Journal of Civil Structural Health Monitoring (2020) 10:177–182
https://doi.org/10.1007/s13349-020-00384-6

FOREWORD

Monitoring and evaluation of bridges: lessons from the Polcevera Viaduct collapse in Italy

Paolo Clemente[1]

Received: 2 January 2020 / Revised: 31 January 2020 / Accepted: 1 February 2020 / Published online: 17 February 2020

Abstract
The collapse of the Polcevera Viaduct at Genoa, Italy, demonstrated that good designs are not sufficient to guarantee long lives for bridges. Bridges should be monitored continuously for the detection of damage and deficiencies and for planning timely maintenance programs. This Journal dedicated a special issue to the monitoring and evaluation of existing bridges. The papers selected and published are introduced in this foreword.

Keywords Monitoring of bridges · Evaluation of bridges · Maintenance · Existing bridges

1 Introduction

On August 14th, 2018, a portion of the Polcevera Viaduct in Genoa, Italy, collapsed and, together with it, also a piece of the Italian engineering. As a matter of fact, the Polcevera Viaduct was part of the history of bridges but also of Italian history. The construction of the bridge began in 1963 to connect the Cristoforo Colombo Airport to the harbor and the city of Genoa and was opened to traffic on September 4th, 1967. It was a strategic infrastructure, connecting Northern Italy to France and a structure representative of an important period for civil engineering, in Italy and in the world.

Designed by Riccardo Morandi, one of the most famous bridge designers of all time, the main part of the viaduct was composed of three balanced systems, referred to as piers 9, 10 and 11, respectively, shown in Figs. 1 and 2 and connected by buffer beams. The failure occurred in pier 9 at the first balanced system on the west side (left in Fig. 1). Piecing together the failure dynamics of the bridge after the collapse was a difficult task. The most credible hypothesis about the dynamics of failure was the rupture of the first cable-stay, near the seaside. Only recently, this hypothesis seems to have been confirmed by a video, which was not available before. Lack of the cable-stay support resulted in collapse of the deck on the west side of the pylon. This resulted in the collapse of the pier 9 balanced system and two buffer beams.

What was the cause of the cable stay failures? The judiciary and their technical consultants will arrive at reliable conclusions. However, all the hypotheses expressed so far have a common denominator: the lack of an adequate maintenance. Morandi himself in 1979, only twelve years after the construction completion, warned about the durability problems of his bridge, linking them to the particularly aggressive environment due to the saltiness from the sea and pollutants of the underlying industries. The viaduct was subject to consolidation works in the 1990s, because the experimental investigations “highlighted the serious state of oxidation of internal cables” … “with advanced reduction of the section”. External cables were added to the four stays of the last balanced system on the east side (namely pier 11). Recently, interventions on the other two balanced systems were announced.

Who knows what would Riccardo Morandi say if he saw the collapse of his bridge. Who knows what would he think about the future of the spans that remained standing. Actually, on June 28th, 2019, also the other two balanced systems were demolished. Therefore, in memory of the great genius, two main bridges of the same type remain. These are the General Rafael Urdaneta Bridge on Lake Maracaibo, in Venezuela, and the bridge over the Wadi al-Kuf in Libya (Fig. 3). We hope that the local authorities will devote the right care to these two great structures, ensuring the necessary maintenance.

✉ Paolo Clemente
paolo.clemente@enea.it

[1] ENEA, Casaccia Research Centre, Via Anguillarese 301, 00123 Rome, Italy

Fig. 1 The Polcevera Viaduct before the collapse of the first balanced system on the left (namely pier 9)

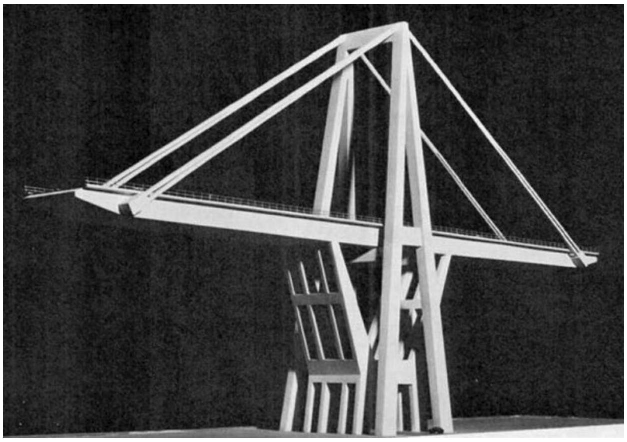

Fig. 2 One of the three balanced systems of the Polcevera Viaduct

Fig. 3 The bridge over the Wadi al-Kuf in Libya

The collapse of the Polcevera Viaduct attracted the attention of the media and shook the public opinion, due to the number of victims but also for the strategic importance of this infrastructure. However, the recent collapses that affected other bridges must also be mentioned. For example, the bridge between Annone and Cesana Brianza collapsed on October 28th, 2016, while a truck carrying steel coils was passing, and the viaduct on the Fossano ring road (Fig. 4), suddenly collapsed on April 17th, 2017, in the absence of travelling loads. These are just two recent cases in Italy.

Fig. 4 The viaduct collapsed at Fossano, Italy

Why all these disasters? Some of these bridges were not built properly, in other cases the necessary maintenance was not guaranteed. In a building field, and not only, where the keywords “maximum price cut” and “spending cut” reign, perhaps the results could not be better.

It is clear that a careful analysis is necessary on what has been done so far and how we shall proceed from now on. From a technical point of view, the way to follow is well-known. The knowledge available nowadays allows designing new structures with a high degree of safety and improving significantly the existing ones against static and seismic actions. It is well-know that the structures need programmed check-ups. They should be controlled continuously, by means of advanced monitoring systems. These allow identifying any damage in its initial phase. It would be thus possible to remedy in time with light interventions before the level of damage becomes more serious and requires heavier and more expensive interventions or becomes irreversible. This is what we usually mean by the term prevention.

Obviously, the government should play its role, promoting a registry office of all the structures, i.e., an archive that contains the “health records” of all the bridges and viaducts. This would allow having a continuously updated picture of the health status of our structures, useful for their sustainable management.

In February 2019, this Journal launched a call for papers on Monitoring and evaluation of bridges, which follows a previous special issue on novel methods in SHM and monitoring of bridges [1]. Several proposals were received. They were subject to the usual review process. Only twelve of them were accepted and published in the last three issues of this Journal. In the following the accepted and published papers are introduced. Some of them present interesting case studies, which are examples of good practice for the future.

Fig. 5 Polcevera Viaduct: new strands on pier 11 [2]

Fig. 6 Polcevera Viaduct: pitting corrosion of prestressing tendons [3]

2 Monitoring and evaluation of bridges

As pointed out by Nuti et al. [2] failures of structures are often tragic events. Sadly, they represent an opportunity to improve our understanding about safety and reliability of structures. The Authors present a review of the Polcevera Bridge collapse and its history. They focused their attention on the monitoring to assess the performance decay due to corrosion (Fig. 5).

Morgese et al. [3] demonstrated that the collapse of the Polcevera Viaduct could have been prevented with a proper real-time structural health monitoring. The authors tried to estimate the remaining service life for the bridge in the absence of structural health monitoring. They concluded that basic engineering principles may provide the backing to estimate the remaining life of the bridge. Based on the combined effects of fatigue and corrosion of the cable stays, they estimated the collapse of the bridge to have occurred in 2016 (Fig. 6).

Fig. 7 Example of concrete cover spalling of a bridge pier [4]

Fig. 8 Cypress Street Viaduct collapse [5]

Furinghetti et al. [4] provided guidelines for the definition of standardized structural health monitoring systems for bridges, considering a cloud computing interface. They started from the consideration that phenomena, such as steel reinforcement corrosion and concrete carbonation, cause an increase of the element deformation, which leads to a progressive deterioration of the entire structure (Fig. 7). The monitoring architecture could lead to the proper maintenance of all the structural elements, preventing the unexpected collapse of the structure.

Bontempi [5] explains the aspects related to structural robustness. Bontempi first introduces the concept of structural integrity and then considers how it varies in time, accounting for the different kinds of progressive collapses (Fig. 8). The analysis is carried out from a practical point of view, as needed by designers.

The behaviour of the suspension bridge in Carquinez, CA (Fig. 9), during the Mw6.0 August 2014 South Napa, CA earthquake is analysed by Çelebi et al. [6]. They use data from an extensive array of accelerometers that recorded the earthquake-excited motions and identified the dynamic characteristics. These are compared with previous studies, which used ambient data of the deck only plus mathematical models.

Fig. 9 The two parallel Carquinez Strait Bridges [6]

Fig. 10 View of the Gresal Bridge [7]

Lorenzoni et al. [7] focused the attention on the evaluation of damping using operational modal analysis. Damping is usually affected by higher uncertainties, even when resonance frequencies and modal shapes have been correctly identified. They report the results of ambient and free-vibration tests performed on five different typologies of road and railway bridges and conclude that the estimation of modal damping return to be more reliable for flexible structures and when SHM and free-vibration data are available (Fig. 10).

Gattulli et al. [8] analyzed data acquired in operational condition on steel and concrete railway bridges belonging to the Italian network and highlighted dissipative sources and features (Fig. 11). They proposed a non-proportional damping index as a basis to determine the influence of different sources of non-proportionality in the damping matrix and justified the high value of damping observed in specific experimental campaigns.

The results of an experimental dynamic analysis and structural modeling of one of the longest bridges in Italy, the Indiano Cable-Stayed Bridge in Florence (Fig. 12), are presented by Clemente et al. [9]. Ambient and traffic-induced vibration tests were carried out, which allowed performing the system identification by means of a finite element model. This model was used to evaluate the effects of the static and seismic loads.

Marcheggiani et al. [10] presented the results of static and dynamic testing of a multi span bridge, which was opened to traffic in 2014 (Fig. 13). The results of an operational modal analysis are compared with those of a numerical model, pointing out that the dynamic load test can supplement the static load tests can supplement the static load tests for the structural evaluation of bridges, both new and existing ones.

Gara et al. [11] presented the results of an experimental campaign carried out during the construction of a base-isolated bridge across the Potenza river in central Italy (Fig. 14). Impact load tests were carried out on hangers and on other tie elements, as well as ambient vibration tests. Test results were compared with the numerical analysis to evaluate consistency between the design and the real structure at different construction stages.

The importance of the vertical component of seismic acceleration for bridges and viaducts is pointed out by Falsone et al. [12]. They show that their analysis is fundamental for collapse prevention of girder bridges subjected to near-fault earthquakes, also with reference to unseating failure and damage to piers and abutments (Fig. 15).

Fig. 11 The two railway bridges [8]

Fig. 12 The Indiano Cable-Stayed Bridge, Florence, Italy [9]

Fig. 13 View of the Adda Viaduct [10]

Fig. 14 The bridge on the Potenza river [11]

Chiaia et al. [13] illustrate the application of an active monitoring system on a 250 m suspended arch steel bridge using sensors of different types (Fig. 16). They point out that the estimation of dynamic characteristics is influenced by several factors, among these the effects of temperature.

Fig. 15 Damage on RC structural elements caused by the earthquake of Santa Venerina in 2002 [12]

Fig. 16 General view of the suspended arch steel bridge [13]

3 Conclusions

The collapse of the Polcevera Viaduct in Genoa, Italy, was the most disastrous events that occurred in the last years. It pointed out the low reliability of infrastructures, erected a few decades ago and probably not subject to a suitable maintenance during their life. The evaluation of the existing bridges and the continuous monitoring of their structural health status is the only way to guarantee an acceptable safety level and to program the necessary interventions in time. This is important first of all to safeguard the life of the public and to extend the life span of infrastructures and reducing the maintenance costs.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

References

1. Clemente P, De Stefano A (2016) Novel methods in SHM and monitoring of bridges. Foreword. Foreword to Novel methods in SHM and monitoring of bridges. J Civ Struct Health Monit 6:317–318. https://doi.org/10.1007/s13349-016-0185-4
2. Nuti C, Briseghella B, Chen A, Lavorato D, Iori T, Vanzi I (2020) Relevant outcomes from the History of Polcevera Viaduct in Genova, from design to nowadays failure. J Civ Struct Health Monit 10(1):87–107. https://doi.org/10.1007/s13349-019-00371-6
3. Morgese M, Ansari F, Domaneschi M, Cimellaro GP (2020) Post collapse analysis of Morandi's Polcevera Viaduct in Genoa Italy. J Civ Struct Health Monit 10(1):69–85. https://doi.org/10.1007/s13349-019-00370-7
4. Furinghetti M, Pavese A, Lunghi F, Silvestri D (2019) Definition of a standardized structural health monitoring system for bridges based on cloud computing. J Civ Struct Health Monit 9(5):607–616. https://doi.org/10.1007/s13349-019-00356-5
5. Bontempi F (2019) Elementary concepts of structural robusness of bridges and viaducts. J Civ Struct Health Monit 9(5):703–717. https://doi.org/10.1007/s13349-019-00362-7
6. Çelebi M, Ghahari SF, Taciroglub E (2019) Responses of the odd couple Carquinez, CA, suspension bridge during the Mw6.0 South Napa Earthquake of August 24, 2014. J Civ Struct Health Monit 9(5):719–739. https://doi.org/10.1007/s13349-019-00363-6
7. Lorenzoni F, De Conto N, da Porto F, Modena C (2019) Ambient and free-vibration tests to improve the quantification and estimation of modal parameters in existing bridges. J Civ Struct Health Monit 9(5):617–637. https://doi.org/10.1007/s13349-019-00357-4
8. Gattulli V, Lofrano E, Paolone A, Potenza F (2019) Measured properties of structural damping in railway bridges. J Civ Struct Health Monit 9(5):639–653. https://doi.org/10.1007/s13349-019-00358-3
9. Clemente C, Bongiovanni G, Buffarini G, Saitta F (2019) Structural health status assessment of a cable-stayed bridge by means of experimental vibration analysis. J Civ Struct Health Monit 9(5):655–669. https://doi.org/10.1007/s13349-019-00359-2
10. Marcheggiani L, Clementi F, Formisano A (2020) Static and dynamic testing of highway bridges: a best practice example. J Civ Struct Health Monit 10(1):43–56. https://doi.org/10.1007/s13349-019-00368-1
11. Gara F, Nicoletti V, Carbonari S, Ragni L, Dall'Asta A (2020) Dynamic monitoring of bridges during static load tests: Influence of the dynamics of trucks on the modal parameters of the bridge. J Civ Struct Health Monit. https://doi.org/10.1007/s13349-019-00376-1
12. Falsone G, Recupero A, Spinella N (2020) Effects of near-fault earthquakes on existing bridge performances. J Civ Struct Health Monit 10(1):165–176. https://doi.org/10.1007/s13349-020-00378-4
13. Chiaia B, Marasco G, Ventura G, Zannini Quirini C (2020) Customised active monitoring system for structural control and maintenance optimisation. J Civ Struct Health Monit. https://doi.org/10.1007/s13349-020-00382-8