CHALMERS

Structural evaluation of possible storey-extension of medium-rise buildings from 1965-1975

Master of Science Thesis in the Master's Programme Structural Engineering and Building Performance Design

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Picture of a common slab block medium-rise building (Björk, Kallstenius & Reppen 1992)

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ABSTRACT

Due to the increased urban migration in Sweden a housing shortage has developed. A solution to this shortage is to increase the number of apartments in the urban areas. To achieve this goal a good solution would be to add storeys on existing apartment buildings. Suitable houses for storey-extension are the three-floor slab blocks that were built during 'the Million programme', because these houses do not meet today's energy standards and are therefore in need of renovation. When performing these renovations a storey-extension could as well be undertaken.

This report examines the possible difficulties and opportunities that exist when adding a storey on an existing building from 'the Million programme'. The report addresses structural engineers that lack experience from previous storey extensions. A suggestion of the procedure of a storey-extension is also presented. Actors with experience from storey-extension in the building industry have been interviewed. Study-visits on suitable building sites have been performed to establish what is important to regard when considering storey-extensions. Critical areas for a storey-extension have been identified. Finally the authors views on how and in what order these areas should be dealt with are presented.

The study concludes a number of different problems and solutions that a structural engineer might encounter in a storey extension project involving a building from 'the Million programme'. Further the study presents a procedure proposal that includes a checklist that might be used as a guide for the designer when performing such a project. In the study the previous mentioned guide is used on a case study, according to Eurocode, to verify and exemplify the proposed procedure.

Key words: Design, 'the Million programme', Storey-extension, Procedure guide

Byggnadsteknisk utvärdering av möjligheter för våningspåbyggnad på flerbostadshus från 1965-1975
Examensarbete inom *Structural Engineering and Building Performance Design*
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SAMMANFATTNING

På grund av den ökade inflyttningen till storstäderna har bostadsbrist uppstått. För att komma till bukt med detta problem så måste fler bostäder byggas. Ett sätt att öka antalet bostäder är att utföra en påbyggnad på befintliga flerbostadshus. Passande hus för en påbyggnad är trevånings lamellhus som byggdes under miljonprogrammet. Dessa byggnader möter inte dagens energikrav är därför i stort behov av renovering. När man då ändå utför nödvändiga renoveringar så är det lämpligt att samtidigt utföra en våningspåbyggnad.

Rapporten undersöker svårigheter och möjligheter som uppstår när man utför en våningspåbyggnad på en befintlig byggnad från miljonprogrammet. Rapporten riktar sig främst mot konstruktörer som saknar erfarenhet från tidigare våningspåbyggnader. Ett förslag på en procedur när man utför en våningspåbyggnad är också presenterad. Aktörer med erfarenhet från våningspåbyggnader har blivit intervjuade för att belysa vad som är viktigt att ta hänsyn till samt tänka på när man planerar och genomför en våningspåbyggnad. Kritiska moment i våningspåbyggnadsprocessen har identifierats och författarna har delgett sin syn på hur och i vilken ordning de kritiska momenten ska behandlas.

Rapporten levererar ett antal problem och lösningar som en konstruktör kan stöta på om han genomför ett projekt som innebär en våningspåbyggnad på ett hus från Miljonprogrammet. Vidare så presenterar rapporten en procedur innehållandes en checklista som kan följas när man genomför en våningspåbyggnad. I rapporten prövas guiden på en fallstudie för att verifiera och exemplifiera den föreslagna proceduren.

Nyckelord: Konstruktion, Miljonprogrammet, Våningspåbyggnad, Procedursguide

Contents

Preface

This master's thesis has been developed by the authors on behalf of NCC Eingineering. The work of the study has been carried out from February 2011 to May 2012. The study was carried out at Chalmers University of Technology at the division of Structural Engineering. Supervisor and examiner has been Björn Engström.

The report is largely based on interviews and study visits. Therefore we would like to thank participants from NCC and also PEAB. A special thanks to our supervisors Dan Engström at NCC Engineering and also Björn Engström from Chalmers who have given us advise throughout the entire period.

Gothenburg May 2012

Robin Nilsson & Johan Sundh

1 Introduction

1.1 Background

There is an overall objective within the European Union to decrease energy usage in 2020 and 2050 by 20% respectively 50% from 1990 (European Council 2010).

Between 1964 and 1975 there was a project implied by the Swedish government called ‘the Million programme’. This decision, as the name implies, resulted in one million newly produced residences. Today, these buildings stand for a large proportion of the Swedish housing market and therefore also stand for a large part of Sweden’s energy usage. To lower the energy usage in Sweden and to reach the energy standards of today and in the future, and also to make sure that the buildings maintain an acceptable living environment, it is necessary to renovate buildings from ‘the Million programme’ (NCC 2011).

The general opinion of the buildings within ‘the Million programme’ are that they are big, tall and stand in huge concrete complexes, but the truth is that about 50% of the houses built during this period are slab blocks that only are three stories high (Hall 1999).

Sweden’s metropolitan regions are undergoing urbanisation and this leads to an increasing housing demand. To avoid that the city’s green and common areas gets exploited, an effective strategy could be to add storeys to already existing buildings.

The two facts mentioned above, that many medium-rise buildings need to be renovated in combination with the increasing demand for housing in the urban areas, justifies that during a renovation it would be very suitable to add a storey to an already existing buildings. From an economic perspective it would also be advantageous to add a storey to an existing building and acquire more rent. This could help justifying a renovation of the entire building, if the energy savings from a renovation do not meet the renovation costs.

Arguably, there are often numerous of reasons that justifies additional storeys. The question is if these extensions are possible to accomplish and what are the critical issues in the process.

1.2 Purpose

The aim of the project is to identify the most common and critical structural issues involved in storey-extension of medium-rise buildings from ‘the Million programme’. This report will highlight problems and how these problems can be solved. The report will also recommend a process procedure for how to add storeys on multi-residential buildings.

1.3 Scope

The project will focus on structural difficulties involved when adding a storey on an existing medium-rise building. Other aspects of a renovation such as energy efficiency, accessibility or economy will not be treated as problems per se, but will be considered as boundary conditions and additional demands.

The report will focus on the most common medium-rise buildings from ‘the Million programme’, which are three storey slab blocks.

1.4 Method

In order to get a good overall picture of the renovation situation today, literature studies of existing material have been made. These literature studies have considered the history of ‘the Million programme’, the new demands and needs for renovation and the problems involved when adding a storey to an existing residential building.

Furthermore, the data has been compiled and served as a basis for interviews with participants of the renovation and building industry. These interviews have given us more information of the most common problems when adding a storey on a building from ‘the Million programme’.

The problems have been listed and described. Solutions to these problems are suggested and listed and a process has been proposed. A checklist is constructed and attached to the report. This checklist can be used with help of the report as a guide for addition of a storey.

In order to verify our process a case structure has been developed. This structure represents a common building from ‘the Million programme’. The proposed procedure is exemplified on the building and every step in the checklist is performed.

2 The Million Programme

2.1 Background

‘The Million programme’ is the common name of the residential building policy that was implemented during the years 1964 – 75. This policy followed from a parliamentary ambition from 1964, where it was decided that a million new residences should be built during a ten-year period. This ambition came as an answer to the growing housing queues in Sweden that had increased since the introduction of the regulated rents in 1942. At the time, the queue included approximately 400.000 people (Jörnmark 2011).

The programme was financed by government loans. The credit rationing regarding these loans allowed larger, industrialised, building projects to profit the most. It is also these building complexes that most people refer to as ‘the Million programme’ (Jörnmark 2011).

This credit rationing also influenced the ability of the municipalities to invest further in these new areas. This lead to a lack of retail stores and municipal facilities, which along with the effects of the more industrialised building process resulted in that ‘the Million programme’ was criticised for being both monotonic and depletive. Meanwhile, other parts of the housing market became more liberalised, which made it possible for more people to buy their own properties. All these factors lead to that even as early as in 1968, these newly produced buildings experienced difficulties with leasing all new apartments (Jörnmark 2011).

After 1970 several construction companies decreased their production and in 1975 it completely stopped due to both financial and leasing problems. This marked the end of ‘the Million programme’, and a total of 1.006.000 new apartments had been produced (Jörnmark 2011).

A common opinion is that ‘the Million programme’ only affected the major cities in Sweden. However, the fact is that, as can be seen in Figure 1, buildings were built throughout the entire nation.

Figure 1 Production of apartments in the number of thousands built during the years 1961-1975 (Modified from Hall 1999)

2.2 Structural design

2.2.1 Initial problems

The difficulties involved in implementing a project as big as ‘the Million programme’ were many. Two key issues were the financing organisation of the project and to find areas to locate all these buildings. However, the largest and most complex problem was how to avoid interfering with the other, nationally important, markets. The

Swedish economy had grown large over the last decades and labour was not available to transfer into to construction. One way to solve this issue was to heavily rationalise the building process. Standardisation, mass production, prefabricated elements and large-scale projects were considered necessary to keep both labour and construction costs down (Hall 1999).

This industrialisation resulted in new and modern solutions for multi-residential buildings. A number of different structural designs were developed, many of these were made non-compliant with other companies solutions. One idea with the construction of the buildings with in 'the Million programme' was to move large parts of the production from the construction site to factory plants, where a more organized and effective production could be maintained (Robertsson 2010).

Many of the buildings from 'the Million programme' were financed by lucrative government building loans according to a parliamentary decision from 1966. This decision stated that a project of at least 1000 apartments, with low labour and low production costs would be granted five-year preliminaries of these loans. In this way, even the smaller municipals could afford to invest in larger housing projects and 'the Million programme' spread throughout the entire nation (Hall 1999).

2.2.2 The structural frame

Bookshelf frame

In the early 1950s, the most significant change of structural design during the entire century occurred. Almost all of medium-rise buildings went from being constructed with load-carrying brick facades and longitudinal heart-walls to being constructed with load-bearing concrete cross-walls. This system is also known as bookshelf frames where the façade only work as non-bearing curtain walls (Björk, Kallstenius & Reppen 1992).

The biggest improvement with this new technique was the time savings. By casting the concrete against smooth casting forms made out of wood, the need for plaster afterwards was eliminated. In the 1960s the technique had evolved and the concrete was now cast against room sized casting forms and one storey high wall moulds. These forms were either made out of plywood or metal and could be re-used several times. This development also made tower cranes necessary in order to move these heavy forms. These cranes should become the single most important feature in order to rationalise the building process and the increase of tower cranes exploded, see Figure 2 (Björk, Kallstenius & Reppen 1992).

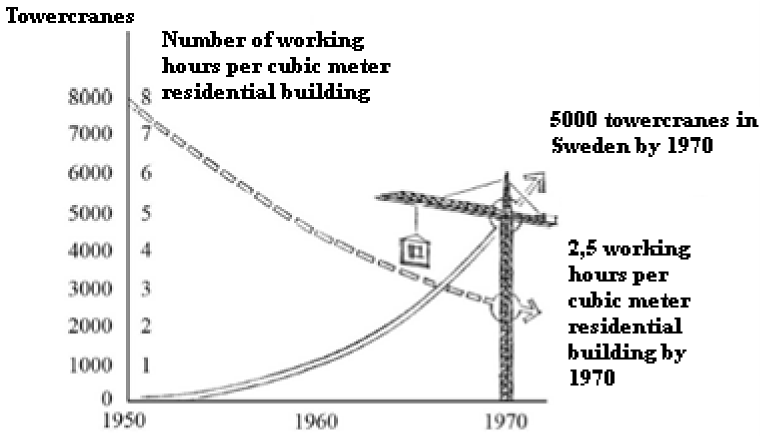

Figure 2 Diagram over the number of tower cranes and the number working hours per cubic meter built residential building (Modified from Björk, Kallstenius & Reppen 1992)

This new way of constructions proved to be the most common method during ‘the Million programme’ and approximately 40 percent of all buildings ware constructed in this way. Most of these buildings are stabilised horizontally through load-carrying diaphragm wall elements. These wall elements are then anchored in the stair and elevator shafts that are cast-on-site and reinforced in order to resist the imposed loads. Figure 3 illustrates a typical bookshelf frame (Vidén & Lundahl 1992).

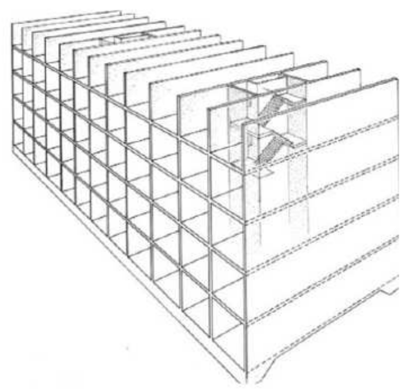

Figure 3 Illustration of a typical bookshelf frame (Björk, Kallstenius & Reppen 1992)

Prefabrication

The idea of the bookshelf frame developed even more and the cast-on-site was soon replaced by prefabricated wall and floor elements. At first, the factories where these elements were constructed were set up as field factories adjacent to the construction site. The wall and floor slabs were then lifted into place with gantry cranes on rails, which allowed buildings up to three stories high. Gradually however, this method was replaced when the wall and floor elements became more sophisticated to include windows, doors and sanitary and heating installations and therefore has to be constructed in stationary factories. The wall and floor slabs were then transported to the work site with custom made vehicles and lifted to place with tower cranes that allowed buildings to rise even higher. The constructions with prefabricated wall and floor elements were in the beginning of ‘the Million programme’ very scarce with a production of about 2500 apartments a year. However, as the technique evolved and the method was cultivated, the production increased and in 1971 about 20000 apartments was constructed (Vidén & Lundahl 1992). Figure 4 shows a typical assembling of a prefabricated building from ‘the Million programme’.

Figure 4 Picture of a typical house built with prefabricated elements (Vidén & Lundahl 1992)

2.2.3 Building types

The rationalisation of the construction process, as well as the construction credit rationing from the government, resulted in a limited number of building types during ‘the Million programme’. The most common types were lower slab blocks, higher slab blocks, tower blocks and balcony access slab blocks. Almost half of all the apartments built during these years consists of three to four stories slab blocks and are characterised by having at least two staircases (Vidén & Lundahl 1992).

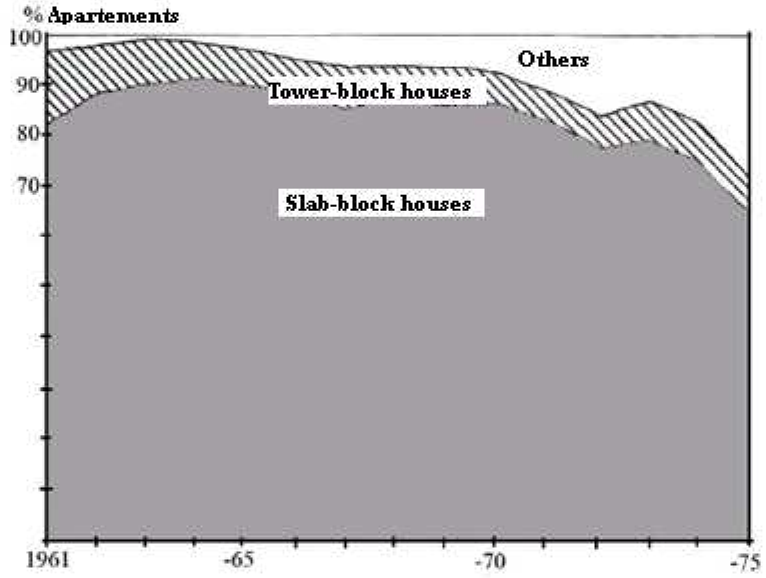

Figure 5 Distribution of the different building types built during 1961-75 (Modified from Vidén & Lundahl 1992)

Lower slab blocks

Slab blocks were, as already mentioned, the most common buildings during 'the Million programme'. These houses exist in a number of varieties spread out all over Sweden as can be seen in Figure 1, and represented between 75 and 90 percent of the annual apartment production, as can be seen in Figure 5. Lower slab blocks, slab blocks with three stories were popular even before 'the Million programme' began and was the single most common building type during those years. Almost half of all buildings were built as slab blocks with three stories, see Figure 6 (Hall 1999). These houses were both environmental and infrastructural very good and due to their low height, they could be constructed without an elevator (The demand for an elevator did not apply on buildings lower than 9 meters between the top floor and the entrance) and therefore kept the costs down (Björk, Kallstenius & Reppen 1992). The biggest difference between the slab blocks constructed during 'the Million programme' and those constructed earlier, was the width of the new houses, which was significantly larger. Due to this, the cost for entrances, the staircases and the possible elevators, could be financed by from bigger apartments (Vidén & Lundahl 1992).

Figure 6 Typical Lower slab-block house, Härnösand (Björk, Kallstenius & Reppen 1992)

Higher slab blocks

Higher slab blocks, see Figure 7, represent a quarter of all houses built during 'the Million programme'. Higher slab blocks have at least five stories (Flerbostadshus 2011) and ware mainly located in the suburbs, but ware also found in inner city areas where a complete remediation of earlier buildings was necessary. Higher slab blocks are always equipped with elevators and the larger buildings were also equipped with a furniture elevator (Vidén & Lundahl 1992).

Figure 7 Typical higher slab-block houses, Gothenburg (Björk, Kallstenius & Reppen 1992)

Tower blocks

Another very common design was the tower block design, see Figure 8. Tower blocks are buildings with a centered staircase that all apartments are arranged around. Tower blocks design was very common during the 1960s when approximately 20% of all multi-residential buildings being built were of this design. The financing rules between 1956 and 1962 benefited this sort of design. When 'the Million programme' was initiated, however, the production had decreased down to 9% (Hall 1999). Most tower blocks are between 6 and 8 stories high.

Figure 8 Typical tower blocks, Stockholm (Björk, Kallstenius & Reppen 1992)

Balcony access buildings and other special buildings

Balcony access buildings are a building type where the apartments are entered via balconies that run along the façade. All together only about 30 000 apartments of this type were built during 'the Million programme'. However, even though they are few in numbers, they have come to characterise 'the Million programme'. This is due to the large-scale in which they exist in the suburbs and the fact that access balconies had barely been constructed before 'the Million programme'. Those being constructed after the Programme have almost all had their own niche, for example student accommodations (Vidén & Lundahl 1992). Medium-rise houses were also built as terrace-houses with either rented or co-operative apartments or as entire blocks with one landlord (Hall 1999).

2.2.4 Exterior

Roof solutions

During the realisation of 'the Million programme', flat roofs and roofs with low inclination became popular. There are many advantages with these kinds of roof solutions. Costs are kept low, future roof installations such as fan systems are facilitated, no risk of snow slips and forming of icicles, the risk of people falling from the roof also decreases drastically, but most important of all is that the run-off of the surface water is kept inside of the building, which means that the drain pipes would not freeze during the winter. Drainpipes that freeze are a common problem for exterior details such as the façade. Problems that were found to occur with these roofs were instead that they were fragile and damage caused by moisture could arise from the slightest scratch. It is also very difficult to detect when there is a stop somewhere in the drainpipes as they are placed inside. These problems are, however, of human nature since close and careful supervision counteracts these problems (Wallin 2007).

Façades

The shape of the façade and the choice of materials are often determined by the structural frame of the building. Load-carrying façade elements often have a concrete plate with visible aggregate or some kind of pattern formed into it. If the joining of these wall-elements were properly cast, there would barely be any maintenance needed. Slab blocks that do not need any load-carrying exterior walls often have a façade that consists of curtain walls with for example liquor polished aerated concrete or by light, prefabricated or built on site stud walls with mineral wool insulation. The surface layer of the façade is mainly made out of bricks, wood or sheet metal (Vidén & Lundahl 1992).

Balconies

Balconies were considered as a part of the new building standard during 'the Million programme'. During this period, there were mainly three different methods that were used for balcony solutions. All three methods however, use a concrete slab. The first method is a cast-in-situ slab. This method is most common in houses with a cast-in-situ concrete frame and the balcony slab reinforcement is then cast into the concrete floor slabs of the house. Between the reinforcement bars, insulation panels are placed to minimize the thermal bridge effect. The second method uses a prefabricated concrete slab that is attached in vertical side skirts that runs along the façade. These side skirts are not attached to the building and this method was less attractive to look at. But since the balconies became structures of its own, the method avoided thermal bridges (Vidén & Lundahl 1992). With time a crossbreed between these two methods was developed, a prefabricated concrete slab that both was attached between side skirts and cast into the framing. This allowed the depth and width of the balcony to expand drastically (Björk, Kallstenius & Reppen 1992).

Foundations

The rationalisation of the building techniques also had effects on the foundations. The aim was to get similar foundations for all buildings within a specific area. These new neighbourhoods that were created during 'the Million programme' were often of considerable size, which resulted in that instead of adjusting the building foundation to the soil conditions, the soil conditions were adjusted to fit the buildings. This was made with both explosives and filler. The size of these neighbourhoods also demanded that otherwise poor construction areas, such as quagmires, were used. Due to these conditions, different solutions were used and therefore it should be distinguished whether the foundation wall is placed on a simple slab or if piles or plinths support the slab (Björk, Kallstenius & Reppen 1992). For buildings with three stories, a simple slab straight on top of a packed bed of grabble was often enough. This method was especially efficient on locations were levelling of the surface was needed. Eliminated parts of the surface were then used for fillings and no extensional material and no extra transports were needed. Edge beams were casted along the slab and also underneath parts of the slab were load-carrying parts are placed. On locations with less firm soil conditions, the techniques with piles and plinths were used. Plinths were used when the soil layer was not thicker than three meters until it reached firm bottom. If the soil conditions were deeper than this, reinforced concrete piles were used to stabilise the foundation. It is under these conditions that suspended foundations are found (Björk, Kallstenius & Reppen 1992).

3 Reasons to renovate

Many reasons to start renovations of buildings of the 'the Million programme' are accumulating. The biggest issue, however, is that many of the installations in the buildings from this time are reaching the end of their service life. Many of the apartments will therefore soon be unfit due to their poor maintenance (Reppen 2009).

3.1 Apartment standards of today

The difference between apartments that were built within the 'the Million programme' and the buildings that are produced today is large.

The most obvious difference is the demand limitations on the energy usage. A newly built apartment should not exceed a usage of 95 kWh/m^2 and year according to Swedish building regulations (Boverket, 2011). In many companies and parts of Sweden it has been chosen to use even less energy than this limit (Johansson 2011). Apartment houses that were built during 'the Million programme' spends a lot more than what is demanded today, common numbers could be around 185 kWh/m^2 and year (Johansson 2011).

However, there are also other standards that differ between 'the Million programme' apartments and a newly built one. During 'the Million programme' it was common to build three-room apartments. Today there is a wish of having a larger variety of apartment sizes. There is also a general desire to have more open plan arrangements (Servin 2011).

Some of the apartments built during 'the Million programme' have never been renovated and therefore kitchens and bathrooms might not meet todays standards. The installations will soon be worn out and the awareness of accessibility has increased. It might therefore be necessary to replace the existing installations, broaden doors and install elevators (Servin 2011).

Overall the standard of the apartments from 'the Million programme' is insufficient compared to the standards of today and are therefore in need of renovation of the exterior insulation and the pipe installations.

3.2 Service life of installations

The most critical installations, and those installations that are most extensive in their renovation procedure, are the pipe installations. These pipes are often built inside of the load-carrying frame and are therefore very hard to reach. Some pipes are naturally more worn down than other depending on the material of the pipe, due to maintenance, habits of the tenants and the quality of the water that runs through it. Guideline indications of service life for the most common and most critical pipes are listed in Figure 9 below.

Pipe	Service life
Cast iron sewage pipe	30-60 years depending of the dimensions.
PVC sewage pipe, made before 1974	20-30 years, all are worn out today.
PVC sewage pipe, made after 1974	30-50 years
Galvanized steel water pipes	30-40 years
Copper water pipes	50-60 years, older connections may be heavily corroded which influences the service life.

Figure 9 Service life for common sewage and water pipes (modified from Reppen 2009)

Renoveringshandboken – för hus byggda 1950-75 [1]is a guide for choosing strategies and selecting technical solutions before a renovation is initiated. It is distributed by 'VVS-Företagen' and is written for the managers of the renovation projects. Common flaws and reasons for renovations are listed for the most common medium-rise buildings from 1950-75, a time period that involves the buildings from the 'the Million programme'.

Leaking wet rooms

Wet rooms are, and will always be, critical areas within a building. With both heat and moisture in abundance, these rooms are bound to be the biggest concerns for renovation. The most common problems involved in wet rooms from the time of 'the Million programme' are due to water and moisture. Leaking wallpapers, leaking PVC carpets (especially at joints, pipe entries at drain connections, leaking pipe entries and corroded floor drains are all problems that derive from extensive water usage. However, there are also a few very common faults that are a result of both poor workmanship and lack of knowledge within the branch. These problems are typically missing sealing layers behind ceramic tiles and badly placed heat pipe entries.

Pipe installations

As can be seen in Figure 9 above, the pipe installations have almost all reached the age where their service life are supposed to end. This poses a huge threat to the buildings from 'the Million programme' and in a few years many of the buildings might be in such a bad shape that the tenants have to move. The biggest issue regarding the pipe installations are that they corrode. The cast iron sewage pipes have a tendency to corrode naturally due to their uneven surfaces. Another common corrosion problem is galvanic corrosion that occurs where, for example, mechanical brass joints are placed on pipes made out of copper. These connections can cause problems since the part made of brass can be heavily corroded and very sensitive during repairs. Missing, or poorly working, systems that include hot water are also a cause for renovation. For example a poor working heated towel dryer can be a source for legionella. The insulations that surround the hot water- and heating pipes are also

[1] The renovation handbook – for houses built between 1950-75

something that needs to be considered. They are often insufficient and a huge source for waste of energy.

Sanitary porcelain and hot water faucet

The sanitary porcelain, if no renovation has been done, are generally in a very bad state. It is often damaged due to normal wear and has a worn down look. To find spare parts to the installations could also be a problem. Since the time of 'the Million programme', the sanitary installations have improved and are nowadays more environmentally friendly. So compared to today's standards the old installations use too much water. This goes for almost all installations, from the toilet to the dimensions of the water pipes. High water consumption leads to both an increased energy consumption and higher risk for extended water damages.

Structural frame

The concrete in the buildings from 'the Million programme' is overall in a very good state and will last for a few decades more. However, the high rate that these buildings were erected in caused many poor executions. One example of this is cavities and cracks between the apartments due to the lack of supervision and quality. These cracks and cavities can cause poor soundproofing. They also lead to an increased risk for vermins that thrives in these cavities. The foundation is also a very common source for problems. This is often a result of poor insulation around either the ground slab or the basement foundation. Cold ground floors and high moisture content are the most common issues. However, it is also important to check the foundations for cracks. If the foundation has a crack in it, it means that the buildings could be exposed to radon from the ground.

Ventilation system

There are three different kinds of ventilation systems from the time period of 'the Million programme'. The most common kind was exhaust air ventilation that was used on up to 70 % of all medium-rise buildings. The two other kind of ventilation systems were natural draught- and exhaust and supply air ventilation with heat recovery (FTX system) that makes 15 % each of the ventilation systems from this time (Vidén, Lundahl 1992). The most common problem for all these systems is the neglected maintenance that would have been needed, especially for the Exhaust Air Ventilation and the FTX system that are relying on mechanical installations. Many of these ventilations may start to leak due to the natural ageing of the building materials. This may lead to an inferior air flux that causes "bad" air and growth of mould.

Electrical installations

Just as with many of the other installations in buildings from 'the Million programme' the electrical instalments are old fashioned and have many disadvantages compared to the instalment standards of today. The most obvious of them are that many sockets do not have any child safeties and that many electrical connections miss a connection to earth. Further on, the number of sockets does not meet up to today's demands. Some of the buildings also use collective electricity metering. This means that the total amount of electricity consumed in the building is measured and then distributed and paid depending on the area of the apartment, rather than the actual consumption of the tenant. This leads to a huge over-consumption of electricity and do not correlate with today's energy saving attitude.

Extensional concerns

Naturally, there are numerous of other reasons for a renovation than the ones mentioned above. One of the most characteristic reasons is closely linked to the flat roofs that became popular during ‘the Million programme’. As mentioned in Section 2.2.3, flat roofs often had an interior drainage system. These systems have often had a lack of maintenance as they are placed in inaccessible places. Poor run-off elevations on these roofs can also contribute to some major problems since water easily assembles if the drainage is not adequate enough. It is also important to recognise that many of the buildings built during ‘the Million programme’ were built under a tight schedule in order to increase the savings. Tight schedules are a known source for errors and these errors can be detected everywhere. However, one place where these errors occur more frequently than elsewhere has shown to be between prefabricated elements. If these elements are badly jointed to each other, cavities could occur which can cause both air currents and affect the thermal resistance in the building. (Reppen 2009)

4 Identification of problems and solutions

Adding of storeys during renovation has been made for several years and it is getting more and more common. The knowledge documented within the sector, however, is still very moderate. Many contractors are even considering adding of storeys, especially on existing apartments, as a source for problems rather than a source for potential profits. In this chapter, many of these problems that have been acknowledged from previous projects will be identified, reviewed and provided with possible solutions.

4.1 Critical problems

This chapter will illuminate the most critical and common problems involved in a storey-extension. The problems will be identified and reviewed in this chapter, and solutions to these problems will then be given in Chapter 4.2.

Foundations

When it comes to additional loads, the most critical part of the building is the foundation. In Section 2.2.3 the most common kinds of foundations of 'the Million programme' are presented. It was concluded that the most common of them, is a simple concrete slab or a suspended foundation.

Since simple concrete slabs often are placed on bedrock or packed beds, which have similar capacities as bedrock, these sorts of foundations are suitable for extra loads. If the concrete slab instead is placed on clay, which are less suitable for extra load, reinforcements might be necessary (Bergstrand 2011). A suspended foundation on the contrary, is designed with an intentional air layer in order to isolate the building. To create this air layer, the foundation had to be elevated with supporting columns. These columns were only designed to support the loads from the original building and are therefore less suitable for extra loads (Sihvonen 2011).

As mentioned earlier, it was generally strived to have a uniform design in each area to facilitate the building projects. This resulted in many buildings with identical foundations, especially for slab blocks with three to four stories as they were built in large quantities. It was common that a few of these houses were built on top of a basement where common areas such as laundry room, waste deposals and storage rooms were placed. These buildings were built without a suspended foundation and where instead designed as a concrete slab foundation that were placed deeper in the soil. These solutions are as already mentioned suitable for extra loads (Sverin 2011).

Load-carrying capacity

One of the biggest concerns when it comes to adding storeys on already existing buildings is whether the structural system can resist any additional loads. Many of the houses built during 'the Million programme' are characterised by the restricted budget by which they were built. This can be noticed on the cast on site concrete frame by the cheap and poor concrete that was used and the fact that many of the walls were left without reinforcement (Servin 2011). Pre-fabricated wall elements also miss main reinforcement. The reinforcement that can be found within these wall elements is only there to control cracking during transportation (Andersson 1968). Since many of the houses were built by wall elements, the walls did not vary in thickness depending on the number of storeys. It is essential to point out that the wall dimensions were not created to resist the loads. They were rather a result of the fire protection requirements and the noise regulations that were commonly applied during this time period. Since the wall dimensions were created according to the requirements mentioned above, and mainly made of solid concrete, most elements should be able to resist additional loads.

Opening of walls

Today's plan arrangements are more open than they were 40 years ago. Therefore it can be desirable to make openings in some load bearing walls in order to adjust the apartments to today's standards.

It can also be desirable to adjust the non-load bearing walls. These adjustments mainly consist of making the often rather small bathrooms wider and more suitable for disabled people. Many of the door openings are also too narrow to fit the standards of today. Previous standard only required a width of 80 cm. Even though neither of the small bathroom or the narrow door openings fulfils today's standards, there are still no requirements to make these changes. A renovation of an original building counts as a reconstruction and is therefore not governed by the same standards that are required for newly produced buildings (Svedin 2011).

Elevator installations

The accessibility requirements from the time of 'the Million programme' were the biggest reason that made three storey buildings popular, since they did not need an elevator. The requirements of today are harder and if storeys are added there will most certainly need access by an elevator. In order to keep the costs down it is vital to only install the absolute minimum number of elevators. One elevator could be enough since the original apartments do not require elevator access as they are reconstructed according to the same regulation as mentioned above. How this affect the extension construction is reviewed in Section 4.2.

Balconies

Balconies are a common source for energy loss within the buildings from 'the Million programme'. Poor insulation between the balcony slab and the structural frame is the biggest reason for this. A common balcony solution from 'the Million programme' was a balcony that was made simply by opening a section in the curtain wall. This kind of solution does not only constitute a major thermal bridge that leads to a high energy loss. It also occupies possible living area from the apartment.

Another common solution during 'the Million programme' was balconies where the balcony slab is simply supported on vertical load-carrying side screens. These balconies were then a freestanding structure, only jointed to the façade to avoid large gaps between the façade and the balconies. This solution does not create any thermal bridges, but the side screens were often made out of concrete elements and can by today's standards seem to be old fashioned.

A problem that most of the balconies have in common is that their concrete cover is too thin and that the concrete is too poor. This has in some cases lead to corrosion of the reinforcement, due to the carbonation process in the concrete. This can, if no precautions are taken, cause a collapse (Vidén & Lundahl 1992).

Extension approach

The biggest problem when adding a storey concerns the connection between the original building and the added part.

Adding of a storey can be divided into two main categories. The first one is simply an extension of the old apartment layout. The new apartments look basically the same as the original ones, which means that the new walls stand on top of the original walls. The profit with this method is that all loads are directed straight down which leads to less labour for both the workers and the structural engineer. The drawback is that the original apartments restrict the options for new apartments.

The other alternative is to completely change the initial layout plan and make the new structure less dependent of the initial building. The advantage with this approach is that one can adjust the layout of the new apartments to the housing market demands. The drawback is that the loads have to be shifted to the original load-carrying system. This means that an effort has to be put in designing a way of connecting the new part to the original building, both functionally and structurally.

It is important to make sure that the loads from the new apartments are transferred properly down to the existing load-carrying system. This can easily be problematic since these houses are old and variations from the original drawings may occur. These variations often results from settlements, but can also be caused by negligence or errors in the erection process. Since the measurements in the original drawings cannot be trusted, the only way to find the exact measurements is by measuring the original building manually (Larsen 2011).

No matter which method that is used, the sound levels always have to be acknowledged. The top tier of the original building is often dimensioned for uphold of the roof structure and is not dimensioned for any additional loads. Therefore, neither the demands on sound or load-bearing capacity are fulfilled. Both methods also share the problems with all the new wiring and ventilation systems that have to be installed. This is important to consider since these installations can require a lot of space.

The actual structural frame of an additional storey would not differ that much from an ordinary one-storey building, and neither would the selection of materials. Traditionally, in Sweden housing construction can be narrowed down to three structural materials; concrete, wood and steel. All these material have their pros and cons. Concrete is the heaviest out of the three and will therefore induce the most loads on the existing building. Wood and steel are two lighter alternatives; the problem if these materials are used will instead consist of making walls soundproof and fireproof.

Fire safety

When adding a storey on an existing building it is important to consider the fire restrictions prescribed, since fireproofing has had a tendency of being neglected in previous storey adding constructions. There are numerous factors to consider when it comes to fire safety, but some of these factors are specific for storey-extensions. One of these problems is that the fire restrictions change when four storeys are exceeded. The load-carrying structure of a four-storey building has to resist loads during 60 minutes before it collapses in case of a fire. This requirement is referred to as R60. A five-storey building however, has to resist loads during 90 minutes, R90. Another problem when it comes to fire could arise due to the raised floors that conceal all the new installations. It is very important that the apartments are insulated from fire even from underneath the floor (Järphag 2011).

If these insulations are missing, fire could spread throughout the installation layer and cause damage on the whole building, see Figure 10. Fire that spread up to the roof trusses is a more general problem. This is often a result of poor fire insulation between the roof construction and the actual building but it can also be a result of installed electrics made by the tenants themselves, for instance due to ceiling spotlights.

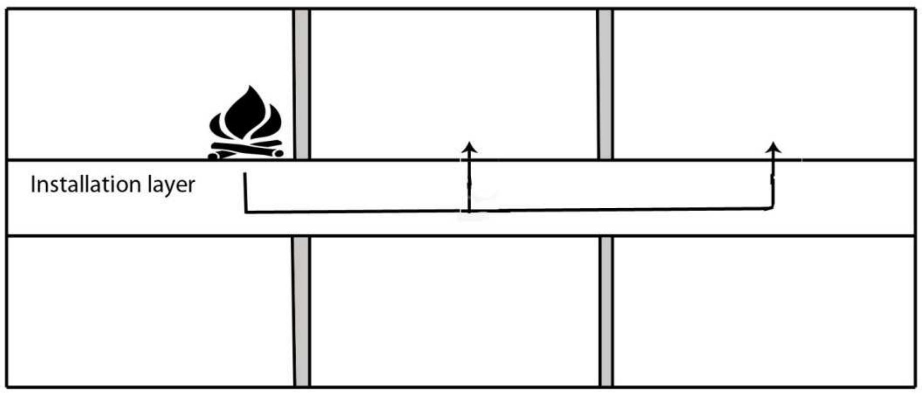

Figure 10 Simplified section view of a fire propagation in the installation layer.

Other problems

When adding a storey to an already existing building there are a numerous of other issues that have to be solved compared to a newly produced building. The biggest difference is the tenants that live in either the initial building or in a building nearby. If it is decided that the tenants should stay during the construction process, it will immediate be followed by restrictions during the construction. These restrictions mainly concern noise levels, working hours and accessibility in staircases.

There is also a big problem connected with the fact that the old roof construction is removed. The building is then immediate exposed for moisture such as rain and snow that easily could penetrate ventilation systems, staircases and other cavities see Figure 11.

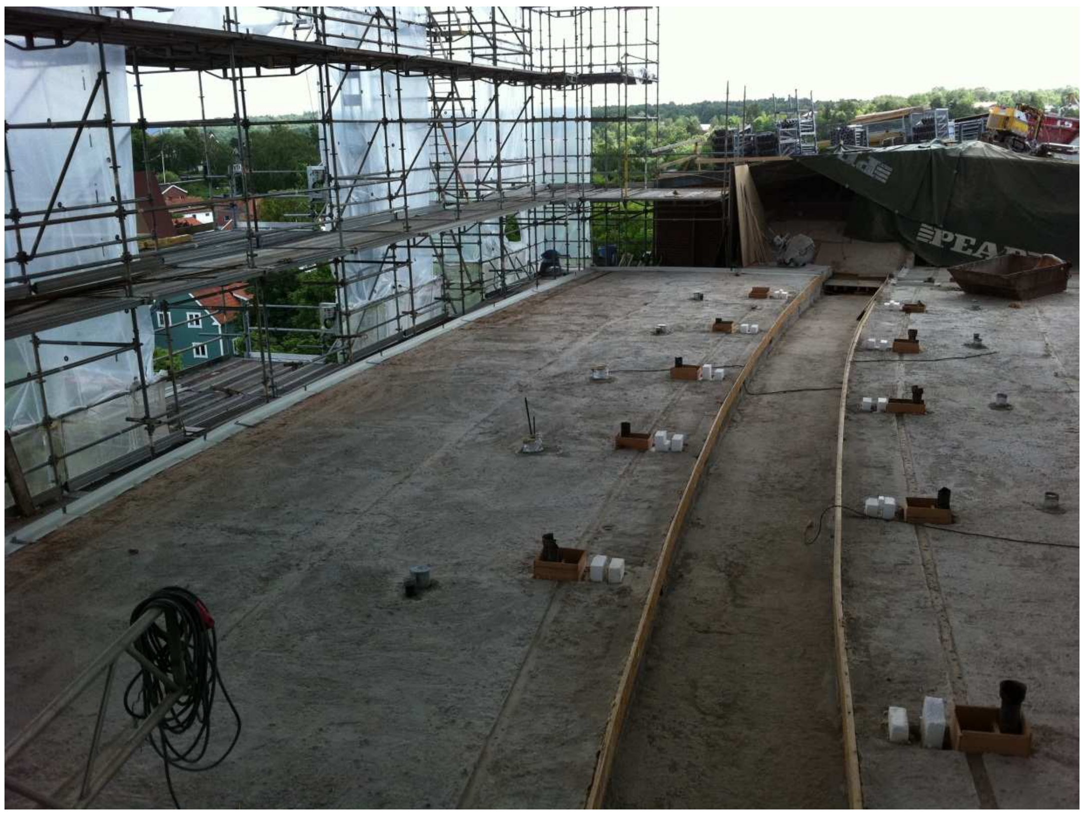

Figure 11 Removed roof structure exposes cavities and holes for rain and moisture, Emilsborg 3.

When adding a number of apartments to a building, the number of tenants will increase as well. This can cause a problem with mainly storage possibilities and parking spaces. The problem with parking spaces differs from county to county since the councillor in each county sets the demand of parking spaces.

The acoustics are a fundamental issue that becomes very critical especially in the connection between the new construction and the initial building. This becomes a problem since the old roof tiers seldom are made for sound isolation. This is something that has to be regarded and fixed when new apartments are constructed on top of the old roof tier. Another problem concerning the acoustics is that the new construction often has to be made with light materials such as wood or steel. These materials are poor as sound isolators that make the apartment dividing walls very thick in order to reach the desired sound requirements.

4.2 Possible solutions

In this section possible solutions to the stated problems in section 4.1 will be reviewed.

Foundation

If the building is placed on top of bedrock, on piles or on a packed bed, it can be assumed that the foundation generally has a sufficient buffer capacity to admit an added storey. However, it can be wise to analyse the dimensions and capacity of the piles (Bergstrand 2011). If the building is placed on such ground conditions, the foundation will not be the governing factor to consider. Instead the load-bearing capacity of the load-carrying walls will be decisive. If the ground conditions are poor, like clay for instance, it can be assumed that the foundation has to be improved and strengthened. Such strengthening is best made with piles that are placed in the ground, by joining sections from inside the building. This method is both inconvenient and expansive and a general opinion is that storey extension under these circumstances should be avoided (Sevrin 2011).

A suspended foundation is easier to strengthen, since it is built up with columns. These columns are exposed which allows workers to go beneath the bottom slab and perform strengthening measures. There are many ways to execute a strengthening of a suspended foundation. These reinforcements can be roughly divided into two solutions. One is to strengthen the building from underneath with piles. The other, and more suitable solution is to distribute the loads on the original column on a wider area. This is done to ease the pressure on the column and to avoid settlements in the soil. The easiest way to reinforce a suspended foundation is by using the latter solution and place two supportive steel-beams, one on each side of the original column, see Figure 12.

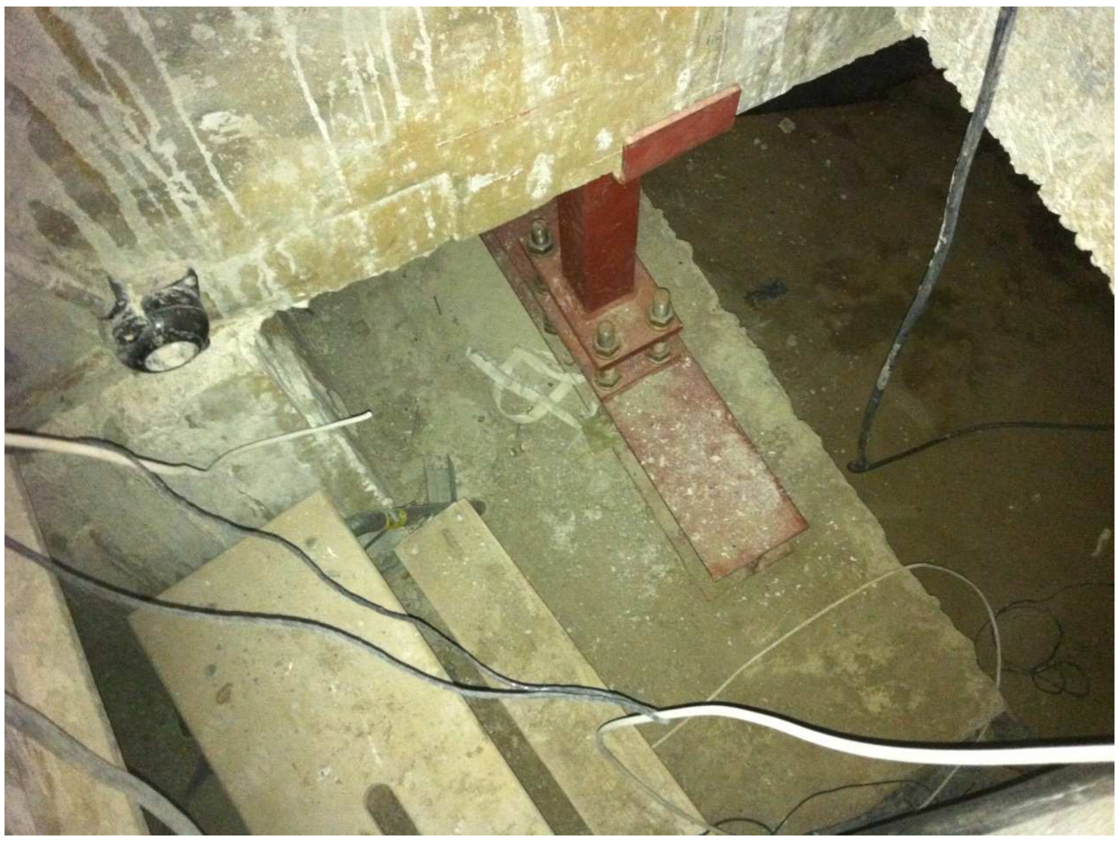

Figure 12 Steel beam supports at a plinth foundation, Fredslyckan

Load-carrying capacity

It is important to make a thorough evaluation of the load-carrying capacity of the bearing walls to see if they can resist the added load. The first examination that should be done is a visual inspection. If the inspector possess adequate knowledge and experience, a visual inspection can be enough. If the object demands further inspections there are a few methods that can be applied, two of these tests are the *Rebound (Schmidt) Hammer Test* and the *Ultrasonic Pulse Velocity Test*. None of these two tests are destructive to the concrete. In order to gather a more reliable strength value it can be necessary to penetrate the surface zone of the concrete. Tests that can be applied when the surface zone is damaged do all measure the force required either to penetrate or to cause a fracture of the object (Illston & Domone

2001). If the survey shows that the load-carrying walls are not sufficient, a strengthening of these walls is considered to be very difficult and therefore also costly.

When increasing the height of a building by adding new storeys, it is important to consider the additional wind-load. Adding a building with two new storeys could make a substantial difference. Since most buildings are built with a bookshelf frame principle (see Section 2.2.1), they can become sensitive for wind on the gable walls. It is important to make an accurate stability calculation to see how the new height affects the wind load. If the calculations show that the building is not stable enough, measures have to be taken. The most frequently used solutions for stabilising a building are with different designs of steel trusses, wind bracings. These braces are then anchored in the building in the form of a cross, see Figure 13.

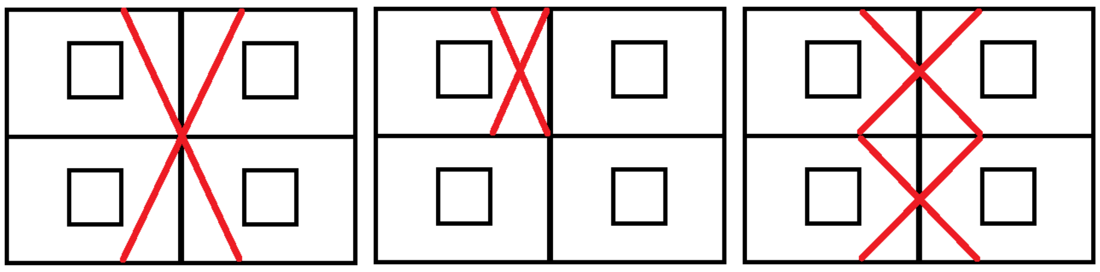

Figure 13 Examples of steel truss crosses and how they can be arranged.

As can be seen in Figure 13, there are numerous of ways and designs that can be used. Which design that suits best is decided by the design of the building. One rule of thumb is that the crosses should not block the windows or door openings.

The idea with this cross construction is to shift the horizontal wind-load to a vertical load. The construction, with help from the inclined trusses, then redirects the loads downwards until they are finally adopted by firm ground. The truss-crosses have to be firmly jointed in to the building. This may not be possible when dealing with precast wall elements. One solution is to attach steel pillars into the wall elements and attach the steel trusses on to them. It is also important to place these crosses all the way down to firm ground to obtain as much stability as possible.

Opening of walls

To make sure that a sufficient load-capacity remains after opening up a load-carrying wall, it is important that the loads are shifted in a proper way. An opening in a load-carrying wall without any precautions will not uphold an adequate load-capacity. The most common solution to allow for new openings is to simply frame the opening with steel beams. The steel frame will then transfer the load, through the load-carrying construction, down to the foundation. See Figure 14. When creating this opening it is important to use temporary supports to prevent the tier from caving in.

Figure 14 Openings of bearing wall to obtain a more spacious layout, Fredslyckan.

Elevator installations

When installing an elevator there are two possible alternatives. Either an elevator is placed inside of the already existing staircase or it is placed outside of the building along the façade. The latter alternative is the most convenient but it is also the least aesthetic as well. It could also cause problem since new ground area has to be occupied. Even though an exterior elevator might be the most convenient solution there are two major drawbacks, described in Section 4.1.

When it comes to an internal solution it is important to examine if there is room for an elevator. A common solution in the original buildings, especially in those buildings without basement, was to place a storage room in the stairway adjacent to the apartment. If these storage rooms are replaced with exterior storage rooms, the space needed for an internal elevator becomes available. If the desirable space is acquired within the original building and a decision to construct these elevators are taken, there are problems that needs to be solved. An elevator is a specious installation and the two major issues both concerns the elevator shaft. The most obvious issue is how the load-carrying capacity is influenced when walls are removed and floors are cut opened. One solution to provide a sufficient substitute for the removed parts is to drape the elevator in a steel truss construction. A solution like this will not only ensure a sufficient reinforcement of the sheer forces but also resist the lateral wind loads that follow when adding stories. The other issue is that an elevator requires an installation pit beneath the elevator shaft. This is a problem since the space for where the excavation takes place might be limited. It might be an even bigger issue depending on the surface underneath the building. Solid ground requires heavy tools and a soft ground requires reinforcement measures in the ground.

Balconies

If the buildings have balconies that are made out of openings in the curtain wall, either exterior or freestanding balconies can replace them. This will lead to both a lower energy consumption and create more living space. Balconies that are installed on the façade do also create a more open impression. How an exterior balcony can be designed depends on the architect's proposal. A common way is to anchor a concrete slab with reinforcement bars that are grouted into the floor slab, but to avoid any extensive cutting in the concrete, other alternatives can be considered. Another alternative is to design freestanding balconies from concrete elements or steel columns that support the balcony slab. Another, slimmer, alternative is to place a steel column inside the façade and then anchor the balcony slab to that column with, for example, a steel strut, see Figure 15.

Figure 15 Inclined steel strut anchors the balcony to the building, Fredslyckan.

Extension approach

A storey-extension can, as described in the section above, be divided into two main categories. One solution is where the apartment layout is maintained and one where the layout is changed. In the latter alternative the new load-carrying walls are placed independent from the original load-carrying walls. The obvious benefit is that the layout can be arranged completely after the demands from the housing market. In order to make a solution like this however, the loads have to be shifted down to the original load-carrying walls. This redirection is easiest made with a beam grid, see Figure 16. In this particular example it is wooden beams that are placed on an existing steel grid.

Figure 16 A wooden beam grid that lies on top of a steel grid (the steel grid is not visible), Fredslyckan.

This grid could then be used for both an acoustic barrier as well as an installation layer for electrical wirings and ventilation system. Another advantage is that openings for staircases can be avoided, if balcony access apartments with an exterior elevator are chosen.

If the layout is the same as the original apartments, the added storey is basically just an extension of the building and the load-carrying walls will be placed on top of the original load-carrying walls. This method is favourable since the theoretical workload will be kept at a minimum. The most obvious drawback is that the new apartments will be accessible in the same way as the initial apartments are. This could be both an economical issue and a design problem, since elevators might have to be installed in the staircases.

When adding storeys especially on slab blocks, it could be useful to utilise the already existing roof slabs and use them as floor in the added apartments, but this is not done without complications. A roof tier is often thinner than the other tiers, since the load and acoustic demands are different for roof structures. In order to make a suitable floor slab, a new slab has to be casted on top of the old one. It is also important to remember that an installation layer with electricity, sanitary drains and ventilation has to be added. A way to create this space is to elevate the floor in the apartment by using non load-bearing wood studs. Even if the load-carrying walls are placed on top of each other, a different layout could be obtained, if openings are made in the walls or create smaller apartments with apartment dividing walls.

Since most of the buildings of 'the Million programme' were built in concrete it would be suitable to continue to build with concrete when adding storeys. However in many cases the ground conditions are too poor to allow further concrete construction. In those cases a lighter construction is more fitting. The surroundings should also be considered since heavy concrete elements demands bigger and more bulky cranes.

Fire safety

It is important to acknowledge that especially concrete and wood have very different fire properties. When choosing a concrete element solution, the concrete itself will be able to withstand the fire due to its fire resisting abilities. This means that the work with isolating the apartment for fire will be kept at a minimum. A wood structure needs a little more attention. A load-carrying wood structure has to be insulated in order to resist both fire and acoustics. In order to do so, these walls tend to be very thick. Wall sections consisting of a framework with double wood girders and three layers of gypsum are not unusual.

When constructing the installation layer, it is absolutely vital that this layer is divided into fragments to prevent fire from spreading underneath the apartments and destroy the entire building, see Figure 17.

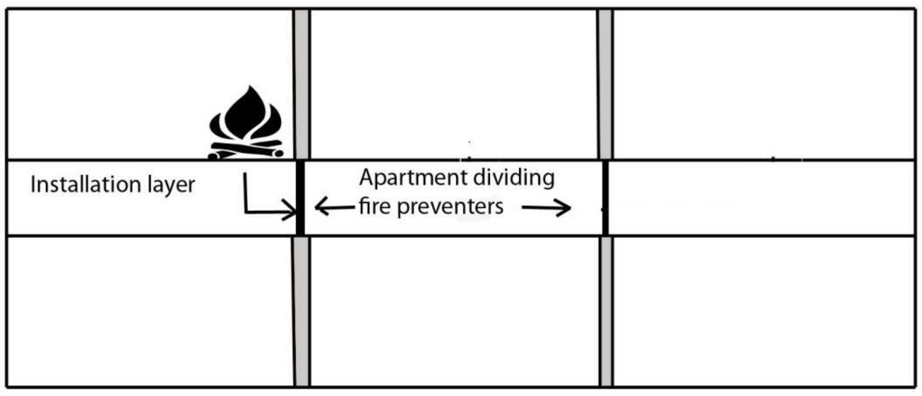

Figure 17 Simplified section of an installation layer with fire preventers.

This is easily avoided if the concrete elements are anchored to the floor slab. The installation floor will then be installed individually in between the concrete elements, which then act as fire preventers. A more problematical solution is the beam grid, where empty spaces exist inside of the grid. It is of great importance that fire preventers are installed when installing such a beam grid.

Another, more general problem with the fire resistance concerns insufficient fire insulations, especially at the roof trusses. If the trusses reaches out too far from the façade they could become a fire hazard, since they will act as a funnel for the fire. It is extremely important to insulate these parts properly and also to consider the placement of the trusses to avoid a collapse of the entire roof structure. The trusses should be placed on each side of a load-carrying wall, see Figure 18.

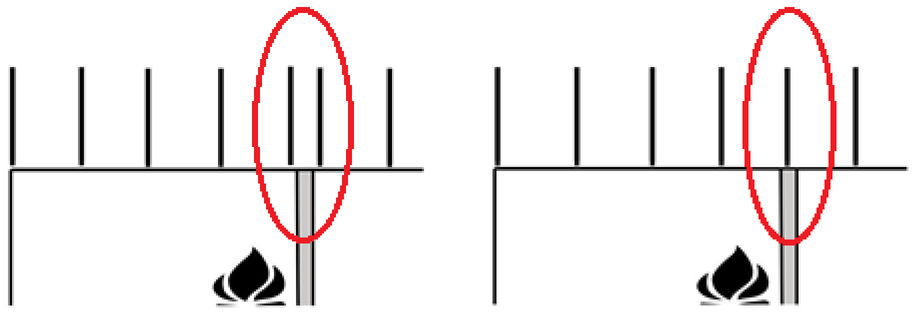

Figure 18 Simplified section of a proper truss arrangement to the left and a poor arrangement to the right (Järphag 2011).

Another issue to consider is reckless usage of the apartments from the tenants. Inside of every apartment a fire-resisting layer, which main purpose is to delay the fire from reaching the structural frame, is applied. A big reason for many fire disasters and the damages they cause are that people install spotlights etc. without knowing that they penetrate the fire-resisting layer. To avoid this kind of situations it is important to perform regular inspections at the apartments. It could also be avoided by the material selection, when erecting the building.

Other problems

The biggest difference between a renovation with a storey extension and a new construction is the situation concerning the tenants. The best scenario for both the tenants and the construction workers is that the tenants are placed in temporary homes during the renovation project. There are social aspects involved, since renovation activities tend to start in the morning and tend to be very noisy. On the other hand, if the tenants stay. There will be interference with the accessibility for the project, since staircases and hallways have to be kept clear.

If a storey extension is decided, even though the original building does not need a complete renovation, it is of great importance that the process is rationalised as much as possible. This is done by planning the construction process in order to erect the extension as effective as possible, this with regard to the tenants. It is important to invest economic resources in both labour and technical solutions to make every sequence of the erection as fast as possible. At large construction sites, that involves multiple or large buildings it can be beneficial to perform the addition in phases. By doing so the problem with the relocating of the tenants is reduced and the construction process can be rationalised further due to the repetitive nature of the phase process.

Another important issue with storey extension is the importance of keeping the work site dry. This is revealed when the old roof structure is removed and the roof tier is exposed. It is therefore vital to protect the building from weather and wind during any storey extensions. One way of doing this is to use tarpaulins, which are a cost effective alternative. This method has many downsides, as it demands extra labour with covering and uncovering the building every day. This leads to longer project times and therefore also extra expenses. A better alternative is the use of a large construction tent that covers the building. This may be a costly alternative, but there are many positive effects so the cost will not be vital. The tent guaranties that the building will be kept dry and that relative moisture content and temperature even can be regulated. This governs a normal construction rate, even during winter. The biggest advantage is probably that the concrete harden at a normal speed throughout the entire year, which will shorten the construction time.

An adequate sound environment is important in multi-residential buildings. Concrete structures insulates well against sounds even without any extensional insulation. The roof slab however is, as mentioned in Section 4.1, made for neither sound insulation nor additional loads. The solution to this problem is to grout an additional layer of concrete on the old roof slab in order to get a slab that can fulfil the sound isolating demands that apply today. The acoustic demands apply, even if the new storey is made out of wood. The acoustic demand along with the fire restriction can easily make the wooden walls very thick. This is not desirable but is necessary to meet the demand.

5 Work process

In Chapter 5, the problems and the proposed solutions in Chapter 4 are presented in an order recommended as a work process. This work process is developed to be a tool for structural engineer that lacks experience and as a reference guide for designers with more experience.

The work process is built up by different steps that are presented in descending order according to the author’s suggestion on how to attack a storey extension problem. The process is also compiled in a checklist that together with this report can be used as tools see Appendix D. A flowchart that illustrates the process is also presented, see Figure 19.

Step 1, Conditions

The first step is to identify all initial conditions involved in the project. The conditions can be divided in to four general types of conditions: conditions regarding the existing building, regulations, requests and other issues.

The initial conditions regarding the existing building are focused on the status of the building and the surrounding area. It is vital to establish how well the building could adapt a storey extension and which solutions that are possible with regard to the existing building. The first thing that needs to be done is to establish what kind of documentation there is regarding the existing building. Are there any original blueprints of the involved elements such as the foundation, the façade and the foundation? This documentation will act as a first indication whether a storey extension is possible at all.

A survey of the existing building and its surroundings should be considered as a demand. Even if blueprints exist it is important to make sure that those blueprints still are up to date. Have there been any modifications on the structure? Is there any damage on the load carrying structure? Those the locations of the load carrying walls coincide with the blueprints? It is also vital that an external survey is performed, not only to examine the foundation, but also to recognize the logistic conditions. Are there any place for a tower crane and available areas to store material?

These surveys are preferably performed by, or under supervision of, experienced designers and geologists

Regulations involve those rules that might affect an extension of the existing building. These regulations can be found at the local Housing and Building department. The regulations that might influence the storey extension are if there is a maximum building height within the city and if there are any esthetical themes, like colours or shapes, which need to be followed.

These regulations might also affect the environment of the building. One typical problem is with regards to parking lots. Each city has its own regulations regarding how many parking lots every apartment must have. If the extension results in to many new apartments, there might not be any space available for new parking lots.

The conditions that involve requests are those conditions that are provided by the client. The client together with the architect has come up with a proposal where the number of new storeys, apartment layouts and desired building materials are defined.

Other issues are those conditions that need some calculations and where external contractors with special knowledge need to be advised.

The balcony solutions are delivered as completed prefab elements. It is therefore the manufacturer of the balcony slab that designs both the slab and the balcony connection. However, the load that is added by the balcony slab needs to be considered by the structural engineer when designing the load carrying elements.

The elevator demands a rigid elevator shaft. This shaft is created by a steel frame structure in which the elevator is installed. When installing an interior elevator, holes in the existing concrete slabs needs to be cut opened. Calculations on the affected floor slabs, and their strength and precautions in order to maintain the strength, needs to be developed. The elevator shaft has to be installed in an elevator pit. In order to create this pit, a hole needs to be opened in the bottom slab as well. Reinforcements in the soil beneath the bottom slab might also be necessary to avoid settling which can put the elevator out of function.

Another condition that characterizes the construction design is the fire safety requirements. As mentioned earlier in the report, every apartment should be considered as an individual cell that has to resist fire for either 60 or 90 minutes depending on the height of the building. This in manly a problem when designing a wood construction since they tend to get very thick walls in order to meet these requirements. Roof trusses and installation layers are also affected by these fire safety requirements see Section 4.1.

Step 2, Load distribution

Step 2 is only considered if the client desires a different apartment layout for the new apartments. If so, this will be a problem if the new load carrying walls do not coincide with the already existing load carrying walls. It is important that the new loads are redistributed in a sufficient way, which is discussed under extension approach in Section 4.2. This step can be excluded if the load carrying walls are placed on top of the original load carrying walls.

Step 3, Calculation of cumulative loads

Step 3 is where the actual design work begins for the structural engineer. A calculation of the cumulative loads acting on the original building and on the bottom slab is made. It is preferable to use a 3D-dimensioning program where a sketch of the building is initially drawn. When the sketch is done, the loads are applied to the drawn building according to the Eurocode. It is important that all loads are considered in order to get a realistic value. Examples of loads are partition walls, installations, snow loads, façades, own weight, etc. It is also important that critical points on the structure, such as holes in the slabs, snow pockets and short slab supports, are identified. These are also applied according to Eurocode. After applying the loads and the identification of the critical points is made, the calculations process can start. This can be done by hand but is best done in the same 3D-dimensioning program. After this procedure is done, the loads acting on the different part of the building are given.

Step 4, Evaluation

When the load calculation is done, a brief evaluation of the project should be made. This evaluation serves as a clearance to advance with the project and it is the calculations from the previous step that underlies this evaluation. Can the building withstand an extension or are reinforcements needed? If reinforcements are necessary, to which extent are they needed and do they fit with in the budget? The evaluation should be done in consultation with an experienced designer and its main purpose is to make sure that time is not spent unnecessarily.

Step 5, Foundation

From the cumulative load calculation made in step 3, the foundation slab is checked if it could resist the new loads. It is important that the preliminary examination of the building is properly done in order to get necessary information about what kind of foundation the building stands upon and in what state the foundation is in. If the foundation is reinforced with piles, a geotechnical engineer should be consulted in order to get an accurate calculation. Concrete slabs and plinth foundations can be calculated with the blueprints and visual inspections. If the calculations show that the foundations are not strong enough, sufficient reinforcements need to be made. These reinforcements can be both expensive and problematic and must therefore be consulted with the client or structural engineer manager depending on the economical agreement.

Step 6, Stability

A building subjected to wind loads must be designed with respect to the global overall stability but also the local horizontal stability of each storey consisting of walls and floor slabs. The walls transfer the horizontal loads down to the slabs, the floor slabs then transfer the load down to the walls on the storey beneath until the loads reaches the foundation. This means that stability is becoming increasingly important to control the higher the building gets as the horizontal loads will increase with height.

The stability of a building can be checked with built in functions that exist in certain design programs. If such a program is not available then the horizontal capacity in the walls, floors and the attachment between them should be checked individually. When dealing with stability control it is important to consider imperfections, therefore second order analysis should be performed. Phenomena as tilting should also not be forsaken when checking the stability.

Step 7, Columns and load carrying wall capacity

In the last two steps, step 7 and step 8, the load carrying capacity of the pillars and/or the load carrying walls are checked. The procedure is the same as in step 5 where the capacity is compared with the cumulative load calculation from step 3. The capacity is controlled for the new parts as well, but it is absolutely necessary for the original elements. If the capacity is not sufficient, reinforcement measures need to be made. If these reinforcements get too problematic it might be necessary the change the initial condition in order to create lighter load. If so, this needs to be cleared with the client. When controlling the columns and the load carrying walls, one should also check for punching problems where loads are concentrated on a small area on the slab tiers.

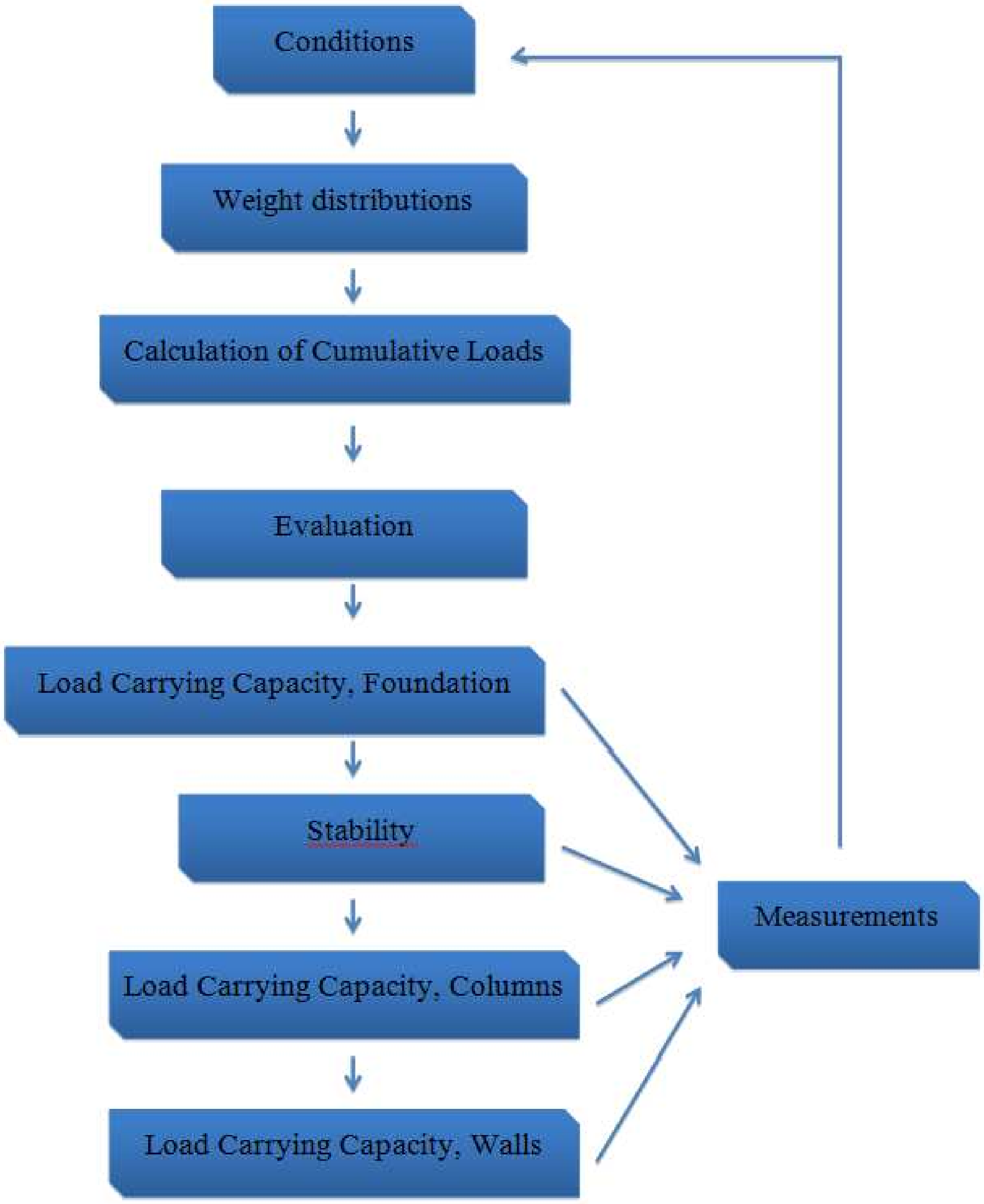

Figure 19 Flowchart illustrating the recommended procedure.

6 Case study of a Million Programme building

In the previous chapter a proposed process has been presented. In this chapter, that process and the associated checklist will be tested on a typical building from the 'the Million programme'.

'The Million programme' is usually characterized by large and tall apartment buildings, even though most of the apartments built during those years actually were much lower character. Therefore the authors have chosen to study a building that is three stories high, this due to two reasons. First, as many of these apartment buildings are located in more central parts of the cities that experience severe housing shortages and therefore are in need of refurbishment and extension. Second, as many of these types of buildings are built with element methods that are very similar, they are easy to categorize.

The most common frame systems for element built apartment blocks are summarized in a number of journals from this period. Gösta Andersson has made a compilation ('*Elementbyggda flerfamiljshus* samt *flerfamiljshus med stomelement av betong'*). This compilation published in '*Byggmästarn'* volume 6 from 1967 and 1968. To verify the model and the way the structure is carried a report from '*Byggforskningsinstitutet, Inventering av stomsystem för elementbyggda flerfamiljhus'*, was used. In this report a number of different attributes from different element methods are listed. These tables can be found in appendix A and B

6.1 Conditions

This part of chapter one will present the conditions that are given for the evaluation of the chosen structure.

6.1.1 Case structure

To make an evaluation, of the load-carrying capacity and other structural measurements such as elevators, staircases and balconies of a typical 'Million programme' building, a fictive representative building has been developed. The building is based on *Göteborgsbostäders* system *Bygg-Tema*, this is because the system represents both 'The Million programme' buildings purely structural and also Gothenburg's housing market from that time period (Johansson 2008).

The fictive building, seen in Figure 20, is a three-storey slab block building with 2500 mm high wall elements. On these wall elements there are reinforced slabs with a thickness of 200 mm (Byggforskningen 1968). The total storey height will therefore be 2700 mm. As the building consists of three storeys the total height of the building becomes 8100 mm exclusive of the roof. The outer and the inner apartment dividing walls are load bearing, built upon non reinforced concrete walls, all according to the *Bygg-Tema* method. These load-carrying elements have a thickness of 180 mm, this is also according to the *Bygg-Tema* method (Andersson 1968). The non-load-carrying walls, which only functions as room dividers, consist of precast lighter wood elements.

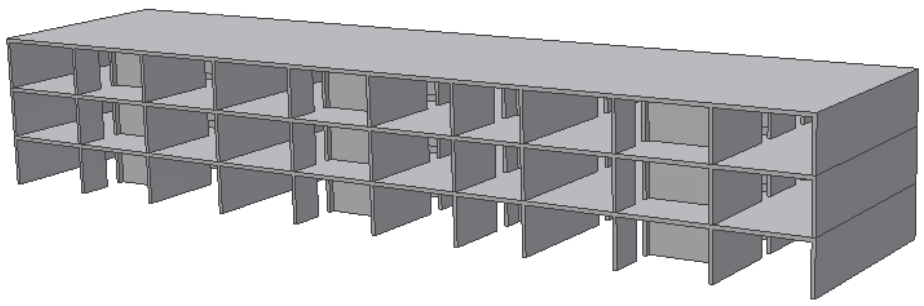

Figure 20 3D-model of concrete frame.

The floor plan consists of three uniform lamellar divided into two apartments each with two rooms. To get two apartments with three or four rooms an extra lamellar consisting of two large rooms have been added as seen in Figure 21. The apartments are dimensioned after the 3M-method. This was a popular dimensioning method during the 1960's and indicates that every centre-line distance is evenly divided by 300 mm (Andersson, 1968). This is a very fortunate building as the spans between the load-carrying walls are short and there are load-carrying walls in two directions that indicate a stable building.

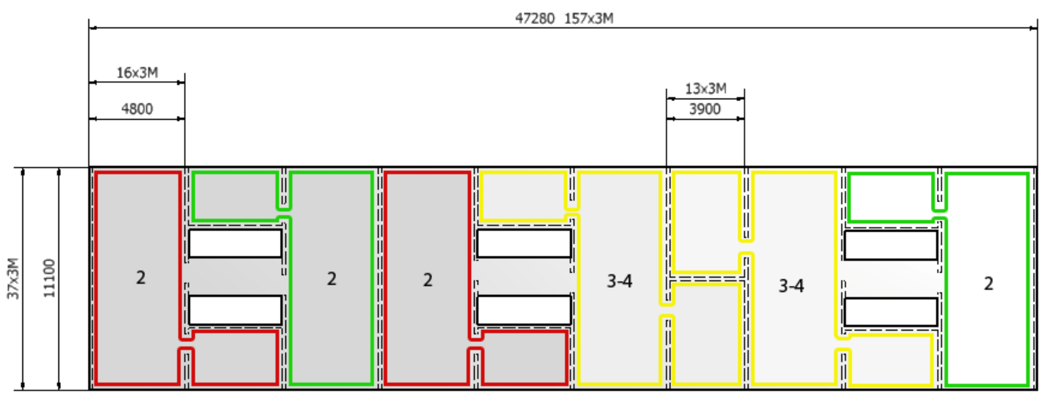

Figure 21 Plan arrangement for the fictive structure, the openings are made for the staircases. The numbers represent the number of rooms in each apartment.

6.1.2 Ground conditions

The building is founded on edge and ground beams of concrete with the width of 1 m and the thickness of 0.3 m with the reinforcement ϕ12s150 according to drawings on the original building. The strength class for the concrete is assumed to be C20/25 as this is a common and low strength concrete especially for foundations. A geotechnical engineer has done a ground investigation. The outcome of that investigation was that the soil consists of moraine that has a ground capacity of 200 kPa and that the ground beams are located 0.5 m beneath the surface. Also the ground water is located 10 m below the ground level.

6.1.3 Regulations

The existing building permit only allows an addition of one extra floor according to local regulations. This floor also needs to correspond to the rest of the building.

6.1.4 Requests

The request from the client is that the added storey has the same plan arrangement as the existing building. This is because those kinds of apartments are suitable for the area. Another request is that the added storey has a concrete frame so that the added storey has the same appearance as the existing building. A concrete frame can also be suitable if it in the future would be possible to add another storey as it is expected that the area will have a housing shortage also in the future. If it turns out that it is not possible to use a concrete frame for the added storey it should be tested with a wooden frame.

The balconies on the added storey should be the same size and be located at the same location as the balconies on the existing building. As the building after the addition will be four stories high an elevator needs to be installed. There is no space inside of the existing building therefore the elevator needs to be installed outside of the building. This means that the elevator will be located outside of the existing building and the added storey needs to be equipped with an access balcony to meet the accessibility rules.

6.2 Calculation of loads

To be able to analyse whether or not the existing building has adequate load-carrying capacity one first has to compile the loads that are acting on the structural members. For this building the programme 3D-structure from Strusoft will be used. In this programme a 3D-model of the existing building with the added storey is compiled as seen in Figure 22.

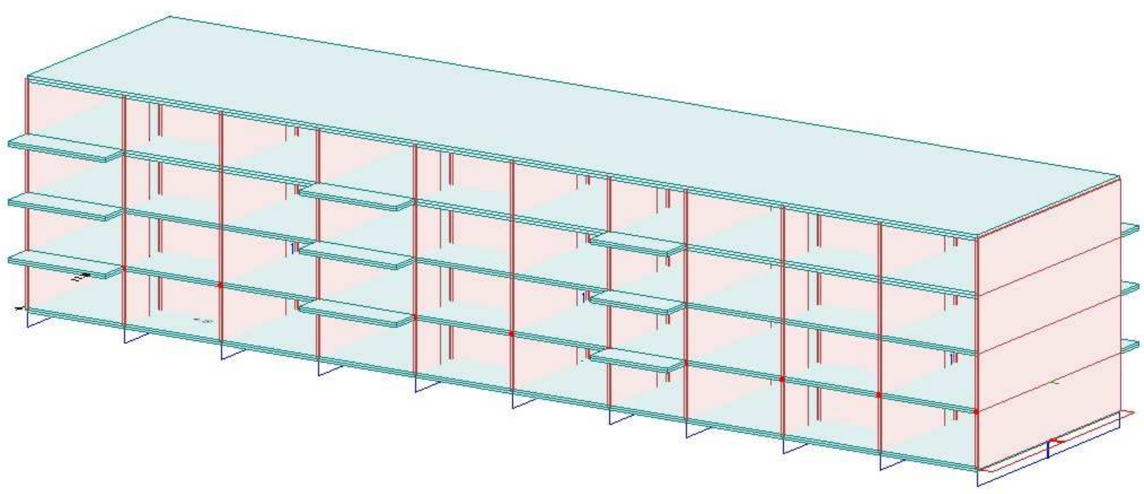

Figure 22 3D-modell of case-building with added storey

When the 3D-model has been created the next step is to add loads according to Eurocode and the national standard. The loads that will affect the case building can be seen in Figure 23. The values and the source of the loads can be seen in Table 1.

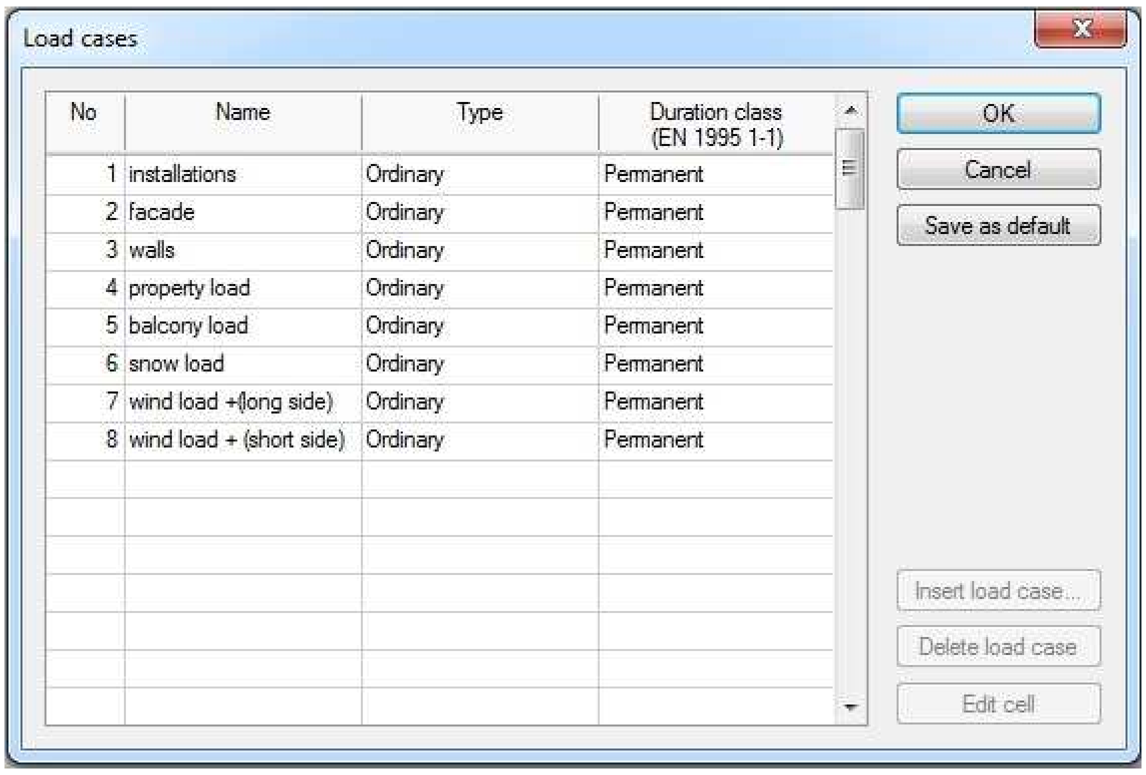

Figure 23 Loads that will affect the case structure

Table 1 Size and psi-factor for the loads affecting the case building

Load	Size	Ψ-factor (EKS 8)	Source
Installations	0.2 kN/m^2	Dead load	Experience value
Façade	12 and 1.5 kN/m	Dead load	See appendix F
Walls	0.5 kN/m^2	Ψ_0=1.0 Ψ_1=1.0 Ψ_2=1.0	SS-EN 1991-1-1
Property load	2.0 kN/m^2	Ψ_0=0.7 Ψ_1=0.5 Ψ_2=0.3	EKS 8 table 6.2
Balcony load	3.5 kN/m^2	Ψ_0=0.7 Ψ_1=0.5 Ψ_2=0.3	EKS 8 table 6.2
Snow load	1.2 kN/m^2	Ψ_0=0.6 Ψ_1=0.3 Ψ_2=0.1	See appendix G
Wind load	See Appendix H	Ψ_0=0.3 Ψ_1=0.2 Ψ_2=0	See Appendix H

After the loads have been created and given a value it is time to tell the program where the loads should be placed. The location that was given the loads on the case building can be seen in the Figures 24-31, the loads are marked in red. It is shown that the loads vary somewhat in how they appear. Installation, wall, property, balcony and snow load are all surface loads. Whilst the façade and wind load can be considered as line loads and these loads also have different values depending on where they are located. The wind load gets a higher value as the building gets higher whilst the façade load has a different value depending on the material of the façade, for the case building the façade on the balconies have the value 1.5 kN/m^2 whilst the load on the floor slabs have the value 12 kN/m^2.

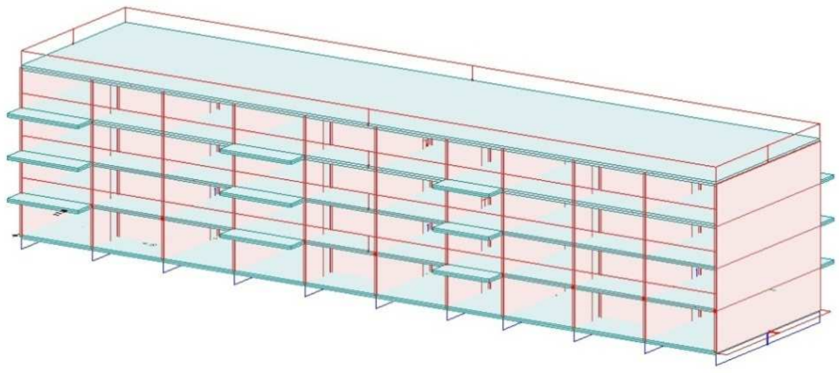

Figure 24 Installation load

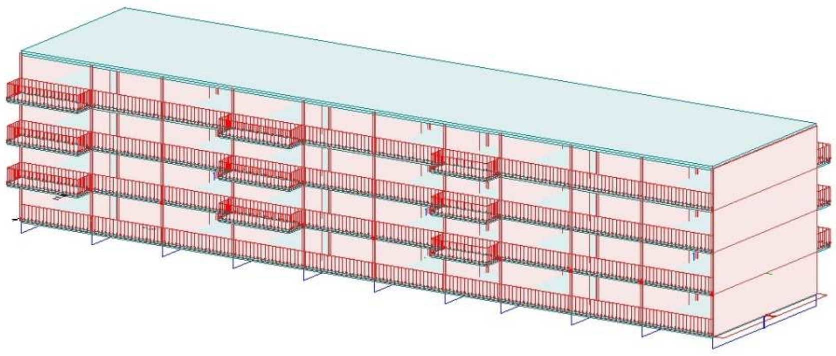

Figure 25 Facade load

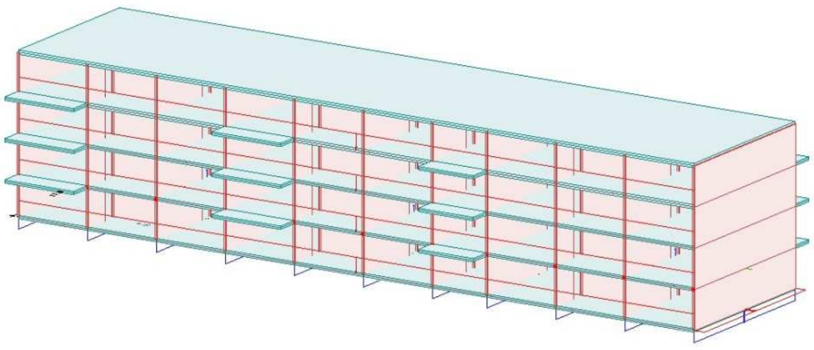

Figure 26 Wall load

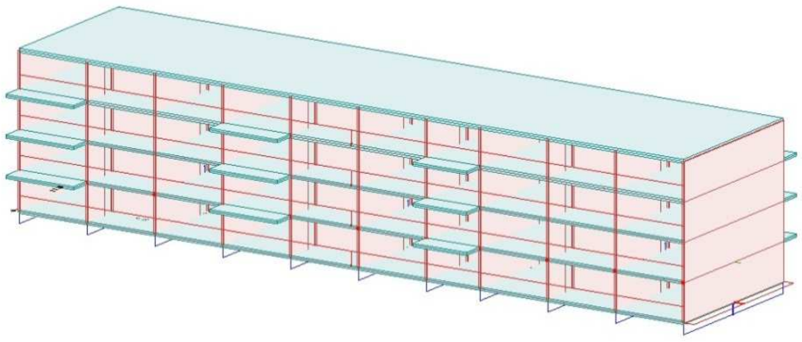

Figure 27 Property load

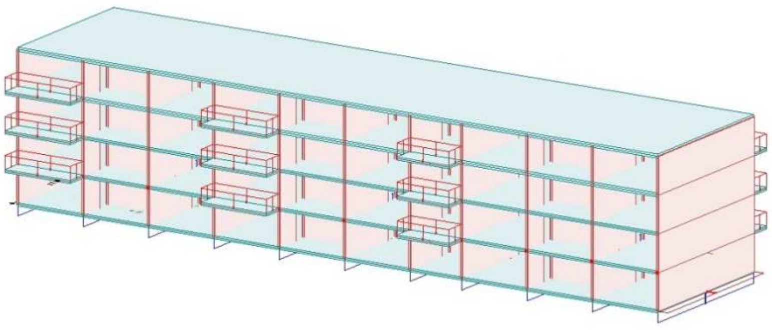

Figure 28 Balcony load

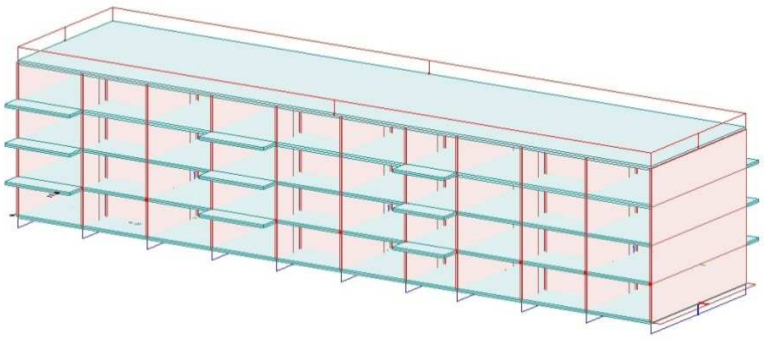

Figure 29 Snow load

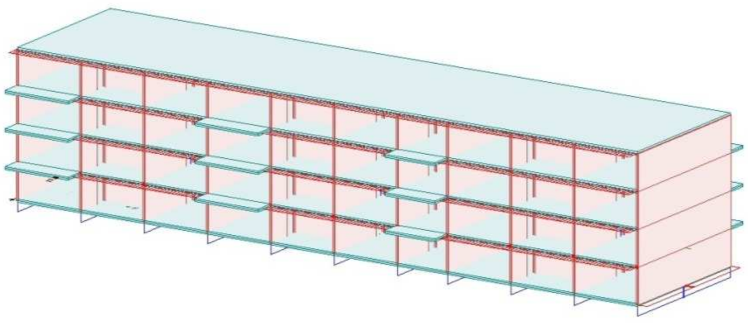

Figure 30 Wind load (long side)

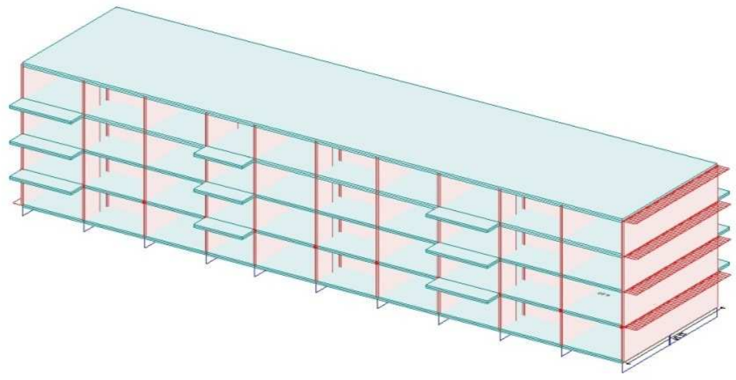

Figure 31 Wind load (short side)

After the loads have been given the value and their location, load combinations need to be selected. For the ultimate limit state the used load combinations are 6.10a and 6.10b according to EKS 8. For the serviceability limit state 6.15b is used, this is also according to EKS 8, Ψ-factors according to table 1. See Figure 32.

$$\begin{cases} \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} \psi_{0,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10a) \\ \sum_{j\geq 1} \xi_j \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10b) \end{cases}$$

Where :

"+ " implies "to be combined with"

Σ implies "the combined effect of"

ξ is a reduction factor for unfavourable permanent actions G

$$\sum_{j\geq 1} G_{k,j} \text{"+"} P \text{"+"} \psi_{1,1} Q_{k,1} \text{"+"} \sum_{i>1} \psi_{2,i} Q_{k,i} \quad (6.15b)$$

Figure 32 Load combinations 6.10a, 6.10b and 6.15b according to Eurocode

The next step when calculating loads and doing it in a calculation program, such as this, is to generate the FEM-mesh. See Figure 33.

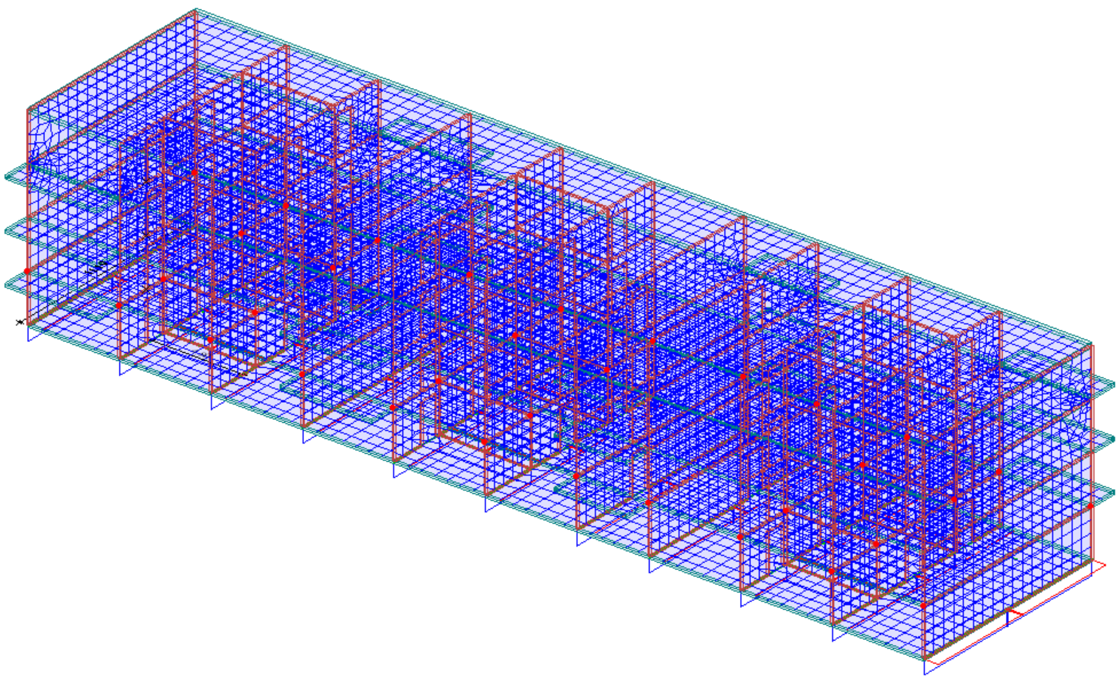

Figure 33 FEM-mesh of case building

After the mesh has been generated the next and last step is to perform the analysis to get the loads acting on the ground and the rest of the load-carrying frame. For the case building the only load-carrying part that is interesting apart from the ground is the walls on the first floor, as the walls have the same dimensions in the whole existing building. The dimensioning load combination for the case-building was 6.10b when the property load is the main load. For the loads acting on the ground see Figure 34, for the loads acting on the walls on the first floor see Figure 35.

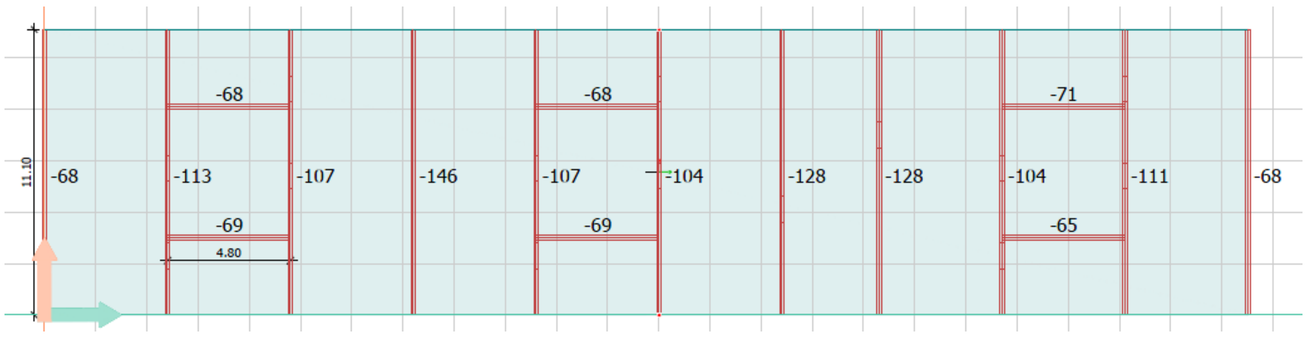

Figure 34 Loads acting on the ground in kNm, load combination 6.10b with property as main load and the wind acting on the longside of the building.

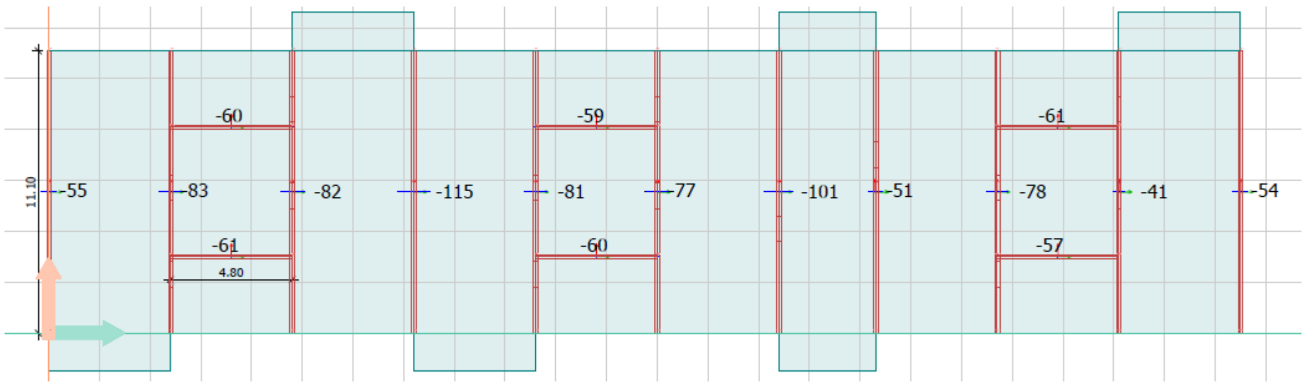

Figure 35 Loads acting on the walls on the first storey in kNm, load combination 6.10b with property as main load and the wind acting on the longside of the building.

Now the loads acting on the structure have been generated and the calculation of loads is completed.

6.3 Evaluation

The conditions and the results from the load calculation are presented for an experienced engineer. This engineer concludes that the loads acting on the case structure are reasonable and it is motivated to perform more detailed calculations to confirm that the building can handle extra storeys.

6.4 Load-carrying capacity, Foundation

From the load calculation the loads on the ground have been given. After a quick analysis of Figure 34 it is clear that the largest load is 146 kNm see Figure 36.

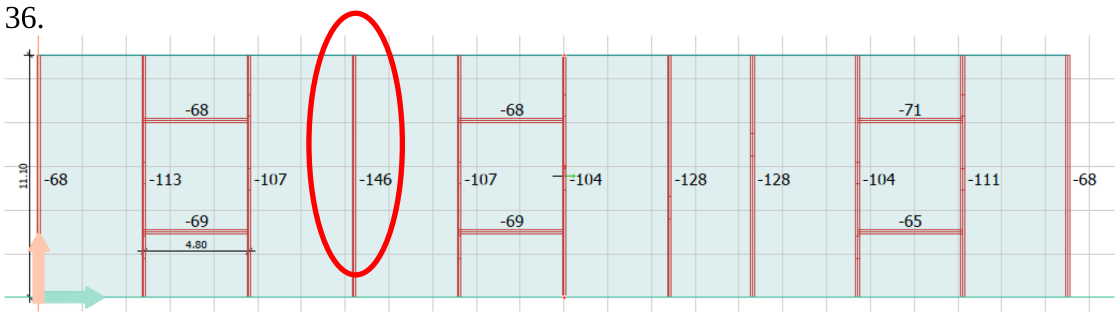

Figure 36 The largest load acting on the ground

This is the load that is dimensioning and is used to check if the ground and the ground-beam have sufficient capacity. The program that will be used for this calculation is the program Foundation from Strusoft. A few assumptions for the input have to be made because all information is not given. The important thing is to stay on the safe side. For the concrete the exposure class was chosen to XC4, life class to L50 and Strength class to C20/25 see Figure 37.

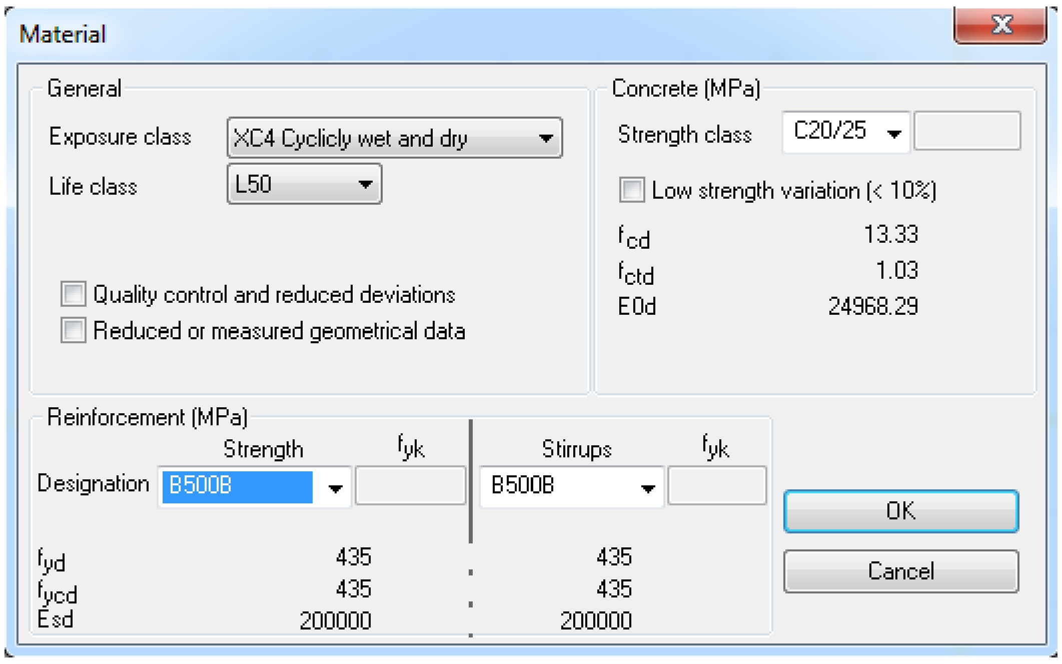

Figure 37 Material input for the ground-beam

For the reinforcement a range of possible diameters are tested, from ϕ10 to ϕ16 the top, bottom and side cover are according to Eurocode see Figure 38.

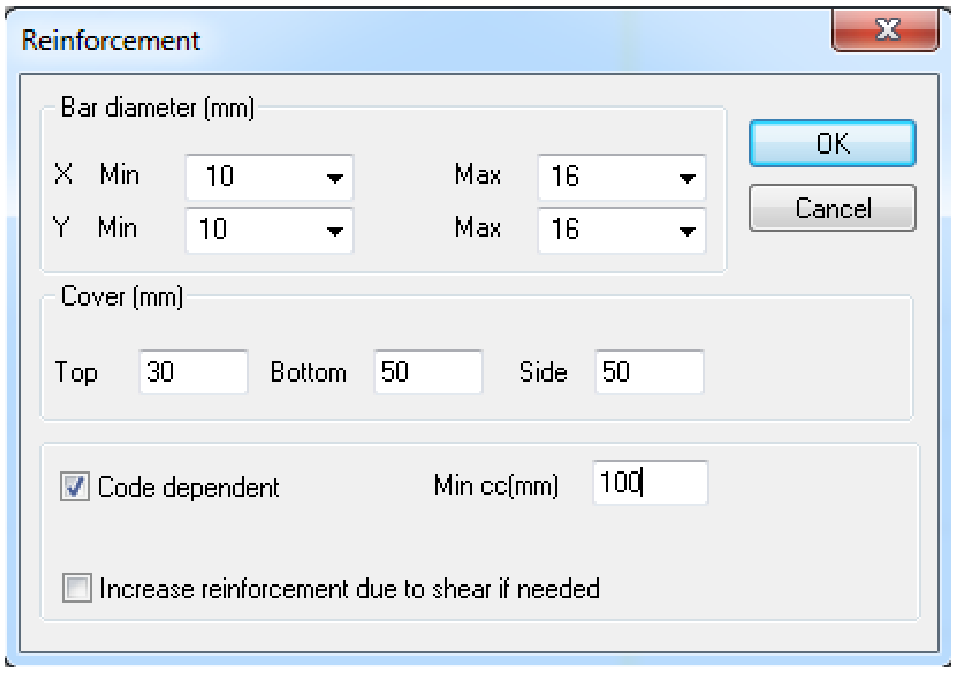

Figure 38 Reinforcement input for the ground-beam

The geometry of the ground-beam and the wall above is given in section 6.1.1 and 6.1.2. These measurements are inserted into the program see Figure 39.

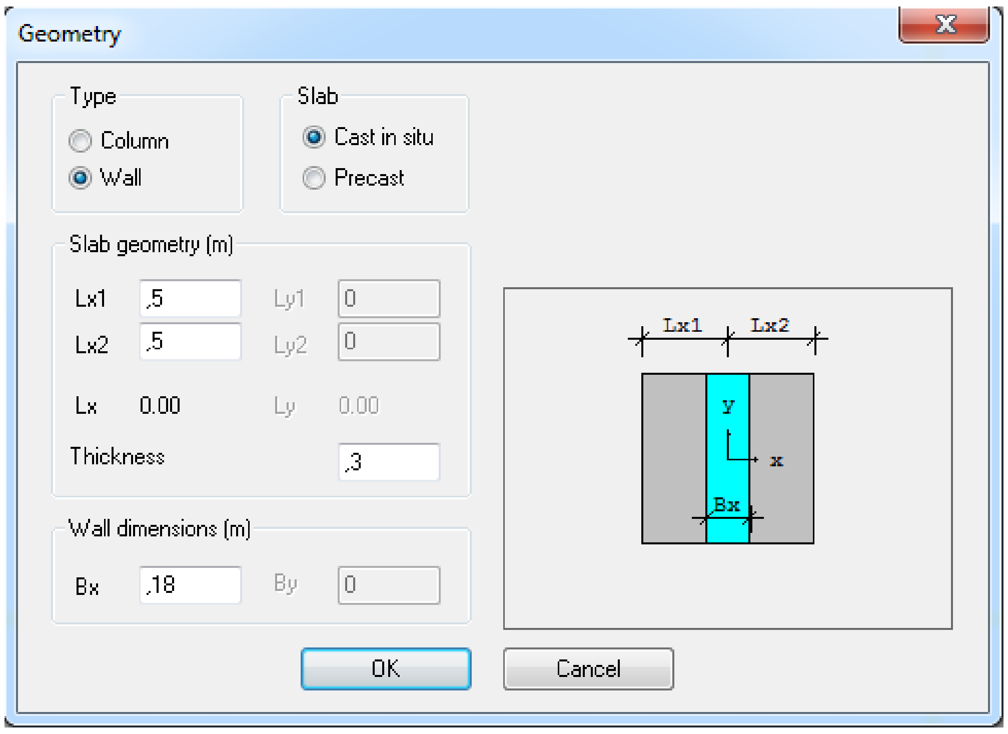

Figure 39 *Geometry of the ground beam and the wall above it.*

The ground properties are given from the geotechnical investigation described in section 6.1.2, these values are also inserted into the program see Figure 40. The partial resistance factors are given the value 1.0 to be on the safe side. The foundation depth is set to 0.8 as the ground beam has the thickness 0.3 m and the ground beam is covered with 0.5 m soil. The ground water is 10 m beneath the ground according to section 6.1.2. The density of the moraine is 18 kN/m^2 and moraine is cohesionless.

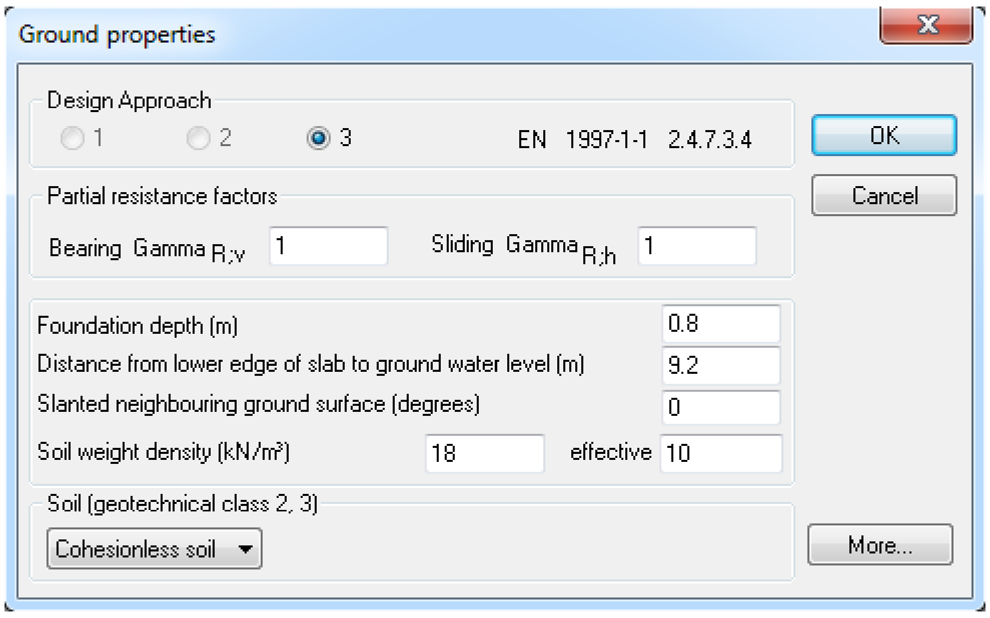

Figure 40 *Ground properties for the case structure.*

The load input for the program is taken from Section 6.2. The largest load acting on the ground was 146 kNm and that wall was 11.1 m long this gives a value of 13,15 kN/m that is rounded up to 14 kN/m see Figure 41.

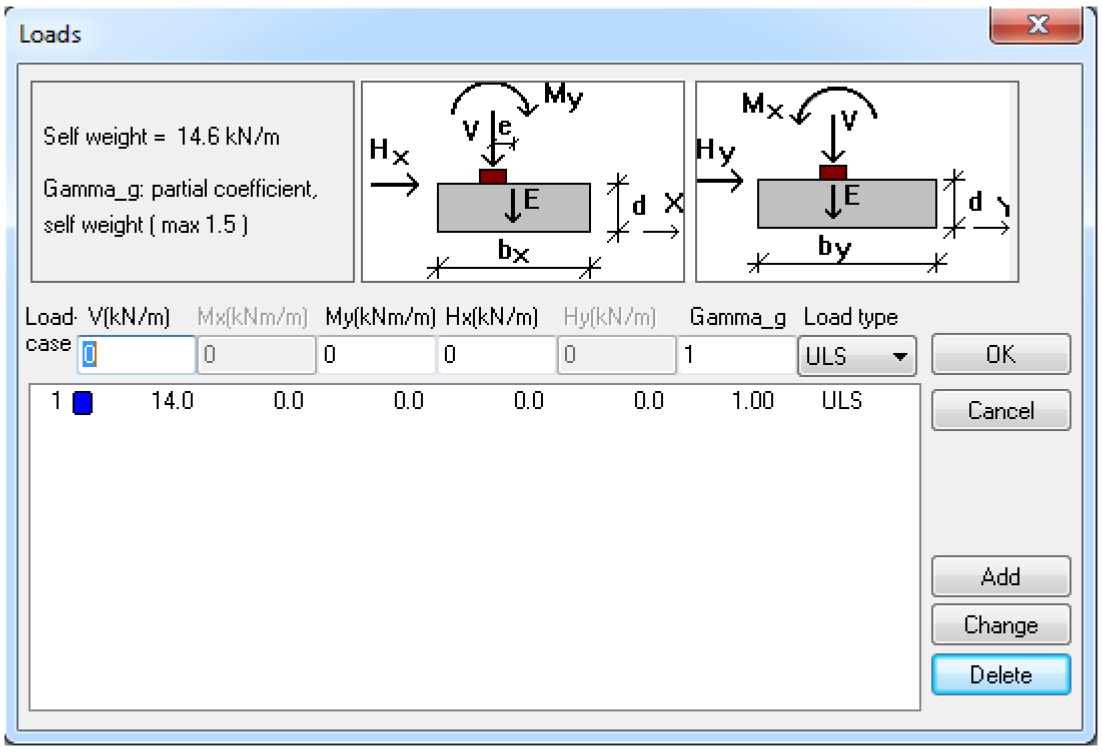

Figure 41 Loads acting on the ground beam

The calculation is performed and the result is that the ground pressure becomes 28.58 kN/m^2 which is well below the capacity of 200 kPa. The reinforcement for the ground beam needs to be ϕ10s200, see Figure 42. This is less reinforcement than ϕ12s150 that was the current reinforcement in the ground beam according to Section 6.1.2.

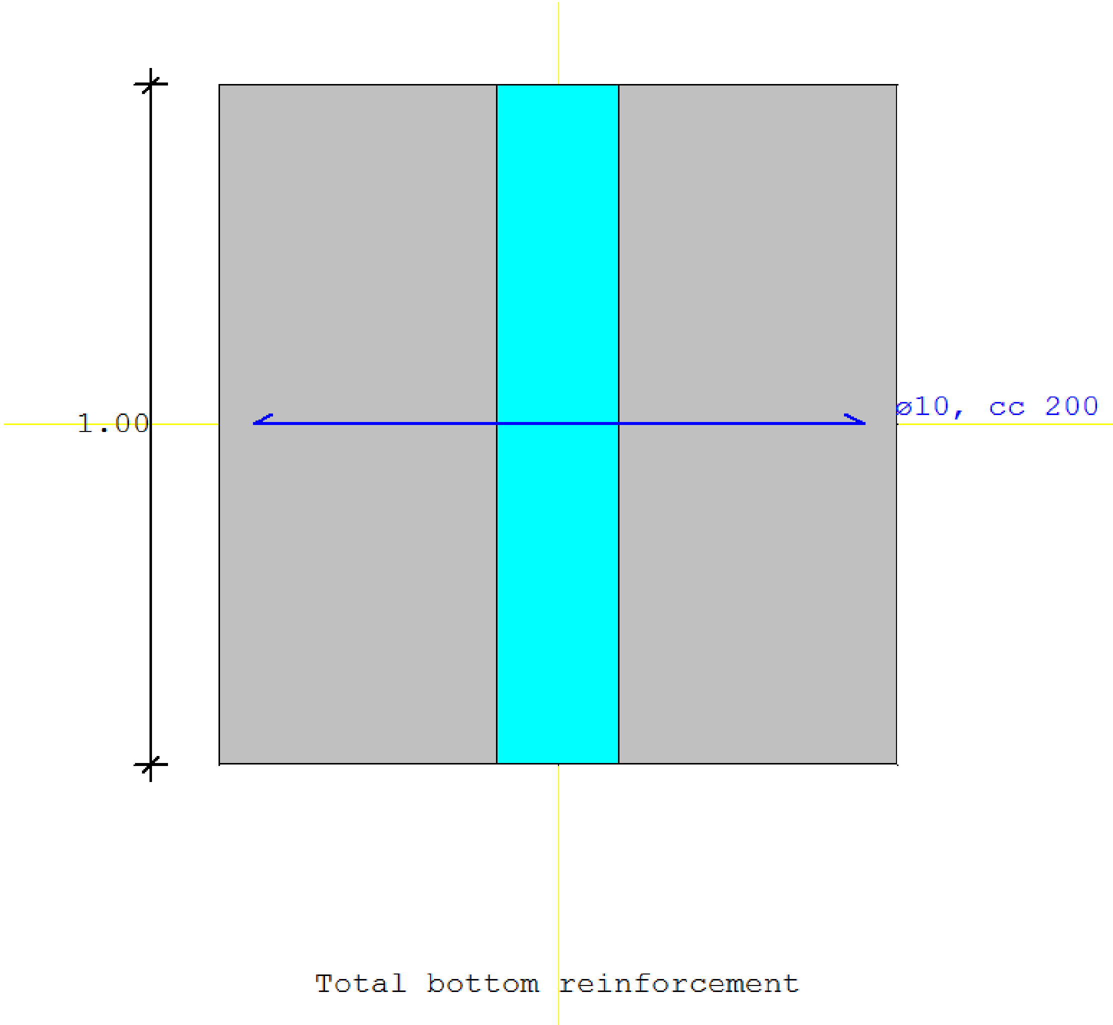

Figure 42 Total reinforcement for the ground beam after calculation

6.5 Stability of structure

The stability of the structure needs to be checked. For this case, FEM-design will continue to be used. In FEM-design there is a function called stability analysis which analyse the global stability of the structure. The results of a stability analysis will give the global buckling mode shape and the critical parameter. In order for the global structure to be stable, the critical parameter must be more than 1. But the developers of the program recommend that the value should exceed 5(Strusoft , 2011). At the first glance at the case building it can be guessed that it will be very stable because of the many load-bearing concrete walls. The program also shows that this is the case as the critical parameter for the worst case is 55,467, see fig 43.

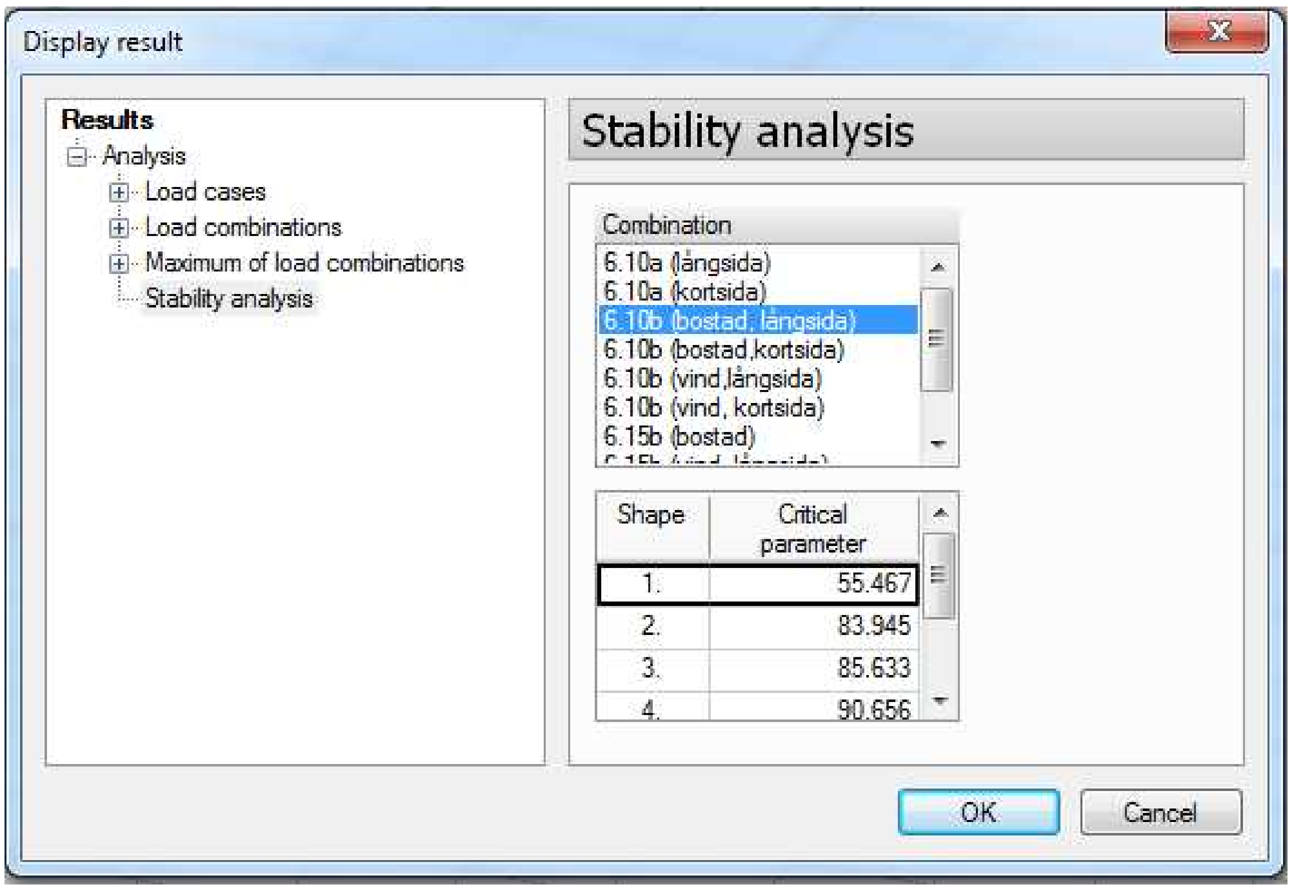

Figure 43 Stability analysis results

6.6 Column capacity

The case building does not have any columns so the column capacity will not be needed to check.

6.7 Wall capacity

The frame of the case building consists of many load-bearing concrete walls. The concrete walls that are important to check are the concrete walls on the first floor as these walls will be affected of the highest load. As mentioned earlier in this report the concrete walls in this building have none or very little reinforcement. This will affect the calculation of the load-bearing capacity of the walls.

First step is as always to determine how high the affecting load is. In figure 35 the loads acting on the walls are visualised and from this it is clear that the largest load on a load-bearing wall in this case is 115 kN/m see figure 44.

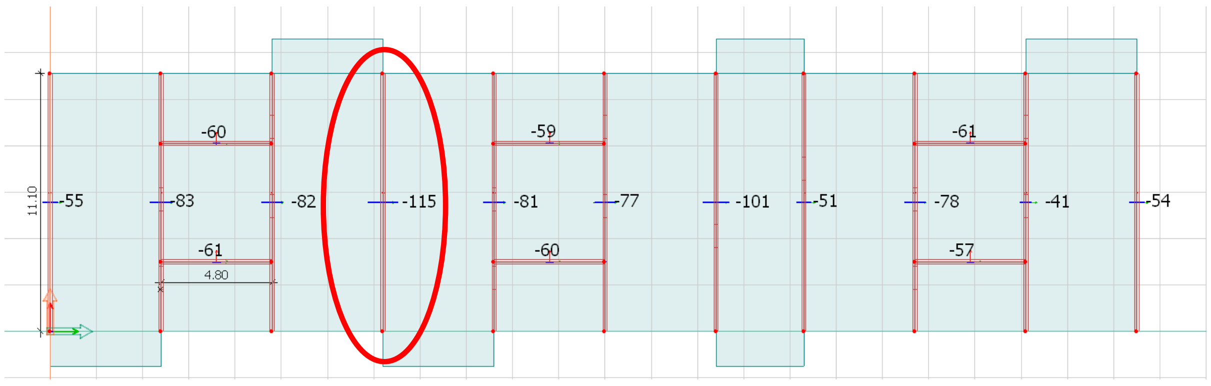

Figure 44 The largest load acting on a single wall

The walls of this building were 18 cm thick and the concrete that was used was C20/25. This gives that the wall affected with the highest load has a utilization rate of 29%, for calculations see appendix D.

6.8 Compiled results

Table 2 Compiled results of case building.

Part	Existing	Needed/Utilization	Result
Ground	Slab 1*1*0.3m Reinforcement ϕ12s150	14.5% of ground capacity Reinforcement ϕ10s200	Ok
Stability	-	9%	Ok
Load-Bearing walls	0.18 cm thick no reinforcement	29%	Ok

7 Discussion

Between the years 1965-1975 one million newly produced apartments were built in Sweden in order to solve the increasing need of residents. This project became known as ‘the Million programme’. These houses constitute a major part of the Swedish housing market and are in severe need of renovation due to their age. Meanwhile urban areas in Sweden are lacking of apartments. A combined solution of these problems is to add storeys during renovation of buildings from ‘the Million programme’. The idea of this master thesis is to create a process for storey additions from a designer’s point of view.

Our approach has consisted of thorough literature studies combined with interviews and study visits in order to get an accurate idea of how these houses were built. The conclusion is that the main part of these houses was built by different prefabricated element systems. These systems resemble each other, which have enabled a simplification and limitation in order to find a solution that can be applied on as many buildings as possible.

An important aspect to consider when reading this report is that even tough storey addition is not unusual, there is no common knowledge in this area. Storey addition has therefore not been treated as a category of its own but rather as case-to-case specific issues. Therefore, the gathering of information has been problematic since the knowledge in this area has been hard to identify.

Another aspect has been the age of the buildings that leads to a lack of knowledge about these buildings and the systems of which they were built. The information has simply been forgotten or not been considered when adding storeys. The information that has been gathered from study visits and interviews are mainly assumptions made by experienced designers and constructors.

The result of this master thesis is a list of common problems and suggestions of solutions for these problems. These problems and solutions are compiled in a flowchart and a checklist that can be used as a tool for designers. It is important to notice that every project has its specific features, which means that for some projects this tool might be insufficient. This tool has in this thesis been applied on a case building that represents an ordinary ‘Million programme’ building. This case study indicates that the checklist is a sufficient tool.

The result of this thesis is the previous mentioned checklist that will aid, especially inexperienced, designers in storey addition projects.

8 Conclusion

The aim of this study was to identify critical problems in the process of adding storeys to already existing buildings and present a way to deal these problems. By analysing the housing market, the construction design actors and how the procedure is performed today we came up with some key issues concerning storey addition. These key issues were gathered and a guide for designers was compiled in form of a checklist.

The checklist resubmits to Chapter 4 and 5 where problems and solutions of the design process are identified and each step of the checklist is analysed and explained. The checklist should be used as an aid when performing storey additions. This means that the checklist only should act as guidance and aims towards less experienced designers. The purpose of the checklist is to suggest a work process and give a possibility to overview the work that has been and should be performed.

The checklist's suitability as a guide is tested on a case study on a typical 'Million programme' building. From this it can be verified that the checklist is useful when performing a storey addition. It can also be concluded that a storey addition is possible, with good margin, to perform on a building from 'the Million programme'.

This thesis has been carried out within the scope that is stated in the beginning of this thesis. These limitations are set to only focus on the structural part of storey extensions. Other aspects, such as economic and environmental issues, have not been discussed. It would therefore be a logical next step to examine how these aspects affect the results presented in this work. Furthermore, it should be noted that this study is developed with a general approach. Mainly due to the limited time period that this thesis has been carried out within. The potential to deepen the knowledge of the different technical solutions presented are therefore large.

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Johansson Christian NCC, 2011-03-23. Interview.

Järphag Thomas NCC, 2011-06-20. Interview.

Larsen Johan PEAB, 2011-06-15. Interview and study visit.

Pfeiffer Annelie 2012-01-26. Interview

Sihvonen Mats NCC, 2011-06-15. Telephone interview.

Svedin Karin NCC, 2011-05-24. Interview and study visit.
Servin Anders NCC, 2011-05-24. Interview and study visit.

10 Appendices

A Chart comparing different element methods

TABELL 8.

System	Tillämpar planmodul 3M		Vånings-höjd	Stomrums-höjd	Rumshöjd
	Ja	Nej	m	m	m
A-system Byggelement AB	x		2,80[a] 2,70[b]	2,60[a] 2,515[b]	2,555[a] 2,47[b]
BPA Byggproduktion AB	x[h]		2,805[c]	2,505	2,50
Göteborgs Byggelement, AB	x	x[d]	2,75	2,57	2,50
Göteborgs Stads Bostads AB	x		2,70	2,52	2,515 2,50[e]
Göteborgsbostäder, Fastighets AB (Byggplats Tynnered)		x	2,77	2,55	2,50
Göteborgsbostäder, Fastighets AB (System Bygg-Tema)	x		2,70	2,52	2,515 2,47[e]
Haningebolaget AB		x[g]	2,75	2,55 2,57	2,50
Hälsingborgs Byggelement, AB	x		2,70	2,52	2,515 2,50[e]
Norrköpings Byggelement, AB	x		2,70	2,52	2,50
Byggnadsfirman Ohlsson & Skarne AB, (System Skarne 66)	x		2,70	2,505	2,50
Byggnadsfirman Ohlsson & Skarne AB, (Tunga systemet)		x	2,70	2,525 2,505[f]	2,50
Skånska Cementgjuteriet, AB, Kalmar		x	2,70	2,52	2,50
Skånska Cementgjuteriet, AB, Malmö		x	2,70	2,505	2,50
Strängbetong, AB (System S)	x		2,80	2,515	2,50
Upplandsbetong (System DINA)	x[h]		2,80[c]	2,505	2,50

[a] Gäller för Malmö-regionen.
[b] Gäller för Stockholms- och Göteborgs-regionerna.
[c] Platsgjutna bärande väggar.
[d] Tillverkar både med och utan 3M, helst med.
[e] Med linoleum alt. parkett.
[f] För parkett alt. linoleum.
[g] Avser att tillämpa fr.o.m. 1969.
[h] 3M i bjälklagselementens tvärriktning, i längdriktningen både med och utan 3M.

Figure 45 Chart comparing different element methods, Byggmästaren.

B Chart of different element systems

TABELL 7. Bärande system i princip.

System	Fasader				Innerväggar			
	Långsida		Gavel		Lägenhetsskiljande		Rumsskiljande	
	Bärande	Ej bärande	Bärande	Ej bärande	Bärande	Ej bärande	Bärande	Ej bärande
A-system Byggelement AB		x	x		x		x	
BPA Byggproduktion AB		x	x		x			x
Göteborgs Byggelement AB		x	x		x		x 1)	x 2)
Göteborgs Stads Bostads AB		x	x		x		x	
Göteborgsbostäder, Fastighets AB (Byggplats Tynnered)		x	x		x		x	
Göteborgsbostäder, Fastighets AB (System Bygg-Tema)		x	x		x		x	
Haningebolaget AB		x	x		x		x	
Hälsingborgs Byggelement, AB		x	x		x		x	
Norrköpings Byggelement, AB		x	x		x		x	
Byggnadsfirman Ohlsson & Skarne AB, (System Skarne 66)	x		x		x			x
Byggnadsfirman Ohlsson & Skarne AB, (Tunga systemet)			x		x		x	
Skånska Cementgjuteriet, AB, Kalmar		x	x		x		x	
Skånska Cementgjuteriet, AB, Malmö		x	x		x		x	
Strängbetong, AB (System S)		x	x		x			x
Upplandsbetong (System DINA)		x	x		x			x

1) för närvarande

2) skall komma enl. tillverkaren

Figure 46 Comparison between different element systems regarding their load-carrying properties, Byggmästaren.

C Interview questions

In Chapter 9.3 the questions that were used for the interviews are written down. These questions are quite general and during the interviews some more in depth questions may have occurred.

1. What is the name of the object that you perform/performed the storey-extension on?
2. Have the storey-extension consisted of apartments, offices or other structures?
3. Did the storey-extension result in more extensive renovation? (Such as elevator, new storage, new water supplies or new electric connections) Or was the capacity of these sufficient?
4. Was the storey-extension performed because there was a need of housing in the area or was it an opportunity to do an extension in connection to other renovation? If so why was the initial renovation executed? Would it be fitting to do a storey-extension in connection with an energy saving renovation?
5. Were the residents able to live in their apartments during the renovation? Where there any renovations going on in their apartments as well?
6. If an extension was performed what went well? Are there any lessons that can be brought for future extensions on other multi-residential houses?
7. How was the foundation examined? Did the foundation require any reinforcements?
8. Where any of the existing storeys changed against lighter options?
9. What kind of frame was used in the building?
10. Where there buffering capacity in the building or was it necessary to reinforce the existing frame?
11. What is important to consider when performing an inventory of a building?
12. Are there any buildings that are more likely to have buffer capacity? (E.g. houses with vertically continuous walls)
13. If a reinforcement of the frame was performed, in what way? And what kind of frame was it?
14. What materials and systems where used to add a storey on the existing building? What do you consider to be the best way to perform a storey-extension on?
15. Which load-carrying problems do you consider to be the largest when performing a storey-extension? How do these problems get solved?
16. Was it important that the construction time was low? Why?
17. As the houses from ‘the Million programme’ is constructed with industrial methods and often have simple geometries, does this simplify a storey-extension? Does it exist any possibility that the similar appearance of houses from ‘the Million programme’ makes it simpler to use prefabricated elements?
18. Was extensive weather protection needed to protect existing building from moisture during the construction period? How was this done?
19. Where the existing house, a rental or condominium? Was the added storey a rental or a condominium?
20. Was there an elevator in the existing building? Was there an opportunity to extend the elevator to the added storey? If no elevator existed did the added storey make an elevator necessary?
21. Was the storey-extension an extension of the existing building or was the plan arrangement changed? Was the extension built as a duplex? Where the added

storeys made smaller to for example minimize the shadowing of other structures?

22. What do you reckon to be the largest problem when considering storey-extension?
23. Which are the most important conditions to make a storey-extension suitable?
24. What are the advantages/disadvantages for storey-extension in general? What are the advantages/disadvantages if one compares storey-extension to demolition and rebuilding?

Questions concerning the construction design in a storey-extension process.

1. What is the first thing one should consider when examines the possibilities for a storey-extension and in what order should other issues be looked at?
2. What are the dimensioning factors? The load-carrying capacity of the concrete? The condition of the foundation? The connections between the elements?
3. Which are the most common reinforcement measures when strengthen the building? Which are the dimension loads? Which factors do you consider when calculating?
4. What is important to consider regarding an opening of a load-carrying wall and how is the load-redirection made? Is there any risk for torsion?
5. What eruditions have you taking in to account from previous storey-extensions?
6. How does different foundations differ when regarding the load-carrying capacity for plinth foundation, simple slab and basement foundation?
7. What problems could arise at the connection between the extended apartments and the initial ones?
8. Which extension method is most preferable? Concrete, wood or steel?
9. What are the main concerns when installing an elevator?
10. Are detached balconies a source for problems?
11. When extending storeys with light materials, for example wood, what are the main concerns regarding noise reduction and fire?
12. How do you take the fire restrictions into account when designing a storey-extension?
13. Are there any other issues to think about?

D Checkbox

Checkbox		Step		Recommendations
		1	**Conditions**	
		a	Existing Building	Geological conditions Assessment of the existing building Terrain and logistical conditions Existing floor plan
		b	Regulations	How much hight is allowed to add? Are there any estethic restrictions?
		c	Requests	Number of storyes Plan arrangement Material Desired types of apartments Architectual proposal
	see 1c	*d*	Balconies	Dimensioning of balconies and the balcony connections. Needs to be considered even if the balconies are prefabricated.
	see 1c	*e*	Elevator Installations	Examine which precautions and requirements that need to be fulfilled when installing elevators.
		f	Fire Safety	Examine in what extent the fire safety requirements affects the layout of the apartments.
		2	**Load distribution**	If a new plan arrangement is desired, the new loads has to be redistributed on to the existing frame. This step is not necessary if the plan arrangement is not changed.
		3	**Calculation of cumulative loads**	
		a	Cumulative loads on the foundation	Loads according to Eurocode (partition walls, installations, snow, facades, imposed loads, own weight)
		b	Cumulative loads on the pillars	Loads according to Eurocode (partition walls, installations, snow, facades, imposed loads, own weight)
		c	Cumulative loads on the load-carrying walls	Loads according to Eurocode (partition walls, installations, snow, facades, imposed loads, own weight) Be aware of weak points in the walls (holes, short beam support lenghts). It is important that all door openings are included in the 3D-model.
		4	**Evaluation**	A general evaluation regarding the existing building and its load-carrying abilities. Should be rewived by an experienced engineer.
	see 3a	*5*	**Load carrying capacity, Foundation**	Which type of foundation (slab, plinths, piles) Necessary reinforcements has to be applied if the buildings capacity is not sufficient enough. Consider adjusting the preliminary conditions.
		6	**Stability**	The added storeys imposes new loads and new hights that affects building with larger dead weight and larger wind loads.
	see 3b	*7*	**Load carrying capacity, Columns**	
		a	Existing columns	Necessary reinforcements has to be applied if the buildings capacity is not sufficient enough. Consider adjusting the preliminary conditions. Check for risk of stamping and punching effects from the columns.
		b	Newly produced columns	Om betong så ingår armering
	see 3c	*8*	**Load carrying capacity, Walls**	
		a	Existing walls	Necessary reinforcements has to be applied if the buildings capacity is not sufficient enough. Consider adjusting the preliminary conditions. Check for stamping effects from the walls on the floor tier.
		b	Newly produced walls	If the new walls are made of concrete, reinforcemnet should be included.

E Wall Calculations

Indata

$bwall := 0.18m$	Thickness of wall
$lwall := 11.8m$	Lenght wall
$Awall := bwall \cdot lwall = 2.124m^2$	Area wall
$afloor := 2.50m$	Distance between floor and ceiling
$N := 115\frac{kN}{m}$	Load on wall

Vertical Capacity

$fctm := 2.2MPa$ Concrete class C20/25
$Ecm := 30GPa$

$Ncel := 0.6 \cdot fctm \cdot Awall = 2.804 \times 10^6 N$	Elastic limit according to "Bärande konstruktioner Del 1" Chapter B3.3.2
$ecel := 0.6 \cdot \frac{fctm}{Ecm} = 4.4 \times 10^{-5}$	Strain according to "Bärande konstruktioner Del 1" Chapter B3.3.2
$ecel < 2.0 \cdot 10^{-3}$	Ok with regular working curve "Bärande konstruktioner Del 1" Chapter B2.1.4 fig 2.12a
$Nu := fctm \cdot bwall = 396\frac{kN}{m}$	Load carrying capacity according to "Bärande konstruktioner Del 1" Chapter B3.3.2

Utilization

$U1 := \frac{N}{Nu} = 29.04\%$ The wall uses 29% of its capacity

Moment Capacity

Assumption of inclination

$ahtest := \frac{2}{\sqrt{afloor}} = 1.265\frac{1}{m^{0.5}}$ ahtest > 1 then ah=1

$ah := 1$

$m1 := 1$

$am := \sqrt{0.5\left(1 + \frac{1}{m1}\right)} = 1$

$\theta 0 := 0.005$

$\theta i := \theta 0 \cdot ah \cdot am = 5 \times 10^{-3}$

Excentricity because of shape irreguleraties in design

$l0 := 2 \cdot afloor = 5\,m$

$ei := \theta i \cdot \frac{l0}{2} = 0.013m$

Smallest excentricity for added pressure

$emin := \frac{bwall}{30} = 6 \times 10^{-3}\,m$

Moment of first order

$MEd0 := N \cdot (ei + emin) = 2.128 \times 10^{3}\,N$

Cross Section Capacity

$accpl := 0.8$

$\gamma c := 1.5$

$fck := 20MPa$

$fcd := accpl \cdot \frac{fck}{\gamma c} = 1.067 \times 10^{7}\,Pa$

$Mrd := fcd \cdot bwall \cdot bwall = 345.6kN$ capacity of the cross section

Moment of second order

Estimate of nominal rigidity

$Ecd := \frac{Ecm}{1.2} = 2.5 \times 10^{10}\,Pa$

$Ic := \frac{\left(lwall \cdot bwall^{3}\right)}{12} = 5.735 \times 10^{-3}\,m^{4}$

$\varphi ef := 3$ from table 3.13 "Byggkonstruktion"

$EI := 0.3 \cdot Ecd \cdot \frac{Ic}{(1 + 0.5\varphi ef)} = 1.72 \times 10^{7}\,\frac{m^{3} \cdot kg}{s^{2}}$

Buckling length

$$Nb := \pi^2 \cdot \frac{EI}{l0^2} = 6.792 \times 10^6 N$$ Theoretical buckling force

Moment of second order

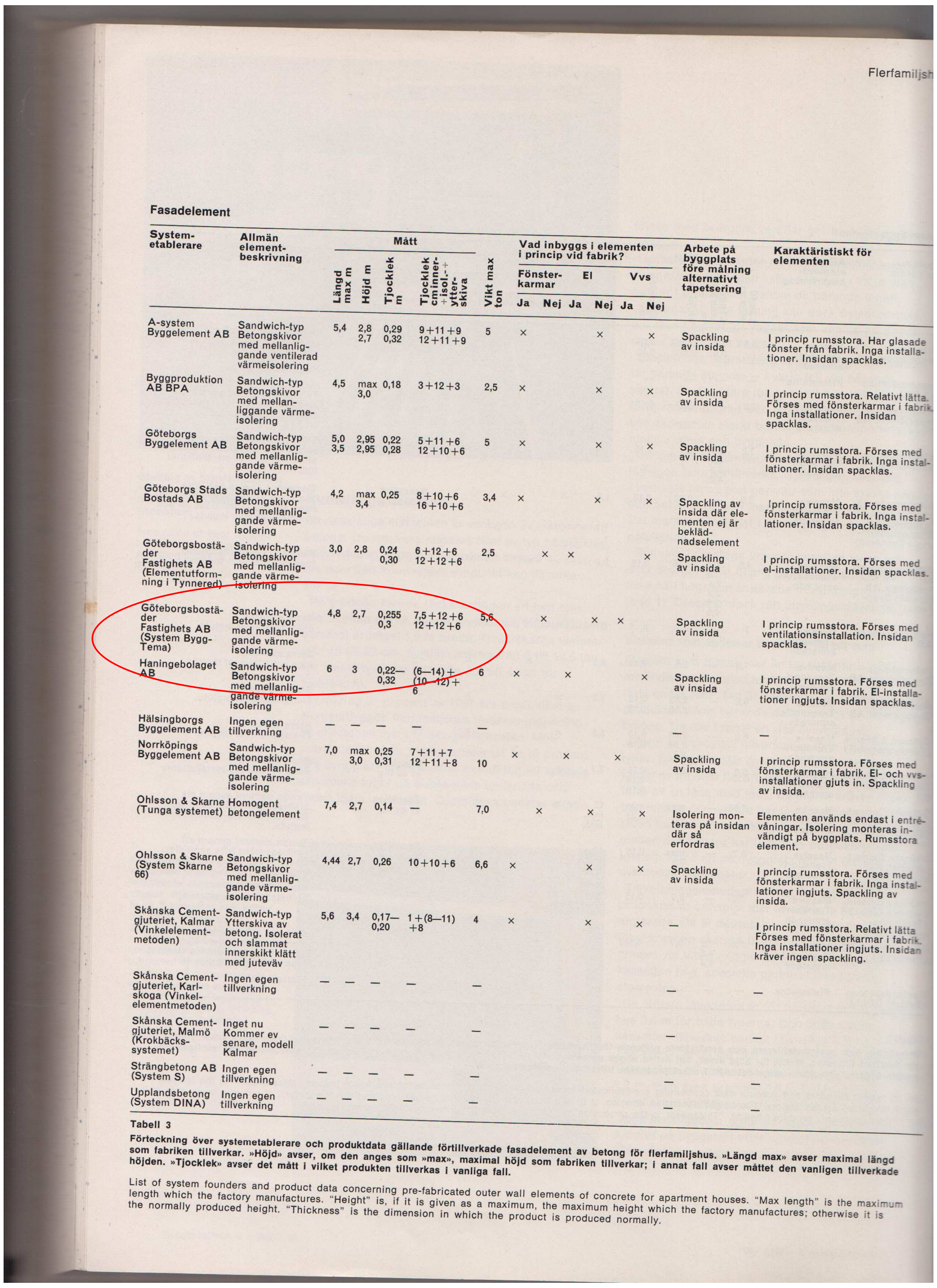
$B := 1.23$ Rectangular shape

$$Med2 := MEd0 \cdot \left[1 + \left[\frac{B}{\left(\frac{Nb}{N \cdot lwall} \right) - 1} \right] \right] = 2.781kN$$

Moment Utilization

$$\frac{Med2}{Mrd} = 0.805\%$$ Moment utilization of 0.81%

F Façade load



Flerfamiljsh

Fasadelement

System-etablerare	Allmän element-beskrivning	Mått: Längd max m	Mått: Höjd m	Mått: Tjocklek m	Mått: Tjocklek cminner-+isol.-+ytter-skiva	Vikt max ton	Fönster-karmar: Ja	Fönster-karmar: Nej	El: Ja	El: Nej	Vvs: Ja	Vvs: Nej	Arbete på byggplats före målning alternativt tapetsering	Karaktäristiskt för elementen
A-system Byggelement AB	Sandwich-typ Betongskivor med mellanliggande ventilerad värmeisolering	5,4	2,8 2,7	0,29 0,32	9+11+9 12+11+9	5	×			×		×	Spackling av insida	I princip rumsstora. Har glasade fönster från fabrik. Inga installationer. Insidan spacklas.
Byggproduktion AB BPA	Sandwich-typ Betongskivor med mellanliggande värme-isolering	4,5	max 3,0	0,18	3+12+3	2,5	×			×		×	Spackling av insida	I princip rumsstora. Relativt lätta. Förses med fönsterkarmar i fabrik. Inga installationer. Insidan spacklas.
Göteborgs Byggelement AB	Sandwich-typ Betongskivor med mellanliggande värme-isolering	5,0 3,5	2,95 2,95	0,22 0,28	5+11+6 12+10+6	5	×			×		×	Spackling av insida	I princip rumsstora. Förses med fönsterkarmar i fabrik. Inga installationer. Insidan spacklas.
Göteborgs Stads Bostads AB	Sandwich-typ Betongskivor med mellanliggande värme-isolering	4,2	max 3,4	0,25	8+10+6 16+10+6	3,4	×			×		×	Spackling av insida där elementen ej är beklädnadselement	Iprincip rumsstora. Förses med fönsterkarmar i fabrik. Inga installationer. Insidan spacklas.
Göteborgsbostäder Fastighets AB (Elementutformning i Tynnered)	Sandwich-typ Betongskivor med mellanliggande värme-isolering	3,0	2,8	0,24 0,30	6+12+6 12+12+6	2,5		×	×			×	Spackling av insida	I princip rumsstora. Förses med el-installationer. Insidan spacklas.
Göteborgsbostäder Fastighets AB (System Bygg-Tema)	Sandwich-typ Betongskivor med mellanliggande värme-isolering	4,8	2,7	0,255 0,3	7,5+12+6 12+12+6	5,6		×		×	×		Spackling av insida	I princip rumsstora. Förses med ventilationsinstallation. Insidan spacklas.
Haningebolaget AB	Sandwich-typ Betongskivor med mellanliggande värme-isolering	6	3	0,22—0,32	(6—14)+(10—12)+6	6	×		×			×	Spackling av insida	I princip rumsstora. Förses med fönsterkarmar i fabrik. El-installationer ingjuts. Insidan spacklas.
Hälsingborgs Byggelement AB	Ingen egen tillverkning	—	—	—	—	—							—	—
Norrköpings Byggelement AB	Sandwich-typ Betongskivor med mellanliggande värme-isolering	7,0	max 3,0	0,25 0,31	7+11+7 12+11+8	10	×		×		×		Spackling av insida	I princip rumsstora. Förses med fönsterkarmar i fabrik. El- och vvs-installationer gjuts in. Spackling av insida.
Ohlsson & Skarne (Tunga systemet)	Homogent betongelement	7,4	2,7	0,14	—	7,0		×		×		×	Isolering monteras på insidan där så erfordras	Elementen används endast i entréväningar. Isolering monteras invändigt på byggplats. Rumsstora element.
Ohlsson & Skarne (System Skarne 66)	Sandwich-typ Betongskivor med mellanliggande värme-isolering	4,44	2,7	0,26	10+10+6	6,6	×			×		×	Spackling av insida	I princip rumsstora. Förses med fönsterkarmar i fabrik. Inga installationer ingjuts. Spackling av insida.
Skånska Cementgjuteriet, Kalmar (Vinkelelement-metoden)	Sandwich-typ Ytterskiva av betong. Isolerat och slammat innerskikt klätt med juteväv	5,6	3,4	0,17—0,20	1+(8—11)+8	4	×			×		×	—	I princip rumsstora. Relativt lätta Förses med fönsterkarmar i fabrik. Inga installationer ingjuts. Insidan kräver ingen spackling.
Skånska Cementgjuteriet, Karlskoga (Vinkelelementmetoden)	Ingen egen tillverkning	—	—	—	—	—							—	—
Skånska Cementgjuteriet, Malmö (Krokbäcks-systemet)	Inget nu Kommer ev senare, modell Kalmar	—	—	—	—	—							—	—
Strängbetong AB (System S)	Ingen egen tillverkning	—	—	—	—	—							—	—
Upplandsbetong (System DINA)	Ingen egen tillverkning	—	—	—	—	—							—	—

Tabell 3

Förteckning över systemetablerare och produktdata gällande förtillverkade fasadelement av betong för flerfamiljshus. »Längd max» avser maximal längd som fabriken tillverkar. »Höjd» avser, om den anges som »max», maximal höjd som fabriken tillverkar; i annat fall avser måttet den vanligen tillverkade höjden. »Tjocklek» avser det mått i vilket produkten tillverkas i vanliga fall.

List of system founders and product data concerning pre-fabricated outer wall elements of concrete for apartment houses. "Max length" is the maximum length which the factory manufactures. "Height" is, if it is given as a maximum, the maximum height which the factory manufactures; otherwise it is the normally produced height. "Thickness" is the dimension in which the product is produced normally.

Figure 47 Chart that describes the facade properties of the chosen building system.

Type of façade	Sandwich element
Length	4.8 m
Height	2.7 m
Thickness	0.255 m
Weight	5600 kg

5600kg/4.8m=1200kg/m which is equal to 12 kN/m as a line load.

The line load on the balconies is an experience value that is on the safe side depending on which kind of handrail that is chosen.

G Snow load

Area	Gothenburg
S_k	1.5 kN/m^2 (EKS 8)
u_1	0.8 (SS-EN 1991-1-3)

$S=S_k*u_1=1.5*0.8=1.2$ kN/m^2 (EKS 8 and SS-EN 1991-1-3)

H Wind Load

Area	Gothenburg
V_b	25 m/s (EKS 8)
Terrain type	III (SS-EN 1991-1-4)
Height Plane 1	2.7 m
Height Plane 2	5.4 m
Height Plane 3	8.1 m
Height Plane 4	10.8 m

We (SS-EN 1991-1-4)	
Plane 1	0.453 kN/m^2
Plane 2	0.488 kN/m^2
Plane 3	0.636 kN/m^2
Plane 4	0.753 kN/m^2

Each plane has the influence area of 2.7 m except for plane 4 that has 2.7/2 as it is the top plane. This gives:

Plane 1	1.22 kN/m
Plane 2	1.32 kN/m
Plane 3	1.72 kN/m
Plane 4	0.26 kN/m