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Rudiments of a New Foundation Concept

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Abstract
House building will in the end shift towards using large-sized industrially produced panels. To benefit in full of new housing methods the accuracy of a foundation must be geared to using large-sized wall panels. Since current foundation methods do not meet this accuracy a new foundation concept is developed to be prepared for future applications. A preliminary test in real practice showed the improved accuracy but also revealed additional benefits regarding costs and simplification of work. This new insight promises already opportunities in present-day house building. A major advantage besides accuracy is that all work can be done in unbroken activity to reply to shattered activities of current construction. The new foundation offers good prospects to have the entire work (including ground floor) contracted out to a subcontractor as an extension to groundwork, which is contracted out as a rule. Pilot tests in practice demonstrate substantial time reduction (30-45% on labour on site and additional by removing intervals between separate activities). Other advantageous aspects regard material use (almost halved though strength and stiffness are increased) and a prospect of pouring concrete for foundation beam simultaneous with concrete for ground floor. The new foundation is suited for strip foundations as well as pile foundations in housing.

Keywords
accurate-foundation, efficient-foundation, reduced costs, integrated design, improved formwork.

1. Introduction: need for new foundation method for housing

The sight of a new housing development displays a traditional scene that is hardly changed through the last centuries. Most of recent innovations are in fact component exchanges, leaving an inefficient principle with inaccurate results unaffected. Furthermore existing foundations are not prepared for tomorrow's industrial building requiring a basis that is exact within some millimetres. Prospective house building tends towards applying industrial produced parts with high exactness. But benefits of these large walls can only be utilized in full if foundation provides a similar exactness that is less than +/- 2 mm.

1.1 Roman principle still serves as model for current foundations

The principle that ancient Romans already used still serves as a model for present-day foundation in housing. Of course there have been improvements, mostly in the last decennia, but these are mainly substitutes of beam or formwork, barely not revising the principle (initially developed for work done by hand). As a result today's foundation work is fragmented, inefficient and inaccurate. However this is hardly noticed in building practice due to common habituation to the arisen situation.

1.2 Alternative for inefficient practice of current methods

A recent study [Moonen, 2001] describes 20-25 separate activities that have to be organised by a building company to make a "simple" foundation. With this in view the development of a new foundation method for housing was not only focussed on accuracy but also on making the organisation less complex. In the new concept improved efficiency became possible by applying fully prefabricated parts (of formwork and reinforcement, see figure 3) and because the sequence of activities on side is changed (see figure 4 and 5). The leading idea is that a specialised subcontractor completely takes over work from a building company and commences a continuous construction process. With the main aim that when this subcontractor leaves site after some days all ground work is done, foundation *and* ground floor are finished, drainage and jacket pipes are in place, earth has been replaced and compressed, and the terrain is levelled.

2. Accurate foundation

Accuracy of the new foundation method is for the greater part realised by a swapped sequence of pouring concrete and refilling soil. First refilling soil, then pouring concrete affects the use of formwork. The primary function of formwork becomes now to hold up *soil* with a horizontal (passive) loading that is much smaller than the hydrostatic pressure of concrete during pouring. The lower loading makes it much more simple to retain accuracy once formwork is placed. In current foundation methods accuracy of the formwork is lost for the greater part when concrete mortar is poured in and compacted by a vibrating needle. In contrast to the new foundation concept where refilled soil gives a good (active) support to retain the accuracy of the formwork. The function of the formwork during the pouring of concrete is now hardly structural but mainly separating concrete mortar from soil.
Pilot projects (figure 2, 4 and 5) show that it is possible to place formwork directly at exact location and height, and to keep this accuracy when concrete is poured. So masonry is not needed to realise the final accuracy. With a side effect that foundation work becomes more efficient and building costs are reduced.
By testing the foundation in real practice additional benefits were found as a result of less material use, less building time, less organisation effort and simultaneous pouring of ground floor and foundation. These aspects makes the foundation method already advantageous in today's building, with improved accuracy somewhat reduced to a side issue.

2. Three-dimensional shells

A shell to be used as permanent formwork is developed to enable a swapped sequence of pouring concrete and refilling soil. This formwork is largely defined to resist temporary loading of refilled soil. The loading of refilled soil mainly applies horizontal on both sides of the formwork. For this reason the shell is developed to link both sides of the formwork to simply balance loadings of refilled soil. Linking can be achieved by applying principles of a truss (figure 2) to an I-shaped beam (figure 1).

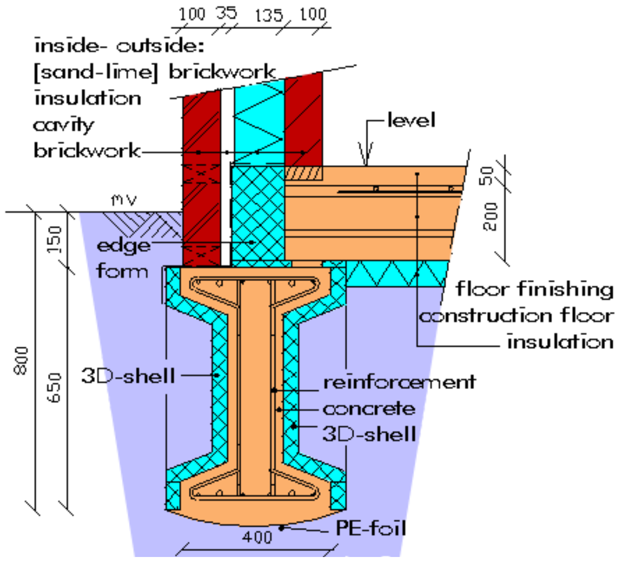

Figure 1: Cross-section of a foundation supporting brickwork wall and floor.

Figure 1 shows a possible application of this foundation supporting a brickwork wall. Reinforcement, 3D-shells and edge-form (also shown in figure 3) are brought to the construction site as a prefabricated composition. Here a mini-excavator puts the composition in a trench. The formwork with reinforcement is horizontal and vertical set to the exact position and soil is refilled. Next the ground floor is prepared so concrete mortar can be poured on top of the floor. This mortar runs through openings of the EPS-edge form in the cavity of the foundation beam. The EPS-edge forms an upright partition to enable pouring of the ground floor and has several openings to pass a vibrating needle for compacting mortar in the beam (see figure 5).

Figure 2: Outline of proposed foundation beam and result of dug up foundation of the pilot project

Figure 2 shows a foundation beam shaped by 3D-shells resulting in an I-shape with framework web. This shape is prospective in structural respect, saves material, gives opportunity to pass through pipes without specific arrangements *and* is needed in construction phase to resist load of refilled soil. To have such a shape 3D-shells of expanded polystyrene (EPS) are developed with bulges in between diagonals, verticals and horizontals (figure 3). The possibility of 3D-EPS-shells is picked up from packing material (f.i. of television sets). Here EPS-elements are shaped in moulds and produced in large numbers at little expense.

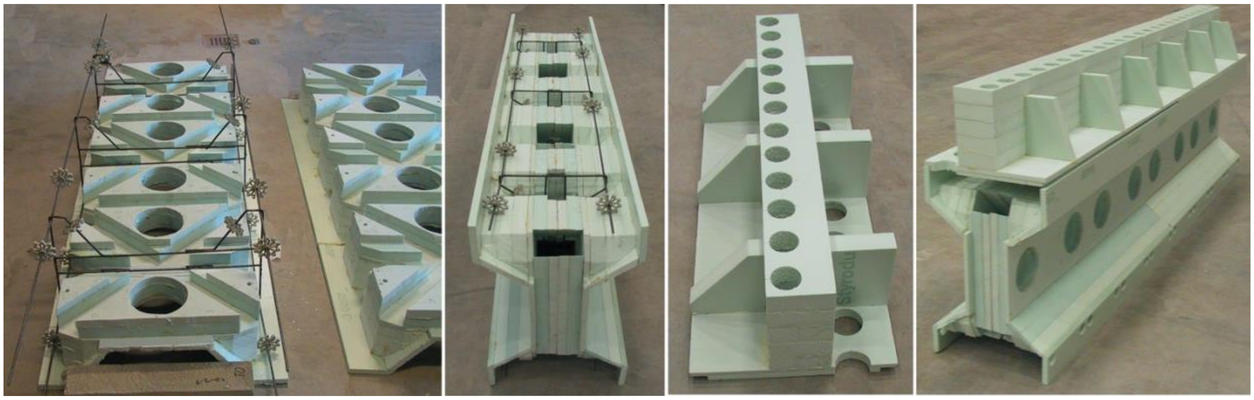

Figure 3: Three-dimensional shell and edge form

An idea of the shape of 3D-EPS-shells is shown in figure 3. The shown 3D-shells are not made of EPS but made of stacked Styrofoam sheets because this study was meant to specify the moulds and to enable a pilot project in which the final shape can be developed. The photo on the left in figure 3 shows 3D-shells used as formwork. Several 3D-shells are placed in a row (with the last shell cut to desired total length). Next standard reinforcement is put in and after that identical 3D-shells for the other side of the formwork are turned over. The shape of the 3D-shells reveals a part of the structural beam as shown in figure 2. The dimensions of channels for verticals and diagonals provide enough concrete cover for reinforcement and also enough flow when pouring concrete to the bottom side. Both sides of the 3D-formwork coincide on several spots. The round openings in the middle are meant for possible passing of (sewage-)pipes at the building site and to save materials. When both sides of the formwork are put in place the 3D-elements and reinforcement all fit together in a solid assembly. On one open side of this assembly a plastic foil is applied and the whole assembly is turned a quarter. Next the 3D-edge-form is put on top of it to get the composition as shown in figure 1. The 3D-edge-form is designed to get a raised border for concrete of the ground floor with openings to let mortar flow into the concrete beam. The solid composition shown on the photo on the right in figure 3 is transported to the building site as prefabricated building part.

3. Practical test

Practical applicability of the developed foundation concept is studied in a pilot project on the campus of Eindhoven University of Technology. Two foundation beams are tested. In between the foundation beams there is a ground floor (PS-combination floor) spanning 1.5 meter.

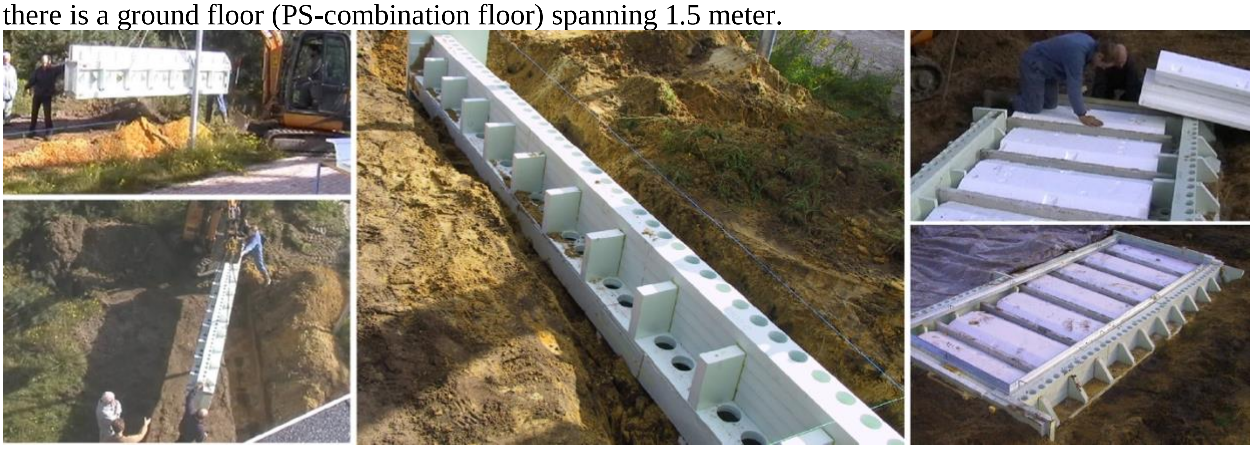

Figure 4: impression of placing prefabricated elements and floor elements in the pilot project

All formwork is prefabricated in a students-workshop and brought to site, where a mini-excavator starts with preparation for building. After that, the mini-excavator makes a trench, picks up a prefabricated form and places this into the trench (figure 4). The formwork is exact positioned and the excavator immediately refills soil (photo in the middle of figure 4). When all forms are placed elements for ground floor are put. The next step is pouring concrete mortar (figure 5). Mortar directly runs out of a truck mixer on top of the ground floor into the hollow section of the foundation. A vibrating needle is used to compact mortar. Some days later the foundation was dismantled (figure 2). Both beams were dug out, brought to laboratory where insulation covering was removed. Both beams were completely filled with mortar without irregularities.

4. Innovations

A major improvement regards efficient excavating (excavator prepares, digs, transports, places and refills thus completes all work in one activity), omitting labour-intensive bricklaying and simultaneous pouring of floor and beams. Also building organization is simplified as work is contracted out to a subcontractor resulting in only one activity for the building company to organize (instead of 20-25 in a traditional setting). Difficulties are not passed on since the subcontractor can finish all work on site with 2 persons in running actions and with just 4 activities to organize (as sending for a plumber and ordering a truck mixer).

Figure 5: pouring concrete mortar on ground floor to fill foundation beams of pilot project

5. Conclusions

- Practical serviceability of a new foundation method for housing is verified by a pilot project resulting in savings of concrete (some 30%) and of labour on site (up to 50%).
- All requisites are industrial elements ready for mass-production. The standard elements are assembled as prefabricated formwork (still enabling a free lay-out).
- All activities on site are carried out in running actions by a team of two persons.
- A swapped sequence of refilling soil and pouring mortar enables *one* pouring for beam and floor.
- Using ground floor as buffer when pouring concrete mortar for beams makes progress of work easier.
- This study shows promising applicability of this method. Yet further study and tests are required.
- It is expected that the improved efficiency and the significant reduction of required materials will at the end result in substantial savings.

4. References

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