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Moonen, S.P.G.

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Advancement of a new accurate foundation concept

S.P.G. Moonen
Eindhoven University of Technology, Eindhoven, the Netherlands

Abstract: A novel foundation method is developed with shell-shaped forms (as indicated in Figure 2 and 3). The forms are made of EPS and used as permanent formwork (stay-in-place concrete form). EPS (expanded polystyrene) is well known in insulation and packaging. Especial packaging shows that EPS can have almost any shape at little expense when produced in large quantities. Based on the specific possibilities of EPS a shell-shaped form is standardised to enable mass-production (complex shape of high quality at low costs). The shell-shaped form has been provided with all kinds of conveniences for passing drains and sewers, for assembling and cutting to any required length, for integrating reinforcement, for saving materials, etcetera. After mass-production the shell-shaped forms are assembled in a workshop to obtain prefabricated foundation strips. In addition, irregular layouts are simple to prefabricate by cutting the last EPS-form of each foundation strip to length. Since reinforcement is added in the workshop too the total substructure becomes a kind of ready-to-construct kit of formwork strips made-to specific design.

1. Introduction

The tendency in house building is to shift towards using large prefabricated elements. Large elements require accuracy within some millimetres. This accuracy starts already for the foundation. Yet foundation in house building is hardly changed in recent decennia, if at all, and is inaccurate, inefficient and inert in today’s construction. A foundation principle that was focused on high accuracy was initially developed as spin-off of a PhD-research (Moonen, 1998 and 2001) to be prepared for prefabricated construction of full-size elements. Several pilot projects and subsequent developments later have led up to a promising foundation method that can be used already in today’s construction (Moonen, 2005). This foundation principle suits for piled foundations as well as strip foundations. This paper describes consecutive activities of the novel foundation applied as strip foundation. Also a comparison of estimated costs (matched against customary strip foundations in Dutch circumstances) is given in this paper.

2. Current foundations are inefficient

A regular foundation in house building (such as the strip foundation in Figure 1) seems simple but is in fact complex in execution (Moonen 2003). Table 1 lists the main activities of a builder when organizing this average strip foundation. The table indicates that a builder has to instruct up to 10 parties involved (such as excavator, carpenter, material supplier, plumber, concrete worker, bricklayer et cetera). Most of them have to return 2-4 times to the site since most activities are interdependent. The novel foundation (with cross-section shown in Figure 2) is in marked contrast with regular foundations. Here the cross-section seems complex but pilot projects as well as Table 1 (column on the right) show that organization and efficiency is largely improved.
Figure 1. Example of regular strip foundation. Simplicity of the cross-section conceals an inefficient process (marked out in Table 1).

Table 1. List of successive activities for a regular strip foundation (column on the left, cross-section shown in Figure 1) compared to the novel foundation (column on the right with cross-section shown in Figure 2).

<table>
<thead>
<tr>
<th>Traditional Foundation</th>
<th>Accurate Foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>activity on site</strong></td>
<td><strong>carried out by</strong></td>
</tr>
<tr>
<td>mark plan</td>
<td>builder [1]</td>
</tr>
<tr>
<td>clear site</td>
<td>excavator [1]</td>
</tr>
<tr>
<td>supply skip</td>
<td>skip collector [1]</td>
</tr>
<tr>
<td>apply batter boards</td>
<td>builder [2]</td>
</tr>
<tr>
<td>supply materials</td>
<td>material service [1]</td>
</tr>
<tr>
<td>excavate site</td>
<td>excavator [2]</td>
</tr>
<tr>
<td>make formwork</td>
<td>carpenter [1]</td>
</tr>
<tr>
<td>supply reinforcement</td>
<td>builder's merchant [1]</td>
</tr>
<tr>
<td>place/cut reinforcement</td>
<td>construction worker [1]</td>
</tr>
<tr>
<td><strong>supply concrete mortar</strong></td>
<td>truck mixer [1]</td>
</tr>
<tr>
<td>cast concrete</td>
<td>concrete worker [1]</td>
</tr>
<tr>
<td>remove formwork</td>
<td>carpenter [3]</td>
</tr>
<tr>
<td>remove materials</td>
<td>material service [2]</td>
</tr>
<tr>
<td>supply/apply services</td>
<td>plumber [1]</td>
</tr>
<tr>
<td>supply mortar and bricks</td>
<td>builder's merchant [2]</td>
</tr>
<tr>
<td>mark brickwork</td>
<td>carpenter [4]</td>
</tr>
<tr>
<td>Bricklaying</td>
<td>bricklayer [1]</td>
</tr>
<tr>
<td>remove debris (brick, mortar)</td>
<td>skip collector [2]</td>
</tr>
<tr>
<td>remove formwork, batters</td>
<td>material service [3]</td>
</tr>
<tr>
<td>refill/compact soil</td>
<td>excavator [3]</td>
</tr>
<tr>
<td>supply materials for floor</td>
<td>builder's merchant [3]</td>
</tr>
<tr>
<td>prepare ground floor</td>
<td>construction worker [2]</td>
</tr>
<tr>
<td><strong>supply concrete mortar</strong></td>
<td>truck mixer [2]</td>
</tr>
<tr>
<td>cast concrete mortar</td>
<td>concrete worker [2]</td>
</tr>
<tr>
<td></td>
<td>specialized subcontractor (on site: excavator and construction worker)</td>
</tr>
</tbody>
</table>

lay out by "total station" supply materials, excavate trenches, place/position ready-to-construct formwork (including reinforcement)
Table 1 indicates that the novel foundation (column on the right) is much simplified compared to current foundations (column on the left). There is no complexity passed on from builder to subcontractor, since activities are developed as consecutive activities by a team (mini-excavator assisted by one construction worker). This specialised subcontractor only has to organise a few suppliers/specialists as indicated. Pilot projects demonstrate that the nett construction time is reduced about 45% (Moonen 2002). And what’s more, work of many (with intervals in between activities) have now become one consecutive activity so overall construction time might be reduced up to 70%.

Another major advantage is that concrete mortar for foundation and floor is supplied and casted in one pour. This is especially favourably in smaller house-building projects.

Figure 2. Vertical cross-section of accurate foundation supporting a cavity wall. Edge form, 3D-shell reinforcement and PE-foil are prefabricated made-to specific design

3. Principle of novel foundation

The foundation is developed upon mass-production of fixed reinforcement and fixed EPS-forms (photos on the right in Figure 3 showing both sides of a mock-up of the 3D-shell form). This fixed formwork is modelled to have a rigid foundation beam with minimum of concrete (I-shaped beam + web shaped as truss, as shown in Figure 11). The form has regular openings to save material and to enable passing sewages and other pipes. Two forms are put together mirror-wise to make the cross-section in Figure 2. The two forms fit well because both sides touch in the middle with many contact faces. And putting two forms mirror-wise makes up a system of trenches that shapes the truss. Some trenches are used to let concrete mortar run to the bottom while other are used to locate reinforcement and provide suitable cover. To get the cross-section of Figure 2 requires a second EPS-form (indicated as edge form in the drawing). This form is put on top of the two shell-shaped forms.

Figure 3. Packaging demonstrates that EPS can be modelled at little cost (two photos on the left). These possibilities of EPS are utilized to develop a fixed formwork (photos on the right showing left and right side of one of the mock-ups of the 3D-shell form).
3.1. Preparatory work

Mass-produced EPS forms (3D-shell and edge form) and reinforcing cage are all semi finished products. All are brought from storage to workshop to be assembled tailored to specific project details. Several 3D-shells are consecutively put. The last 3D-shell can be cut to any length to make the exact required length. Next the fixed reinforcing cage is put. The cage fits well in the hollows of the forms. This reinforcement can also be cut to length. Additional reinforcing bars can be added if required. The formwork strip is closed by other 3D-shells put mirror-wise. At the intended bottom side a PE-foil is added. Next the composite can be turned a quarter to add the edge forms (also put consecutively with the last one cut to length).

Figure 4. Part of cross-section (in Figure 2) that is prefabricated in a workshop. Length, additional reinforcement and bottom width can be geared to specific project requirements.

Since the total reinforcing cage is part of the prefabricated formwork the total substructure becomes now a kind of ready-to-construct kit of formwork strips made-to specific design. Figure 4 shows the assembly that is prefabricated, ready for being dug in on site. The rigid foundation beam comes into being when the cavernous space in between the 3D-shells is filled with concrete mortar (last step of on-site activities). The amount of concrete in Figure 2 is equal to the 0,2 x 0,6 m\(^2\) strip in Figure 1. Yet, stiffness and strength of an 0,850 metre high beam (Figure 2) are disparities compared to an 0,2 metre high beam (Figure 1).

3.2. Work on-site

On site an excavator makes trenches to position formwork strips. The trenches are narrow because the foundation is developed to have all activities done from ground level. Since construction workers don’t go down the trench the trench is just 50 mm wider than the foundation strip. This will reduce groundwork.

Figure 5. Work on-site starts with marking the plan and digging small trenches
The same mini-excavator is ideal for transporting foundation strips in open terrain and to put the foundation strip into the trench (Figure 6). The foundation strip has good possibilities for vertical and horizontal positioning (provisions to adjust are not described in this paper). Because the foundation strip is made of EPS the lightweight foundation strip can be easily adjusted to exact position and height. The pilot project indicates that an overall accuracy of maximum 2 mm is possible.

Next the position of the foundation strip is fixed by backfilling soil. This is also done by the mini-excavator. Clearing, digging, refilling and levelling is done in a continuous activity, so the excavator only shows up one time to finish work. This simplifies and speeds up construction compared to current foundation methods where the excavator has to return two times.

In this phase also piping is brought in. Subsoil pipes are mainly hollow pipes to a meter cupboard and drains and sewers. To simplify and to speed up this installation work a number of openings are provided in the foundation strip at intervals of 0.25 metre (as can be seen in Figure 3 and 11). The next step could have been to cast concrete mortar to fill the underground cavity in between the 3D-shells. In this set-up casting concrete mortar is however postponed because it is quite difficult to pour mortar in the narrow opening. Pouring is much simplified if the ground floor is prepared first. This sequence also facilitates to simultaneously cast concrete mortar for foundation and ground floor.
The photo on the right in Figure 8 shows a beam and insulated block flooring. Here insulation blocks are put direct on the subsoil and the inverted ‘T’ shaped concrete beams are put on the insulation blocks. This type is chosen in the pilot to study a situation with a piled foundation. The cross-section on the left in Figure 8 shows a situation with a strip foundation and a solid concrete oversite. Here PE-foil is put on the subsoil as damp proof membrane. Then rigid insulation (EPS) is laid. An additional layer of PE-foil can be laid over the insulation prior to the concrete being poured. A small reinforcing mat is also required. The sketch in Figure 8 shows that insulation of the floor makes contact with insulation of the permanent formwork. The edge form becomes in later use the bottom part of cavity insulation (Figure 2) so there will be an almost closed insulation screed. Figure 8 shows a small opening in this insulation screed. This light spot is a local opening to let concrete mortar flow into the foundation with a diameter of 90 mm at 250 mm intervals. Calculations show that the thermal performance is hardly reduced by the openings because the major part of the concrete beam is wrapped up with insulation.

The last step is pouring concrete on top of the floor. The edge form of the foundation strip creates a buffer that simplifies filling of the foundation cavity. The bottom side of the foundation is covered with PE-foil to separate concrete mortar from soil (and to prevent abstraction of moisture from mortar). The foundation strip has several openings that allows a vibrating needle to reach the bottom side of the foundation.
This foundation method was initially developed for using self compacting concrete (SCC). With this in mind a system of trenches was developed to let concrete mortar flow and to form the truss structure as sketched in Figure 11. In the pilot project flow concrete (that is normally used when pumping concrete) is used in stead of self compacting concrete to reduce costs. Figure 11 sows that flow concrete suits to fill all parts of the complex shape.

The last activity on site is to finish concrete surface. After concrete is hardened a small part of the insulation on top of the foundation beam can be removed to support the outer cavity wall.

![Figure 10](image10.png)  
**Figure 10.** After hardening of concrete the superstructure can be made.

The foundation was dug up afterwards (photo on the left in Figure 11). Both foundation beams were brought to the laboratory to remove the insulation cover (photos in the middle of Figure 11). Here we observed that all parts of the beam were perfectly filled, that bugholes (surface voids) were small and that there was no honeycombing, all indicators that all mortar is well vibrated. The concrete beams are also tested in our structural laboratory showing that the performance is largely improved compared to current strip foundations.

![Figure 11](image11.png)  
**Figure 11.** Several days later the foundation was dug up and dismantled. The concrete beam proved to be a very rigid beam with I-shaped cross-section.

### 4. Calculation of costs

The effect on total costs of below-grade for strip foundations is studied by a bureau for product development (Koolen, 2005). The actual numbers in Figure 12 are only indicative because they apply to a specific Dutch situation. The main purpose is in comparison different types of foundations and to get information for further improvements. Figure 12 shows comparative cost indicators of three strip foundations. The column on the left refers to the foundation in Figure 1. The column in the middle refers to a very simple cross-section with concrete poured directly into the trench (as sketched in Figure 12). The column on the right refers to the novel foundation. This calculation is mainly based on observations in two pilot projects.
A detailed cost calculation is initially made for all three foundation types. These costs are assembled in four subgroups for a better understanding. The four subgroups are: brickwork, concrete work, reinforcement and formwork.

Figure 12 indicates that foundation costs might somehow be halved. Compared to regular strip foundations (column on the left) the cost reduction is entirely effected by omitting brickwork (because the amount of concrete is the same in both cross-sections). Compared to trenchfill foundation constructions (column in the middle) reduction is mainly obtained by far less concrete use. Figure 12 also shows that costs of the accurate foundation (column on the right) are mainly determined by formwork. As a result of this observation we are now developing an alternative composition that, for one, aims to reduce costs of formwork.

![Figure 12. Comparison of cost calculates for three types of strip foundations (in a Dutch situation, reference date December 2004)](image-url)
5. Conclusions

Pilots of the novel foundation demonstrate that now a specialized sub-contractor can do all foundation work in a continuous labour process. This set-up suits the present building-trend in which a building company contracts out a lot of work and mainly involves itself with co-ordination. Based on observations in a pilot project it is expected that this set-up minimizes labour (40-50%), materials (omitting brickwork), total construction time (50-70%) and costs (45%) compared to a traditional substructure. A further argument in favour is simplification of organization. Other advantages are difficult to quantify but can be a major improvement (in specific situations). One of these advantages is the possibility to cast concrete mortar for foundation beam and ground floor simultaneously. Another advantage is an overall accuracy of maximum 2 mm. Also the possibility of prefabrication (even if the lay out is complex) can be an advantage in specific situations.

Further study and optimizing the foundation is however required, since the preliminary pilot project has generated new ideas to furthermore improve house building. Yet the progress of developing a new foundation already shows significant advantages on many aspects confirming the inefficient way we build today.

6. References


