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Development in Assembling Sandwich Facade Units

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ABSTRACT

An important development in the area of industrial building is the construction with sandwich load bearing external facade units. These units are built-up with a concrete panel inside, an insulating layer, an external brick wall and are completely finished with windows and piping. In combination with prefabricated inner walls and floor systems, the structure of a building with finished front can be realized without scaffolds in short time. The high-rise (100 m) apartment building Porthos in Eindhoven has been constructed with this industrialized method in a 3–day building cycle for each floor. The purpose of this research is the indication of further relevant development in this way of building. We focused on the activities on the building site. The working conditions, use of equipment and the resulting dimensional accuracy of the external facade have been analyzed. The dimensional quality of the finished façade is very good but the working conditions are heavy. It is a challenge for the further development of prefabricated building products to ensure also a controlled and ergonomic processing of these technically sophisticated units.

KEYWORDS: Case-study, Dimensional Accuracy, Physical Stress, Sandwich Façade Units

Figure 1 Apartment building Porthos in Eindhoven

1. PROJECT DESCRIPTION

The apartment building Porthos is one of the three apartment buildings with which the Eindhoven urban district Woensel is extended at present. The building is a design of Engelman architects from Roermond and Hurks Bouw– and Vastgoed Eindhoven is responsible for the construction. The 33–storey building counts three up to four apartments on each floor. In total the building counts 108 housing units with a total floor area of 17,500 square meters.

The building is composed of prefabricated parts. Each floor has been built with approximately 51 prefabricated wall and floor elements. Twelve sandwich external façade units are placed on each floor. These load bearing façade units consist of a concrete panel inside, an insulating layer, an air cavity, an external brick wall. Furthermore the units are completely finished with framing and glazing and sometimes with brise-soleil. Also the piping for electricity, air treatment and sanitary has already been mounted in factory.

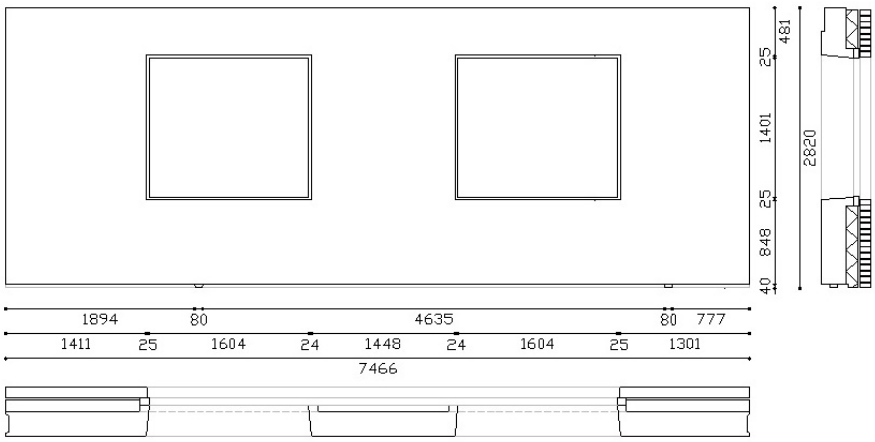


Figure 2 Elevation and section of a sandwich façade unit

2. PROCESS DESCRIPTION

2.1 Prefabrication

The height of the facade units is 2820 millimetres, the height between two floor surfaces. The length varies of 7500 up to 1000 millimetres; the thickness varies from 400 up to 500 millimetres. The elements are manufactured in a factory. First of all the bricks are laid in the steel formwork. These bricks are covered with mortar. Anchors are mounted in the external facade for the eventual connection between the walls inside and outside. Then insulating layer is attached and the concrete panel inside is poured. When the concrete has hardened sufficiently, the unit can be stripped and moved to the storage where casings, glazing and such are mounted. The units vary in weight from 11 to 20 metric tons. With a low loader two or three units at the same time are transported from the storage to the site.

Figure 3 Mounting of casings and glazing; storage of the units

2.2 Preparation

Before the façade units can be assembled on site, some preparations must be done. The dimensions are setted out, the jobsite is cleaned-up, the shores are put ready and the Compression tape is fixed. For longitudinal and cross direction14 points are setted out with Total station according to the MOUS-system (van Hoof, 2003). With a folding ruler from these points it is indicated where the panel inside in longitudinal direction must be mounted. The ends of this panel are marked with a pencil.

A correction is made if the underlying façade unit deviates more than 3 millimetres. In the vertical direction filler plates are used that are positioned in height with a rotating laser. A forced position is obtained on the underside near both ends of the façade unit.

2.3 Mounting

The facade units are mounted directly from the low loader with a tower crane. On the floor the unit is manoeuvred by the mechanics in the correct position and is kept above the starter bars. When the guard-rail is removed the unit can be placed over the starter bars. At placing the units are aligned with the upper edge of the lower unit and the marks.

When the unit has been positioned over the starter bars it is manoeuvred on the underside with a pounding bar on the marks. As soon as the shores have been mounted and tightened the upper edge of the unit can be positioned in the cross direction. With a long plumb level the unit is positioned vertically by turning the shores. When it is positioned temporarily with the shores it is disconnected from the crane. Afterwards wet mortar is injected in the seam under the unit with a compressor. In the same way also the vertical joints between the units are filled. When the wet mortar has hardened sufficiently the gains are poured with the compressor.

As soon as the sandwich units are fixed the earlier removed guard-rail is mounted. The guard-rail is slid over the starter bars on the top of the unit. As soon as the wet mortar in the gains has hardened sufficiently the shores are removed. The remaining holes are filled with mortar and finished with a filling knife. The bearing structure and the façade are assembled at the same time and without scaffold. A team of nine mechanics constructs every three workable days a windproof and impermeable storey. Activities occur simultaneously over two or three successive floors. The construction time of the apartment building lasts only 95 workable days. The construction time has been reduced by almost a half.

Figure 4 Getting the façade unit in the right position

3. DIMENSIONAL RESEARCH

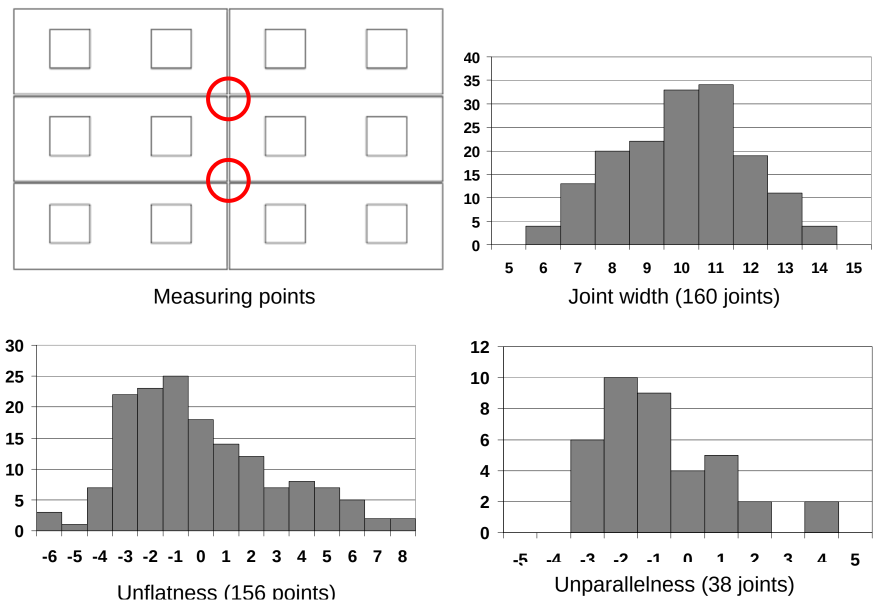
The success of this constructing method depends entirely on the precision of the production and positioning of the units. The joints between the facade units are comparable with the joints in the masonry of these units. The design measure is 10 millimetre with a tolerance of only a few millimetres. A great accuracy is demanded because a small deviation can disturb the façade already. In the joint the following complete or partial dimensional deviations appear:

- Deviations of setting out in X-, Y- en Z-directions;
- Deviations of positioning the inside panel of the unit in relation to the marks in X-, Y- en Z-directions;
- Deviations of the thickness, height and length of the units;
- Twist and curvature of the units.

The dimensional accuracy of the facade has been examined (Brouwer, 2005). For that 160 joint widths and unflatness in 40 intersections of joints have been measured. Twenty-six of these intersections are located above each other, whereas fourteen intersections are located between the eleventh and fourteenth floor.

Table 1 shows the measured joint dimensions. About 95% of the joint widths vary between 7 and 13 millimetres. The average joint width is 10.1 millimetres, with a minimum of 6 and a maximum of 14 millimetres. The unparallelness of the joints is similar. The unflatness of two adjoining units varies from –6 to 8 millimetres.

Table 1 Measured joint dimensions in 40 intersections in millimetres.



The visibility of the dimensional deviations in the joints has been examined with the D–value, a standard for the visibility of dimensional deviations (Vastert, 1995). The D–value 1 means that dimensional deviations are invisible, whereas D=5 means that the deviations are clearly visible. At D=3 the dimensional deviations are with effort indeed visible, but mostly accepted. Most of the carefully built facades with regular patterns have a D–value of approximately three.

The examined facades with dark grey joints (40% diffuse reflection) between panels with black bricks (45% diffuse reflection) have D–value D=2. This corresponds with the fact that from the ground floor no dimensional deviations are visible. All visual requirements are fulfilled.

4. PHYSICAL STRESS

Apart from the dimensional research also the physical stress at the mounting of the sandwich units has been examined. The façade units are assembled by 7 mechanics. Two mechanics position the elements, four mechanics fixate the elements and one person below connects the unit to the crane. The total size of the team (9 persons) depends not only on the mounting of the sandwich façade units but also on the assembling of the floor units, walls and stairs. The physical stresses have been calculated on that day of the three-day cycle on which the biggest part of the assembling work of the façade units was done.

The posture and the kind of labour of the mechanics have been recorded on video during a whole workday for the calculation of the physical stresses. Combined with the duration of the activities the stresses are calculated. The calculation of the stresses is based on the total use of energy of the body (Peereboom; 2000). During the whole working day the use of energy is measured that depends on the basic energy for the vital functions of the body, posture or movement of the body and on the load of the work.

The energetic load of a mechanic during one working day is the sum of used energy during all the activities of that person. The total used energy has been divided by the worked time to get the used energy per minute (table 2). With the traffic-light model has been defined if the performed labour is acceptable (green), needs attention (orange) or is not acceptable (red).

Table 2 Used Energy of mechanics A – G at the mounting of the façade units

Mechanic	Whole working day		
	Duration (minutes)	**Used Energy (kJ)**	**Used Energy (kJ/min.)**
A	510	8285.8	**16.2**
B	510	7651.6	**15.0**
C	510	6765.5	**13.3**
D	510	6927.7	**13.6**
E	510	6282.3	12.3
F	510	6593.9	12.9
G	510	5632.9	11.0

Four of seven mechanics (A, B, C en D) end with their use of energy in the orange (grey) dangerous area. As an example the activities and the energetic load of mechanic A have been elaborated in table 3.

Table 3 Used Energy of mechanic A during one day

Activities of Mechanic A	**Used Energy (kJ/min.)**	**Duration (minutes)**	**Used Energy (kJ)**
Moving materials and equipment	32.0	16.20	518.4
Putting ready shores	31.4	4.80	150.9
Removing concrete trash	13.5	6.60	89.1
Fixing compression tape	14.0	49.00	686.0
Manoeuvring façade units	37.5	7.40	277.5
Positioning units above bars	19.5	11.80	230.1
Removing guard-rail	29.1	8.40	244.8
Placing units over starter bars	19.0	6.60	125.4
Positioning units on floor	17.0	4.40	74.8
Adjusting underside unit	28.9	34.00	984.2
Positioning unit vertically	11.7	42.60	499.5
Fixing shores on unit	37.5	16.40	615.0
Disconnecting unit	17.0	5.00	85.0
Removing lifting eyes	17.0	6.40	108.8
Fixing guard-rail	21.8	45.20	986.3
Remaining activities	12.5	116.70	1458.8
Pause	6.0	70.00	420.0
Sum of activities façade units	**16.7**	**451.50**	**7554.5**
Placing floor unit (core)	12.5	58.50	731.3
Sum remaining activities	**12.5**	**58.50**	**731.3**
Sum activities of mechanic A	**16.2**	**510.00**	**8285.8**

Mechanic A consumes no less then 8285 kJ this day. This means 16.2 kJ per minute. For placing floor units he consumes 731.3 kJ. The remaining 7554.5 kJ he uses for the mounting of façade units. The use of energy per minute is 16.7 kJ. The used energy of the remaining mechanics is similar. The high use of energy per minute (18 kJ) of mechanic C is further caused by injecting the wet mortar in the joints between the façade units. Preparing (18.5 kJ) and moving (26.1 kJ) mortar cause the high use of energy of mechanic D.

The mounting of the façade units proves to be physically heavy work. The units from 11 up to 20 metric tons must be manoeuvred to the desired position using physical strength. Next the mechanics must place the heavy, not well manageable unit over the starter bars on their knees. With a pounding bar and physical strength the unit is positioned on the marks. At the same time the unit is attached to the floor with shores of 24 kilogram's. The shores are attached to the element with a ladder. The mechanic always gets down on his knees to inject the wet mortar in the joint under the unit.

The following activities cause the high use of energy of the mechanics in particular:

- Preparation, transport and processing of the mortar;
- Positioning of the facade units;
- Mounting of the shores and
- The attachment of the safety equipment.




Figure 5 Physical stresses at the mounting of the units

5. CONCLUSIONS

Industrial building means that products are fabricated in a factory under controlled circumstances by specialists and with specialized equipment. The dimensional accuracy in the factory is also maintained in this 100 meters high building. Dimensional deviations remain restricted on site to only a few millimetres. The product quality of the technically sophisticated units in the fabric and of the interlinked units on site proves to be similar.

The process quality on the other hand considerably differs in factory and on site. Although the labour on site is relatively restricted, the mounting of the industrial fabricated units remains according to traditional methods and the physical working conditions proved to be heavy. It is a challenge for the further development of prefabricated building products to ensure also a controlled and ergonomic processing of these products. This means for the façade units for example that not only, windows and piping need to be included but also ingenious facilities for the positioning and fixation of these units.

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