PRESTRESSED AAC MASONRY IN PREFABRICATION OF A NEW BUILDING SYSTEM (BCE)

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SUMMARY

Autoclaved aerated concrete (AAC) is a low-energy material based on simple components, refined into an advanced product. Forming a hybrid with HPC under prestressing, the material AAC is refined into a full building system, containing all sorts of building components within the structural capacity, which is at the level of a full concrete system. This new BCE-system allows for a project related production based on just a few standard block sizes.

ABBREVIATIONS

AAC = Aerated Autoclaved Concrete
BCE = Block Composed Element
HPC = High Performance Concrete
PFA = Pulverized Fuel Ash
HD/F = Hollow Core (Deck Width/Depth in cm)
K60 = Compressive Cube (15 cm) Strength (60 N/mm^2)

INTRODUCTION

The industrialization of AAC started with the blocks, which have been produced since the 1920's. They soon gained a high reputation for capacity (strength, insulation) and precision in masonry, which has been further improved with time. Today, mortar (thin layer) joints are normally only 1-3 mm. So, the proportion of joints in an AAC-masonry is very small, around or less than 2%, which means that the masonry is in practice a homogeneous structure.

The composition, or recipe, of the material has been refined with time, which is confirmed by the fact that densities down to 350 kg/m^3 and up to 750 kg/m^3 are now available on the European market. The original lime-recipe (Ytong) has for energy reasons been replaced by a so-called cement-recipe (Siporex), in which the relation between mineral binders has been displaced in favour of Portland cement. The silicious component is normally taken from sand, which has to be ground to sufficient reactive area. An attractive alternative is to use PFA as an additional material, without grinding, up to 70% in a reinforced product (the limit is dictated by the condition to avoid cracks due to temperature shrinkage), or to full replacement (100%) in blocks. The BCE-system is based on the application of blocks and thus ideal for a full conversion to the use of PFA. It has been discussed, especially in the USA, whether it would be wise to build conglomerates around coal-burning utility plants, where surplus PFA

and hot steam for feeding the autoclaves are readily available on the exit side of production. Considering the difficulty to dump PFA, whether in concrete (> 30% of C) or as landfill, this idea might catch on as it meets the conditions of environmental protection.

The early success of AAC called for a completion into a full building system, including vertical and horizontal members, which must be reinforced, in analogy with heavy concrete. To rationalize the production, cases of prefabricated reinforcement were included in the form, in which the slurry foamed into mature AAC around the steel, ready for autoclave curing. Reinforced members were introduced already in the 1930's (Siporex), and this company has maintained a large proportion of reinforced material, above 60% in the 1960's (Rosenborg, 1998), while the European average has remained as low as 16% in the 1990's (Dubral, 1992). The reason for this is the competition with reinforced heavy concrete members (Bohnemann, 2000), in which the material strengths permit a comparatively low use of steel.

In an AAC-member, steel does not only serve as a compensation for lack of tensile strength, but serves also as compressive reinforcement, for compensating the lack of shear capacity and to supply anchorage strength towards the element ends. It adds up to a large amount of steel and an expensive product. This becomes especially evident with lintels in which practically all load-bearing capacity depends on steel, being enclosed in AAC. The intention behind the present BCE-technology is to eliminate, by an alternative production method, the disadvantage of the present technology. In forming a hybrid between AAC and heavy concrete under pre-stressing, the capacity of these new members is radically higher than before, at less material expense. Steel is replaced by HPC. The cost is paid by the complication of using two concretes in combination, but this is primarily a matter of management and quality control.

The advantage is that by applying the BCE-system any kind of element is formed by combination of just a few (6) standardized block sizes.

FORMING A HYBRID OF AAC AND HPC

AAC blocks can be stacked dry, either in a vertical (walls) or a horizontal (floor) direction, (Bagheri, 2006). After drilling holes or sawing slits, the stacks are first pre-stressed, then poured with HPC over pre-wetted surfaces and cured into full building members. By choosing the density 500 kg/m^3 (AAC) and the strength K60 (HPC), the stress distribution in the member remains stable, as the creep factors are close to equal (ϕ= 1.0) for both materials. Reducing the density of AAC leads to a sharp increase of creep, which in a hybrid with HPC would roll over the strain on the concrete. More dangerous would be the opposite, to choose a lower quality concrete, implying a higher creep and a roll over of strain on the AAC, which could be fatal. Reducing the quality of concrete to K40 calls for a hybrid combination with AAC of density 450 kg/m^3 (ϕ= 1.4) to keep the stresses stable. This implies the lowest possible concrete strength for pre-stressing, by which deformations would be 33% higher and the AAC limiting strength 25% lower than with the combination 500/K60. One important reason for choosing the higher combination is the possibility to carry all significant loads on a floor, up to 5.5 kN/m^2, with a 9 m span (L/d= 30). With the same combination, roof elements carrying all snow loads in Scandinavia can have a span of 12 m (L/d= 40).

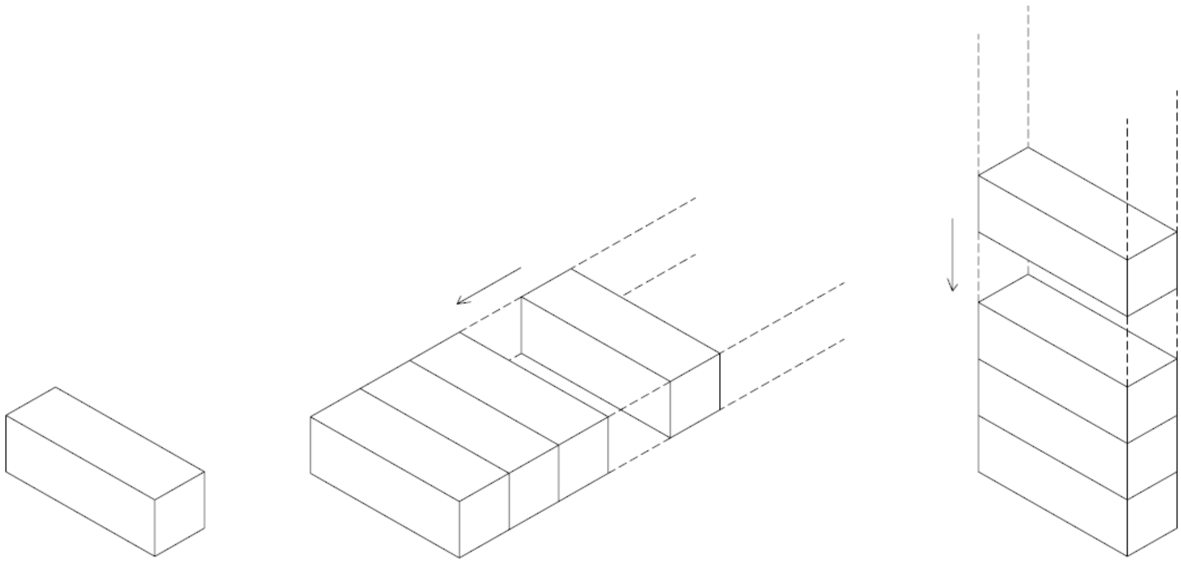


Figure 1. Blocks stacked in the horizontal or the vertical directions.

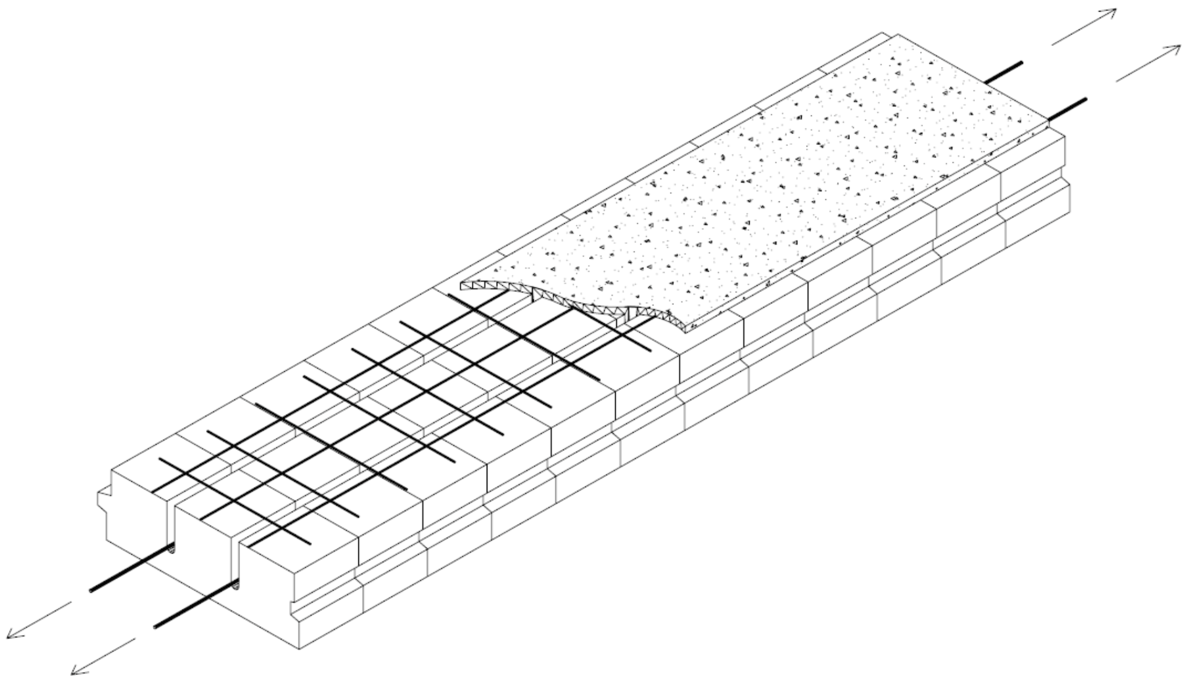


Figure 2. The complete floor panel,including prestressing strands and tensile reinforcement.

Dry stacking will limit the size of elements, with vertical members to 3.0 m^2 and with horizontal members to 7.2 m^2. Larger element sizes are possible with pre-stressed masonry (with thin-bed joints), in integral walls up to 30 m^2, i.e. ten times as large as with stacked blocks. Vertical pre-stressing requires a good bond between steel, concrete and AAC. The grouting must be preceded by a thorough wetting of the cylindrical holes and using liquefied, self-compacting concrete. Pre-stressing increases the vertical capacity of the wall by 25-30% (Aroni, 1966). Combining with lintels, it is possible to build an integral wall with window and door openings. An integral wall weighs about one third of an equivalent concrete (massive) wall. The surfaces on both sides are ready for plastering.

Figure 3. Stack of blocks forming a slender and prestressed wall panel.

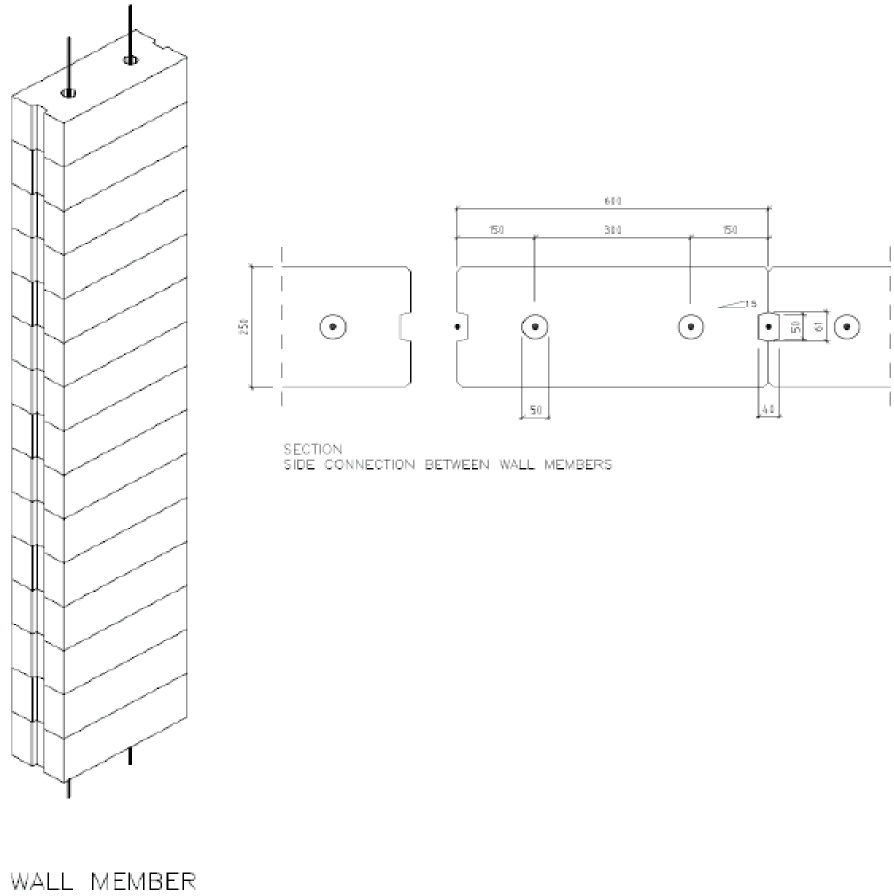
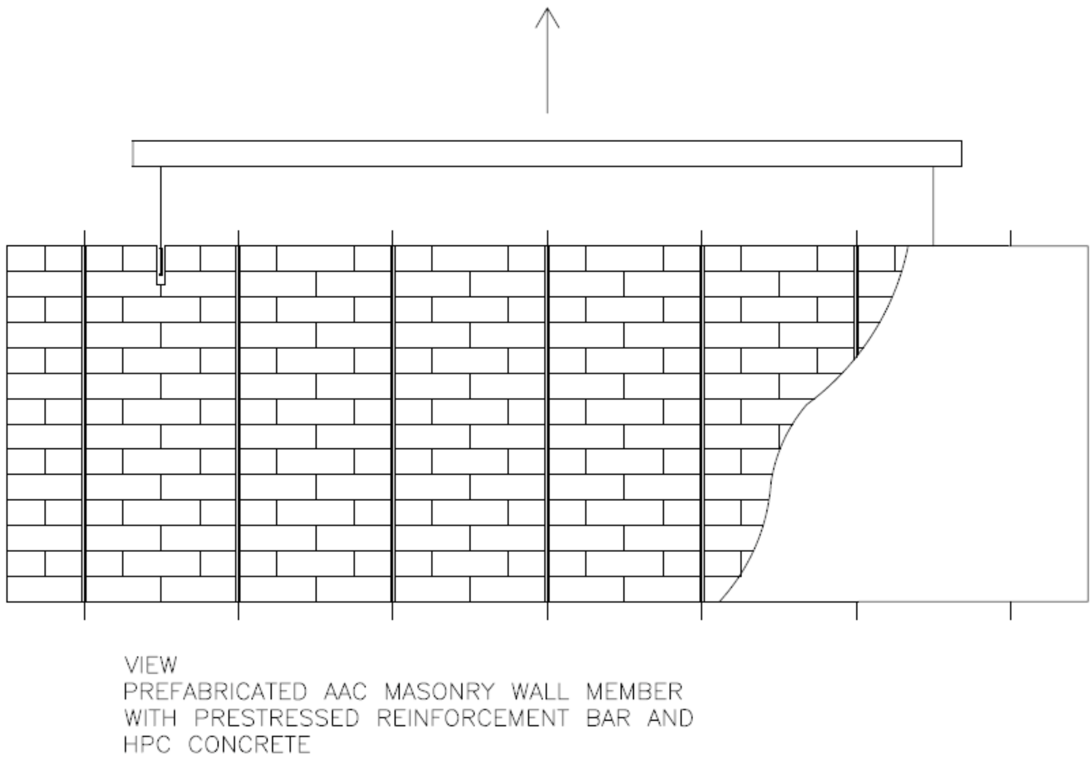


Figure 4.



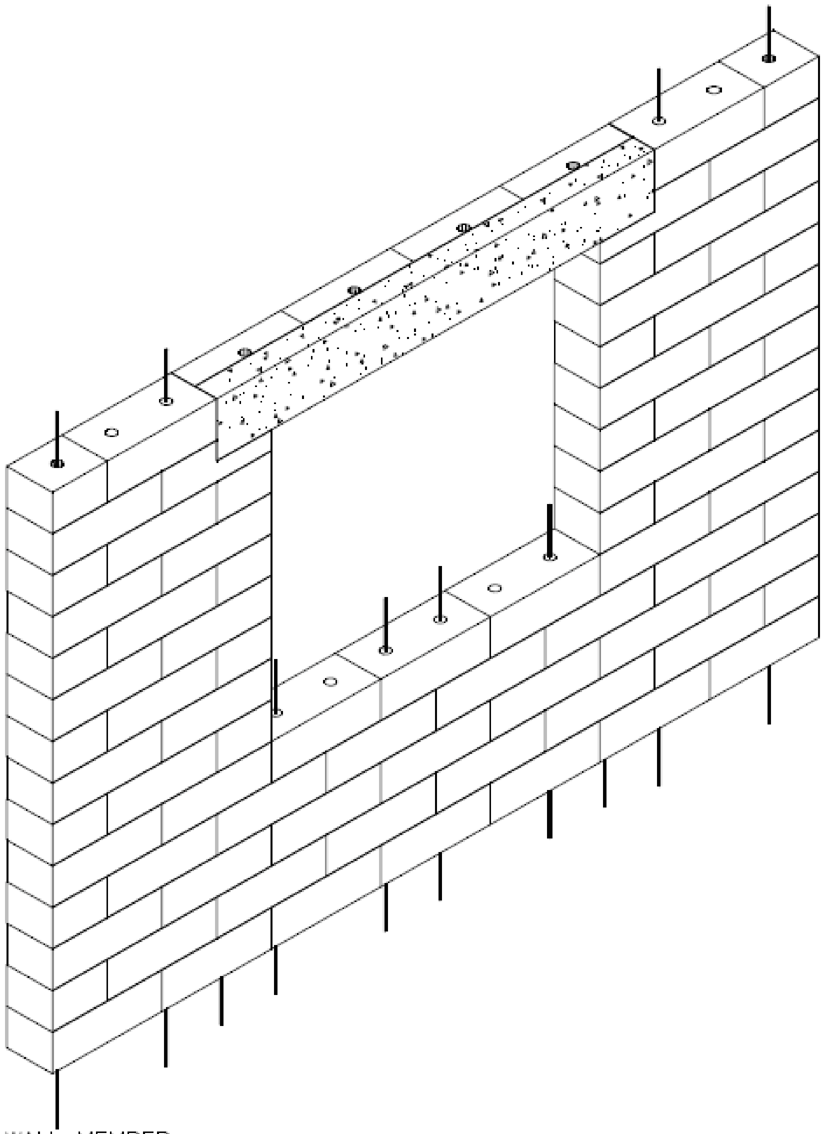


Figure 5. Integral wall (prestressed) with window opening and lintel (c.f. Fig 9).

The vertical pre-stressing induces compressive stresses enhancing the twisting capacity of the horizontal joints, which stabilizes the wall panel in manufacturing, transportation and site erection. Pre-stressing also compensates for tensile gravity stresses, when the wall is hoisted from the top, which is practical in erection at the building site.

HORIZONTAL MEMBERS

Horizontal pre-stressed members are comparatively stiff, as they remain un-cracked up to the service load level. Deformations above this level grow dramatically, which is characteristic of pre-stressed systems. Only two slits are needed. With 500/K60, the creep factor is roughly one in both materials. The short-term deformations are doubled with infinite time. Sideways, a tongue-and-groove structure, milled in cured material, which requires hard metal tooling.

The AAC cover under the pre-stressing strands is taken as minimum 50 mm. The protective effect corresponds in concrete to the double, or 100 mm, which contains REI 60.

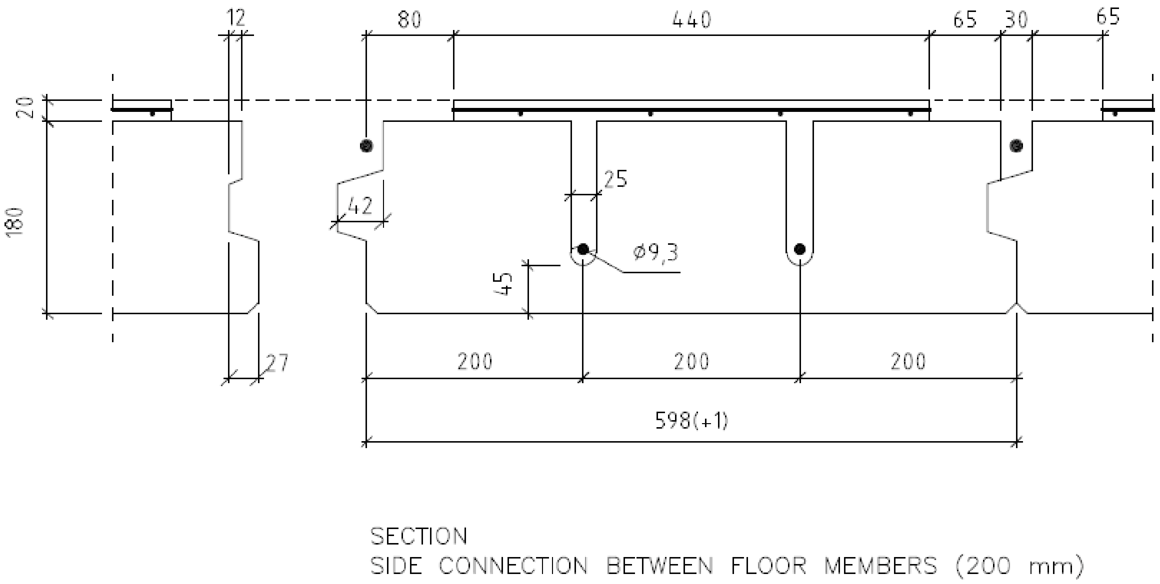


Figure 6. The principal solution of a hybrid floor panel.

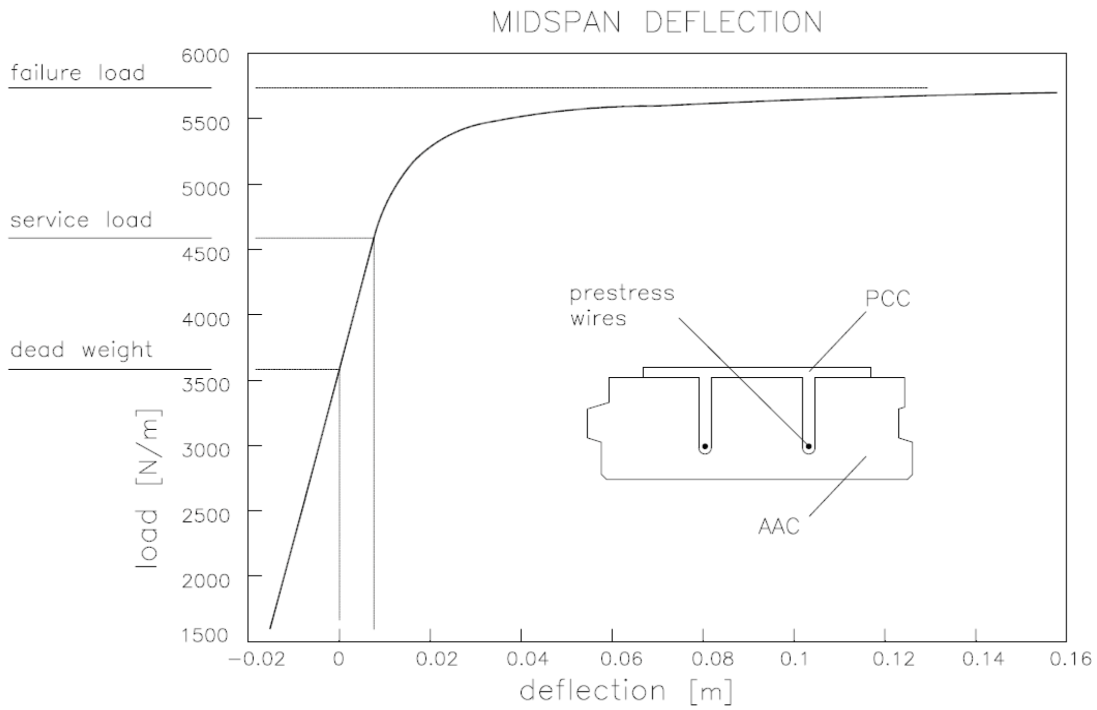


Figure 7. The relation between load versus midspan deflection.

The pre-stressing of long-span elements induces a risk of upward buckling, which must be prevented by fixing at the middle. The upward deformation is reduced by the declining force of the strands towards the ends. But the rotation at the end remains negative, which helps to centre the reaction force between wall and horizontal member. A further reduction of the eccentricity comes from the pre-stressing of the wall, which increases the total load and counteracts the cracking near the joint.

Lintels and beams are made to order with either symmetrical (doors) or asymmetrical (windows) shapes. Window beams have a shear centre close to the line of action from the reaction force. It counteracts the twisting of the beam (this statement is currently being investigated by FEM-analysis). Door lintels are extremely simple with a single pre-stressing strand. Longer beams spanning over window holes in exterior walls, carrying the connected floor, can normally be made without any extra shear reinforcement. Only with large spans and heavy characteristic loads is an extra shear reinforcement needed in design.

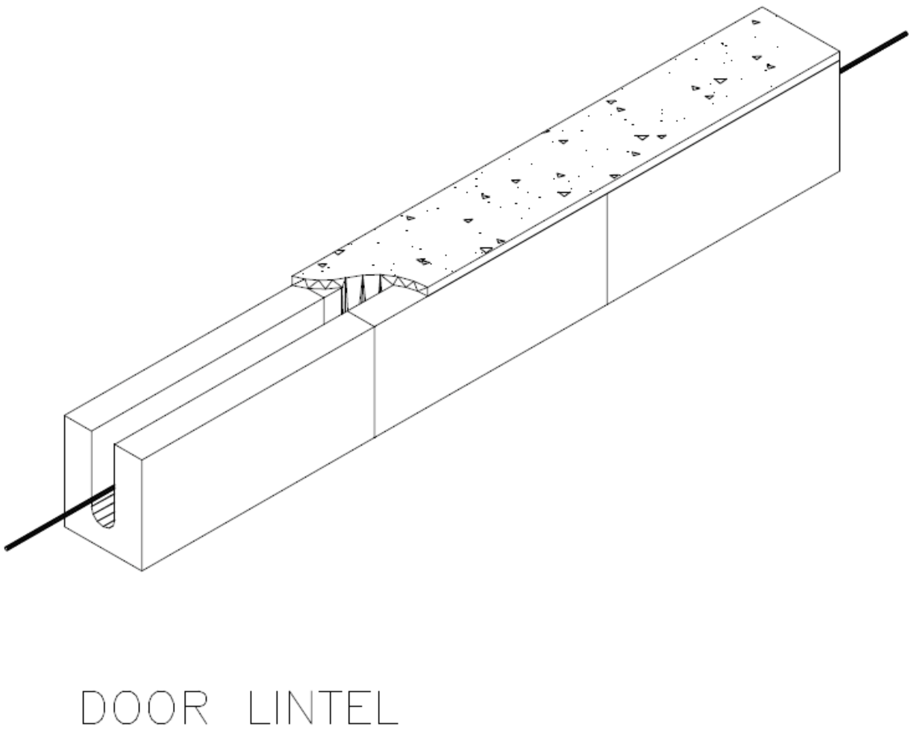


Figure 8. A short door lintel may have only a simple prestressing strand.

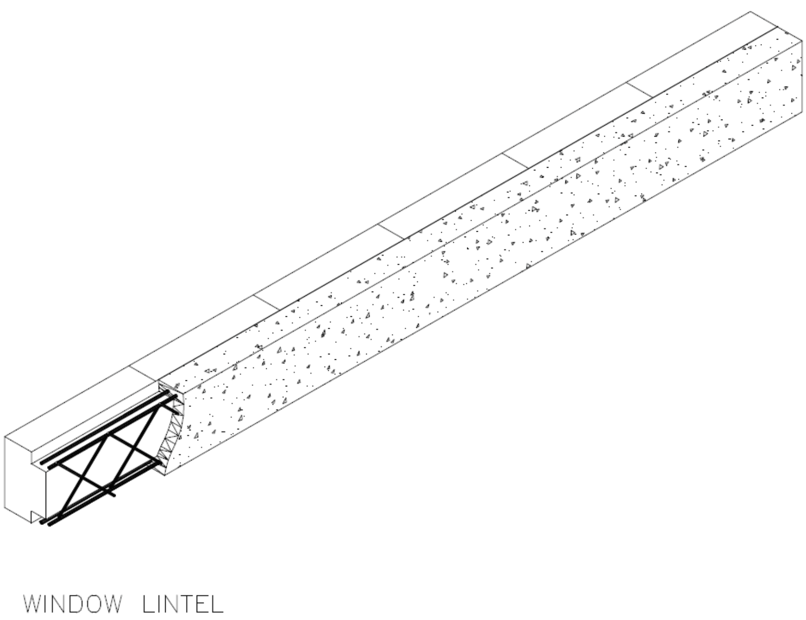
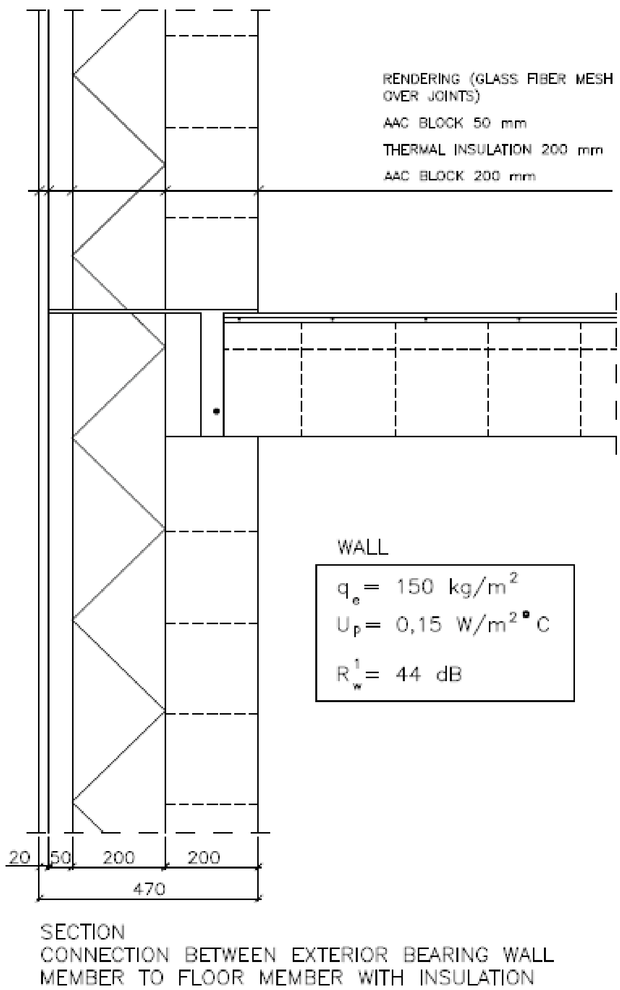


Figure 9. A long, asymmetrical window lintel with special shear reinforcement.

VERTICAL MEMBERS AND JOINTS

With integral walls, the total length of joints is kept at a minimum. Horizontal joints can transmit the load from connected roof and floors. Vertical joints must be filled with sealants kept under pressure by long, expanding screws connecting adjacent integral walls. With a wall depth of 470 mm, which is very much in Swedish practice, (insulation depth 200 mm), the thermal loss coefficient is down to 0.15 W/m^2°C. Building with wall elements (< 2 m^2), the total depth can be reduced to 420 mm, which is better from a practical standpoint, the coefficient is further reduced by 10% to 0.135 W/m^2°C, which is a current figure for northern Europe. With wall elements the same width as the horizontal elements, it is also possible to further reinforce the structure, in vertical joints and in seams, to compatibility and energy absorption, in case of seismic loading. Such cases involve gravity reactions proportional to weight, so the forces are smaller with a comparatively light structure such as with the BCE-system. Knowing that a major part of the demographic development in the 21th century takes place in seismic prone areas of the globe, it becomes evident that the building technology should focus on compatibility, energy absorption and efficient reinforcement systems to this end.



FLOOR MEMBER'S SPAN (m)	WALL MEMBER'S WIDTH mm	THE MINIMUM SUPPORT LENGTH OF FLOOR MEMBER OVER WALL MEMBER mm
L < 5	200	65
5.0 ≤ L ≤ 7.5	250	90
7.5 < L ≤ 9.0	250 – 300	120

Figure 10. Wall section.

GENERAL DISCUSSION ON DEVELOPMENT OF PREFAB SYSTEMS

The pre-stressed BCE hybrid may be interpreted as a development, coming either from the concrete or the AAC side. These sides have long been competing on the same market, in Sweden fiercely, to the point when the AAC industry has given up. AAC products are now imported. But the aversion between materials remains to this day. What is the explanation for this, one wonders? Why not combine the two materials, in an effort to take a step, or possibly two, forward?

On the international market, AAC is expanding rapidly. But concrete is expanding even more, to the point, when the global energy put into cement has become a threat to climatic stability. It has been suggested that AAC may imply a relief to energy stress, replacing concrete. Also, considering the thin concrete seams used with BCE, it means a relief to coarse aggregate supply, which is critical in parts of the world. For environmental reasons, it is certainly becoming critical everywhere, with time also in a country like Sweden.

The concrete prefab industry has not been very successful in developing a rational production. Only the HD/F members lend themselves to full industrialization and they are reasonably low-weight. Other massive products, such as walls cast in battery-forms, are heavy indeed. To meet a large truck in road traffic loaded with only two wall panels, is a strong indication towards change.

A preliminary analysis indicates that the reduction of CO_2 emissions, exchanging concrete with BCE in comparable products, is around 30%. Taking advantage of the possibility to integrate with PFA and steam from an electricity generation plant (coal powder feeding) can take this figure above 50%, possibly up to two thirds. But this is guesswork so far but indicating an impressive potential for the BCE system.

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