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Nota Técnica:
Mampostería con madera sismorresistente en Europa

Technical Note:
Timbered masonry for earthquake resistance in Europe

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RESUMEN

Europa es un continente que está sujeto a una significativa actividad sísmica. Por esta razón, se debe analizar el comportamiento sísmico, no solo de las nuevas estructuras, diseñadas sobre la base de códigos más exigentes, sino también de los diversos tipos de estructuras antiguas.

En este artículo se analizan las estructuras constituidas por mampostería y madera, que se pueden encontrar en Portugal, Turquía, Francia, Inglaterra, Grecia, Rumania, Italia, España, Alemania y Escandinavia. Aunque estas estructuras presentan diferencias en cuanto a detalles constructivos, su sistema estructural es idéntico: el sistema estructural de madera absorbe principalmente las cargas horizontales, mientras que la mampostería garantiza la resistencia a la acción de la gravedad.

El estudio presentado incluye un breve informe acerca de la sismicidad de los países en que existe el tipo de construcción mencionado, conjuntamente con la descripción de los sistemas constructivos específicos de cada país.

Palabras clave: madera, mampostería, edificios tradicionales, comportamiento sísmico.

SUMMARY

Europe is a continent that is subject to significant seismic activity. Thus, the buildings' seismic behaviour must be analysed, including not only the new structures, designed under more rigorous codes, but also older ones.

This article examines a traditional type of building that uses timber frame/masonry, which is found in Portugal, Turkey, France, England, Greece, Romania, Italy, Spain, Germany and Scandinavia. Although the structures differ in terms of construction details, their structural system is basically the same: the wooden structural system bears mainly the horizontal loads while the masonry supports the gravity loads.

The study includes a brief report on the seismicity of each country where this traditional type of building made of timbered framed masonry is found, together with the description of these buildings' constructive systems.

Keywords: *timber, masonry, traditional housing, seismic behaviour.*

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1. INTRODUCTION

Timbered masonry buildings are found all over the world and examples date from the 16th century right through to the present day. They are usually made of wood frames filled with masonry of clay bricks or rubble stone. This type of construction is mostly used because the materials are cheap and easy to find. It is also recognized that these structures have a better resistance than non-timbered ones (1) and they exhibit reasonable behaviour under earthquakes. Finally, the aesthetic aspect of these buildings is also often a choice of architects and owners.

The idea of a wood structure with a masonry infill is quite old. The best example is the town of Herculaneum which was buried by lava after the eruption of Vesuvius in 79 BC. Archaeologists found an entire two-storey timbered masonry building (Figure 1) that was identified as opus craticium (2).

References to the good behaviour of timbered masonry buildings can be found related to the himis buildings in Kocaeli earthquake in 1999 (3) and to experimental studies on pombaline buildings in Portugal (4).

Such structures have not been experimentally studied in all countries where they were found, perhaps because not all the countries consider them as historical heritage, but Portugal has carried out studies and research related to the behaviour of pombaline architecture. The latest program of experimental studies simulated an interior wall of a type known as "frontais" in a pombaline building, and showed that when subjected to cyclic loading these walls exhibit a high nonlinear force-displacement response and good ductility (5). Studies and research have also been carried out on pombaline buildings that were set to be demolished, thus determining the characteristics of wood and masonry elements through destructive testing, in situ or in the laboratory, on samples taken from the full scale walls of the structure (6).

Figure 1. A timbered masonry building dated of 79 BC.

This paper presents an overview of the timbered masonry building solutions that can still be found in different European countries, linking their use to their location, where earthquakes and environmental conditions are important factors.

2. SEISMIC HAZARD IN EUROPE

Seismic activity in Europe varies from country to country; in some countries they occur very rarely while others are frequently shaken by earthquakes of greater or lesser intensity. As shown in Figure 2, seismic activity is concentrated mainly in South Eastern Europe, but here and there, in the rest of the Europe, seismic sources can be found that can cause devastating earthquakes (e.g. in Portugal, the boundary between the African and Euro-Asian plates).

This section briefly describes the seismic activity in European countries where earthquake-resistant buildings of the type examined in this paper have been found.

Portugal is subjected to two types of seismic action, defined by the level of maximum expected peak ground acceleration. Type 1 is a large magnitude earthquake at large epicentral distance and of long duration, typically caused by an earthquake originating in the zone of confluence between the Euroasiatic and the African plates; type 2 is a medium magnitude earthquake at small epicentral distance and of short duration, typically caused by an earthquake in a fault in the Tagus Valley, near Lisbon (8).

The history of Portugal's seismicity contains many low magnitude earthquakes (Figure 2), but the most important one remains the 1755 earthquake, where the seismic intensity in southern Portugal (Algarve) was estimated to be IX-X on the Mercalli intensity scale (8).

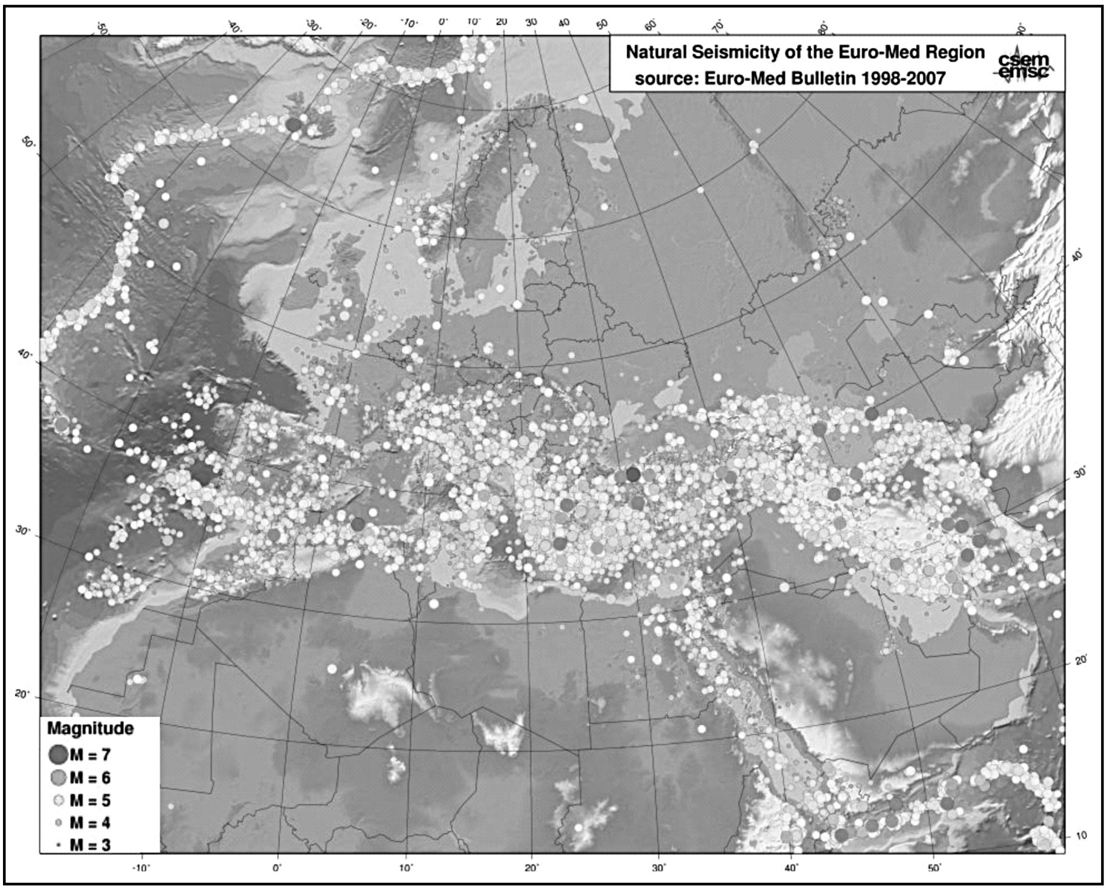

Figure 2. Earthquakes magnitude distribution in the Euro-Med bulletin between 1998 and 2007 (7).

The seismicity of Turkey is known to be severe, as shown in Figure 2. Most earthquakes happen in the eastern part of the country, but very strong earthquakes have also occurred in other locations.

According to information from the Turkey Earthquake Charitable Foundation (TDV), thirteen important earthquakes occurred in the years of 325, 427, 478, 865, 986, 1462, 1500, 1509, 1719, 1754, 1766 and 1894 (9) in the history of Turkey. The latest, was the Kocaeli earthquake on 17th August 1999 and it reminded Turkey of its seismic history by killing many people and causing severe material damage.

Greece is also a seismically active country, accounting for more than half of the continent's seismic energy release. The seismic culture is borne out by the very good behaviour of the 200 year-old timber framed buildings in Lefkas during the earthquake on 14th August 2003. The magnitude was 6.2 and the maximum horizontal PGA (peak ground acceleration) was 0.42 g (10). None of the buildings collapsed, contrary to the reinforced concrete ones, thereby proving this to be a very capable seismic resistant system.

Nowadays, even though civil engineering has evolved a great deal, the unique character of earthquakes still takes people by surprise. The last major earthquake in Italy, L'Aquila, April 6, 2009, with a magnitude of 6.3 on the Richter scale, once again showed this unique character. The horizontal PGA was between 0.34 g and 0.67 g and vertically it was between 0.22 g and 0.42 g. Although, the New Italian code NTC 2008 (for a return period of 475 years) defines values of 0.30 g – 0.35 g for horizontal PGA and of 0.18g for vertical PGA (11).

Spain's seismic history is marked by deep earthquakes in Granada region in the south of Spain. The best example is the 1954 earthquake that had a 7 magnitude on Richter scale and a 640 kilometres depth (12). Nevertheless, the latest seismic event, with epicentre near Lorca, was at 2 kilometres depth and with a 5.1 Richter magnitude, produced important damages.

Seismic activity in France is moderate. As shown in Figure 2, in the south of the country the seismicity is somewhat more intense.

The seismic activity of Germany is generally low, but not negligible. The strongest documented earthquake in this zone occurred near Basel in 1356, with a magnitude of 6.6 on the Richter scale, and an intensity of IX on Mercalli scale, with the epicentre near the south of Germany's current border. There is also a zone of enhanced seismicity in Saxony-Thuringia in the east of the country. The northern part of Germany has the lowest seismicity, but there are no aseismic locations (13).

The history of seismic engineering in Romania presents four major earthquakes: October 1802, January 1838, November 1940 and March 1977. Although the first two were very strong only the third prompted questions about and interested structural engineering, leading to the development of the first rules of anti-seismic building design in Romania (14). Today, seismic engineering is very concerned with the protection of buildings during earthquakes. This is borne out by the buildings' design code, which is changed quite often, with the last version issued in 2006.

Seismic activity in the Nordic countries has a hazard level that is scarcely taken into account, while in United Kingdom it is very low, as shown in the seismic hazard map in Figure 2. There is some data that England had a 6.5 MW (moment magnitude) earthquake in 1700 (15) (the strongest in history), but the information is sparse.

3. TIMBERED MASONRY BUILDINGS IN EUROPE

3.1. Portugal - The "pombalinos" and the "gaioleiros" buildings

The *pombaline* ("*pombalino" in Portuguese*) building is a structure no more than four storeys high, with arcades at ground floor level and with wood framed masonry walls (*frontais*) which, together with the floors' timber beams, form a cage (*gaiola*) (Figure 3a) and constitute the resistant structure. They were named after the Marquis of Pombal, who ordered their construction after the 1755 earthquake that destroyed Lisbon, because he wanted buildings to have a seismic resistant structure.

The *pombaline* buildings have a unique structure: external structural masonry walls (Figure 3a); internal timber-masonry structural walls (called *frontais*) (Figure 3b), and internal partition walls (Figure 3c).

All these structural elements combined result in an anti-seismic structure (Figure 4) that behaves very well, as experimental studies have shown (4). In one study on a full scale *pombaline* wall taken from a real building, it could be observed that the wall was able to dissipate energy over many cycles without losing its structural integrity (Figure 5) (4).

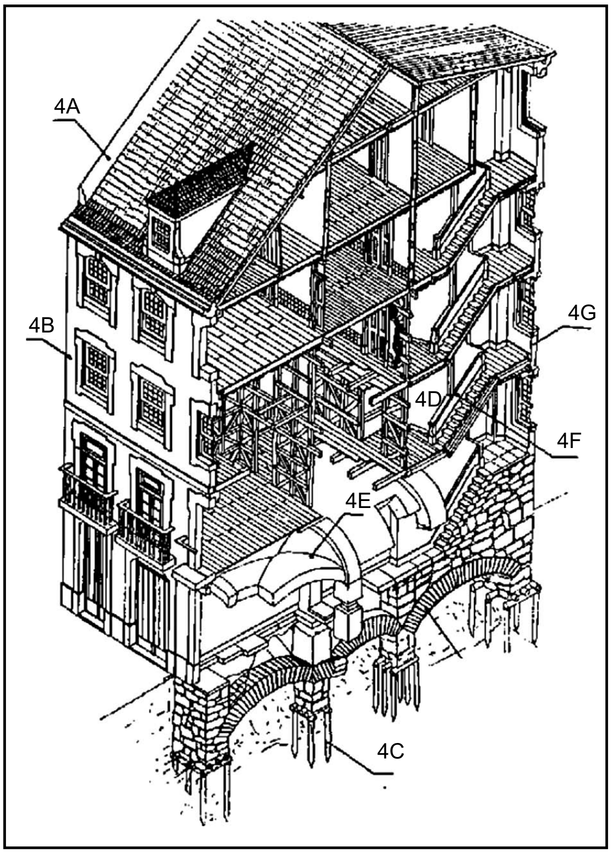

Figure 4. Pombaline building (16).

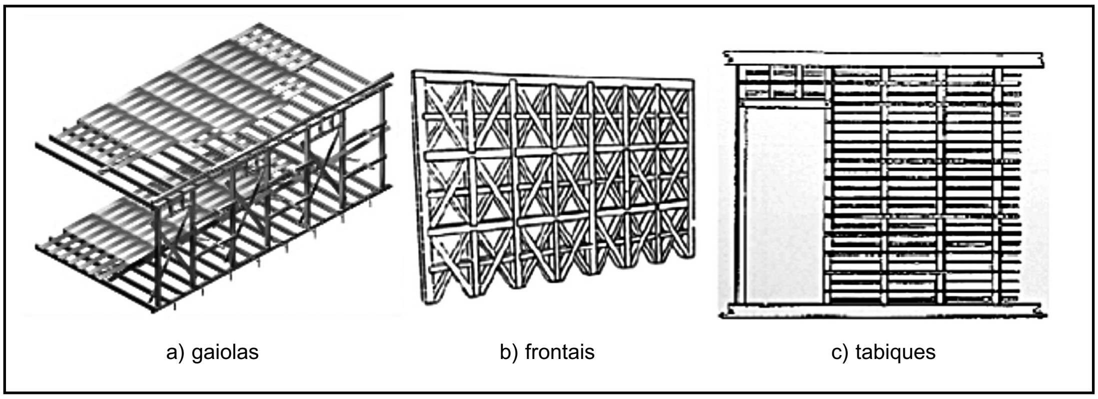

Figure 3. Pombaline building wall types.

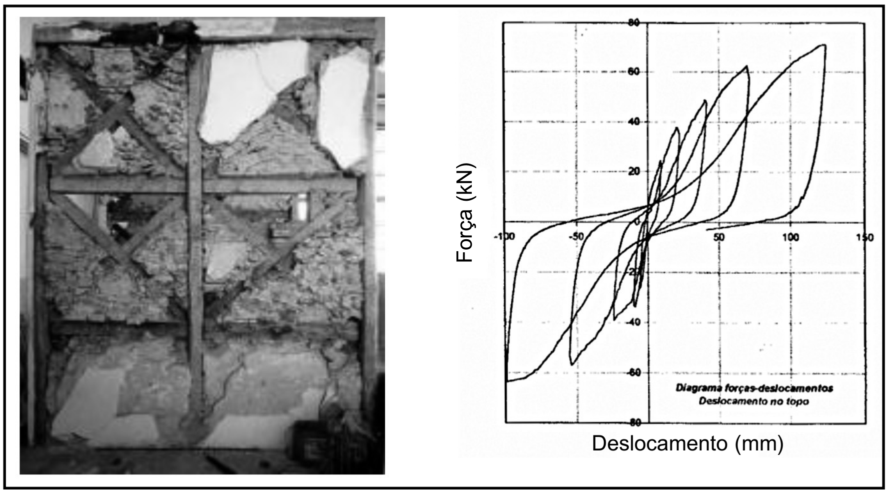

Figure 5. Tested pombaline wall (4).

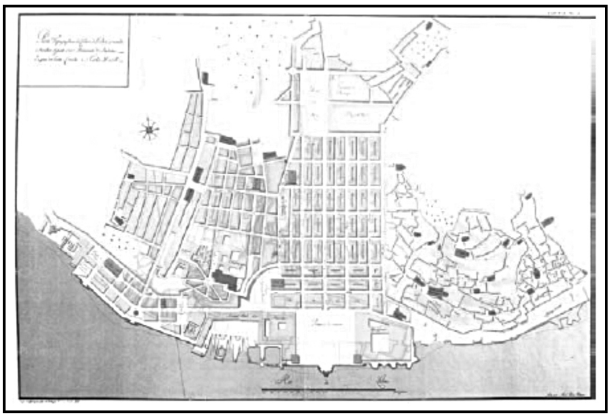

Figure 6. The location of pombaline buildings, from Eugénio dos Santos's plan (17).

These *pombaline* buildings are mainly in the Baixa de Lisboa (Lisbon's downtown area) (Figure 6) and they were built between 1755 and about 1880. After this period, people seemed to forget about the earthquake that had destroyed Lisbon and the buildings that were erected based on a *pombaline* structure started to be weaker. This was because of poor execution and the decline in the use of the typical *pombaline* St. Andrew's crosses, which led to them becoming another type of building known as *gaioleiros*, in the period 1880-1940.

3.2. Turkey - the "himis" buildings

The timber framework of the *himis* has studs more or less every 60 cm (Figure 7). The studs are tied at mid-storey height by other timber elements. The infill masonry is either brick or rubble stone. The walls are only 10 to 12 cm thick and seem rather weak in terms of earthquake behaviour. Studies on the behaviour of *himis* after the Kocaeli earthquake in 1999 showed that the structure could dissipate seismic energy and exhibited good behaviour through the straining and sliding of the masonry and timber elements. The closely-spaced studs prevented the propagation of the "X" cracks thereby reducing the possibility of out-of-plane failure of masonry (3).

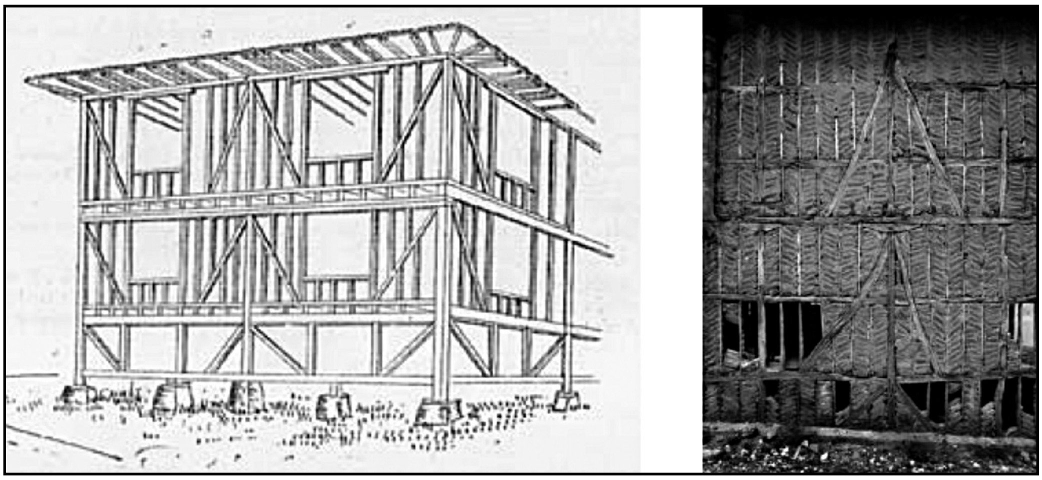

Figure 7. The timber framing of a traditional house in Turkey (18) (left) and a timber framed masonry building in Golcuk, after the 1999 earthquake (3).

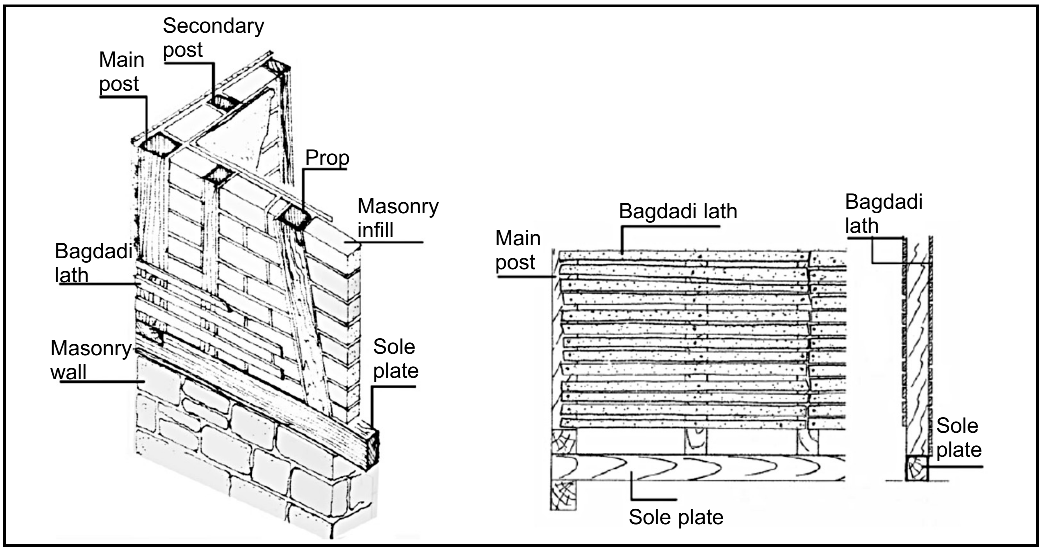

Figure 8. The bağdadi construction technique became more popular than himis technique (18).

Himis were first built in the 15th century and they were used until the end of the 18th century when the *ba€dadi* buildings took over, with plaster replacing the masonry infill (Figure 8).

Over the past two centuries, many of the more ordinary houses in the northern part of Anatolia were constructed entirely using the *himis* technique.

3.3. Greece - The timber framed buildings in Greece

The double-bearing system found in Greece, with masonry and timber framing, has certain features unique to it. These buildings have ground floor masonry walls 0.5 -0.7 m thick, while the upper storeys are made of a single layer of masonry that is 0.10 - 0.15 m thick. The ground floor is different from the upper ones. As shown in Figure 9, the first load bearing system is the masonry, the second is the timber frame and, should the masonry fail (Figure 9, right), the timber frame is activated to carry the load, thus preventing the total collapse of the building.

Another special item found in these Greek buildings is the sub-foundation (Figure 10). This is thought to behave like an ancient base isolation system (10).

This constructive solution was used in the early 19th century and it can be now be found in the center of the old town of Lefkas, the island known to have the highest seismicity in Greece.

3.4. Italy - The "casa baraccata" buildings

After the 1783 earthquake in Calabria, the Bourbon government of time decided to reconstruct the entire area using a building system known as *casa baraccata*. This system was described by Giovanni Vivenzio in his book "History of Earthquakes" (1783) (19). At the same time as the *casa baraccata* structural system was imposed, especially in Calabria region, anti-seismic

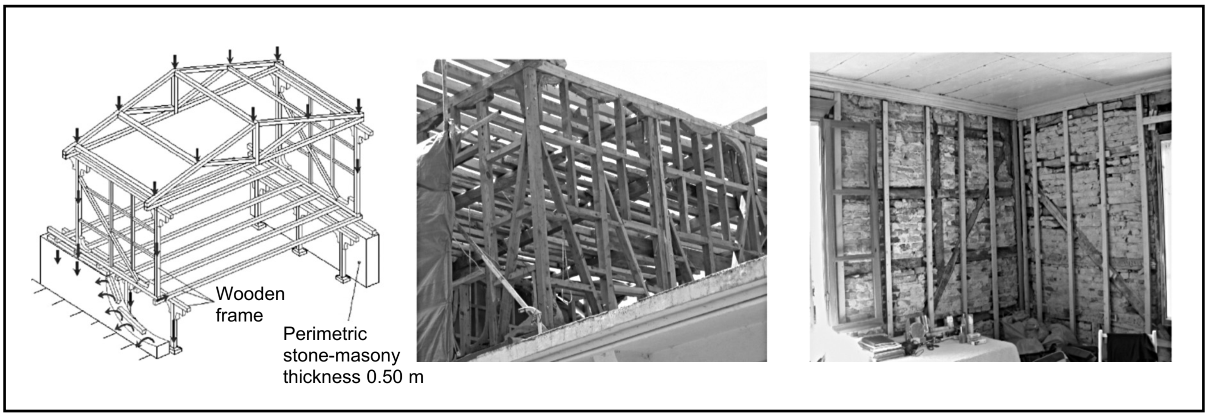

Figure 9. Timber framed building in Greece (10).

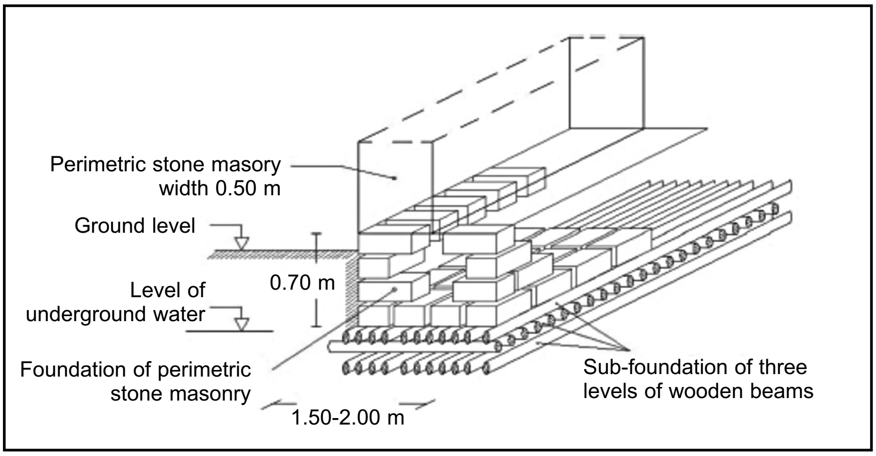

Figure 10. Foundation of timbered framed buildings in Greece (10).

construction standards were also issued. These regulations were inspired by the Lisbon standards post 1755, which regulated the *pombaline* buildings (20).

The *casa baraccata* system was born in the 14th century in central Italy and spread particularly in the second half of the seventeenth century. The system consists of a masonry structure with an inner timber frame (Figure 11). The timber frame is made of timber elements placed both vertically along the corners of the walls and along the two diagonals of each wall. The timber elements are connected to each other to ensure 3-D behaviour. The frame system was designed to withstand the horizontal seismic forces when the masonry cannot counter resistance. The system proposed in the Bourbon regulations provided for a two-storey building, symmetrical lengthwise and crosswise, and with the side blocks lower than the main central ones (21).

Because it was imposed by law, this type of structure was widely constructed throughout the entire Calabria region, which is the most seismically active in Italy (Figure 2).

3.5. Spain - The "telar de medianería" buildings

The timber framed masonry structural system, that can be found in Madrid area, was regulated and controlled by the local government at least from the 17th century, but until the 18th century it was slowly substituted by masonry work mainly because of the fire in Plaza Mayor in Madrid in 1790 (23).

Timber-framed partition walls or "*telares de medianería*" were built as structural walls, having a main wood vertical structure surrounded with ropes of sisal fibers. The spaces or "*cuarteles*" left between wooden vertical and horizontal elements were filled with masonry ("*mampostería*") of different materials, especially adobe bricks or rubble, as shown in Figure 12 (23).

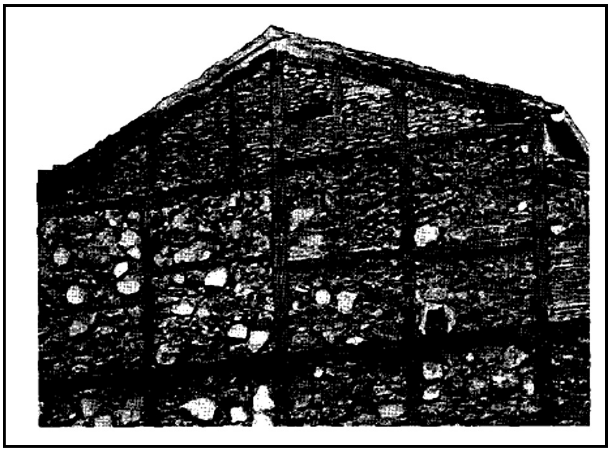

Figure 12. Timber-framed masonry wall (telar de medianería) (23).

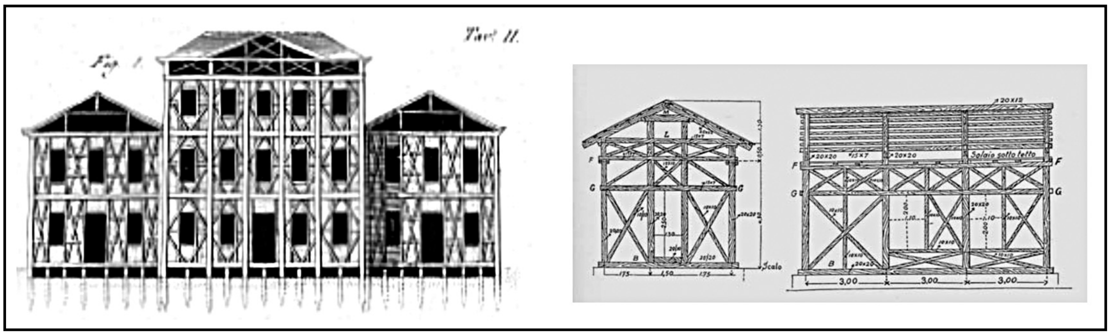

Figure 11. Casa baraccata system with timber framed masonry (22, 19).

As it is seen in Figure 2, Madrid area is not a significant seismic hazard zone, and thus the seismic resistance of the *telar de medianeria*, though seems to be proper to seismic prone areas, is still under the question.

3.6. France - The "colombage" building

The term *colombage* (meaning half-timbered house) has been described as a set of "pieces of wood", "beam in a wall" and beam in "joist framing". This building style has been used in France at least since the Middle Age and until the 19th century (24). The façades were improved from the 17th century to look more luxurious and modern, but the structure is the same.

The structure of the *colombage* buildings (Figure 13) uses wood-frame structure as its main material, and this can be filled with masonry or plaster.

Although the system of a wooden structure filled with masonry seems to be anti-seismic, some details (Figure 14) suggest the opposite: wooden bracings are not placed symmetrically and they lack continuity (which they normally exhibit when they need to carry horizontal forces).

Figure 13. The colombage building type made of timber framed masonry or plaster (24).

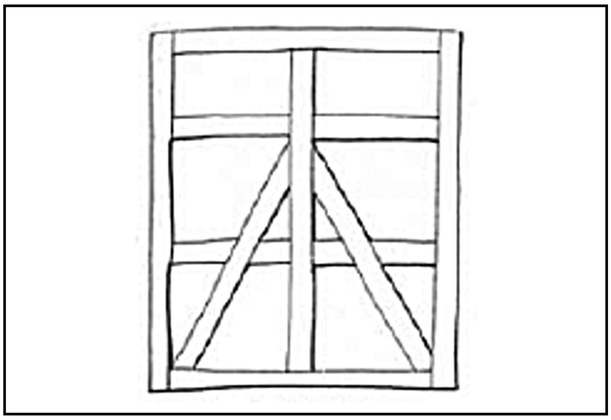

Figure 15. Decorative elements for wood frame (24).

The wood frame is merely a decorative element, reproducing a person in different situations, for example with the arms horizontal (Figure 15) (24).

Many French towns and villages have good examples of timber framed masonry buildings. Normandy and the eastern Alsace region probably has the largest number. The architecture varies slightly from town to town, with the exposed wood sculpted in different ways.

Since *colombage* buildings are found mostly in northern France, an area with moderate seismic activity (Figure 2), they are not subjected to earthquakes so it is not easy to evaluate their actual seismic resistance.

3.7. Germany - The "fachwerk" buildings

Although Germany is not greatly affected by earthquakes, timber framed masonry buildings can be found in many areas of the country. Having this type of construction in this non-seismic area reinforces the idea

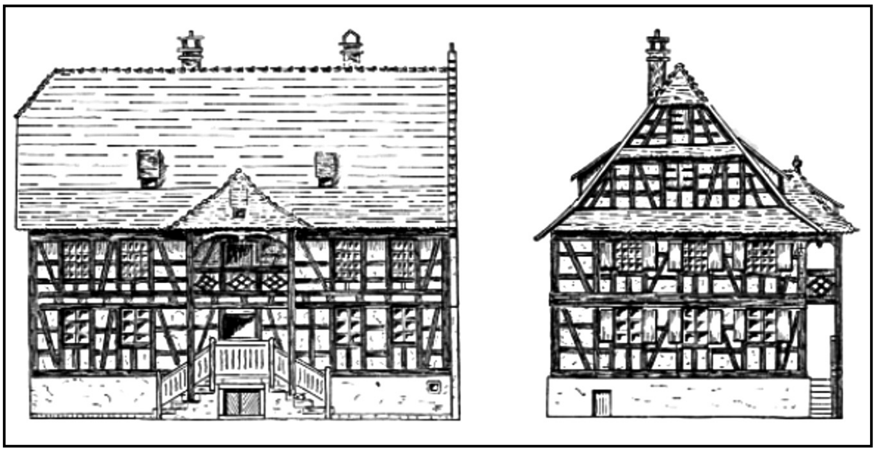

Figure 14. Maison á colombage façade from different angles (24).

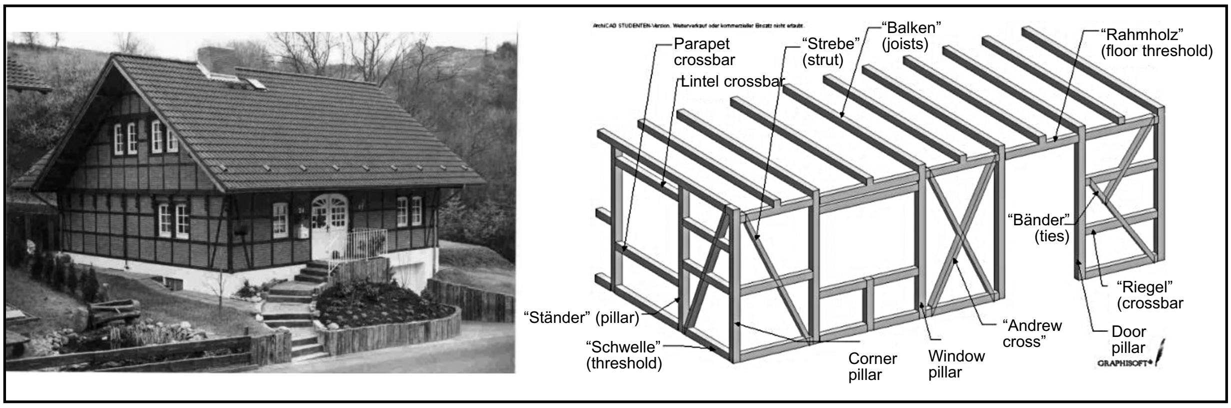

Figure 16. Fachwerk building (left), elements comprising the structure (right) (25).

that the *fachwerk* building was not explicitly designed to carry horizontal forces, although it shows a complete system for transmitting horizontal loads to the ground (Figure 16).

The *fachwerk* buildings present diagonal bracings in the form of a St. Andrew's cross, as in Portugal's *pombaline* buildings where it has an anti-seismic role.

Fachwerk buildings can be found both in southern Germany, where there is moderate seismic activity, and in the north, where seismic activity is minimal. They are widespread and there are about 2 million houses built with wooden frames filled with masonry, adobe or plaster. They were built until 1970. There are documents that testify to the occurrence of this type of construction in 1320, but most of them date from the end of the 18th century.

3.8. Romania - Timber framed buildings in Romania

In Romania, structures with wooden frames filled with masonry are not as widespread, but they do exist as a traditional type of building in the history of construction. Figure 17 shows the wooden frames filled with masonry

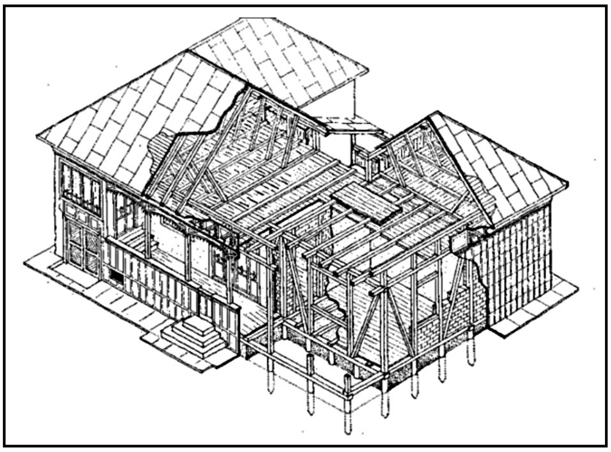

Figure 17. Traditional timber framed masonry house (26).

Figure 18. Example of timber framed masonry building, 2010, Busteni, Prahova.

in a 1936 building in Giurgiu County, an area with a design peak ground acceleration (PGA) of 0.20 g (Vrancea area has the highest PGA of 0.32 g). Houses of this type are being built nowadays, but the main reason seems to be the architecture, not resistance to earthquakes. The wooden frames are left visible (Figure 18) and they could be popular because the opportunity to use these construction materials (wood and brick) is easier or cheaper than the usual reinforced concrete material.

Timber framed masonry structures may be found here and there anywhere in Romania. There are also more wood frame adobe infill houses, which had quite good behaviour in the most recent major earthquake, on March 4 1977, in Vrancea.

3.9. Scandinavia (Denmark, Sweden and Norway) - Timber framed masonry buildings in Scandinavia

In Scandinavia, the timber framed walls take the form of a timber cage based on the repetition of a little *module* in plane (Figure 19) (approximately 80-150 cm wide) filled with brick masonry. They have a masonry

Figure 19. 18th century timber framed building in Lund, Sweden (27).

foundation (stones, sometimes bricks inserted in order to level the horizontal surface) and are two or three storeys high. The position of the wooden floors is shown on the outer walls' surface by the main beams (Figure 20) (27). Figure 19 shows a different arrangement of the bricks that seems to be mainly for aesthetic reasons, but may also be the solution to conduct forces in several directions.

This type of structure was built between the 16th and 19th centuries, being favoured because wood means that small elements can be made that can be easily replaced if they deteriorate, and because the masonry was easy to find. Another advantage of using timber is that, although an element may deform over time because it carries loads, the rest of the structure can bear the loads that the deformed element was supposed to carry, thus preventing the collapse of the building. The internal forces can be redistributed because the timber skeleton is a ductile framed structure.

These buildings can be found in some areas of Scandinavia where the timber-frame masonry structure was the commonest style for buildings, both private and public, especially in areas where bricks were readily available. This happened in Denmark and Sweden more than in Norway or Finland, and in towns or villages more than in the countryside (27).

With no significant local seismicity, the timber framed masonry houses were not built to withstand earthquakes, even though this system appears to have the necessary features that would enable it to bear horizontal forces, too. Some construction errors noted prove this as some elements were deformed only by bearing gravitational loads (Figure 20).

3.10. England - The "Half-timbered" buildings

The style that developed under the Tudor monarchs (1485–1603) derived from changing social and cultural trends in England. An increasingly wealthy merchant class combined with the land redistribution from Henry VIII's dissolution of the monasteries to provide the opportunity for both nobility and merchants to construct grand homes and estates. As England became more politically stable, there was less need for the nobility to occupy fortified castles. A major design element for newly-constructed private residences was half-timbering, which was common in the forested districts of England (28).

Oak was used to create a skeleton which was filled in with wattle and daub, plaster or bricks. The infill materials were often laid in a herringbone pattern. This was possible with bricks because they had no structural requirements; the wooden posts resist the forces and the bricks served mainly as decorative infill.

Many of the earlier medieval or Tudor manors were remodelled and modernized during Elizabethan period (1550-1625). The material of choice for those who could afford it was the stone; brick was becoming less popular as the full influence of the Italian Renaissance began to be felt.

In the 19th century another style emerged, the "Tudorbethan", where materials that simulate real bricks and wood framing are generally used.

Figure 20. Deformation of structural wood elements due to excessive loading (27).

Figure 21. English farmhouse (1630), timber frame filled with wattle and daub, Worcestershire, England (29).

Half-timbering is characteristic of English vernacular architecture in East Anglia. Warwickshire, Worcestershire (Figure 21), Herefordshire, Shropshire and Cheshire are other counties where half-timbered buildings can be found (28).

4. CONCLUSIONS

4.1. What led to the choice of a timber framed masonry building?

Earthquakes alone did not influence the birth of timber framed masonry buildings. Another important factor was access to materials, as in some countries masonry was a luxury material (in England, in the early years of the use of timber frame masonry), while in other countries it was used by lower social groups. Generally, the idea of building houses with wood frames filled with masonry spread from one country to another. For example, after the Lisbon earthquake of 1755, the Marquis of Pombal decided to use the pombaline system for an entire neighbourhood. The system has very good anti-seismic features, based on the St. Andrew's cross and the cage walls system used for interior walls. In 1783 a powerful earthquake destroyed Calabria, and the Bourbon government of the day followed the example of Pombal by establishing a committee of engineers to find the best solution and thus the *casa baraccata* system was chosen. Anti-seismic construction standards were issued at the same time, and these were to be applied in this region. If local seismic culture in Portugal and Italy, based on the occurrence of earthquakes, led to the development of anti-seismic standards, other countries paid little attention to earthquake resistance at that time. In Turkey, although seismic activity is quite severe, people only began to worry about earthquake resistant houses and regulations for them quite late in the day, which meant that the first seismic code was only published in 1940. But in the period 1940-1999 the earthquake codes were not widely used (30). The last big earthquake, Kocaeli 1999, revealed design and execution errors and inappropriate behaviour of materials (for example, hollow brick masonry proved to suffer brittle failure). The L'Aquila earthquake in 2009, where peak ground acceleration exceeded the standards' values, showed that it is not enough to renovate homes simply from an aesthetic point of view; attention must be given to structural rehabilitation.

Another factor that could influence the choice of the timber framed masonry building solution is architecture. The wooden frames are not visible in Portugal's *pombaline* structures, but in almost all other countries' buildings they are visible, whether they are countries with seismic activity or not. Wood is a material that has always been easy to find, easy to use, and it allows small items to be made so, in time, carpenters became specialized in wood construction and the execution has become quite fast. For most types of timber framed masonry structures, the purpose of masonry is to carry gravitational forces, representing a primary resistance system. Once this system fails, the wooden structure begins to work. In the three systems mentioned above the masonry also has an anti-seismic role, being designed to carry horizontal forces, too. In *himis* the mortar joints between bricks is designed to be weak, because the bricks' motion during earthquakes enables enough energy is dissipated without the entire panel cracking. Traditional timber framed masonry buildings show flexibility, energy dissipating capability and they can withstand many cycles of earthquake loads.

4.2. Which of the timber framed masonry buildings described has the strongest system?

This is difficult, as there are no experimental studies to confirm the strength of each system. Most have passed the "tests" of great earthquakes, thus demonstrating earthquake resistance despite the fact that wood is not a very durable material in terms of time, for biological reasons.

The pombaline system, especially designed after the big 1755 earthquake, seems to be the most adequate timber-framed solution for seismic resistance purposes. Experimental tests have demonstrated a high resistance to many cycles of loading (4).

The himis system has passed the test of Kocaeli 1999, where many masonry and concrete buildings collapsed near himis buildings that were damaged, but remained standing (31).

The timber framed masonry buildings in Lefkas, Greece, sustained the earthquake in 2003 with little damage and no collapse, compared with the new reinforced concrete structures.

Italy's casa baraccata structures in Calabria exhibit a very effective anti-seismic system, but these buildings were not constructed throughout Italy.

Telares de medianería in Spain are found in a low seismic hazard area and though they seem to be able to withstand earthquakes, it looks like they weren't built having this objective.

Looking at the *colombage* structures and noting the non-symmetry of the wooden frame, it seems that architecture was the primary reason for choosing that type of structure, and earthquake resistance was not really taken into account. The German *fachwerk*, although it has a symmetrical structure and the St. Andrew's cross that is also characteristic of the *pombaline* buildings, was not built to withstand earthquakes because Germany is a country with a very low seismic activity.

In Romania, too, a country with high seismic activity, a few buildings were found with timber framed masonry, but not many, and the reason of choosing the solution seems to have less to do with earthquake resistance than architecture, with wooden frames being left visible in the most recent structures.

In Scandinavia timber framed masonry structures were built to bear the gravitational forces, though in some cases their structural elements were undersized and thus significant deformation appeared. Where wood and bricks were available they were widely used, and this type of structure is very widespread in the Nordic countries.

England's half-timbered structures date from 1500, but these were mostly built for architectural reasons, too.

It is difficult to draw a comparison between these types of buildings, which are based on the same system but have different characteristics. Symmetry is an important feature which might be expect to find in anti-seismic constructions, and whose absence suggests that the possibility of earthquakes was not taken into account.

At first sight, these timber framed masonry structures can be put into three categories:

- Buildings designed to be earthquake resistant;
- Buildings designed to bear only gravity loads, but with a system that can also carry horizontal forces;
- Buildings designed to carry only gravitational forces, without earthquake resistant capabilities.

Figure 22. Shows the distribution of these buildings in the studied areas.

Although some buildings are stronger and more resistant to earthquakes (pombaline, himis, etc.) and others are less resistant (colombage, half-timbered) the influence of earthquakes on a local culture in house construction is very clear. Maybe in some countries the system is too strong given the seismic requirements (fachwerk, telar de medianeria), and in other countries the system (although very efficient in terms of earthquake resistance) is not widespread, although the seismicity demands high strength (Romania). The experience of each country, whether neighbouring or not, has helped the development of seismic engineering in one way or another by spreading an idea, with each country leaving its fingerprint in its own specific way. Thus there are many structures that seem to be different but which were actually born of the same idea, to protect against earthquakes.

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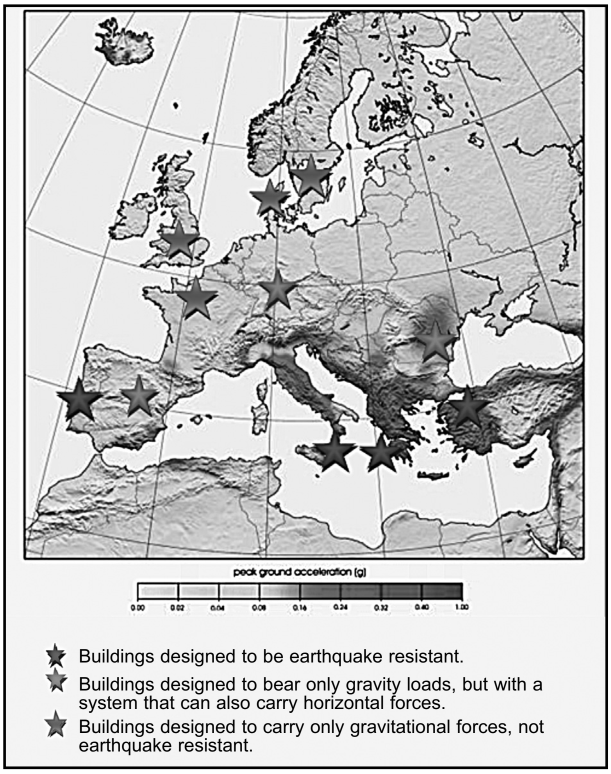

Figure 22. Peak Ground Acceleration Map with 90% non-exceedance probability within 50 years (32).

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