History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

The role of construction history in safety assessments: A case study of reinforced concrete "Gerber" bridges in Italy

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ABSTRACT: In Italy, in 2016, the collapse of the Annone Brianza overpass revealed an inherent vulnerability of half-joint reinforced concrete bridges. On 6 May 2020 the National Ministry of Infrastructures and Transport approved the new "Guidelines for risk management, safety assessment and monitoring of existing bridges": the document list Gerber bridges as critical structures and highlight the importance of "an accurate investigation of the technical and administrative documentation of the existing bridges". In this paper, Italian case studies on Gerber reinforced concrete bridges are traced from the very first use of this bridge typology to the analysis of current deterioration phenomena occurring in the existing structures. The reported case studies highlight the crucial role of construction history investigation in the preservation of infrastructural heritage.

1 INTRODUCTION

In Italy in 2016 the collapse of the Annone Brianza overpass showed an inherent vulnerability of half-joint reinforced concrete bridges. On 6 May 2020 the National Ministry of Infrastructures and Transport approved the new "Guidelines for risk management, safety assessment and monitoring of existing bridges" (Italian National Ministry of Infrastructures and Transport, 2020). In addition to the procedures and tools corresponding to the general purposes of this document, it identifies critical issues related to different bridge structure typologies. In particular, it provided a detailed classification of "critical elements" (i.e. those bridge parts that are particularly subject to degradation phenomena and whose possible malfunctions can significantly affect the overall structural behaviour of the structure). These elements include Gerber girders in reinforced concrete bridges, requiring a mandatory and urgent general safety assessment of the structure of Gerber bridges. The topic, underlined by the Italian code, is addressed by recent international research (Desnerck et al. 2018).

The internal steel reinforcement layouts of the Gerber joints do not comply with current design practice and codes; moreover, Gerber joints are difficult to inspect and, due to their shape, they are particularly subject to water infiltration. The Guidelines highlight the importance of "an accurate investigation of the technical and administrative documentation of the existing bridges" in order to acquire the knowledge necessary for any conservation project regarding both the chosen design and construction procedures and the transformations of works during their useful life. The cited document highlights both the importance of the role of the historical research in the monitoring and preservation of existing bridges emerges and the urgent need to focus analysis on the remaining reinforced concrete Gerber bridges on Italian territory.

This paper presents the results of the construction history-based survey addressing the safety assessment of existing Gerber bridges.

In the disciplinary framework of enhancing cultural values of infrastructural heritage in maintenance operations (Pelke & Brühwiler 2017), the analysis focuses on the introduction and diffusion of this structural typology in Italy and on the listing and classification of existing Gerber bridges; then, recurrent degradation phenomena are identified and discussed through literature dedicated to maintenance interventions. The case studies of the Magliana bridge and the Marconi bridge on the Tiber in Rome are discussed in detail.

2 FIRST APPLICATION AND DEVELOPMENT OF THE STATIC SCHEME

The progressive introduction of the static scheme of the cantilever beam (cantilever bridges) was developed with the intention of transforming the continuous beam on several supports into a statically determined system through the introduction of a strictly indispensable number of hinges. The solution permitted simplification of calculations, optimization of stresses on the structural elements and compensation of vertical failure whilst developing construction processes without falsework.

The scheme of the cantilever bridge, which had been systematically developed in the 19th century, with the rise of iron and steel as construction materials, dates

 DOI 10.1201/9781003173359-54

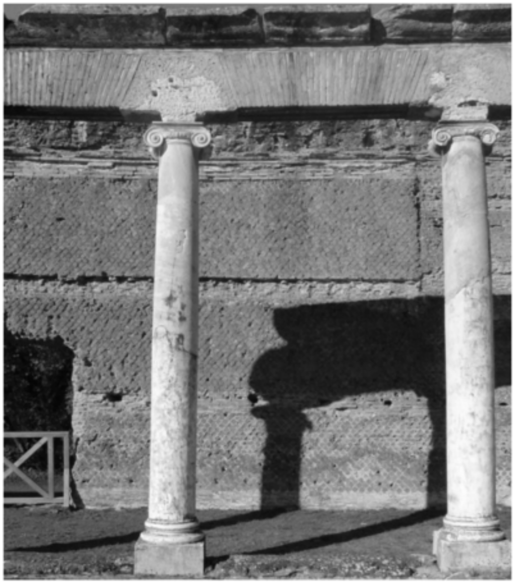

Figure 1. Maritime Theatre at Villa Adriana (courtesy of G. Cinque).

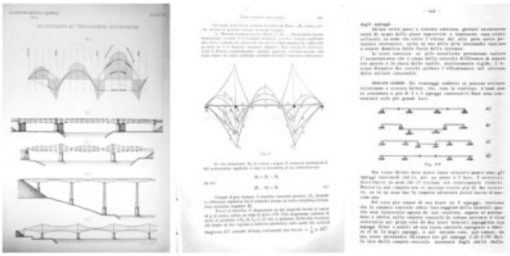

Figure 2. Gerber patent (1866) and Italian bridge design manuals.

back to ancient times. Bridges that follow the cantilever principle have been used in tropical countries since prehistoric times (Steimann 2011). The lintel with disconnections is also witnessed in Greek and Roman architecture, for example in the forum of Pompei or in the Maritime Theatre at Villa Adriana (Di Pasquale 1996) (Figure 1), where the architraves, consisting of a single wedge-cut or brick element, were supported by large stone cantilever capitals; this rather empirical adopted solution was probably due to the need to avoid cracking in the architrave following subsidence of the foundations, as well as to facilitate the construction procedure of these structures by breaking the architrave into several blocks. As noted in the literature (Wilcox 1898, Mehrtens 1900, Panetti 1900, Timoshenko 1983, Steimann 2011), the development and systematization of this bridge typology took place in the second half of the 19th century.

In 1811, Thomas Pope in his "Treatise on Bridge Architecture" had already proposed the adoption of a hinge-cut scheme for a bridge over the Hudson and, in 1833, the construction of a cantilever-type bridge in Paterson (New Jersey) by M. A. Canfield was attested in (Wilcox 1898). Then, between the 1840s and the 1860s several engineers (Fairbairn, Clark, Ritter, Culmann) tried their hand at the subject, obtaining substantial theoretical and design solutions. The scheme, already known as a cantilever bridge, *portes à faux* in French, took the name "Gerber girders" from the German engineer Heinrich Gerber (1832–1912), in the 1860s. Although it was not always mentioned in the treatises of the time (Wilcox 1898), Gerber was nonetheless recognized as the author of the first bridges built with this static scheme: the bridge over the Main in Hassfurt (1867) – in which the central span beam was placed on the two lateral cantilevered beams by means of hinge joints – and the Sofia Bridge in Bamberg (1867). The system (Figure 2) was patented in 1866 (Gerber 1866).

In 1877, Charles Shaler Smith (1836–1886) built the Kentucky viaduct, the first large-span cantilever bridge in America: in this structure and in the subsequent Niagara viaduct built in 1883 by Charles Conrad Schneider (1843–1916) the assembly of the beam was carried out without fixed scaffolding. The names of the two American viaducts identified the types that classify the construction procedures without falsework which were later adopted for the construction of structures of this type. In 1889, the opening of the Forth Bridge on the Firth of Forth, by John Fowler (1817–1898) and Benjamin Baker (1840–1907), marked the end of the experimental period of this structural typology and its definitive systematization for large span metal truss bridges.

At the end of the century the Gerber bridge developed in numerous schemes, "some with the appearance of arched trusses, others with that of suspended bridges, to form a multiform family, which retains this very distinctive character: the use of trusses consisting of trunks protruding cantilevered from the supports" (Panetti 1900).

3 INTRODUCTION IN ITALY

In Italy, the Gerber bridge entered engineering practice late; this was testified to by the well-known and widespread *Manual of the Engineer* (Colombo 1877) edited by engineer Giuseppe Colombo (1836–1921) from the first edition of 1877 to 1917, the year in which it was entrusted to other colleagues (Azimonti et al. 1919); still, in the 1926 edition of this Manual, the Gerber beam was not included in the chapter dedicated to structural schemes.

In 1886, Camillo Guidi (1853–1941), in his "Lectures on Graphic Statics", mentioned the "continuous beam with hinges" (Guidi 1887). In 1904, Guidi dedicated a paragraph of his lectures on "Bridge Theory" to the Gerber girder, highlighting the possibility of obtaining with this scheme the same economic convenience of the continuous beam (Guidi 1905). In 1905, Antonio F. Jorini (1853–1931) dedicated chapter VI

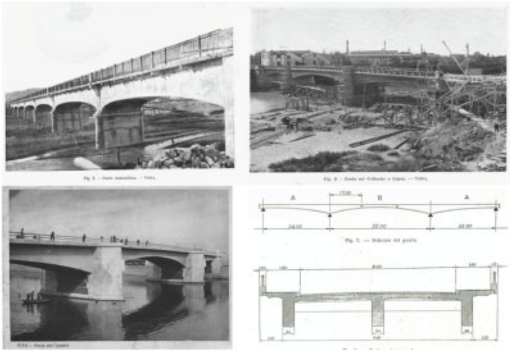

Figure 3. Gerber bridges in Italy, 1932–36 (Ferrobeton 1933–48).

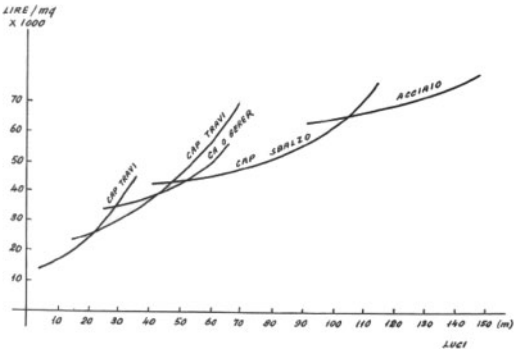

Figure 4. Diagram showing the application of Gerber scheme to cast in situ ordinary reinforced concrete bridges (Rinaldi, 1974).

of his manual "Theory and Practice of Bridge Construction" to "continuous beams with hinges". In the manual, where the calculation of a three-span beam, with two hinges in the central span, was illustrated, the convenience of introducing hinges into the continuous beam schemes was defined because "with the choice of the number of hinges, and their position in the continuous beam, it is possible to obtain a statically determined structure, in which the internal stresses are independent of the vertical movements of the supports" (Jorini 1905). The author also pointed out "the possibility of mounting the trusses with false systems, without the help of service scaffolding" (Jorini 1905).

In Italy, given the limited development of large-span metal viaducts at the end of the 19th century (Nascè 1982) when compared to other industrialized countries, the spread of Gerber-type bridges was directly due to the introduction of reinforced concrete.

In 1930, Giuseppe Albenga (1882–1957) in chapter V of his "*Lezioni di Ponti*" (Lessons on Bridges) reported the convenience of adopting hinged patterns in continuous reinforced concrete trusses. "Introducing as many hinges as there are superabundant support conditions", with the warning "not to drop more than two hinges between two consecutive supports and not to have more than two supports between two successive hinges" (Albenga 1930). In the Manual, there are no examples of Gerber bridges in reinforced concrete built in Italy, but the "very frequent use in reclamation areas" of cantilevered beams is mentioned, in particular for "three-span schemes characterized by two intermediate piers and small cantilevered bank spans" (Albenga 1930). On the other hand, not even the two editions, published in 1924 and 1932 respectively, of the "Ponti in cemento armato Italiani" manual by G. Santarella and E. Miozzi, reported built examples of Gerber bridges (Santarella & Miozzi 1924, 1932). In 1933, the catalogue of Ferrobeton – at the time one of the main Italian companies active in the sector of reinforced concrete construction – reported the construction of the following bridges known as Gerber-type girders: the bridge over the Amendolea river in Calabria; the bridge over the Leira torrent in Voltri and the bridge over the Volturno in Capua (Figure 3) designed by the engineer Giulio Krall (1901–71).

Only in 1953, when Albenga published an updated edition of his "*Lezioni di Ponti*" (Albenga 1953) reporting greater dissemination of the typology also for large-span bridges, were examples of reinforced concrete Gerber bridges built in Italy cited: the bridge of the Empire over the Arno in Pisa, designed by Krall (1901–71) and built by Ferrobeton himself in 1936 (Krall 1937); and the Belvedere overpass in Vercelli, designed by Antonio Giberti (1883–1963).

The diffusion of the typology was also testified by the updated edition of the same Albenga manual, dedicated instead to theory (Albenga 1958): the third chapter was entitled "the simple beam and the Gerber beam", testifying the dissemination of the latter structural typology for reinforced concrete buildings.

In 1974, Giuseppe Rinaldi in his manual *La costruzione dei ponti* (Rinaldi 1974) reported a series of economic considerations on the use of different types of reinforced concrete bridges, in the light of the development of the freeway network (1956–73): even if "recently Gerber type bridges have been carried out with positive results", there was an overall decrease in the application of this static scheme (Figure 4). The Gerber girder, considered more suitable for casting, was regarded as ideal for spans within 65 metres and "limited for higher spans by the costs of centering" (Rinaldi 1974).

4 FOR A CENSUS OF THE EXISTING GERBER BRIDGES IN ITALY

On Italian road bridges, the existing reinforced concrete Gerber bridges were mostly built between the 1930s, as in the rest of Europe (Legat et al. 1948), and the 1970s. In Italy, the static scheme spread first in the autarchic period (1936–40), as the most suitable for material savings according to the easy calculation, and later during the reconstruction after WWII and the

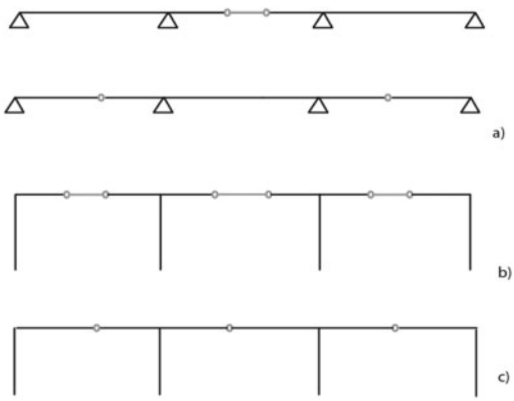

Figure 5. Sketches of the major static schemes adopted for Gerber bridges built in Italy (the authors, 2020).

Figure 6. Colle Isarco viaduct, 1962 (courtesy of the Fondazione Gentilini); Velino viaduct, 1963 (Zorzi 1963); Niagara viaduct, 1895.

development of the national road network of the 1950s and 1960s.

Italian Gerber bridges feature a remarkable morphological variety and can be classified according to the three static schemes reported in Figure 5. The first scheme represents an articulated girder with multiple supports: considering the general principle that a Gerber girder must have as many hinges as there are intermediate supports, an articulated girder is placed between the two overhangs (internal hinge – Niagara Type) or between the central piers and the abutments (external hinge – Kentucky type) (Figure 5a). The second diagram describes a sequence of cantilevered piers and suspended span (Figure 5b). The third scheme describes a sequence of multiple statically determinate frames (Figure 5c).

The first scheme (Figure 5a), was widely adopted for the construction of ordinary roads and urban bridges built mainly between the 1930s and the 1950s with exclusive use of reinforced concrete cast in situ. Some significant examples were among the first bridges featuring this static scheme: the aforementioned bridge over the Arno river in Pisa, rebuilt by the same construction company Ferrobeton in 1947; the Magliana bridge over the river Tiber in Rome (1938); and the Marconi bridge over the river Tiber in Rome (1939). The second scheme (Figure 5b) was mainly used for the construction of highway bridges built in the 1960s. Also taking advantage of the more widespread industrialization of the building sector and of the pre-stressing technique in reinforced concrete construction, these bridges feature prefabricated suspended spans and cantilevered piers cast in situ. Noteworthy examples of this typology are: both the Rio Sanda bridge over the Teiro bridge on the Voltri-Albissola highway (1955) and the Settefonti viaduct of the Autostrada del Sole highway (1959), entirely featuring the use of Innocenti scaffoldings supporting the cast; and the Colle Isarco viaduct for the Brennero highway (1962), depicted in Figure 5 and instead characterized by the combined use of the cantilever construction technique, pre-stressing systems and prefabricated elements (Gentilini 1970).

On developing the same optimization goal of the execution of avoiding falsework, the third scheme (Figure 5c) representing a sequence of multiple statically determinate frames was in the viaducts designed by engineer Silvano Zorzi (1921–94) (Iori & Capurso 2019). Noteworthy examples of these are the Stura viaduct of the Turin-Savona highway (1968–70) (Zorzi 1970) and the Poala viaduct at Veglio Mosso (1972–73) (Zorzi 1974). While it is true that, from the construction site point of view, the adoption of this static scheme resulted once more in the effectiveness of the Gerber bridge that had driven its rapid evolution in the 19th century (Figure 6), on the structural level today this scheme proves to be completely devoid of the recent concept of "structural strength" (NTC 2018 2.1).

In addition to the types mentioned, Gerber girders were even adopted for special works, such as the bridges designed by the engineer Riccardo Morandi (1902–89). In his research on "balanced structural systems", Morandi relied on this bridge typology several times. It was used for both the project of articulated girders on multiple supports – as in the case of the Quercia-Setta viaduct on the Autostrada del Sole (1957–58), which also featured prefabrication of the elements forming the suspended span (Morandi 1967) – and the conception of special schemes, such as cable-stayed bridges (i.e. the existing Carpineto viaduct (1976) on the Basentana road (Morandi 1977)).

4.1 *Common aging and deterioration phenomena*

Evident signs of deterioration emerged quite early compared to the time of construction of reinforced concrete bridges and have amplified notably over time. In addition to these evident aging-related causes, the arrangement of the secondary reinforcements in the cantilever extremes, designed according to the calculation code of the time period (1930s–1960s), were

Figure 7. Detail of deterioration in supporting device and reinforced concrete half-joint (courtesy of Rome Municipal Archive, Bridge Office and Micheloni et al. 2018).

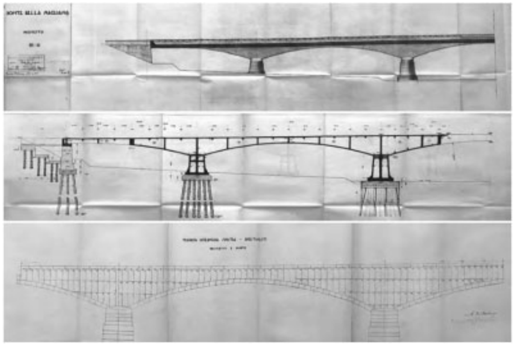

Figure 8. Magliana bridge, 1939 (courtesy of Rome State Archive).

judged "incorrect" from 1992 (CNR, 1992, 10037/86) onwards, when the STM was ruled under the Eurocode 2 (EN 1992-1-2:2004), this arrangement is, thus, considered as a crucial cause of structural vulnerability of for existing Gerber bridges (Desnerck 2018).

The vulnerability of Gerber schemes has numerous aging time-related causes. Most of them are common issues for reinforced concrete structures, such as the natural aging of the materials (with particular regard to the joints), the phenomena of carbonation of concrete with material detachments, the onset of oxidative phenomena in the steel and the consequent formation of cracking states, and the change in loading conditions. Others are, instead, specifically related to the Gerber bridge half-joint shape: leakage of water through the joint causing deterioration of the concrete and corrosion of the reinforcing steel and errors during execution, such as misalignment between the cantilever extremes, are very common (Figure 7). Furthermore, even half-joint elements, placed on the protruding nib of the structural element, are particularly subject to premature aging, causing dangerous discontinuities in the road surface that, due to even contained disruption, alter driving comfort. In the context of this joint deterioration phenomena, it is necessary to understand how Gerber half-joints were built in Italy and whether it is possible to trace the adoption of some recurrent details or solutions. In executive practice, indeed, the use of metal devices (hinges, pendulums, rollers) derived from metallic construction practices was combined with the extensive use of lead sheets, steel plates and the design of special reinforced concrete pendulums devices (Cestelli Guidi 1949, Malerba 2018).

5 TWO BRIDGES IN ROME

Insight into the two bridges located in Rome, which were among the first Italian examples of Gerber bridges in reinforced concrete proved useful to illustrate specific deterioration phenomena in relation with the construction history of the two bridges. The two case studies feature many common aspects: both bridges were designed according to urban planning of the Universal Exhibition of 1942 (E42), conceived during the fascist regime and not opened due to World War II. The two structures also adopted a similar static scheme of suspended span on a half-joint. In both case the decks feature a movable part in the central span enabling navigation of the river. Furthermore, the two bridges have a very similar history: the late 1930s design and construction sites opened in 1938 and suddenly interrupted by WWII, closing only in the mid-1950s. The deterioration phenomena, observed in the two bridges, can be attributed to different causes, mostly linked by the general lack of both adequate knowledge of the two structures and a maintenance programme.

5.1 *The Magliana bridge*

The Magliana bridge was designed by engineer Carlo Cestelli Guidi and the architect Cesare Valle between 1937 and 1940 in the framework of the urban planning for the E42. Unlike the first design hypothesis which envisaged a five-span bridge, the final project, approved after the opening of the construction, was a 255.80-meter-long structure, with seven spans, featuring a curved intrados profile of the girders and 12-meter-long movable steel girders placed in the central span (Figure 8). After WWII, during which the bridge was seriously damaged, works restarted in 1946 and the bridge was, finally, completed and load-tested in 1950. The deck, supported by box-shaped piers, consists of five longitudinal ribs stiffened transversely and completed with a horizontal slab. The two lateral spans feature Gerber half-joints (Figure 8). The fixed joint equipment was made of lead plates, the rollers with metallic devices, while the pendulums were built in reinforced concrete. A travertine plate coating features in all the structure, except the girder intrados.

In 1976, after 26 service years, according to evident signs of deterioration, the structure was subjected to an investigation. Despite the change in the hydraulic

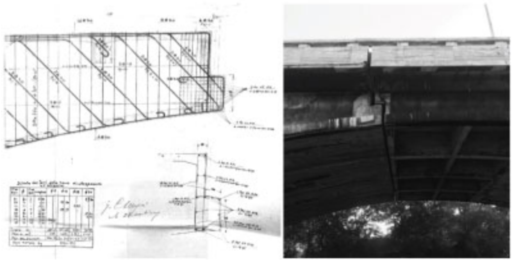

Figure 9. Magliana bridge reinforcements details, 1939 (courtesy of Rome State Archive) and picture of the half-joint, 2020.

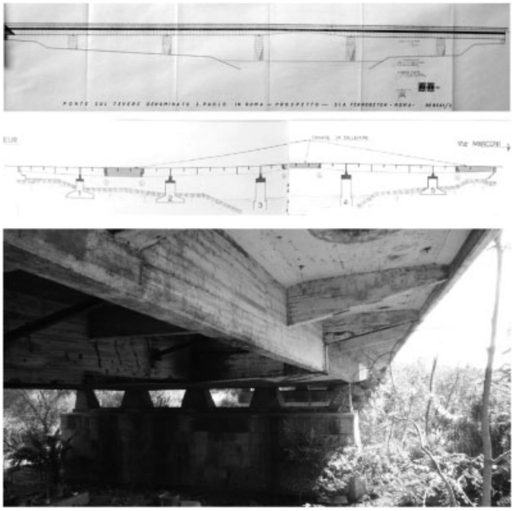

Figure 10. Marconi bridge, 1950–74 (courtesy of Rome State Archive).

regime of the river with respect to the project hypothesis, the consequent lowering of the piers was considered negligible and the bridge structure appeared overall to be in a good general state of conservation. The attention of the engineers entrusted with the investigations was focused on Gerber half-joint: the local presence of cracks and a "macroscopic expansion between the faces of the joints and the fully visible deterioration of the metallic joint equipment" were reported as major effects of the aging of the structure. In particular, the metal cylinders of the rollers were highly deformed, corroded and blocked by the presence of other materials. The joint equipment was, thus, replaced and the central opening deck was covered with a reinforced concrete slab, removing its original function. Similar problems arose 40 years later. Further investigations were carried out in the years 2017–18. In the global decay of the structure and its travertine coating, the Gerber half-joint appeared to be severely damaged: the novel shaped lead plates had not contained displacement between the joints within the correct limits; consequently, the damage was advanced, albeit to a lesser extent but such as to make it significant. Furthermore, the mortar of the support appeared disjointed so as to move the support axis and deform the support itself.

In both of the two maintenance interventions, no historical investigation regarding the construction material and details or calculation reports showing the rebar arrangement and dimensioning (Figure 9) were taken into consideration in the maintenance design as comparative terms for the in-situ surveys. The main cause of the damage was identified in the inefficiency of the rainwater run-off system and in the continuous water leakage through the joint.

5.2 *The Marconi bridge*

Several reasons can be found for the damage of the G. Marconi Gerber bridge over the river Tiber in Rome, designed by the engineers Guido Viola (1895–1984) and architect Giuseppe Samonà (1898–1983).

Construction started in 1938 after the competitive tender was awarded to the Vitali company. Work was interrupted in 1941 when only the foundations and the piers had been built. The construction of the deck started in 1950 and was completed only in 1955 by the Ferrobeton company and engineer Krall. The bridge, originally designed as a five-span girder bridge, was transformed into a six-span structure during the construction phase: the deck, 32 metres wide, rests on five piers, two of them in the riverbed, and on two terminal abutments, for a total length of 228 metres. The second bay, the fourth and the sixth feature half-joint suspended beams. The deck structure consisted of five longitudinal ribs strengthen by a cross element and lower and upper slabs. The three suspended beams are 18 metres long consisting of five longitudinal ribs strengthen by a cross element and an upper slab (Figure 10). Supports were designed as high-strength concrete prisms fitted at the tops with metal plates in cylindrical profile (Figure 11).

Since the end of the 1960s, the bridge has been subjected to periodic monitoring due to "anomalous signs of deterioration of the structure in correspondence of the half-joint beams" (Leone, 1977). Initially attributed to the malfunctioning of the road joints that had been lost, the signs of deterioration in process of creased over time and were attributed to the deformations of the joint devices. In 1974, a widespread disintegration of the concrete of the Gerber joint with depressions of several centimetres occurred. An accurate analysis was then started and it was possible to specify the causes of the damage.

Despite the suspended beam, due to the concomitance of these conditions there was a series of small cracks, but the work was still structurally responsive to the functioning-loads; however, consistent differences between the design project and the ex-built structure were identified. In particular, the geometry of the half-joint was undersized compared to the one presented on the original design, thus reducing the contact surface:

	Years	Bridge name	Designer	Client	Firm	Archives	Picture	startic scheme
1	1932	Volturno bridge in Capua	G.Krall	Voltri Municipality	Ferrobeton	Voltri Municipality Archive		
4	1936	Ex Impero bridge over the river Arno in Pisa (re-built 1947)	G. Krall	Pisa municipality/ANAS	Ferrobeton	Pisa State Archive & ANAS Archive		
6	1948	Pescara bridge overe the Pescara river (reconstruction)	C. Cestelli Guidi	Pescare Municipality	Rotundi	Pescara Municipality Archive		
7	1949	Poggio Mirtetobridge over the river Tiber	C. Cestelli Guidi	ANAS, Roma	Ugo Allegri & C	ANAS Archive		
11	1954	Lerone viaduct, Voltri-Albissola motorway	A. Assereto, R. Antola	ANAS, Genova	Sugliani e Tissoni	ANAS Archive		
14	1958	Casalmaggiore bridge over the river Po	G. Borzani	Parma and Cremona Discrit	Fincosit	Parma District Archive		
17	1959	Quarcia Setta viaduct, Sole motorway	R. Morandi	Società Autostrade	Sogene	R. Morandi Found & Sogene Found, Central State Archive		
18	1959	Settefonti viaduct, Sole motorway	C. Castiglia, F. Levi	Società Autostrade	Edilstrade Ligure (brevetto BBRV)	Società Autostrade Archive		
19	1960	Eur lake bridges in Rome	E. Schmidt, G.Belloni	ANAS, Rome	Grassetto	ANAS Archive		
30	1971	Bridge over the Po river, Centro Padana motorway	B. Gentilini, L.Gentilini	Centro Padane Motorway	E. Romagnoli (BBRV)	Centro Padane Motorway Archive & Ing. Gentilini Foundation		
31	1972	Poala viaduct in Veglio Mosso	S. Zorzi, L. Lonardo, E. Faro	Ministry of Public works	CIS Compagnia Italiana Strade (Torino)	Vercelli Genio Civile Archive		

Figure 11. Extract from the census of Gerber bridges in Italy.

dimensions of the project were not respected in construction, and protruding nibs of the cantilever element were made with a size of 24–25 cm and contact area of only 18 cm.

Furthermore, the comparison between the in-situ survey and the original design drawings disclosed further "errors" in the construction phase: among these, the incorrect execution of the concrete casting corresponding to the roller supports compromised thermal expansion effects.

6 CONCLUSIONS

In this paper the Italian case studies of Gerber reinforced concrete bridges are traced as of the very first use of this bridge typology to the analysis of current deterioration phenomena occurring in the existing structures. The investigation discloses the inner critical issues embodied by the choice of this construction and structural solution, discussing the convenience of the adoption of this articulated structural system compared to the aging phenomena detected. In recent years, many specialized studies in the field of structural engineering have focused on identifying the specific causes of degradation and obsolescence, manifested in individual case studies (Malerba, 2018).

Considering the broad application of this bridge typology, a systemic approach to the problem of the safety assessment of these structures was attempted, in light of the evolution of the knowledge of the materials and of the calculation theory and codes (Desnerck 2016). In this research framework, this article supports the role that could be played by construction history culture in addition to traditional tool of structural engineering praxis such as diagnostic investigations, tests and modelling surveys.

While knowledge of the original project drawings together with the evolution of the design and calculation code provides clear and useful data for the elaboration of safety analysis, the construction site facts prove fundamental for the verification of any discrepancies in the execution phase of an individual work. In this sense, the two reported case studies of the Magliana and the Marconi bridge in Rome demonstrate antithetical approaches to maintenance projects. While the first one overlooks the historical investigation, the latter states the operational value of the history of construction as a knowledge basis for conservation design and causes of decay.

Furthermore, in the disciplinary perspective (Pelke & Brühwiler 2017), this paper argues that through construction history it is possible to undertake a census of Gerber bridges (Tab. 1) and, incorporating the causes of decay and the calculation code evolution, to establish the risk classes of existing structures, demonstrating the effectiveness of a construction history-based strategy in infrastructure heritage preservation.

ACKNOWLEDGMENTS

Research supported by the Tor Vergata University of Rome Research Grant no. E84I19002380005, project "EpoCA", within a research agreement with the Rome State Archive.

REFERENCES

Albenga, G. 1930. *Lezioni di Ponti*. Milan: Hoepli.

Albenga, G. 1953. *Lezioni di ponti. La Pratica*. Milan: Hoepli.

Albenga, G. 1958. *Lezioni di ponti. La Teoria* Milan: Hoepli.

Azimonti, C., Baroni, M., Belluzzo, G. & Semenza, G. 1919. *Manuale dell'ingegnere*. Milan: Hoepli.

Castiglia, C. & Levi, F. 1962. Viadotto dell'Autostrada del Sole a Settefonti presso Citerna. In *Realizzazioni italiane in cemento armato precompresso*: 135–138. Rome: AITEC.

Cestelli Guidi, C. 1944. *Esperienze sul modello di un ponte a travata in cemento armato*. Rome: Istituto di Scienza delle Costruzioni, Università di Roma.

Cestelli Guidi, C. 1949. Il nuovo ponte sul Tevere alla Magliana. *L'industria Italiana del Cemento* 9: 271–276.

Cestelli Guidi, C. 1987. Il ponte sul Tevere alla Magliana a Roma. In AICAP (ed.), *Carlo Cestelli Guidi*: 68–69. Rome: AITEC.

Colombo, G. 1877. *Manuale dell'ingegnere*. Milan: Hoepli.

Desnerck, P. et al. 2018. Strut-and-tie models for deteriorated reinforced concrete half-joints. *Engineering Structures* 161: 41–54.

Di Pasquale, S. 1996. *L'arte del costruire. Tra conoscenza e scienza*. Venice: Marsilio.

Ferrobeton 1933. Impresa Generale di Costruzioni, 1908–1933 (Catalogo). Rome: Ferrobeton.

Gentilini, B. & Gentilini, L. 1970. Viadotto del colle Isarco nel tratto Brennero-Cave dell'Autostrada del Brennero. In *Realizzazioni italiane in cemento armato precompresso*: 180–185. Rome: AITEC.

Gerber, H. G. 1866. *Balkenträger mit freiliegenden Stützpunkten*. Patent 6 December 1866.

Guidi, C. 1887. *Lezioni di statica grafica*. Turin.

Guidi. C. 1904. *Lezioni sulla scienza delle costruzioni*. Turin: Vincenzo Bona.

Iori, T. & Capurso, G. 2019. Silvano Zorzi, designer strutturale. *Archi* 5: 19–22.

Jorini, A. F. 1905. *Teoria e pratica della costruzione dei ponti*. Milan: Hoepli.

Krall, G. 1937. Un nuovo ponte sull'Arno a Pisa. *Industria Italiana del cemento* 4: 112–123.

Legat, A. W. et al 1948. *Reinforced concrete bridges*. London: Concrete Pubblication Limited.

Leone, I. 1977. *Lavori di consolidamento delle seggiole Gerber e di altre strutture portanti del ponte Marconi in Roma*. Rome: Geosonda.

Malerba, P. G. 2018. Ponti articolati e continui: 150 anni di esperienze. Una approfondita analisi dell'evoluzione delle principali tipologie dei ponti Gerber e Cantilever. *Strade e autostrade* 130: 80–83 & 131: 60–63.

Mergoni, D. 1955. L'Autostrada della Riviera Ligure. *Strade e Traffico* 22: 5–26.

Mehrtens, L. 1900. *A hundred years of German bridge building*. Berlin: Julius Springer.

Morandi, R. 1967. Viadotto Quercia Setta Autostrada del Sole. In *Costruzioni in Cemento Armato. Studi e Rendiconti*: 176–77. Milan: Italcementi.

Morandi, R. 1977. Il viadotto Carpineto 1 per le strade di grande comunicazione Basentana. *Industria Italiana del Cemento* 10: 817–830.

Nascè, V. 1982. *Contributi alla storia della costruzione metallica*. Turin: Alinea.

Panetti, M. 1900. Le costruzioni metalliche moderne nei loro recenti progressi. *Ingegneria e Arti Industriali* 22: 343–50.

Pelke, E. & Brühwiler, E. 2017. *Engineering history and heritage structures – Viewpoints and approaches.* Zurich: IABSE.

Rinaldi, G. 1974. *La costruzione dei ponti*. Rome: Editrice Eredi.

Santarella, L. & Miozzi, E. 1924. *Ponti Italiani in cemento armato*. Milan: Hoepli.

Santarella, L. & Miozzi, E. 1932. *Ponti Italiani in cemento armato*. Milan: Hoepli.

Steimann, D. B. 2011. *A Mathematical study of cantilever bridge design*. Vancouver: Read Books.

Timoshenko, S. 1983. *Strength of materials*. Toronto: D. Van Nostrand Company.

Wilcox, R. M. 1898. *Theory and calculation on cantilever bridges.* New York: D. Van Nostrand Company.

Zorzi, S. 1970. Viadotto sul torrente Stura, Autostrada Torino-Savona. In *Realizzazioni italiane in cemento armato precompresso*: 58–63. Rome: AITEC.

Zorzi, S. 1974. Viadotto sul torrente Poala a Veglio Mosso. In *Realizzazioni italiane in cemento armato precompresso*: 56–59. Rome: AITEC.