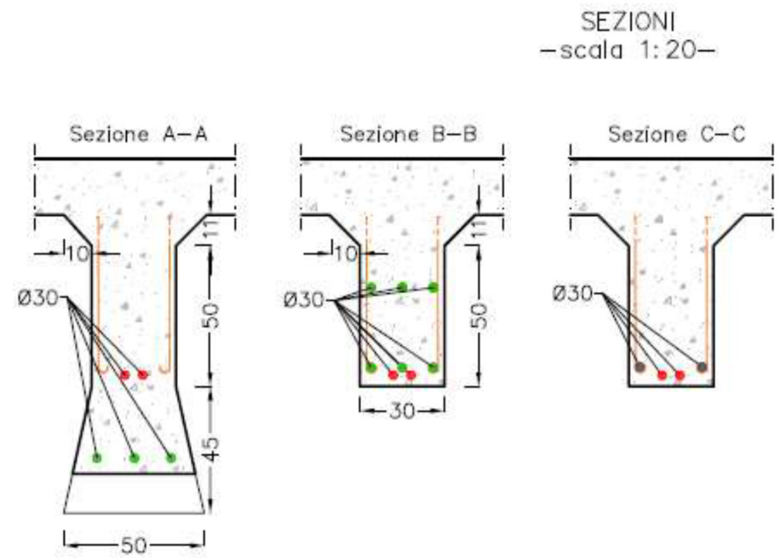
Direct Visual Inspection of the Conservation Status

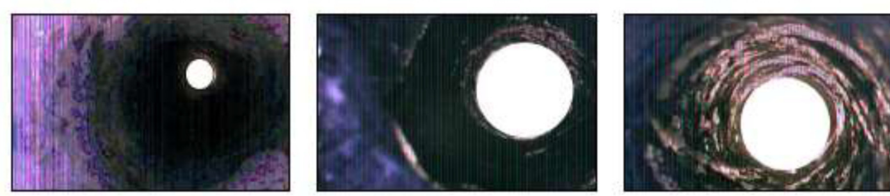


Visual survey: identification of corrosion of the steel elements and expulsion of the concrete cover

Electromagnetic Analysis and Endoscopic Survey







1st phase beams - Reinforced bars in the cross sections; endoscopic survey within little coring holes

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Determination of mechanical properties of concrete

ID	Elemento	Forza di estrazione [kN]	Resistenza calcestruzzo [MPa]
		F	Rc
5	Campata B – Pila Dx	19,62	18,44
7	Campata A – Pila Dx	36,26	34,08
8	Campata A - Impalcato	44,27	41,62
11	Campata C – Trave 5	26,51	24,92
12	Campata C – Trave 3	34,22	32,16
51	Campata A – Trave 3	25,59	24,06

Pull-Out (PE)

Ultrasonic (UT)

ID	Elemento	Metodo	Velocità [m/s]
U1	Campata B -Trave 5	Rifrazione	3938
U5	Campata B -Pila Sinistra orografica	Rifrazione	3967
U7	Campata A -Pila Sinistra orografica (fessura orizzontale)	Rifrazione	3049
U30	Campata A-Trave 5	Rifrazione	4599
U31	Campata A-Trave 5	Trasparenza	4829
U32	Campata A-Trave 3	Rifrazione	3501
U33	Campata A-Trave 5	Trasparenza	4411
U36	Campata C-Spalla Sinistra orografica (fessura orizzontale)	Rifrazione	3084
U37	Campata C-Trave 5	Rifrazione	4162
U38	Campata C-Trave 5	Trasparenza	4256
U39Bis	Campata C-Trave 4	Rifrazione	4353
U40	Campata C-Trave 4	Trasparenza	4160
U41	Campata B-Trave 5	Trasparenza	4190
U42	Campata A-Spalla Destra orografica	Rifrazione	3883
U43	Campata A-Trave 5	Rifrazione	4283
U44	Campata A-Trave 5	Trasparenza	4667
U45	Campata A-Trave 7	Rifrazione	4123
U46	Campata C-Trave 7	Rifrazione	4279
U51	Campata A - Pila Sinistra orografica	Rifrazione	3759

ID	Elemento	Rapporto L/d	Compressione	
			$f_{c,rott}$ [Mpa]	R_c [Mpa]
5A	Campata B Pila Dx	1.03	62,7	63,5
5B		1.03	56,2	56,9
6	Impalcato Campata B	1.02	43,2	40,1
7A	Campata A Pila Dx	1.03	68,8	69,6
7B		1.02	70,4	71,0
8	Impalcato Campata A	1.02	55,3	51,3
51	Campata A Trave 3	0.87	48,4	42,2

Compression Test

Carbonation (CH)

ID	Elemento	Carbonatazione carotaggio
		d_k [mm]
5	Campata B Pila Dx	12
6	Impalcato Campata B	20
7	Campata A Pila Dx	23
8	Impalcato Campata A	15
51	Campata A Trave 3	25

Materials Caracteristics

The Path of Knowledge in compliance with NTC 2018

1. Geometric survey;
2. Historical analysis of event and interventions undergone;
3. Materic survey, constructive survey and conservation stats;
4. Mechanical characterisation of the materials.

Geometria	Dettagli costruttivi	Proprietà dei materiali
Individuazione tipologia costruttiva. Rilievo travi e impalcato. Individuazione entità carichi gravanti su ogni elemento. Rilievo quadro fessurativo e degrado	Verifiche esaustive in situ.	Prove esaustive in situ. Prove di compressione su carote. Prove di trazione su spezzoni barre acciaio.

LC3

FC = 1.00

Mechanical Properties of Concrete

Materiale	E [MPa]	γ_m [kN/m^3]	R_{cm} [MPa]
Calcestruzzo impalcato*	10 600	25.1	44.5
*Calcestruzzo riferito alle travi di I fase ed alla soletta d'impalcato			

Mechanical Properties of Steel

Materiale	f_{ym} [MPa]	f_{um} [MPa]
Barre armatura lenta	242	345

Materiale	f_{um} [MPa]
Laminati in acciaio	418

Definition of Factor of Confidence (FC) and of the mechanical parameters of concrete and steel → STRUCTURAL ASSESSMENT

Structural Assessment - Conclusions

- The bridge **does not comply** the safety requirements defined by the Italian Structural Code for 2nd category bridges;
- **Shear problems** are due to the absence of specific rebars able to adequately support the tangential stresses;
- The safety requirements for **occasional loads** such as buses, trucks and articulated vehicles are not met;
- The activation of **fragile failure mechanisms** due to the shear can be foreseen.

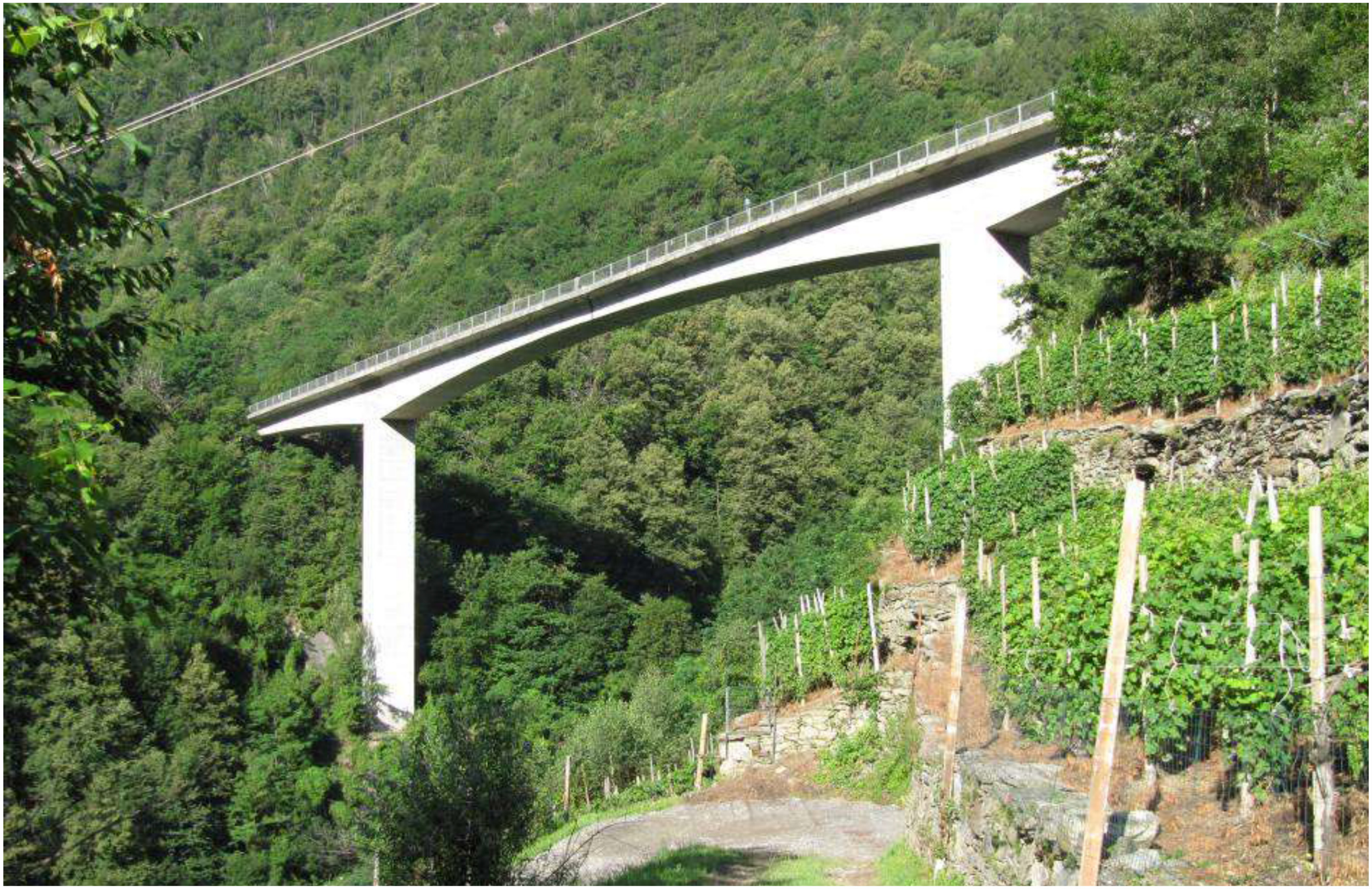
⇩

A TRANSIT LIMIT AT A MAXIMUM WEIGHT OF 35 kN WAS IMMEDIATELY SETTLED

⇩

A project for the Retrofitting of the structure was accordingly drawn up; works began on July 2019 and the bridge was re-opened on May 2020

Valdone Creek Bridge – Sondrio



Inspection and monitoring of Valdone Creek Bridge

Structural Monitoring

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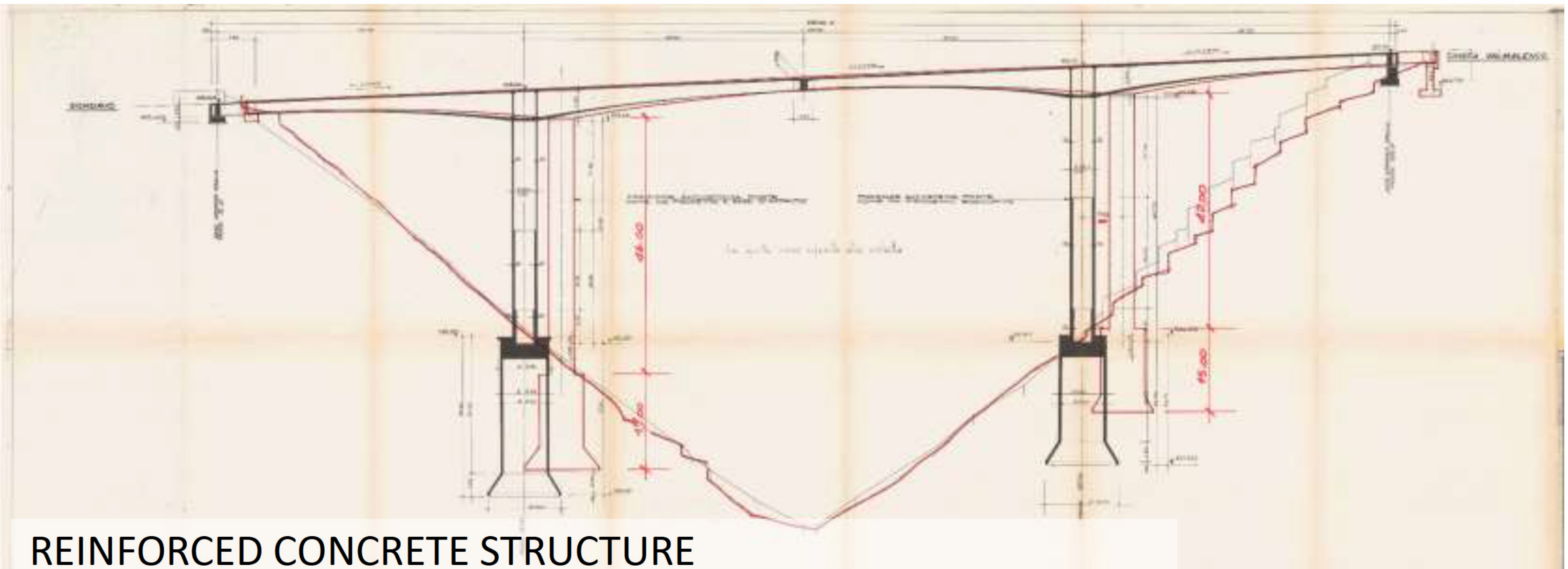
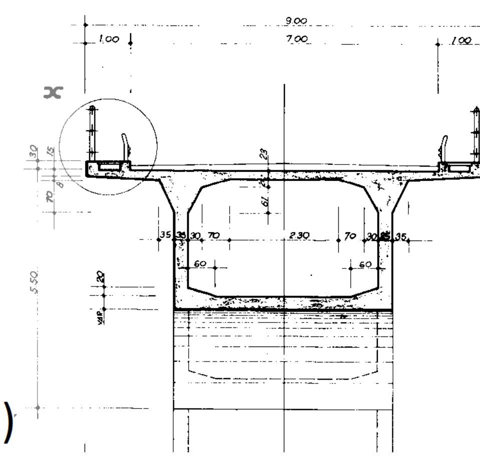
Valdone Creek Bridge – Sondrio



REINFORCED CONCRETE STRUCTURE

CONSTRUCTION METHOD: POST STRESSED ELEMENTS

- Design: ing. E. Segre ing. G. Pedrazzi (1979)
- Construction 1981-1982
- two lanes 3,5 m and sidewalk 1,0 m
- three spans 56+100+56 m (tot. 212 m)
- static scheme T T with shear joint in the middle span
- deep foundations ϕ 8,60 m (depth 17m; 15m)
- n°2 hollow piles 4,5x5,0 sp.0,20-0,65m (h 46m; 42m)
- hollow beam with variable depth (from 5,5 to 2,20 m)

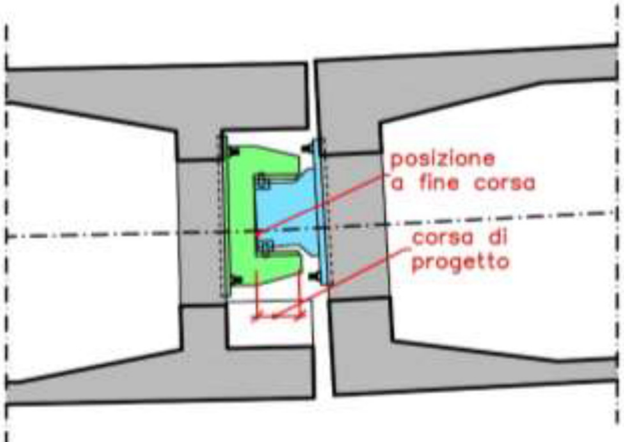


Technical features

Critical Issues

FUNCTIONAL ISSUES

- transversal dip on the road above the central link (13,8 cm)
- improvement of protection of safety fence



survey of the upstream side contact device (longitudinal section)

PROBLEMS: safety hazard and low comfort for transiting vehicles
dynamic stress on structures due to impact of mobile loads, social problem

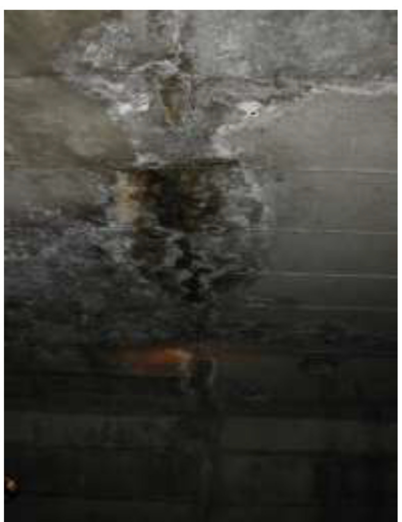
Critical Issues

STRUCTURAL FLAWS:
seized link in keystone

Joint upstream side

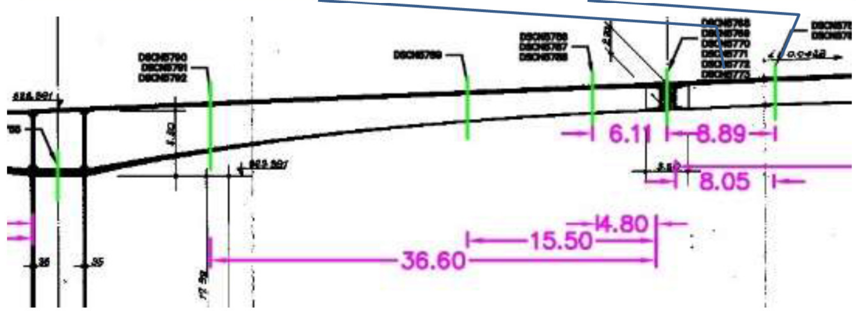
Joint downstream side

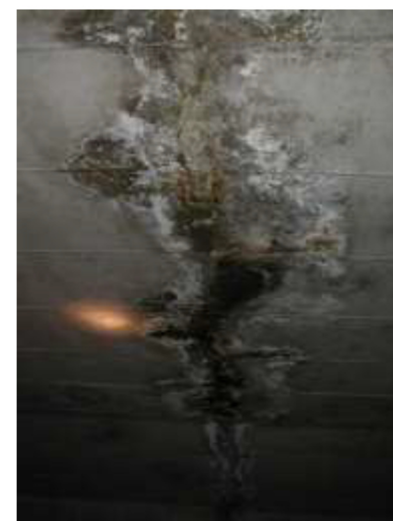
cracks at extrados of the deck along casting recovery lines



crack right side

crack left side





PROBLEMS: modification of constraint conditions, actual conditions different from design conditions, potential unexpected failure kinematisms

Structural Monitoring

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Monitoring System

- measurement of concrete deformation (4 transducers)
- measurement of crack opening variations (4 transducers)
- measurement of joint opening variations (8 transducers)

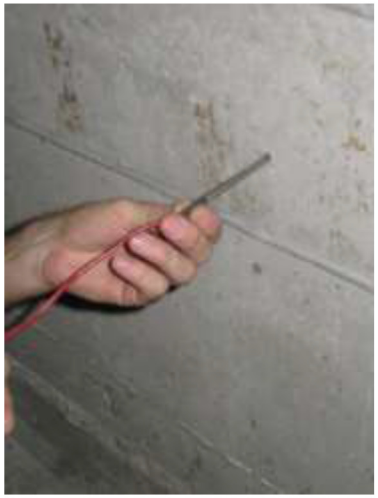
Potenziometric trasdurcers:

- range: 25/100 mm
- linearity: 0.25 % / 0.15% del f.s.
- repeatability: < 0.01 mm

CRACK & JOINTS MEASUREMENT

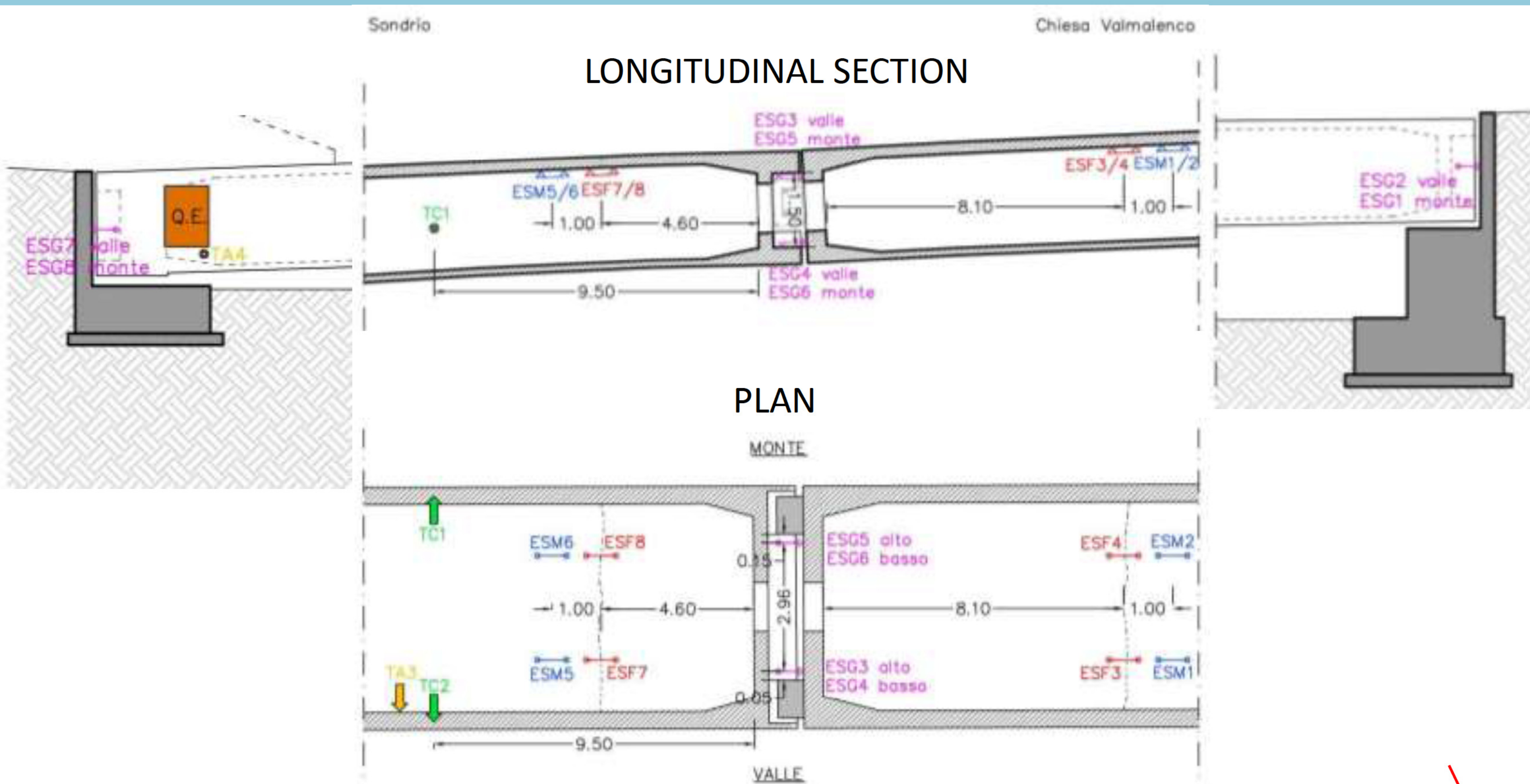
Monitoring System

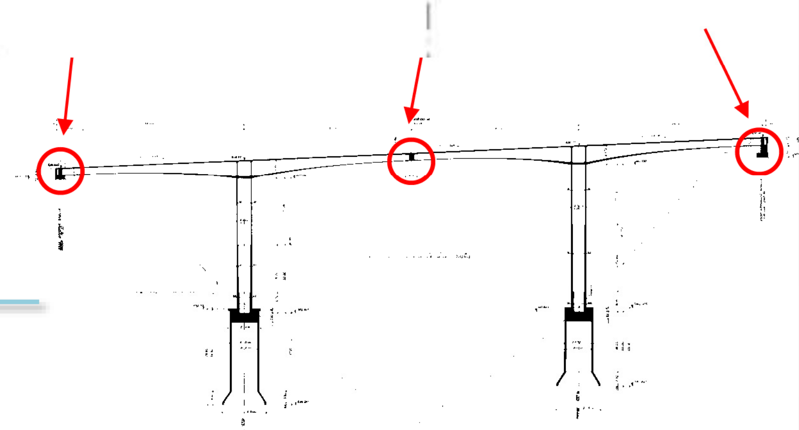
- measurement of concrete temperature in north and south wall (2 thermal probes)
- measurement of internal and external air temperature (2 thermal probes)
- removable unit to log data



TEMPERATURE MEASUREMENT

Monitoring System





LAY-OUT OF MONITORING SYSTEM

Structural Monitoring

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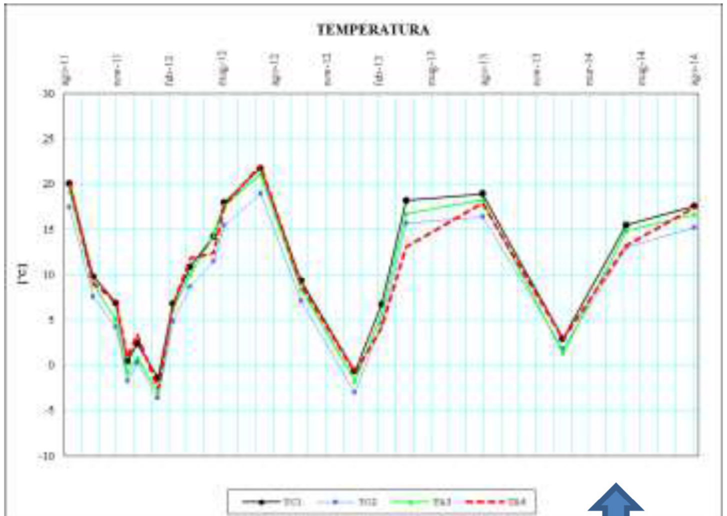
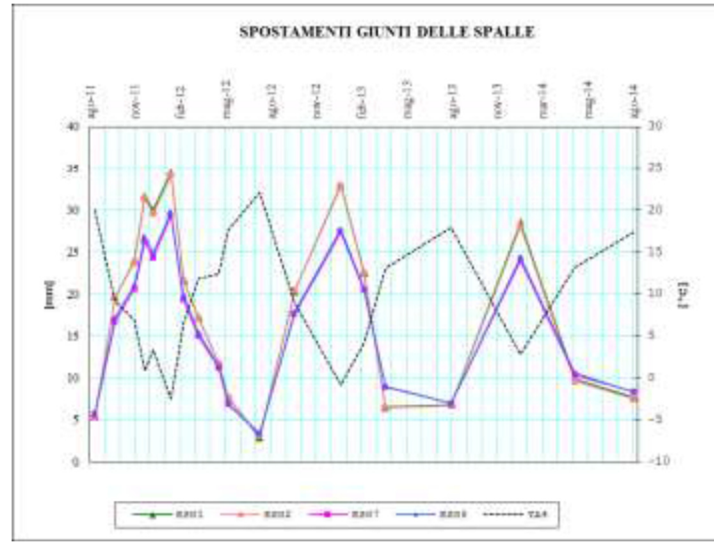
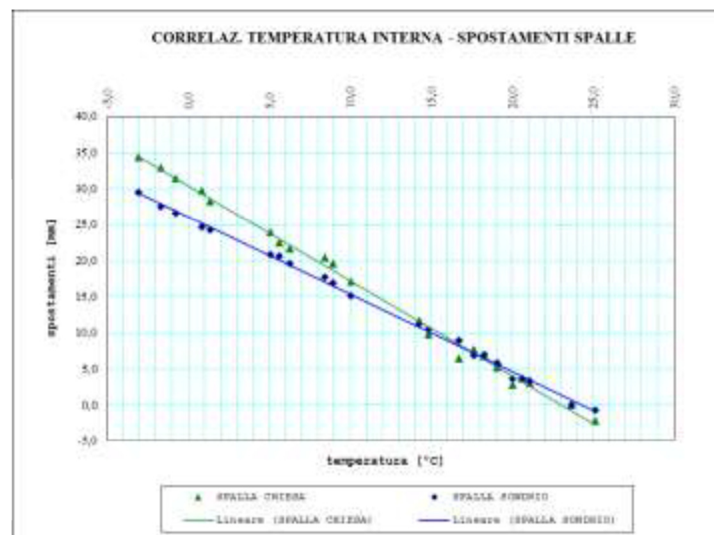
Diagrams – Temperature and Abutments Joints







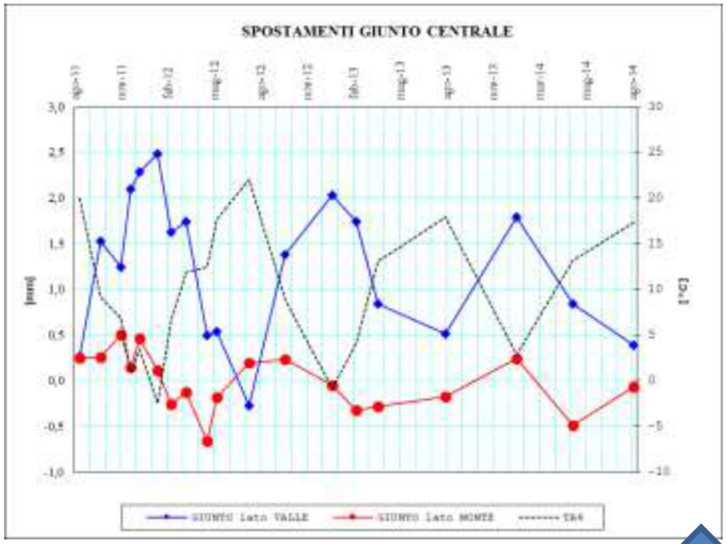
- thermal gradient
  Structure T vs External Air T = ± 5 °C
  Structure T vs Internal Air T = ± 2 °C

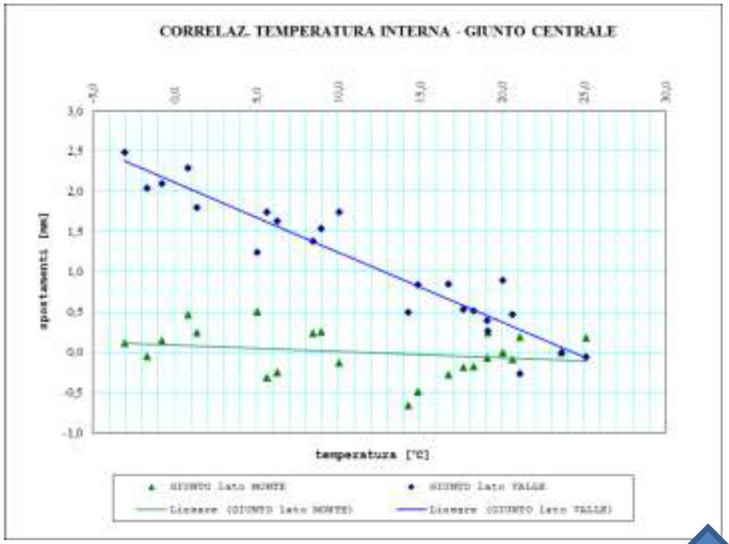
- average displacement of abutments joints are phased with each other and counter phased with the temperature:
- Coefficient of the Linear Regression is sound (R^2 = 0,996-0,997)
- as the temperature increases, the abutments joints closes, as expected on the basis of structural considerations.

Overall displacement of the bridge deck is therefore directly related to the thermal forcing without presenting drift phenomena over time

Structural Monitoring

Diagrams –Key Joints





- Upstream side key joint displacement is counter phased with the temperature as expected on the basis of structural considerations.
- Downstream side key joint displacement is irregular – upper and lower displacements are sometimes discordant

- The linear regression of displa-cement of upstream side key joint has a Coefficient of the Linear Regression (R_2 = 0,896) lower than the previous one
- For the downstream side key joint the quality of the regression is poor, so confirming the inadequacy of its structural behavior

overall calculated ΔL 59,23 mm ➔ overall measured ΔL = 65,48 mm ➔ rate 90,46%

The data confirms that the downstream key metal joint is at the end of its stroke and does not operate correctly neither with the reduction in length of the deck in correspondence with low winter temperatures.

Structural Monitoring

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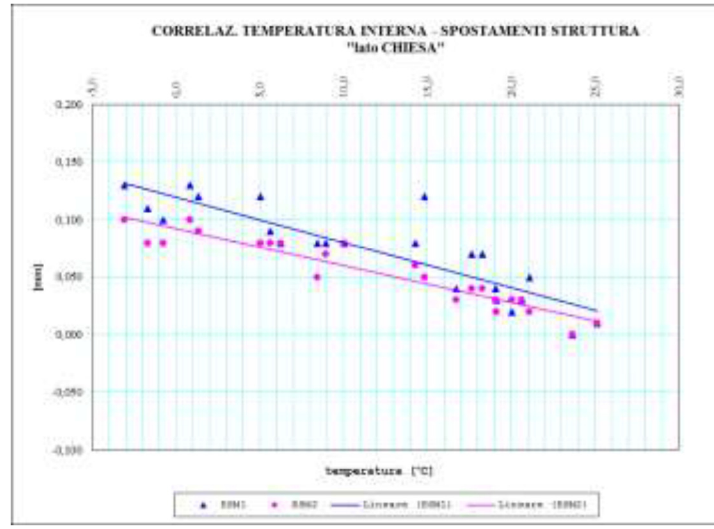
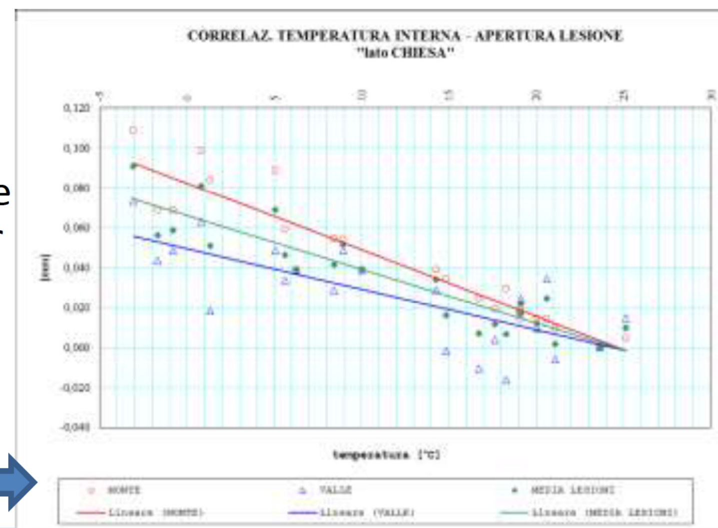
Diagrams – Cracks Behaviour





- concrete deformation is counter-phased with the temperature – good Correlation Coefficient
- crack opening variation is counter-phased with the temperature (max displ. 0,1-=,2 mm): as the temperature increases, there is in fact a greater hyperstatic compression (or less hyperstatic traction) and therefore a closure of the lesion
- linear regression between crack opening and thermal forcing is not really satisfactory in this last case ($R^2 = 0.560 \div 0.877$)

It is possible to suppose that the internal actions responsible for the openings are combined to other entities (e.g. upstream/downstream, top/bottom temperature gradient, wind) or that the phenomenon is not stable and has a drift.

Structural Monitoring

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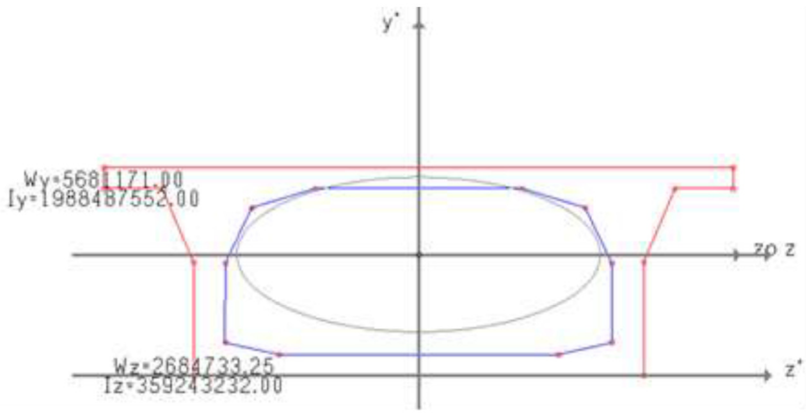
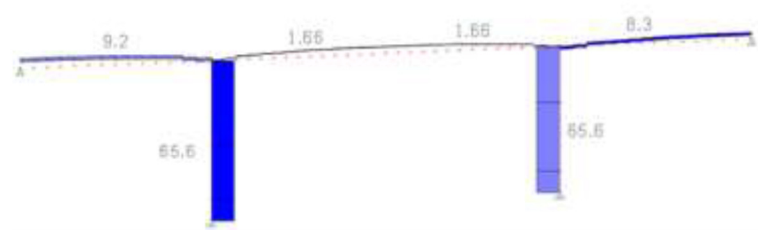
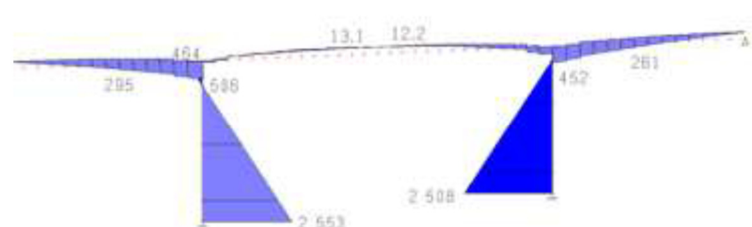
Structural 3D Model

- 3D view
- geometry [cm]
- thermal deformation (Δt +10°C) [m]
- diagrams A, S, M [kN, m]







FEED-BACK OF NUMERICAL MODEL WITH MONITORING RESULTS

Structural Monitoring

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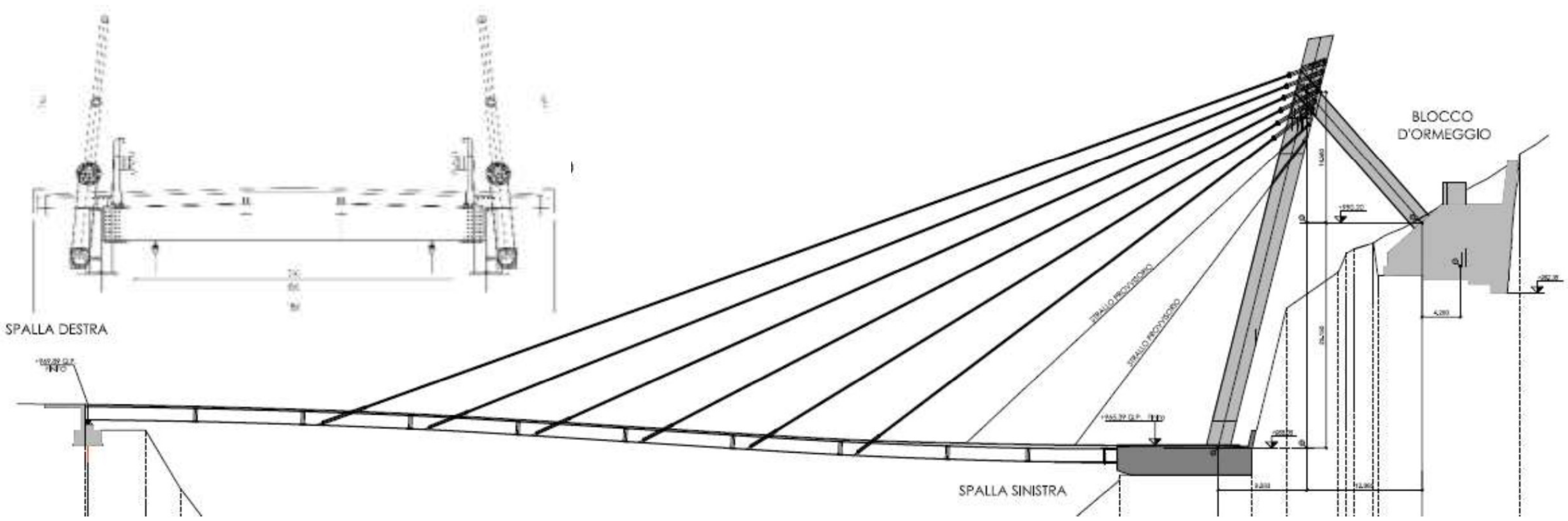
Pai Valley Bridge – Sondrio

LOAD TEST AND DYNAMIC CHARACTERISATION OF A NEW STRUCTURE

FOPPOLI MORETTA e ASSOCIATI
società di ingegneria

Ponte Sulla Val Di Pai – Sondrio



CABLE-STAYED BRIDGE

- Design and site management: prof. M. De Miranda, ing. M. Erba (2015)
- Construction 2016-2017
- two lanes 3,5 m and sidewalk 0,75 m
- Single span 118 m
- static scheme: steel-concrete deck supported by two group of cables converging into an antenna connected to the mooring block by means of steel girder
- direct foundation in R.C.
- antenna: twin rectangular pillars in R.C., λ shape, 46,1 m in height, tilted upstream
- steel girder TT-section

TECHNICAL CHARACTERISTICS

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Dynamic Characterisation

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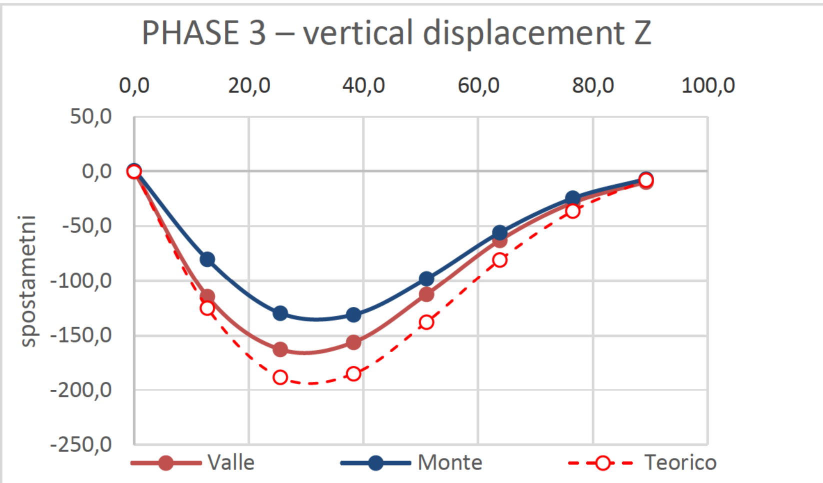
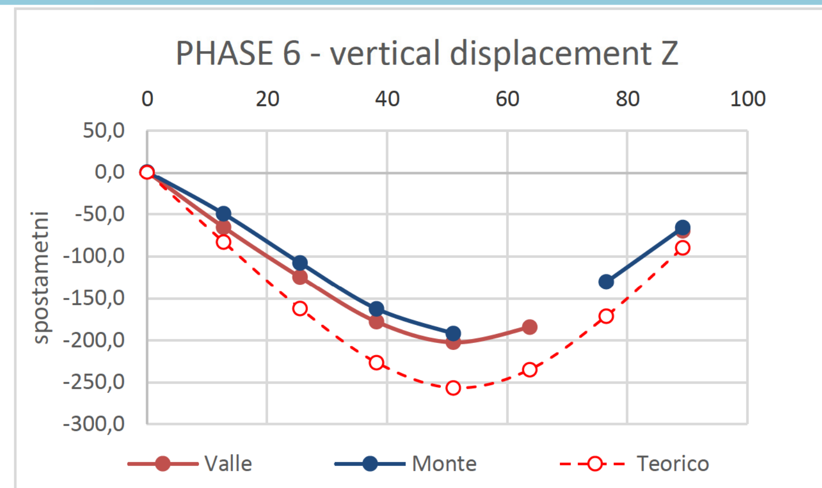
Static Load Test

STATIC LOAD TEST:
- Loading - trucks
- Measurement - topographic motorized total station – 16 measuring positions

DIFFERENT LOAD PATTERNS EACH APPLIED IN SEVERAL LOADING PHASES

Static Load Test





FASE e linea di misura	TEORICO spost.massimo (z) nodo	TEORICO spost.massimo (z) mm	SPERIMENTALE rilevato mm	SPERIMENTALE differenza mm	RAPPORTO spostam. sper./teor.	RAPPORTO medio di fase
2 valle	5	-134,00	-113,2	-20,80	84%	76%
2 monte	6	-53,70	-36,6	-17,10	68%	
3 valle	5	-188,30	-162,8	-25,50	86%	79%
3 monte	8	-184,90	-131	-53,90	71%	
5 valle	9	-183,60	-132,8	-50,80	72%	69%
5 monte	10	-72,50	-47,7	-24,80	66%	
6 valle	9	-256,90	-202,6	-54,30	79%	77%
6 monte	10	-256,90	-192	-64,90	75%	

Eng. Carlo Erba (construction manager) and Eng. Emanuele Moretta (test manager)

OUTPUT OF STATIC LOAD TEST

Dynamic Characterisation

Structural Model – Modal Analysis

MODO 1

MODO 2

MODO 3

MODO 4

MODO 5

MODO 6

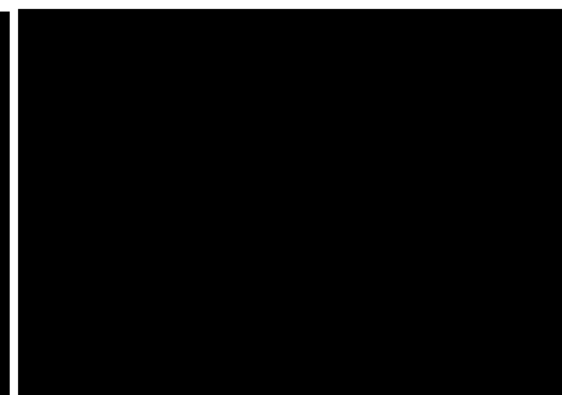
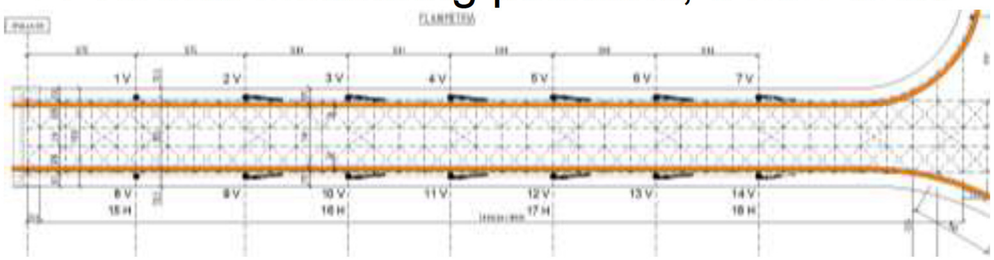


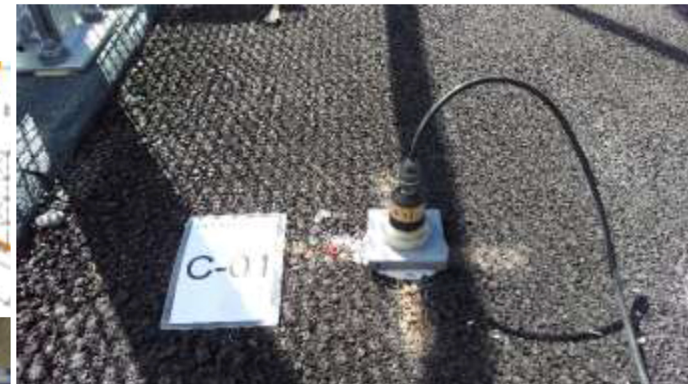
TABLE: Modal Participating Mass Ratios

OutputCase	StepType	StepNum	Period	UX	UY	UZ	SumUX	SumUY	SumUZ
MODALE	Mode	1	1,44	0,01%	0,00%	34,89%	0,01%	0,00%	34,89%
MODALE	Mode	2	1,05	0,00%	0,14%	0,10%	0,01%	0,14%	34,99%
MODALE	Mode	3	0,83	0,00%	46,35%	0,01%	0,01%	46,48%	35,00%
MODALE	Mode	4	0,8	0,02%	0,07%	4,23%	0,03%	46,55%	39,23%
MODALE	Mode	5	0,63	0,00%	1,88%	0,00%	0,03%	48,42%	39,23%
MODALE	Mode	6	0,59	0,00%	41,31%	0,00%	0,03%	89,74%	39,23%

Dynamic Characterisation

14 vertical measuring positions; 5 horizontal





- ➢ environmental noise
- ➢ forcing with motor vehicle

Dynamic Characterisation

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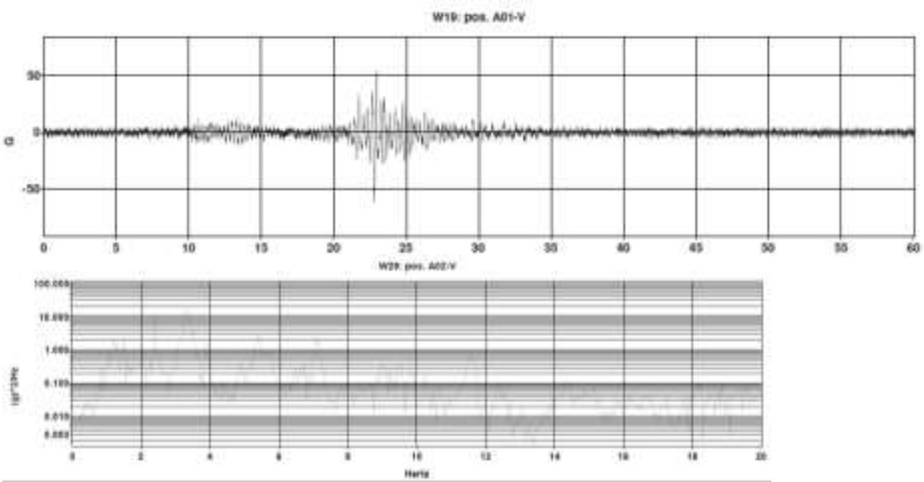
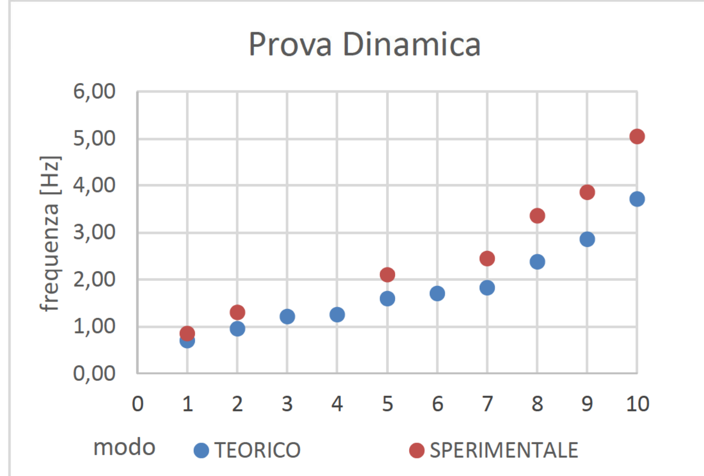
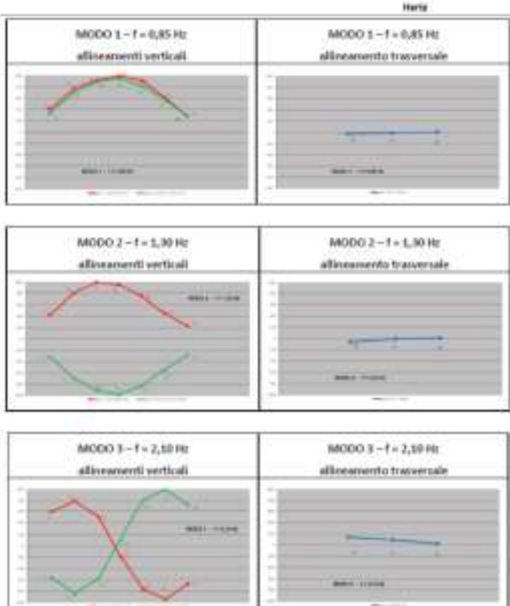
Dynamic Characterisation



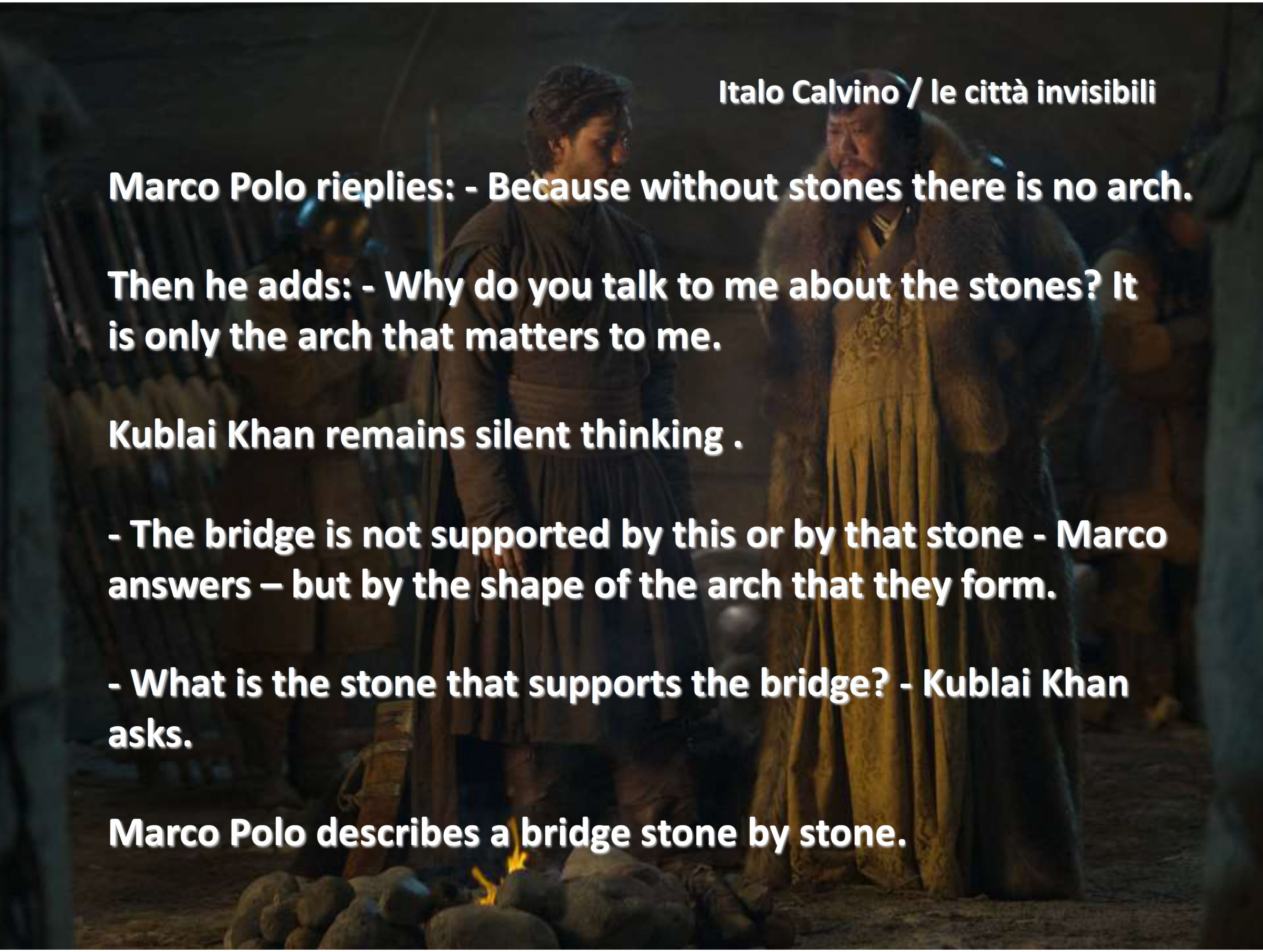




TEORICO			SPERIMENTALE			modo	rapporto
modo n°	periodo s	frequenza Hz	rilevato n°	periodo s	frequenza Hz	teorico corrisp.	frequenza teor./sper.
1	1,44	0,69	1	1,18	0,85	1	82%
2	1,05	0,95	2	0,77	1,30	2	73%
3	0,83	1,20	3	0,48	2,10	5	76%
4	0,80	1,25	4	0,41	2,45	7	74%
5	0,63	1,59	5	0,30	3,35	8	71%
6	0,59	1,69	6	0,26	3,85	9	74%
7	0,55	1,82	7	0,20	5,05	10	73%
8	0,42	2,38	8	0,19	5,40		
9	0,35	2,86	9	0,14	7,05		
10	0,27	3,70					

OUTPUT OF DYNAMIC TEST

Dynamic Characterisation


Italo Calvino / le città invisibili
Marco Polo rieplies: - Because without stones there is no arch.
Then he adds: - Why do you talk to me about the stones? It is only the arch that matters to me.
Kublai Khan remains silent thinking .
- The bridge is not supported by this or by that stone - Marco answers – but by the shape of the arch that they form.
- What is the stone that supports the bridge? - Kublai Khan asks.
Marco Polo describes a bridge stone by stone.

THANK YOU FOR YOUR ATTENTION

Bibliography

- *Linee Guida per la Classificazione e Gestione del Rischio, la Valutazione della Sicurezza ed il Monitoraggio dei Ponti Esistenti,* All. al parere C.S.L.P. n.88/2019, 17.04.2020;
- CNR-DT 213/2015 *Istruzioni per la Valutazione della Sicurezza Strutturale di Ponti Stradali in Muratura*, 16.10.2015
- UNI TR 11634:2016 *Linee Guida per il Monitoraggio Strutturale*;
- UNI 10985.2002 *Vibrazioni su Ponti e Vidotti: Linee guida per l'esecuzione di prove e rilievi dinamici*;
- Heyman J., *The masonry arch*, Ellis Horwood Ltd, Chichester, 1982;
- Foppoli D., *From Palladio to Reinforced Concrete – NDT applied to the old and new Bridge of Bassano del Grappa*, Proceedings of International Symposium on Non-Destructive Testing in Civil Engineering (NDT-CE 2015), Berlino, 2015, pp. 378-387 The e-Journal of Nondestructive Testing;
- Del Bianco G., Foppoli D., Felicetti R., *Efficacia delle Prove Non Distruttive per l'Analisi di Ponti in C.A.: Sperimentazione in Sito Presso il Ponte di Stazzona (SO)*, Atti del 18° congresso nazionale sulle prove non distruttive monitoraggio diagnostica, Milano 2019;

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Bibliography

THANK YOU FOR YOUR ATTENTION

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Bibliography

- D.M. 17 gennaio 2018 *"Aggiornamento delle «Norme tecniche per le costruzioni»"*
- Circolare 21 gennaio 2019 n° 7 *"Istruzioni per l'applicazione dell'aggiornamento delle «Norme tecniche per le costruzioni» di cui al decreto ministeriale 17 gennaio 2018"*
- D.P.C.M. 09/02/2011 *"Valutazione e riduzione del rischio sismico del patrimonio culturale con riferimento alle Norme tecniche per le costruzioni di cui al decreto del Ministero delle infrastrutture e dei trasporti del 14 gennaio 2008"*
- *UNI EN ISO 9712:2012 " Qualificazione e certificazione del personale addetto alle prone non distruttive"*
- *UNI/PdR 56:2019 " Certificazione del personale tecnico addetto alle prove non distruttive nel campo dell'ingegneria civile"*
- Circolare 03 dicembre 2019, n.633/STC *" Criteri per il rilascio dell'autorizzazione ai Laboratori per prove e controlli sui materiali da costruzione su strutture e costruzioni esistenti di cui all'art. 59, comma 2, del D.P.R. n. 380/2001"*

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