Survey report

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Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **7 (1964)**

PDF erstellt am: **25.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-7890

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Survey Report

Rapport de synthèse

Zusammenfassender Bericht

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1. Foreword

The purpose of this Report is to give an extensive worldwide review of the present state of structural prefabrication. Its completeness, however, is somewhat impaired for the following reasons:

1. As already implied in the title, the Report is limited to ordinary or prestressed concrete elements (with or without hollow brick) having a structural function.

2. The information it contains is based on the National Reports submitted by a restricted number of countries, viz.: Belgium, East Germany, France, Great Britain, Holland, Hungary, Italy, Spain, Sweden, Switzerland and U.S.A.

Nevertheless, it is assumed that this Report presents a comprehensive and adequately complete picture of structural prefabrication in the world. This is justified because the conclusions drawn for a given country may usually also be applied to other countries having a similar social and economic structure and also because prefabrication in the majority of the above-cited countries has reached a higher level of development to be striven for by those countries where this technique is, at present, but little used.

At any rate, this Report examines the design and erection of prefabricated structures in various countries and analyzes the relation between in-situ and precast techniques.

This relation is most critical in those countries which have a high standard of social and economic development, for the following reasons. The development of any kind of activity involving both labor and machinery brings about a gradual increase in the use of machinery and a decrease in the use of labor. This decrease, however, is offset by an improvement in the workers' skill, since the simple and laborious manual operations are, generally speaking, replaced by mechanized equipment whose operation and maintenance are entrusted to the worker [1]).

From an economic standpoint, prefabrication prevails in highly developed countries where the salary scales (and hence the cost of labor) are high and the cost of mechanical equipment is low. However, a comparison between the civil construction and other industrial activities shows that the former has not followed the development rate of the latter, for reasons mainly due to its peculiar nature.

Therefore, along with the most significant and interesting cases of advanced construction technique in each country, there is frequently found a very artisan aspect in the construction activity at the same time.

Technical and organizational difficulties, not found in other industrial activities, have in some countries prevented technical development in the building industry, so that it is out of date and inadequate with relation to their economic expansion.

2. Prefabrication in Housing [2])

The crisis in the building sector in those countries is actually due to the economic expansion which, on the one hand, because of full employment, causes a shortage and a high cost of labor and, on the other hand, gives rise to a large and urgent demand for houses, workshops, viaducts, etc.

Prefabrication is therefore needed for two reasons. Firstly, it reduces labor (hence, the larger cost saving) and, by advancing the laborers to the level of industrial workers, it discourages them from transferring to other activities. Secondly, because it is suitable for large-scale planning, prefabrication makes it possible to carry out, within a short time and with a limited number of skilled workers, the urgent building projects required by the economic expansion.

Because of its specific nature, housing is perhaps the sector which poses the greatest problems in organizing and rationalizing to a well-defined prefabrication plan. Nevertheless, there is everywhere a definite trend towards prefabrication, but the level and extent of this technique in the different countries varies in accordance with local conditions.

Structural prefabrication in the housing sector usually concerns:

1. *Wall panels* having almost generally a load-bearing function. They are made of lightly reinforced concrete containing cavities, hollow bricks or

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[1]) As a general rule, by industrializing the civil construction industry, prefabrication promotes development of this sector of activity, and is therefore to be considered as the guide line for any present and future evolution trends of the construction technique.

[2]) This Section comprises residential housing proper (apartment houses) and buildings for schools, offices, hospitals, etc., where the technological features are similar to residential housing.

light weight materials. The panels, when placed in position, are usually already provided with door and window frames, facings, ducts, etc.

2. *Floor panels* of reinforced or prestressed concrete, often containing hollow bricks or tiles. The panels are frequently delivered complete with both flooring and ceiling finishes applied.
3. *Beams and columns.*
4. *Staircase flights.*
5. *Foundations.*

It is appropriate to describe briefly the present trend in prefabricating these elements both in regard to their design and production.

As to design, one notices a trend towards total prefabrication, aiming at members which are complete with finishes, facings, frames, etc., in order to reduce as much as possible conventional work on the site. In other words, it is clear that in housing the cost saving due to prefabrication is obtained in the finishing operations rather than in the structure of the building.

There is also an increasing tendency to utilize the load-bearing capacity of nearly all the prefabricated members (including wall panels).

It is necessary, however, to consider whether this trend, at least at the present time, is more rational from both an economic and structural point of view compared with the classic solution involving a load-bearing frame and closing walls (whether prefabricated or otherwise) and for tall buildings to ascertain whether the overall factor of safety is of the same order in both constructional systems.

As far as the technological and production aspects are concerned, it must be pointed out that prefabricated members are usually manufactured in special sites. These may be small workshops near the construction yard or real factories, equipped with industrially organized fixed facilities (involving formwork, tensioning benches, steam curing equipment, etc.) capable of serving a number of construction yards situated even within a large radius.

It is worth mentioning that prefabrication in the housing field, at present, tends towards the latter type of setup. This requires that the construction jobs using prefabrication must necessarily be of considerable size, so as to make possible a satisfactory amortization of the factory facilities.

Prefabrication in housing therefore is, and will continue to be, applied to public projects and large private construction jobs[3]).

The above considerations are based on the housing situation in some of the following countries.

Belgium. The large number of interesting buildings reported show a

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[3]) This means that real estate companies will have to join forces in order to get the considerable means required for large-scale housing projects. Contractors will have to do likewise to enable them to face this new condition of the housing industry.

remarkably wide use of the prefabrication technique. Of particular interest are the reinforced concrete frames for school buildings up to 3 stories in height.

East Germany. Prefabrication in housing is steadily expanding. Statistics show that it increased from 33% in 1960 to 67% in 1962 of the total housing construction.

The prefabricated members may be divided into three classes:

a) members weighing up to 750 kg. For example, outside wall elements of less than story height which are superimposed on one another in two rows;
b) members weighing up to 2000 kg. The outside wall elements are of story height;
c) members weighing up to 5000 kg. The outside wall elements, of story height, form 5 to 6 m long walls and contain door and window frames, ducts, etc.

France. Housing prefabrication started some fifteen years ago and is therefore highly developed and widely used. In 1953, the number of prefabricated apartments built was 5000, whereas in 1959 it increased to 60,000. The early small and simple workshops are now replaced by fixed industrial establishments costing up to 2 million dollars each.

The output of these establishments (up to 4 apartments a day) makes possible an amortization rate on the fixed plants of 10% of the cost of the apartments.

Great Britain. Heavy prefabricated concrete members are fairly well used. They are mostly grids of beams and columns forming the frame of the building, to which wall panels are later added for closing purposes. Of special interest is the use of prefabrication in school buildings and recent developments in multistory housing.

Holland. Along with the usual heavy prefabrication systems and those of partial prefabrication there is a trend to produce housing walls in situ, using movable formwork and pumped concrete.

This method, which under certain aspects is the opposite of the prefabrication concept, is nevertheless worth mentioning since it represents a system requiring a minimum of labor and construction equipment.

Italy. Prefabrication in housing has only recently been introduced, the first undertakings using mostly French patents. However, 4 contractors have now under construction in Milan a housing project costing 130 million dollars.

Sweden. The general trend is to use partial prefabrication, employing the conventional housing construction procedure and single prefabricated members.

However, there are a few prefabrication methods, one of which is the "Skarnes Heavy System" involving inside load-bearing walls, and the other is the "Gothenburg" system which makes use of a load-bearing frame consisting of prefabricated beams and columns slotted to allow mutual insertion.

U.S.A. Although European type apartment houses are seldom built, prefabrication (mainly for school, office, hospital, etc., buildings) presents an interesting system producing the horizontal members at ground level and raising them by the well-known "lift slab" method.

3. Prefabrication in Industrial Building

Industrial construction [4]) almost everywhere has long accepted the prefabrication technique, with an easiness and readiness greatly superior to those of the housing sector.

The reason is that in this case it is possible to formulate a prefabrication plan on a mass-production basis for the large number and few types of elements which are required and because of the smaller incidence of the finishing operations which makes prefabrication practically feasible. Prefabrication may take place at the building site or in a large manufacturing plant.

In the first case, the main load-bearing beams and other secondary members (trusses, floors, etc.) are prefabricated at the base of the building, using equipment designed to meet the particular site requirements.

In the second case, the members are prefabricated on an industrial scale in factories which are capable of supplying a large variety of parts meeting nearly all the requirements of an industrial construction.

This trend is important and is likely to increase in the building industry with the contractors engaged in assembling industrially prefabricated members. The transportation and lightness requirements of these members encourage a wide use of prestressing.

A general survey of prefabrication in the industrial building field shows greater uniformity in both design and construction site technique than in the housing sector.

In what follows we shall therefore for each country point out only the procedures that deserve mention for their unusual nature and importance from a technical and construction site viewpoint or for the concepts involved.

Belgium. Use is made of advanced prefabrication systems.

Of special interest is the Preflex system which uses a Differdange H-beam provided with concrete encasement. The manufacturing process is as follows.

A steel reinforcement cage is welded to the bottom flange of the steel beam. The beam is subjected to bending by external loading and, while loaded, concrete is cast round the cage and accelerated curing applied. On release of the load, the beam tends to return to its original position and compresses the concrete slab which is bonded to it.

At the end of this process the beam consists of a steel part that is bent and in tension and a concrete part that is bent and in compression. This beam

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[4]) This term includes industrial buildings proper (workshops, storehouses, garages, etc.) as well as large structures (exhibition halls, sport edifices, and so on) where the construction technique is similar.

finds a number of uses in both the industrial and bridge-and-viaduct prefabrication fields. Its main feature is a very small depth/span ratio.

East Germany. Prefabrication is widely used and in a rather elaborate nature, especially as regards the connection of single elements, such as beams, columns, trusses and roofs.

France. The heavy prefabrication methods used by the Boussiron Company for workshops with parallel halls having a 20 m span and 12 m spaced columns are of interest. The roof-forming members, produced at a high industrial rate, are assembled on site by means of an extensive use of prestressing.

The prefabrication system that was employed for the roof and floors of the singular Palais des Expositions at Rond Point de la Défense in Paris is also remarkable.

In the construction by the Boussiron Company of the Marignane hangar roof consisting of two 101.5×60 m double-curvature thin shells, each of the 4,200 ton shells was built at the base of the hangar and then lifted by 16 jacks 19 m high.

Great Britain. The tank sections (Windsor tank 7.3 m high with a 48.8 m diameter and a 13,640 cu.m capacity), the multistory parking garages and the power stations (Aberthaw Power Station) are worthy of mention.

Holland. Most important industrial buildings show a high degree of prefabrication. An interesting structure is the thin-shell roof built for the "Royal Netherlands Tourist Association" of the Hague. The conoidal thin shells of the rotunda are 10.5 m long, 6.5 cm thick and weigh 4 tons each, whereas the cylindrical shells of the square building have the dimensions of 10.5×2.7 m $\times$ 6.5 cm and weigh 4.5 tons each. All were cast by superimposing one shell on another, separated by a sheet of paper only. The first mold, carrying the entire pile of shells, was of shaped concrete.

Hungary. Same as in East Germany. Remarkable are the water tanks, consisting of prefabricated and prestressed wall elements (Gnädig-Thoma system), and the elevated tanks.

Italy. There is an increasing tendency to use industrially produced members of types and sizes suitable for standardization.

As to prefabrication at the base of buildings during construction, special mention must be made of the Alfa Romeo factory in Arese (Milan) and of the S.A.D.E. thermal power station in Porto Marghera (Venice).

Highly remarkable are the recent sport buildings in Rome for the Olympic Games (designed by P. L. Nervi) where use was made of the special Ferrocemento technique (prefabricated concrete slabs heavily reinforced with steel mesh). Similarly in the recent Fiumicino airport hangar (designed by R. Morandi) the prestressed concrete design proved more advantageous than the steel design.

Spain. Worthy of pointing out are two of the structures designed by C. F. Casado. The first is the trolleybus hangar in Madrid, where prefabricated three-hinged arches, whose thrust has been relieved, practically cover a 42 m span, and the second is the Santana factory in Linares with elegant prefabricated shed portals (grids of 15×10 m columns) supporting the edge beams.

Switzerland. Remarkable are the large (9×18 m) prefabricated monolithic thin shells at the Birrfeld construction site and the thin shells made of small prestressed segments to form a monolithic structure (roof at Wangen near Olten).

4. Bridges and Viaducts

This sector shows nearly everywhere a high degree of prefabrication, for reasons which, in some respects, are the same as those indicated for industrial buildings.

Prefabrication here usually takes place at the construction site. Generally speaking, the main prefabricated elements are simply supported longitudinal beams or, less frequently, Gerber type beams.

Normally, the beams are prefabricated and placed in position as follows:

— lateral placing: appropriate centering is set up at abutment level to support the beam mold. Concrete is placed, and when the beams have cured (and possibly been prestressed) they are placed in position sidewise with respect to their final position;
— longitudinal placing: use is made of a temporary steel centering supporting one end of the concrete beam;
— lifting: beams of small span and weight are produced at the base of the structure and then raised and placed in position by jacks or a crane.

The transverse beams and the slab for the floor are usually cast in situ. However, these secondary load-bearing elements are sometimes produced at the base of the structure, thus showing a trend towards nearly total prefabrication.

In some countries (for example, Italy) specialized companies are equipped to supply bridges and viaducts (with spans up to 40 m) which are entirely produced at the site (main beams, sections of transverse beams and floor slabs are all pretensioned).

This sector also includes special prefabricated structural elements, such as railway sleepers and expressway guardrails, for which there is at present a large-scale demand. However, no information has reached the Survey reporter from any country. It is hoped that some future communication will deal with these interesting, though highly specialized, prefabricated elements.

The international situation of prefabrication in this sector abounds with too many almost identical examples to allow illustration of them in detail as they deserve.

The survey will therefore be limited to the most interesting cases.

Belgium. In this sector, too, the use of Preflex beams is of great advantage.

France. Mention should be made of the De Lattre de Tassigny Bridge, Lyons (53 m span beams) and the De L'Hippodrome Bridge, Lille (67 m span beams), both of which were built by placing the beams sidewise, and the La Guaira-Caracas Expressway (132 m span) arch bridges constructed by French companies.

Great Britain. Worthy of pointing out is a series of city viaducts including the Chiswick overpass, and railway bridges where use was made of prefabrication and prestressing because of the reduced traffic interruption involved.

Attention must also be called to the standardization program of the Prestressed Concrete Development Group in cooperation with the Ministry of Transport for bridges with spans up to 16 m with inverted T-sections and up to 30 m with box-sections.

Holland. Of interest are: 1. the bridge on the Meuse River at Roermond (4 spans of 60, 80, 72.5 and 57.5 m respectively) constructed, in accordance with a Gerber type isostatic system, with prefabricated and prestressed beams of a maximum 50 m span; and 2. the peculiar 60 m span Nabla girder bridge on the Haringvliet estuary, whose cross-section is an equilateral triangle.

Hungary. The Szolnok caisson multiple-span bridge (15 spans of about 15 m each) is remarkable for the improved prefabrication system used and the speed of construction.

Spain. The Merida 106 m arch bridge built in four parts on the ground and the Vega Terran and Merida bridges constructed by tipping the half arches deserve mention.

Switzerland. Of special interest are the 15 overpasses across the Geneva-Lausanne expressway, whose mass planning was highly accurate.

Remarkable is the Altstetter viaduct (near Zurich) made of prefabricated elements whose width equals that of the roadway, weighing 55 tons each and connected together by prestressing cables.

U.S.A. The U.S.A. show numerous multiple-span bridges of extraordinary length where improved prefabrication techniques made possible by large mass production were used (for example, the 24 km long Pontchartrain Bridge).

Of great interest is the Hood Canal Floating Bridge (2 km long) resting on floating caissons.

5. Hydraulic Structures

An examination of prefabrication in this sector (especially in Italy) calls for some special considerations regarding the interest and advantages.

Besides the usual considerations, such as rationalization of the building site, reduction of labor and cost, etc., others may in this case be pointed out.

a) The local conditions, which often make it particularly difficult and expensive to construct in situ certain hydraulic structures or parts of them.

For underwater structures one must add the difficulty of procuring compact concrete, which still exists in spite of the progress made in underwater concreting technology (Contractor, Prepakt, etc.).

b) The necessity of reducing the construction time of some hydraulic works, as, for example, the lining of already operating canals (which must be carried out in the short periods when the canals are empty), the construction of river works (to be done only during low-water), etc.

For sea structures the working period has to be reduced to a minimum mainly because of the uncertainties of the behavior of the sea. In this case, therefore, prefabrication increases not only the speed and safety of the work but the success probability of the whole job itself.

c) The location of some hydraulic works, which may sometimes require a large distribution of labor, equipment and materials (often even of mixing water) in many points widely spread over large areas.

d) The features of some hydraulic structures (for instance, small irrigation and reclamation works) which are characterized by particularly high surface area/volume ratios and, at the same time, by economic and technical burdens per unit of formwork required for construction in situ.

e) The possibility of floating transport of heavy members (caissons, docks, tunnel elements); the use of floating cranes, etc.

Our usual brief survey of the international prefabrication situation shows as follows.

France. Interesting structures are:

— the Le Havre maritime station, whose 26 ton beams came by rail from Rouen (90 km away);

— the Le Havre 1200 m long Bellot quay consisting of forty-eight $25 \times 25 \times 3.5$ m prestressed concrete elements weighing 1300 tons each, built on the mainland and floated to their destination and placed on Benoto piles.

Floating was also used by the Société des Grands Travaux de Marseille in constructing the Havana (Cuba) tunnel composed of five 107 m long prestressed concrete pipe elements. Provisionally closed at their ends, balanced and counterweighed, the elements were gradually sunk in place and connected together.

Great Britain. Mention should be made of the recent Quay no. 1 at the 982 m long and 27 m wide Tees Dock supported by three rows of prestressed concrete piles. The piles consist of prefabricated cylindrical elements about 1.8 m long with internal and external diameters of 1.45 and 1.91 m respectively. The cylinders were lined up and united by prestressing until they formed 13 to 20.5 m long piles. The deck consists of prefabricated prestressed concrete beams and slabs.

Holland. The geographical conditions of the country pose particular problems in this sector. We recall what was done in a very short time to plug a large number of dam breaches caused by the disastrous flood of February 1953:

$11 \times 7.5 \times 6$ m pontoons with a wall thickness of 15 cm were then used. Similar elements are often employed in closing the last section of new dams in tidal water; the pontoons are provided with large openings for letting the tidal water through when the dam is under construction and are closed upon completion of the structure.

As regards underwater tunnels, it is worth mentioning the wide use of the system which prefabricates the elements, floats them to their destination, sinks them and connects them together. One of the first tunnels thus built is that under the Nieuwe Maas River in Rotterdam, carried out in 1938—1942.

Italy. Worthy of pointing out is the important 4.20 m reinforced concrete Volturno pressure pipeline.

Of interest also are the long and highly flexible prestressed concrete slabs (designed by Zorzi) for lining the power canal of the Pontecorvo (Rome) hydroelectric power plant. The slabs are 25 to 30 m long, 1.25 m wide and 3 cm thick. They are reinforced with steel mesh and prestressed longitudinally by pretensioning (ten 3 mm wires per slab). They were produced in 10 to 12 superimposed layers, using special vibrating and finishing machinery.

Of maritime works we shall mention the important external and internal quays of the new port in Genoa and the heavy prefabricated structural members of the 5th dry dock, also in Genoa, which was floated into position.

A remarkable structure is also the ANIC loading dock at Gela (Sicily) built by the Vianini Company on a prefabricated and prestressed pile foundation.

6. Structural Problems Related to Prefabrication

The development and increasing use of prefabrication techniques in various sectors of the construction industry pose new problems in the design, production, safety, specification, etc., of the prefabricated elements.

The trend towards complete industrialization will bring about standardization of types and sizes of different elements and this will affect the pattern of design of large prefabricated constructions.

The main problem in the production of the prefabricated members is an economic one, i. e., reduction of overhead charges in the cost of each member. This can be achieved by setting up large, centralized and highly mechanized factories, where the cost of overheads can be distributed over a large output of elements.

This is possible because of the low transportation cost of medium sized elements within radii of 30 to 50 km.

As far as the statical aspect of the design of prefabricated members is concerned, which is of major interest to us, there is a need for a thorough investigation aimed at finding the differences and novelties, with respect to the conventional methods, which need to be taken into consideration during the calculation, standardization and specification stages [5]).

In this connection it is amazing to note the scarcity of experimental research in the prefabrication field, especially as regards the connections of the elements and the resulting overall factor of safety of the structure as a whole.

This research seems to be of primary importance, especially with regard to major structures, such as residential buildings of 10 stories or higher. In fact, some doubts about the static behavior of these structures in the face of horizontal actions (wind, seismic effects) seem to be justified.

Our Association has long been interested in the structural aspects of prefabrication, as is shown by the papers which have appeared in the "Publications" and by the reports presented at the various congresses (cf. the attached references).

More recently, I.A.B.S.E. has also set up a "Subcommittee on Prefabricated Structures" under the chairmanship of this reporter.

The first act of this Subcommittee was to gather, on an international scale, facts and data on structural prefabrication for Theme IVb "Design and erection of prefabricated structures" of this Congress. These facts and data are contained in the 11 National Reports used in preparing this Survey Report.

After this first necessary step on an international level, a systematic study could be undertaken of the most interesting topics relevant to structural prefabrication. With this object in mind, I have prepared for our Subcommittee a list of such topics, entitled "Classifications (and Recommendations) for Prefabricated Structures". This list is included in the separate volume containing the national reports on prefabrication.

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[5]) Sweden has State Specifications for precast concrete elements, especially for pipelines.

Summary

The writer reviews the development of structural prefabrication in eleven countries (Belgium, East Germany, France, Great Britain, Holland, Hungary, Italy, Spain, Sweden, Switzerland, U.S.A.) and outlines its possible future evolution.

Mention is then made of the many new problems raised by the prefabrication technique, with special regard to statical analysis and specifications.

Résumé

L'auteur passe en revue le développement de la préfabrication dans onze pays (Allemagne de l'Est, Belgique, Espagne, Etats-Unis, France, Grande-Bretagne, Hollande, Hongrie, Italie, Suède, Suisse) et esquisse son évolution future possible.

Il mentionne ensuite les nombreux problèmes nouveaux qu'a entraînés la technique de la préfabrication, particulièrement en ce qui concerne les études et les prescriptions.

Zusammenfassung

Der Autor betrachtet die Entwicklung der Vorfabrikation von Bauwerken in elf Ländern (Belgien, Deutsche Demokratische Republik, Frankreich, Großbritannien, Holland, Italien, Schweden, Schweiz, Spanien, Ungarn, U.S.A.) und umreißt ihre wahrscheinliche Weiterentwicklung.

Es werden dann die vielen neuen Probleme aufgezeigt, die durch die Vorfabrikations-Technik hervorgerufen werden, mit besonderem Bezug auf die statischen Untersuchungen und Vorschriften.