SCHOOL OF ENGINEERING AND BUILDING ENVIRONMENT

CONCRETE FORM & CONSTRUCTION

BSV11135

COURSEWORK 1

EVALUATION & APPRAISAL OF CONCRETE CONSTRUCTION TECHNIQUES AND DETAILS

YELDA YELDANLI
40294284
27/10/2017

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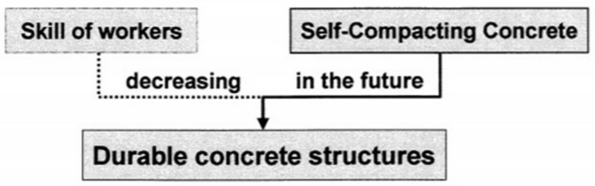
1.1 Introduction

Self-compacting concrete (SCC) is one of the most significant recent advances in concrete technology. Mechanical vibration was, in itself, a major advance in the early twentieth century but it brought with it a number of problems including noise, vibration induced health problems for operatives and, arguably, some loss in concrete performance. Removing the need for vibration avoids all of these problems and brings many advantages including reduced labour costs and better surface finishes (Claisse, 2010). It is produced off-site by the addition of a superplasticiser and a stabiliser to the mix. The addition of these chemical additives significantly increases the ease and rate of flow (Stacey, 2011).

In this paper, firstly, self-compacting concrete technology is described. It starts within historical context, gives detailed information about the mixture methods and concludes with some significant research findings from sustainable point of view. Before an application of the technology is investigated, second part briefly mentions about composite concrete columns which appear as one of the building components in precedent study.

1.2 Self-Compacting Concrete Technology

Self-compacting concrete (SCC) the technology developed in Japan emerges from the problem of the durability of concrete structures which was a major topic interest in early 1980s. The reduction in the quality in constructions effected by the gradual reduction in the number of skilled workers in Japan’s construction industry has lead the solution for the achievement of durable concrete structures independent of the skill shortages which was self-compacting concrete can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. (Ouchi, 2001)



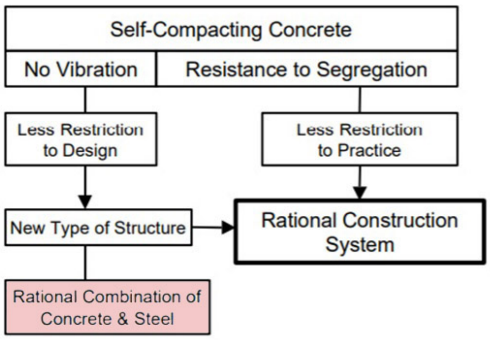


Figure 1 (Left) Necessity of self-compacting concrete; (Right) Rational construction system achieved by making full performance of self-compacting concrete (Ouchi, 2001) (the red filled box is to indicate the combined system used with self-compacting concrete in following part which examines the Tama Art Library)

The reasons for the employment of SCC can be summarized as follows; the reduction of construction time, labour, equipment and noise in construction sites because of the elimination of vibrating equipment. In addition, SCC makes the construction of heavily congested structural elements and hard to reach areas easier, and helping to achieve higher concrete quality. (Nehdi, et al., 2004)

The method for achieving self compactability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone of reinforcing bars. Okamura and Ozawa have employed the following methods in the following page explained detailed to achieve self-compactability.

1 Limited coarse aggregate content
2 Limited fine aggregate content in mortar
3 Low water-powder ratio
4 High dosage of superplasticizer

The frequency of collision and contact between aggregate particles can increase as the relative distance between the particles decreases and then internal stress can increase when concrete is deformed, particularly near obstacles. It has been revealed that the energy required for flowing is consumed by the increased internal stress, resulting in blockage of aggregate particles. Limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal proportions is effective in avoiding this kind of blockage. Highly viscous paste is also required to avoid the blockage of coarse aggregate when concrete flows through obstacles. When concrete is deformed, paste with a high viscosity also prevents localized increases in the internal stress due to the approach of coarse aggregate particles. High deformability can be achieved only by the employment of a superplasticizer, keeping the water-powder ratio to be very low value (Fig. 2) (Ouchi, 2001).

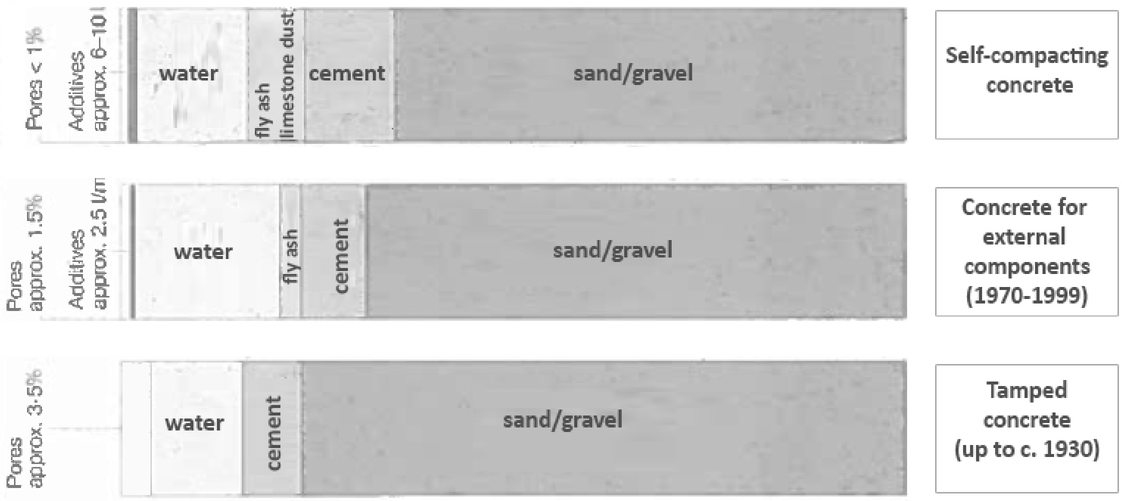


Figure 2 Comparison of concrete mixes (parts by vol./m3) (Peck, 2006)

Self-compactability can be largely affected by the characteristics of materials and the mix-proportion. A rational mix-design method for self-compacting concrete using a variety of materials is necessary. Okamura and Ozawa have proposed a simple mix-proportioning system assuming general supply from ready-mixed concrete plants. The coarse and fine aggregate contents are fixed so that self-compactability can be achieved easily by adjusting the water-powder ratio and superplasticizer dosage only.

Figure 3 shows;

1 Coarse aggregate content in concrete is fixed at 50% of the solid volume.

2 Fine aggregate content is fixed at 40% of the mortar volume.
3 Water-powder ratio in volume is assumed as 0.9 to 1.0, depending on the properties of the powder.
4 Superplasticizer dosage and the final water-powder ratio are determined so as to ensure self-compactability.

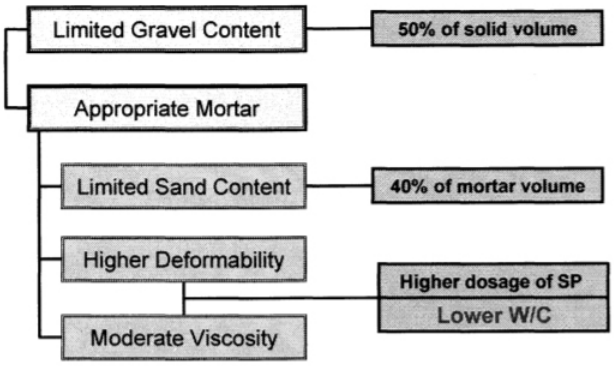


Figure 3 A rational mix-proportioning method (Ouchi, 2001)

In the mix-proportioning of conventional concrete, the water-cement ratio is fixed at first from the viewpoint of obtaining the required strength. With self-compacting concrete, however, the water-powder ratio has to be decided to take the self-compactability into account because self-compactability is very sensitive to this ratio. In most cases, the required strength does not govern the water-cement ratio because the water-powder ratio is small enough for obtaining the required strength for ordinary structures unless the most of powder materials in use is not reactive. The mortar or paste in self-compacting concrete requires high viscosity as well as high deformability. This can be achieved by the employment of a superplasticizer, which results in a low water-powder ratio for the high deformability (Ouchi, 2001).

In general, although SCC has the same ingredients as normal concrete, the key point for producing SCC depends on the mix proportions to obtain a highly fluid concrete while preventing bleeding and segregation during transportation and placing. (Sadek, et al., 2016)

For sustainable development, there are ongoing researches about reusing of marble and granite powders in self-compacting concrete in the field. The aim is to explore alternative solutions to dispose huge amounts of solid wastes are generated every day from marble and granite industry with increasing the environmental awareness. Up to now, most of these wastes are landfilled causing serious environmental problems (Sadek, et al., 2016). The wastes produced by ornamental stone industries (not just produced by the marble industry) can be utilized in the construction sector. To date, the main application of the waste stone sludge in the construction sector is its use as fine aggregates and as cement replacement (Galetakis & Soultana, 2016). Gencel, et al., (2012) report that incorporation of marble powder provides concrete paving blocks that have adequate quality. Corinaldesi, et al., (2010) proved in their studies that the marble powder is very effective for the cohesiveness of mortar and concrete. When the marble powder is used to manufacture composite cement as an additive, the manufacturing of this cement is more economical, feasible and eco-friendly (Aruntas, et al., 2010).

Self-compacting concrete (SCC) is one of the most attractive alternatives utilizing the marble powder in the concrete industry. In fact, as a mineral admixture marble powder usually can be used to reduce the amount of the cement in concrete mixtures (Uysal & Sumer, 2011). Using the waste marble powder in SCC as mineral additives enhances its mechanical and durability properties (Sadek, et al., 2016). In addition, the marble powder can be used in combination with limestone filler and tile waste successfully in SCC (Tennich, et al., 2015).

1.3 Composite Concrete Columns

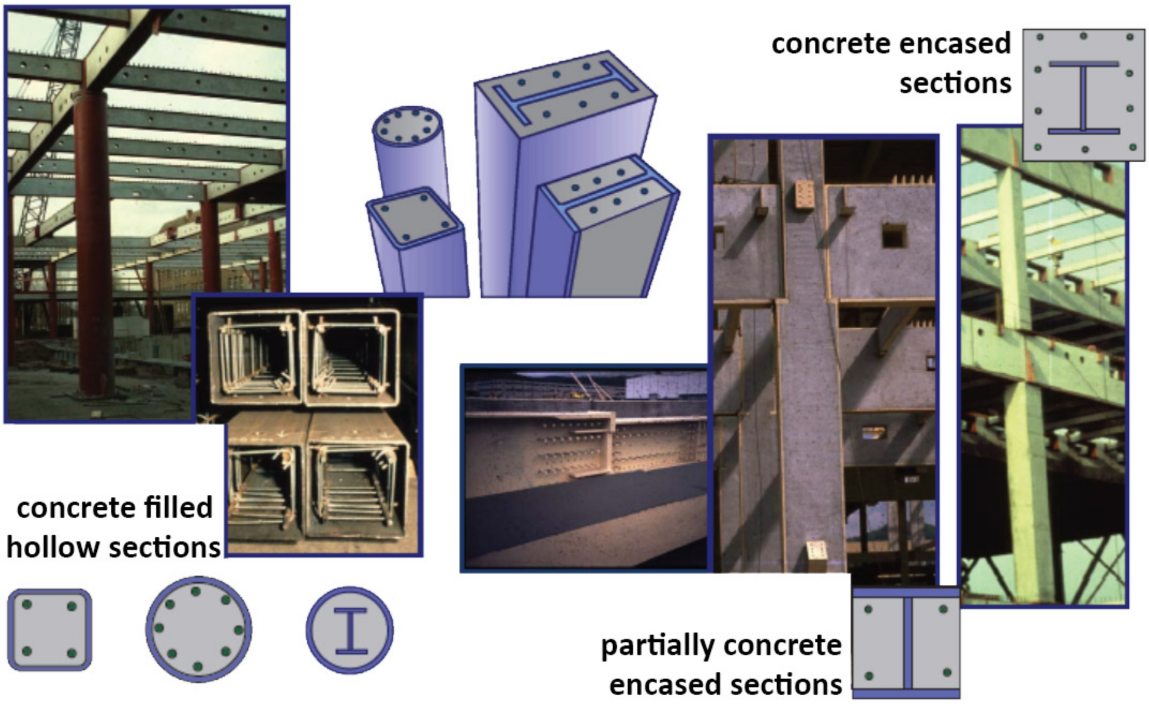


Figure 4 Images and typical cross-sections of the composite columns according to simplified method (Hanswille, 2008)

Composite referred as the columns of structural steel, concrete and reinforcing steel by Holger Eggeman, programme director of Engineering Sciences of German Research Foundation. Combining of these materials had number of motivations, steel columns were often encased in concrete to protect them from fire, while concrete columns were combined with structural steel as a reinforcement (Eggeman, 2006). According to Eurocode 4 for the design of composite structures of steel and concrete, there are two methods for the design of composite columns: a simplified design method and a more sophisticated general design method. The simplified method works for the design of composite columns and composite compression members with concrete-encased sections, partially encased sections and concrete-filled rectangular and circular tubes (see Fig. 4) (Hanswille, et al., 2017).The advantages and disadvantages for each of the composite concrete columns classified by simplified method shown in table 1;

	Advantages	Disadvantages
Concrete Encased Sections	• high bearing resistance • high fire resistance • economical solution with regard to material costs	•high costs for formwork •difficult solutions for connections with beams •difficulties in case of later strengthening of the column •in special case edge protection is necessary
Partially Concrete Encased Sections	•high bearing resistance, especially in case of welded steel sections •no formwork •simple solution for joints and load introduction •easy solution for later strengthening and additional later joints •no edge protection	•lower fire resistance in comparison with concrete encased sections.
Concrete Filled Hollow Sections	•high resistance and slender columns •advantages in case of biaxial bending •no edge protection	•high material costs for profiles •difficult casting •additional reinforcement is needed for fire resistance

Table 1 The advantages and disadvantages for each of the composite concrete columns classified by simplified method

1.4 Conclusions

Self-compacting concrete (SCC), relatively new product, is being increasingly used by the precast industry as it minimises the health and safety risk related to mechanical vibration techniques and redices labour costs while improving the visual quality of the units minimising surface air-bubles. The technology become more tempting and ideal within complex geometries. Thanks to its ability to flow into moulds without any need for vibration, it is the most appropiate use for the constructions where composite columns employed with reinforcement where vibration of the wet concrete would prove difficult (Stacey, 2011).

Due to its favouring by off-site manufacturing techniques and the findings encourages the mixture for being more sustainable, it is reasonable to expect self-compacting concrete dominates the construction industry near future.

Figure 5 An image from inside of Tama Art Library

1.5 Precedent Study: Tama Art University Library

The building is the library of an art university located in the suburbs of Tokyo, in the Hachioji campus. Composed of two floors of about 2400 m^2 and a partial basement, the building has a total floor area of 5500 m^2. The site situated between the main entrance gate and the centre of the campus (Cecilia & Levene, 2009).

Figure 6 Site Plan

The production of architecture starts intellectually with the conceptual ideas unique for each location then continues physically through the appropriate selection of materials and construction systems as an integral part of the design process regarding to aesthetic and functional needs of the building.

Understanding the architect's motivation is an essence to evaluate and critically appraise construction techniques and details.

1.5.1 Concept

Toyo Ito, the architect of the project, tells that the first impetus the design was therefore to question how an institution as specialised as a library could provide an open commonality for all. Initially the proposal was to place all the volumes in a single level set in underground which was proved impossible by various reasons. Then the idea formed as placing a wide-open gallery on the ground level that would serve as an active thoroughfare for people crossing the campus, even if it was not their intention to go to library. Despite having to work above the ground, a space above the ground that resembled a grotto by carving out the volume let the flows and views of the people freely penetrate the building. The concept sketches are shown in Figure 7, below. (Ito, 2007)

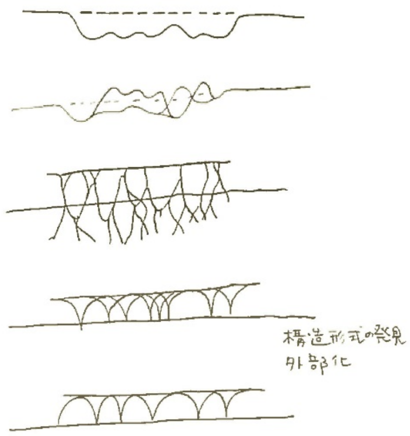


Figure 7 Concept drafts (Ito, 2007)

Three spatial characteristics appears in this project.

• The space is made up continual series of slender arches.
• Each of the rows of arches follows curvilinear paths. They intersect each other with a slightly curved surface to create a grid.
• The floor at ground level follows the slope of the site (1/20).

The arches have been designed to follow gentle curves at different angles, articulating the space into different blocks of triangles and squares. Due to the placement of the furniture that penetrates the space, paradoxically contradicting characteristics were attributed to the reading area: "flow" and "stand". (Ito, 2007) Figure 8 illustrates the flows emerged by the equipment's placing. The construction is of in-situ concrete formed around flanged steel plate cores that are augmented with steel reinforcing rods positioned on either side. In effect this is a steel building with a concrete skin. (Phillips & Yamashita, 2012)

Figure 8 Flows emerged by furniture placement (Left) Structural grid; (Middle) Ground floor; (Right) 1st Floor

The ground floor of the building has a sloping floor that blends with the external landscape; it is designed to be like promenade, a place where students can walk through the building from one side to the other. It can also serve as a gallery or lecture space. The main library space is on the first floor; here 100.000 books are on display, while another 100.000 books are stored in the basement (Phillips & Yamashita, 2012).

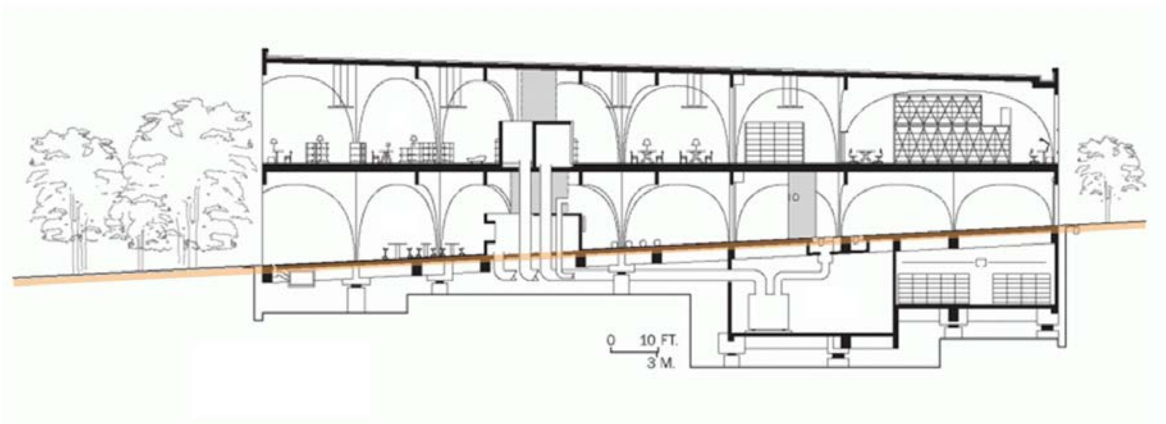


Figure 9 Longitudinal Section, slope indicated

1.5.2 Construction Techniques and Details

While talking about arches, it is worth to mention that Louis Kahn, one of the United States' greatest 20th century architects, known for combining Modernism with the weight and dignity of ancient monuments, searched for souls in buildings and conducted the dialogue: "You say to a brick, 'What do you want, brick?' And brick says to you, 'I like an arch.' And you say to brick, 'Look, I want one, too, but arches are expensive and I can use a concrete lintel.' And then you say: 'What do you think of that, brick?' Brick says: 'I like an arch.'" In one of the discuss with Mutsuro Sasaki, the structural engineer of Tama Library, he touches the origins of the arch. "There has been nothing new with the arch since Roman times," he says. "So, I went back to its origin and looked at it with 21st-century computer technology." (Fortmeyer, 2008). Masonry is the base for the invention of concrete is one of the main construction materials used by the construction industry today. The form of an early cement, the main constituent of concrete, seen as lime mortar approximately 1400 years ago in eastern Turkey to bind the stone together which is the first recorded use of limestone (Wood, 2017). In this context, for Ito's imagination comes true, concrete is the most appropriate in Tama Library.

The composite structure encased in 200mm of self-compacting concrete. The concrete cast into wooden shuttering that was precisely made in factory. As a result, the structure appears deceptively delicate, while carrying high live loads from first floor book stacks, and giving no hint of the extensive base isolation structure beneath (Gregory, 2007). The arches spans vary from 1.8 to 16 metres. The external concrete walls on the north and west sides of the building are curved, as is the glass that is fitted flush within them. (Phillips & Yamashita, 2012)

The Sequence of Construction

Firstly the entire structure stood in place as a steel plate skeleton that traced out a template of the building's final profile (Gregory, 2007). For achieving the slender proportions where the arches meet the ground was difficult by using the plate system, claims Mutsuro Sasaki. Because of their variable shapes and subtle dimensional differences, the myriad cross-shaped bases required another method to maintain their elegant appearance without compromising strength or rigidity. So Ito and Sasaki designed crossed steel slabs 22 to 50 mm (1 to 2 inches) thick to support the bottom 50 cm of each arch, while flanged plates are used above (fig 11) (Pollock, 2008). Thereafter the concrete was poured.

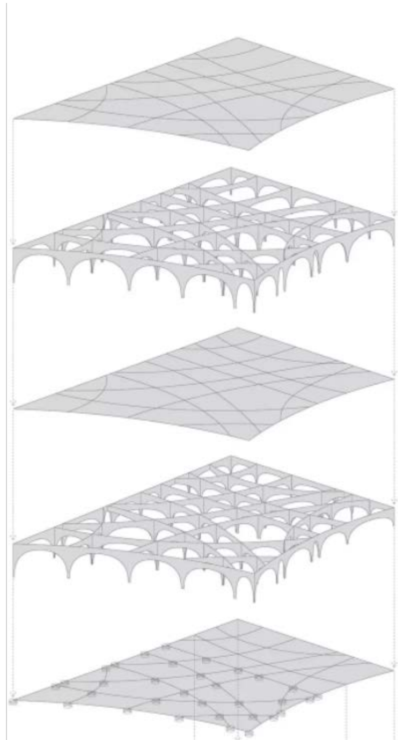


Figure 10 Diagram of steel and concrete frame on each floor

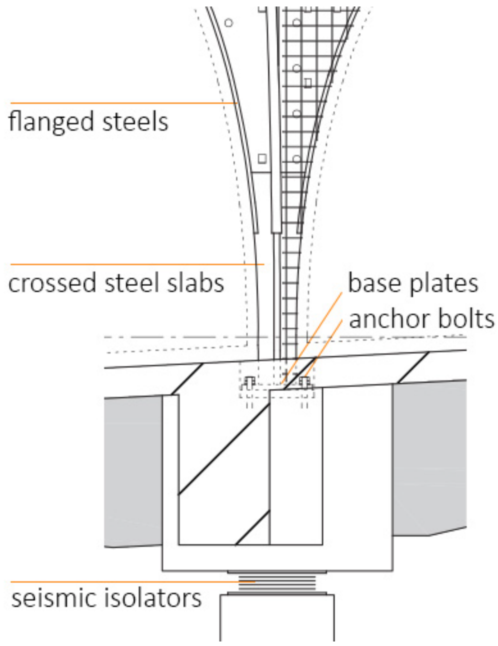


Figure 11 Detail Section from where the arches meet with the ground

Below grade, rubber isolators help offset the seismic weakness inherent in the arches' dainty feet. But thanks to the concrete's smooth surface and the arches' seamless profile lines, all of these underpinnings are imperceptible (Pollock, 2008).

Details

Modeled as Bezier curves, the arches' precise but irregular shapes were developed by connecting three fixed points: the two ends plus the apex, which is a constant height on each floor. Their resultant span lengths had a profound impact on construction, since every building component is different. Still, Ito was determined to maintain uniform and exceptionally thin walls throughout the building. Yet, these challenges were nothing that extra steel could not handle. It was structural engineer Mutsuro Sasaki's idea to decrease dimensions by forming the concrete arches around a bolted framework of flanged steel plates(see Figure 11, Detail). But this compounded the level of complexity. Ranging from 9 to 16 mm(0.4 to 0.6 inches) in thickness, the plates reduced the finished wall depth from the 300mm(12inch) industry standard to the desired 200mm(8 inch) (Pollock, 2008).

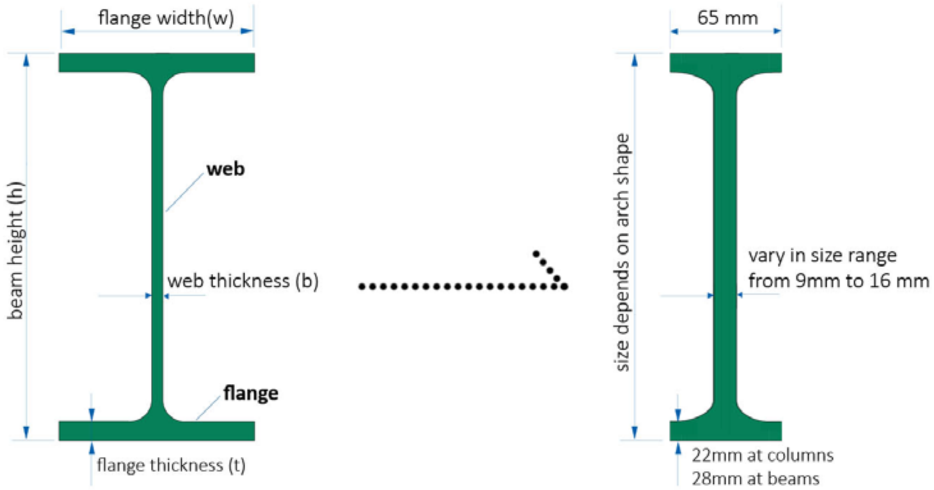
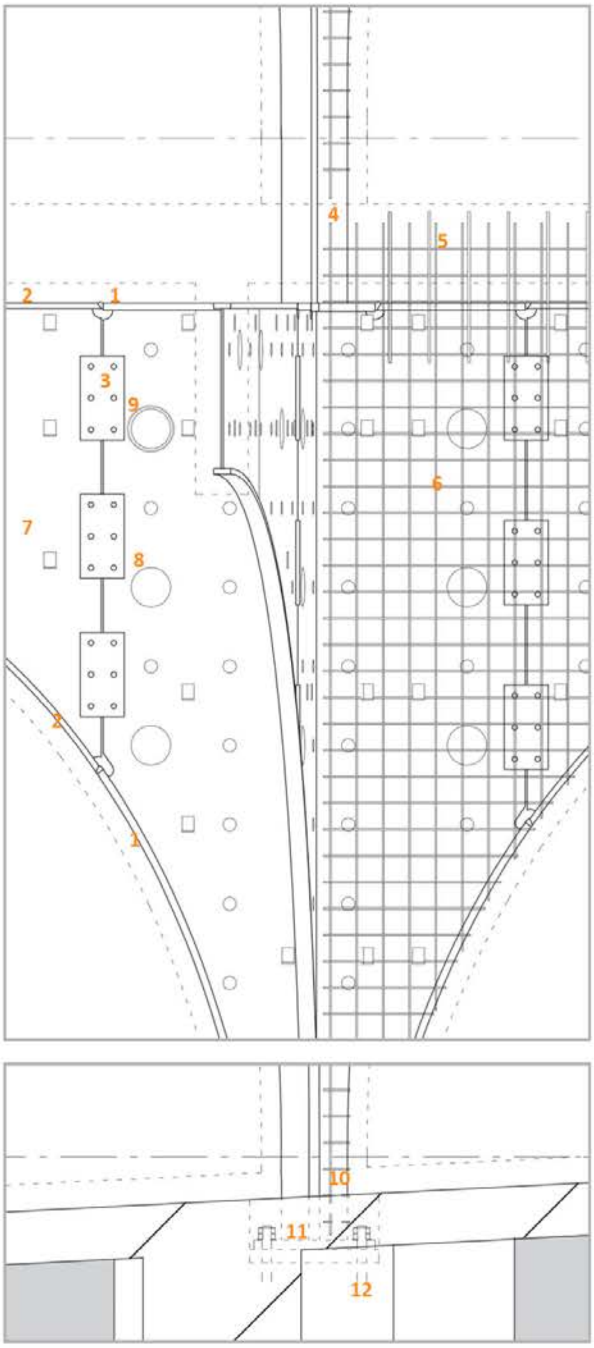
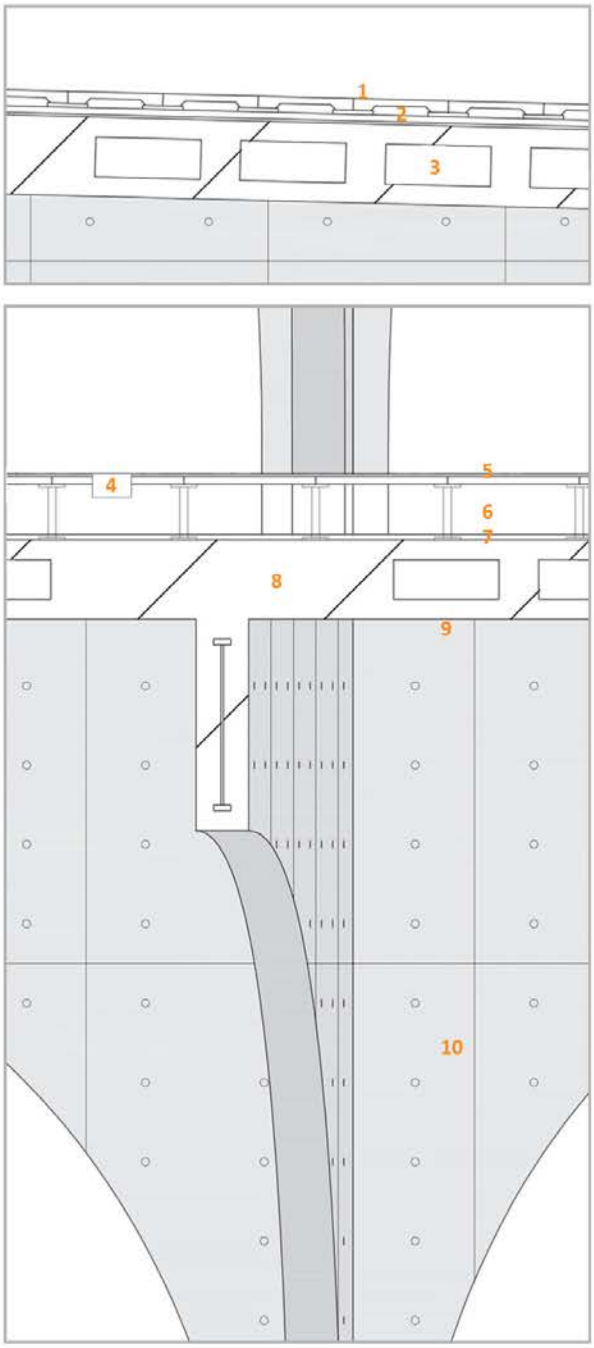


Figure 12 Formation of flanged beams to achieve desired wall thickness

And by increasing the density of reinforcing bars, architect and engineer were able to support even the widest openings without adding unwanted wall depth (Pollock, 2008) .



1 Flange Columns FB 28x65 mm
2 Flange Beams FB 22x65 mm
3 Steel Plate 9x167x329 mm
4 Web bottom at column
5 Reinforcement
6 Wire fabric hanger
7 Web (beam)
8 Hole (150 mm) : concrete connection
9 High tension bolt
10 Reinforcement D6 @ 100x100)
11 Base plate 36x460x460 mm
12 Anchor bolt



1 Asphalt prepared roofing
2 Insulation 255mm
3 Void Slab 15mm
4 Air Conditioning Outlet
5 Carpet Tile 500x500mm
6 Raised Accessed Floor
7 Insulation 20 mm
8 Concrete panel 45mm
9 Exposed Concrete Ceiling (Hydrophobizing agent finish)
10 Hydrophobizing agent finish

2 Precast Concrete Technology

2.1 Introduction

In today's "production" of architecture, what was once the manual assembling of building materials is now often the combining of industrially prefabricated semi-finished goods. However, the term "prefabricated" can lead the planner wrong direction. For precast concrete elements are not ready to use semi-finished goods, but rather factory produced bespoke components for specific applications. They are produced as invidual elements for specific applications, and the architect really acts as a planner in their development (Peck, 2006).

Precast concrete systems enable fast and effective completion of many different types of buildings and other structures. Units are custom designed, formed and cast according to precise instructions, and partially "cured" in a location away from the actual building site (Lu, 2014). These units are made in the factory while the final completion of installation is carried out on site, furthermore precast concrete can be interpreted as manufactured concrete (Yee, 2001).Casting off-site is the manufacture and pre-assembly of components, elements or modules before installation into their final location. Superior quality, through factory-based quality control, precision engineering and design standardisation is the key advantage of off-site systems over conventional forms.

This research gives an overall information about precast concrete systems by explaning respectively; pros and cons, external limitations, formwork process, colour and texture possibilities regard to their aesthetic potential, the cultural influence, connecting and joint systems and environmental affects of the technology. Later, the precedent study is analysed regarding to construction techniques and building details.

2.2 Precast Concrete Technology

This is a well-established modern method of construction, delivering robust components via offsite manufacturing. The advantages of precast concrete arise from fabricating components in factory conditions and include;

• Excellent quality control: protected from the vagaries of the weather;
• Precision moulds: a close control of tolerances;
• A wide range of fine finishes & crisp edge details: effects by the concrete density and formwork contours;
• Batching of sand, aggregates and cement : providing consistent colour and dependable performance characteristics;
• The integration of details and services;
• Pre tensioning;
• Large components which are simple and rapid to install.

The production of precast concrete, however, does have limitations, including;

• The transportation of heavy components;
• The size and shape of components can also be limited by transportation;

• The form of the precast component needs to be removable;
• The need for repetition to amortise or limit the impact of the cost of the mould.

The maximum size of precast component will be limited by the road transport regulations and the specific location of the size, for example the presence of the low bridge on the route to site. However very large components can be transported (Stacey, 2011). The length of a unit should not exceed 12m, the normal vehicle length, the height should not exceed 4,5m and the weight should not exceed 7 tones to ensure that a crane can easily transport and erect the material on-site. The nature of the site, the availability of tower crane and storage should be considered before transferring the precast elements to site (Concrete, 2012). In the UK a load of over 25.9m long by up to 4.5m high, and over 4.3m wide, requires both notice to the police and a 'vehicle mate', in accordance with Road Vehicles(Construction and Use) Regulations. The typical component miles or delivery distance of a precast concrete component in Britain is 100 miles.

For each precast manufacture, there is an optimum utilisation of each mould. A single wooden mould can be typically used to cast about 30 units before repairs will be necessary. To speed up the production process, the precaster will use additives in the mix to speed up the curing process, typically striking in 24-hour cycle. Therefore, if cost of the component is critical, there is a need to achieve good repetition.The diagram in fig 13 shows an analysis of the repetition of units and how this reduces the cost of the mould over a large number of units. The life of a mould is dependent on whether it is made from wood, polymer composite or steel. On a large project it may be necessary to have more than one mould for the same component – this may due to wear, or the need to deliver all of the components within a given construction programme (Stacey, 2011) .

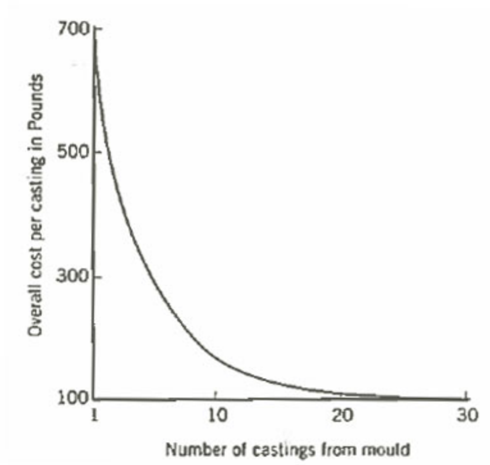


Figure 13 Diagram shows the relation between the repetition-economy of production (Trent Concrete Ltd.)

As discussed above, precast concrete is at its most effective if the moulds can be used many times, amortizing the cost of the mold across say 25-30 times. The need to reuse moulds, however, is a restraint on the imagination of an architect. It is possible to provide a family of elements that come from same mould by using stop sections and inserts (fig 14). It is essential in the design of of a precast concrete component that the form can be removed from the mould, thus draft angles should be included and under cuts need to be avoided. The precast component easily should be withdrawn from the mould.

Figure 14 (Left) Stop section used in molds; (Right) Craftmanship integrated to create timber moulds

The surface finishes of elements cast vertically hardly differ from those of in situ concrete. Where it touches the formwork, the concrete of the course mirrors the inside face of the formwork, but the open side a manually trowelled or floated finish is customary. This result in two different surface finishes: the formwork side and the smooth side. Besides the use of form liners, which leave an imprint of concrete, it is also possible to treat the surface of the open side using various of techniques. The options for working the surface and the choice of tools for doing so are limited only by the architect's imagination (Peck, 2006).

In terms of aesthetic aspects, coloured concrete is usually more successful with precast concrete than with in-situ concrete because the quality of the concrete, the humidity of the air and the curing time can be better controlled in the works than on the building site. Coloured concrete, owing to the choice of aggregate, also influenced by the curing time within the formwork. Typically the longer, the darker. The key issues here are the moisture absorption properties of the shutterface. Nevertheless, even with precast elements, coloured concrete is still a difficult subject which requires detailed, careful planning and preparations. The production of coloured concrete calls for considerable experience and knowledge about concrete mixes and the effects of pigments in order to achieve a reproducible, constant product (Peck, 2006).

From the cultural viewpoint; timber formwork offers an opportunity to continue the timber craft tradition. Tadao Ando, Japanese architect who created a new architecture with concrete, noted at a conference in London, that the carpenters making shuttering for his projects in Japan would expect to achieve a tolerance of ±1 mm in 6000 mm. The precision of his concrete is a result of cultural continuity and the continuity of this craft tradition. The exemplary use of concrete by Swiss architects, is facilitated by continuity of carpentry craft traditions within Switzerland (Stacey, 2011) . Xilin Lu, professor in Civil and Structural Engineering at Tongji University, refers that precast concrete structures reflect the local construction culture, so precast concrete structures in different countries and regions can show different cultural characteristics. The future development of structural systems may promise to be colorful and to enrich the local cultural environment.

The jointing and connecting of precast concrete elements work un a similar way to a giant "building kit" and is subject to similar, simple rules, provided the "builders" adhere to certain principles (Peck, 2006). Effective design and construction is achieved through the use of suitable connections to cater for all service, environmental and ultimate load conditions. The structural systems are composed of precast concrete elements that are joined together in a mechanical way, for example using bolts, welds, reinforcing steel, and grout and concrete in the joints, as shown in figure 15 (Engström, et al., 2008).

Figure 15 Grouted dowels (left), bolted steel plates (Engström, et al., 2008)

The structural connection interacts closely with the adjacent structural elements, and the design and detailing of the connection is influenced by the design and detailing of the adjacent elements that are to be connected. Therefore, the connections and elements must be designed and detailed implicitly so that the flow of forces is not only logical and natural, but the forces to be resisted by the connection can be transferred into the element and further on to the overall load-resisting system. Standardised types of structural connections are often listed in design handbooks or catalogues from precast element producers, although this is not just a question of selecting an appropriate solution from listed standard solutions. To improve the detailing, to find proper connections in specific situations when the standard solutions do not fit, and to develop innovative solutions, the designer must be prepared to work with connections in a more creative way.

It is necessary to distinguish between a 'joint' and a 'connection'. A 'joint' is the interface between two or more structural elements, where the action of forces (e.g. tension, shear, compression) and or moments may take place. A 'connection' is an assembly, comprising one or more interfaces and parts of adjoining elements, designed to resist the action of forces or moments. The design of the connection is therefore a function of both the structural elements and of the joints between them. This is explained in figure 16 for the case of a beam-to-column connection. In addition to the actions of forces connection design must consider the hazards of fire, accidental damage, effects of temporary construction and inaccurate workmanship, and durability (Engström, et al., 2008).

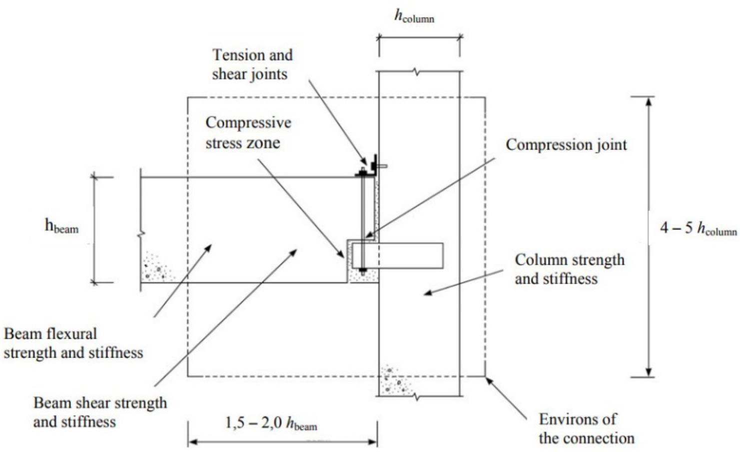


Figure 16 Definition of 'joints' and 'connections (Engström, et al., 2008).

Typical components are joints with joint fills, tie bars, anchor bars and other coupling devices, and the connection zones of the connected precast concrete elements, see figure 17. Often the joint is provided with a joint fill of grout, mortar or concrete, depending on the width of the gap to be filled. Often considerable concentrated forces are introduced in the concrete elements through the joints and the connection zones will be strongly influenced by this force transfer. For instance, tie bars, anchor bars etc. need to be anchored in the connection zones.

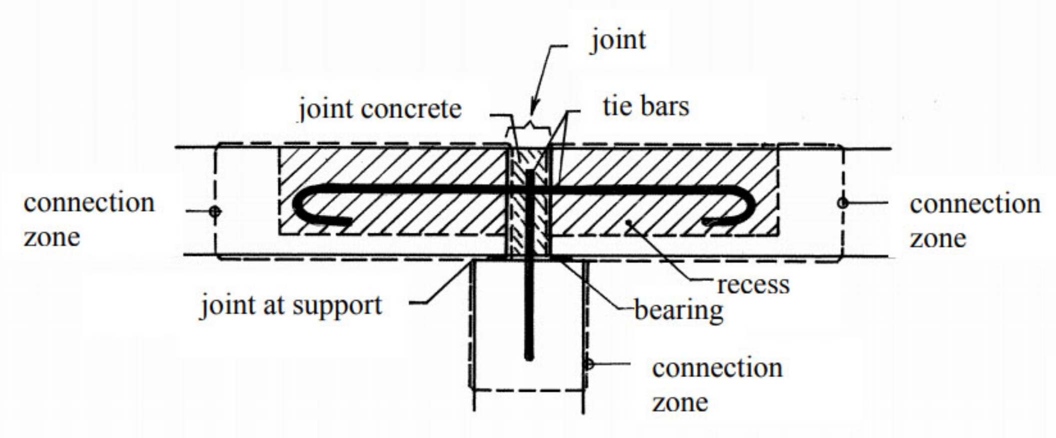


Figure 17 A structural connection consists normally of several components. (Engström, et al., 2008)

There are several ways to obtain tensile capacity in connections. Considering the safety aspect only, the order of preference is as follows:

1 Bolting
2 Grouting reinforcing bars at the site
3 Embedding reinforcing bars in epoxy or polyester at the site
4 Welding

The main rule of design of the connection zones to transfer the forces, originating from the joint, to the principal load resisting system of the structural member (Engström, et al., 2008).

Consequently, the facts are stated that claim the sustainability strengths of precast units:

1 Speed of construction: Precast components can be manufactured in much larger sizes, reducing shipping and erection time, and costs in parking garages and other structures. Lighter, larger wall panels allow for a faster and more economical enclosure. Lightweight precast mixes and newer, alternative reinforcement technologies reduce the energy required to produce, transport and erect by as much as 50 percent.

2 Maximizes available space: Precast concrete wall sections can be produced with longer spans, and in more narrow thicknesses, allowing more usable space within the same building footprint as other construction methods (fig 18).

3 Smaller footprint: Because precast concrete is formed offsite, casting can begin while foundations are being placed. Fewer trucks and less time are needed than would be for transporting other building materials to the jobsite. The result is a smaller site construction footprint with less dust and waste.

4 Durability: Factory-controlled precast ensures a low water-cement ratio (0.40), ensuring the concrete will resist water penetration, which results in a higher quality concrete than what is typically poured onsite.

5 Energy conservation: The national energy code recognizes mass walls as requiring considerably less insulation than other construction types. Concrete, a thermal mass, absorbs and then slowly releases heat. The lagged effect of heat transfer can reduce the heating and cooling loads and the equipment needed to condition a building. Lighter-colored concrete helps reduce the heat-island effect and associated HVAC costs.

6 Recyclability: Precast concrete by nature is a highly durable material, outlasting many other construction types. Not only is it resistant to moisture, mold, severe weather and other environmental factors, it can be designed to allow for expansions and changes that reuse existing precast components in new designs (Anon., 2009).

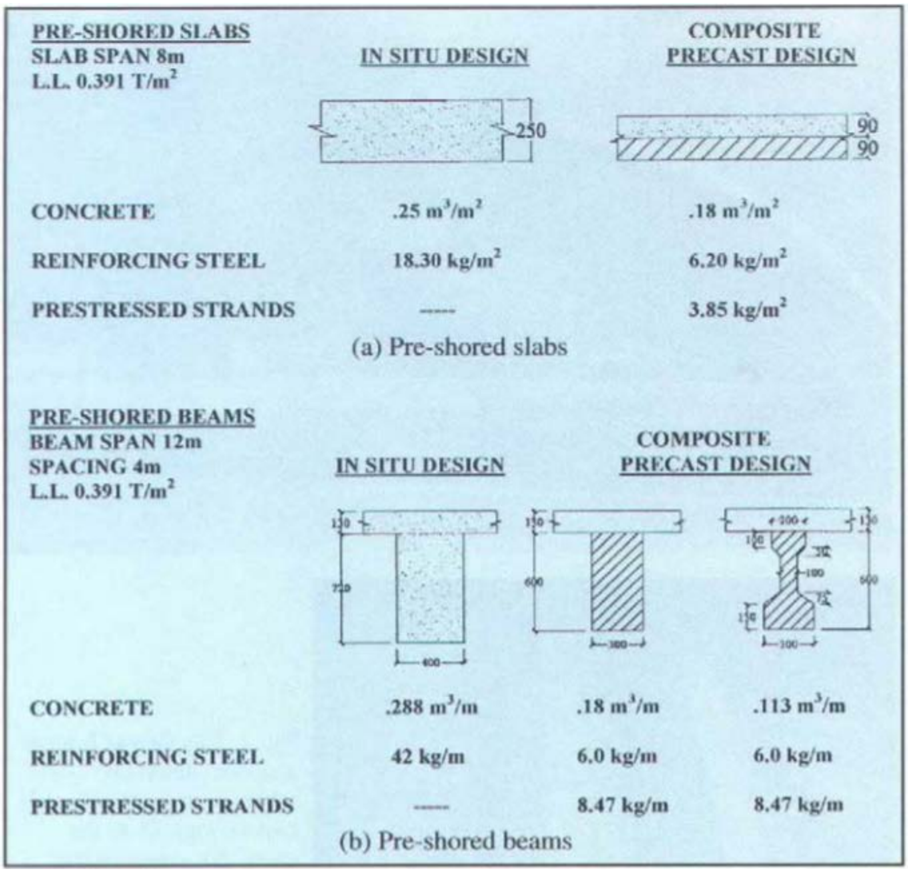


Figure 18 Materials savings using precast concrete (Yee, 2001)

2.3 Conclusions

Precast concrete is often selected for its robustness and the high quality of finish. The study shows precast units ensure highest precision and constant quality by using modern method of construction, benefiting from the quality control a factory environment can provide. It is claimed that the technology offers limited flexibility to architect mostly leads to modular grid in terms of making benefit of the costs being reduced by the help of using the moulds repeatedly. However, the wide range of advantages given for artistic taste such as implementing complicated formwork patterns on the surface and providing far better constant colour.

In search of ideal design for the products, being innovative, unobstrusive, long-lasting, understandable, honest, little design as possible, environmentally friendly are the parameters of the famous German industrial designer Dieter Rams. From that viewpoint, with all the aspects mentioned precast concrete becomes encouraging for the ones who seeks good level of design.

Figure 19 The entrance to the courtyard is via a cut-away corner (Phillips & Yamashita, 2012)

2.4 Precedent Study: Four Boxes Gallery

This gallery is located in Northern Denmark, designed by Japanese architects Atelier Bow-Wow, on a former farm property that has been converted into an art school. (Phillips & Yamashita, 2012). The 250 square meter gallery is set on the green lawn of the school between the Craftsmen's School and the red brick Idé-Pro factory.

The building is named the Four Boxes Gallery because of its layout: outdoor galleries and a light big indoor gallery make up the two lower boxes of the building. The middle, third box is a smaller exhibition room, and the fourth box at the top is a private workshop area for artists in residency.

The appraisal of the selected building aims to analyse the details employed regarding to the concrete technology. The following briefly mentions about the concept to give an idea how the concstruction type, in this case chosen by the client beforehand, has influenced the production.

2.4.1 Concept

In one of the interviews of Momoyo Kaijima, the partner architect of Atelier Bow-Wow, claims that they were advised to use prefabricated concrete, since it is affordable, faster to use and easier to work with during the Danish winter. And describes the form like an upwardly striving bento box in which each individual room has grown out of the whole, the building supplements the creative workshops, residential facilities and common rooms of Krabbesholm School, by adding long-awaited exhibition facilities to the complex.

In Japan a dinner of rice and fish/meat is called a bento meal. A bento box with individual compartments for different ingredients is available both as a cheap mass-produced product and as an exclusive example of fine craftsmanship. Just like an actual bento box, the Four Boxes Gallery endeavours to present its contents as elegantly as possible by providing a simple structure (Etherington, 2009).

Figure 20 Plans and Section; Overall form is a development of a diagrammatic plan which encompasses the box forms

2.4.2 Construction Techniques and Details

The gallery is built entirely of precast concrete panels which are of different heights, enclose a three storey volume placed between two equally sized exterior grass courtyards. It is observed in figure 21 that the widths of each floor generated by the width of precast units which are 2.40m in “y” axis. It indicates that the design was optimized so that the smallest number of large units could be used.

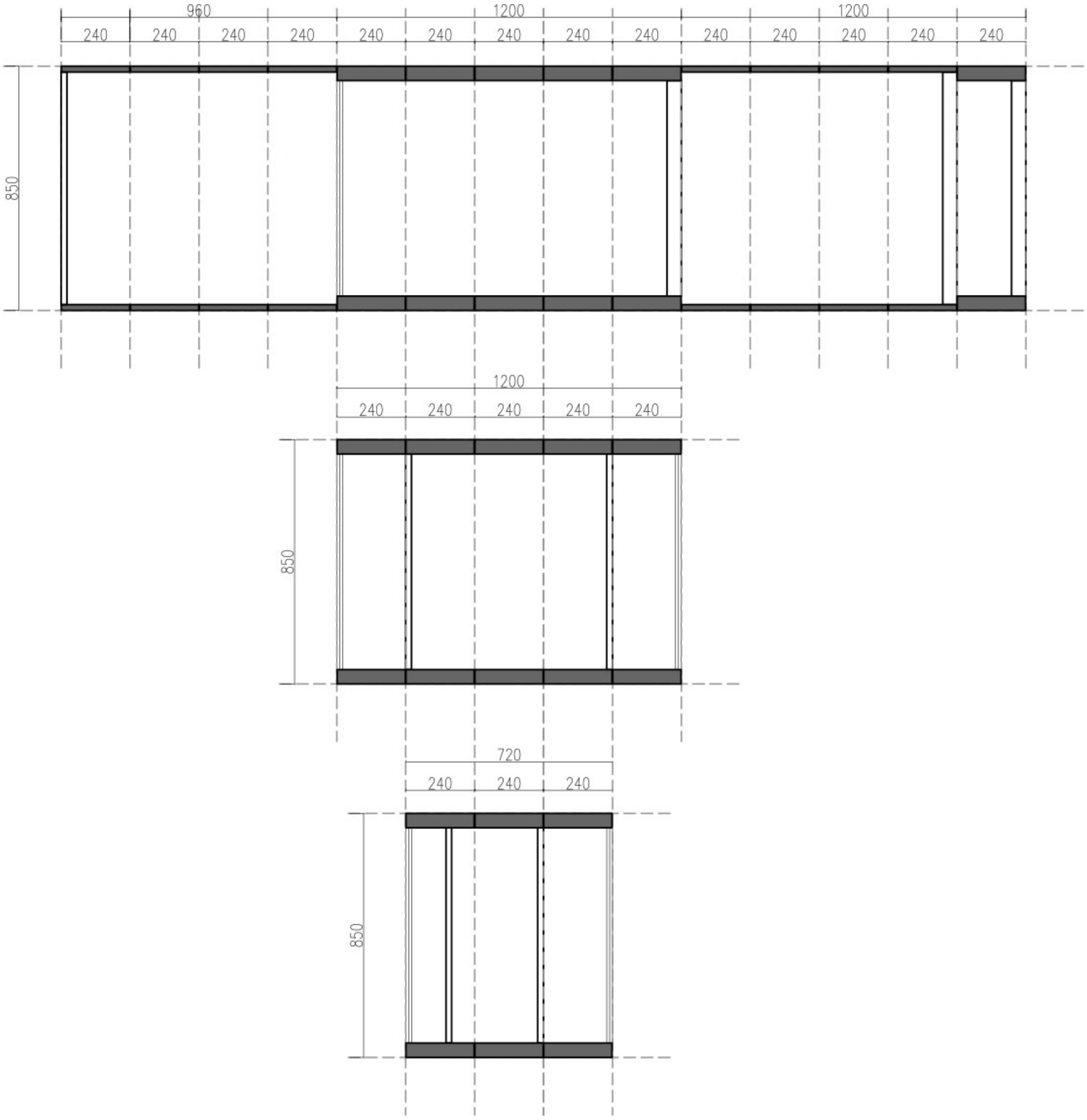


Figure 21 Plan diagram shows the repetiton of the precast units

The approach is reflected over the surface by the formwork lines help relieving the plainness effect of the façade and give the observer a chance to read the mathematic in the contribution of the each floor.

The block-like building has very few openings longitudinal sides whereas the windows located along the lateral walls without interruption. Regarding to standardised manufacturing, these placements of openings, simple façade design, makes sense as there is no necessity to cast another solid units might have occurred in different size.

Figure 22 Windows along the facade (left); fairly small openings seen on longitudinal walls (right)

Painting and texture are the issues comes along with precast. Figure 23 shows the gallery interior is dominated by white painted colour, good selection for exhibition spaces, used in the concrete surfaces facing inward on the other hand the walls look out are remained as concrete as the other panels in outdoor.

Figure 23 White colour in the walls facing inwards whereas concrete texture seen on the walls look ot the window

Details

It is observed that the monolithic effect of the building is saved by avoiding the use of disruptive details. For example, the paraphet (see section detail_1) is a special design because the normal detail, metal capping, could not be reconciled with the architectural concept. The paraphet detail had to be invisible from the outside. Instead of using an additional, new material to cover the parapet, the roof edge was also cast in concrete.

The use of precast concrete sandwich panels comprise an outer layer of concrete, a layer of insulation and a backing leaf of concrete. They offer a reliable and cost-effective route to providing low-U values and thermal mass. Only the internal leaf is considered to act structurally. Sandwich panels combine structure fare-faced finishes and insulation in one component. These prefabricated products offer significantly reduced site time as well as factory-based quality (Stacey, 2011). Mainly in the industry, the two concrete skins of panels are tied together using preparatory ties with a very low coefficient of thermal conductivity (see fig 24).

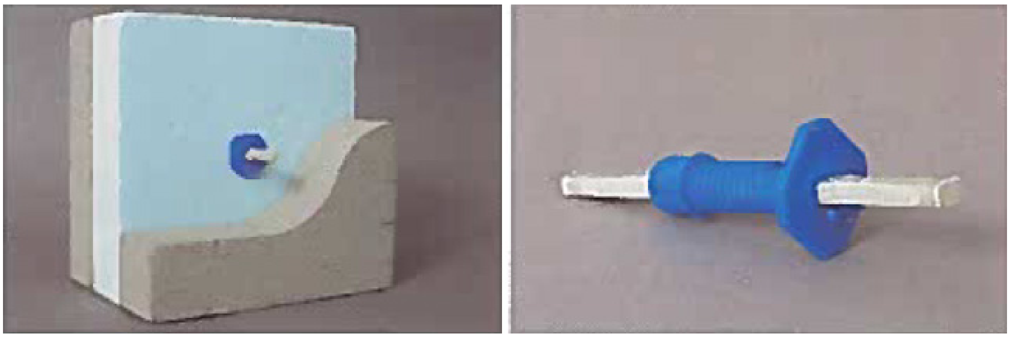


Figure 24 Thermomass wall ties (Stacey, 2011)

Because the insulation below the ground slab in contact with the gravels regarding the durability, presumably the extrude polystyrene insulation was employed here. But it is considered that the insulation between the sandwich panels might differ, in this case, looked like wool insulation.

The wire loop connectors are to make connection between precast walls (see plan detail_1). Transverse reinforcement can be provided in the form of wire loops for ease of erection where there is no site formwork required. They will need to fixed to the formwork and the flexible folded wires will need to be pulled out to make a connection when ready on site. The load will be transferred from one concrete panel to the other panel via wire rope loop.

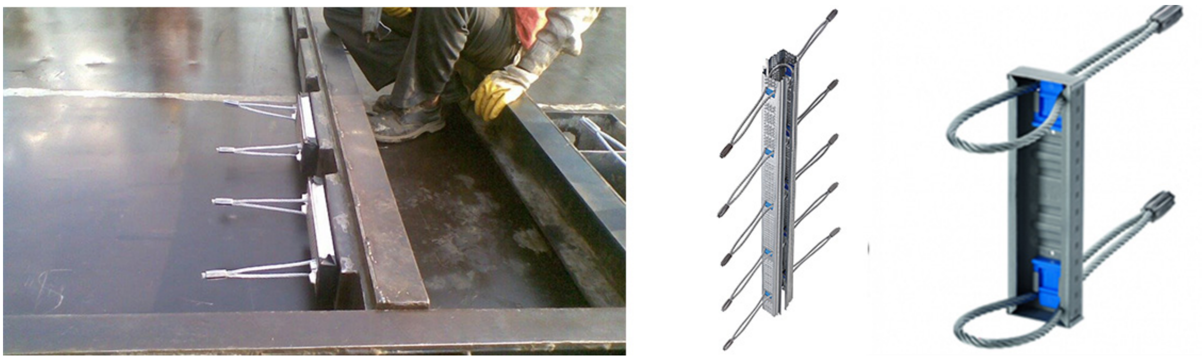


Figure 25 (left) The wire loops engaged to formwork, (middle&rigth) exemplary images of the wire loop connectors

Hollow core slabs were lapped to load-bearing concrete sandwich panels with inserting reinforced bars into slab keyways. No filling required on this connection just like as the same approach between the wall panels. It is obvious that any use of cast in-situ concrete had been avoided.

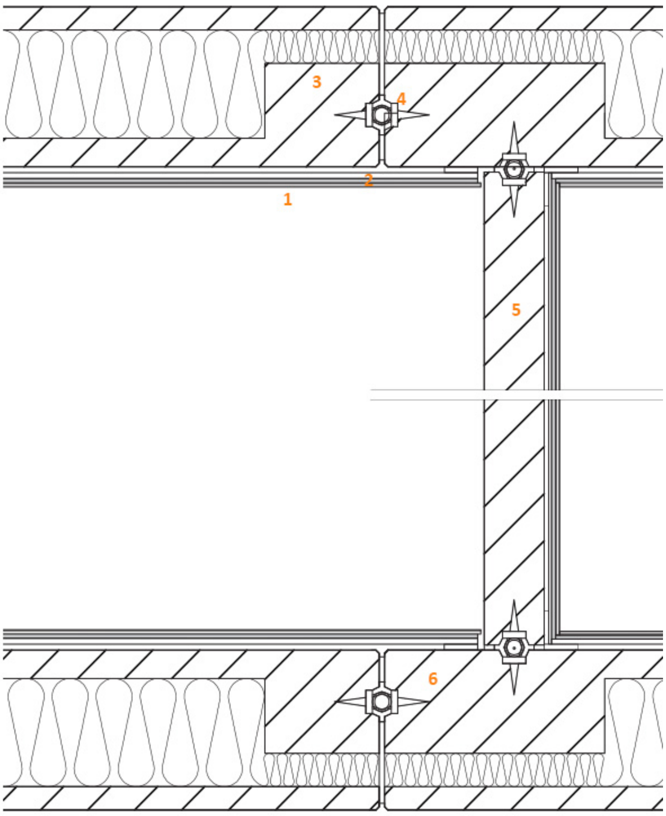
Figure 26 Aluminium cladding / timber sash

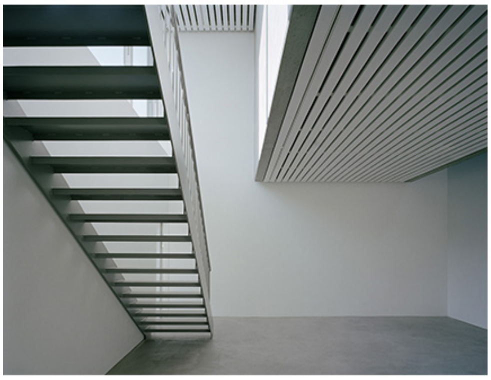
Timber and aluminium utilised together in the frames. The constructions consist of an all-timber sash and frame with external alu-cladding offering protection against the weather. The advantages are as follows;

- Low maintenance
- Natural look inside
- Long lifetime
- Protection against the weather

PLAN DETAIL _ 1

1 Plasterboard 12.5 mm, paint finish (RAL 9003 signal white)
2 Plywood 12.5mm, firing strips 22 mm
3 Concrete sandwich panel 480 mm
4 Wire loop box joints
5 Precast concrete panel 180 mm
6 Concrete sandwich panel 480 mm



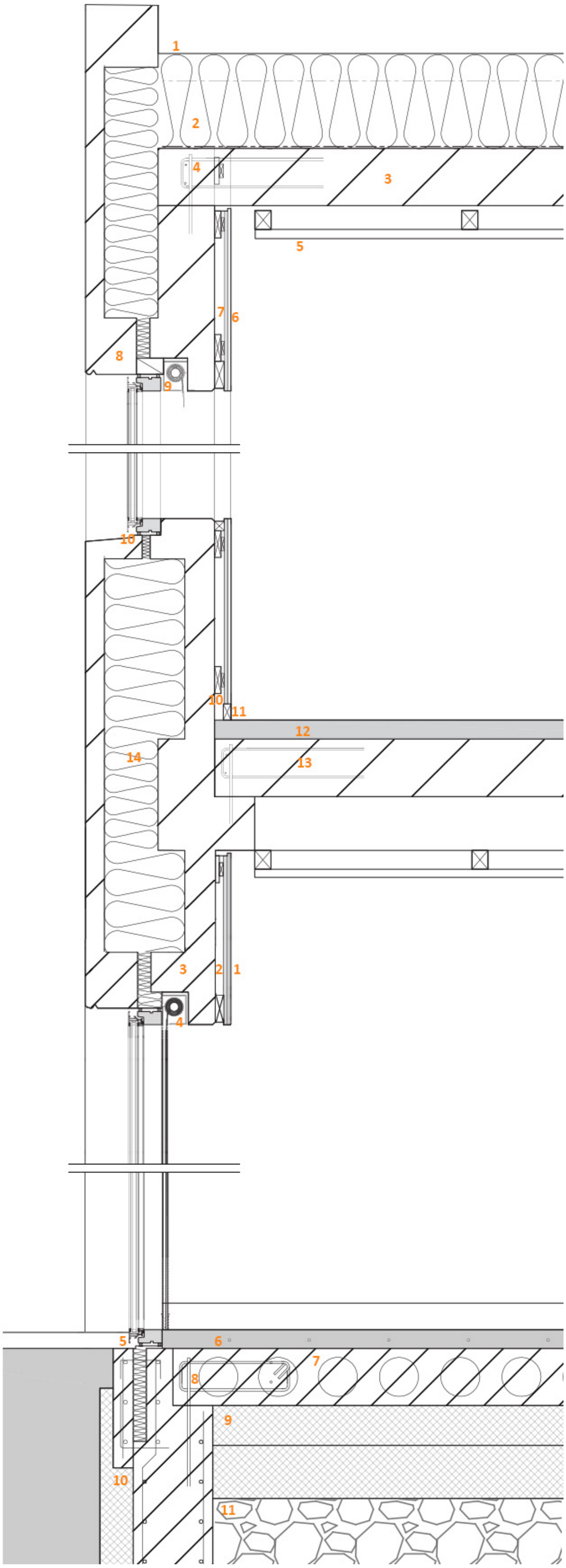


SECTION DETAIL _ 2

1 Double-layered felt roofing
2 Insulation 250-300 mm with slope 1:40
3 Precast concrete 215 mm
4 Steel reinforcing bar joints
5 Wood louvres 34x98 mm, paint finish (RAL 9003 signal white)
6 Plasterboard 13 mm, paint finish (RAL 9003 signal white)
7 Plywood 15mm, firing strips 22 mm
8 Concrete sandwich panel
9 Roll curtain
10 Aluminium and wood sash
11 Aluminium plate 1 mm, paint finish (RAL 9003 signal white)
12 Polish finish concrete 70 mm
13 Precast concrete
13 Insulation (wool)

SECTION DETAIL _ 3

1 Plasterboard 13 mm, paint finish (RAL 9003 signal white)
2 Plywood 15mm, firing strips 22 mm
3 Concrete sandwich panel 480 mm
4 Roll curtain
5 Aluminium and wood sash
6 Polish finish concrete 70 mm
7 Precast concrete panel 150mm
8 Joint??
9 Insulation 350 mm
10 Insulation
11 Pebbles



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