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DESIGNED FOR MACHINES. ITALIAN BRIDGES AND VIADUCTS (1965-1990)

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Gianluca Capurso, Francesca Martire

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Highlights

During the sixties, the aim of reducing the production time and costs made it impossible to postpone in Italy the mechanisation of building sites and the industrialisation of construction processes of bridges and viaducts. The Italian building site abandoned the artisanal dimension, and the character of the works was irreversibly transformed. Triumphant were the free cantilever bridges, the viaducts made of high piles and beams, the precast modules, and the hyper-technological self-launching falseworks. The building fervour dissolved the identity of the Italian School of Engineering, which only a few solitary talented designers tried to keep alive.

Abstract

This contribution is a result of the researches, carried out by the authors as part of the SIXXI project - History of Structural Engineering in Italy in the 20th Century (ERC Advanced Grant, PI Sergio Poretti, Tullia Iori - www.sixxi.eu), about the transformation of Italian Engineering after the second half of the sixties. It reconstructs the evolution of the building systems introduced in the building sites of bridges and viaducts, from the presentation of industrial patents to the first applications abroad and then by national designers and companies, to examine what impact they had on the production of Italian engineering.

Keywords

Mechanisation, Infrastructures, Viaducts, SIXXI research project, History of Engineering.

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1. INTRODUCTION

Within the SIXXI project, currently in progress at the University of Rome Tor Vergata, (ERC Advanced Grant, PI Sergio Poretti, Tullia Iori - www.sixxi.eu), aiming to reconstruct the history of structural engineering in Italy in the twentieth century [1], one dedicated research has been focused on understanding how and why, in Italy, after the completion of the “Autostrada del Sole”, the infrastructure construction sector underwent a deep transformation [2].

The attention was therefore focused on the introduction of new technologies in bridge and viaduct construction sites, starting from the mid-1960s, which, in addition to guaranteeing considerable time savings, allowed labour savings for the construction of deck structures. These were, to a large extent, methods imported from abroad. Also for this reason, to tell the story of infrastructure construction in Italy in those years, one cannot help but look beyond borders.

By aiming to understand the international framework, a general survey has been carried out using the technical literature of the time and some more recent studies such as [3] and [4], enriched by some investigations on the archives of foreign companies and public bodies. To analyse the construction of Italian works, the explorations on the archives with which the SIXXI team had already established valuable synergies for studies on the history of structural engineering, were combined with research on other documentary and photographic archives, of companies and designers chosen among those most involved in the use of advanced technologies on national construction sites.

The contribution reconstructs the evolution of the various systems introduced in the construction sites, from the presentation of industrial patents to the first experimental applications abroad and then by national designers and companies, to examine what impact it had on the production of Italian engineering.

2. CLONE EFFECT

On July 6, 1950, Ulrich Finsterwalder, an engineer at the company Dyckerhoff & Widmann AG (Dywidag) and an expert in pre-stressing reinforced concrete, presented an innovative patent, No. 4931, in West Germany for the construction of "highly stressed reinforced concrete load-bearing structures, particularly in the form of bridge constructions". In the patent, the pre-stressing induced in concrete with post-tensioned reinforcement is exploited within a new construction process that allows doing without the traditional type of temporary works. In fact, it makes it possible to "hold" the deck in balance, suspended in the void, supporting it from the abutments.

Dywidag immediately applied the system for the 62-metre span bridge over the Lahn (1950-1951) in Balduinstein. The bridge cantilevered from the two abutments at the rate of one "ashlar" per week. In each ashlar, which is three metres long, the threaded rods, produced by the same company, pre-stressed the concrete by compensating the bending moment generated by the cantilever configuration until the central ashlar was built.

The technique proved to be particularly efficient. In just a few years, Dywidag proposed it again for increasingly demanding works and between 1962 and 1964 built by means of this technique the 208 metres-span Bendorf Bridge over the Rhine (Fig. 1). In Europe, a real cloning phenomenon of the "Dywidag bridges" was triggered. They were built in Austria, Norway, Holland, and Sweden, also thanks to partnerships with other companies and the sale of the use of the patent (Fig. 2).

From the beginning of the 1960s, other European companies also began to exploit the cantilever method, also called, in French words, "*peau-à-peau*". The object of the German patent, on the other hand, was not a specific machine or technology, but rather a constructive process that, therefore, any company could reinvent by adapting the different pre-stressing systems commercially available.

In Italy, some engineers began to experiment with the new technology, convinced that the pre-stressing of concrete mix is the winning weapon to challenge steelwork.

Riccardo Morandi, for example, chose the "*peau-à-peau*" method for the bridge over the Polcevera, whose construction site began in 1961. By using his own patent

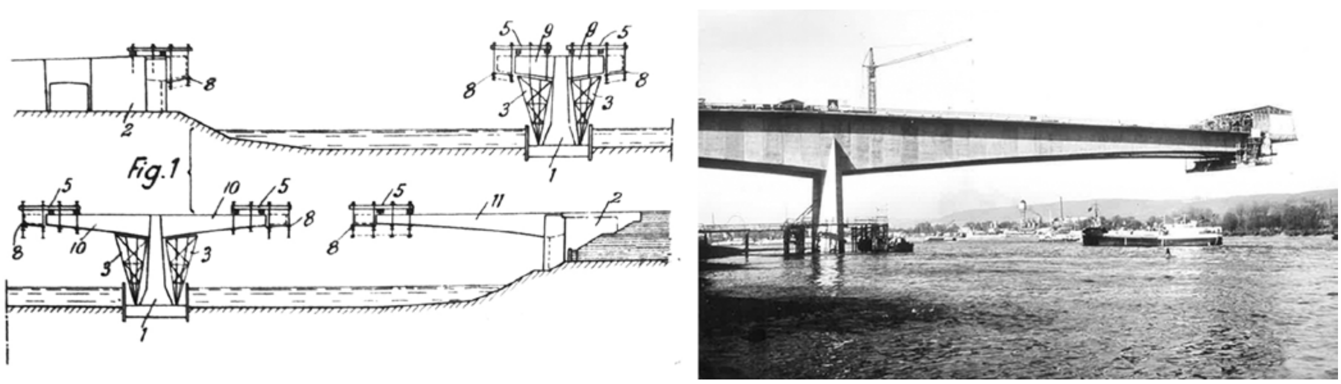

Fig. 1. *Dywidag, Italian patent n. 476948, "Procedimento per la costruzione di ponti con grandi distanze fra gli appoggi, in cemento armato", June 30 1951 (Archivio Centrale di Stato, Rome); Bendorf bridge under construction.*

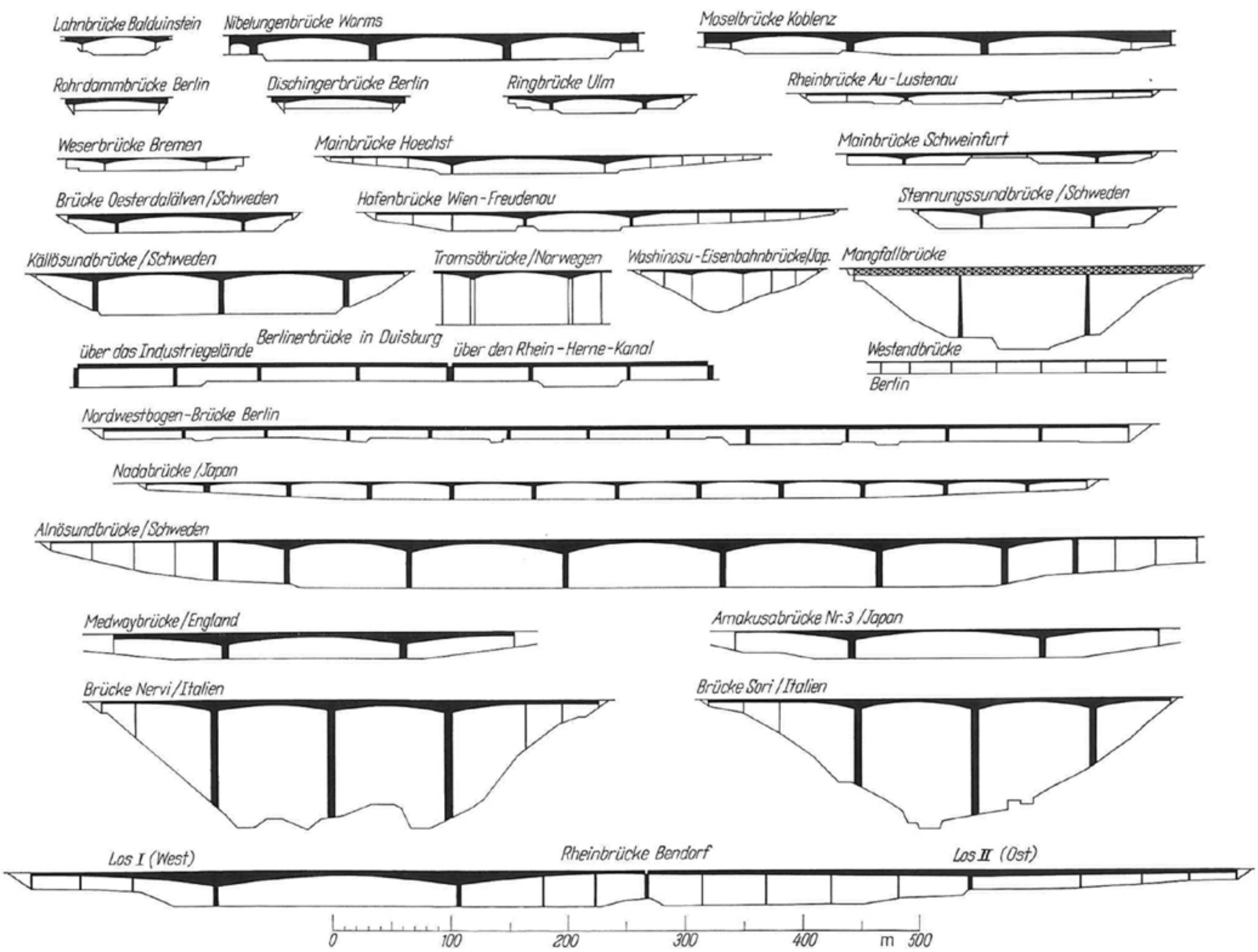

Fig. 2. *Scheme of the evolution of bridges built by the Dywidag cantilever system between 1950 and 1967 ("Dywidag Berichte", 4, 1967).*

for the pre-stressing of harmonic steel wires, the method allowed the girders to be supported without ribs, so as not to interrupt the traffic of the railway park below, until the girder, almost complete, could finally be anchored by the final tie rods [5].

Silvano Zorzi also explored the possibilities of the technique, applying the Dywidag patent to the viaducts of the Genoa-Sestri Levante motorway that cross the Nervi, Sori and Veilino torrents (1963-1965). The bridges have spans ranging from 70 to 100 metres and reach an altitude of 100 metres at the bottom of the valley, being three of the highest built with the original Dywidag system. The Autostrade Company's projects initially included sequences of parabolic arches, but the Superintendence of Liguria rejected the solution because of its impact on the landscape.

The cantilever system, therefore, convinced Zorzi, in charge of the new executive design, for the low rate of workforce required, evident if this site is compared to the very crowded ones on the Autostrada del Sole, a few years earlier.

An analysis of the project's prices reveals [6], anyway, the considerable impact, on the cost of the works, of dismantling the equipment from a pile, transporting it down, pulling and reassembling it on the next pile: the problem stimulated the search for even more convenient solutions, as will be seen hereinafter.

Outside the country, also the less famous Italian engineer Alfredo Passaro decided to test the free cantilever, using it for the Shambat Bridge over the Nile in Khartoum, Sudan (1962-1965) [7]. With the Recchi Company, however, Passaro chose the Freyssinet pre-stressing system, and the firm purchased directly from STUP – the company founded by the French engineer – the sliding formwork for casting the ashlars.

After the first experiments, the "free cantilever" system, particularly suitable for spans of over 70 meters and

Fig. 3. *Ferrata Viaduct at Cineto Romano, Rome-L'Aquila motorway, A. Gervaso, 1969-1970. San Cosimato Viaduct on the river Aniene, Rome-L'Aquila motorway, A. Gervaso, 1969-1970 (Amedeo Gervaso Private Archive, Lugano); Incoronata Viaduct at Polla, Salerno- Reggio Calabria motorway, A. Passaro, 1967-1968 (Alfredo Passaro Private Archive, Napoli).*

up to 200 meters, was successful in the typical field of application of the arc solution. The cantilevered bridge, with its characteristic beam shape with a variable section, with a curved intrados that indicates the origin of two shelves, thus became the leitmotiv in the most demanding crossings of the Italian motorway network, of which, since 1964 and in about ten years, more than 5,000 kilometres were built [8]. On the many new motorways and expressways, the structural engineers most experienced such as Amedeo Gervaso [9], Alfredo Passaro, Lino and Bruno Gentilini and Giorgio Belloni, as well as Zorzi and Morandi, designed bridges with the cantilever system, with ever-increasing spans.

In the absence of originality, all the projects seem to speak a single, foreign language, conditioned by the construction system (Fig. 3). The glorious Italian School of Engineering [1], suddenly, looks like it was in difficulty and struggling to express the identity that distinguished it during the years of Reconstruction and the economic miracle.

Exceptions are some attempts to customise the product, for example by modifying the look of the piles, with specially designed variants of self-erecting formwork systems, as in the Colle Isarco viaduct on the Brenner Motorway [10], designed by the two Gentilini brothers, or by emptying the lower slab of the girder, as Zorzi did in the Bisagno viaduct (1966-1967). Among the attempts of the Paduan engineer to preserve the identity of the School, two works certainly stand out: the bridge over the Tagliamento at Pinzano (1968-1970), where the initial cantilevered configuration adopted during construction was finally transformed into a perfectly proportioned three-hinged arch structure, and the viaduct over the Gorsexio stream for the Voltri-Alessandria motorway (1971-1978), where he completely redefined the relationship between the girders and the supports, thanks to the introduction of lamellar piles at the top [11].

3. BRIDGES AND CONSTRUCTION SITES IN MOTION

In the 1960s, construction companies began to master the new cantilever technique. This extended the bridge spans that could be built without using the arch, now an illustrious pensioner. The all-steel solutions, traditionally not part of the Italian construction site, were chosen for the execution of exceptionally demanding works, such as the viaducts on the Lao (1964-1970) and the Sfalassà (1970-1972) of the Salerno-Reggio Calabria motorway. The simpler crossings, with smaller spans, less than 45 metres and spread over all the sections, became the preferred field of application for prefabricated decks, almost exclusively pre-stressed, in the version of the isostatic truss on two supports.

Soon, however, engineers and construction companies began to notice the monotony and some inefficiency of traditional prefabricated solutions. The former tried to avoid the boring image of the infinitely repeated trilithon, while construction firms studied ways to reduce operations on-site and speed up the production of components, in the workshop or worked on-site to set then in place [12].

One of the most extravagant attempts was the application of the bridge launching method [13]. The idea, born

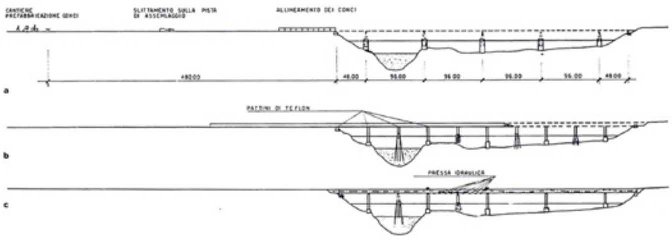

Fig. 4. *F. Leonhardt, the bridge on the Caroni River, scheme of the launching [13]; construction site.*

in the field of steel construction, is simple but was used, for the first time, in the project of a pre-stressed concrete bridge only in 1961 in Venezuela, by Fritz Leonhardt, Wolfhart Andrä and Willi Baur, for the crossing of the Rio Caroni (Fig. 4).

The system was then perfected in the construction of the Innbrücke at Kufstein in Austria (1966-1969), becoming "incremental", as the casting of ashlar was alternated with an advance of equal length of the cast girders, with a considerable reduction of the necessary site space.

Italian companies soon became curious about the system, as demonstrated by Del Favero's construction of the bridge over the Semorile ditch on the Genoa-Sestri Levante motorway (1967-1968), designed with the advice of the Hungarian engineer Thiamér Koncz (Fig. 5). However, despite the low rate of labour required, the modest installation costs, and the apparent simplicity of the procedure, the spread of the method was not "viral" [2].

The most important attempt to identify alternatives to prefabricated systems for the construction of bridge

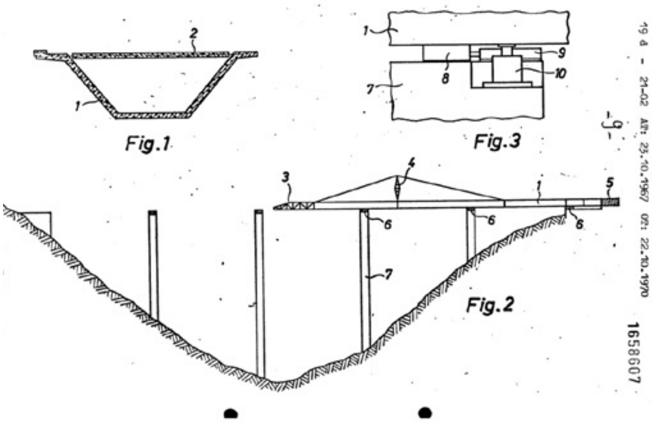

Fig. 5. *T. Koncz, German patent n. 1658607, 1967 (European Office Patent Archive). Del Favero Company, the bridge over the Semorile ditch.*

decks, however, is certainly the one that exploited the potential of the self-launching falseworks, machines that make it possible to move the formworks for the casting of decks, without interruption, at height and without temporary supports, from one pile to the next.

The German company Polensky & Zöllner and the Austrian one Strabag, who won important contracts in West Germany, made the use of these machines systematic in Europe at the beginning of the 1960s. After the construction of the first viaducts with this technology, however, it became clear that work-planning strategies had to be implemented to optimise the use of this expensive equipment. In order to amortise the costs incurred, it was necessary to reuse them on average on at least four construction sites [14]. Obviously, this affected the design of the viaducts: the more similar and standardised they were, the easier it was to reuse the equipment.

In Italy, meanwhile, the protagonist in infrastructure projects was no longer the bridge – an object completed and placed on the single crossing – but the long, very long viaduct, developed up to tens of kilometres, whose proportions remain difficult to perceive. The viaduct was used as an urban overpass, to solve traffic problems, and as a substitute for the embankment on expressways. In cases where the project foresees many spans of constant width, not exceeding 50 metres, the use of the self-launching falsework was effectively competitive [15].

The one who interpreted the use of these sliding machines in the most refined way was Zorzi, which always used the most up-to-date technology to guarantee competitiveness to its design proposals [16, 17].

In those years, he was looking with interest at the very efficient German falseworks and to the mushroom-shaped viaducts made with a new type of translating device, patented by Dywidag and used by Finsterwalder, for the first time, in the viaduct over the Elz valley between Kehrig and Kaifenheim [18].

The “Dywidag type” machine allowed the formwork to be shaped freely, hanging from the metal ribs surrounding the casting square (Fig. 6). Zorzi used it, at the

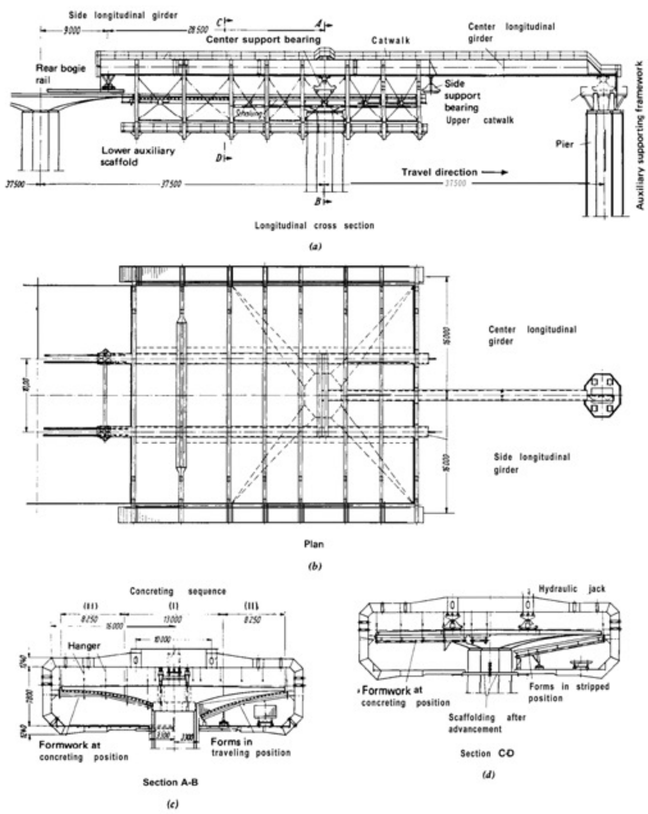

Fig. 6. *U. Finsterwalder, Dywidag, viaduct on the Elztal between Kehrig and Kaifenheim, Germany, 1964-1965, view during construction and scheme of the self-launching falsework.*

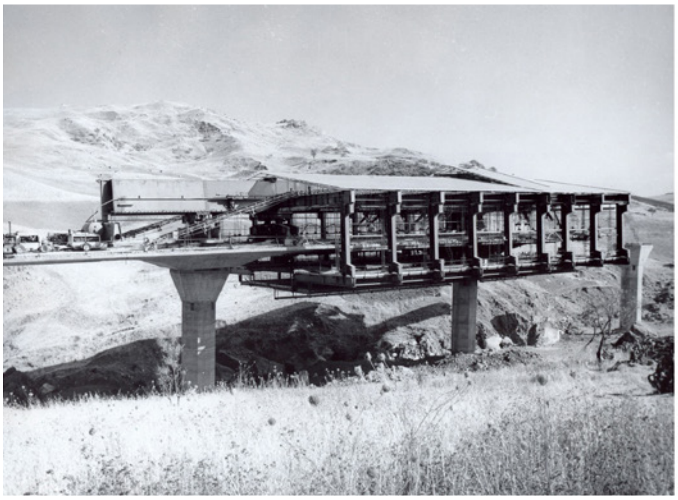


Fig. 7. *S. Zorzi, Fichera viaduct, Palermo-Catania motorway, 1971-1972, self-launching falsework (Inco Archive, Mendrisio); view from below (De Col Engineers private archive, Belluno).*

first opportunity, for the 7 kilometres of the Fichera viaduct (Fig. 7) on the Palermo-Catania motorway (1971-1972) [16].

Fig. 8. *S. Zorzi, L. Lonardo, Viaduct on the Teccio river, Torino-Savona motorway, 1973-1976 (photo by Sergio Poretti, SIXXI Archive, University of Rome "Tor Vergata").*

The most elegant and at the same time spectacular result, however, appears today the viaduct over the Teccio, for the doubling of the Turin-Savona motorway (1973-1976). On a sequence of very high piles, made transparent thanks to the expedient of the lamellar supports already used in the viaduct over the Gorsexio, the machine was launched at dizzying heights and drew a very thin pre-stressed ribbon (Fig. 8).

Zorzi then tested the system on a large scale in the third mainland bridge over the Lagos Lagoon (1976-1980), in Nigeria, built by a Joint Venture led by the local branch of Borini & Prono. It confirms Zorzi's attempt to preserve the quality of the viaduct's design even outside Italy, in countries where it was apparently impossible to propose a formally refined project, using entirely mechanised construction procedures (Fig. 9).


Fig. 9. *S. Zorzi, third mainland bridge over the Lagos Lagoon, Lagos, Nigeria, 1976-1980 (Inco Archive, Mendrisio).*

4. PREFABRICATION AND OTHER STORIES

Despite the interest aroused by the self-launching false-works, their application was limited, in Italy, mainly to works inserted in special environmental or urban contexts, and to Zorzi's solitary research [15].

The major Italian construction firms, which in those years joined together to dedicate themselves also to the building sites of the Rome-Florence express railway, aimed instead at perfecting the prefabrication techniques of the decks.

The experience of the Ferrocemento company and one of its structural engineers, Pellegrino Gallo, is emblematic [19, 20]. On the Rome-Florence "Direttissima" railway, the company built the Montallese viaduct (1980-1981), over two and a half kilometres long, and then the Faella, Riofi, San Zeno and Chiana viaducts (1986-1990), for a total length of 8 kilometres, with giant single-cell box modules, each capable of covering spans of 25 metres (Fig. 10). These decks, entirely produced in the workshop, were the result of studies and research conducted by the company since the end of the fifties, in which a strategy of progressive reduction of the operations to be carried out to build bridges and viaducts had been put in place. In the eighties, the executive procedure was perfected to such an extent that the production and installation of modules were achieved, at the rate of four spans in 5 working days.

In the meantime, the lack of long-term planning on roadworks was discouraging large investments in such expensive equipment. For this reason, also construction companies in Italy began to adopt cantilever building techniques based on the assembly in situ of prefabricated segments.

The technique, which originated from Freyssinet's experiments at the turn of World War II, was perfected by Jean Muller in the small bridge at Shelton, near New York, introducing the "match-casting" procedure [2]. In just a few years, the technique became so reliable that it could be used in the construction of the Chillon Bridge in Switzerland (1966-1969): its sinuous, variable-profile deck is the result of the assembly of 1376 prefabricated elements glued with epoxy resin [21].

Compared to these experiences, particularly advanced, in Italy, the technique was introduced and spread with years of delay. Abroad, however, it was applied by the companies Ferrocemento, Impresit, Girola and Sideco SACIC for the construction of the central span of the remarkable 245-metre span of the "General Manuel Belgrano" bridge over the Rio Paranà (1968-1973), using a new mineral material, the "tixojoint", instead of the epoxy resin.

It was only in the Eighties that we finally saw large-scale applications on Italian construction sites. In particular, on the Udine-Carnia-Tarvisio motorway, prefabricated segments gained considerable success because

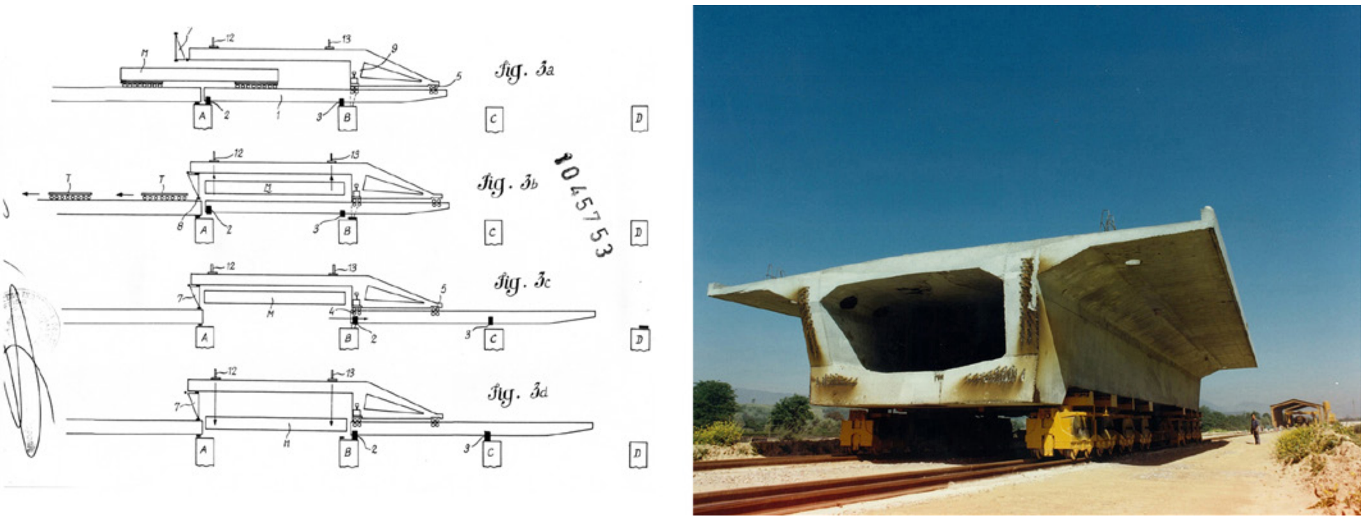

Fig. 10. *Ferrocemento, P. Gallo, patent n. IT1045753, "Procedimento e dispositivo per il varo in opera di impalcati prefabbricati costruiti in un pezzo unico monolitico", December 21 1972; transportation of the giant decks of the S. Zeno viaduct, Rome-Florence "Direttissima" railway, 1986-1990 [20].*

they made it possible to select the optimal solution freely with the minimum cost between different span sizes and number [23].

5. EPILOGUE

In the 1990s, research seemed to focus more on improving the mechanical characteristics of materials and their durability, given the problems that emerged in the management of existing infrastructure, in some cases suffering from rapid degradation. It is no coincidence that Mario Paolo Petrangeli, in those years, elaborated and publicised the theory of the machine bridge, whose parts could easily be replaced at the end of their useful life [24].

On the construction sites, the systems developed over the previous three decades were continuously being improved. In some cases, there was a remake of some of the most successful works designed by Zorzi, such as the Fadalto motorway viaduct (1988-1990) and the one on the Bormida valley (1998-2000). On their own construction sites, the State Railways preferred isostatic solutions, thanks to the adoption of the "long welded rail", decreeing the success of the giant prefabrication, of which the "Modena viaduct system" (2002-2006) for the High-Speed Milan-Bologna Line represents one of the most significant applications [25].

6. CONCLUSIONS

The investigations carried out have made it possible to reconstruct the transformation of the infrastructure sector from the 1960s to the 1980s, helping to shed light on the history of Italian engineering in this period.

In particular, from the study presented, it emerges how the introduction of new technologies, modern and advanced, irreversibly changed the approach to the design of the large structure and how the national yard completely abandoned its artisan dimension. The choice of structural schemes and shapes is no longer determined by the static solutions in operation, but by the construction systems and equipment used for prefabrication, handling, laying, or casting. The traditional building site, in which it had been possible to create unique pieces, was transformed into a mechanised factory, where work times and procedures were increasingly similar to those of an industrial production chain.

Together with other factors linked to public works policy in the same years, mechanisation influenced the progressive homologation and standardisation of viaducts, which now extend as far as the eye can see. In the operational fervour of these years, the identity of the Italian School of Engineering and the Made in Italy product, which only a few solitary talents tried to survive, suddenly dissolved.

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