Development of the Porte de Lilas system in The Netherlands

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Abstract

This paper describes structural systems built during the 1950s, such as the Porte de Lilas system used in Paris (1953), and their further development in Amsterdam and Delft in the 1960s. The advantages of these types of structure are that it is relatively easy to carry out many types of rehabilitation, renovation and appropriate transformation. In Western Europe, particularly in The Netherlands, close attention was paid to the evolution of the French construction system. This system was used to build a hotel in Amsterdam and an apartment building and block of flats for students in Delft. These serve as examples to illustrate the construction techniques and the modifications that have been made either to meet safety standards or modern requirements with regard to space and the facilities provided in the buildings.
Keywords: prefabricated, steel gantry, construction system, Porte de Lilas.

1 Introduction

Jean Fayeton [2, 3], one of the Modern Architects in France, introduced the debate on methods and results in the building industry and illustrated the influence of the construction techniques on architecture. The Porte de Lilas project in Paris, two twelve-story buildings constructed according to new technical design and based on the use of a steel frame and prefabricated exterior wall panels, demonstrated that under certain conditions the steel framework could compete with reinforced concrete for the economic construction of residential buildings. He looked for a new association between steel and reinforced concrete that would produce finished surfaces, remove the need for scaffolding or formwork and eliminate any concreting at high elevations.

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In Western Europe (The Netherlands, Denmark) close attention was paid to the evolution of the French construction system. For example, the French construction system was used to build a hotel in Amsterdam and an apartment building and block of flats for students in Delft in very short construction time.

2 Prefabricated system – France Porte de Lilas – process of construction using steel framework

There were two 11 storey buildings, each with 154 dwellings. The vertical elements were metal frames. The module of 4.40 m was used in both directions, which facilitated the variation in of the various types of residence (F2, F3, F4, and F5). The framework consisted of a series of gantries with three spans, which had welded frames that were fabricated at ground level. The posts were manufactured on site by assembling shaped steel profile HN beams that were provided by the factory in the required lengths. The frame was lifted by hoisting entire gantries, using a mast for the two first gantries. A travelling carriage mounted on the gantries that were already in position was advanced by one span for each operation. After adjustment of the frame, flights of prefabricated stairs were welded onto the frames. The gantries were lifted at the rate of one gantry every two days, (Mondin [5–7]). The vertical loads and the horizontal elements were supported by the frame. This was composed of gantries (sometimes reinforced or equipped with diagonals to provide wind-bracing). These gantries, which were the full height of the building, were assembled on the ground, and then lifted as single units. Temporary struts/spacers ensured the rigidity of the unit (Fayeton [2]).

Some transverse bracing was included in Y1 and Y6 between X1 and X3 and in Y3 and Y4 between X2 and X3 see Fig. 1.

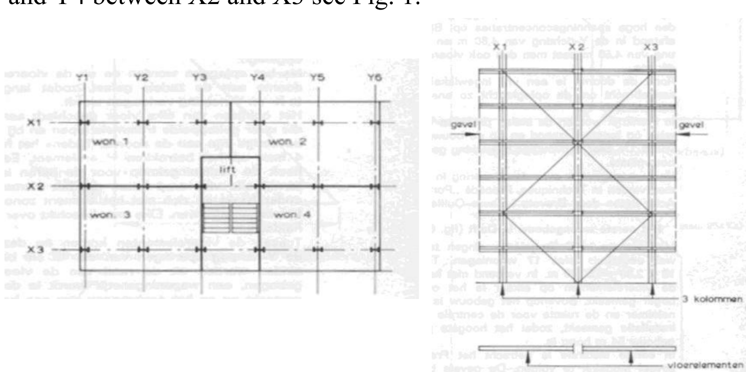


Figure 1: Back to back residential units and frames Y1 and Y6.

In Y2 and Y5 temporary transverse braces were added to provide stability during the hoisting process. These were removed after the floors had been installed and the joints had been filled with concrete. In X2 temporary longitudinal braces were introduced.

The floors were formed of 4m square 22 cm thick slabs of reinforced concrete see Fig. 2, (thus slightly smaller than the spaces between the supporting posts) and, cast above each other, on ground floor.

The panels were lifted by a travelling electric winch rolling over the main horizontal beam at the top of the frame, see Fig. 3. The provisional spacers were installed and the bands of filling concrete were cast on site (Fayeton [2]).

It was clear, that when the floors were lifted into position vertically the corbels would bump into the saddles. For this reason the floors were lifted 20 cm out of alignment. When the floor element reached the required height and was still suspended on the cables, it was pulled 20 cm inwards and placed on the saddles.

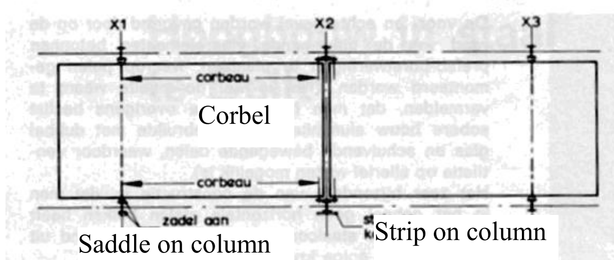


Figure 2: Floor elements, dimensions ca. 4.1 x 6 m^2 with their bearings.

The factory-made facade elements had a mesh of 4.40 m, a crushed 20x40 Durax concrete core (density 600 kg/m^3), washed coarse ground external facing and an internal facing of lime mortar. They were installed on the framework by a special carriage, provided with brackets, (Mondin [6, 7]).

The prefabricated frontages were 4.40 m long (span dimension) and for the complete panel span 4.40 x 2.50 m. These elements were assembled on the posts of the frame. The interior divisions made of Dufaylite (honeycomb layers of paper or cardboard), so that the need for plastering was eliminated.

The main advantage of this construction process is a considerable reduction in the labour required especially the skilled labour, which was reduced to a third.

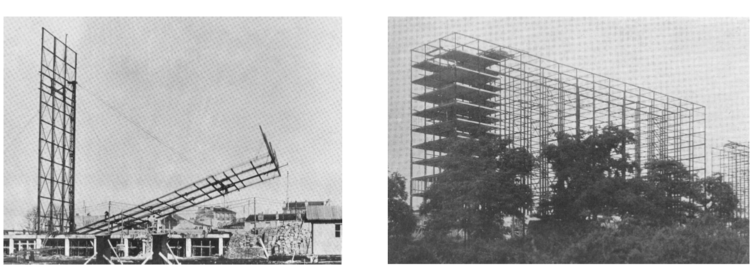


Figure 3: Lifting of a gantry that was assembled on the ground and view of the Porte de Lilas buildings under construction showing the gantries, some floors and the travelling winch.

A special feature of the structure is that no longitudinal steel beams were used. The steel construction consisted exclusively of columns and with some cross beams for the links.

The Dutch system based on the Porte des Lilas system.

2.1 The residential buildings in Delft

These were designed to be 17 storey blocks of gallery flats, see Fig. 4. Total height was 50.40m (18 x 2.80m). The ground floor ceiling was higher than those of the upper floors.

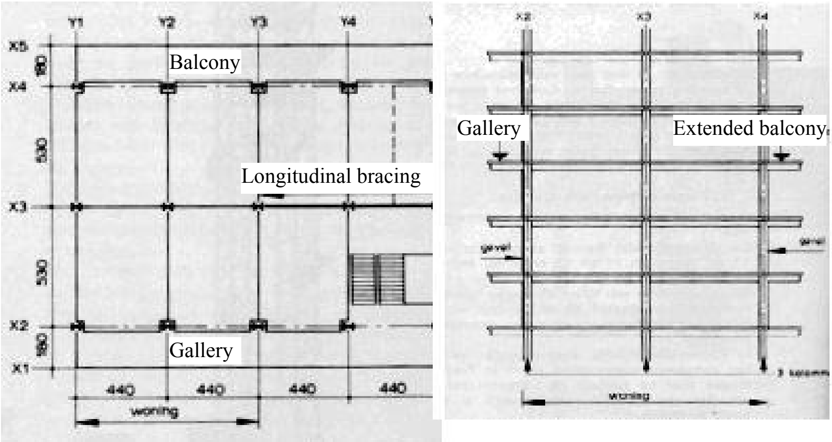


Figure 4: Framework of the first building with transverse bracing and a cross-section of the frame without transverse bracing.

The Dutch engineer Corsmit [1] analysed the buildings of the French system. Initially an attempt was made to follow the French system as closely as possible. However the facades were not on the edge of the floor but directly outside the columns. In addition the galleries or balconies were outside, so using the French system would have created a cold bridge. Therefore the galleries and balconies had to be constructed as separate elements which needed support. Attaching steel supports to the outer columns was not feasible owing to cost and the bending moments that would have been generated in the columns.

The following option was seriously considered: First, construct the building without galleries and balconies. The steel structure would consist of columns with transverse bearing beams as links. The horizontal links would be formed by floors that would be fixed by brackets at the four corners. Up-turned L-shaped concrete prefabricated elements would be suspended against the columns. The console columns would have a tension force upwards, a lateral force and under pressure (Fig 5). The moment arising from the overhang would be taken up by the console column. The heavily reinforced floors had to be at least 18cm thick. The span is approximately the length of the diagonal.

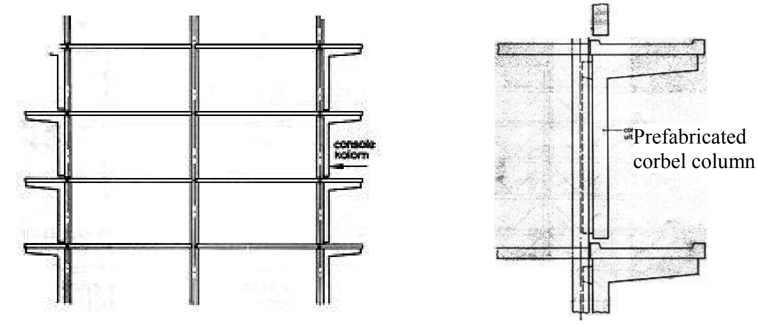


Figure 5: Structure with corbel columns.

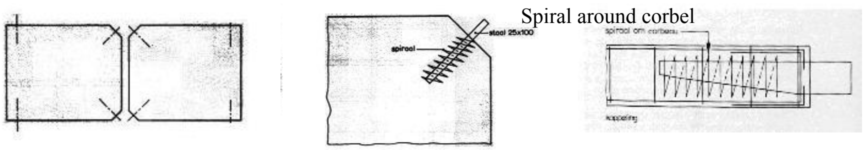


Figure 6: Floor elements with corbels and the joint of upper and lower reinforcement.

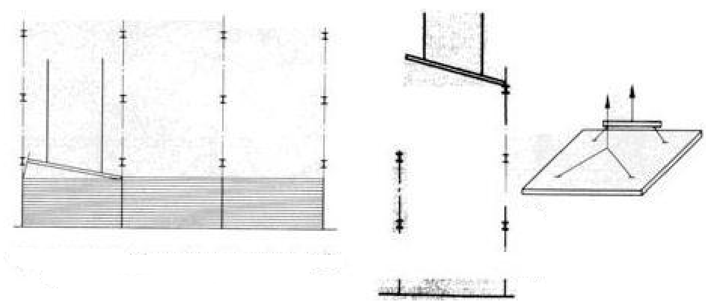


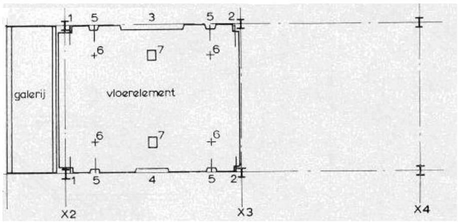
Figure 7: The floor element is inclined. The inclined floor element is hoisted to its position. Harness of the floor element. At the desired height, first the lower side of the element is positioned and then the floor is lowered into place.

A sufficiently safe solution was found by using an 18cm thick floor and providing the brackets with a welded-on spiral (Fig 6). The top and bottom reinforcements were linked to the edges to prevent splitting.

According Corsmit [1] this construction would have several consequences that had already been investigated by the French for open porch housing in order to develop a construction method for gallery flats. However, in Delft a construction method was developed in which the frames have horizontal members to support the galleries and balcony elements as well as vertical columns. Extra costs arose from the cost of the horizontal beams, whereas a cost reduction could be attributed to the disappearance of the console columns, the consoles, the saddles and bearing strips on the columns, and above all from the fact, that the floor elements could easily be reduced to a thickness of 13 cm and could have lighter reinforcement, see Fig.7.

On the low side there was short gap so that the floor could be slid along the base of the K-brace. On the high side however there had to be a longer gap because the floor had to be lowered along the linking bars that were moved apart.

For this reason and also in relation to the columns, the edges of the floor elements were specially shaped see Fig 8.



1. Gaps for outer columns. The extra space is for the moulds by x3 that must be free of each other. The floors are cast 10 cm to the outside to accommodate this.
2 Gaps for middle columns
3 Long gaps for the linking struts on the high side.
4. Short gaps for the linking struts on the low side.
5. Small gaps for the vertical guiding cables and linking struts
6 Crane hooks
7 Hoisting gaps. The hoisting gear is lowered through these holes, as do the hoisting cables for the lower floors.

Figure 8: Floor slab.

The temporary bracing could be removed from the unbraced frames. The horizontal layer protected them against horizontal buckling; the forces were transferred to the frames with bracing. Great attention was paid to the stability of the building which in the transverse (y) direction was obtained from the frames with wind bracing. In the residential building every second frame had wind bracing.

The longitudinal brace (Fig 9) is fitted in X2 (Fig. 8) and in most cases was over three spans, thus 3 x 4.40 = 13.20m.

For the upper storeys this was reduced to one span, but for the ground floor this was 5 spans and thus 22m. This was primarily to ensure that the forces of the foundation piles were not too variable.

To lift the roof slab (18th storey) the winch trolley had to be at a higher level. For this reason the frames were temporarily extended by 3m and a temporary steel floor (Floor 19) was laid for the winch trolley. When the gantry had been laid down three steel pipes were placed on it and fastened to each of the three columns. Each tube was fitted with pulleys over which the cables for the hoisting winch ran, see Fig. 10, (Nieuwmeijer [8]).

The assembly rate for the building was very satisfactory. As soon as the third frame was in place a rate of one frame per week could be achieved. Temporary bracing bars were installed between the frame that had just been hoisted and the part of the structure that was already in place. The winch trolley was then moved one frame further.

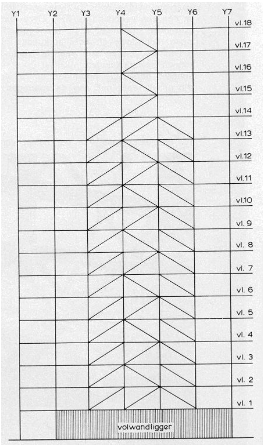


Figure 9: The longitudinal bracing used in the building.

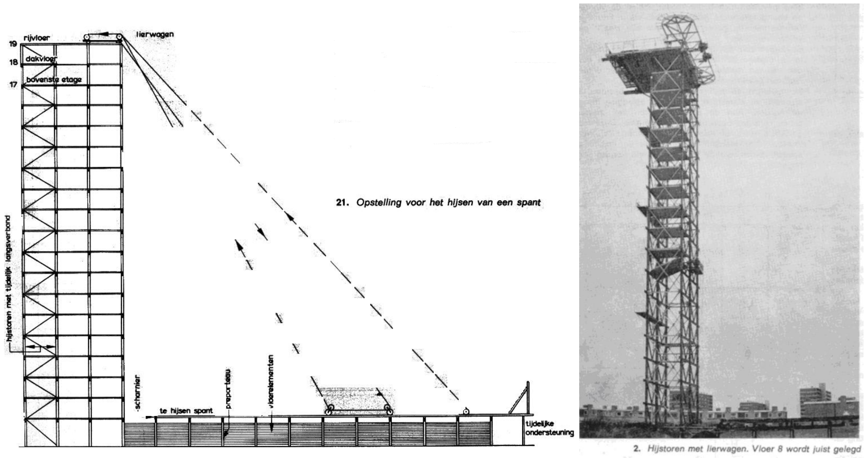


Figure 10: The lifting of a frame.

2.2 The second and third residential building in Delft

The second building was very similar to the first one, but was intended to house students and since the individual dwelling units were not wider than one span it was possible to use frames with only one transverse brace.

The third building, also intended for students, was different since the technical requirements for such residential buildings required that there should be a central corridor. It was impossible to make such a corridor with the previously described structural layout.

The bracing system shown in Fig. 11, on the left, was considered, but this design was uneconomical, especially because of the measures needed to take up the horizontal forces.

After some research the bracing system shown in Fig. 11, on the right, a two column system with K-bracing, was chosen. The ‘lower apex’ of the triangle formed by the diagonals of the K-braces was not in the centre of the horizontal, but was a little lower. In the frame the beam is hinged to the column.

At the ends of the building the longitudinal bracing was given a structural width of two spans. It was only necessary to make one door leading to the balcony per two frames (spans) because double apartments were made for married students at the ends of the buildings. A heavy mobile crane was used to mount the first two frames, complete with the longitudinal bracing, in the traditional way. The crane trolley was placed on these so that it was possible to use the method of lifting the entire frame for the remaining frames.

After this operation, the anchors to which the floors were to be attached were welded onto the beams in the middle of the building. Thus the building consisted of two halves each stabilized by a longitudinal brace at the end.

2.3 The Alpha Hotel (opened April 1971 [9])

The hotel building had two wings of fourteen and sixteen floors respectively, attached to a central core. At the appropriate stage of construction all the side elevations, possibly up to 200 feet high, were hoisted up from the ground and locked into position in a matter of hours.

The complex internal layout of the hotel, see Fig 12, demanded a clear, uncomplicated plan. The dimensions of the building are:

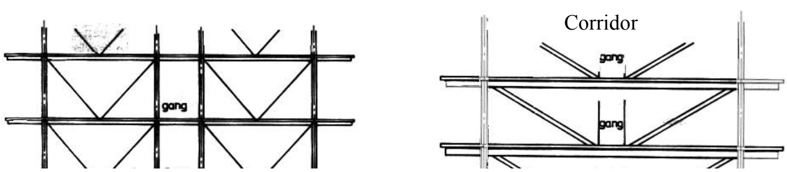


Figure 11: Conceptual design of a frame for the third building and design used for the frames of the third building.

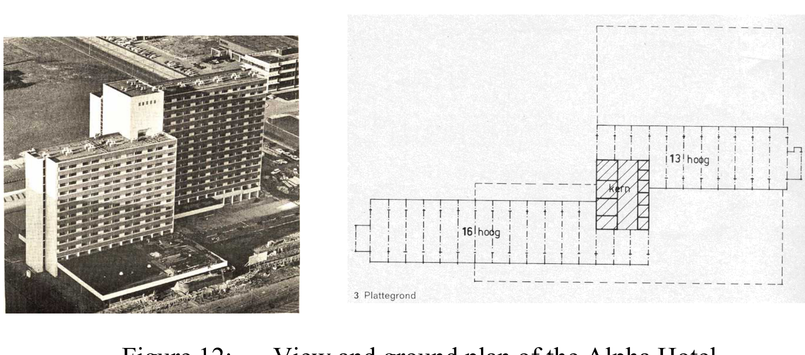


Figure 12: View and ground plan of the Alpha Hotel.

- long (northern) wing 68 m long, 15.18 m wide and 45 m high, 16 storeys
- short wing (southern) 48 m long, 15.18 m of wide and 36 m high, 13 storeys
- Core building 12.5 x 16.5 m and 50 m high, 18 storeys.

2.3.1 Construction of the wings

The bearing structure is a steel frame with 4.0 m spans and has prefabricated pre-stressed concrete floors; these floor elements are 3.975 m long and 1.50 m wide. Unlike the three buildings previously built by N.V Staalproject, in which the Porte des Lilas system was used to manufacture the prefabricated floor elements on the building site, here the floor elements were manufactured in a factory. This reduced the construction time by twelve weeks, (Hogeslag and Berkelder [4]).

In addition to the required improvement of the finish of the floor elements the quality of the finish of the entire building was also improved by the prefabrication in a factory.

The central core building was a stiff and relatively easily constructed element to which the wings were attached. There were no links to carry the horizontal loads to the foundations in the longitudinal direction of the wings. The linking of the frames to the central core building had therefore to be provided by the floors. During the assembly process the top floor of the northern wing also had to transmit the hoisting forces to the central core building.

The floors had to serve as beams projecting from the core. For this reason it was important that the floors were as monolithic in character as possible. Reinforcement bars of ø12 were cast in the floor elements and in the elements next to the columns 2 bars of ø16 were cast. These were welded to the horizontal of the frame immediately after the placing of an element

Reinforcement bars were also placed in the longitudinal joints. In order to take up the shear forces in the joints notches were made the plate. These work as dowels after the filling of the joints. Moreover, in the transverse direction of the floor elements ø 14 bars that were cast into the elements were welded through. To prevent variations in the load of plates that were next to each other the longitudinal joints were cup shaped. This attempt to achieve a monolithic character for the floors fitted into the scheme of requirements of the fire service department for buildings of this type.

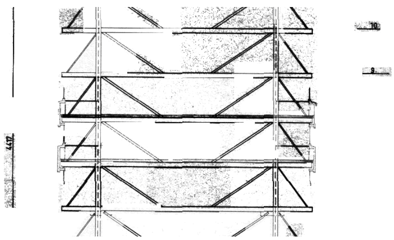


Figure 13: Frame with transverse bracing.

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2.3.2 The frame-bending machine

The steel frames were constructed as lattice trusses see Fig.13; taking the horizontal load perpendicular on the long facade and the stability in the planes of the frames is provided by the each of the frame itself.

The choice of a system with a central corridor for the hotel floors dictated that the frame could not be a full lattice truss. The frames had K-bracing, but the central corridor made it necessary to disconnect the central node. The strength was not greatly affected but the stiffness of the whole was greatly reduced.

2.3.3 Gable construction – assembly

Owing to the constraints of time the half frames for the low wing were assembled conventionally, while the Porte des Lilas method was used for the long wing. Moreover the southern wing was too low and too short for any advantage to be gained from using the Port des Lilas method, while the difference in height between the two wings made it necessary to manoeuvre the hoisting equipment. The fact that the building of the central core had to progress without interruption also played a role.

The rails of the hoist trolley were supported by means of 3 m columns on the heads of frame columns which were made with their upper ends level with the top surface of the roof slab. The height of 3 m under the crane rail columns created enough space for the placing of the roof slab elements.

At the first stage of the assembly (hoisting the first five frames) the crane rails were partially on the half frames. During the further progression the crane moved over the building in stages of three 4 m slab spans times 4m. A slab that had to be lifted from behind the crane trolley was attached to the link to the frame that was to be lifted.

3 Conclusions

We might conclude that the "Dutch" Port de Lilas system provided advantages: The prefabricated floor slabs considerably reduced the time and cost of construction, even though it was necessary to install transversal steel beams to support the floor slabs. There was no need for central columns for the transverse floor slabs. An innovation was the use of bracing only in the separation walls. In the Netherlands, the system was used to construct a combined steel-concrete, structure, whereas in France the entire bearing structure was made of steel. Construction costs were dramatically reduced as a result of the disappearance of console columns, the associated extra reinforcement of the floor elements and the reduction of the floor thickness to 13 cm. Extra costs derived from the necessity addition of horizontal beams. In the French system some temporary braces were installed when building the steel structure and only when the whole steel structure was ready was the installation of the floor slabs start, whereas in the Netherlands, a steel tower structure with permanent bracing and slabs floors was built. After the first tower was completed the rest of the steel structure was assembled and the floor slabs installed. This method assured rigidity, although some years later, additional braces were incorporated to increase stiffness against the wind.

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