DEMOLITION OF BRIDGES WITH EXPLOSIVES

Experience in the last decade in Italy with reinforced concrete bridges

By Roberto Folchi and Gianluca Auletta

Abstract

All over the world, 20 percent of the bridges deck surface is running ahead of their life cycle. Consequences were not taken in proper consideration due to lack of consciousness on the actual status of maintenance and on related risk for the public and environment. This has lead, in the last three decades, to a progressive decrease in funding for maintenance and repair with financial resources diverted to new constructions.

This situation is changing because of the relevant safety and economical issues involved. In this trend, in Italy, in the last 10 years, some 300 road bridges were demolished with 40% of those by means of explosives. This within a large road reconstruction project supervised by ANAS, the Italian Road Authority, to have the Italian highways matching to the latest European standards.

In this article information on the background of this infrastructure demolition program are given, as well as on its execution based on the experience of the author in the demolition with explosives of 100 of those bridges.

1. Structural Deficiency of Old Bridges

1.1 Aging of Bridges

Aging does not progress at the same speed in different types of bridges.

There are hundreds of (ancient) bridges built two thousand years ago that are still in service, with their dead load up to five times that of modern bridges, carrying live loads (cars and trucks) up to 10 times that was foreseen at the time they were built (horses and carriages). Apart from cosmetic deficiencies due to weathering, tenths of earthquakes and plundering, they still maintain a high structural safety margin toward the ultimate resistance.

Figure 1. Ancient Roman round arch bridge "S. Angelo" in Rome, built A.D. 134 (photo by Wampile).

Figure 2. Bridge "Tiberius" in Rimini, Italy, built A.D. 21 (photo by Heiko Trurnit).

This is not the case with old bridges of modern conception, built in the second half of the 20th century in pre-stressed concrete **(see figures 3-7)**. Those suffered an aging speed of 30 to 50 times faster than their predecessors of ancient Roman age. Several of them are running ahead of their life-cycle in just 40 years, some others are already ahead of it, especially if referring to the latest safety standards for ultimate resistance and seismic loads.

Figure 3. Bridge "Tanagro," Italy, built 1970. Reinforced concrete arch surmounted by twin full concrete pylons carrying single 32 m simply supported spans four I girders carriageway.

Figure 4. Bridge "Italia," Italy, 1968. Single box pylons with internal wall, carrying double 45 m simply supported spans four I girders carriageway.

Figure 5. Bridge "Battendiero 1," Italy, 1970. Single box pylons for single 32 m simply supported spans four I girders carriageway.

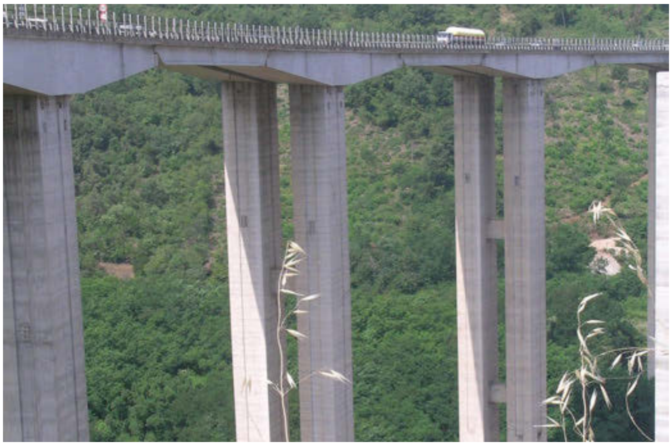

Figure 6. Bridge "Lontrano," Italy, 1968. Single thick walls box pylons with quadruple 25 m long cantilevers carrying double 32 m spans carriageways.

Figure 7. Bridge "Noce" Italy, 1970. Single thick walls box pylons carrying single 32 m spans carriageway double box girder.

1.2 Why are Old Bridges Lasting Less Than Ancient Ones?

Before the industrial revolution (early year 1800) no relevant changes were expected in society and in technologies for the coming centuries. In the two thousand years preceding the Roman age, transportation didn't change much in both quality and quantity. Why did the Romans expect it to change for the coming two thousand years? In fact they didn't. So they built roads and bridges that had to last forever. They built simple and effective structures, standing in service with acting stresses in the range of 10 percent of construction material's ultimate resistance (mainly compression stressed, such to activate a material's maximum resistance).

On the opposite side, 20th century bridges were put in service with acting stresses of up to 40% for concrete and 60% for steel for the ultimate resistance. This was to save on quantity of materials and manpower to reduce total construction costs but with no consideration for depreciation or better, to construction costs scaled on the duration its service life.

Those bridges were designed assuming traffic was not expected to increase, and it was unknown what the long term behavior of the construction materials would be (e.g. modern Portland concrete and of its interaction with reinforcing and tensioning steel bars at high strain rates, with resonance, fatigue, weathering, chemical aggression from pollution and defrosting salt). Concrete was thought to last forever as the Roman age one which, on the contrary, was made with volcanic ashes and other components that can't be compared with it. What happened instead, is that frequency of crossings increased by a factor of 100, truck's size and payload increased by a factor of 10 together with a vehicle's speed doubling so that the vehicles kinetic energy increased to more than 30 times. This together with an increased efficiency in the possibility to release this kinetic energy to the bridge structure due to more efficient brakes and higher asphalt grip, generating extra stress and high oscillations. And again, concrete, even if strained within its elastic range, showed an unexpected attitude to creep causing cracks in the lower bulb of the girders, with reinforcement's exposition and corrosion so that a lack of maintenance would drive to irreversible damages in the structure **(see figure 8-11)**. Concrete carbonation also paid a role in accelerating corrosion of reinforcements causing or increasing cracks. Other micro cracks were generated and extended by those high oscillation cycles following each other in a sequence of millions. Last but not least, accuracy in execution and quality of materials were sometimes below requirements. All the above factors interacting with one another, amplified their impact in a synergy which accelerated the speed of aging.

Figure 8. Large cracks in the lower bulb of a reinforced concrete pre-tensioned I girder.

Figure 9. Re-bars and tensioning bars exposed and corroded after concrete cover collapse in the lower bulb of an I girder. Due to excessive re-bars, concentration concrete could not properly wrap around.

Figure 10. Reinforcement bars exposed and corroded in a box type concrete pylon.

Figure 11. Reinforcement bars exposed and corroded in a grid full concrete quadruple rectangular piers pylon.

1.4 Accidental Collapses

Bridges ahead of their life-cycle may suffer major damages. In worst case scenarios, it would collapse while in service with the possibility of lost lives and impact on social life and economy **(figures 12 and 13)**.

All over the world, accidental collapses are increasing in frequency due to lack of safety inspections, monitoring, maintenance, live loads reduction, temporarily bracing and rehabilitation, eventually because of a delayed intervention or a definitive decommissioning.

Figure 12. Collapse of a highway overpass causing casualties, 2016.

Figure 13. Collapse of a highway overpass causing no casualties, 2017.

2. Highways Rehabilitation and Reconstruction Project Involving Bridge Demolition

2.1 Actions Undertaken

In the last 10 years, the Italian roads authority started a large highway refurbishment and reconstruction project to match the latest European standards. This included demolition and replacement of almost all old bridges. Activities performed included a preliminary survey and inspection for engineering analysis, structure rehabilitation and strengthening, demolition and replacement.

Engineering analysis proved to be of reduced accuracy for old bridges. Algorithms of structural software require a model in which mechanical characteristics and geometry are known exactly and for the whole structure. This was not easy to obtain with old bridges due to several singularities along the structure for the mechanical resistance, some of them hidden. Costs and time for a reliable survey plus rehabilitation following, frequently exceed the cost for demolition and new construction. For superstructures, only in few cases rehabilitation and strengthening become an option (carbon fiber overlay, girders re-tensioning with external steel wires, deck replacements, and supports replacement). On the contrary it becomes an option for foundations and pylons, standing with service stresses two orders of magnitude below ultimate resistance, even being halved after replacement of the reinforced concrete superstructures with a new one in weathering steel (also known as COR-TEN steel). So for superstructures, demolition and replacement became the most frequent option but pylons were generally restored and left in place for an expected extended life cycle equal to that of the new superstructure. Total bridge demolition and replacement was decided just when layout of the highway had to be moved apart (e.g., to rectify the roadway).

2.2 The Infrastructure Involved

Most of the actual road bridges, in Italy, were built in a large infrastructure construction project in the 1960s and 1970s.

Some of those bridges with 40 to 60 years of service, run close or even ahead of their life-cycle, standing with structural deficiencies which, in a few cases, caused accidental collapse.

Affected bridges were built with reinforced concrete, with pylons of a maximum height reaching 130 m (430 ft). The horizontal span length varied, generally 16, 32 or 45 m (about 50, 100 and 150 ft), on generally four post-tensioned I girders, sometimes only three. Some of the pylons had longitudinal cantilevers, for spacings up to 80 meters (some 260 feet). Some other pylons had transverse cantilever to sustain both carriageways; others were built above arches for a spacing up to 145 m (480 ft). Examples of those kind of bridges is given in **figures 3-7** (see also reference 1).

At the time of construction, it was the general practice to contract only a few kilometers of highway at a time. Consequently, tens of different companies were involved in the construction of those bridges. Because no standardization of the construction design was still set in place, almost each bridge was built with its own unique shape and structure, according to best practice and experience developed by each construction company with their trusted engineers and teams. Design was executed by the best Italian structural engineers, each of them working with individual and unique design concepts for spans and pylons. Design geometry and resistance parameters were targeted to minimize concrete and iron quantities, to save money taking advantage of the low cost of high qualified manpower which permitted execution of complicated shapes of the structure.

This condition produced the iconic highway bridge appearance with slim and elegant pylon's geometry, so many angled surfaces and spans with a minimalist form. These cost saving oriented designs also included shallow foundations, even in earthquake sensitive areas.

2.3 Kind of Bridge Structures

About 80% of the bridge structures were belonging to the whole multispan plate girder bridge deck on concrete pylons. Consisting on isostatic spans built with squared I beams (prefabricated on site) linked by a 20 cm thick slab and by 3 to 5 rectangular cross-girders (sometime also post-tensioned). Generally all girder bearings were steady by one side (at least the central ones, to fix the span at the pylon) and sliding at the opposite bearings (central ones free in the longitudinal direction and side ones transverse, to accommodate the span's thermal strain) as in the sketch in **figure 14**. Pylons were mostly of box type with an internal wall but also twin or triple cylindrical full concrete or squared full concrete.

The remaining 20% of the bridges belong to the box girder bridge and concrete arch bridge (sketch in **figure 15**) with spans up to 90 m.

Resistance of concrete at the time of the construction was respectively 45 MPa for the girders and 25 MPa for the pylons. Reinforcement steel 250 to 380 MPa and tensioning cables some 1,600 MPa.

In surveys residual resistances at 70% up to 50% were recorded.

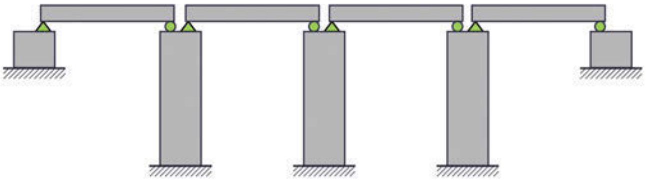

Figure 14. Sketch of a multispan plate girder bridge deck on concrete pylons (as bridges in figures 3-6.).

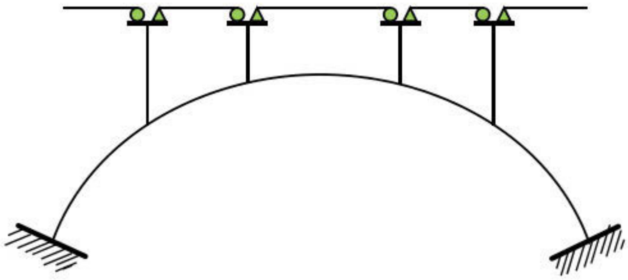

Figure 15. Sketch of a concrete arch bridge surmounted by concrete pylons supporting a pre-stressed concrete multispan plate girder (as bridge in figure 7).

3. Bridge Demolition Works

3.1 Deconstruction and Mechanical Demolitions

Both partial and total demolitions were originally designed to be executed by mechanical means: the lower bridges by breaker and crusher on hydraulic backhoe excavator, the tallest bridges by the deconstruction technique. Deconstruction consists of preliminary removal of the spans by means of a launch girder for bridges. Each girder is hooked individually to the launch girder above than disconnected from slab and cross-girders longitudinally by means of diamond cuts. They then had to be cut transversely into small sections to be lifted and moved back on the span behind to be demolished by a hydraulic crusher on backhoe excavator. Pylons are demolished little by little by cutting them in square pieces by diamond saws operated from a scaffold, with pieces being thrown inside the pylon and picked up at the toe to be crushed.

Reckless attempts in tall bridges were also made to tear down spans by mechanical demolition with excavator standing with its crawlers on top of the next span, with collapse induced by rotation on the next pylon's supports. After severe damage to the pylons ahead and accidents with the excavator pulled below because it was stuck in the falling span, this practice was interrupted.

3.2 Demolition with Explosives

In search of a safest but also cost effectively and faster alternative, explosives became an option. By the end of the demolition project, the explosive demolition technique had almost entirely replaced the deconstruction one. Deconstruction was delivering the same result but was 5 to 10 times more expensive and took 5 times longer than explosives.

Explosives were used to create plastic hinges triggering collapse in a given sequence and direction of the sole spans (reference 2) or of the whole bridge **(figures 16-27)**. Concrete fragmentation was achieved by detonating small diameter explosive charges (generally 35 to 190 grams dynamite but sometime up to 500 grams).

Preliminary cuts of the reinforced concrete were executed with diamond tools or small breakers on remote controlled excavators. Reinforcements and tensioning bars were left in place.

Safety factor of the residual structure to be blasted remained high during explosives demoiltion preliminary cuts

Figure 16. Preparing the spans to blasted, by breaker on remote controlled excavator for preliminary decks demolitions and by remote controlled wagon drill for boreholes in the girders

Figure 17. Spans ready to be blasted for extended explosives demolition due to constraints at footprint (steep slopes and structures to be safeguarded). I girder type (as bridges in figures 3-6).

Figure 18. Spans ready to be blasted - box girder type (as bridge in figure 7).

Figure 19. Spans to be demolished by safeguarding own pylons or with the new superstructure already in place built right above (before the blast).

Figure 20. After the blast.

Figure 21. Spans and pylons blasted in sequence (redundant detonating cord circuit and firing sequence by redundant non electric detonators).

Figure 22. Spans and pylons blasted in sequence, safeguarding own pylons.

Figure 23. Concrete debris, re-bars and tensioning steel left from the extended explosives demolition of a 650 ton span overlaying this new pylon standing 17 meters right below it (see figure 17).

Figure 24. Heads of the girders from both sides of the spans are seen rotated and laying above the deck.

Figure 25. Span at the ground among own pylons. Collapse determined by hinging the beams close to their bearing spots.

Figure 26. Spans more extensively demolished for better adjustment on the steel sloped footprint, to prevent its sliding toward the pylon below.

Figure 27. Spans and pylons at the ground, ready for mechanical breaking.

and mechanical demolitions and drilling activities. Lack of the service live loads helped for this purpose, increasing the design safety factor more than two times.

In case of steep slopes at the footprint, where falling spans or pylons could slide toward the closest acceptor such as the pylon ahead to be left in place, or just slide away down making it impossible to retrieve for removal and crushing [reference 2], explosives were spread out in the structure for extended fragmentation. In some cases disintegration was needed to keep structures safe that were standing right below the span to be demolished (as the case of the pylon in **figure 23**).

4. Conclusion

As experienced in Italy in the last decade, the whole world is expecting the need to upgrade their infrastructure. This means maintenance and repair but also replacement by demolition of bridges found close or ahead of their life cycle.

Mechanical demolition and deconstructions would remain the first choice for demolition of low structures, up to 15 or maybe 30 meters when easily accessible by a large excavator with longer booms and crawlers securely laying at the ground. Deconstruction by means of a launch girder for bridges would also still be an option but just for few a cases, due to the higher risks involved, higher costs and longer execution time. For bridges above 10 meters, explosive demolition would be the best choice for safety, timing and costs.

5. References

1. Data on 100 bridges being demolished by the authors, with brief description and photos: https://issuu.com/nitrex-ntx/docs/nitrex_100_ponti

2. R. Folchi, G. Auletta "Controlled Demolition of the Pietrastretta Bridge in Italy," Journal of Explosives Engineering, January/February 2017.

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Roberto Folchi is founder and main shareholder of NITREX, a contracting company operating in the field of explosives demolition, underwater blasting, tunnelling and controlled blasting for open pit projects. He started his activity in the explosives engineer business in 1982 as technician. He graduated in Mining Engineering in Rome in 1984 and has over 35 years experience in the explosives industry.

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