Earthquake-resistant construction techniques in Italy between 1880 and 1910: alternatives to reinforced concrete

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Abstract

The series of earthquakes that struck Italy between the late nineteenth century and the first decade of the twentieth century spurred a lively debate about earthquake-resistant buildings that, through the influence of foreign experience, resulted in specialised literature and competitions that gave rise to a series of interesting patents. Innovative construction solutions for seismic areas were largely developed after the earthquake that struck the cities of Messina and Reggio Calabria in 1908, alongside the parallel advances in reinforced concrete. New earthquake-resistant construction solutions were based on a reassessment of traditional construction methods that used bricks, timber or metal, and in some cases they were combined with recently introduced materials such as expanded metal mesh.

The aim of this paper, which is based on a historical-critical research of specialised literature, design competitions and patents (filed at the State Central Archive headquartered in Rome), is to highlight the advances made in Italy in the field of earthquake-resistant construction systems as alternatives to reinforced concrete technology.

Keywords

Earthquake-resistant construction, patents, Messina and Reggio Calabria earthquake, earthquake-resistant technology, 1908.

Introduction

It is well known that over the centuries Italy has been hit by violent earthquakes causing extensive damage to the architectural heritage of urban centres. The Italian regions of Campania, Sicily and particularly Calabria were struck by a series of high-intensity earthquakes between the last decades of the nineteenth century and the first decade of the twentieth century. This caused an extensive debate among the major building figures of that time, and in turn led to experimentation with different construction solutions aimed at reducing the vulnerability of buildings by increasing their ability to withstand the effects of an earthquake.

Whilst many of the post-earthquake reconstruction works in the second half of the nineteenth century resorted to the *baraccata* system (in some cases imposed by specific building regulations issued after the disasters), the major innovations in the field of earthquake-resistant construction occurred after the violent earthquake that struck the cities of Messina and Reggio Calabria on 28 December 1908. The focus on earthquake-resistant buildings increased significantly in Italy after this event, leading to a widespread use of reinforced concrete in seismically active areas, and also to the publication of the first technical standards on reinforced concrete in 1907.[1] During the years immediately after the 1908 earthquake, and also influenced by foreign experience, specific literature in connection with earthquake-resistant construction was published including booklets, design studies and journals – congresses and competitions were held, and multiple patents were filed. I will attempt to describe how a new branch of research developed simultaneous to the advances of reinforced concrete, which revisited and modernised traditional construction systems of brick, timber or iron structures, with the addition of new industrially produced materials.

This paper focuses on the discussion that developed in Italy as regards alternative technologies to reinforced concrete, by referring to the competitions and congresses that encouraged new solutions as an evolution to traditional construction techniques. The patents filed in those years are also highlighted.

Earthquake-resistant construction systems and standards between the nineteenth and the twentieth centuries

The violent earthquakes that hit Italy in the second half of the nineteenth century spurred multiple reactions in the field of earthquake-resistant construction, and also gave rise to specific regulations aimed at setting technical requirements for post-earthquake reconstruction. In Italy, the first earthquake-resistant standard proper, (i.e. containing technical requirements deliberately conceived to make buildings more resistant to seismic effects), was issued after the catastrophic 1783 earthquake that struck the cities of Messina, Reggio Calabria and other smaller towns. The *Royal Instructions for the Reconstruction of Reggio* issued by the Bourbon government on 20 March 1784 validated the *baraccata* construction system. Such a system had been recorded by Giovanni Vivenzio in his book *Istoria e teoria de' tremuoti*.[2]

The structure consisted of a timber frame, with uprights, beams and diagonal members acting as bracing, within a masonry structure with box-like behaviour. This construction system was not actually new, given the fact that *baraccata* buildings were apparently already present in Calabria back in the seventeenth century, and had also been erected in L'Aquila after the 1703 earthquake.[3] In addition, the system recalled – in spite of some differences – the so-called *"Pombalina gaiola"* or cage system (named after the Portuguese Minister, Marquis of Pombal, who was in charge of the city reconstruction) introduced after the devastating 1755 Lisbon earthquake. The confidence invested in this construction system was confirmed by subsequent studies and by the regulations that came into effect after the violent earthquakes of Messina and Reggio Calabria. Such regulations reintroduced, with some suitable variations, the *baraccata* system.

After the earthquake that affected Umbria in August 1859, the Building Regulations for the city of Norcia were issued.[4] Among other technical requirements, these regulations recommended the use of the *baraccata* system. The same construction system was suggested by engineer Luigi Pesso, and was thoroughly described in his memoir, *Sul consolidamento delle fabbriche nelle Calabrie contro i danni dei terremoti* (1876).[5] (Fig. 1).

A few years later, with the *Building Regulations for the towns of the Island of Ischia damaged by the 28 July 1883 earthquake*,[6] this construction method was officially adopted for the reconstruction of the island buildings (many of which still keep these characteristics).[7] Such requirements were also adopted in Liguria after the 22 February 1877 earthquake[8] and, again, in Calabria after the 16 November 1894 earthquake.[9] The use of earthquake-resistant timber structures similar to those of the *baraccata* system was proposed for other geographic seismic zones during that time. For example, after the 1880 Manila earthquake, engineer Manuel Cortés y Agulló recommended the *baraccata* buildings with wooden or iron skeletons, which, in his opinion, would have guaranteed greater resistance to the seismic effects compared with simple masonry buildings.[10]

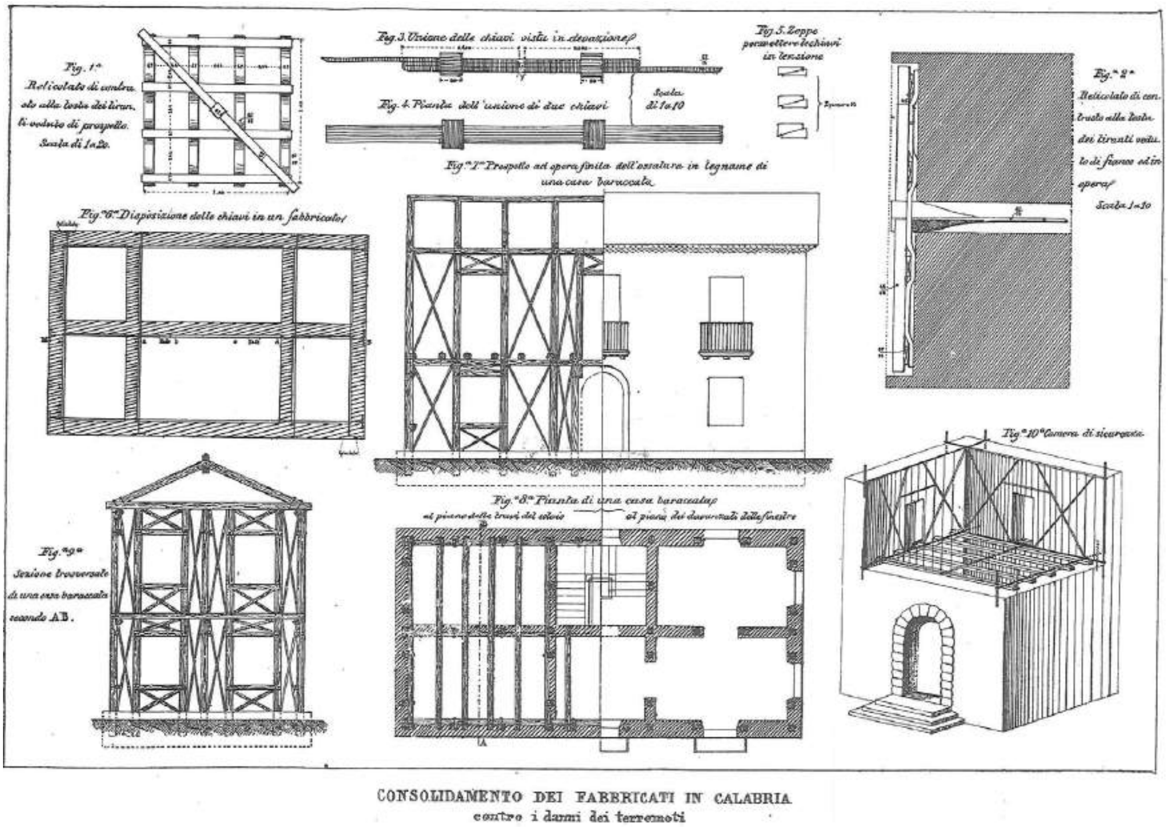

Figure 1. Seismic prevention systems: iron chains and baraccata system (L. Pesso, 'Sul consolidamento…, cit.)

The preference given to such construction systems is also confirmed after analysing earthquake-resistant building patents that were filed between the second half of the nineteenth century and the first years of the twentieth century; these patents show that most experiments were variations of the same construction solution.[11] Even though after the 1905 earthquake that hit Messina and Calabria, the *baraccata* system (not yet included in the relevant regulations)[12] continued to be used, the first applications of reinforced concrete for structures began in the field of earthquake-resistant construction, not only for the reinforcement of historical buildings, but also for new construction.

The discussion about earthquake-resistant buildings after the 1908 Messina and Reggio Calabria earthquake

The earthquake that struck the Messina Straits in 1908 can be regarded as a watershed, after which the problem of how to develop the most suitable construction system to withstand seismic effects became of utmost importance, and which impelled the entire scientific community to pay closer attention to this field of study.

The technological response crossed local boundaries, spurring proposals and reflections from a large group of scholars and professionals, who, by means of both specialised literature and the professional associations of which they were member, encouraged studies and projects of a different, innovative nature.

Specialised journals highlighted the Italian government's incapacity to manage the emergency, whilst pointing to the need for a national association in order to analyse which construction methods should be best adopted to reconstruct the destroyed cities so that the buildings were sufficiently resistant to the effects of any future seismic event.[13] To such end, the Board of Directors of the National Association of Italian Engineers and Architects created a committee to develop the technical standards to be observed when building in seismic zones. The committee, headed by engineer Luigi Luiggi, President of the Association, gathered renowned professionals that included engineers Alberto Pacchioni, Eduardo Mariano Cannizzaro, Gustavo Giovannoni and geologist Gioacchino De Angelis d'Ossat.

The result of their studies is documented in the general report containing the *Norme edilizie per i paesi soggetti a terremoti* (Building Standards for the Towns Struck by Earthquakes) published in April 1909 in the *Annali della Società degli Ingegneri e Architetti Italiani*.[14] The document, after briefly stating the main effects of earthquakes on buildings, analysed the different construction systems in use, which were divided according to the materials used. Among the systems analysed, and considered to be suitable for seismic zones (besides reinforced concrete structures) were the buildings made of reinforced masonry, and the wood-and-masonry and iron-and-masonry mixed buildings according to the *baraccata* system. In particular, for reinforced masonry, reference was made to the *Lescasse* method, which was named after the French engineer who published it for the first time in 1876 after he had used this method in Japan.[15] (Fig. 2) His method consisted of strengthening the masonry with a system of horizontal (flat) iron reinforcements and vertical (round) iron reinforcements to create a more structurally monolithic fabric.

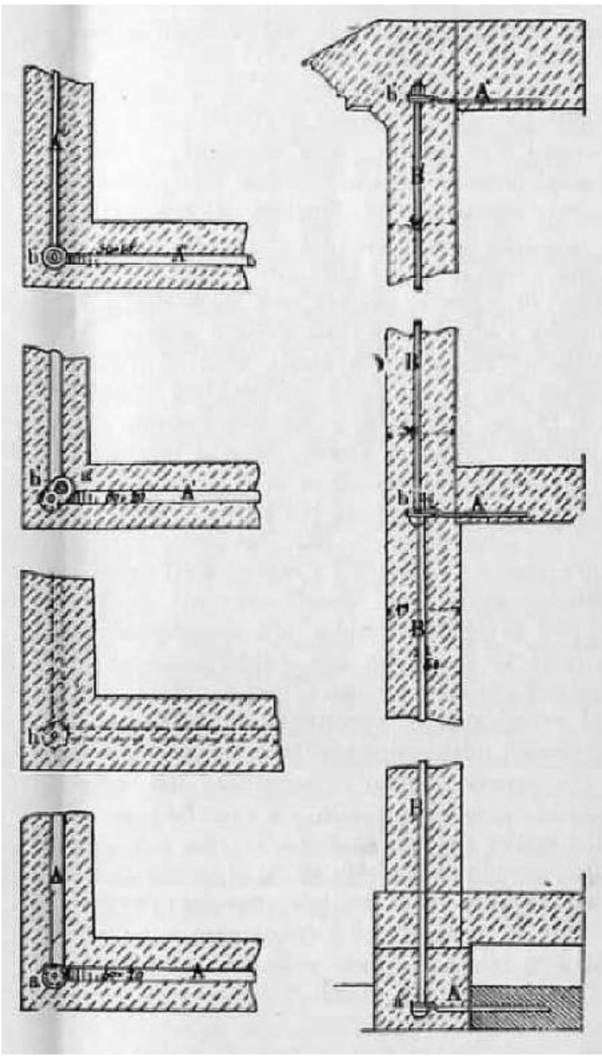

Figure 2. Reinforced masonry according to the Lescasse method (G. De Angelis d'Ossat, A. Pacchioni, 'Norme edilizie per ..., cit.)

For the traditional wood *baraccata* system it was determined that its effectiveness depended on building a well-connected timber skeleton, with light infill materials covered with metal cables or metal mesh to secure the plaster. Such a system was suitable for buildings of no more than two floors high, with a square and compact floor plan.

The report also analysed – taking into account both Italian and international perspectives – the effectiveness of standards and requirements issued after earthquakes, and how these standards informed the criteria to select the site, orientation of buildings, and the design of individual construction components (foundations, masonry at height, arches, vaults, floors, roofing, stairs, balconies, frames, etc.). The report also examined regulations borne out of the recent earthquakes that had affected Italy, particularly Norcia (1859), Ischia (1883) and Liguria (1887). In order to prove the validity of specific construction solutions, the document reported the response adopted in the Philippines after the 1880 earthquake, in San Francisco after the 1906 earthquake and in Japan – one of the most seismically vulnerable areas in the world – and in which earthquake-resistant building experimentation was of particular interest, as demonstrated, by the frequent references made to the systems implemented by John Milne.[16]

The report included a series of rules to be observed when building in seismic zones, and ended with a substantial bibliography recommending essential texts to refer to when studying earthquake-resistant construction methods. Such a bibliography was a snapshot of the state of the art at that precise historical moment and it eloquently illustrates the technical knowledge about earthquake-resistant buildings, through the study of similar international experience.

As proof of the renewed interest aroused by earthquake-resistant construction, several competitions and congresses were held, including the *Concorso per costruzioni edilizie nelle regioni italiane soggette a movimenti sismici* (Competition for Building Constructions in seismically threatened zones in Italy), which was announced in 1909 by the Lombardy Cooperative Society of Public Works. The competition programme was prepared by a special Committee appointed by mutual agreement between the Society and the Milan College of Engineers and Architects. Its members included some of the most renowned experts in the field, including seismologist Mario Baratta.

The programme was published by some of the most influential specialist journals of that time,[17] and was expressly intended to attract suitable entries for new types and systems for constructing residential and industrial buildings for future adoption by Italian regions most threatened by earthquakes. Competitors were given great freedom as to how to present their proposals. Designs, drawings, essays, reports, photographs, construction models or construction element models as well as samples of materials, everything would be accepted, all of them accompanied by a thorough technical report. The competition became internationally famous and 214 competitors, Italian and international, took part.

It can be inferred from the jury's report that particular attention was given to the analysis of the types of foundation to be adopted in the buildings, which were divided into three main categories:

1) Rigid foundations;

2) Foundations (independent) from the ground, in order to minimise transferring vibrations from the ground to the building, through the application of rollers, balls, springs or other devices.

3) Foundations falling within an intermediate category between the two types above, characterised by placing an artificial layer of sand or detrital material between foundation and ground so as to cushion the effect of seismic shock waves.

As regards the possibility of making the building independent from its foundation through balls and rollers, earlier precedents were referred to. These included the project designed by engineer David Stevenson (1868) to build lighthouses in Japan, and for which he suggested placing seismic isolators with bronze balls between the foundation and the structure (a system that, however, had proven to be ineffective). Another solution was tested by seismologist John Milne, who had experimented with isolation by means of movable iron balls inside iron cups. These systems were assessed as insufficiently resistant to strong earthquakes and hard to construct. The failure of these experiments, the practical difficulties connected with construction, maintenance, and limited durability and, in some cases, high manufacturing costs, led the jury to rule out the proposals including this type of foundation. Objections were also raised against the third type of foundation. Rigid systems were approved, in particular the suitably reinforced concrete foundation, which, regardless of the geological nature of the ground, was considered able to keep the walls and the piles as united as possible with the foundations.

The dominant construction type was the *baraccata* system in the broadest sense of the term: from the *baraccata* system, which consisted of a traditional wooden framework 'buried' in the masonry structure, to its more modern variations characterised by an iron structure that could be combined not only with blocks of bricks, light tuffaceous stone materials, and perforated and shaped cement blocks, but also with cork sheets, lignum-silex, metal mesh and lathwork. The materials used were divided into four essential categories:

1) Shaped and hollow bricks;

2) Shaped and hollow cement concrete mixes;

3) Cork mixes or wood sawdust materials;

4) Natural materials.

The first category specifically included baked clay bricks with perforations and indentations so as to create suitable joints in order to obtain a tightly connected masonry structure, similar to the one proposed by lawyer Bagalà di Palmi (outside the competition), which was a brick system with T-shaped indentations.

Among the competing projects, the one with the slogan *Pro Calabria e Sicilia* by engineers Vittorio Gianfranceschi and Giulio Revere stood out. This project proposed a system, which was then patented, consisting of masonry with suitably reinforced hollow concrete blocks.[18]

Traditional masonry constructions were regarded as suitable only for small-sized buildings as long as restrictions on height, suitable thickness, quality of materials and skilful use of metal chains and ring beams were observed.

A considerable number of the projects submitted (43 in all), included the use of a reinforced concrete framed system as an alternative to the most common practice of creating mixed structures in which the use of reinforced concrete was limited to horizontal supports (beams and floors). Nevertheless the Jury recognised how the good performance of this construction system was closely connected, (more than for the other technology solutions), with the good quality of the raw materials and with the quality of construction.

It should also be noted that four of the projects submitted to the competition were based on the principle of resistance due to the shape of the building and there were proposals for circular, hexagonal and octagonal plans for entire buildings or parts thereof,[19] including a contribution made by Venetian architect Giuseppe Torres. Based on the direct observation of building performance in Messina during the 1908 earthquake, Torres discovered that cylinder-shaped elements such as apses and towers were the most earthquake resistant. The proposed method therefore included the use of a circular floor plan, which was considered to be safer as it was equally resistant to earthquakes from any direction. The original solution of a circular plan building, which was developed for the reconstruction of Messina after 1908, is attributed to Torres. His method of a reinforced concrete "earthquake resistant house", which was applied in a large number of projects, was also patented (27 January 1909) and published in *La casa antisismica* (1909).[20] His proposal, which provocatively went as far as defining an entire city of buildings arranged in a circular matrix, is illustrated by the drawings kept in his archive, such as the projects for various circular houses, for the Chamber of Commerce and Town Hall of Messina (both competitions in 1911), or for the 'Puleo house' in the same city. However, these projects were not realized, except for a small number of buildings designed in Abruzzo after the 1915 earthquake. The most economical type of house, which was defined as a 'hut', was built in Collarmele (L'Aquila); a single small building erected by the Venetian Relief Committee for the earthquake victims, while two others were built in Avezzano: one of them financed by Neapolitan Prince Federico Spada and the other by the architect himself. It should be noted that another earthquake-resistant construction criterion based on the principle of resistance due to shape can also be seen in the slightly earlier works of seismologist Guido Alfani (1905), (Alfani promoted the use of parabolic shaped masonry), and was noted in the writings by Marco Aurelio Boldi (1910), Francesco Ruffolo (1912), and Francesco Masciari Genoese (1915), among others.[21]

The Jury of the competition decided not to award the first prize, given the fact that "it has not been able to find, in any of the valuable works submitted, and in each single point, the total compliance with the competition requirements, the perfect balance between theory and its practical and economically convenient application".[22] The second prize was awarded to engineer Arturo Danusso, and the thirdto the abovementioned *Pro Calabria e Sicilia* project. In his thorough report, Turin-born engineer Danusso, one of the most outstanding personalities in the scientific field, presented the design calculation of a building subjected to seismic activity, according to the rules of rational mechanics, linear elasticity and material strength.[23]

The full version of Danusso's report on earthquake-resistant buildings was presented at the XII Congress of Italian Engineers and Architects[24] (Florence, 3 to 9 October 1909) which represented another important opportunity to discuss the problem of buildings in seismic zones since an entire section of that Congress was devoted to earthquake-resistant construction. Simultaneously, a specific competition on this subject was announced. Eighteen projects were presented; they were analysed by a Committee made up of representatives of each of the main Italian Associations of Engineers, including engineer Cannizzaro, one of the protagonists of the debate about earthquake-resistant construction in Italy, due to his experience in reconstructing Messina after the 1908 earthquake[25] and Marsica after the 1915 earthquake.[26] Many of the projects submitted, including one by Danusso which was awarded the first prize, proposed reinforced concrete framed structures, with a few exceptions such as the project presented by architect Francesco Paolo Rivas from Palermo, who proposed two alternative solutions: one structure with a timber frame and the other one with concrete blocks.[27] There was a particularly animated discussion within the Congress as regards the building types and standards to be adopted "…in those *seismically* threatened Italian Regions, and especially the Calabria-Sicily Region,"[28] which had to be adapted to economy, stability and hygiene criteria without adversely affecting aesthetic appearance.

During the congress, there were initiatives to create a permanent institute for seismic technical studies in Italy run by seismologists and engineers. This institute would foster the study of seismology applied to construction, assess projects to be executed in seismic zones, disseminate knowledge, and coordinate theory and experimental research on this subject. The desire for such organisations was also articulated in the report containing the *Norme edilizie per i paesi soggetti a terremoti* report under *Building Standards*, in which the Committee expressed the need to create dedicated institutes for seismic studies that were to be established "In the main Towns of those regions more prone to earthquakes,"[29] in order to "…permanently state the models of the most common buildings, constructed according to the special building regulations, in accordance with local authorities, owners and constructors."[30] These institutes were never created.

However, the idea was revisited a few years later, after the earthquake that hit the area of Marsica in 1915, when the creation of a Geodynamics Building Institute was proposed. Such an institute was to be founded in Avezzano in collaboration with the Italian Geological Society. The purpose of this institute (which was intended as a prototype) was to create:

> "A real technical-scientific centre available not only for those who want to conduct theoretical studies and those who want to actually make buildings, but also, more directly, for those who have the job of assessing and controlling [the construction]."[31]

As stated in the report by Roman engineer Gustavo Giovannoni who proposed a reinforced masonry system.[32] (Fig. 3).

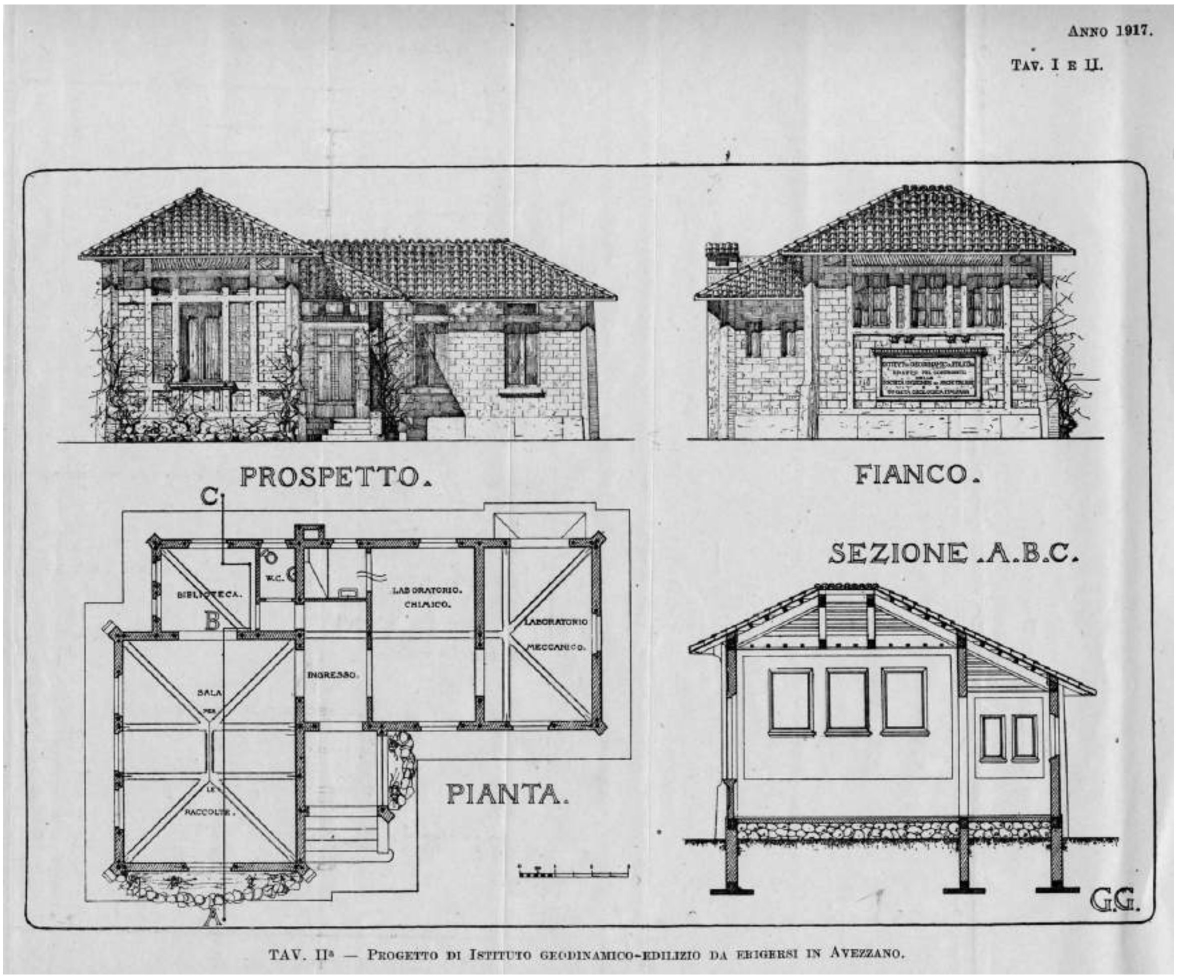

Figure 3. Project of the Geodynamics Building Institute. Avezzano. Engineer Gustavo Giovannoni (G. Giovannoni, 'Per le costruzioni nei paesi …, cit.)

Patents related to alternative solutions to reinforced concrete

In a cultural debate about the topic of earthquake-resistant buildings, the analysis of patents seems interesting. Such patents emerge as proofs of an experimental design approach, each contributing to define the technical (research) scope of this field of study. Whilst patents for earthquake- resistant buildings can be traced back to the second half of the nineteenth century, specifically the ones filed after the 1883 Casamicciola earthquake, it was after the 1908 Messina earthquake that saw a large increase of interest in this field, proof of which is the huge number of patents filed between 1909 and 1910 dealing with construction systems.[33]

The patents are part of the document collection of the Italian Ministry of Agriculture, Industry and Commerce and are kept at the State Central Archive headquarters in Rome. The patents substantiate the heterogeneity that characterises the professional *status* of proponents, including, in addition to engineers, small entrepreneurs, master-builders and well-established construction companies.

Upon analysing the patents, besides the solutions based on the application of the new reinforced concrete technology,[34] other solutions were developed based on 'revisiting' traditional construction techniques. The systems proposed (I will analyse some solutions as examples) included the use of bricks, timber or metal, which in some cases were combined with new and recently introduced materials such as Eternit and lignum-silex. It should be noted that, in some instances, the studies are supported – even then – by rigorous calculation methods similar to those offered by modern construction science.

Masonry structures

Within the large category of masonry structures, there are two main types that reassess the traditional construction type. The first one includes masonry that features a 'tongue-and-groove joint', the second, reinforced masonry. Both types have several variants.

The solution proposed by engineer Francesco Pisani, from the Civil Engineers Corps, features a masonry construction consisting of 'special' bricks, shaped in such a way as to create a tongue-and-groove jointed system (without mortar) to create a masonry construction as monolithic as possible. The construction system was explained in the publication entitled *Osservazioni e note sul terremoto calabro-siculo del 28 dicembre 1908 e sul modo di resistere degli edifici in muratura contro gli urti sismici. Proposta di una nuova forma di materiale laterizio per costruzione di muri monolitici asismici (Observations and Notes on the Calabria-Sicily Earthquake of 28 December 1908 and on the Way in which Masonry Buildings Withstand Earthquakes. Proposal of a New Form of Brick Material for Constructing Aseismic Monolithic Walls)*,[35] containing an explanatory text and some drawings. Pisani's proposal was the result of the direct observation and survey of a large number of buildings damaged in Calabria and Messina after the earthquakes that struck this area on 8 September 1905, on 23 October 1907, and particularly on 28 December 1908. After realizing that "in the above mentioned towns, the single masonry structure is not known, for houses, as the most suitable type based on the weather and the needs of local life",[36] he directed his studies to solving the problem related to the construction of monolithic walls. Taking into account two essential earthquake resistant principles, i.e. as much homogeneity as possible in the density of the materials and the progressive reduction of the weight of the building elements from the bottom to the top, Pisani proposed the use of tongue-and-groove jointed bricks "to be used full and therefore heavy in the lower parts of the building and gradually perforated, and therefore lighter, as going upwards".[37] With this system, walls of any form and size could be built, erected dry by means of a tongue-and-groove joint system. This system was illustrated by specific drawings, which guaranteed perfect jointing between the elements. The problem of how to connect the elements in the corners was solved by means of special elements, of two shapes matching the tongue-and-groove jointed bricks. The construction system was illustrated by means of some practical examples, which showed possible combinations among the elements in order to build different types of walls.

A similar system was presented by Ulisse Manfredi, who proposed a construction system made up of custom bricks with special internal grooves within which elements were fitted vertically so as to form a monolithic structure without the aid of mortar. (Fig. 4) The possibility of constructing walls of different thicknesses (300 mm, 450 mm and 600 mm) was ensured by combining seven different types of bricks, one of which (marked A) and measuring 290 mm x 140 mm x 65 mm, was arranged vertically.[38] Nevertheless, it should be noted that – in spite of differences among patents – the tongue-and-groove joint brick system was not new and at the end of the nineteenth century, it had already been recommended by Milne, who applied it in some Japanese buildings, as reported by engineer Alfredo Montel.[39]

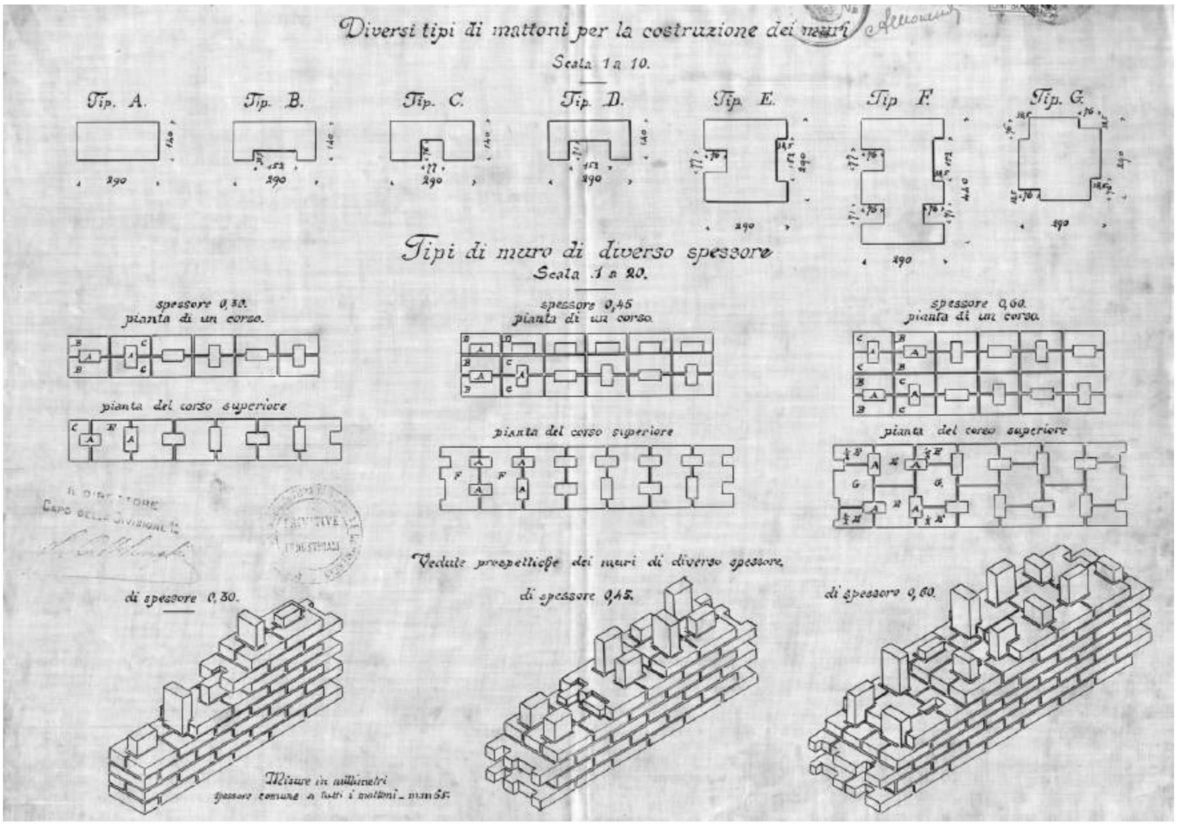

Figure 4. Masonry construction system by Ulisse Manfredi (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 100457. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

A series of patents belongs to the reinforced masonry category, including the *Grooved Brick for Building Reinforced Walls* by Leopoldo Gigli from Florence. This system consisted of the use of solid or hollow bricks, made of either baked clay or concrete. Their particular feature lies in the presence (in each of the elements) of a "groove or cut through which an iron or steel wire can be easily pass through inside the brick as reinforcement".[40] (Fig. 5).

Shaped concrete blocks were also described in the patent by Francesco Castorina (Fig. 6),[41] in the project by engineers Vittorio Gianfranceschi and Giulio Revere (already mentioned), and in that by constructor Drinnaco Valentini.[42]

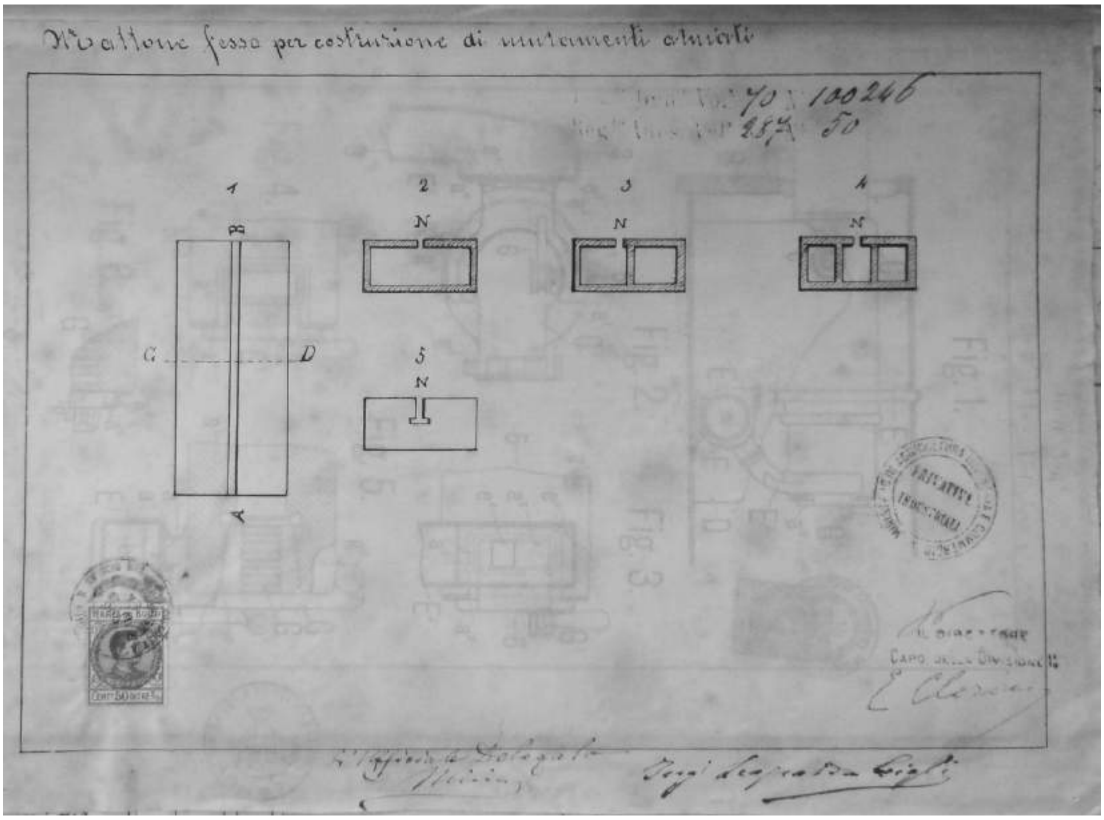

Figure 5. Grooved Brick for Building Reinforced Walls by Leopoldo Gigli (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 100246. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

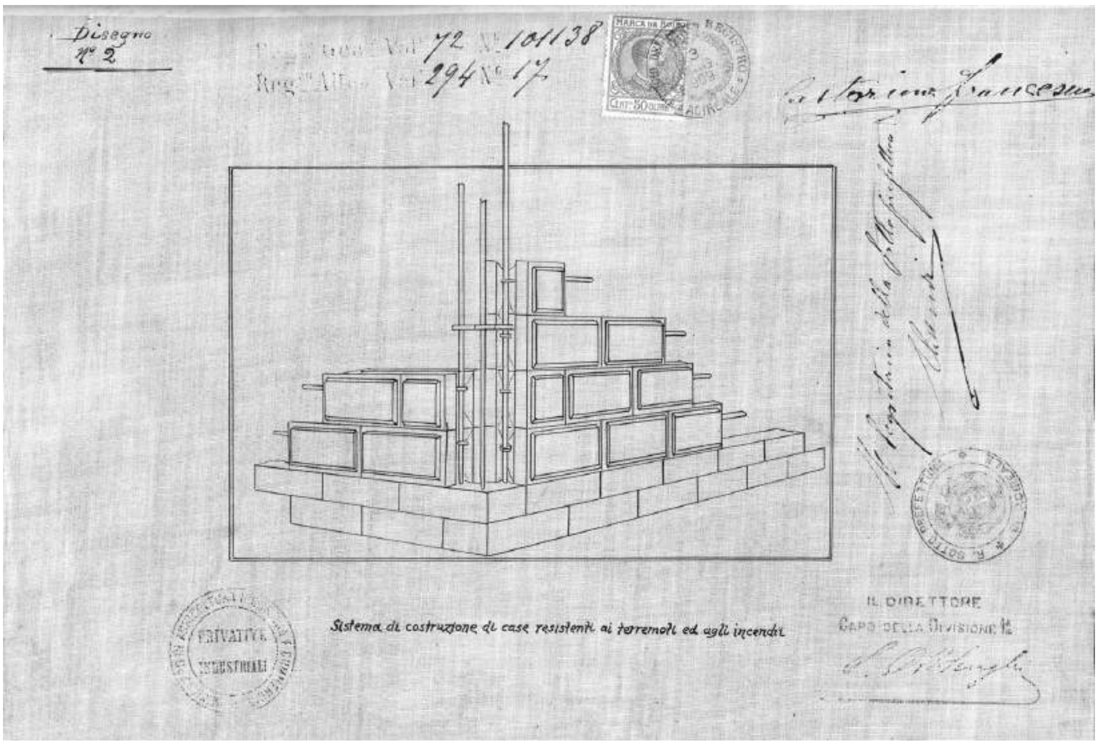

Figure 6. Concrete blocks for earthquake construction system by Francesco Castorina (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 101138. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

This final project mentioned also included an iron T-shaped perimeter plate to which the iron beams of the floors were to be anchored by means of bolts. At the same time, this prevents the beams of the floors from becoming loose and the walls from over turning. (Fig. 7)

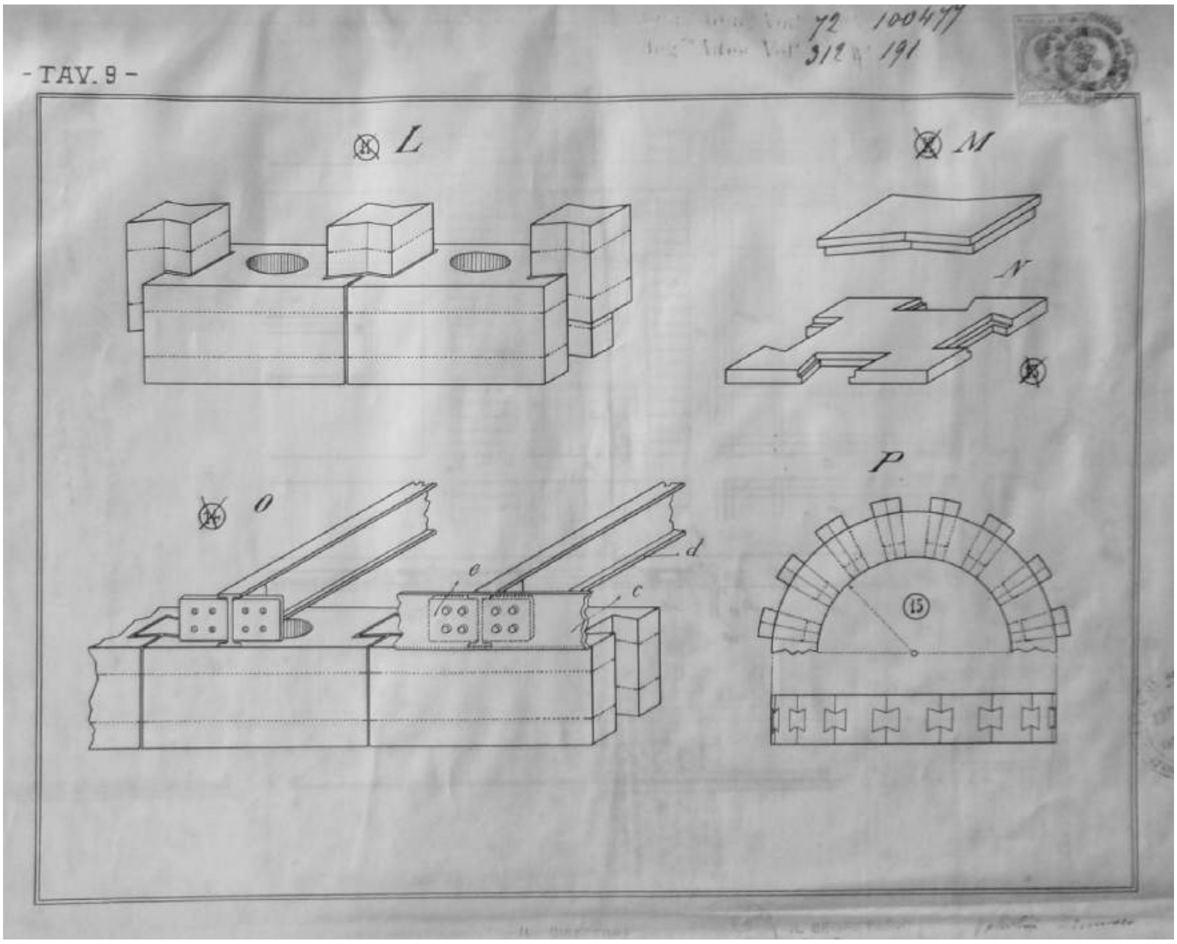

Figure 7. Concrete blocks for earthquake construction system by Drinnaco Valentini (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 100477. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

Timber Structures

Among the patented timber structures, the *baraccata* system variants continued to prevail, including Luigi Lanza's *Type of House with Timber Skeleton and Stretched Sheet*, which utilised a traditional timber skeleton made up by uprights, beams and diagonal rods with a skin (both inside and outside) of metal mesh and cement mortar, and covered with Eternit slates.[43] (Fig. 8)

The use of traditional materials was proposed by Pasquale Frezza from Calabria, who in his *Construction System of Earthquake-Resistant Houses* [44] suggested a timber cage resting on a concrete foundation, which was characterised by bolted connections and an infill wall made up of bricks and small empty clay conduits, elements that were already widespread in Calabria in the 1783 post-earthquake construction practices, and which met the infill material lightness requirement that was requested in seismic zones. (Fig. 9)

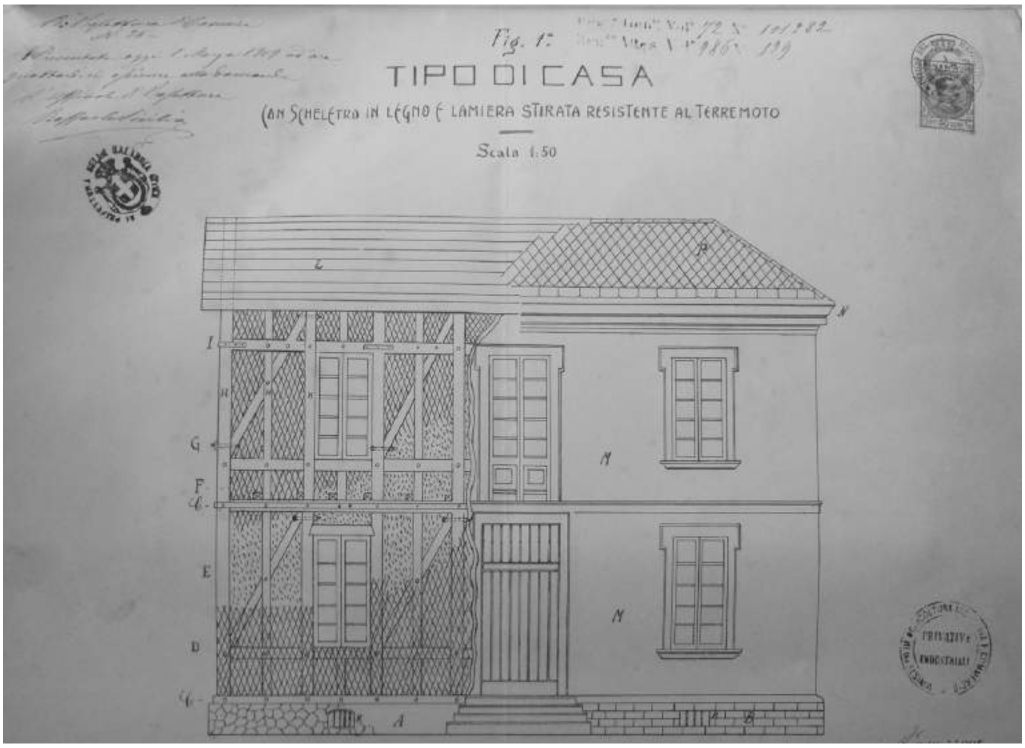

Figure 8. Type of House with Timber Skeleton and stretched sheet by Luigi Lanza (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 101282.By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

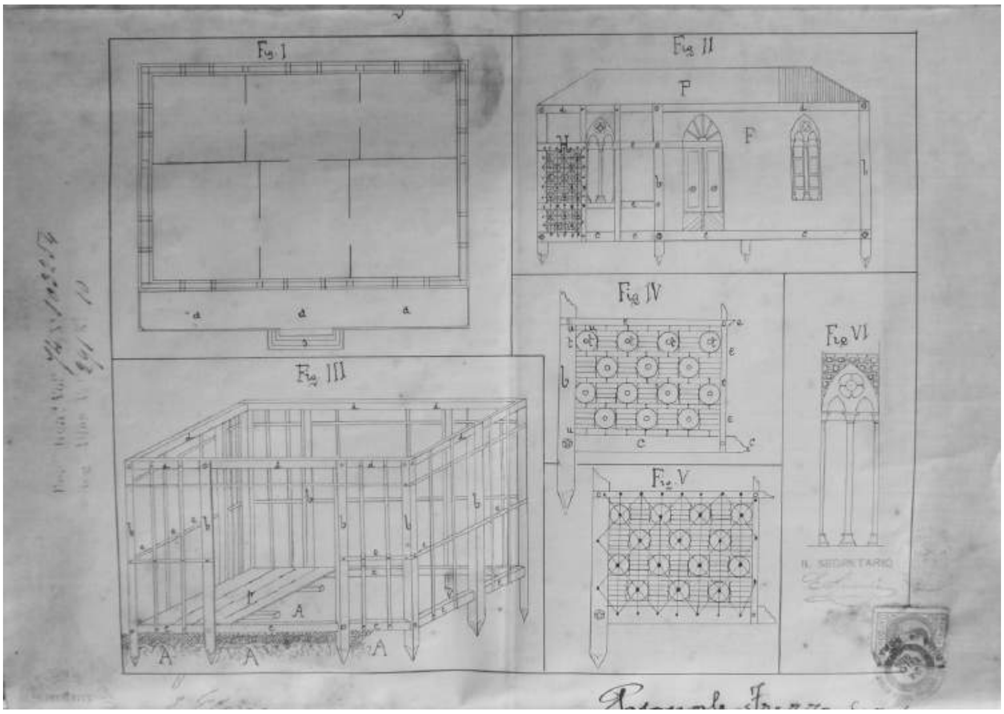

Figure 9. Type of House with Timber Skeleton by Pasquale Frezza (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 103254. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

Raffaele Di Martire presented an invention made up of timber beams reinforced with metal wires applied to the lower edge, which were subject to tension.[45] Such wires were folded on the heads and anchored with nails to the upper edge. Specific details were designed for the corners in order to prevent the wires from penetrating the wood and becoming damaged when folded. As a result of this innovation, the resistance to bending of the timber beam was significantly increased. (Fig. 10).

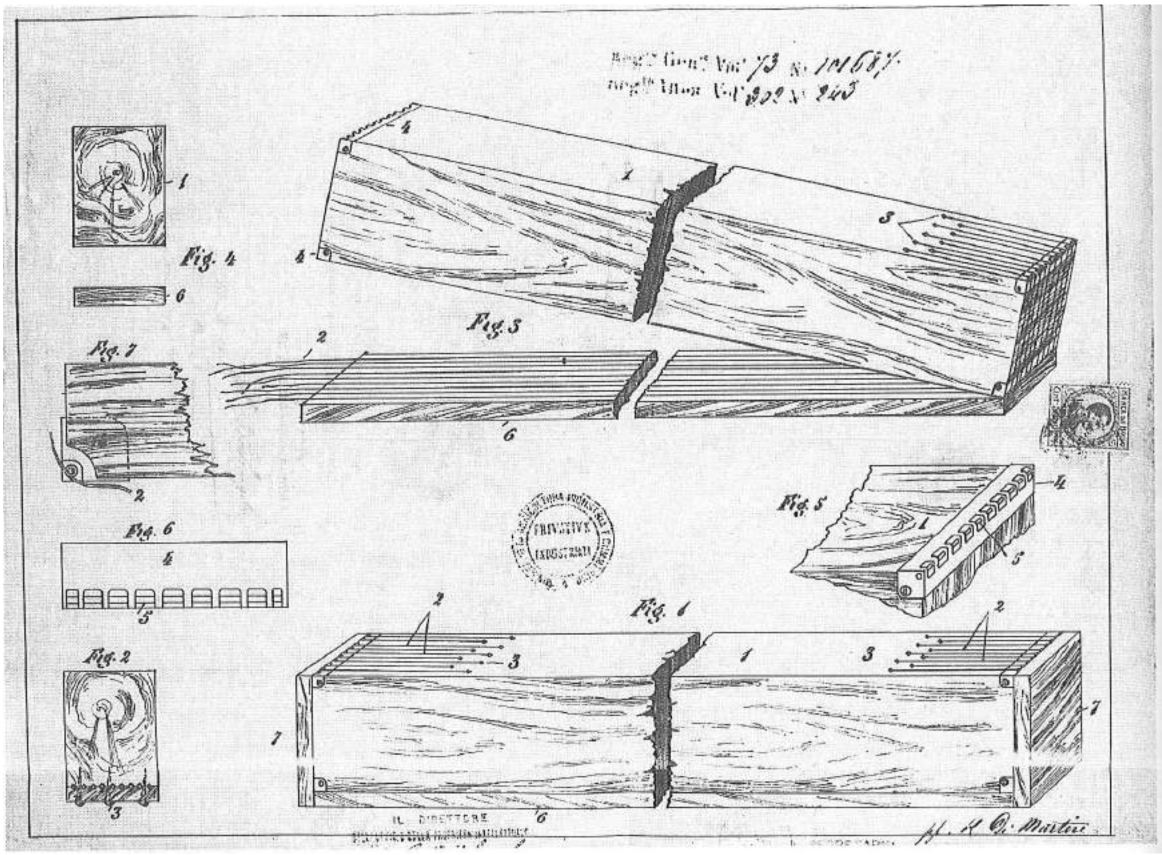

Figure 10. Reinforced timber beam by Raffaele Di Martire (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 101687. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

Iron Structures

A significant number of patents employed the use of iron structures. The lightweight construction system proposed by Luigi Lanza is characterised by the use of iron beams of different sizes, with H-shaped sections for columns and I-shaped sections for beams.[46] The variously proposed infill panels include hollow clay blocks, tiles and mortar applied on an expanded metal mesh. The infill panels are restrained (reinforced) by metal wires, which zigzag between the flanges of the iron sections to create a lightweight system that also limits seismic effects. (Fig. 11)

A similar system was proposed by Arnoldo Schindler with a framed structure made up of a pair of I-shaped beams running horizontally that limit wall thickness, combined with T-shaped vertical uprights at openings and wall crossings, to which two layers of metal mesh to be rendered are connected.[47] (Fig. 12)

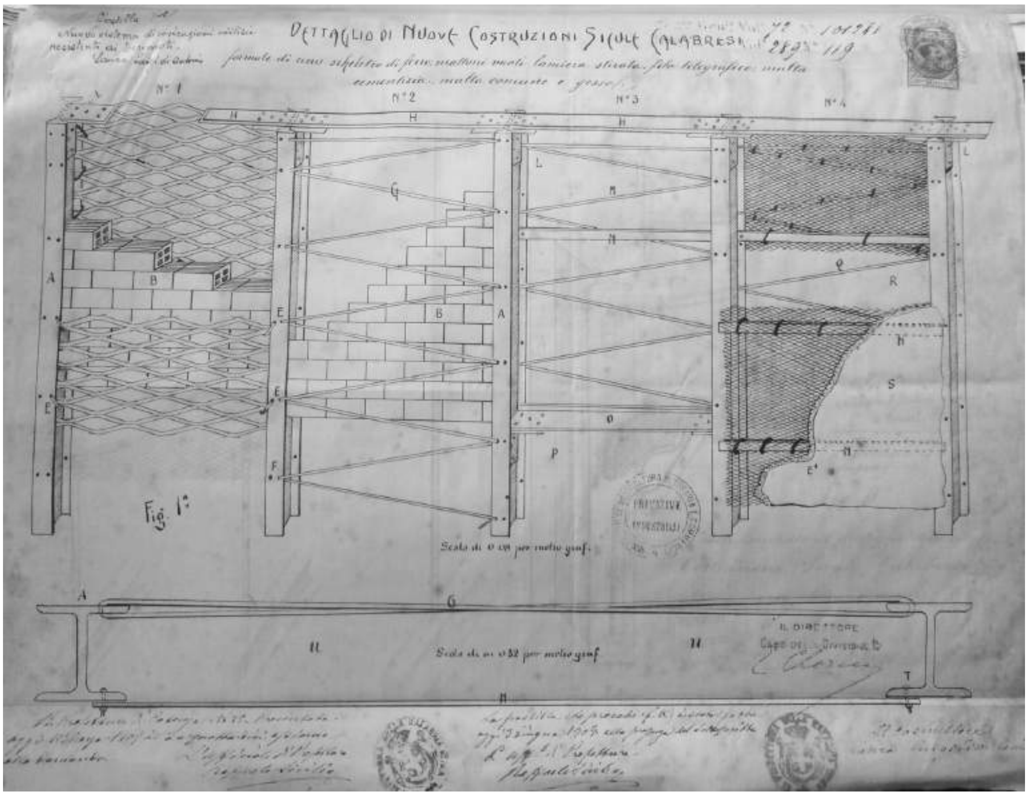

Figure 11. Construction system by Luigi Lanza (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 101281. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

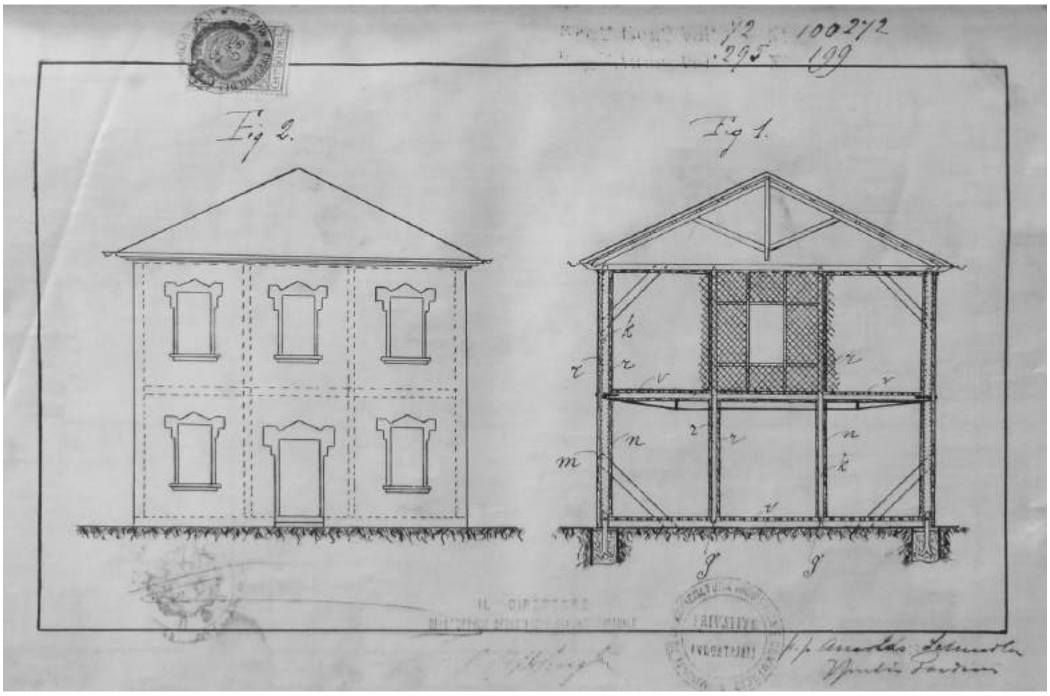

Figure 12. Elevation and section of the construction system by Arnoldo Schindler (State Central Archive, Italian Ministry of Agriculture, Industry and Commerce, Central Patent Office, no. 100272. By courtesy of the Ministry of Cultural Heritage and Activities, ACS, 2016, permission no. 1419/2016)

Engineers Paolo Baravelli and Aristide Giannelli patented a system for buildings with a metal skeleton which was published in 1913 in the *Annali della Società degli Ingegneri ed Architetti Italiani*.[48] The study was supported by a rigorous calculation method, which took into consideration the structure's hyperstatic condition, adopting analytical methods developed by Giannelli.

Conclusions

The frequent earthquakes that affected southern Italy between the nineteenth and the twentieth centuries spurred a deep reflection on the issue of earthquake-resistant buildings. This paper reports the state of the art of seismic knowledge and construction technologies especially in relation to the debate held in Italy immediately after the 1908 Messina and Reggio Calabria earthquake. Particular focus is given to research on proposals for new construction systems created as alternatives to reinforced concrete technology. Although highly reliable, reinforced concrete technology had some disadvantages as regards material quality and workmanship, the latter being in the hands of companies using patented techniques, which resulted in high costs. The analysis of alternative solutions to reinforced concrete, supported by the description of the main systems proposed and by figures, shows the interest of technical knowledge in structures built in seismic areas, with designs dealing with futuristic solutions (seismic insulation) or revisited versions of traditional masonry construction techniques. The proposals using timber and iron framed structures are also mentioned. The solutions including iron were limited by the high cost of the metal, even more so than those using reinforced concrete. Records show some important solutions that were awarded prizes, given recognition by the committees of competitions, or were the basis for patents. The different solutions for earthquake-resistant construction systems based on a reassessment of traditional construction techniques have a strong cultural value in that they mirror the construction skills of that time that tried to find solutions to the appalling destruction caused by earthquakes, an issue of contemporary relevance today.

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