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An historical research on the development and application of prestressed concrete in Italy.

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Abstract

Given the diverse and rich morphology of the Italian Peninsula, bridges have played a major role in the development of this country starting from the Roman times with road systems like the Aurelia and the Cassia, still standing today.
Since ancient times, the development of a road and a bridge infrastructure network has always been the expression of a State's organizational structure and power, being tied to a military or trading nature.
Without doubt, the advent of concrete has allowed to quickly build and connect the country from north to south by developing an intense network of roads and bridges. Prestressed concrete has played a crucial role in Italy's infrastructure projects starting from the 1950's with the construction of the Autostrada del Sole. Prestressed concrete represents a significant milestone in the evolution of bridge engineering, enabling the construction of structures with longer spans, increased durability, and enhanced structural performance. Through historical research, this study highlights the evolution of prestressed concrete technology in Italy, tracing its inception to early experiments and its subsequent refinement over the decades. The study explores the pioneering efforts of the Centro di Studio sugli Stati di Coazione Elastica at the Polytechnic of Turin for the development and application of prestressed concrete in Italy from 1945 to 1962. This study highlights key engineers, patents and case studies that have contributed to the technological advancement of prestressed concrete in Italy.

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1. Introduction

The year 2024 marks the 200th anniversary of the introduction of Portland Cement, one of the key ingredients of modern concrete. In these 200 years, no other building material has changed and contributed to the development of our modern cities and infrastructure as concrete. Indeed, the technology of this material evolved greatly in this timeframe, with the development of new and more advanced systems. Pre-stressed concrete is one of them, defined as an *“entirely new material” that led to a “revolution in the art of building” (Ordonez, 1979).*

With the technique of prestressing, the relationship between concrete and steel is transformed into a “coaction”, where the reinforcement is used to create a preventative state of tension in the concrete itself, which is then able to withstand tensile stresses due to the mechanism of the sum of the effects (Iori, 2003).

This paper will be focusing on the introduction of pre-stressed concrete in Italy from its development to our current times.

1.1. First Experimentation with Pre-stressed Concrete

The first experiments with pre-stressed concrete are attributed to P.H. Jackson, in San Francisco in 1886, who was granted the first patent in the United States for prestressed concrete design. The initial approach on the development of pre-stressed concrete was based on using low carbon rods having a relatively short elongation within the proportional limit of the steel. This system was later optimized by using high carbon cold drawn wire by Eugéne Freyssinet (1876-1962), a French structural engineer considered the pioneer of modern pre-stressed concrete. Freyssinet was an engineer and a prolific bridge builder, but more importantly was a very skilled craftsman. From a young age, he started working using his hands, and by the age of 20 he was already a competent craftsman. Freyssinet's craftmanship skills and background influenced him to seek an engineering solution to his structures through simplification of forms and economy of means.

After graduating in 1905, Freyssinet started building several concrete arch bridges, breaking his own world record for span length after each bridge (Veudre, Boutiron, Châtel-de-Neuvre). During this period, he was able to understand that high-strength steel along with high-quality concrete are necessary to create permanent pre-stressing in concrete. Freyssinet registered his first patent on prestressed concrete in 1928 in France, and a year later in Italy (Figure 1). As Freyssinet quoted: “*I reached my goal. So now I'm looking around to see what I can use this discovery of mine for. And in my opinion, modern society needs housing, parks and highways.*”

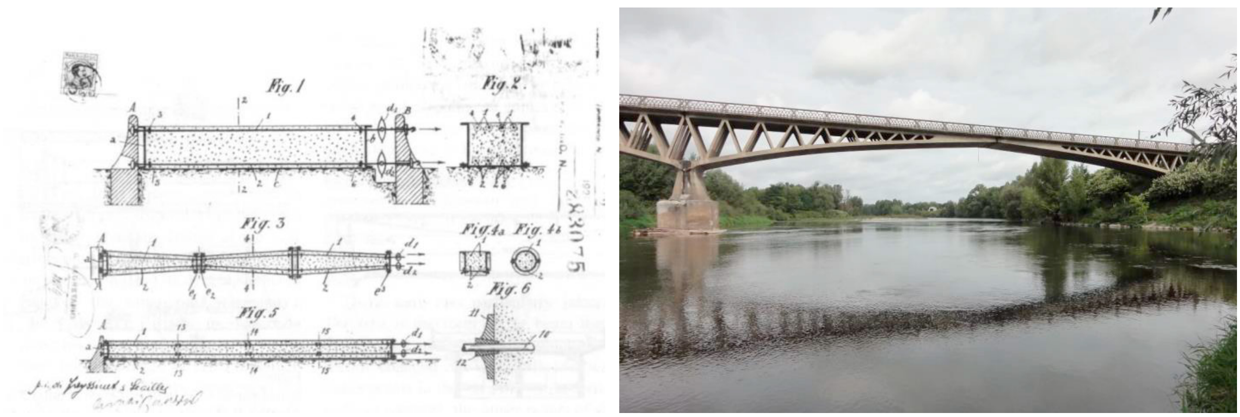


Figure 1 (a) Italian patent n.2830875 by E. Freyssinet and J. Séailles: Processo di prefabrication of reinforced concrete, October 1929 (Courtesy of Archivio Centrale dello Stato); (b) Concrete Arch bridge of Châtel-de-Neuvre by E. Freyssinet (Courtesy of www.freyssinet.com).

In 1946, Freyssinet designed and built the Luzancy Bridge, which is considered the first example of a prestressed concrete structure in Europe (Figure 2).

Figure 2 (a & b) Views of the Luzancy Bridge by E. Freyssinet 1946 (Courtesy of www.structurae.net).

Other contemporary figures that contributed to the development of prestressed concrete that are worth mentioning are Gustave Magnel (1889-1955), a Belgian engineer, and Edward Hoyer, a German engineer who developed prefabricated prestressed floor beams.

2. The development of prestressed concrete in Italy

In Italy, the Polytechnic of Turin stood as a key player in the field of prestressed concrete, boasting influential engineers such as Gustavo Colonnetti and his student and successor Franco Levi. These remarkable individuals dedicated most of their careers to advancing the knowledge and applications of prestressed concrete in Italy, and in the World.

2.1. Gustavo Colonnetti, and the development of prestressed in Italy

A prominent figure in the development of prestressed concrete in Italy is Gustavo Colonnetti (1886-1968), an engineer born in Turin that played a key role in the advancement of this system across the country. Director of the Polytechnic of Turin from 1922 to 1925, Colonnetti was transferred to the chair of Construction Science in 1928, the same year when Freyssinet introduced the first patent on prestressed concrete.

With the advent of fascism, Colonnetti refused to join the fascist party and escaped from political persecution in Switzerland in 1943. During his exile, he founded a university campus for Italian refugee students in Lausanne, of which he was the director. Some of the engineers who will be the "*architects*" of the new prestressing technology in Italy were involved in this school either as faculty members as for Franco Levi and Aldo Favini, or as students as for Silvano Zorzi.

In 1939, Colonnetti published a series of articles on the development of prestressed concrete in Europe. He truly believed in this technology, and was determined to promote it amongst the community of Italian engineers and scientists as transpired from his 1939's writings published in the journal *Il Cemento Armato*: "*iron conservation must not be sought in absurd returns to decidedly outdated building technologies – nor in the adoption of no less absurd surrogates – but rather by proceeding, unperturbed, using all means available and the aid of science and experience, with the development of more advanced technologies*" (Colonnetti, 1939)

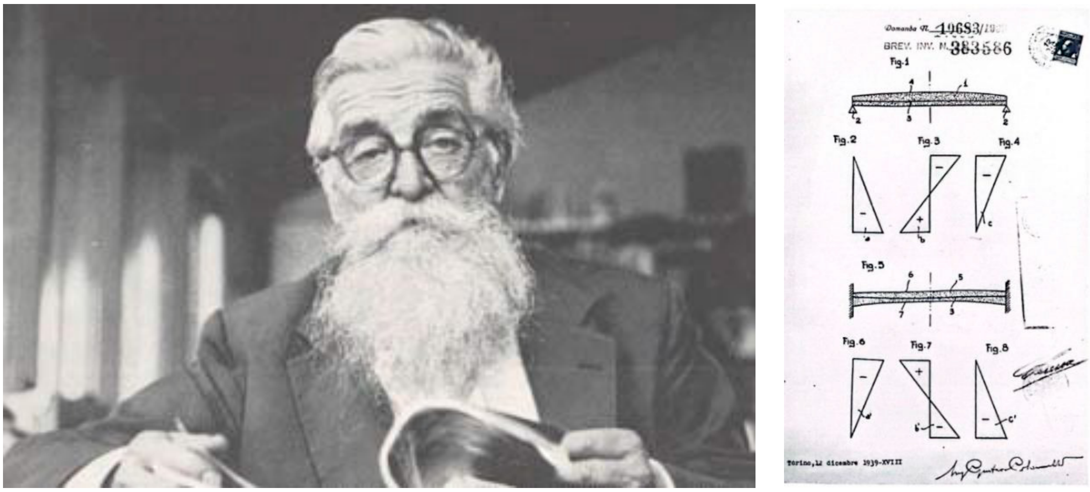


Figure 3 (a) Engineer Gustavo Colonnetti (Courtesy of Polytechnic of Turin); (b) Patent n. 383586, G. Colonnetti Trave armata ad armature preventivamente tesa, 1939 (Courtesy of Archivio Centrale dello Stato).

The first true application of prestressing in Italy were carried out on concrete pipes. Manufactured by Vanini, these prestressed concrete pipes were made by spirally wrapping and weaving a steel wire around an already cured pipe, and then protecting it with a layer of fibre-reinforced concrete (Italian Patent n. 314685 by Guido Vanini & C., 1933) (See Figure 4). With this patent, Vanini claimed the rights to a machine that was capable of prestressing pipes using steel wire under tension. Few years later, in 1939, the S.C.A.C., Società Cementi Armati Centrifugati, further developed its already famous centrifuged concrete poles by inserting tensioned high-strength wires along the length.

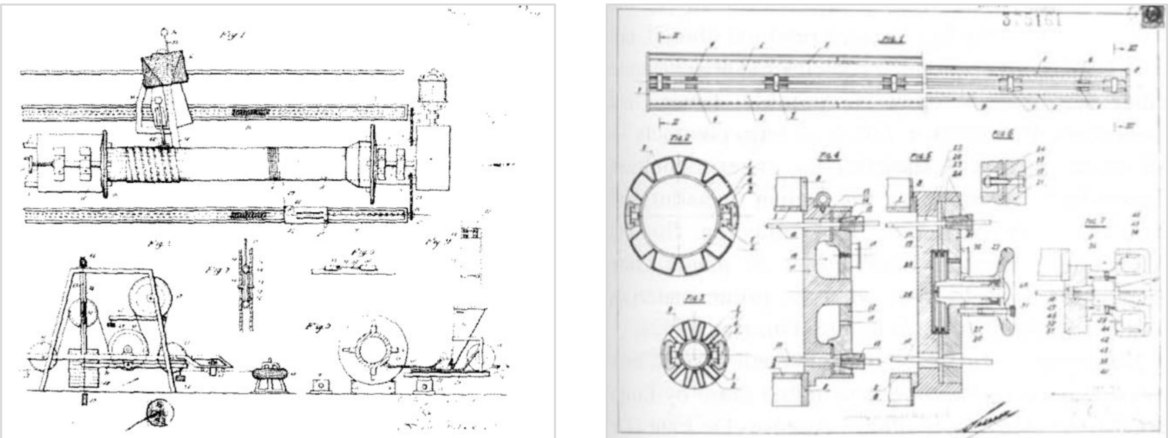


Figure 4 (a) Patent n.314685 by Guido Vanini (Courtesy of Archivio Centrale dello Stato); (b) Italian Patetnt n.375161 by Società Cementi Armati Centrifugati SCAC (Courtesy of Archivio Centrale dello Stato).

However, the first patent on prestressing concrete beams is attributed to Eng. Colonnetti, who developed a new innovative method for the calculation of partially prestressed beams (Figure 3) patented in December 1939.
This patent blended the best aspects of the systems previously developed by E. Freyssinet himself and, in Germany, by Franz Dischinger (Marro, 2011).

Despite Colonnetti's great effort and enthusiasm for this technology, the implementation of prestressing in Italy delayed a few more years, primarily due to the unavailability of high strength steel caused by the war.

Regardless of the delays on the application of prestressed concrete in real structures, the war years accelerated the research and experimentation of this system due to the pause on large-scale building and construction caused by the conflict. Several experimentations took place both in academic laboratories, industries and also led by private engineers interested in this technology as for the case of Riccardo Morandi that published his patent in 1944. On the academic front, the Laboratory of Construction and Briges Institute of the Polytechnic of Milan (1941) was one of the protagonists of this study.

On the same year (1941), the Società Anonima Cemento Armato Precompresso was founded in Turin encouraged by Giovanni Agnelli. New Italian patents soon were developed by other important figures as Franco Mattiazzo (1942), Augusto De Fant (1942), Luigi Magistretti (1940). After the conflict, Colonnetti returned to Italy and was elected the President of the National Research Council (Consiglio Nazionale delle Ricerche - CNR) in 1945. This marks the beginning of a new chapter for prestressing concrete in Italy.

2.2. Franco Levi: Successor and Student of Gustavo Colonnetti

Franco Levi, student and successor of Colonnetti, played a pivotal role in advancing the field of prestressed concrete in Italy. Levi facilitated a crucial link between Colonnetti, with his groundbreaking research on the study of "*coaction*", and Freyssinet's works in prestressed concrete and related technical papers, with which he came in contact during his time in France.

Born in Turin in 1914, Levi graduated in civil engineering from the École Centrale in Paris in 1936 and from the Polytechnic of Milan in 1937. In 1938, he was an assistant to Prof. Colonnetti at the Polytechnic of Turin. Shortly after, racial laws were introduced in Italy and excluded him from the University. From 1938 to 1943, Levi took refuge first in France, and then in Switzerland.

During his exile in France, Levi came across Freyssinet's patents and work developing a great interest on the subject: "*Reading Freyssinet's statements was a true revelation for me: torn away for a few hours from the anguish of that sad period, I lived moments of pure enthusiasm, contemplating the exciting possibilities that arose from this way of 'educating' structures for the tasks they are destined for.*" (Levi, 2002)

Upon his return in Italy, Levi carried out a key role both as Director of the Istituto di Scienza delle Costruzione (Department of Costruction Science) of the Polytechnic of Turin where a special attention was devoted to the development of prestressed concrete, and as a designer contributing to the construction of important structures as the Palazzo delle Esposizioni in Turin (1961), which represents a celebration of prestressed concrete. In 1978, Levi received the Freyssinet Medal in recognition of his significant contribution to the field of prestressed concrete, coinciding with the 50th anniversary of Freyssinet's first patent (1928). As Eng. Riccardo Morandi once said: "*If Freyssinet is considered the father of prestressed concrete, Franco Levi is indeed the uncle*." (Marro, 2011)

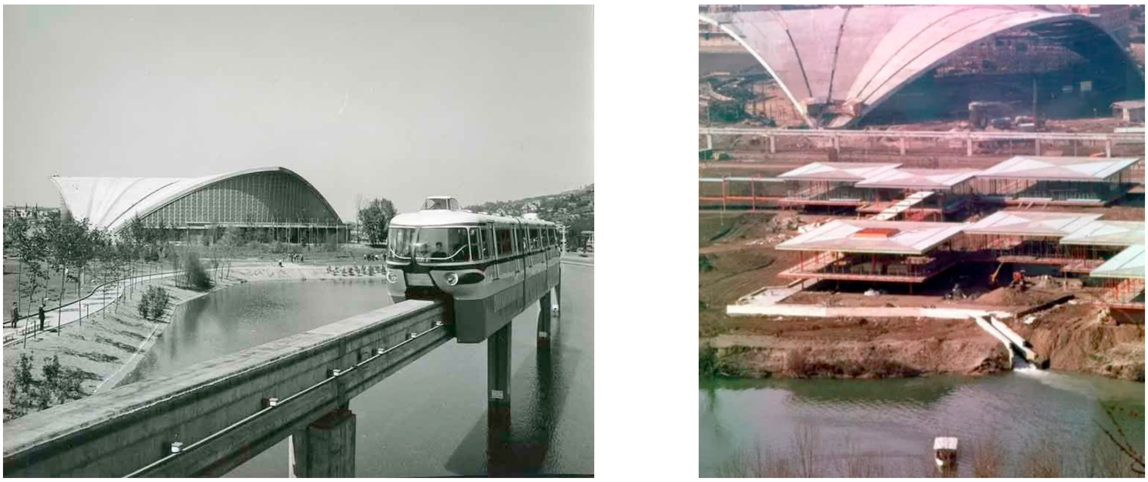


Figure 5 (a) View of Palazzo delle Esposizioni in Turin. Photographed by Paolo Monti, 1961. (Courtesy of Wikimedia-Commons). (b) Photograph of the Palazzo delle Esposizioni under construction. (Courtesy of Archivio di Stato di Torino).

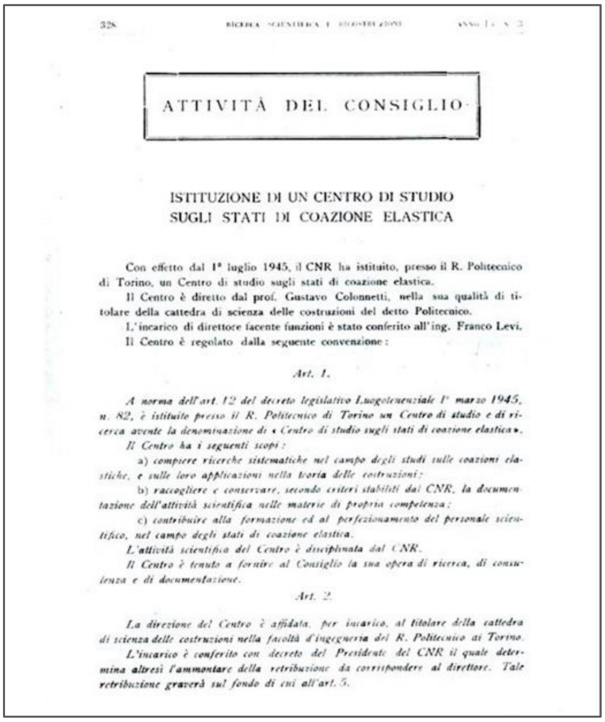
2.3. The Role of the Centro di Studio sugli Stati di Coazione Elastica at the Polytechnic of Turin for the development of prestressed concrete in Italy

In 1945, the Centro di Studio sugli Stati di Coazione Elastica (Study Center on Imposed Elastic Constraints) was founded at the Polytechnic of Turin by G. Colonnetti within the statutes of the CNR under the law CNR 1st July 1945 (Figure 6a), and remained active until 1961 Led by Professor Franco Levi, the Center was entrusted by the Italian Ministry of Public Works to review and approve all projects of prestressed concrete structures designed across Italy. Several key engineers at the time assistant professors at the Polytechnic of Turin were active in this committee, to name a few Professor Giorgio Macchi (1930-2023), who served in the committee between 1953-1954, and Professor Piero Marro (1930-2023), who served until 1961, when the center was dismantled.

The focus of the Center was to conduct research, dissemination and improve the laboratory testing procedures for the advancement of prestressed concrete.

The contract drawn between CNR and the Polytechnic of Turin included a detailed list of obligations from both parties. The original contract was stipulated for five years, upon automatic renewal. The contract specified that the director of the center had to be the Professor of Construction Science within the School of Engineering of the Polytechnic of Turin and being compensated of 12.000 Lire per year. At the end of every year, the group was asked to prepare a report on the status and results of the research, and achievements.

During the initial two years, more than 40 scientific papers were published, providing detailed insights into the calculation methods and testing procedures of this system. Notably, 20 of these publications were authored and curated by Franco Levi (Marro, 2011).



ATTIVITÀ DEL CONSIGLIO

ISTITUZIONE DI UN CENTRO DI STUDIO SUGLI STATI DI COAZIONE ELASTICA

Con effetto dal 1° luglio 1945, il CNR ha istituito, presso il R. Politecnico di Torino, un Centro di studio sugli stati di coazione elastica.

Il Centro è diretto dal prof. Gustavo Colonnetti, nella sua qualità di titolare della cattedra di scienza delle costruzioni del detto Politecnico.

L'incarico di direttore facente funzioni è stato conferito all'ing. Franco Levi.

Il Centro è regolato dalla seguente convenzione:

Art. 1.

A norma dell'art. 12 del decreto legislativo Luogotenenziale 1° marzo 1945, n. 82, è istituito presso il R. Politecnico di Torino un Centro di studio e di ricerca avente la denominazione di « Centro di studio sugli stati di coazione elastica ».

Il Centro ha i seguenti scopi:

a) compiere ricerche sistematiche nel campo degli studi sulle coazioni elastiche, e sulle loro applicazioni nella teoria delle costruzioni;

b) raccogliere e conservare, secondo criteri stabiliti dal CNR, la documentazione dell'attività scientifica nelle materie di propria competenza;

c) contribuire alla formazione ed al perfezionamento del personale scientifico, nel campo degli stati di coazione elastica.

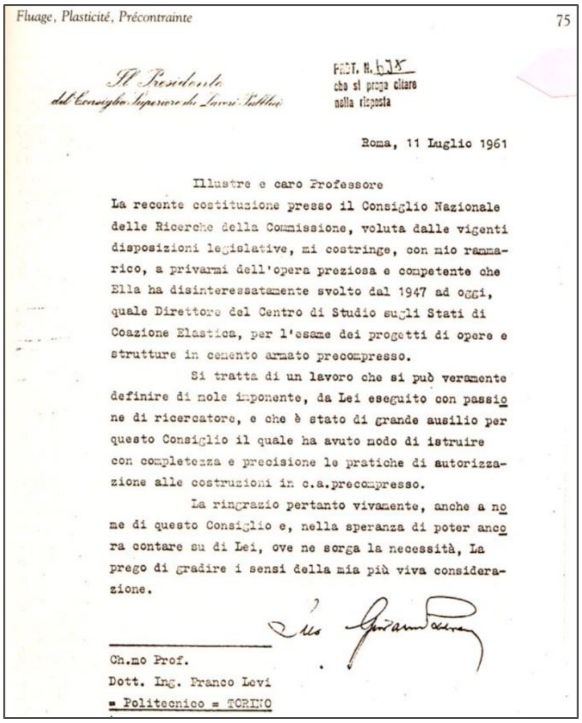
L'attività scientifica del Centro è disciplinata dal CNR.

Il Centro è tenuto a fornire al Consiglio la sua opera di ricerca, di consulenza e di documentazione.

Art. 2.

La direzione del Centro è affidata, per incarico, al titolare della cattedra di scienza delle costruzioni nella facoltà d'ingegneria del R. Politecnico di Torino.

L'incarico è conferito con decreto del Presidente del CNR il quale determina altresì l'ammontare della retribuzione da corrispondere al direttore. Tale retribuzione graverà sul fondo di cui all'art. 5.



Fluage, Plasticité, Précontrainte 75

Il Presidente del Consiglio Superiore dei Lavori Pubblici

PROT. N. 638 che si prega citare nella risposta

Roma, 11 Luglio 1961

Illustre e caro Professore

La recente costituzione presso il Consiglio Nazionale delle Ricerche della Commissione, voluta dalle vigenti disposizioni legislative, mi costringe, con mio rammarico, a privarmi dell'opera preziosa e competente che Ella ha disinteressatamente svolto dal 1947 ad oggi, quale Direttore del Centro di Studio sugli Stati di Coazione Elastica, per l'esame dei progetti di opere e strutture in cemento armato precompresso.

Si tratta di un lavoro che si può veramente definire di mole imponente, da Lei eseguito con passione di ricercatore, e che è stato di grande ausilio per questo Consiglio il quale ha avuto modo di istruire con completezza e precisione le pratiche di autorizzazione alle costruzioni in c.a.precompresso.

La ringrazio pertanto vivamente, anche a nome di questo Consiglio e, nella speranza di poter ancora contare su di Lei, ove ne sorga la necessità, La prego di gradire i sensi della mia più viva considerazione.

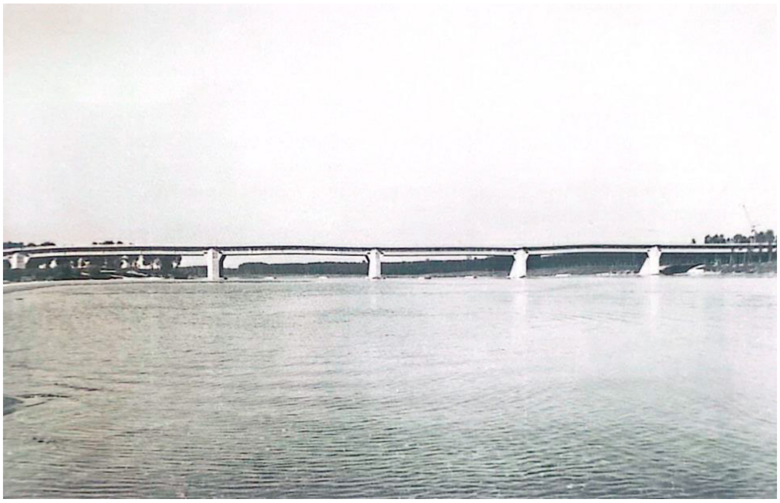
Ch.mo Prof.
Dott. Ing. Franco Levi
= Politecnico = TORINO

Figure 6 (a) Centro Studi Sugli Stati di Coazione Elastica Agreement (Courtesy of DISEG Polytechnic of Turin); (b) Correspondence Letter to F. Levi by the President of the Council of Public Works (Courtesy of DISEG Polytechnic of Turin).

In 1946, the Center organized the First conference on reinforced concrete after the war in collaboration with the associations of engineers and architects of Turin as an attempt to disseminate the knowledge of prestressed concrete and the activity of the Center. During this conference, a workshop was organized at the laboratory of the Polytechnic of Turin, where a 12-meter prestressed beam and a floor-slab were tested to showcase this technology to the community of engineers, architects and builders.

In 1947, the Ministry of Public Works issued a decree regarding the use of prestressed concrete in Italy. From 1947 till 1961, hundreds of projects were submitted to the Center that examined the projects, identified errors, and suggested amendments; simultaneously, this process gave insightful research ideas to the engineers at the Center. This mission was terminated in 1961 (see the letter to Professor Franco Levi by the President of the Council of Public Works, in Fig.6(b)).

From 1945 onwards, it was a prolific time for prestressed concrete structures in Italy. The country was undergoing a large post-war reconstruction effort. In 1949, the Italian National Association of Prestressed Reinforced Concrete was established. In these years, the large network of infrastructures that crossed Italy from North to South was built (Autostrada del Sole) consisting of approximately 1200 km of roads and bridges. Inevitably, prestressed concrete was one of the main protagonists of this heroic work.



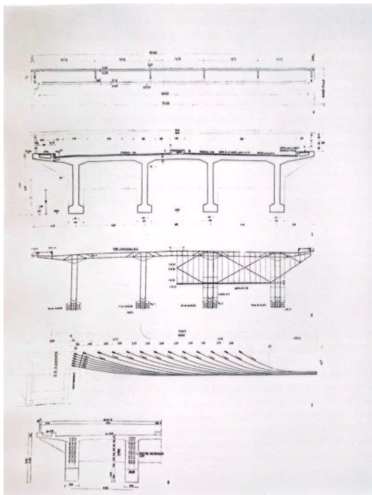
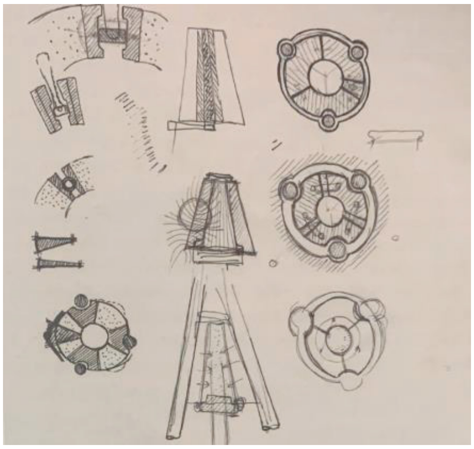


Figure 7 (a) View of the bridge (Courtesy of Macchi Progetti Publication); (b) Original construction drawings (Courtesy of Macchi Progetti Publication).

One of the project worth mentioning is the Ponte sul Po a Mortizza, designed by Silvano Zorzi and Giorgio Macchi between 1957 and 1959. At the time, this bridge represented a great engineering achievement with its 1175 meter in length crossing one of the largest rivers in Italy, the Po River (Figure 7). Initially, Zorzi had envisioned to use continuous prestressed concrete beams with a connecting pour and cap cables on the supports. However, the solution proposed by the construction company presented a reduction of the deck section of 30%, which led in a reduction of 20% of the prestressed steel needed. Despite Zorzi's vision, this solution resulted to be more economical and indeed was selected. Zorzi himself will describe their effort as: "We are the inventors of the simply supported beam" (Macchi, 2019).

In addition to reviewing new projects, new systems were tested and patented at this center as per the Tecnicavi System. This new anchorage system was developed and patented by Giorgio Macchi and Franco Levi in 1959 at the Turin center. This system was later commercialized by Società Tecnicavi, a company founded by Giorgio Macchi, Ernesto Segre, an estimated colleague of Macchi at the Polytechnic of Turin and Ambrogio Gadola, owner of a reputable construction company in Milan. The company was active until 1995, and was later sold to the French company Freyssinet.



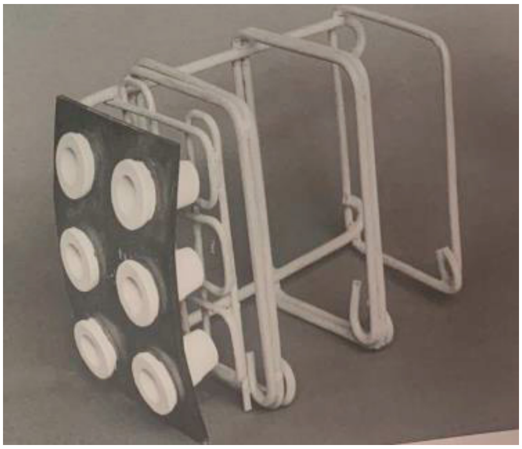


Figure 8 (a) Drawings of the Tecnicavi system by Macchi (Courtesy of Macchi Progetti Publication); (b) Tecnicavi Anchorage System (Courtesy of Macchi Progetti Publication).

3. Prestressed Concrete Today

The legacy of prestressed concrete is undeniably significant. This technology has been a driving force, contributing immensely to the advancement of bridge engineering not only in Italy but also on a global scale.

In Italy, the majority of prestressed concrete structures have now reached an age where maintenance and interventions are necessary. Furthermore, the increased frequency of natural and man-made disasters in recent times represent an additional threat to the performance and durability of our existing structures.

As defined by the Eurocode 2020, structural performance is the basic aspect of social performance of any concrete structure. The awareness of durability issues is crucial, especially for prestressed concrete structures if not adequately designed, constructed, and subjected to regular inspections and maintenance. Failure to meet the criterion of robustness can lead to serious consequences, including the collapse of the structure. Italy has been marked by several bridge collapses, often attributed to a lack of maintenance and improper interventions. A notable case is the collapse of the Viaduct of Polcevera in Genoa in August 2018.

In recent years, the topic of durability and performance has been greatly discussed in major international committees as per the FABRE Consortium, Eurocode, *Fib*, and ACI.

As emphasized in the Italian Guideline Document "*Guidelines for the Classification and Management of Risk, Safety Assessment, and Monitoring of Existing Bridges* (2020)", pre-stressed concrete bridges are especially critical structures, as neither conventional investigative techniques nor visual inspections provide a comprehensive understanding of their actual conditions. Exceptional care should be taken when developing a maintenance program for these structures, together with defining a testing program that are cost effective but at the same time provide the right amount of information to determine the health of the structure. The complexity of this system requires special attention and care to extend the life of these structures.

Acknowledgments:

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