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The First Reinforced Concrete Structures in Urban Renewal in an Italian Provincial City

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Abstract: For reinforced concrete, we may consider two histories: one focuses on the influence reinforced concrete has exerted on the process of renewal of the architecture of twentieth century; the other pertains to the manners in which the development of this material effectively came about in various geographic areas. The research group at the University of Trento analysed the complex of military constructions produced in the city, and, specifically, it undertook in-depth study of the manner in which the use of reinforced concrete spread to civilian architecture.

Keywords: Reinforced concrete, military engineering, construction history

Introduction

After the "insights" of Lambot (1850), Coignet (1861) and Monier (1867) numerous engineers and architects from throughout the world undertook studies and research into the use of concrete (in Germany Wayss, Bauschinger, Mattias Könen, Mörsch, Back, Kleinloghel and Döring, in Austria Neumann and Emperger, in France Hennebique, in Italy Vacchelli, Raddi, Colonnetti, etc.). However, although little known, a fundamental contribution to evolution of the technology was made by studies carried out within the technical departments of the military engineers where theoretical research was accompanied by the construction, testing and improvement of prototypes in an extremely short space of time.

The innovations in military engineering satisfied the need not so much for new and original solutions as for improved industrialisation of the processes involved in building defences, saving labour and materials, improving their sustainability, enabling them to merge better into the landscape, and, finally, producing structures ever less vulnerable to weapons which were becoming continually more powerful. The rapid evolution of weapons led not just to changes in the shape and location of the defences, but also to the adoption and spread of natural and artificial materials and experimentation of new building techniques.

This experimentation was encouraged by the presence in the Habsburg Empire of a number of companies producing the new materials. In the Austro-Hungarian Empire, for example, these factories played a fundamental role: Skoda made steel elements with the required shape and composition and Henkel perfected additives for the concrete mixture to speed up setting, enable the concrete to be laid at temperatures below zero, seal it, etc..

Use of reinforced concrete technology spread rapidly, thanks to its versatility and strength. Astute experimentation immediately highlighted the possibilities for improving the material and studies therefore began on the composition of the concrete and the use of iron rebars. Specifically, research was aimed at improving adherence between the steel and concrete by bending the smooth bars into a hook shape and at improving the mixture by introducing various types of siliceous, basaltic and granitic inert.

Fervent experimentation was carried out in numerous buildings, particularly in those countries (the Austro-Hungarian Empire, Germany and France) which, due to constant changes in size and therefore frontier during the second half of the 19th century, were obliged to construct defences able to withstand the new weapons. For example, the Austro–Hungarian Empire invested massive resources in building modern defences in the north and south of the Empire, particularly after the third war of independence (autumn 1866) when they lost the Veneto and needed to reinforce the southern frontier. Work therefore began to design and build a series of defences in the Adige valley to surround the city of Trento, last bastion on the road to German territory. For Trento, this meant the revival of an idea dating from the early Middle Ages when numerous castles were constructed along the main routes leading to the city to protect Trento enclosed within an imposing city wall.

The Austro-Hungarian Empire replaced the castles with modern defences: forts (23), fortified lines and blockhouses located so as to close the pass from possible attacks along the incoming roads and provide maximum protection for the stronghold.

Concrete was used to build military structures in support of the fortifications, such as accommodation, factories, warehouses, stables, etc. In Trento, the widespread use of reinforced concrete to build military structures also influenced civil building techniques where the potential of the new artificial material soon led to its use initially for single decorative elements, then for the entire structure first of bridges, viaducts and industrial buildings (the Vittoria mill, the Cavazzani bakery) and later detached houses and blocks of flats.

Reinforced Concrete in Military Structures

The material's remarkable resistance to impact and thus the possibility of building defences resistant to the destructive effect of shell fire emerged right from the earliest uses.

However, in the beginning concrete was used to replace the earth covering the parts exposed to direct fire. It was therefore necessary to verify the quantity and quality (fineness, degree of curing and chemical composition) to guarantee maximum resistance. Tests were carried out at the Ministry's laboratories to analyse first standard test pieces, then blocks and finally entire structures.

As can be seen from archive documents, the Ministry of War made it obligatory to perform numerous analyses on the materials which had to guarantee the greatest possible resistance in the least possible time. The best results were obtained with Portland cement and this became obligatory for the most important structures. Rhine trass cement or pozzolana could be used for secondary structures only.

Binder from Kufstein and iron from Donawitz in Styria were used to construct the Trento fortifications.

Ministry manuals specified the use of two standard mixtures, differing in the quantity of cement and therefore the end resistance – "calcestruzzo al quarto" (325 kg of cement) and "calcestruzzo al settimo" (200 kg of cement).

"Calcestruzzo al quarto" consisting of 1 volume of Portland cement, 1.5 volumes of coarse sand and 4 volumes of silica gravel, provided the greatest resistance to impact and was ideal for the parts of the structures most exposed to fire.

As it was "poorer", "calcestruzzo al settimo" consisting of 1 volume of Portland cement, 3 volumes of sand and 7 volumes of gravel, provided less resistance to impact and if hit by projectiles split into large blocks creating deep funnels.

Laboratory experiments on life size structures led to definition of minimum thicknesses for the concrete elements. Particular attention was paid to the elements (roofs, vaults, etc.) which might be hit by cannonballs or bombs.

For example, the results of research and experiments led first to the proposal of vaulted roofs consisting of two 1.5 m thick layers of concrete sandwiching a 1.0 m layer of sand or masonry debris to deaden the vibrations produced by shell explosion. Later, coke powder (light and with a high insulating capacity) was used for the filling. Subsequent research showed the filling to be ineffective and solid roofs began to be made. Experiments led to definition of an optimum thickness of 2.5 m. The funnels produced by the explosion of mines or shells in fact reached a maximum depth of 0.65 m, continuing to a depth of 1 m in exceptional cases only. Any further increase in thickness would therefore have had no influence on resistance, while increasing weight and above all construction costs. To increase resistance, iron mesh and then iron beams were later inserted between the two layers of concrete. The gap was also used to house ventilation conduits, indispensable for the safety and functionality of the structure, but also requiring maximum protection.

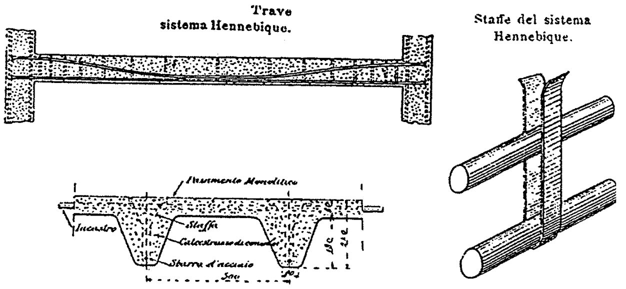

Figure 1: Hennebique System

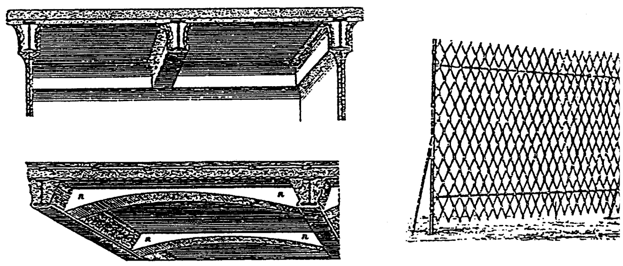

Figure 2: Golding System

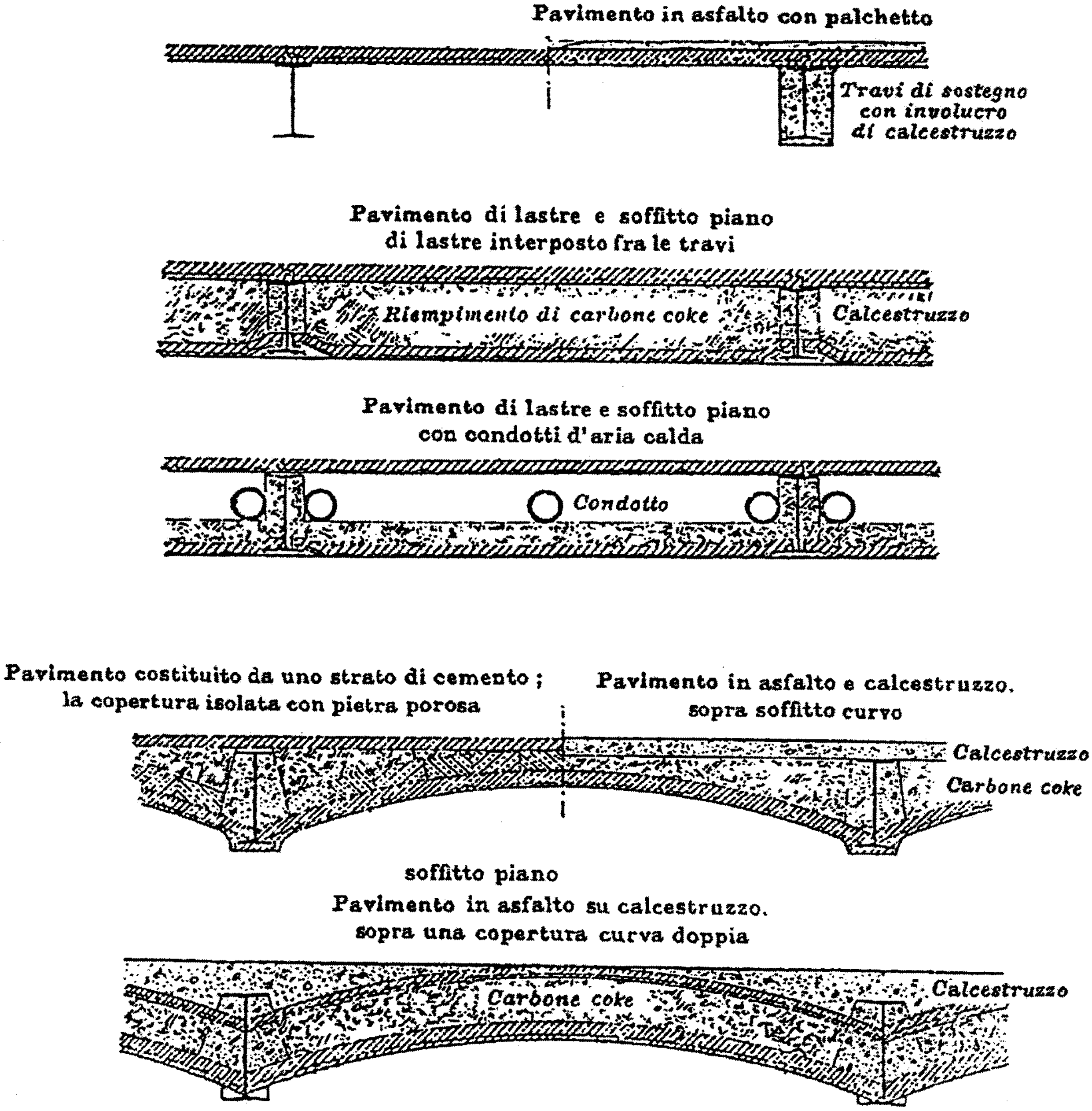

Figure 3: Monier System

In the military field, this technology was used to make scheme arch roofs with struts 1/10 of the chord, vertical load bearing structures, simple partitions, stairs, intermediate floors, etc..

The technique developed by the Habsburg military has remarkable similarities with the Monier system in which slabs of concrete reinforced with metal rebars were laid on iron H-beams.

In the techniques used by the military, there are also constant references to the Hennebique system (1892-1899), Golding system (1896), Aragon system, Mantel system, etc..

Experimentation into materials was followed by research into the optimum shape for the buildings which had to adapt to the morphology of the land.

In the case of fortifications, research led to construction of the first fortifications with a well or turret to house and protect the cannon. Merging perfectly into the landscape, these casemates with a circular plan were made first from concrete, then metal armoured reinforced concrete.

The Austro-Hungarian experience then moved on from the disappearing turret to rotating armoured domes which although visible also guaranteed greater resistance.

In less than twenty years, reinforced concrete became the preferred material for military structures and it was then also used for secondary buildings such as barracks.

Concrete and the Trento Fort

Use of concrete began to spread in Trentino when it was decided to construct a fort to protect the southern border of the Empire. The military introduced the material and instructed the local workforce in its technology.

At first, the cement came from the north Tyrol with Kufstein cement being particularly in demand. At the beginning of the 1890s however, under pressure from the military engineers, Trento City Council promoted the setting up of a number of factories (including the Frizzera cement factory at Piedicastello) which continued to expand. Locally made cement was used exclusively to make urban military and civil structures.

In 1907, the ministry of public works issued "Directives for the preparation and construction of reinforced concrete structures", with provisions covering the composition of the mixture, size of the iron rebars, their bending, etc..

This directive stressed the desirability of using technology which had previously undergone "close examination by the competent authorities". Each request for authorisation to build military and civil structures had to be accompanied by drawings, static calculations and descriptions. In the case of larger scale works, calculators-constructors were to be consulted.

To ensure maximum responsibilisation, all documents had to be signed by the commissioner, the designers responsible for the drawings and calculations and the construction company.

The Directive made it obligatory during the design phase to specify the place of origin, nature and proportions of the constituent materials in the mixture, the characteristics and quantity of the water and the hypothetical resistance to compressive stress of the concrete after 28 days.

The materials used had to be certified by specific examining bodies and in the case of Portland cement concrete, the volume constancy, setting time, grinding fineness and resistance to compressive stress and bending had to be known. Laboratories were set up in all cement powder factories to satisfy the certification requisites.

Despite the obligation to use "controlled" materials, the quality of the materials to be used also had to be verified in test laboratories.

The Directive provided detailed instructions on the calculation procedure which must give a result with a margin of stability equal to that given by the method specified in the regulation itself.

The Law gave indications for correct laying of the concrete which had to start immediately after mixing and end before the conglomerate began setting. For example, Article 5 specified that before being worked, the mass must not be left for more than one hour in hot dry conditions and for more than two hours in cold damp conditions. Unused concrete must be protected from external agents such as the sun's rays, wind and heavy rain and must be remixed before being used. It also specified that the concrete must be laid without interruption (each layer must be a maximum of 15 cm thick) and each cast must be followed by thorough compacting.

The Directives gave extremely detailed indications regarding the iron rebars which must be free of "dirt, grease and rust". Above all, the design specifications regulating the dimensions of the bars and their installation (the layer of concrete covering the bars etc.) had to be respected.

The regulation also included provisions for fabricating the wooden formwork.

Indications were provided for the calculations, specifying extremely high values for accidental overload. In many cases, up to 50% increases in overload were specified, evidence of the experimentation underway and the absolute uncertainty of the calculation.

These provisions were issued in support of a drive to promote use of concrete technology which was to be used to make military support structures such as barracks, factories, bridges, etc.. The indications formed part of a series of regulations which on one hand promoted the building of barracks (Law no. 93 of 11 June 1879, modified by law no. 100 of 25 June 1895), making the Empire's municipalities responsible for design and construction, and on the other defined their formal, functional and technological characteristics (technical manuals H34 and H35).

In Trento, various military structures were constructed over a period of less than 30 years, including the Madruzza infantry barracks (1883 - 86), the military hospital (1891 - 94), the barracks for light infantry and bersaglieri in Via Barbacovi (1894 - 96), the barracks for the Tyrolese light infantry in Via Perini (1905-08), the military baths in Piazza Centa, the swimming pool in Via Madruzzo, the military firing ranges at Bondone and Mas dell'Aria, the manège and riding academy in Via alla Mantovana, the munitions depot at Ischia-Podetti, the Maso Desert barracks (1913-1914) and the sappers barracks at San Bartolomeo (1914). A further two structures remained on paper, the field artillery barracks which was to have been built south of the Perini barracks and the mounted bersaglieri barracks at Campotrentino, for which detailed drawings, descriptions and calculations were prepared.

These structures illustrate the progressive spread of the use of reinforced concrete and evolution of the technique. Trento's military buildings in fact show that concrete was initially used exclusively to make individual prefabricated elements of a limited size. For example, in the Madruzza barracks, Portland cement tiles were laid in service rooms and cement tiles were used for the roof. Portland cement was later used to seal foundation structures. For example, in the light infantry and bersaglieri barracks in Via Barbacovi, built near a torrent, the foundations were made from stone assembled with Portland cement.

Subsequently, skeleton structures were created with reinforced concrete beams and slabs resting on vertical stone and mortar elements, making it possible to cover large spans and above all bear considerable loads. In structures with stone or brick walls, the central load bearing walls were later eliminated and replaced with short thick concrete pillars. This was the case with the Perini barracks where single relatively small load-bearing elements were introduced to support massive foundation plinths. This paved the way for the great revolution in structures which were no longer bound by the dimensional rigidity of box-type plans with stone or brick walls.

During the next stage, the barracks were constructed with concrete skeletons. In the sapper barracks, the secondary buildings were constructed with a skeleton frame made from pillars resting on trapezoidal plinths and connected via beams and spandrels. Various concrete technologies were also introduced for floor and roof slabs, taking the Hennebique and Monier systems as the starting point and constructing slabs mixed with lightweight elements.

Prefabricated solutions were also developed for floor and roof elements, and adopted particularly after 1913.

Conclusions

Concrete was therefore introduced into the architecture of the city of Trento by the military, first to build forts, then barracks and support structures. Its introduction was imposed, but indispensable to modernise the defences to stand up to weapons different from those used in the past. This modernisation might seem an end in itself, but it also had a great effect on civil architecture. The Directives for the preparation and construction of reinforced concrete structures, taken on board by the City's own building regulations, encouraged the use of concrete, producing a slow evolution in the plan, elevation and style of all buildings.

The second half of the 19th century saw definition of the plan, elevation and style characteristics and organisation of barracks, previously established in existing buildings. E and H plans were adopted for this type of building, an apparent break with the massive design of the past. The new forms and the success of skeleton type structures enabled highly rational compact layouts to be created. Adoption of plans with a composite geometry also modified the façades, which were no longer solid but complex with indentations and elevations. Ornamentation of the façades was abolished, reinforcing the austerity characteristic of barrack type buildings and emphasising a sort of "minimalism", while at the same time reducing costs and construction times.

A simplification dependent on the spread of new materials and new technologies, with reinforced concrete in the forefront.

Military buildings are not however considered as having any particular value, having exclusively negative connotations, a reminder of the times and events of war, intolerance, isolation, etc.. When no longer used, the hypothesis of demolition is therefore often considered the most appropriate.

In recent years, however, military structures as a whole are being reassessed and in the case of fortifications, protective measures have been introduced leading to their valorisation and preservation. These measures are introduced more to protect the memory than for the intrinsic value of the structure. In common with the rest of Italy and Europe as a whole, in the Trentino, fortifications have been included in the architectural heritage to be protected without careful consideration of their value. Barracks, largely abandoned during recent decades, are not considered as having any value. One wonders whether more in-depth analysis might not produce a more objective evaluation. Perhaps the simple fact that these buildings in general incorporate a large part of the technological innovation of the 20th century might be enough to change the opinion. In our history of architecture, in recent years technological aspects have in fact come to be considered on a par with morphology and style, bearers of value which justify preservation.

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