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Reconstruction Post-War 1945 – Structures and Materials in Le Havre

Isabela P. Cruz
Delft University of Technology, Faculty of Architecture, Delft, The Netherlands

George Nieuwmeijer and G. Jan Arends
Delft University of Technology, Faculty of Architecture, Delft, The Netherlands

ABSTRACT: This paper traces the evolution and knowledge relating to construction materials, structures and reconstruction work implemented in post war (1945) France. The study focuses on the city of Le Havre, France, which suffered severe bomb damage in September 1944. The information was collected from French specialist magazines and technical literature in the fields of architecture and civil engineering published before and immediately after the Second World War. It highlights the great effort invested in reconstruction, style and urban design by Auguste Perret, one of the most brilliant architects of modern France. The focus is on the building sector, the optimisation of construction methods through industrialization and innovative structure systems, as well as the use of construction materials and structures such as steel, reinforced concrete and pre-stressed concrete. Special attention is devoted to structural details, improvements in formwork and the use of prefabrication.

1 INTRODUCTION

In Europe, the Post War Reconstruction Period (1945-1968) was characterized by the repair of war damage and an explosive growth in the building industry. One of the best examples of this is the city of Le Havre, where the implementation of a new construction order encompassing volumes, nature and density was used to rebuild a large residential and commercial area that had been severely damaged during the Second World War (WWII).

This paper attempts to contribute to the knowledge relating to construction materials, structures and reconstruction work during the post war period in France and to understanding of the evolution of pre-stressed concrete and the emergence of prefabrication methods. This period is characterized by the development and use of what are now common construction materials and structures. Special consideration is given to the structural details as well as the appearance of new techniques, in particular, the use of prefabrication.

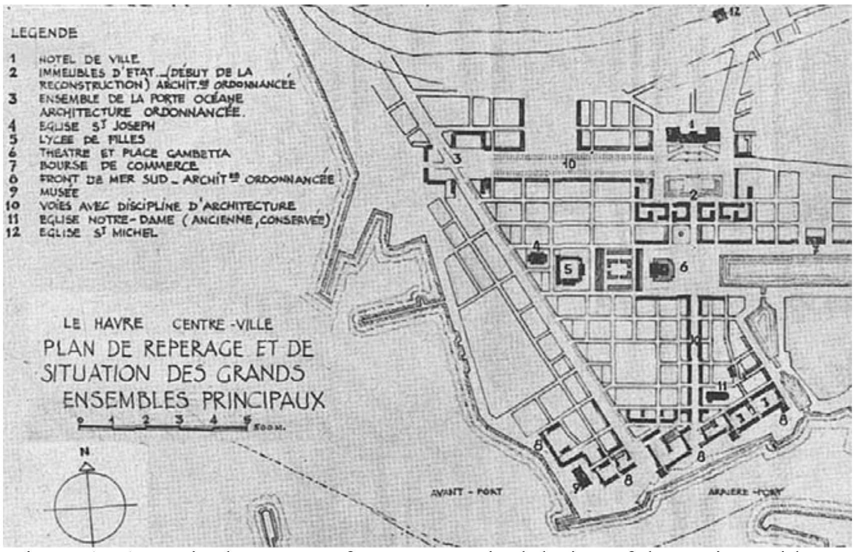
The subject of the present study is the city of Le Havre in France, which suffered the loss of its administrative, cultural and residential infrastructure. A huge effort was invested in the reconstruction of this city and many technological innovations were used. The reconstruction plan started in 1945 and was designed and supervised by the Chief architect Auguste Perret, then aged 71.

This paper is based on information acquired from French specialist magazines and technical literature in the field of architecture and civil engineering published before and after WWII.

The destruction caused by the heavy bombing of Le Havre in September 1944 was mainly located in the residential district on the seafront. Only three churches and perhaps ten houses remained in an area of more than two square kilometres in the centre of the city. All trace of the street pattern disappeared and after the bombing more than 80 000 people were left homeless.

The reconstruction of the city was strongly influenced by the doctrine of Perret (Mayer 1949). As both architect and contractor, he played an important role in the definition of the specific aesthetics of reinforced concrete. The urban plan presented by Perret in 1946 was designed on a modular base of 6.24 m, which formed a grid-like web. The choice of 6.24 m was explained by Dalloz (1960) as a module that took into account the width of a residential unit. A modular base of six metres could be conveniently divided into either two three metre wide rooms, or one room of four metres, leaving two metres which would be sufficient for the installation of a bathroom or a kitchen. On the 6.24 grid, Perret laid out his buildings simply, but elegantly. Streets and small groupings of houses were located in the new centre of the city. The buildings were designed by a group of his disciples and followers (Mayer 1949).

The design of the reconstruction project of Le Havre traced a homogeneous space, regulated by two frameworks. A composition was made up of three monumental sets - L'Hôtel de Ville (the Town Hall) square, La Porte Océane, Le Front de Mer Sud - connected to each other by three axes - Boulevard Foch, Boulevard François-Ier and Rue de Paris (Paris Street) which gave astonishing legibility to the city, see Fig. 1.



Key:
1. The Town Hall
2. Public Buildings
3. The Ocean Door
4. Saint-Joseph's Church
5. Girls' School
6. Théâtre et Place Gambetta
7. Bourse de Commerce
8. Front de Mer Sud Architecture
9. Museum

Figure 1 : Areas in the centre of Le Havre. Final design of the project with modifications (Dalloz, 1956).

2 RECONSTRUCTION MATERIALS

2.1 Post-War situation

In France extensive rebuilding was necessary after WWII and these required large volumes of concrete. The designers were challenged by the materials and methods of construction to be adopted. The optimum mechanical strength of the concrete prepared from a laboratory test-sample could not be guaranteed when the concrete was manufactured in large quantities.

However, American cements were perfectly well defined and of multiple types, as well as of excellent quality and regularity. To manufacture concrete of the same quality, the French cement producers had to improve their equipment and the variety and value of their products.

The nature and size of the aggregate was improved and regularly checked, according to the parameters established in the laboratory. For certain civil engineering projects requiring large quantities of concrete at that time there was no French quarry that could provide gravels or other aggregates that fulfilled the required technical specifications.

French manufacturers of construction materials followed American technical achievements in the manufacture of concrete, however, they had to take into consideration all the comparative problems of each country and had to adapt American concepts to the prevailing situation in France.

The new materials made in France were a consequence of newly improved designs which overcame the constraints imposed by the building sites.

2.2 Developments during the 1950s

2.2.1 Calculation at rupture.

According to Chambaud (1956), calculation of the strength of materials previously related exclusively to working conditions in the elastic phase. In this phase, the strains and the deformations were proportional to the forces applied and reversible, i.e. they disappeared at the same time as the forces. The resistance of structures was therefore regarded as assured when the elastic constraints under the working loads did not exceed a limit considered acceptable and fixed by the rules. However, all the materials used in construction, in particular steel and concrete, presented a plastic phase after the elastic phase, which precedes the point of rupture by varying degrees. This plastic phase is characterized by large unrecoverable deformations, see Fig. 2. Indeed, it is an essential condition when using these materials.

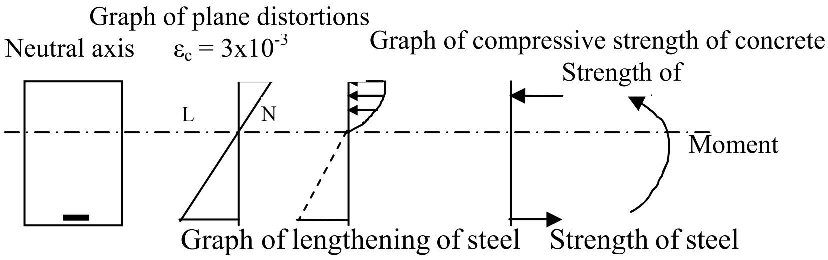


Figure 2 : Schematic view of bending in reinforced concrete.

In steel the point of separation between the elastic and plastic phases is very clear. In concrete, however, it is less clear because the phenomenon of creep complicates the observable indications, although qualitatively the consequences are the same.

It was not known to what degree resistance calculations could account for these circumstances. Greater knowledge of the conditions of strength and safety coefficients was needed. For steel construction, only few improvements to traditional methods of calculation were necessary because large deformations took place suddenly after the elastic phase.

However, for reinforced concrete the partial overlap of the two phenomena, (elastic and plastic), an autonomous theory was formulated to account for elastoplastic bending. This determined the approximate rupture loads of a given element. The elastoplastic theory also helped the specification of the dimensions of an element that would be required to enable it to resist specific loads before rupture. This had been impossible when conventional calculation methods were used.

The main advantages of a method to calculate rupture that could be applied to pure and combined bending are briefly outlined. The traditional calculations, based on fixed values for the modulus of elasticity for concrete and steel in the purely elastic state, could not be used to evaluate the rupture loads and, consequently, did not quantify the effective safety coefficient for two reasons: generally, in the plastic phase the stress is not proportional to the load, it increases less quickly than the load, and secondly in combined bending the most unfavourable forces of rupture cannot be obtained by applying a uniform factor of increase in the service load. Therefore, it was impossible to fix a constant safety coefficient in advance and apply this coefficient over the strains.

The traditional methods of calculating the strength of reinforced concrete tried to obtain a safety coefficient (defined as the multiplying factor of increase, applicable to the unfavourable forces to reach the point of rupture) of approximately 2, but decreasing to 1.8 and even 1.7 in the elements strongly reinforced in compression and working at the acceptable maximum rate. They were increased to 3 or more in certain hollow concrete structures.

The objective of the method of calculating rupture was precisely to solve these drawbacks: to predict the breaking loads with acceptable accuracy; the application to the results of variable safety coefficients and freely choose them according to the works; and to choose and install devices so that the construction remained in the elastic range, under the working loads.

The data required for the rupture design were the compressive strength of the concrete and the graph of tension versus deformation of steel. From these data, and by applying certain general principles resulting from experiments, it was possible to obtain the rupture loads by inference.

These principles, valid for pure or combined bending, in the state immediately preceding the rupture, are summarized on Fig. 2: neutral axis as in the classic theory; stretched fibres of the concrete not contributing to the strength at the point of rupture; compressed zone of concrete working at an average uniform rate, compressed reinforcements working at elastic limit with an effectiveness coefficient of about 60 to 70 %; maximum limit of deformation of the steel is its elastic limit at the point of rupture of steel; hypothesis of plane deformations in the section of rupture, except a correcting factor taking into account the possible slip of stretched steel, limit to a rate of about $3x10^{-3}$ of the last shortening of compressed extreme fibre of the concrete.

It was then possible to pass from the rupture forces to the service forces or reciprocally by applying a suitable safety coefficient to the unfavourable strain. It was recommended that a safety coefficient varying from 1.4 to 1.5 for the dead load, and from 1.7 to 2.5 for the life load should be taken. It is understood that the principal conditions which could influence the safety coefficients were as follows: type and proposed use of the building; nature of calculated elements; consequence of eventual damage in case of accident; nature of strain (relative importance of the random strains); design of the works (hyperstatic and isostatic); and characteristics of the studies.

To summarize, the method of rupture calculation developed for the bending resulted in savings in steel and concrete and enabled a safe effective coefficient to be selected in advance according to the proposed use of the building.

2.2.2 Steel

According to Autissier (1956), the role of steel in reinforced concrete is to absorb tension. The types of steel used vary: cylindrical steel (smooth bars, profile) and non-cylindrical steel. However, most of the steel used was cylindrical, i.e. round bars. Special bars that could increase adherence were also used. These included insulated or assembled profiles, superficial frameworks, cables of extra hard steel and reheated steel wire for binding. In Fig. 3 different types of reinforcement are shown.

1. The different types of ribs formerly used for round steel bars.
2. After the 1948 introduction of the standards, the steel reinforcement used with elastic limits of 4 to 6 N/mm^2 and diameters of 8 to 40 mm.
3. A framework of a Christin floor using welded wire trellis mesh 125 × 200 with 3 to 9 mm diameter steel.
4. Arched roof using expanded welded steel mesh 75 × 200 mm.

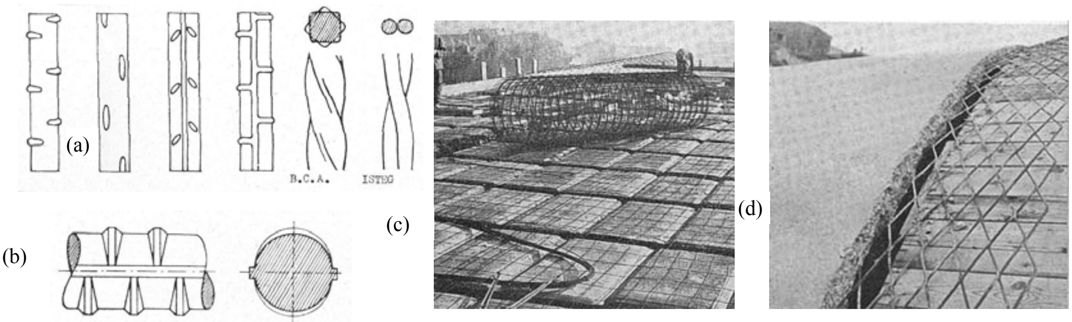


Figure 3 : Different types of ribbed bars, welded wire trellis and expanded steel mesh, (Autissier 1956).

2.2.3 Reinforced Concrete

The preparation of reinforced concrete requires three main independent operations: formwork, reinforcement and casting. Casting was subdivided into three phases: manufacture, transport and installation. Some improvements in the formwork were made at that period, including protecting by using a thin steel sheet and using laminates. Eventually wood was replaced by metal in the form of pre-fabricated units, allowing multiple re-use and giving an improved finish.

According to Autissier (1956) the reinforcements supported buildings under varying loads. Consequently they were specified to high degrees of accuracy. A plan for the location of reliable reinforcement was usually adopted. Some such systems can be seen in Fig. 4.

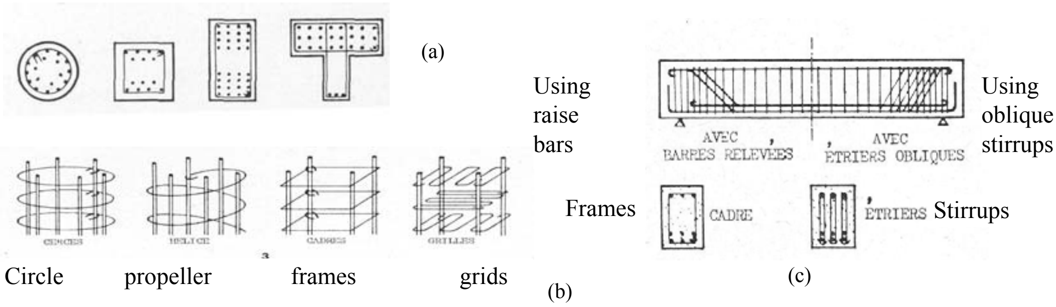


Figure 4 : Some reinforcement systems for tension (a), for compression columns (b) and some reinforcements in a beam positioned on two supports (c), (Autissier 1956).

The department store "14 N/mm^2, which at the time was a civil engineering achievement made possible by the application of the A La Boule D'or", see Fig. 7, is an example of a reinforced concrete structure in Le Havre that was calculated by using elastoplastic theory (Franche 1956). The challenge was to open the front of the store to the outside as much as possible. The framework was to follow the semicircular part of the frontage. The new calculation methods permitted the design of large open spaces. Some features of the reinforced concrete framework could be quantified: The concrete stresses sometimes reached elastoplastic theory.

2.2.4 Pre-stressing Concrete

Attempts to pre-stress the concrete were initially unsuccessful (Worontzoff 1956). The first researchers used soft steel bars that could only be tightened slightly. After a certain time, the concrete was shortened; it shrank under the effect of creeping and withdrawal and the tension of the steel reinforcement fell to zero. Freyssinet's contribution was to clarify the phenomena of differential deformation and to introduce the use of high tensile steel that was initially manufactured by stretching. With this it was possible for the steel to adopt sufficiently high rates of tension to compensate for the tensile drop due to the differential deformations of the concrete and steel and to preserve enough tension to counterbalance decompression under the effect of the loads, see Fig. 5. The pre-stressing of the concrete started with the discoveries of Freyssinet.

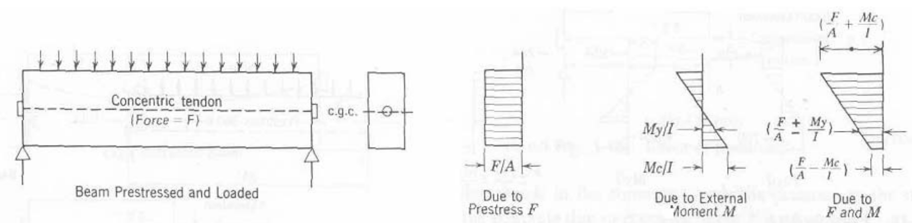


Figure 5 : Stress distribution in a section of a concentrically pre-stressed beam.

Two principal ways to carry out the pre-stressing of the concrete were available to the manufacturer: pre-stressing by using adherent wire (pre-tensioning) and post-tensioning.

The pre-stressed steel wires in the moulds are anchored and tightened by supports on fixed solid masses on the ground or on beams with side stops. The moulds were then filled with vibrated concrete that was hardened by accelerating by heating, see Fig. 6. The tension of wire was then slackened. The wires tended to shorten. By adhering to the concrete, the wires transmitted the tension force that they had previously undergone to compress the concrete.

Pre-stressing by anchored cables: the element to be pre-stressed was poured in the mould after the pre-stressing cables had been placed inside the mould and isolated from the concrete by means of thin iron-sheet sheaths. It was also possible fix the conduits in a predetermined position. When the concrete hardened sufficiently, the cables were extended by means of hydraulic jacks, which were supported by the concrete at the ends of the element. When the desired tension was reached, the ends of the cable were anchored in devices, which the tensile load of the cable transmitted to the concrete, see Fig. 6. The empty space between the cable and the sheath was then filled by mortar injected under pressure.

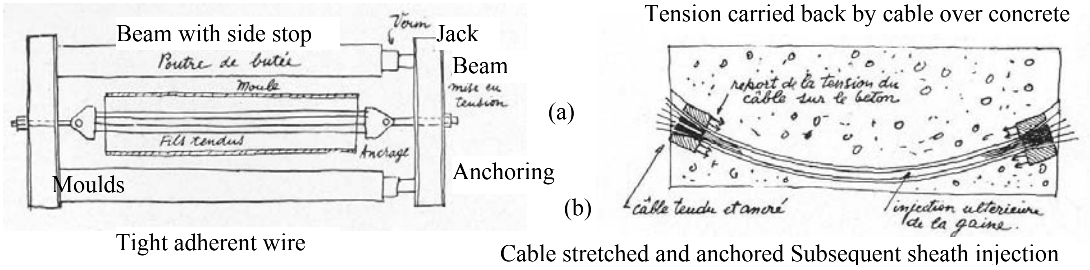


Figure 6 : (a) Diagram of a manufacturing bench for adherent wire. Tensioning of wire bench of beams pre stressed by wire adherents. (b) Principle of pre-stressing by cables. Cable stretched and anchored, (Worontzoff 1956).

A beautiful example of the application of this innovative technique is The Saint-Joseph Church, see Fig. 7. The format adopted was that of a bell-tower, in which a tower lantern forms a unit with the nave of the church. With pre-stressed concrete it was possible to solve a problem that had been studied extensively in the Middle Ages: four groups of four pillars of 1.20 m × 1.20 m resting over concrete wells at more than 12 m depth, support the tower itself at 25m high through four V shaped brackets. These transition elements support the bell-tower and the total height of the church which is 104 m. The truncated pyramid is composed of four V-shaped brackets, originating in four angles from a base of 19 m broad, and subdivided upwards to eight points, which form the eight tops of the octagonal beam that supports the shaft of the tower of approximately 13 m in diameter. The bases of these brackets are to some extent braced by pre-stressed beams.

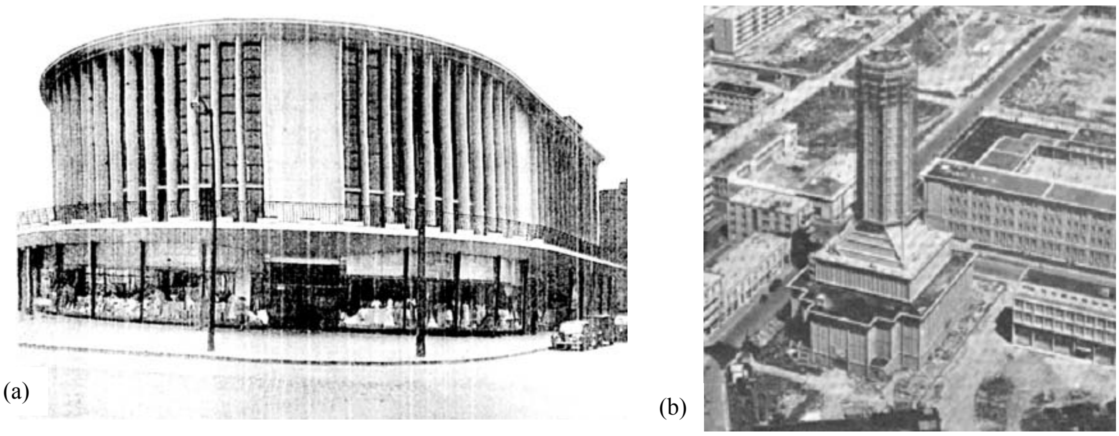


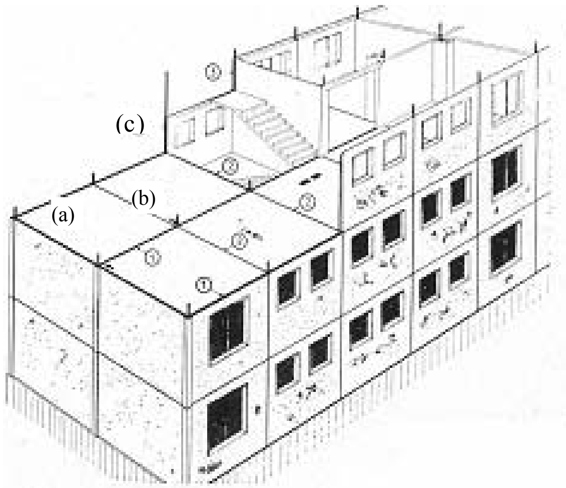
Figure 7 : (a) Overall view of the building “A la Boule d’or” (Franche, A. 1956), (b) Aerial view of *L’Eglise Saint-Joseph* (Dalloz, 1956).

3 INDUSTRIALIZATION OF MATERIALS FOR RECONSTRUCTION

At that time Blumenthal (1946) had to put great effort into fitting out the construction building yards in France. “The problem of tools and mechanization of building yards acquired particular importance due to the shortage of manpower and the need to build quickly and economically".
Regarding offsite prefabrication of units for apartment buildings, according to Fougea (1956), the elements of the framework were manufactured in permanent factories which served an area of a radius of 30 km to 50 km. These factories received all the materials such as cement, steel,

aggregates, and insulating materials used in the prefabrication process directly from the places of production or extraction. They produced finished concrete elements, which were then sent to the building site for assembly. The only equipment installed on the site was a powerful hoist and a compressor.

The framework comprised exterior wall panels, frontage panels, floor panels, partitions and stairs see Fig. 8. All the manufactured elements left the factory completely finished, including external and internal facings in their final state. All the necessary fixing devices for the complementary installations were in place.



Key:
(a) Longitudinal chain cordon
(b) Transverse chain cordon
(c) Vertical chain cordon of anchorage

Figure 8 : Schematic view of an entire building manufactured in the factory (Fougea 1956).

On site only certain simple installation operations were carried out including: assembly without further adjustments, the positioning of elements of the framework, execution of the chaining, immediate fixing of the interior woodwork, finishing of sanitary facilities, slopes and railings, and installing electric cables through conduits. The only remaining work was painting, for which traditional methods were used. The optimization of the design of the buildings and their component elements required long and thorough study. The shapes of the elements and the materials used were designed according to their purpose, which required seeking optimum qualities to obtain: mechanical resistance, water tightness, heat and noise insulation etc.

To manufacture all the elements, complicated moulds had to be created. These did not consist of improved formwork but were produced by machines working to a high degree of accuracy and leaving little room for human error. Operation: vibration of the mould, translation or swivelling of the pulley, ejection of the finished product, was carried out by one man alone, using the levers on a dashboard.

Manufacturing was carried out in factories equipped with moulding machines and equipment such as boilers, sprays, compressors, hydraulic pumps, transformers, concrete batching and mixing plant, sanding machines, overhead bridges, monorails with their hoists and all steam pipes, hydraulics, compressed air and electricity. This was a construction plant with the following advantages: lower costs achieved by reducing the number of working hours; improvement in working conditions; improved quality, particularly in terms of frontages and the appearance of the ceilings and interior surfaces; fewer details; and additional construction possibilities. Despite this, an objection often arose in the form of the threat to architecture posed by standardization, leading to uniformity and monotony.

This use of the new building methods meant abandoning many traditional methods and the redefinition of relationships among the various parties involved: project superintendent, industrial architect, and sub contractor.

An example of how this technique was implemented in Le Havre is the set of buildings forming *Le Front de Mer Sud*, (Tournant 1951). They were residential buildings along the quay, housing families in 1 to 6 bedroom apartments, with large commercial spaces on the ground floor which could be transformed into garages in the future. The main characteristics of the buildings are as follows: they were built on a square web of 6,24 m, two spans long. The fronts were made of 7 types of spans; they were laid out in 12 small groups, some of which had a commercial area on the ground floor; they were distributed in groups of three and eleven storey buildings, constructed over a mezzanine, a ground floor and a basement; and in buildings with a ground floor over an empty sanitation space. Finally, there was the 5 storey Poterne building where the diversity in the unity of the design was primarily obtained by using two main framework systems, one with columns and one with small pillars broken up on every floor by beams and by a variety of fillings and colours.

4 CONCLUSIONS

After WWII in France, as in many other European cities, the rebuilding of destroyed cities was an urgent task. Le Havre represents a symbolic example of a well defined and studied reconstruction project based on the architectural principles of one of France's great architects: Auguste Perret.

His urban reconstruction plan based on the use of a modular grid system of 6.24 m was practical because it facilitated the installation of prefabricated structural elements.

The development of prefabrication methods accelerated in the 1950's because of the need for economical and speedily erected structures in the post war reconstruction period. The building site was transformed into a place for the assembly of prefabricated structural elements, which reduced the number of workers and therefore the cost of construction.

The risk of monotony in style introduced by the uniformity of prefabrication was avoided by the inclusion of structural beams and columns in the facade, in alternating sequences.

Although the pre-stressing process of concrete was already known before the war and widely used, it was employed in particular during the post war reconstruction and helped to reduce costs and construction times. Pre-stressed concrete and the pre-stressed elements were also pre-fabricated.

The methods of calculation for reinforced concrete and pre-stressing were much improved during this reconstruction period. The elastoplastic theory was consolidated and thus empirical calculations were abandoned.

In the reconstruction plan, blocks of apartments were interspersed with commercial and administrative areas, maintaining a diversity of activities and life in the rebuilt areas. Further research into evaluating the urban impact and results of this mixed architectural composition would be valuable.

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