IMPROVING EFFICIENCY AND EFFECTIVENESS IN THE DESIGN, MANUFACTURING AND CONSTRUCTION OF THE BEAM AND BLOCK SLAB SYSTEMS

By

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Declaration

I hereby declare that the content of this thesis, entitled improving efficiency and effectiveness in the design, manufacturing and construction of the beam and block slab system, is a true reflection of my own work, and that this thesis, in whole or part, has not been submitted for a degree to any other university or institution.

BP Khuzwayo **date**

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People that took their time to respond to the questionnaire(s) and participate during formal and informal interviews.

Moreover and most importantly, I thank the Lord and my family for encouragement and continual support.

Abstract

Beam and block slab systems have become a preferred suspended flooring technology in South Africa. Their structural efficiency and relatively low cost makes them suitable for low to medium cost developments. Like all other structural components, they are required to demonstrate sound structural integrity.

Concerns were raised by some manufacturers and users in Durban (South Africa) about (a) the lack of basic technical information which makes it difficult to identify methods of improving efficiency and effectiveness of these flooring systems in general, (b) the efficiency and effectiveness of concrete masonry rebated filler blocks - with respect to the load carrying capacity and protecting the structural topping from fire, (c) what constitutes acceptable quality of a deliberately roughened precast concrete surface, (d) interfacial tensile bond strength of special connections and (e) an alternative rib that can span 5 metres without temporary props. These issues were investigated by the student.

Thus, this project aimed at improving the structural efficiency and effectiveness in designing, manufacturing and constructing beam and block slab systems was undertaken in Durban, South Africa, between 2012 and 2013. Pilot studies (involving questionnaires), interviews with manufacturers, site visits, and testing of non-structural and structural components were also undertaken.

The first aim (in order to address concern (a)) was to provide users of beam and block slab systems with basic technical information about the possible ways to improve efficiency and effectiveness in the design, manufacturing and construction of beam and block slab systems by undertaking an exploratory (pilot) study to better understand users of these systems concerns. The second aim (to address concern

(b)) was to investigate, by conducting a series of strength to weight ratio tests, how efficient or inefficient these filler blocks are, examine the structural integrity with respect to the integrity of the manufacturing methodologies and the product thereof, and formulate a method to quantify the fire-resistivity of concrete masonry rebated filler blocks to the structural topping with respect to confining fire. The third aim (to address concern (c)) was to determine what constituted acceptable quality of a deliberately roughened precast concrete surface through a literature review and by conducting a survey to learn about the construction methodologies used by manufacturers. Site visits were undertaken to validate information given by the contractors. The fourth aim (to address concern (d)) was to determine interfacial tensile bond strength through physical testing of deliberately roughened concrete ribs which are sometimes used in special connections. The fifth aim (to address the last concern (e)) was to make an assessment by undertaking a basic comparison study between one local beam and block slab system that uses a shallow rectangular precast pretensioned rib to beam and block slab systems used in the United Kingdom and propose an ideal section (precast pretensioned rib) that spans up to 5 metres without temporary props.

With respect to the first aim, it was found that the lack of technical knowledge, including access to critical information about the design philosophy, manufacturing and construction standards of these flooring systems leads to reluctance in selecting them. The outcome of the second aim is that all concrete masonry rebated filler blocks tested were found to be effective because they supported more than the required construction load but some were shown to be inefficient as more materials, such as binders, are wasted in producing over-strength filler blocks and also, undertaking trial mix designs and the testing of samples prior to batch production will reduce costs. A method is formulated in the thesis that could also show that concrete masonry rebated filler blocks provide significant protection to the structural topping thereby preventing fire progression. With respect to the third aim, although a broom or brush is effective in providing a surface roughness (Rz) of 3 mm, it is not always efficient when considering factors like the variation in uniformity, appearance of laitance and roughening frequency, which are not addressed by the South African codes. The outcome of the fourth aim is that connections should be designed such that they do not rely purely on the tensile bond strength but through reinforcing bars (or ties) taking the full tension load causing delamination. With respect to the fifth aim, a basic comparison study indicates that T-section beams are more efficient than common rectangular ribs (±150 mm wide x ±60 mm deep) since they can eliminate completely the use of temporary props for spans of up to 4.51 m. Consequently, further research is underway to design an inverted T-section rib by using high strength precast pretensioned concrete that can span up to 5 m without using temporary props.

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Chapter 1

Introduction

1.1 The beam and block slab system

A beam and block slab system, also known as a rib and block slab system, is a one way spanning suspended flooring system. The slab consists of precast pretensioned reinforced concrete ribs supporting rebated filler blocks that are made of concrete, burnt clay, fired briquettes, shale, clay or expanded polystyrene overcast with an in-situ concrete structural topping (as shown in Figure 1-3), SANS code 1879 (2011: 4).

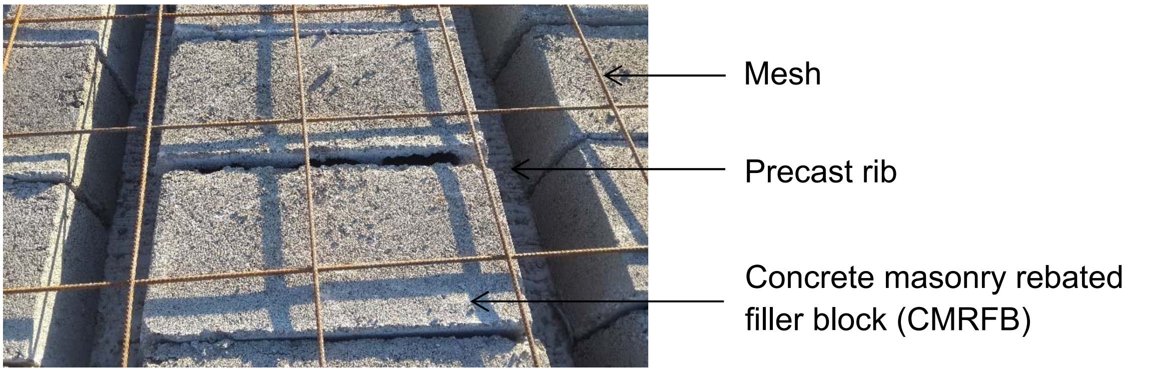


Figure 1-1: Above detail of a typical beam and block slab system

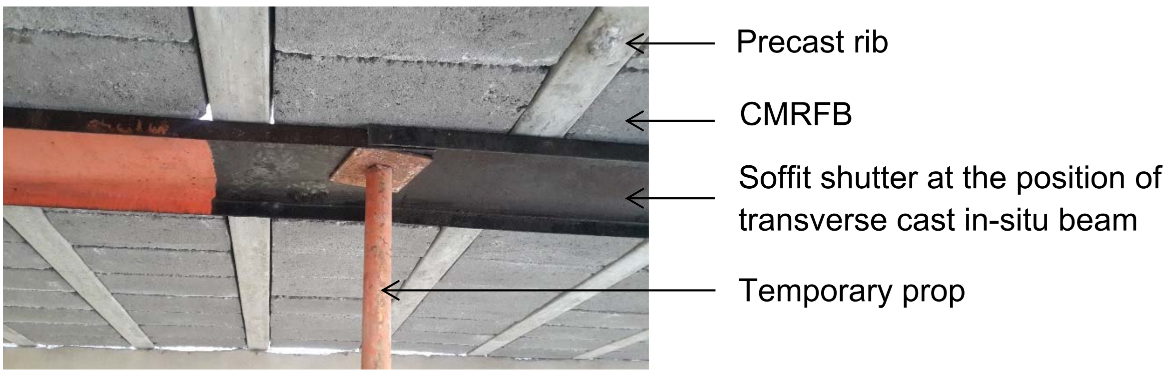


Figure 1-2: Soffit detail of a typical beam and block slab system

The technical detail of a typical beam and block slab system consisting of non-structural filler blocks and structural topping as recommended by the SABS code 0100-1 (2000: 55 and 56) is given in Figure 1-3 below.

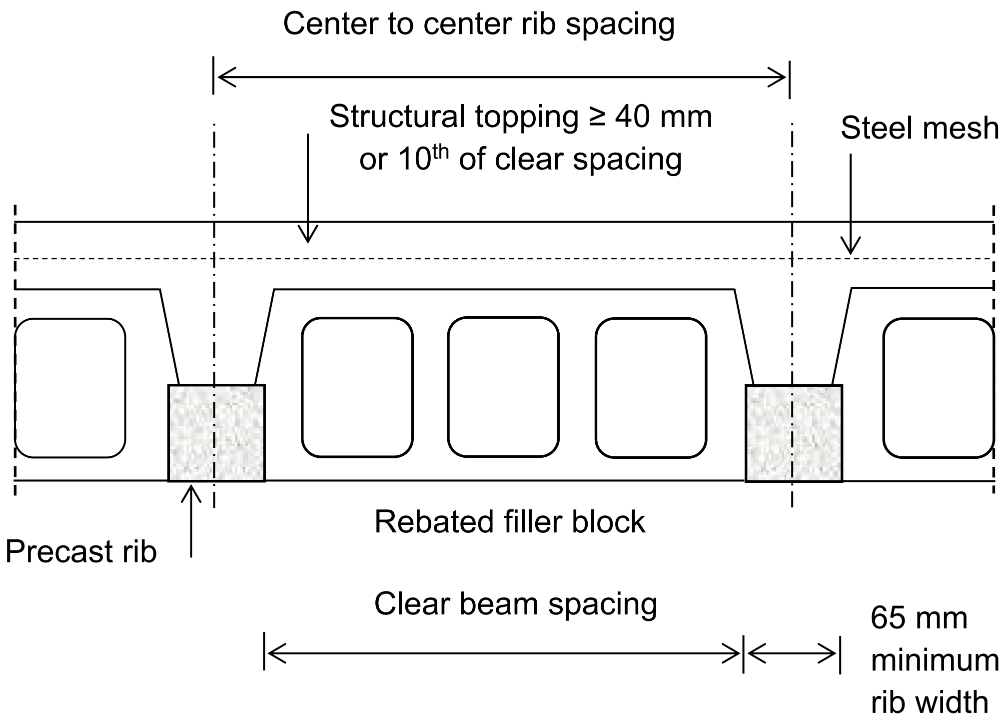


Figure 1-3: Technical detail of a typical beam and block composite slab system

1.2 Function of beam and block slab systems

The beam and block slab systems have been used as alternative suspended flooring systems since the 1940's (Precast Building Units 2011). Their applications have mostly been in residential, commercial, and industrial building schemes. These flooring systems are a proven economical, structurally efficient and versatile alternative to the conventional reinforced concrete slabs for spans of up to 7.5 m. They are suitable for light to medium loading arrangements. These systems normally cater for standard slab depths of 150/170 mm, 200 mm and 255 mm. The 170 mm and 255 mm thick slabs are convenient because they conform to 85 mm brick courses. The most common rib spacing is 560, 600, and 650 mm (Dean de Klerk 2013: 22).

The precast ribs initially support rebated filler blocks, concrete, and other construction loads with assistance from temporary props before developing the full composite action. Rebated filler blocks are available in different heights ranging from 60-350 mm, providing from 110-400 mm thick slabs or more, if double blocks are used (Dean de Klerk 2013: 22). The beam and block slab systems shallower than 150 mm and deeper than 255 mm are not very common in KwaZulu Natal and therefore, fall outside the scope of this study.

1.3 Current limitations of the beam and block slab systems

Precast ribs require temporary propping before and after casting concrete. The props may only be removed once the concrete has set and attained a minimum strength, and the composite interaction is developed between a deliberately roughened top surface of the rib and the thickened T portion of cast in-situ concrete (forming a composite T-section beam). According to annex D (informative) of SANS 1879 (2011: 13) the responsible engineer has to give approval for the props to be removed after the required strength of at least 17 MPa is achieved. These slabs generally require minimal props for a period between 7 and 14 days. This code also requires that a load transfer transverse rib is provided at every 8^{th} to 9^{th} (or 1.5 to 1.8 m maximum) filler block throughout the cross direction of the span (transverse direction) of the ribs. Providing a load transfer rib within the depth of the slab requires an additional soffit shutter/formwork.

1.4 General concerns with the current beam and block slab systems

- The horizontal shear resistance between the precast interface and cast in-situ concrete.
- The durability of precast pretensioned ribs with a 15 mm concrete cover over the steel when used in coastal areas.
- The fire-resistance of precast ribs with regards to the concrete cover over the pretensioned steel when a minimal concrete cover of 15 mm is used.
- The fire-resistance of the structural topping when the expanded polystyrene filler blocks are used with respect to the containment of fire/heat from progressing from one floor to the next.
- The contribution of fire-resistance of concrete masonry filler blocks to the structural topping.
- The evaluation of fire-resistance of concrete masonry filler blocks.
- The safety aspects of the beam and block slab systems with expanded treated and untreated polystyrene filler blocks with respect to fire resistance.
- The structural efficiency and integrity of concrete masonry rebated filler blocks.
- Plastering expanded polystyrene filler blocks with a normal sand-cement plaster.
- Differential shrinkage effects at both simply and continuous spans.
- Effective vibration of structural topping or non-vibration of structural topping with respect to the integrity of the shear interface.

1.5 Purpose of the study

The **primary aim** of this study was to provide the users of beam and block slab systems with basic technical information about the possible ways to improve the efficiency and effectiveness in the design, manufacturing and construction of beam and block slab systems. Efficiency implies investigating how well a design, manufacturing or construction procedure is undertaken and effectiveness implies how useful it is.

An exploratory (pilot) study to better understand users of these systems concerns was carried out by the student by interviewing users (see Questionnaire 1, Annexure A). Issues including thermal resistance to increased temperature (fire loading with respect to the concrete cover pretensioned steel and cast in-situ topping), bonding of normal sand-cement plaster with the soffit of expanded polystyrene filler blocks, and horizontal shear resistance were covered.

A presentation was then made by the student at the 7th Built Environment Conference in Cape Town in 2013 (Khuzwayo 2013: 88-98) and the comments received by attendees were useful in identifying other areas of concerns. These comments gave direction to where improvement of technical knowledge is needed and where the respective standard specifications provide inadequate details and recommendations.

For example, the structural efficiency and integrity of concrete masonry rebated filler blocks used in the country were amongst the issues raised which needed research in order to determine whether or not these blocks are structurally efficient.

The **second aim** was to investigate the structural efficiency of concrete masonry rebated filler blocks (including expanded polystyrene type). This was achieved by assessing the strength to weight ratio. Further to this, the structural integrity was examined with respect to the manufacturing methods. The student studied the current construction practices by the manufacturers which affect the reputation of the filler block manufactures as well as the beam and block construction industry.

A second survey (see Questionnaire 2, Annexure B) was used to get feedback from the manufacturers of these filler blocks. As a consequence, a method was formulated (and described later in this thesis) to quantify the fire-resistivity of concrete masonry rebated filler blocks to the structural topping. The method can be used to estimate the fire resistance of the structural topping with respect to confining fire/flames from one floor to the next.

Another issue that was raised by several respondents was the integrity of the precast rib concrete interface and how it can be optimized in order to enhance the horizontal shear resistance (rolling-shear). The **third aim** was to determine what constituted acceptable quality of a deliberately roughened precast concrete surface (see Chapter 2: literature survey) through a literature survey. The roughened surfaces of 120 precast pretensioned ribs taken from sites were assessed for the qualities identified in the literature. Horizontal shear tests (push-off tests) proved to be unnecessary as the surveyed literature provided adequate knowledge.

A third survey (see Questionnaire, Annexure C) was used to learn about the construction methodologies used by manufacturers and site visits were undertaken to validate information given by the contractors.

The **fourth aim** was to determine interfacial tensile bond strength through physical testing of deliberately roughened concrete ribs which are mainly used in special connections. The tension at the interface is often caused by differential shrinkage, uplift of the cast in-situ topping over the supports primary caused the nature of some types of structural connections.

Two common type connections (mentioned later in Figure 2-5 and Figure 2-6) that are directly affected by direct tensile stresses are investigated. The interfacial tensile bond capacity is investigated by considering the surface roughness (Rz) of 3 mm (undulation) and 17 MPa in-situ concrete when the temporary props are removed as specified by SANS 1879 (2011: 13). The factors such as the cleanliness and treatment of the concrete surface are also considered.

Tensile capacity of in-situ concrete on precast ribs was undertaken in order to determine the magnitude of tensile stresses when the compressive strength of in-situ concrete reaches 17 and 25 MPa concrete.

The **fifth and final aim** was to make an assessment by undertaking a basic comparison study between one local beam and block slab system that uses a shallow rectangular precast pretensioned rib to beam and block slab systems used in the United Kingdom. The lessons learned from aims one to four in this thesis lead to a proposal for an alternative rib for a beam and block slab system spanning up to 5 metres without temporary props.

Chapter 2

Literature review

2.1 Brief summary

This chapter consists of a literature review of factors to consider in the design, manufacturing and construction of beam and block slab systems. Below is a brief summary of the main issues covered by each section:

- Section 2.2. This section provides a basic introduction to the most common standard specifications used in designing, manufacturing and constructing the beam and block slab system.
- Section 2.3. This section covers a list of standard specifications dealing with some issues affecting beam and block slab systems.
- Section 2.4. The main issues addressed by the codes (in 2.3) and some guides to good practice with respect to this flooring system as a whole are discussed in this section, viz:
    - Design requirements
    - Material properties
    - Durability requirements
    - Manufacturing and construction accuracy
    - Bearing of precast ribs
    - Temporary supports
    - Typical standard connection details
    - Design loads
    - Construction requirements

- Section 2.5. Particular issues regarding the concrete masonry rebated filler blocks addressed by the SANS 1879, SANS 1215, SANS 9001/ISO 9001 and SABS 0100-2 are discussed in detail here.
- Section 2.6 The expanded polystyrene filler blocks are discussed in this section covering only the basic aspects like how it is made and fire performance.

2.7 The shear interface is discussed in detail. The SABS 0100-1 and SANS 1879 and the studies by Gohnert (1999, 2000 and 2003) are covered in detail. The fundamentals of surface roughness, types of precast surface roughness, surface treatment prior to casting the in-situ concrete topping and the causes of interface separation are also covered in this section.

2.8 Structural-fire requirements in both the South African standards and international literature.

2.2 Background

The beam and block slab systems used by the South African construction industry are mainly supported by standard specifications such as SABS 0100-1, SABS 0100-2 and SANS 1879. Some codes of practice mentioned later in this chapter such as SANS 10155 and SANS 9001 are there in order to ensure that sound structural flooring systems are attained. There are other available codes that can be used as a guide in the absence of the relevant codes like SANS 1215. The latter is used as a guide for concrete masonry filler blocks.

2.3 Design, manufacturing and construction standard specifications

The following is a list of South African codes used to design beam and block slab systems:

- South African Bureau of Standards, Structural Use of Concrete, SABS 0100-1.
- SANS 1879, Precast Concrete Suspended Slabs.
- SANS 10400-T, The Application of the National Building Regulations. Part T: Fire protection.
- SANS 10160-1, Basis of Structural Design, SANS 10160-2 Self-Weight and Imposed Loads, SANS 10160-7 Thermal Actions and SANS 10160-8 Actions During Execution.
- SANS 10155, Code of Practice for Accuracy in Buildings.

The following is a list of South African codes used for manufacturing and construction:

- South African Bureau of Standards, Structural Use of Concrete, SABS 0100-2.
- SANS 1879, Precast Concrete Suspended Slabs.
- SANS 9001/ISO 9001, Quality management systems – Requirements.
- SANS 10155, Code of Practice for Accuracy in Buildings.

2.4 South African literature

There is a lack of sufficient technical information in South Africa with regards to some specific details such as:

- The assessment of differential shrinkage cracking of structural topping in beam and block slab systems that are using either pretensioned or reinforced ribs.
- Plastering expanded polystyrene filler blocks with a normal sand-cement plaster.
- How to assess the vibration of the beam and block slab systems as a result of moving loads.
- Acoustical properties of beam and block slab systems.
- The effects of fatigue on beam and block slab systems.
- The containment of heat transmission and fire progression in beam and block slab systems.

The lack of detailed information can often lead to incorrect use of these flooring systems, especially from a structural and fire-hazard point of view. For example: a beam and block slab system with expanded polystyrene filler blocks may not be used in suspended floors on a multistory building purely from a fire containment point of view, even though the fire-rating may be well within the acceptable limits with respect to the cover.

In pursuit of the most economical structural solutions that would improve the efficiency and effectiveness of the design, manufacture and construction of beam and block slab systems, both local and international literature was surveyed in order to identify any shortfalls within the South African body of knowledge.

2.4.1 Design requirements

Beam and block slab systems are designed to meet the minimum requirements for the Ultimate and the Serviceability Limit State. At the Ultimate Limit State, the slab is designed to provide sufficient axial compression strength resulting from the pretensioning force, flexural strength and both vertical and horizontal shear capacities. For vertical shear, the slab is checked for both cracked and uncracked sections in bending and for horizontal shear; the top of the precast rib and in-situ concrete is checked for the horizontal shear strength. At the Serviceability Limit State, these flooring systems are checked for vertical deflection or camber (both up and downwards), tensile and compressive bending stresses. Excessive deflection demerits the appearance of the structural member and could affect the finishes (e.g. glazing and partitions). Big crack widths affect the durability of the structure especially over a long-term period.

2.4.2 Material properties

2.4.2.1 Concrete

The manufacturing of precast pretensioned ribs requires high-strength concrete with a characteristic 28-day strength of 40 MPa or above. The cast in-situ structural topping is generally made from a characteristic 28-day strength of 25 to 30 MPa concrete. The characteristic 28-day strengths above 30 MPa are rarely used for structural toppings for beam and block slab systems as they become uneconomical. A 30 year creep coefficient of 2 is often assumed for design purposes unless other means of calculating the actual value are available and justifiable. A 30-year differential shrinkage strain of 300 x 10^{-6} is commonly assumed to act between the precast ribs and cast in-situ concrete. This is a conservative value resulting from the uncertainty in determining the age difference.

2.4.2.2 Pretension wire

The pretension wire needs to conform to Figure 3 of SABS 0100-1 (2000: 14) with respect to the stress-strain relationship. Most manufacturers use 4 mm diameter, 1750 MPa high tensile strength pretensioning wire, which can be used in bundles with up to 10 wires to increase flexural strength. The same wire can be used to make hooks (also referred to as shear connectors) which are fixed at ±600 mm centers. Other manufacturers prefer to use a few 5 mm diameter wires. It is important to note that the dimensions and properties of cold drawn wires may vary with respect to the nominal diameter, nominal tensile strength, nominal 0.1% proof stress, nominal cross section, nominal mass, specified characteristic breaking load, specified characteristic 0.1% proof load and load at 1% elongation.

2.4.3 Durability requirements

The structural integrity of concrete requires that concrete should be able to resist chemical attack, abrasion, weathering action and other mechanisms to which the structure may be subjected to. Fulton's concrete technology (2009: 155 and 156) gives more details with regard to the durability of concrete based on two main factors, namely:

- The concrete system (the nature of concrete):
    - Intrinsic factors (e.g. concrete permeability).
    - Extrinsic factors (production and/or construction processes).
- Aggressiveness of the exposure environment:

- Physical attack (abrasion).
- Chemical attack (nature and concentration of aggressive agents).

Furthermore, it gives some integrated factors that should be considered by the structural designer and the person carrying the construction works in recognition of the aims of the designer, namely:

- The designer must have a thorough understanding of all mechanisms participating in the deterioration process which could involve chloride action and carbonation taking place in precast pretensioned ribs.
- The theory behind the reliability of the 'Practical Service Life Models' in giving an indication of the as-built structural durability performance which could require careful control of crack widths and concrete quality of precast ribs.
- The procedures that can be implemented to characterize the potential durability of concrete to be used in the structure from the materials knowledge point of view. Procedures may involve improved ways of vibrating concrete, ensuring accurate concrete cover over reinforcing steel or pretension wire and proper handling of precast ribs during transportation and on-site storage.
- The procedures for assessing and certifying the actual durability of the as-built structure. More studies are being conducted worldwide with respect to this.

Understanding the fundamentals involved in achieving the desired structural durability is important. Durability requirements are often ignored when optimizing the cost of beam and block slab systems. This is a common problem happening almost around the globe in many construction fields. Strict procedures can be implemented in both precast and cast in-situ structural components to enhance their durability that could save costs of refurbishment (e.g. provide good quality concrete and adequate concrete cover over pretension wires).

2.4.3.1 Concrete cover over pretensioned wire in coastal areas

Some precast ribs used along coastal areas may not conform with the minimum concrete cover requirement for various conditions of exposure as presented in Table 5 of SABS 0100-1 (2000: 21) which should be used in conjunction with Table A.8 and A.9 (2000: 64 and 69). Concrete cover varies between mild, moderate, severe, very severe and extreme exposure conditions. For example 15 mm concrete cover of pretensioned wires is insufficient when used without any additional finish (e.g. sand-cement plaster) in Durban.

2.4.4 Manufacturing and construction accuracy

The structural components used as precast elements in the beam and block slab systems need to comply with Grade 1 of the SANS 10155 (2009: 8 to 34). The permissible deviations for materials and dimensions of precast ribs, pretensioning wires, concrete topping and concrete masonry filler blocks are presented in Tables 2.1 to 2.6.

Table 2.1: Cross sectional dimensions of precast ribs.

Description	**Distance**	**Tolerance**
Width	≥ 65 mm	± 3 mm
Depth	≥ 60 mm	± 3 mm

Table 2.2: Cutting length of precast ribs

Description	**Distance**	**Tolerance**
Length cut by sawing	any length mm	± 10 mm

Table 2.3: Out of straightness

Description	Measuring tool	Tolerance
In-plan horizontal bow	3,0 m straight edge (spirit level)	10 mm downward (↓)
Elevation vertical bow	3,0 m straight edge (spirit level)	20 mm upward (↑) 10 mm downward (↓)

Table 2.4: Pretensioning wire

Description	Specified	Tolerance
Concrete cover over the wire	≥15,0 mm	0 mm

Table 2.5: Precast concrete

Description	Specified	Tolerance
Characteristic 28-day strength	40 MPa	-0 to +10 N/mm²
Characteristic strength at transfer	30 MPa	-0

Table 2.6: Filler blocks (excluding expanded polystyrene filler blocks)

Description	Tolerance
Dry mass	± 5 %
Wall thickness	± 2 mm
Length parallel to ribs	± 8 mm
Width perpendicular to ribs	± 3 mm

2.4.5 Bearing of precast ribs

The rib must sit at least 80 mm onto the load-bearing wall (or structural support). The common practice is to measure the as-built dimensions of all load-bearing walls before cutting the precast ribs. If the construction standards are guaranteed Grade 1, the ribs may be cut according to the designed lengths as per the structural/layout drawings. The rib must always sit with its entire width (common width 65-150 mm) on the load-bearing support (e.g. brick-wall).

2.4.6 Temporary supports

SANS 1879 (2011: 13) requires that temporary supports are placed in both transverse and longitudinal directions with a spacing of not more than 1,0 m transverse to ribs and 1.5 - 1.8 m parallel to the ribs (every 8^{th} to 9^{th} block for most slabs) respectively. Transverse props may be placed at every rib but may not exceed 1 m unless a support beam plank designed by a competent person is used to transfer the loads.

The vertical deviation measured from the top of the bearing plates of props as a result of unwitting erection at different levels, considering the settlement of temporary support foundations during construction (as a result of construction loads and self-weight) must never exceed 5 mm downwards. A parabolic upward pre-camber may prove useful and is recommended to reduce vertical downwards deflection. This is normally limited to 2 mm per linear meter of rib span.

2.4.7 Typical standard connection details

Through experience on these flooring systems (2007 to 2013), made by different manufacturers for different projects, it has proven useful that the manufacturers of beam and block slab systems provide some typical connection details indicating how their flooring system integrates with other structural elements made from cast in-situ concrete. The efficiency is achieved by informing the designer or the user about the possible ways in which efficient construction methods can be utilized. The design engineer can then decide whether the standard details can be used without any modification or some changes are necessary and should be designed for.

Below is a list of commonly used standard details that are provided in the manufacturer's catalogue FloCon Design Handbook (1991: 10/1 to 10/9);

- Pocketing the precast ribs into an existing vertical load bearing structure (e.g. masonry wall: one and two leaf wall).

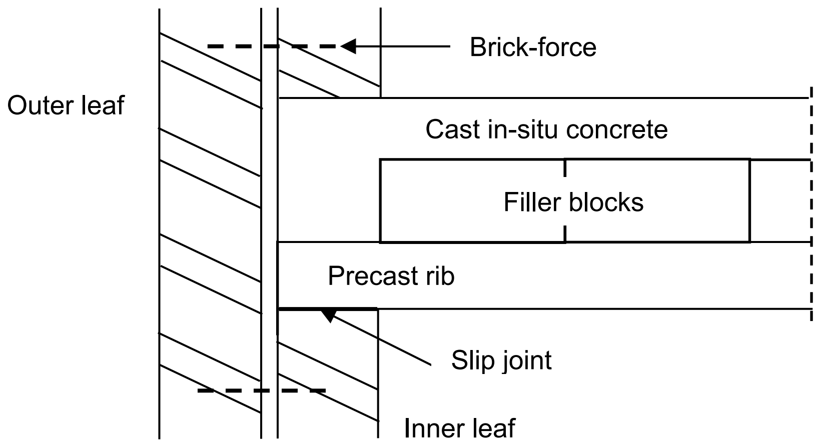


Figure 2-1: Precast rib inserted inside pocket

- Flooring system supported on a shelf angle section that may be bolted into the existing concrete structure (or masonry wall – if suitable). Notes pertaining to any details that need to be designed by the engineer should be clearly indicated.

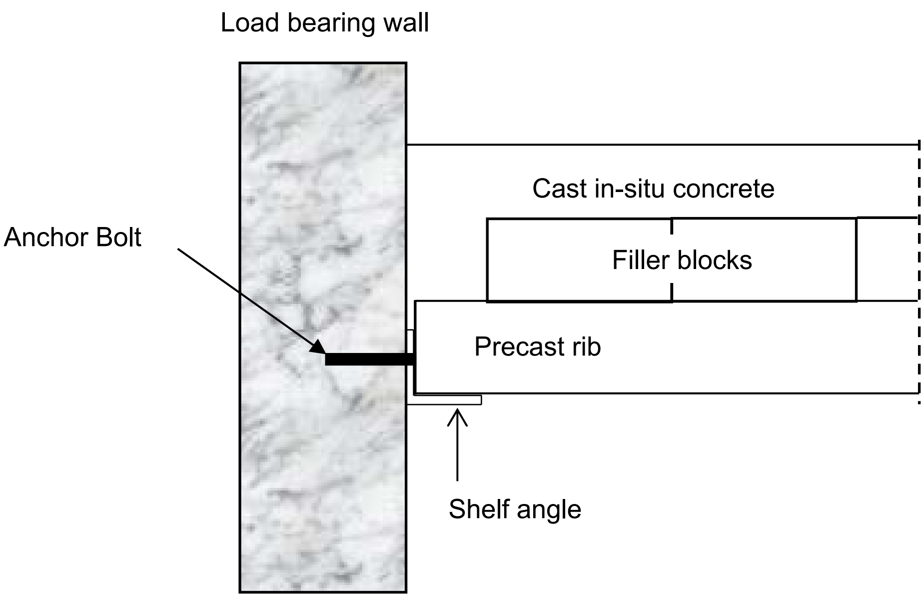


Figure 2-2: Precast rib supported by a shelf angle

- End/support detail of the flooring system bearing on a single or double leaf masonry wall (or concrete wall). The position of slip joints should be indicated when necessary (e.g. two layers of Malthoid).

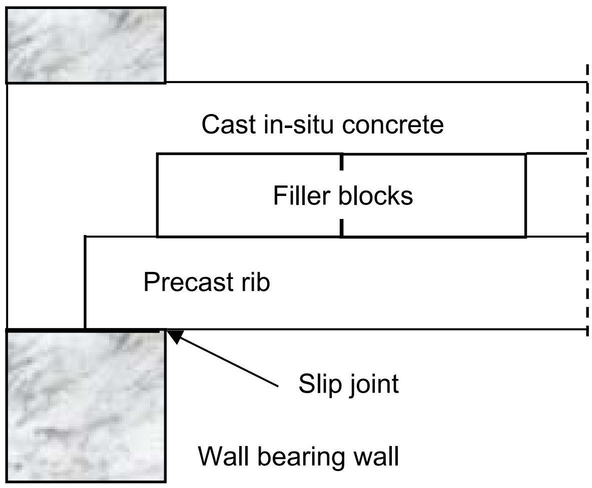


Figure 2-3: Rib supported by a load-bearing wall

- Additional ribs to support concentrated loads (e.g. a wall built on top and supported by this flooring system).

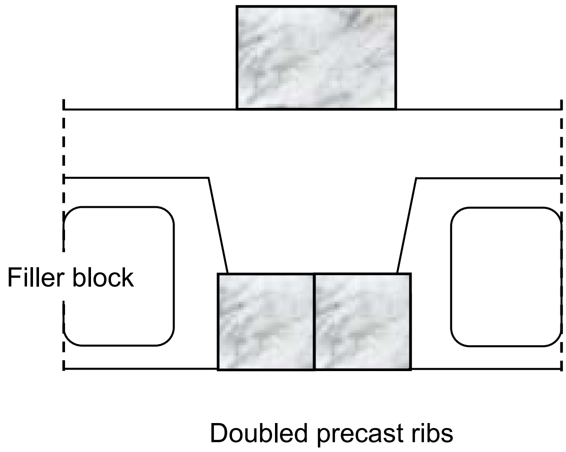


Figure 2-4: Additional rib at concentrated load

- Where the span of ribs change direction, (e.g. the precast ribs spanning in the North direction start spanning in the South direction). The detail at this intersection requires adequate attention (this is covered under objective 4).

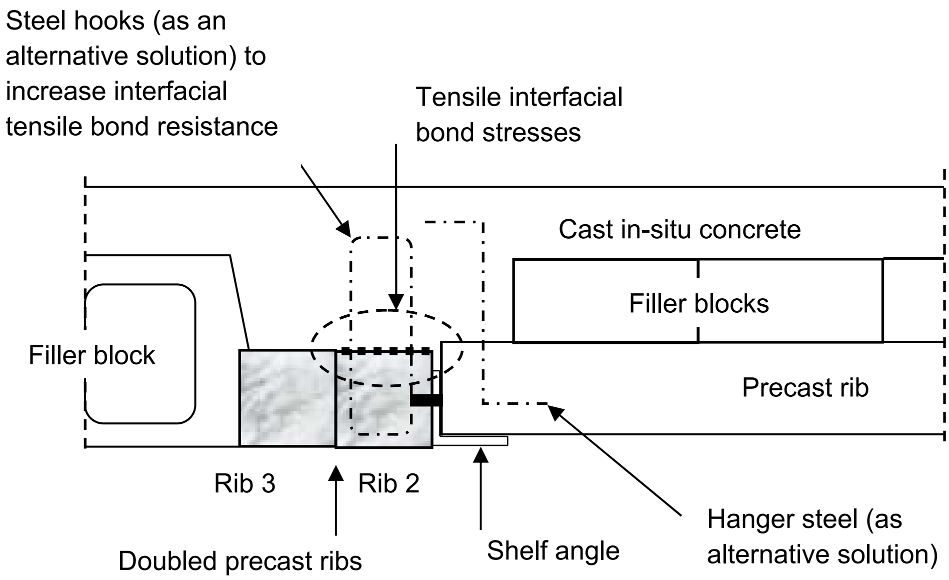


Figure 2-5: Precast ribs where the direction of the span changes

- End and transitional detail of a slab bearing; reinforced concrete down-stand beam; reinforced concrete slab-beam (i.e. a beam within the depth of the slab); down-stand structural steel beam, and; structural steel beam contained within the depth of the slab.

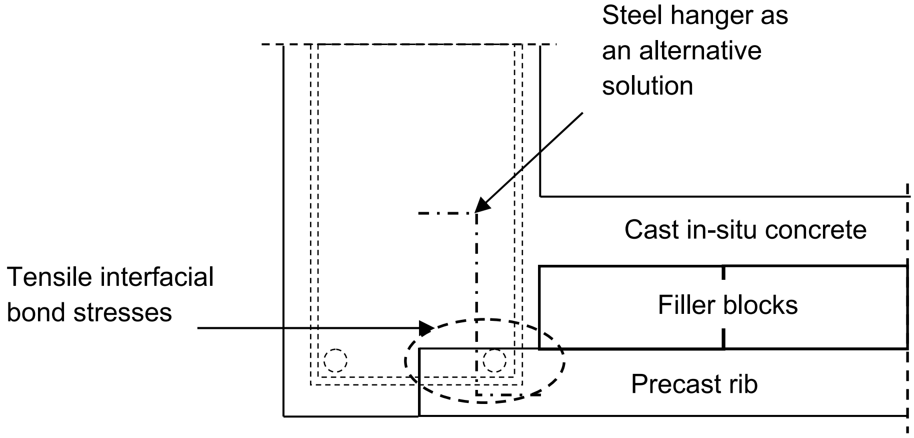


Figure 2-6: Precast rib connecting into the cast in-situ up-stand beam

- Stepping slab on the top or bottom (consider the stepping, parallel and perpendicular to the precast ribs).

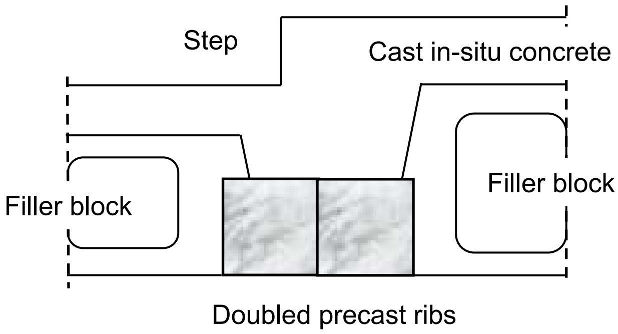


Figure 2-7: Step at the top of a beam and block slab system (parallel to ribs)

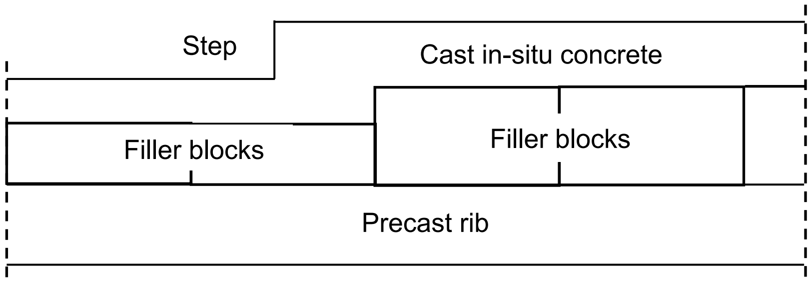


Figure 2-8: Step at the top of a beam and block slab system (perpendicular to ribs)

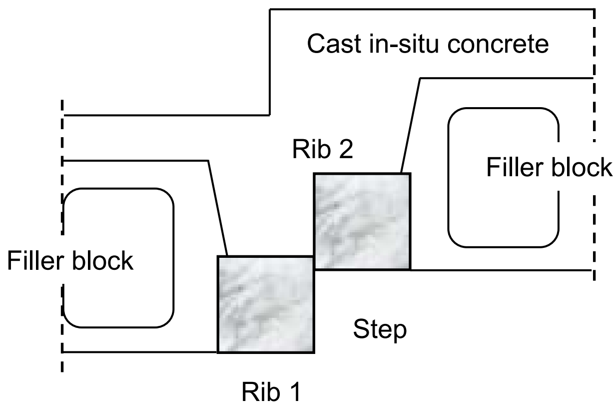


Figure 2-9: Step at the bottom of a beam and block slab system (parallel to ribs)

- Reinforced concrete staircase connecting into the beam and block slab system.

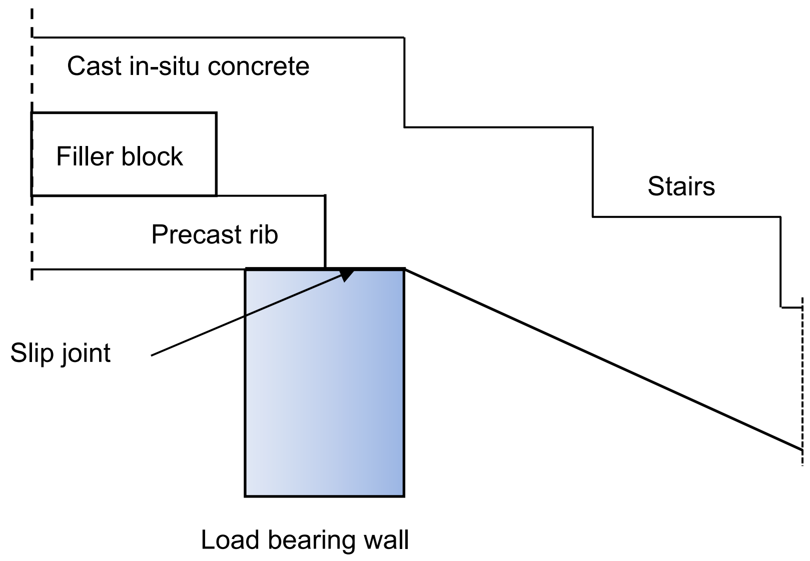


Figure 2-10: Cast in-situ staircase connecting into a beam and block slab system

- A beam and block slab system with a cantilevering conventional reinforced concrete slab or additional reinforcing steel incorporated in the in-situ structural topping.

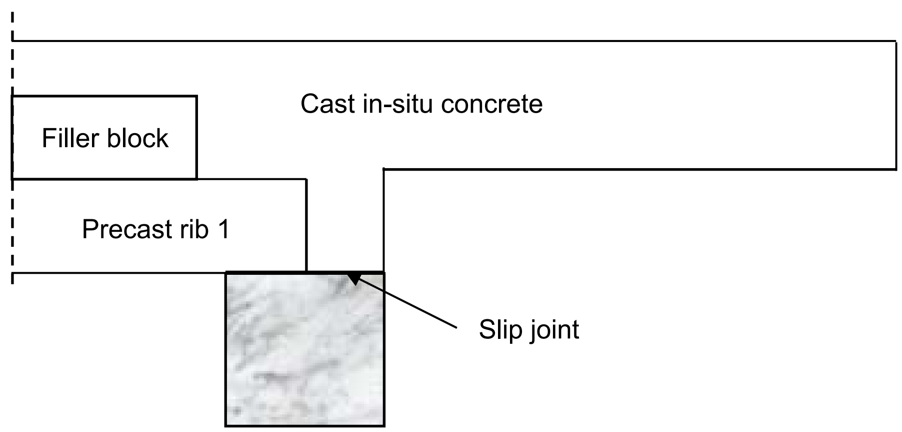


Figure 2-11: Precast rib inserted inside pocket

The required flexural strength of the beam and block slab systems is not only achieved by increasing the size or number of pretensioning wires, but by also using these ribs in groups of generally two or three. The design resistant for double and triple ribs may be provided.

The manufacturer or a building contractor may carry out erection of the beam and block flooring components. This varies from project to project. However, the person erecting the precast elements should follow the recommendations given by SANS 1879 (2011: 13) and check for other instructions provided by the manufacturer of that particular flooring system.

Some of these slabs are suitable for continuous spans where they should be designed for the induced hogging moments. Again, experience has shown lack of such important information. Most engineers (manufacturers) provide resistance for simply supported spans and no information for negative moments over the supports have been cited.

2.4.8 Design loads

Design loads must be based on the most adverse action effect, which is a product of the nominal characteristic load (s), and partial load factor (s). Table 1 of SANS 10160-2 (2011: 13) may be used to determine the appropriate live load intensity for this flooring system. Table A1-10 of SANS 10160-2 (2011: 24 to 32) may be used to get the densities of the materials used to quantify the dead loads (but mainly A1 to A6).

Other load actions may need to be considered, which result from the differential shrinkage, creep, temporary propping and requirements for robustness and stability in order to achieve a sound structural system. Thermal actions may also induce significant forces that should be considered.

2.4.9 Construction requirements

The recipient of precast ribs and filler blocks at the construction site must ensure that all the slab components are free of any breakages (e.g. structural cracks). Damaged components are dangerous to use for construction. The slab should be erected as recommended by Annex D – of SANS 1879 (2011: 13). Any additional and specific notes from the manufacturer about the erection of their product must also be considered and followed.

General procedures for construction with regards to mixing, transporting, placing, compacting and curing concrete are key elements for achieving a good product as recommended by SABS 0100-2 (1994: 18-37). The certifying engineer should inspect the slab to ensure that everything is according to the design. The contractor or the appointed competent person should prepare test cubes for confirmation of the design strength.

2.5 Filler blocks

Filler blocks have a similar function as void formers if intended to reduce the self-weight of the flooring system.

2.5.1 Rebated filler blocks to SANS 1879:2011

This code of practice on precast concrete suspended slabs addresses some elementary requirements for filler blocks that are used for the beam and block slab systems, namely:

- Resistance to construction loads of these filler blocks (void formers) of 3.5 kN (clause 4.4.4).

- Testing procedure of these blocks (clause 5.7). A localized load is applied on a 50 x 50 x 10 mm hardwood pad (or material of similar stiffness). The load is imposed in a more unfavorable position, both axial and lateral on the top shell of the filler block. The block should sit at the edges similar to the precast ribs.
- Tolerances in dimensions when manufacturing these blocks are ± 5 mm length, ± 3 mm width and ± 3 mm depth (clause 4.3.1).

- The recommended nominal dimensions are a length of 440 – 485 mm perpendicular to precast beams, a width of 200 – 225 mm parallel to precast beams and depth/height 100 – 355 mm (total), (Annex C, C.2 - 'informative').

- The minimum bearing of 35 mm onto the beam/rib/plank (Annex D, D.1 – 'informative').

2.5.2 Rebated filler blocks to SANS 1215:2008

The manufacturing methodology and materials for common concrete masonry units used to build vertical walls is similar to that of filler blocks used for beam and block slab systems. Most manufacturers follow similar guidelines as given by The Cement Institute on "How to make bricks and blocks" (2013: 1 to 7), which are also in line with SANS 1215 (2008: 7, 8, 9 and 10). They usually modify them to suit the local design, manufacturing and the application requirements/conditions depending upon the type of available mix ingredients. Appendix D in SANS 1215 (2008: 17) gives a list of recommended aggregates that can be used to manufacture these concrete masonry units.

In Durban, some manufacturers prefer to use crusher-sand instead of river sand and small sized aggregates because of the following possible reasons, namely:

- To protect the environment against over exploitation of river sand and since crusher-sand/crusher-dust is a by-product of larger aggregates (solid waste material), it is likely to be cheaper.
- It is often economical to use this product if there is a nearby quarry compared to transporting other more suitable materials from a distant source.

The 42,5N or similar SANS approved high-strength cement is often used since the early/rapid strength is required to maximize the production which should comply with SANS 50197-1 (2000: 4 to 29) and SANS 50197-2 (2000: 5 to 26). Lower cement content is preferable since cement is more expensive than aggregates.

2.5.3 Quality control to SANS 9001/ISO 9001

2.5.3.1 Strength

Regular testing is essential in order to ensure the safety of the public and good reputation of the product and company. This also helps to identify any problems ranging from poor selection of materials to declining quality of workmanship. These issues can be addressed at early stages in order to avoid losses.

2.5.3.2 Dimensions and shape

Filler blocks that have defective shapes may result in improper fitting and could result in unsafe working conditions during placement and sometimes even impair the strength or stability during construction (refer to Figure 2-12). Due to inaccuracy of block construction and setting out of the ribs on site, it is not practicable to achieve a snug fit and therefore, arch action is not feasible. Excessive deviation from the desired/correct shape could also result in notable difficulties in merging with some structural components.

Figure 2-12: Chipped edge of a rebated filler block

2.5.3.3 Shrinkage

Shrinkage tests may be necessary on filler blocks used in beam and block slab systems in order to evaluate the possible cracking of normal sand-cement plaster because of differential or excessive movement (or both). The SANS 1215 (2008: 10) defines shrinkage as “The difference between the length of a specimen (filler block) that has been saturated with water and its length after drying to a constant length, under specified temperatures and humidity conditions and expressed as a percentage of the dry length”. The drying shrinkage is determined in accordance with clause 5.6 and the limitations are based on materials used, which generally range between 0.06% and 0.08% of normal and high shrinkage respectively.

2.5.4 Manufacturing process

2.5.4.1 Mix design for the concrete masonry filler blocks

A large number of interrelated factors determine the optimal strength of the mix when making these filler blocks. Trial mix designs using the materials that are readily available on site from nearby quarries or supply points are essential to evaluate the economy of the product. However, this technique requires some technical knowledge and experience in the design of such products, which some manufacturers lack.

While considerable focus is on the mix design, proper curing is also important in order to achieve the maximum strength. The strength of the concrete masonry filler blocks from the material's perspective is influenced by the following factors as presented by The Cement Institute, "*How to make concrete bricks and blocks*" (2011: 4):

- The geological history of the material.
- The ratio of aggregate/cement content.
- Amount of compaction which is also dependent upon other factors such as:
    - The physical method employed.
    - Moisture content.
    - Geometric shape of aggregates.
    - Grading of these aggregates.
    - The ratio of aggregate/cement content.
- The size of the filler block.

2.5.4.2 Trial mixes

There are different methods that are used to proportion concrete masonry mix designs namely, nominal proportions, table of trial mixes, "eye-ball" mix design and the C&CI method of mix design as presented by Brian (2009: 101). These methods are more relevant to concrete for ordinary concrete structural elements (e.g. foundations, surface beds etc.).

The majority of beam and block manufacturers use the nominal proportions approach. This method is preferred because of the following reasons:

- Less sophisticated.
- Requires less effort to apply or implement repetitively.
- Suitable to use with crushed stone.

This method does not consider the difference between specific cements and aggregates. Table 8.1, Brian (2009: 102) provides equivalent mix designs of 1:4:4 which yield to low strength. This is ideal for filler blocks, as they do not form part of the final structural system.

2.5.4.3 Tests control and strength

Concrete with inadequate strength is dangerous. Concrete strength needs to be just enough to resist the forces applied to it. Excessive strength is uneconomical. The important criteria to economize filler blocks are to be able to design for the required strength, select appropriate and most suitable materials to achieve that strength, manufacture the block according to the design specification and provide proof that the strength has been met. Regular testing is necessary in order to monitor the strength of filler blocks. This can be verified by undertaking trial mix design or physically testing some filler blocks. A compression-testing machine is used to test the strength as seen in Figure 2-13.

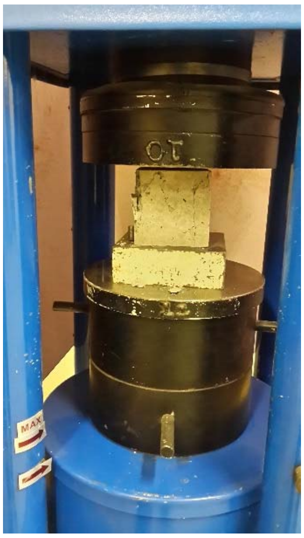


Figure 2-13: Concrete cube in a compression-testing machine

2.5.5 Curing of concrete masonry filler blocks

“Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration”, Curing of concrete (2006: 1). Concrete masonry filler blocks require adequate curing in order to achieve maximum design strength. Proper procedures are often neglected by some construction practices. An example in Figure 2-14 is the filler blocks exposed to direct sunlight. The SANS 0100-2 (1994: 34) requires concrete to be protected immediately from moisture loss and maintained at a temperature suitable for continued hydration.

Figure 2-14: Newly cast concrete masonry filler blocks exposed to direct sunlight

2.5.6 Function of concrete masonry filler blocks

Although concrete masonry filler blocks are much heavier than expanded polystyrene filler blocks, they have good qualities when subjected to fire, namely:

- They shield the structural topping from direct flame radiation (soffit fire loading). However, this feature can be jeopardized by the presence of big gaps between the filler blocks if there is no normal sand-cement soffit plaster finish employed.
- They also shield the web of precast rib against the flame radiation.

The other qualities are durability, versatility and resistance to sound penetration.

The fire resistance of concrete masonry filler blocks depends on the type of aggregates used, the density of the aggregates, the overall density of the filler block and its geometry/shape. In the unfortunate event of fire, the integrity of the structure depends, predominantly, on the actual member integrity (e.g. fire-rating) and heat/fire confinement. It is therefore, important to quantify the fire-resistance of the filler blocks so that one can determine the true performance of the concrete topping from a structural-fire point of view (see section 4.3.3.6).

2.6 Expanded polystyrene filler blocks

Expanded polystyrene filler blocks are often made from polymerized styrene, also known as EPS. EPS is a rigid, lightweight plastic foam material produced from solid beads of polystyrene, which contain some blowing agents. Steam is then used to expand these beads into a lightweight prefoam. EPS is produced in different densities for different applications such as: EPS decking blocks (void formers), roof insulations, building blocks, deep roof profile, insulation panels, cavity walls, expansion joints, cornices and under flooring.

The prefoams are generally processed in the moulds to form large blocks, which are then cut to the required thickness to cater for 150-170, 200 and 255 mm thick beam and block slab systems. Some are moulded to suit specific shapes as shown in Figure 2-15. The physical strength of cut-to-suit expanded polystyrene filler blocks should comply with SANS 1879 (2011: 8, 9 and 10).

Figure 2-15: Expanded polystyrene filler blocks (Pilanberg group 2013)

All surfaces receiving the cast in-situ concrete and normal sand-cement plaster need to be reasonably flat to within 5 mm when measured with a 3 m straight edge. Any irregularities, which exceed this limit must be trimmed to comply. The surface texture is generally smooth. EPS is a flammable material but some EPS filler blocks are treated with a fire retardant. These foams shrink away from a heat source for a short duration but ignite fully when exposed for a long period.

2.7 Shear interface

2.7.1 Shear interface between precast rib and cast in-situ concrete

A study by Gohnert (2000: 9) concluded that all manufacturers of the beam and block slab systems should ensure good and consistent quality of their products in order to maintain predictable results. During testing, some precast beams failed prematurely at the shear interface, and it was assumed that a lack of consistency in manufacturing these beams had been the possible cause.

Gohnert (1999: 24) also revealed that SABS 0100-1:1992 (which is now SABS 0100-1:2000) is consistent with the international norms regarding the shear stress resistance for ribs without shear links. In South Africa, the beam and block slab systems are often used in light loaded structures, thus resulting in low shear, hence shear links are not common. It is a common practice to deliberately roughen the top surface of the precast ribs in order to activate the composite action with the cast in-situ structural topping.

Some horizontal shear test (push-off tests) done in these studies indicated that some precast ribs failed to reach the design strengths, as presented in Table 42 of SABS 0100-1 (2000: 157). The results indicated a notable decline in horizontal shear strengths for ribs with an undulation (R_z) of less than 1 mm. Precast beams that had an undulation (R_z) exceeding 3 mm indicated better results.

It was also found that "the roughness of the surface had a profound effect on the horizontal shear capacity and is a far better indicator of strength than the compressive strength", Gohnert (2003: 1). There was an upward trend in the shear strength with an increase in compressive strength of in-situ concrete but compromised by the lack of correlation between the horizontal shear strength and compressive strength.

The blame was assigned to code (SABS 0100-1) since at that time it did not specify the minimum roughness amplitude (R_z) as illustrated in Figure 2-16:

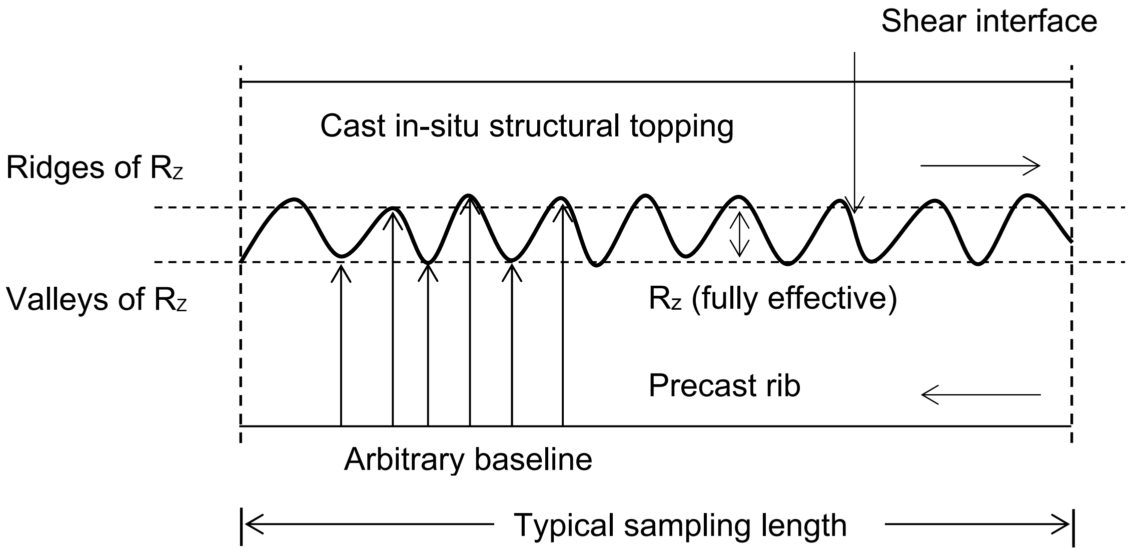


Figure 2-16: Theoretical model of a precast and cast in-situ concrete beam illustrating an effective surface roughness (R_z)

Figure 2-17 indicates the typical general arrangement of a precast rib and concrete masonry rebated filler blocks and the interface (between the blocks) determining the horizontal shear strength which is dependence on deliberately made undulation (R_z).

Figure 2-17: Interface detail of a beam and block slab system

Not all standard ribs rely on shear lugs/studs/links for the horizontal shear resistance. The hooks are often used for handling purposes and do not have any significance in providing the horizontal shear strength. A study by Loov and Patnaik (1994: 48) proved that such links are unstressed and ineffective until the horizontal shear stresses exceed 1.5 to 2 MPa and this confirms the importance of ensuring the integrity of the roughening.

Figure 2-18: Hooks (U-bars) for handling

2.7.2 Shear at the interface of precast rib and cast in-situ concrete to SANS 1879:2011

SANS 1879 (2011: 6) on Precast Concrete Suspended Slabs requires that all beam and block slab systems used in South Africa must have a deliberately formed undulation/roughness (R_z) on the top interface of at least 3 mm measured along the spacing of not more than 40 mm (clause 4.3.4) when determined in accordance with clause 5.5. At least 10 sets of readings of the average difference between the ridge and adjacent valley are measured preferably, with a digital caliper from a convenient arbitrary horizontal line. The code does not talk about other issues that affect the effectiveness of a roughened surface such as:

- The acceptable variation in frequency of the roughness within the 40 mm segment.
- The spacing of the segments.
- The uniformity of the roughened surface

2.7.3 Shear at the interface of precast and cast in-situ concrete to SABS 0100-1:2000

The precast ribs and cast in-situ concrete topping are designed to act monolithically, in other words they are designed as composite sections. The assumed integrity of this design is valid provided there is no relative movement between the two surfaces. The code advises how the horizontal shear force due to design loads should be assessed depending on whether the interface is in the tension zone or the compression zone.

Furthermore, it gives guidelines to quantify the average horizontal shear stress. The allowable shear stresses are given in Table 42 in this code, which depends on how the surface finish has been made, namely:

- As-cast.
- As extruded.
- Brushed, screeded or rough-tampered.

2.7.4 Fundamentals of surface roughness

The Federation Internationale de la Precontrainte, (FIP) published a guide to good practice, a paper entitled "*Shear at the interface of precast and in-situ concrete*" (1982: 12) which made recommendations for the inclusion of photographs or samples. These had to be accompanied by notes giving the specification about the peak-to-peak amplitude, frequency and uniformity of the surface. The construction methodology to achieve the required quality was also recommended.

There are at least two issues concerning the type of texture of surface roughness, namely:

- The non-uniformity of the profile along and across the rib (see Figure 2-19) which could result in incorrect readings of the surface roughness value (R_z). The effects may be significant if this happens at the zones of dominant unfavourable positions (e.g. at the span ends where differential shrinkage is high, or at the positions of hogging moments, where tensile bonding is important to counteract the uplift of the structural topping, and is influenced by the integrity of the contact area).

Figure 2-19: Non-uniformity of the top interfacial surface of a rib

- The frequency of the profile along the beam (refer to Figures 2-20 and Figure 2-21). It is believed that the variation in frequency can affect the horizontal shear strength capacity**.** The size of undulation is also influenced by the size of aggregates used, which will further influence the interlocking mechanism (i.e. the course aggregates from the cast in-situ concrete can sink in the valley where the undulation is more pronounced thus increasing the shear strength adversely where the surface roughness is less pronounced and only fine aggregates can participate in resisting the shear or break-off). It is therefore understood to be a worthwhile exercise to investigate the influence of the variation in frequency on a roughened surface.

The variation of the pitch of the ridges or high spots (see Figure 2-21) has an effect with respect to the direction of resistance of the relative movement. This would require further investigation if the design is based on the horizontal shear resistance on the distribution/shape of the shear force diagram acting along the length of the rib.

Figure 2-20: The variation in frequency of the surface roughness (R_z)

Figure 2-21: Change in the pitch of ridges

2.7.5 Types of surface roughness

The type of surface roughness as indicated by the guide to good practice, "*Shear at the interface of precast and in-situ concrete*" (1989: 8 and 9) is presented in Table 2.7

Table 2.7: Types of concrete surface

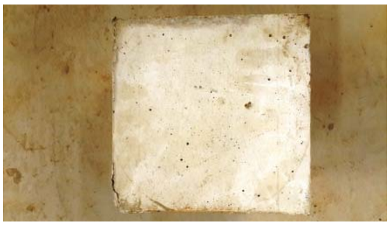
Surface description	Illustration	Comment
Type i *A smooth surface, as obtained by casting the unit against a steel or timber shutter.*	 Figure 2-22: Surface type i	*This cannot be deliberately specified on surfaces where the composite action is critical, however the surfaces that are in contact with the formwork or casting bed produce such an appearance.*
Type ii *A surface which has been trowelled or floated to a degree where it is effectively as smooth as (i).*	 Figure 2-23: Surface type ii	*Not suitable for the design of composite interface.*
Type iii *A surface which has been trowelled or tamped, so that the fines have been brought to the top, but where some small ridges, undulations have been left.*	 Figure 2-24: Surface type iii	*This surface was possibly the most common type of smooth surface considered in the design in the past, although, in practice, it will usually be rough to some extent.*

Table 2.7: Types of concrete surface, continued…

Surface description	**Illustration**	**Comment**
Type iv *A surface which has been achieved by slip-forming and micro-beam screeding.*	 Figure 2-25: Surface type iv	Same as (*ii*)
Type v *A surface obtained in a precast unit produced by some form of an extrusion technique.*	 Figure 2-26: Surface type v	*This surface would generally have the same roughness as type (vi).*
Type vi *A surface which has been deliberately textured by brushing the concrete when wet ideally to a specified depth.*	 Figure 2-27: Surface type vi	*This is possibly one of the most common types of rough textured surfaces.*

Table 2.7: Types of concrete surface, continued…

<table>
<tr><th>Surface description</th><th>Illustration</th><th>Comment</th></tr>
<tr><td>Type vii
As for (vi), but where the texturing is more pronounced, obtained typically by brushing, by a transverse screeder, by combining with a steel rake or by tamping with a former faced with a suitable expanded metal.</td><td>
Figure 2-28: Surface type vii</td><td>This is also possibly one of the most common types of rough textured surface.
This surface is at least as effective as (ix).
Many codes of practice recommend this surface.</td></tr>
<tr><td>Type viii
A surface where the concrete has been thoroughly compacted but no attempt has been made to smooth, tamp or texture the surface in any way leaving a rough surface with coarse aggregate protruding (but firmly fixed in the matrix).</td><td>
Figure 2-29: Surface type viii</td><td>This is a very rough surface but there can be problems with it since the concrete near the top may be poorly compacted.</td></tr>
</table>

Table 2.7: Types of concrete surface, continued…

Surface description	Illustration	Comment
Type ix *Where the concrete has been sprayed when wet, to expose the coarse aggregate without disturbing it.*	 Figure 2-30: Surface type ix (Texturelib 2013)	This surface is very rough and very ideal for composite interfacial. Quantifying its roughness in accordance with SANS 1879:2011 would be a difficult task because of the lack of roughness pattern compared to surface type vi.
Type x *A surface which has been provided with mechanical shear keys.*	 Figure 2-31: Surface type x (Pilansberg group 2013)	This type of precast rib is now unpopular around the Durban area, South Africa. There is no definite and technical reason why manufacturers do not want to use it. It seems that the pretensioning is just the preferred solution.

Table 2.7: Types of concrete surface, continued…

Notes: • *These alternatives are presented in the order of increasing roughness.* • *Surface (iv) – (x) have some measure of roughness.* • *There are no clearly defined boundaries between these different surface types and what is actually achieved will depend very much on the workmanship in individual cases.*

The majority of beam and block slab systems in Durban, South Africa use precast ribs that are roughened to the equivalence of surface type vi and vii.

2.7.6 Surface treatment

Apart from other important issues discussed by the guide on "*Shear at the interface of precast and in-situ concrete*" (1982: 12) were the requirements for surface treatment and workmanship. The horizontal shear strength of in-situ concrete is partly dependent on the cleanliness and wetting of the surface prior to concreting and adequate compaction and curing.

SABS 0100-2 (1994: 31 and 34) make the following recommendations: the dampening of the concrete surface prior to placing the new wet concrete (clause 10.4), the curing and protection of newly placed concrete (clause 10.8) and, the cleaning of the concrete surface prior to placing the new wet concrete (clause 10.4).

All the factors listed above are influenced by the quality of the precast interface. Most codes, including SANS 1789:2011 acknowledge the surface roughness as the main factor to govern the strength of the horizontal shear interface. The shear strength is also dependent upon the quality of workmanship. The guide on "*Shear at the interface of precast and in-situ concrete*" (1982: 1) acknowledges the fact that the demands of the design codes and standard specifications do not always relate to the types of surface which can be realistically achieved in practice.

2.7.7 Causes of interface separation

2.7.7.1 Tensile stresses

In very rare occasions these slabs can be subjected to interfacial tensile stresses causing delamination of the composite section. Figure 2-32 shows a typical precast rib of a beam and block slab system under direct tension force.

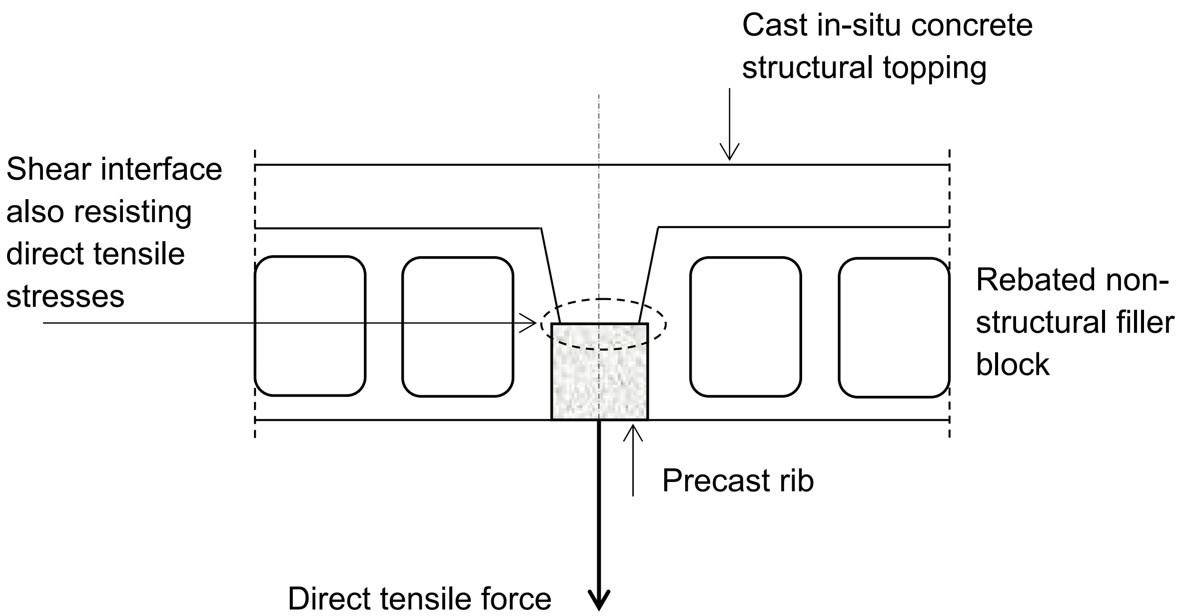


Figure 2-32: Typical section of a beam and block slab system subject to direct tension force

The next Figure 2-33 indicates a region of dominant tensile stresses because of a load from the transverse beams.

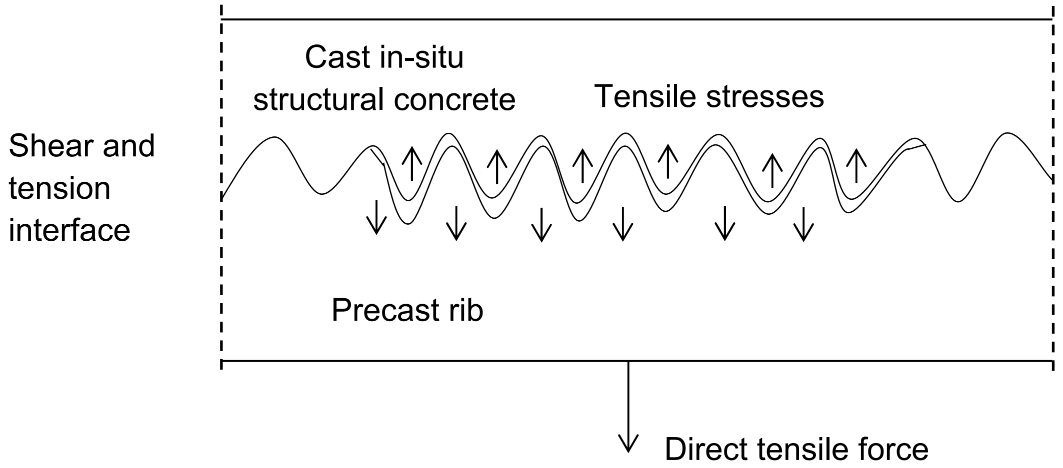


Figure 2-33: Possible split-up of a precast rib and cast in-situ concrete resulting from a direct tension force

2.7.7.2 Differential shrinkage

Differential shrinkage may be defined as the reduction in the volume of concrete. The fine and coarse aggregates, including the binder will absorb water, which will later evaporate through capillary tubes, "*Shear at the interface of precast and in-situ concrete*" (1982: 21). In a typical beam and block slab system, the sections with thinner sections (topping) have a tendency to shrink more than the thicker sections (sections above the rib and transverse stiffeners). This is caused by the accelerated loss of water. Using aggregates with higher porosity/voids, which require more water, will also increase shrinkage. The differential shrinkage is also increased by using a mix with a high water/cement ratio. Higher relative humidity (i.e. coastal area) and longer curing will decrease shrinkage.

Newly cast in-situ concrete could cause addition bending moment in precast ribs. If so, the effects should be accommodated at the Serviceability Limit State for deflection and Ultimate Limit State design for ultimate flexural strength.

Shrinking of newly cast in-situ concrete could also increase horizontal shear forces between the precast pretensioned rib and cast in-situ concrete. Induced forces may have a significant effect on the overall horizontal shear resistance which the engineer may need to consider in the design.

2.8 Fire rating

2.8.1 South African codes

Most manufacturers acknowledge the fact that their beam and block slab systems have to comply with the minimum fire design requirements set by SABS 0100-

1:2000. These flooring systems may also need to comply with some special requirements as specified by the client.

The choice of the flooring system and the type of filler blocks to use depends upon the nature of the building. The increasing demand of beam and block slab systems in the construction industry now requires some strict quality control regulations. This should ensure uniformity and consistency in the products that are deemed to be providing fire protection in order to ensure the safety of occupants with respect to structural-fire. In the United Kingdom, some manufacturers of concrete masonry units for building give a thermal resistance of their products (Concrete Block Association 2007). However, these are based on block-work with mortar or sealed joints.

The thermal actions given by either the parameters of the building or nominal exposure to fire loading may be used as the basis for the design of the structural elements (Beeby and Narayanan 2005: 205). The common exposure periods range between 30, 60, 90, 120, 180 and 240 minutes. There are two main issues involved with respect to fire, namely:

- The member resistance to fire loading.
- The containment of fire within the source. This is generally a major concern for multi-storey buildings.

Domestic houses often need a minimum fire rating of 30 minutes. This is to give people enough time to evacuate the building. Table 44 of SABS 0100-1 (2000: 168) gives the minimum dimensions for the geometry of the concrete section required to achieve the targeted fire rating which also applies to the design of precast pretensioned ribs.

SANS 1879:2011, recommends a concrete cover over the pretensioning wires to be not less than 15 mm which gives 30 minutes fire rating (refer to Table 2.8 and Figure 2-34). The sections as thin as 60 mm use a very small cover over the pretensioning wires in order to increase the effective depth for flexural strength.

Table 2.8: Fire rating with respect to concrete cover over pretension wires

Cover (mm)	**Rating (minutes)**
15	30
25	60
30	90
40	120
50	180
65	240

Figure 2-34: Concrete cover over pretension steel

Common ribs are generally 65-150 mm wide with fire rating as presented in Table 2.9.

Table 2.9: Fire rating with respect to the width of rib at the soffit

Cover (mm)	**Rating (minutes)**
50	30
70	60
80	90
90	120
100	180
125	240

Table 2.10: Fire rating with respect to overall depth (excluding combustible items)

Cover (mm)	**Rating (minutes)**
100	30
110	60
140	90
160	120
175	180
190	240

Some manufacturers of beam and block slab systems are in favor of using the expanded polystyrene filler blocks compared to concrete masonry filler blocks. Untreated expanded polystyrene filler blocks melt very quickly under heat thus leaving the ribs and the concrete topping exposed directly to heat. Such behaviour leads to accelerated deterioration by heat and therefore, questions the containment of the fire of multi-story buildings from the point of view of fire progression.

Reference should also be made to SANS 10400-T: 2011 with respect to fire safety and protection requirements in multistory buildings.

Concrete is a popular building materials used in many countries around the globe. It has numerous advantages and features, including its efficiency in structural performance during fire conditions. The use of the beam and block slab system, in South Africa has become a very popular alternative slab system especially in the development of low-cost housing schemes. The structural integrity of these precast pretensioned concrete ribs when exposed to elevated thermal and direct fire loading is still a major concern for most structural engineers.

It is a common building practice in South Africa to cover the beam and block slabs with one of the following types of ceilings: normal sand cement plaster, rhino board, tongue and groove South African Pine, drop/suspended ceiling, polystyrene (tile ceiling), and polymethyl-methacrylate. Most ceilings used in houses do not provide a fire shield to the structural components/members. However, it is noted that some beam and block slab systems are covered with sand-cement plaster (or other suitable finishes) that is capable of providing fire protection to the structural elements.

2.8.2 Other literature

The consequences of fire on a structural member may result in a categorized level of damage (classes of damage), (FIB: 2008 117-118) as indicated by Table 7-2 of "*Fire design of concrete structures – structural behavior and assessment*", namely: Cosmetic surface damage, structural surface damage, structural cross-section damage and structural damage to members and components. The limited thickness of these structural components (topping and ribs) allows for faster heating of the core. This also makes them intolerant to local damage, which could significantly affect the structural integrity.

There has been some research which has provided better understanding about the behaviour of concrete structures subjected to fire loading. The deterioration, deformation and spalling of concrete has not been properly studied and constitutes a research gap, which some research bodies such as the International Federation for Structural Concrete have contributed towards closing. Improved knowledge in surface treatments, thermal insulation (including, cladding and shielding), mix design and careful choice of materials have proven to have a huge positive contribution towards improving thermal and fire loading resistance of concrete structures. This has even greater benefits for precast concrete elements because of the excellent off-site manufacturing control. In general, concrete cover to reinforcement, detailing of reinforcement, the magnitude and pattern of the load and orientation and exposure of the member have so far been noted as the utmost primary concerns.

2.8.3 Fire rating of concrete masonry filler blocks

The majority of codes of practice like the American Concrete Institute 216.1-07 / TMS-0216-07 and South African Bureau of Standard 0100-1 base the fire resistance of concrete masonry as a function of the type of aggregates used to make the block and the equivalent thickness.

A method known as the ‘equivalent thickness’ transfers the equivalent amount of concrete that was used to form a hollow block into a solid thickness to give a resistance. The thickness is the only dimension that is changed. Other dimensions remain the same. Therefore, the percentage of solid to hollow should be determined.

Chapter 3

The benefits and drawbacks of the beam and block slab systems

3.1 Introduction

Use of beam and block slab systems mean that a larger volume of work is completed at the precast plant (off-site) where the manufacturing control conditions are deemed to be good and reliable and a smaller volume completed at the construction site where the production can be influenced by a significant number of substandard construction practices.

All precast components such as ribs and filler blocks should therefore be of good quality. The cast in-situ concrete topping can come from a ready-mix plant or mixed on site. Ready-mix concrete is often reliable because it is produced by concrete specialists. However, SABS 0100-2 (1994: 51) still recommends that concrete cube tests (samples) are taken for compressive strength testing to verify the required strength.

Concrete mixed on site is usually subject to a number of factors, which could affect its compressive strength and durability, ranging from poor workmanship to lack of knowledge and experience about the actual materials being used. Sometimes, even the quality of ready-mix concrete can be jeopardized by substandard construction practices.

The construction method, cost, strength, weight, volume of production, durability, quality and many other factors are generally the issues to consider when optimizing the structural efficiency of these flooring systems. Different stages of the production process of this flooring system respond differently to these contributing factors but it is important to acknowledge the effect that each factor has on the design, manufacturing and construction (ie. the design engineer needs to acknowledge the manufacturing and construction factors that could affect the design).

The cost is generally the most influential factor in the production of beam and block slab systems. Therefore, the optimum design of beam and block slab systems involves the science of finding the best possible ways to maximize the benefits at each stage of the manufacturing and construction process which covers the following:

- The selection of construction materials.
- The manufacturing of ribs and filler blocks.
- The transportation of these precast ribs and filler blocks to site.
- The time spent by labour when assembling these elements on site etc.

All these factors mentioned above can be strongly affected by the actual design of that particular beam and block slab system.

An example is where the best structural solution could be based on maximum strength, minimum cost, minimum weight or any combination of these. Optimizing the design with different variables will require analysis of all modes of failure (e.g. vertical shear, horizontal shear, flexural strength and deflection) to reach their Ultimate or Serviceability Limit State (or both) simultaneously.

Limit state design refers to a design method used in structural engineering. The fundamental distinction between Ultimate and Serviceability Limit State is the loss of static equilibrium. Figure 3-1 shows a concrete masonry rebated filler block after a flexural strength test. This block cracked at the top and bottom shell when it reached its ultimate load carrying capacity. SANS 1879:2011 recommends a design load of 3.5 kN which allows for concentrated loads such as a wheel barrow filled with concrete.

Figure 3-1: Concrete masonry rebated filler block after reaching its Ultimate Limit State

Optimum design is linked to minimum strength to weight ratio (Iyengar 1997: 42). Chapter 4 deals with the strength to weight ratio of concrete masonry rebated filler blocks produced by different manufacturers in Durban, South Africa. Expanded polystyrene filler blocks were also tested for comparison. Optimizing efficiency with respect to strength to weight ratio is not an easy task, since the filler blocks have numerous dependent design parameters and this gets even more complicated if considering some parameters that are dependent on some dependent design variables. As an example, the strength of concrete masonry filler blocks is dependent on the mix design while the mix design depends on the properties of the construction materials.

3.2 The potential benefits of using the beam and block slab systems

The benefits of using beam and block slab systems are:

- Rapid construction.
- Structural efficiency (ratio of the load supported over the self-weight of the flooring system).
- Cost effective.
- Minimal formwork required.
- Minimal propping required.
- Factory controlled quality excellence.
- Reduced amount of in-situ concrete.
- Non-skilled labour can be employed for installation.
- Reduced erection time and labour cost over conventional reinforced concrete slabs.
- Most conventional reinforced concrete slabs can be replaced by a beam and block slab system.
- They are suitable for sites without cranes or with limited access.

3.3 Precast construction

Precast concrete construction is where concrete is cast in a mould to form its shape. The product can then be cured in a more controlled environment and by this, the maximum strength can be achieved. The publication by the Cement & Concrete Institute with the title, Concrete for Precast Small Items (2003: 1) advises about some important points that are key to economizing this construction system, namely:

- Maximum stone size should be compatible with the minimum dimension of the precast element.
- Rapid strength concrete should be used.
- Surface damage and breakages must be avoided.

Precast products are also susceptible to damage during transportation and improper storage. It is of utmost importance that care should be exercised when working with precast ribs and filler blocks.

3.3.1 The benefits of using the beam and block slab systems as a partially precast construction method

The advantage of using the precast and cast in-situ construction method is the ability to optimize some factors based on the special demands of your project, such as:

- High-quality concrete and durability.
- High level of dimensional tolerance.
- Rapid construction.
- Avoidance of false-work/formwork.

3.3.2 The challenges associated with precast concrete construction with respect to the beam and block slab systems

It is important to consider both the advantages and disadvantages of any construction method you intend to use. For the precasting operation to be successful and achieve the desired optimization, it is important to evaluate and manage the risks and drawbacks. Some risks are difficult to avoid completely and the situation can still be optimized by understanding their influence on the problem and making necessary adjustments. Some possible drawbacks are:

- Unexpected camber of ribs.
- Limited building design flexibility.
- Limitation of mass for members carried by either hand or using a crane.

3.4 The benefits of using concrete as a structural material in beam and block slab systems

The concrete itself is a composite material. It is composed of aggregates and a binder. The structural economy and efficiency of concrete as a building material are seen through the following benefits:

- Flexibility to personalize the design/structure.
- Concrete is inherently durable.
- Minimized maintenance.
- Compatible with reinforcement.
- Structural strength becomes cost-effective and increases with time.
- Sound insulation.
- High structural stiffness.
- Good abrasion resistance.
- It is easy to use in one-way structural systems.
- It can be assumed to be less or more monolithic.
- Connections are monolithic with the entire frame.

3.5 The difficulties of using cast in-situ concrete construction

Some drawbacks that need to be kept in mind are listed below:

- Requires a high labour component and mechanical equipment on site.
- Erection of formwork is time consuming.
- Quality control is difficult but achievable.

3.6 Filler blocks

3.6.1 The benefits of using expanded polystyrene filler blocks

- They provide fast and economical construction.
- Are suitable for industrial and domestic construction.
- Are safe to use (those complying with SANS 204).
- Are easy to handle, lightweight yet strong.
- Is environmentally friendly and CFC (chlorofluorocarbon) free.
- Are recyclable.

3.6.2 The benefits of using concrete masonry filler blocks

- They are fire resistant and incombustible.
- Rigid and provide a level walking and working platform.
- Durable.

Chapter 4

Research methodology

4.1 Research methods

Qualitative methods involving surveys (pilot studies), observations of construction procedures as well as samples taken from construction sites and interviews and quantitative method involving testing of samples were used in this thesis.

4.2 First aim:

- Provide the users of beam and block slab systems with basic technical information about the possible ways to improve the efficiency and effectiveness in the design, manufacturing and construction of beam and block slab systems by undertaking an exploratory (pilot) study to better understand users of these systems concerns.

4.2.1 Background

Engineers, architects, quantity surveyors and clients often have an influence on the choice of the particular flooring system to be used in a civil engineering or building project. It is therefore assumed that the willingness to opt for a particular construction method is based mainly on the technical knowledge and the past experience of the professional team. The thoughts that come to mind result from different preferences and the level of responsibility of the individuals forming the professional team. The examples given below have relevance to a discussion regarding beam and block slab systems:

- The structural engineer may be interested in the structural efficiency of this flooring system whilst also being apprehensive about fire-rating and cracking.
- The architect may be concerned about how the finishing details (e.g. ceiling and lights) integrate with the ‘as-built’ configuration of this flooring system and how they should be fixed.
- The quantity surveyor may be focussing on the possible savings resulting from its economy and fast erection.

It is therefore clear that reliable facts, and technical knowledge about any structural system form the foundation for the selection process and therefore, any lack of evidence/information could lead to reluctance, if not total avoidance to use a product, even if the product presents the best structural solution for that particular project.

4.2.2 Methodology

Specific questions relating to fire-rating, member cracking, shear interface and the application of finishes (e.g. sand-cement plaster), were formulated in an online questionnaire. Invitations to respond to the questionnaire were sent through emails with the website link: http://rsidemoodle.dut.ac.za/limesurvey/admin/admin.php. This questionnaire was sent to architects, structural engineers, manufacturers, academics and those that had their details available from previous work experience. Another invitation was also published in “OUTLOOK, the monthly newsletter of the South African Institution of Civil Engineering in the Durban and Pietermaritzburg regions (February / March 2013: 4). The question posed to the respondents by the student (2013: 93-95) can be viewed in Questionnaire 1, Annexure A, of this thesis.

Questions 1 to 15 formed part of the paper that was published by the student (2013: 88-98). This thesis only addresses the issues that came up in question 16 (general comments) and only comments relating to technical issues around the beam and block slab systems will be addressed in fair detail (see Chapter 6 - Discussion).

4.3 Second aim:

- Investigate, by conducting a series of strength to weight ratio tests, how efficient or inefficient these filler blocks are.
- Examine the structural integrity with respect to the integrity of the manufacturing methodologies and the product thereof.
- Formulate a method to quantify the fire-resistivity of concrete masonry rebated filler blocks to the structural topping with respect to confining fire/flames from one floor to the next.

4.3.1 Background

The majority of the beam and block slab systems used in Durban, South Africa use non-structural rebated filler blocks (i.e. they simply work as void formers). The concrete masonry and expanded polystyrene rebated filler blocks are the most common types. The prime factors influencing these choices are:

- The reduction in self-weight of the flooring system resulting from the reduced mass of the filler blocks or the void formers used. This directly affects the structural efficiency (strength to weight ratio) of the flooring system.
- The fire-resistance of the selected filler blocks which affects the fire-rating of the flooring system.

Although all concrete masonry rebated filler blocks are non-structural, their ‘structural’ integrity is important in order to ensure the safety of the people working on the construction deck. Keeping a close eye on the structural efficiency is also important, because not only does it affect the safety of the people working on the deck and underneath (e.g. the electricians fixing the electrical conduits and the structural engineer undertaking inspections) but also, it directly affects the overall structural efficiency of the flooring system. Any extra self-weight in these ‘non-structural’ blocks reduces the load carrying capacity of the suspended flooring structure.

Five manufacturers (named for the purpose of this thesis as Manufacturers: A, B, C, D and E) of beam and block slab systems undertaking most of their business in Durban and the outskirts (in KwaZulu Natal – South Africa) were approached and requested to donate 10 concrete masonry rebated filler blocks of each type they produce. Only filler blocks suitable for casting 150/170 mm (small), 200 mm (medium) and 255mm (large) thick slabs, as shown in Figure 4-1, 4-2, 4-3, 4-4 and 4-5, were studied.

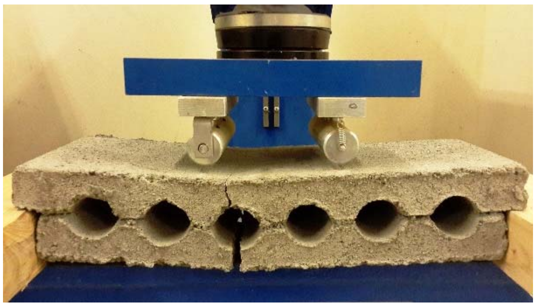


Figure 4-1: Cellular type concrete masonry rebated filler block (small)

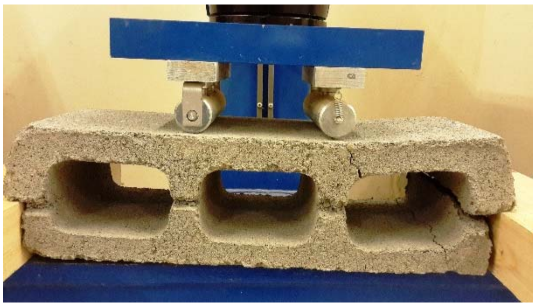


Figure 4-2: Triple-core type concrete masonry rebated filler block (small)

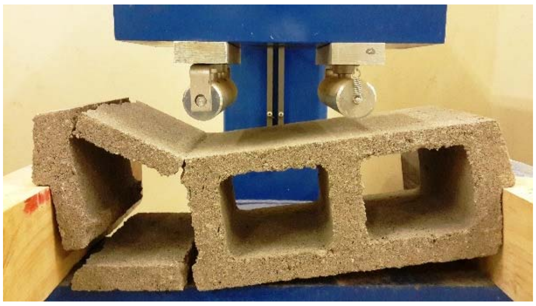


Figure 4-3: Triple-core type concrete masonry rebated filler block (medium)

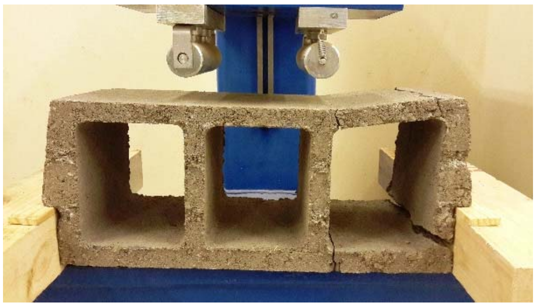


Figure 4-4: Triple-core type concrete masonry rebated filler block (large)

Figure 4-5: Double-core type concrete masonry rebated filler block (small)

It should be noted that this filler block is not fully comparable to other filler blocks since the point load is not located close to the vertical member. Square brackets/ […] will be used when referring to the overall slab thicknesses mentioned above (e.g. [200]).

These sample blocks were selected randomly from stacks where ordinary customers would come and purchase them for immediate usage. They were all between the age of 7 and 10 days and air-dried for 48 hours prior to testing. There was no specific set condition for air-drying. A wall-mounted fan was used to circulate air in a standard ventilated laboratory. All five manufacturers confirmed that these blocks are only sold to the public at least seven days after casting. On receipt at the concrete testing laboratory at the Durban University of Technology in 2013, the dry mass of each block was recorded, including any defects like structural cracks and chipped corners/edges. These blocks were used to fulfil the **second aim**, which was conducted through a process of two activities as discussed below:

4.3.2 Activity 1 – Structural efficiency

Concerns were raised by some manufacturers wanting to know whether or not these blocks are working at optimum structural efficiency and if not, how they could rectify the situation. As a consequence, a short study with the title, "*Structural Efficiency of Concrete Masonry Rebated Filler Blocks for the Beam and Block Slab Systems used around Durban, South Africa*" was presented and published by the student (Khuzwayo: 2014) in the proceedings of the 8th CIDB Postgraduate Conference, 10th – 11th February 2014 at the University of the Witwatersrand, Johannesburg, South Africa.

4.3.2.1 Summary of the methodology for activity 1

Two symmetrical point load testing systems were used, each having a bearing length of 150 mm perpendicular to the length of the span of the block, as shown in Figures 4-1, 4-2, 4-3, 4-4 and 4-5. However, this is not exactly in line with the testing procedure recommended by the SANS 1879 (2011: 8-9). This was done since the testing method presented by this standard specification is likely to cause a localized failure.

This study required that all blocks be loaded symmetrically in order to achieve a symmetrical distribution of forces throughout the entire block. These blocks were only loaded axially until failure occurred. Failure load was recorded to the nearest tenth of a kN. Some manufacturers informed of inconsistency of the results received when conducting in-house tests. It was therefore decided to conduct **test 1** and use **test 2** to confirm if the inconsistency is significant or minor. There were thirteen different sizes of filler blocks. Test 1 consisted of 10 filler blocks of each type. Test 2 consisted of three filler blocks from each of the previous types. Test 2 was conducted three months after test 1.

Test 3 was done using expanded polystyrene rebated filler blocks. These were tested by using a conventional method where steel weights were added until failure occurred as shown in Figure 4-6. These filler blocks could not be tested using the beam press machine because of the high level of deformation. The blocks were cut to almost the same breadth as the concrete masonry filler blocks (200 mm) and supported on the edges similar to the ribs. The failure load was recorded and the results were used for comparison for the discussion in Chapter 6.

Figure 4-6: Expanded polystyrene rebated filler block

4.3.3 Activity 2 – Structural integrity

4.3.3.1 Background

This activity was fulfilled by working through a series of sections ranging from part 1, 2, 3 and 4, which were:

1. Naming the elements making up the block.
2. Categorizing the blocks based on the effective span over effective depth ratio (from largest to smallest).
3. Development of theoretical models and conducting a linear analysis thereof.
4. Evaluate the construction methods/practices implemented when making these filler blocks via Questionnaire 2.
5. Fire rating of concrete masonry rebated filler blocks

4.3.3.2. Part 1 – Naming the elements making up the block

The first part was to identify an easy way to name the elements that make up these blocks. The names had to be easy to remember, self-explanatory and compatible with the terminology used in the South African National Standards. Figure 4-7 indicates the designation for each element.

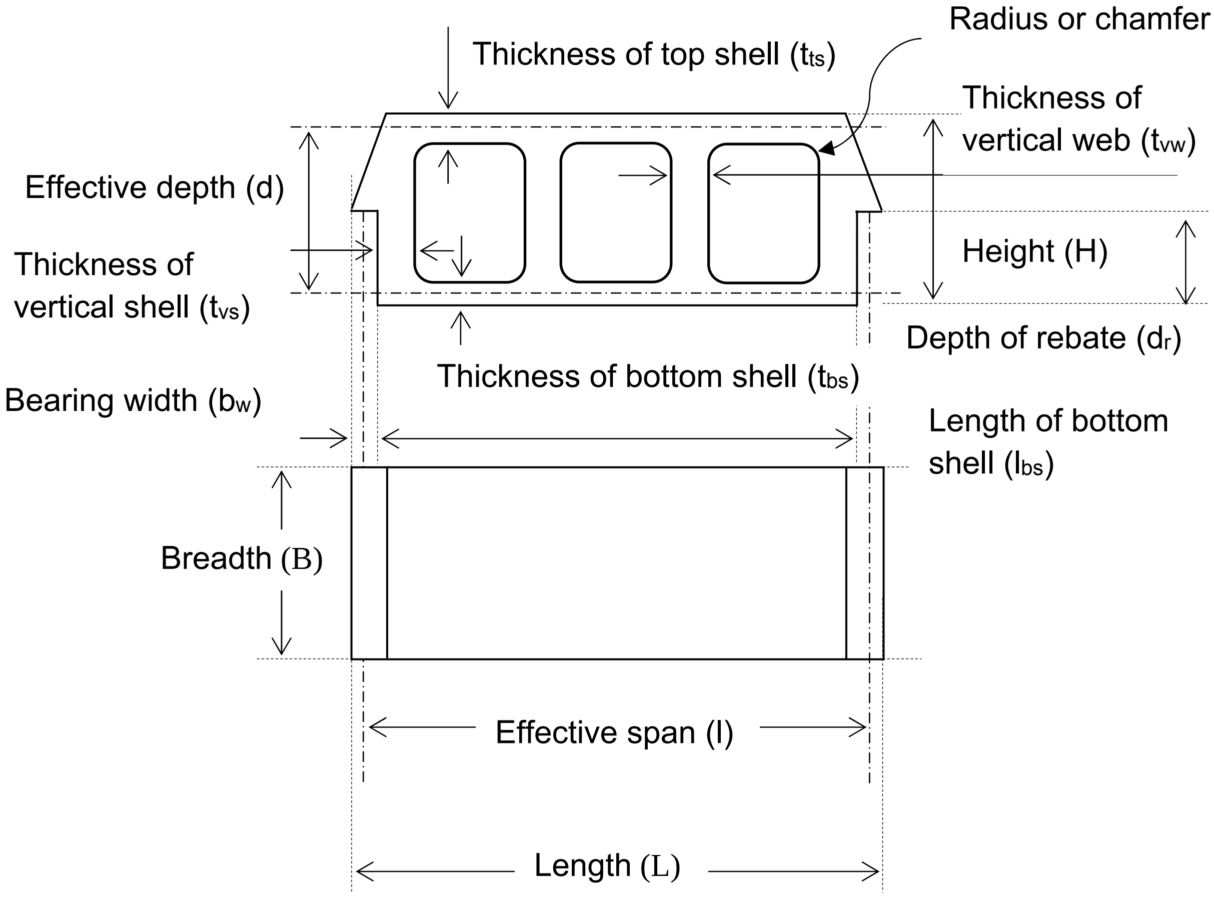


Figure 4-7: Names of the elements making up the filler block

4.3.3.3 Part 2 – Categorizing the blocks

The dimensions measured according to Figure 4-7 were used to categorize them based on the effective span over effective depth ratio as shown in Table 4.1.

The other property recorded was the number of vertical webs (which form either a double or triple core type used in most filler blocks). The size of radius or chamfer was not recorded.

Table 4.1: Geometric dimensions of concrete masonry filler blocks

Element	**Dimension**
Length of bottom shell (l_{bs})	
Breadth (B)	
Height (H)	
Bearing width (b_w)	
Thickness of the top shell (t_{ts})	
Thickness of the bottom shell (t_{bs})	
Thickness of the vertical shell (t_{vs})	
Thickness of the vertical web (t_{vw})	
Depth of rebate (d_r)	
Effective span (l)	
Effective depth (d)	
Effective span/effective depth ratio*	
*Note: Similar to effective span over depth ratio	

4.3.3.4 Part 3 – Theoretical models and analysis

A theoretical model of each filler block type was developed from the as-built dimensions by completing Table 4.2.

Table 4.2: Modelling dimensions

Block type	Dimension
Core spacing (C_s)	
Effective depth (d)	
Effective rebate depth (d_{r-eff})	
Effective bearing width (b_{w-eff})	

The typical models shown in Figure 4-8 and 4-9 below were used to do a linear elastic analysis of each block type. This was done using frame analysis software (viz. Prokon 2013). Two point loads were applied at each of the intermediate nodes (e.g. node 6 and 7) of the top shell such that the block model was loaded symmetrically. The average self-weight of each filler block type measured from the 10 samples during Test 1 was added to the point loads for the first test only. The self-weight was excluded on the second test in order to determine the theoretical structural efficiency (as the self-weight approaches zero). There were no load factors applied. Therefore, the load on the first test was based on the average mass of the filler block type from Test 1 plus 3.5 kN divided by half (refer to Figure 4-8). The minimum load yielding to minimum member forces and moments used in the second test was 3.5 kN divided by half (refer to Figure 4-9). The average mass of the filler block type was ignored. It is not possible to achieve this in practice.

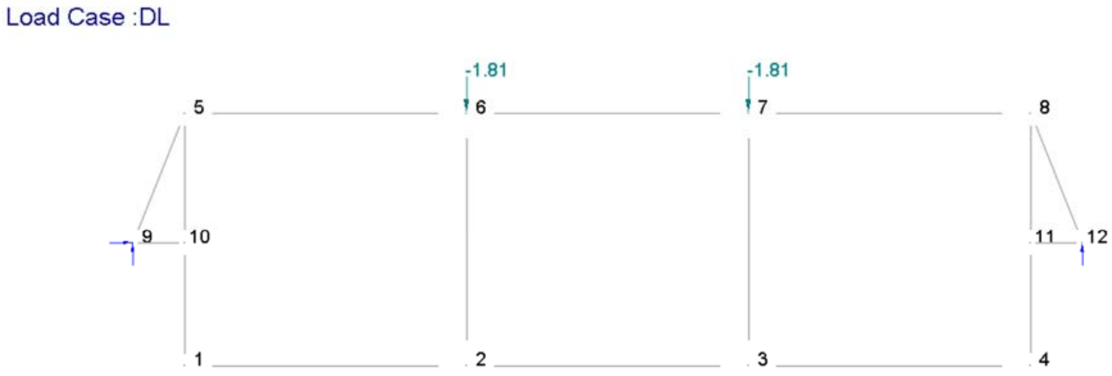


Figure 4-8: Typical theoretical model of a filler block including self-weight (DL - dead and live)

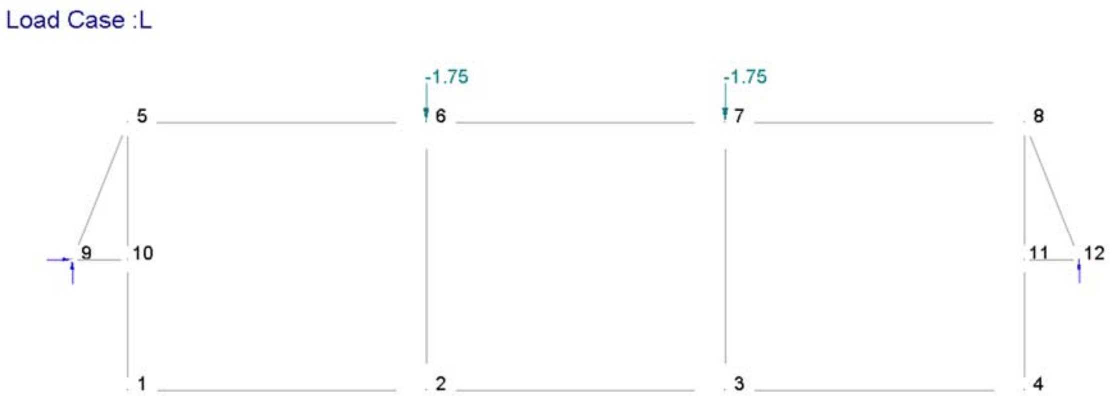


Figure 4-9: Typical theoretical model of a filler block excluding self-weight (L – live)

The maximum axial, shear and bending moments resulting from the self-weight and the testing load of 3.5 kN were recorded.

The following basic procedure was undertaken in order to understand the structural integrity of each block type:

1. The blocks were arranged in order of a decreasing effective span over effective depth ratio (largest to smallest/reading from left to right).
2. A link between the effective span over effective depth ratio and the actual block size used to build the desired slab thickness (i.e. 150-170, 200 and 255 mm) was investigated for any non-uniformities. The ratio of each block type should follow a pattern corresponding to the overall depth of the slab it is intended to be used for.
3. A link between the effective span over effective depth ratio and the magnitude of the maximum axial, shear and moments generated by each block type in response to the applied loads was investigated.

4.3.3.5 Part 4 – Construction of filler blocks (Questionnaire 2, Annexure B)

The second questionnaire was used mainly to investigate the construction methods used by the manufacturers of beam and block slab systems when producing the concrete masonry rebated filler blocks.

The results from this survey were then used to investigate the possible positive and negative effects that the manufacturing practices may have on the structural efficiency of these filler blocks.

Further to this, the responses were used to find ways of improving the structural efficiency of these filler blocks, which will ultimately improve the efficiency of the beam and block slab systems.

4.3.3.6 Part 5 – Fire resistance of CMRFB

Proposed method:

- Identify the type of aggregates used to produce the element.
- Determine the thickness of the structural topping (t_{st}).
- Determine the sum of the contributing equivalent thicknesses of the elements above and below the structural topping namely,
  - o Filler block (te_{fb})
  - o Finishes (te_f)

The equation below can be used to determine the overall thickness of beam and block slab systems. In addition, the figure below illustrates the procedure to determine the overall fire rating of the slab.

$$Te_s = t_{st} + te_{fb} + \sum te_f \qquad \text{eq. 1}$$

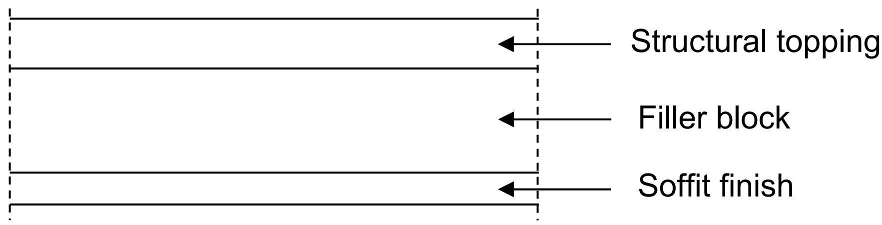


Figure 4-10: Effective thickness of assembly of structural components

The equivalent thickness of the filler block can be determined by using the following equation:

$$Te_{fb} = V_s / l_{bs} \times B \qquad \text{eq. 2}$$

Where,

V_s : volume of solids

l_{bs} : length of bottom shell (refer back to Figure 4-7)

B : breadth of filler block (refer back to Figure 4-7)

The volume of solids can be computed by deducting the volume of voids (v_v) from the gross volume (v_g). The following assumptions are made (refer to Figure 4-11 and 4-12):

- Only the volume of concrete within the length of the bottom shell is considered (i.e. the nibs are ignored).
- Chamfers are ignored and considered as square corners.

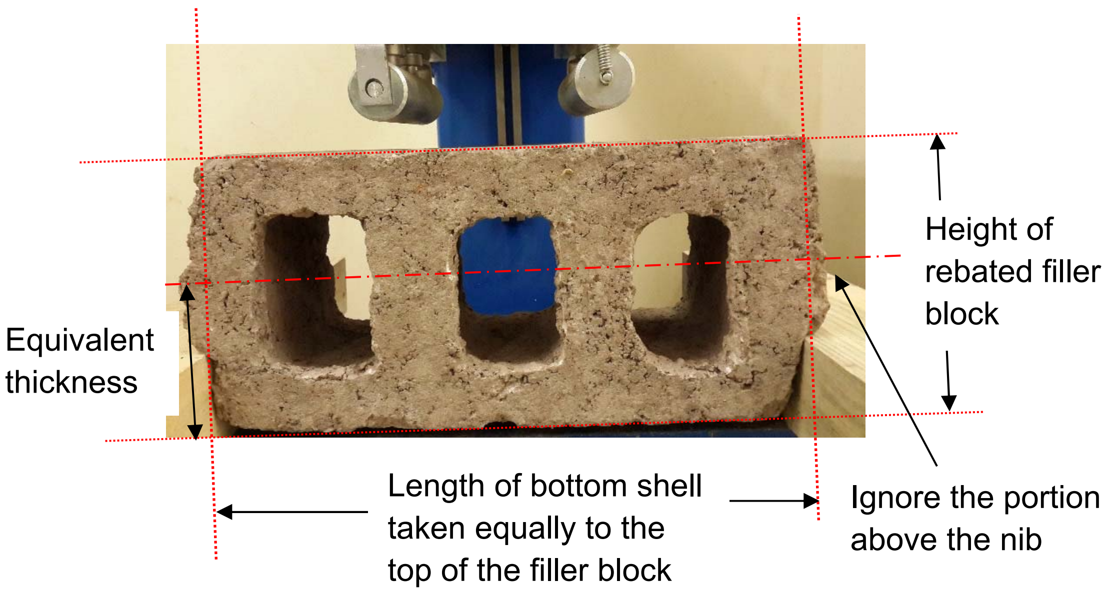


Figure 4-11: Length and height of filler block with respect to fire resistance

Figure 4-12: Breadth (B) of the filler block with respect to fire resistance

The following information was recorded in table form leading to the calculation of the equivalent thickness of filler blocks:

- Length of bottom shell (l_{bs}) mm
- Breadth (B) mm
- Height (H) mm
- Gross volume (V_g) x 10^6 mm^3
- Number of voids
- Thickness of vertical shell (t_{vs}) mm
- Thickness of vertical web (t_{vw}) mm
- Length of void (L_v) mm
- Thickness of top shell (t_{ts}) mm
- Thickness of bottom shell (t_{bs}) mm
- Height of void (H_v) or Radius (R) mm

- Volume of voids (V_v) x 10^6 (mm^3)
- Percentage of voids (%)
- Volume of solids (V_s) x 10^6 mm^3
- Equivalent thickness of filler block (T_{efb}) mm

4.4 Third aim:

- Determine what constituted acceptable quality of a deliberately roughened precast concrete surface by conducting a survey to learn about the construction methodologies used by manufacturers. Site visits were undertaken to validate information given by the contractors.

4.4.1 Background

SABS 0100-1 (2000: 157) specifies the tool that can be used to make the undulation/surface finish for the intended horizontal shear strength. SANS 1879 (2011: 6 and 8) specifies a minimum surface roughness (R_z) of 3 mm and how it can be measured. None of the cited South African codes gave any recommendations, methodology and details on how to achieve the desired roughness. Achieving a uniform surface roughness is not an easy task to accomplish because, “a brush” (refer to Figure 4-13) “or rake can produce a vast range of roughness” (refer to Figure 4-14) “depending on the stiffness of the instrument, the amount of pressure applied and the viscosity or age of the mix”, Gohnert (2003: 385).

Figure 4-13: Bristles of a broom used to roughen the surface of precast concrete

Figure 4-14: Roughening of a precast concrete surface by using a broom

The research question was: what are the fundamental manufacturing and construction challenges affecting the integrity of the shear interface?

4.4.2 Methodology

To find a solution to this problem, three activities were undertaken:

- An investigative study of Codes, Standards and Recommendations was undertaken. Two South African codes, namely, SABS 0100-1:2000 and SANS 1879:2011 were studied in Chapter 2 (refer to 2.7) in order to determine what requirements the manufacturers of beam and block slab systems are expected to meet and how. The study of international literature (FIP: 1982) was necessary in order to compare and contrast the available information.

- Further to the above, all five manufacturers of beam and block slab systems in Durban, South Africa were visited and interviewed via Questionnaire 3, (Annexure C) in order to learn/observe and understand the construction methodology they employ when making these precast ribs with respect to the roughening of the top surface of the beams. The quality of the workmanship and quality-control working styles was observed.
- Further to this, 120 off-cuts of precast pretensioned ribs were collected from two manufacturing sites in order to scrutinize the quality of their shear interface. The quality of the interface was investigated with respect to the uniformity of the roughness, its variation in frequency and appearance of laitance using the scales below:

4.4.2.1 Level of uniformity

- Very poor – complete lack of specified roughening pattern.
- Poor – showing inconsistency of a roughening pattern.
- Neutral – not biased to either side.
- Good – satisfactory in quality of roughening pattern.
- Very good – absolutely consistent in roughness pattern.

4.4.2.2 Appearance of laitance

- Invisible – cannot be seen by the naked eye.
- Low – appearing slightly on the surface.
- Medium – excessive contamination where the surface can be removed by a wire brush, pressure water or pressure air without damaging the roughened surface.
- High – excessive contamination where the removal of laitance will damage the surface.

4.4.2.3 Variation of roughness frequency,

- Low – unnoticeable by naked eye and can only be detected by measuring or using an instrument such as a laser scanner.
- Medium – noticeable without using an instrument but still within the norms of the production quality expected for that particular roughening tool.
- High – gives the impression that a completely different tool had been used.

Recommendations and conclusions of this section of the study were drawn on the basis of the site evidence, available literature and the limitations of the construction methodology within the selected sites in Durban (South Africa) and is presented in Chapter 5 and discussed in Chapter 6.

4.4.3 Shear interface (Questionnaire 3, Annexure C)

This questionnaire enquires about the procedures used by the manufacturers to deliberately roughen the concrete surface of precast pretensioned ribs.

The aim was to investigate whether or not the manufacturers of beam and block slab systems understand the conditions necessary to achieve the composite action safety for low shear situations in beam and block slab systems.

4.5 Fourth aim:

- Determine interfacial tensile bond strength through physical testing of deliberately roughened concrete ribs which are mainly used in special connections.

4.5.1 Background

60 of type 'A' from 120 precast pretensioned concrete ribs used to partly fulfil the third aim (interfacial integrity of precast ribs) were further used to perform interfacial tensile bond tests. The surface roughness (R_z) of 120 beams donated by two manufacturers of beam and block slab systems was measured in accordance with clauses 4.3.4 and 5.5 of SANS1879 (2011: 13). Only the surface to be filled with cast in-situ concrete was measured (refer to Appendix D). The ribs had been roughened using a strong brush whilst concrete was still green. They were cutoffs from a 13 m long casting bed. The ribs had a minimum 28 day characteristic compressive strength of 50 MPa.

Annex D (D1) of SANS 1879 (2011: 13) recommends that the props can be removed once the cast in-situ concrete reaches a compressive strength of 17 MPa. Some manufacturers (refer to Questionnaire – 3, Annexure C under general comments) had witnessed the delamination of precast ribs from the cast in-situ concrete topping.

4.5.1.1 Problem statement

Manufacturers wanted to know what tensile stress was required to separate the interfacial bond of beam and block slab systems in compliance with SANS 1879:2011. Consequently, it was suggested that test 1 and test 2 are done at 10 and 4 days respectively or vice versa. The targeted concrete cube compressive strengths were 25 MPa (at 10 days, in case the removal of props was delayed) and 17 MPa (at 4 days, in case the props were removed early).

4.5.1.2 Connection example

Below is an example of a structural detail where the interfacial bond strength needs to be quantified in order to ensure that the localized tensile stresses developed do not exceed the allowable limit, which would result in delamination of two concrete faces followed by the failure of composite action.

- The edge of precast ‘rib 1’ is supported on a shelf angle via normal gravity bearing. The shelf angle is then supported by the precast rib via a vertical shear force through the bolt (s).
- The precast rib then takes this localized load into the composite structural system via interfacial tensile bond (between the top surface of precast rib and cast in-situ concrete).

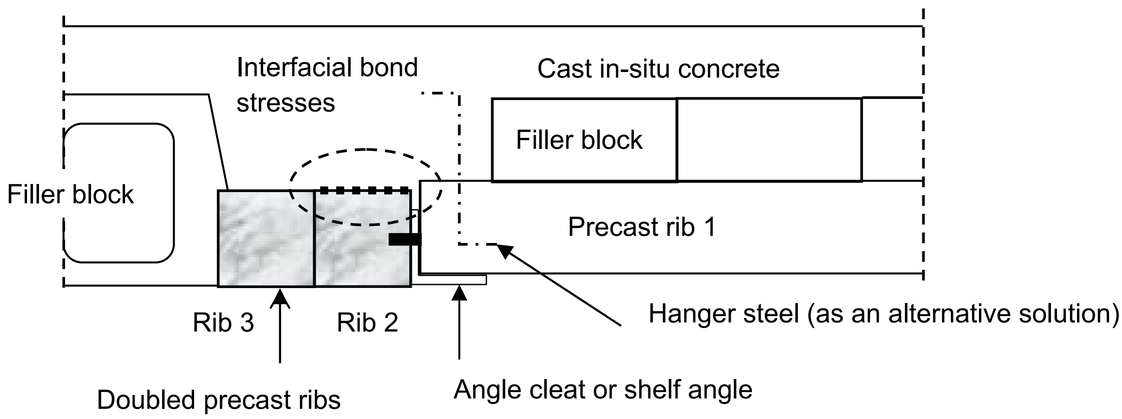


Figure 4-15: Typical detail of a change in the direction of the span

4.5.1.3 Materials

The interfacial bond tests were done using a 28-day characteristic compressive strength of 30 MPa cast in-situ concrete made from the following ingredients:

Table 4.3: Concrete ingredients

30 MPa mix ingredients	Quantity per m³	Description or comment
Water (kg)	205	Tap water
Cement (kg)	350	CEM II/B-M (S-V) 42.5 N
Stone (kg)	1020	19.0 mm Natal Group Sandstone
Sand (kg)	770	Umngeni River Sand

These materials are commonly used in making the concrete mix for structural cast in-situ toppings. However, the quantities differ depending on the mix design requirements. The sizes of timber/plywood formwork are presented in Table 4.4. Some prepared timber box formworks are shown in Figures 4-16 and 4-17.

Table 4.4: Formwork sizes for cast in-situ concrete beams

Test	Size	Quantity
Test 1	250 mm length x 105 mm width x 165 mm depth	60 boxes
Test 2	450 mm length x 105 mm width x 145 mm depth	20 boxes
	250 mm length x 105 mm width x 165 mm depth	36 boxes
	100 mm length x 100 mm width x 100 mm depth	2 boxes

Figure 4-16: Preparation of positioning of timber/plywood formwork

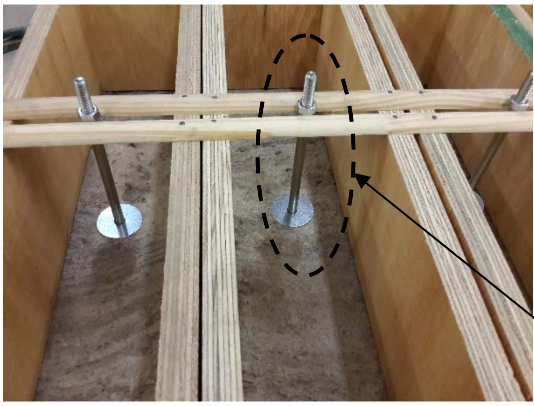


Figure 4-17: Fully prepared timber box formwork

4.5.2 Methodology

4.5.2.1 Surface preparation

Contaminants such as loose laitance, dust and sand were removed from the samples by washing them thoroughly with a fire hose (pressurized water) the day before testing. During the day of testing, the samples (top surface of precast ribs) were sprayed sufficiently with water prior to casting the concrete topping.

4.5.2.2 Concreting

The placing, protecting and curing of concrete was executed in accordance with clauses 10.2, 10.3 and 10.8 of SABS 0100-2 (1994: 29, 30 and 34).

4.5.2.3 Test 1

The first 60 interfacial bond tests (on type ‘A’ ribs) were done on the 10th day after casting. The concrete cube strengths were taken initially at 7 days (to evaluate the current compressive strength and predict a compressive strength at 10 days), then during testing (on the 10th day), 14 days and 28 days (as standard procedure). The interfacial bond stress was calculated based on the contact surface area and the force required to rapture the bonded concrete surfaces.

4.5.2.4 Test 2

The second 58 interfacial bond tests (for type ‘A’ beam) were tested on the 4th day after casting. Beam A7 and A60 were damaged during Test 1. The concrete cube strengths were taken initially at 3 days (to evaluate the current compressive strength and predict the compressive strength at 4 days), then during testing (4th day), 5 and 10 days and then 14 and 28 days later (as a standard procedure). The rest was done as per the procedures during the first test.

4.5.3 Testing procedure

In principle, the testing procedure required that the two surfaces of concrete structural elements cast at different times and combined via a roughened surface be ruptured/separated by exerting a direct tensile force. Figure 4-18 illustrate this. Test 2 cast in-situ beams were constructed centric to the previous location. There was no damage to the interface of the precast ribs. Concrete spills were removed by a steel wire brush.

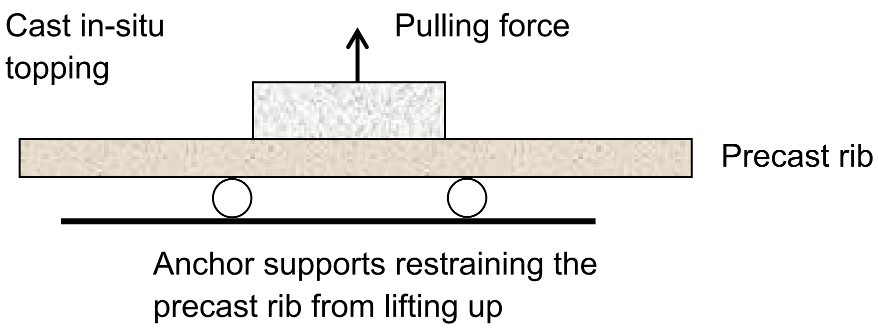


Figure 4-18: Pulling of cast in-situ structural topping (or beam)

A number of different options were evaluated in order to achieve a testing procedure similar to that shown in Figure 4-18. Financial limitations (e.g. purchasing a suitable testing machine) resulted in modifying an existing beam press machine which is operated by a desktop computer (refer to Figure 4-19 and 4-20) in order to attain the same results.

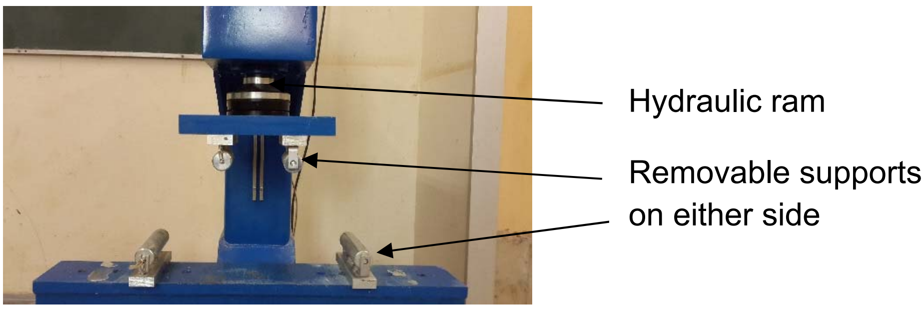


Figure 4-19: Unmodified beam press machine

Figure 4-20: Desktop computer for controlling the beam press machine

There were a few modifications made as depicted in Figures 4-21, 4-22 and 4-23:

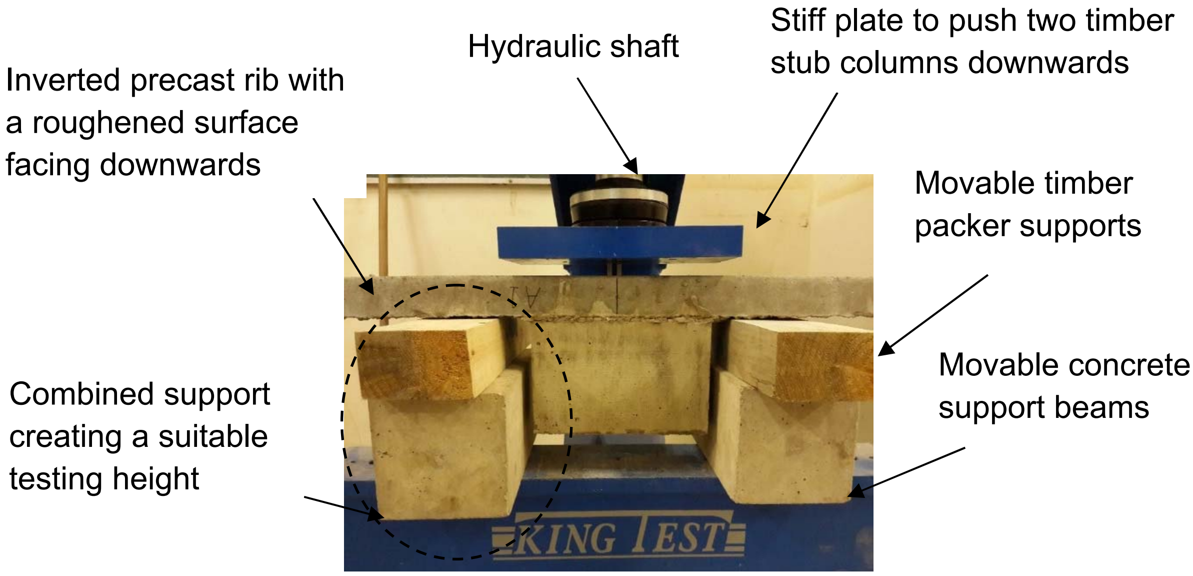


Figure 4-21: Placement of the testing sample in the beam press machine

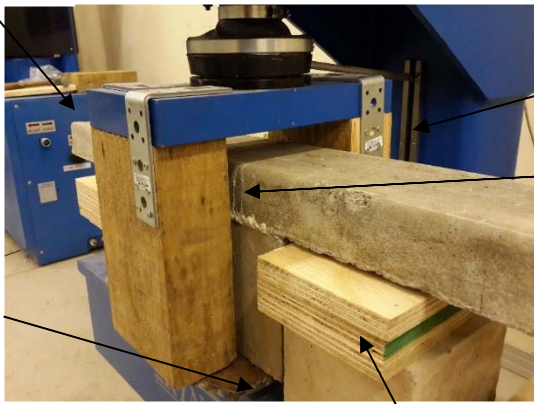


Figure 4-22: Temporary modified beam press machine (first view)

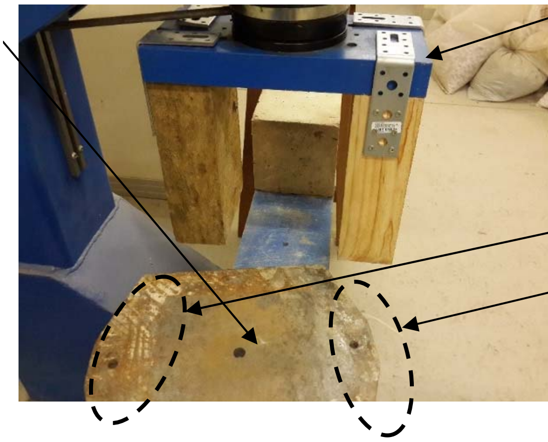


Figure 4-23: Temporary modified beam press machine (second view)

The result is shown in Figure 4-24.

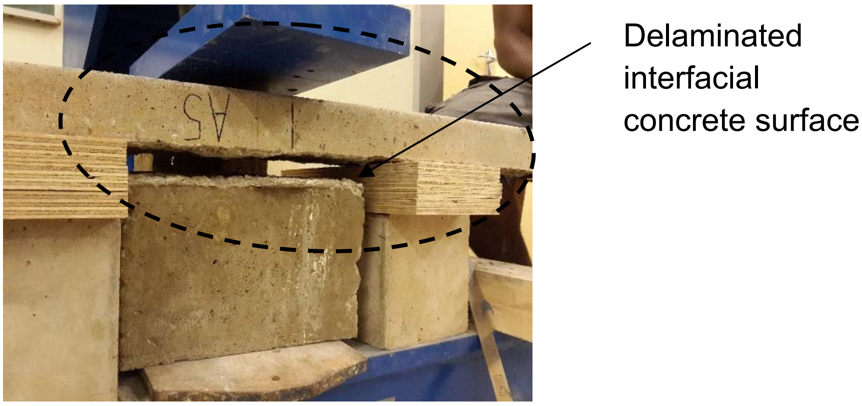


Figure 4-24: Breaking the precast and cast in-situ concrete elements

The CAD diagram below shows the summary of the test setup.

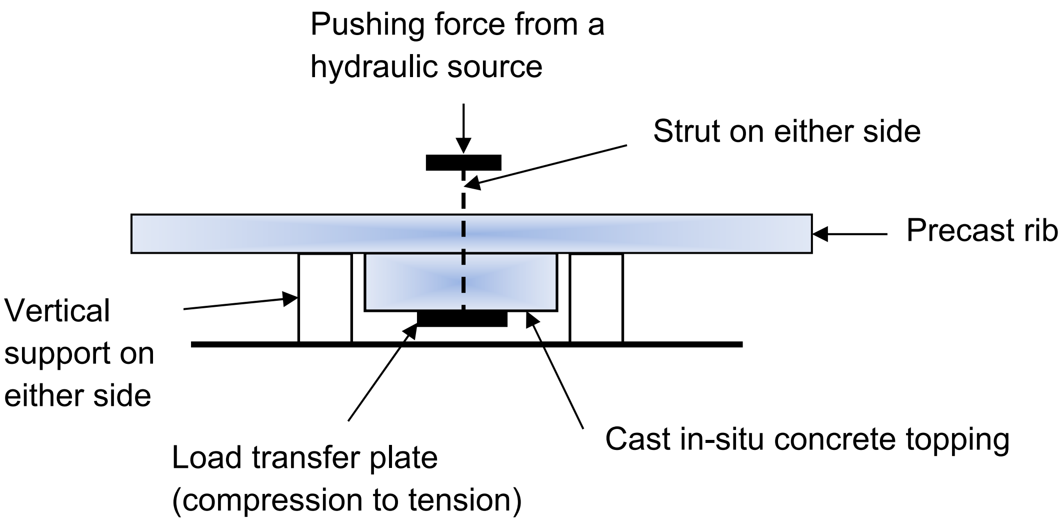


Figure 4-25: Test set-up (Front view)

4.6 Fifth aim:

- Make an assessment by undertaking a basic comparison study between one local beam and block slab system that uses a shallow rectangular precast pretensioned rib to beam and block slab systems used in the United Kingdom.
- Propose a design for a precast pretensioned rib that spans up to 5 metres without temporary props.

The contents of the assessment study is covered in Chapter 6 (discussion).

Chapter 5

Results

5.1 First aim:

- Provide the users of beam and block slab systems with basic technical information about the possible ways to improve the efficiency and effectiveness in the design, manufacturing and construction of beam and block slab systems by undertaking an exploratory (pilot) study to better understand users of these systems concerns (Questionnaire 1).

5.1.1 Introduction of the results (Questionnaire 1)

The results for questions 1 to 4 and 5 to 15 from Questionnaire 1 are presented below:

There were 35 respondents in this survey. 32 (91.43%) of them had been involved in the design of or had worked with beam and block slab systems. The other 3 (8.57%) had no previous involvement with these systems. 68.57% of the respondents were consultants followed by 14.29% from the manufacturing sector, 11.43% from the construction sector and 5.71% from the academic sector. There was no input from architects. 62.86% of the respondents had done more or equal to 10 beam-and-block projects and 37.14% less than 10 projects. 68.57% of the respondents belong to some statutory body (e.g. Engineering Council of South Africa, South African Institute of Architects, Master Builders etc.) and 31.43% did not. The technical portion of the survey covered by the questionnaire (question 5-15) is summarized in Table 11.1 below.

Table 11.1: Responses to 11 technical questions (5 – 15)

Question	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
5	34.29	31.43	20.00	11.43	2.86
6	25.71	31.43	25.71	17.14	0.00
7	8.57	22.86	45.71	17.14	5.71
8	2.86	31.43	37.14	20.00	8.57
9	8.57	17.14	57.14	14.29	2.86
10	14.29	25.71	45.71	11.43	2.86
11	17.14	20.00	28.57	17.14	17.14
12	5.71	28.57	22.86	28.57	14.29
13	5.71	45.71	20.00	14.29	14.29
14	5.71	45.71	22.86	17.14	8.57
15	17.14	42.86	8.57	17.14	14.29

5.1.2 Address the concerns of the industry

The technical comments from question 16 are presented and addressed in Chapter 6 in order to avoid redundancy here.

5.2 Second aim:

- Investigate, by conducting a series of strength to weight ratio tests, how efficient or inefficient these filler blocks are (Activity 1).
- Examine the structural integrity with respect to the integrity of the manufacturing methodologies and the product thereof (Activity 2 which is

subdivided into Part 1, Part 2, Part 3 and Part 4 including Questionnaire 2, and presented in Table 5.14).

- Formulate a method to quantify the fire-resistivity of concrete masonry rebated filler blocks to the structural topping with respect to confining fire/flames to a floor and preventing it from spreading (Activity 2, Part 5).

5.2.1 Activity 1 – Structural Efficiency (Table 5.1, Table 5.2, Table 5.3, Table 5.4 and Table 5.5 and Figure 5-1, Figure 5-2 and Figure 5-3)

Table 5.1: Test 1 mass of filler blocks (S – small, M – medium and L – large)

Block type		1 [S]	2 [M]	3 [L]	4 [S]	5 [L]	6 [S]	7 [M]	8 [L]	9 [S]	10 [M]	11 [L]	12 [S]	13 [L]
		Dry mass of each block (kg)												
Sample number	i	18.5	17.7	26.2	12.5	14.4	11.6	12.3	15.1	13.2	12.9	15.1	16.2	21.7
	ii	19.3	17.6	25.9	12.9	14.6	11.7	13.3	15.6	13.7	13.0	14.8	16.2	23.3
	iii	19.7	18.2	26.4	12.2	14.7	11.7	12.8	17.1	13.5	12.9	15.2	16.5	20.8
	iv	20.1	17.8	25.8	12.5	14.7	11.7	12.6	15.4	13.4	13.3	15.6	16.2	22.6
	v	21.1	15.5	26.0	12.5	15.1	12.2	12.9	15.3	14.0	12.7	15.9	15.6	22.5
	vi	21.1	18.0	26.2	13.0	14.8	11.6	12.9	15.4	13.4	13.1	15.5	16.3	22.3
	vii	20.7	18.1	26.3	12.8	14.8	12.0	12.6	17.0	13.5	13.1	15.0	16.6	23.6
	x	20.2	18.0	25.6	12.5	14.9	11.6	13.0	15.5	13.4	13.0	15.6	15.5	21.6
	xi	20.4	18.1	25.7	12.9	14.1	11.7	13.1	15.5	13.2	13.3	15.5	16.2	22.8
	xii	20.5	18.2	26.8	12.9	15.0	11.8	12.5	15.5	14.4	12.8	15.5	15.9	21.7
	Average mass	20.2	17.7	26.1	12.7	14.7	11.8	12.8	15.7	13.6	13.0	15.4	16.1	22.3

The dispersion of data from the mean is not calculated since the spacing of the ribs used by different manufactures vary.

Table 5.2: Test 1 force at failure of filler blocks (S – small, M – medium and L – large)

Block type		1 [S]	2 [M]	3 [L]	4 [S]	5 [L]	6 [S]	7 [M]	8 [L]	9 [S]	10 [M]	11 [L]	12 [S]	13 [L]
		Force at failure (kN)												
Sample number	i	11.1	7.8	13.0	4.5	2.6	1.9	5.1	4.5	6.7	6.6	7.2	9.1	10.7
	ii	9.3	7.6	13.8	5.7	2.0	3.4	6.8	5.9	7.4	7.8	7.4	11.0	12.1
	iii	11.6	8.4	13.9	5.1	3.9	3.3	5.5	7.0	6.8	6.2	6.9	7.6	7.8
	iv	10.9	6.7	14.1	4.9	3.7	3.3	6.4	4.4	7.4	6.9	7.7	6.6	15.0
	v	11.7	7.1	15.1	4.6	4.2	5.6	7.0	5.7	7.4	1.4	8.2	5.6	11.1
	vi	15.7	7.8	13.2	5.2	3.6	3.2	6.4	4.9	8.0	7.0	8.4	9.4	11.5
	vii	12.4	7.3	13.8	5.7	4.2	3.7	6.9	6.2	7.8	7.4	5.7	8.5	16.4
	x	13.8	7.5	12.2	4.5	3.7	4.1	6.7	6.0	7.0	8.1	7.3	7.9	10.5
	xi	13.0	7.5	12.7	5.7	2.5	3.0	5.7	3.3	7.5	7.2	8.6	10.3	12.2
	xii	12.7	6.8	13.5	6.0	5.1	3.6	4.8	5.2	7.7	5.6	7.2	8.9	12.6
	Average force	12.2	7.5	13.5	5.2	3.6	3.5	6.1	5.3	7.4	6.4	7.5	8.5	12.0
	*Pass/Fail	P	P	P	P	P	P	P	P	P	P	P	P	P

*Pass (P) denotes failure force equal or above 3.5 kN and Fail (F) denotes failure force below 3.5 kN.

Table 5.3: Test 2 mass and force at failure of filler blocks (S – small, M – medium and L – large)

	Block type	1 [S]	2 [M]	3 [L]	4 [S]	5 [L]	6 [S]	7 [M]	8 [L]	9 [S]	10 [M]	11 [L]	12 [S]	13 [L]
		Dry mass of each block (kg)												
Sample number	i	19.6	18.7	22.5	12.5	15.8	11.3	13.3	15.2	13.6	12.6	15.7	15.9	21.2
	ii	20.8	18.3	23.6	11.6	15.9	11.0	13.5	15.1	13.0	12.6	15.9	16.0	23.9
	iii	19.7	18.4	22.7	12.4	16.2	11.2	13.9	15.6	14.2	12.7	15.7	16.1	21.2
	Average mass	20.0	18.5	22.9	12.2	16.0	11.2	13.6	15.3	13.6	12.6	15.8	16.0	22.1
		Force at failure (kN)												
Sample number	i	7.3	4.7	4.5	5.7	5.4	2.3	3.8	4.6	10.2	7.0	9.4	4.8	15.8
	ii	8.5	6.4	7.4	2.0	4.3	2.3	4.0	4.3	8.5	6.8	7.8	3.1	18.8
	iii	9.4	4.6	5.3	3.6	4.8	2.2	4.1	2.7	9.3	8.0	8.8	4.1	10.7
	Average force	8.4	5.2	5.7	3.8	4.8	2.3	4.0	3.9	9.3	7.3	8.7	4.0	15.1
	*Pass/Fail	P	P	P	P	P	F	P	P	P	P	P	P	P

*Pass (P) denotes failure force equal or above 3.5 kN and Fail (F) denotes failure force below 3.5 kN.

Table 5.4: Test 1 and test 2 structural efficiencies of filler blocks (S – small, M – medium and L – large)

Block type	1 [S]	2 [M]	3 [L]	4 [S]	5 [L]	6 [S]	7 [M]	8 [L]	9 [S]	10 [M]	11 [L]	12 [S]	13 [L]
Structural efficiency - Test 1	61.8	42.9	52.9	41.8	24.6	30.4	48.8	34.4	55.3	50.3	49.5	53.7	54.8
Structural efficiency - Test 2	42.8 ↓	28.9 ↓	25.5 ↓	31.5 ↓	30.8 ↑	20.6 ↓	29.8 ↓	25.8 ↓	69.9 ↑	58.6 ↑	56.0 ↑	25.5 ↓	69.6 ↑

Notes:

Structural efficiency = Load at failure (kg) / Self-weight of the block (kg).

The load at failure read from the machine is converted from kN to kg.

E.g. the structural efficiency for filler block type 1 = (12.2 x 1 000 / 9.81) kg / 20.2 kg

= 61.57 (unitless).

Figure 5-1 and Figure 5-2 show a graphical representation of structural efficiency for Test 1 and Test 2. There is no ideal value for the theoretical structural efficiency.

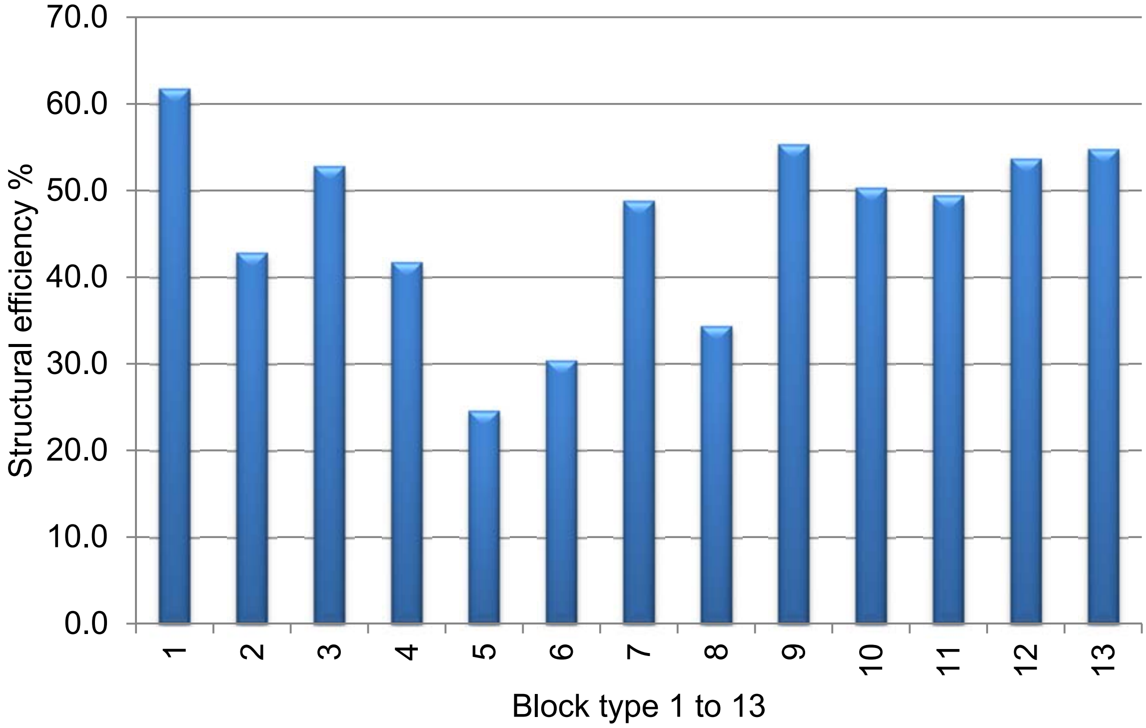


Figure 5-1: Test 1 structural efficiencies

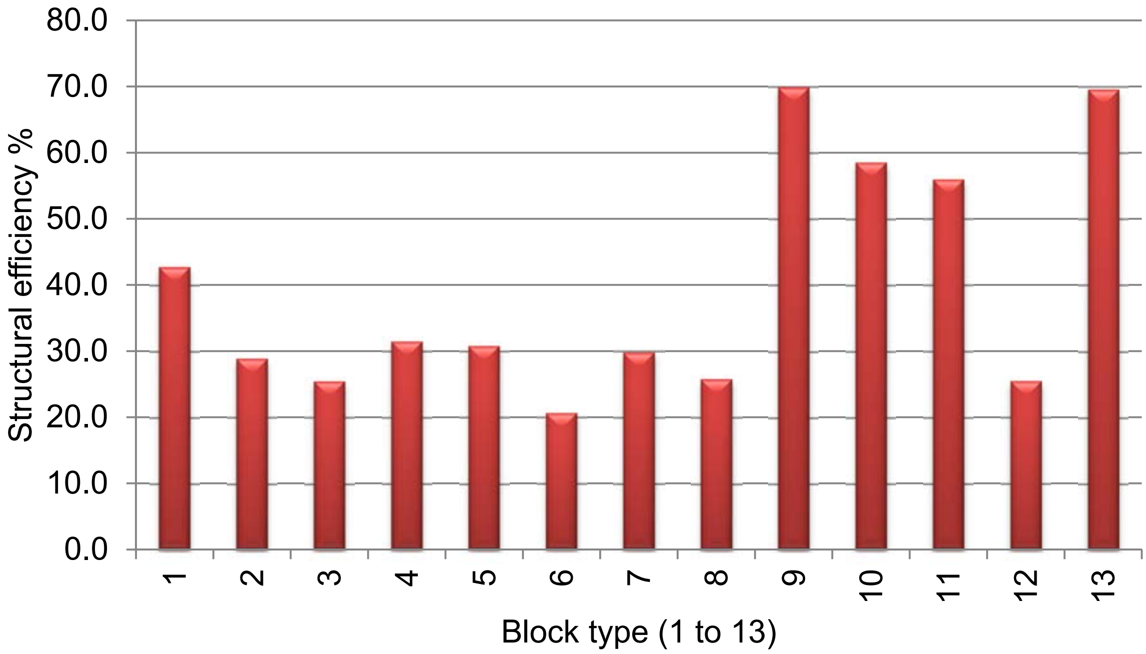


Figure 5-2: Test 2 structural efficiencies

Table 5.5: Test 3 mass, force at failure and structural efficiencies of poly-blocks

Block type		A	B	C
		Mass of each poly-block (kg)		
Sample number	i	0.17	0.21	0.27
	ii	0.21	0.21	0.24
	iii	0.21	0.22	0.24
	iv	0.18	0.22	0.28
	v	0.20	0.22	0.28
	vi	0.20	0.20	0.25
	vii	0.22	0.21	0.27
	x	0.18	0.21	0.24
	xi	0.18	0.20	0.26
	xii	0.23	0.20	0.24
	Average mass	0.20	0.21	0.26
		Force at failure (kN)		
Sample number	i	1.08	1.41	1.46
	ii	1.08	1.46	1.28
	iii	1.08	1.51	0.98
	iv	1.08	1.51	1.58
	v	1.08	1.46	1.06
	vi	1.08	1.41	0.96
	vii	1.08	1.41	1.16
	x	1.08	1.32	1.00
	xi	1.08	1.32	1.00
	xii	1.08	1.37	1.08
	Average force	1.08	1.42	1.16
Structural efficiency		557.0	691.2	459.8

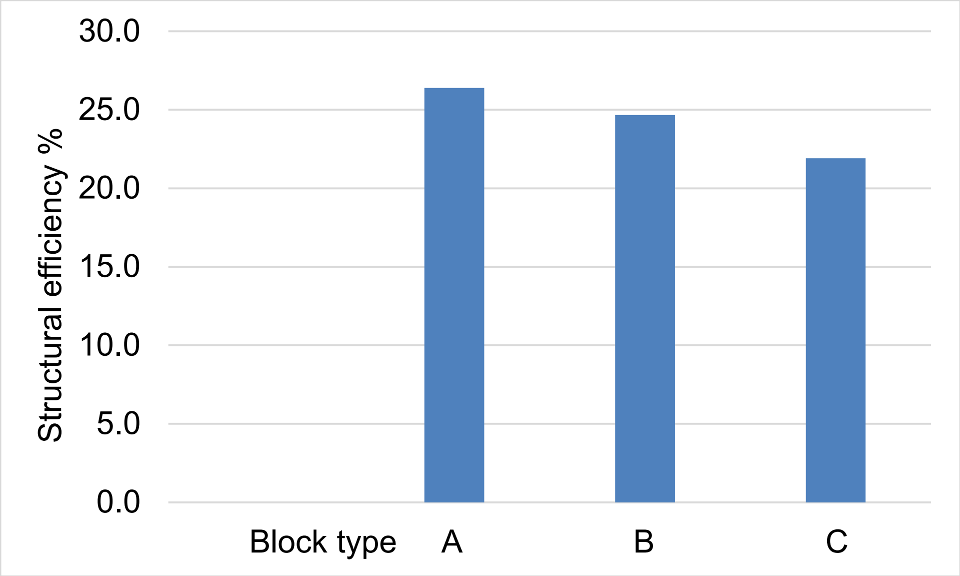


Figure 5-3: Test 3 structural efficiencies of poly-blocks

5.2.2 Activity 2 – Structural Integrity

5.2.2.1 Part 1 – Naming the elements making up the filler block

There are no results to present here as the methodology and the format were discussed in Chapter 4 (please refer to 4.3.3.2).

5.2.2.2 Part 2 – Categorizing the blocks

The results in Table 5.6 below presents the effective span over the effective depth ratio of each block type as well as the overall slab depth each block is normally used to make (inside the square brackets i.e. […]).

Table 5.6: Effective span over depth ratio of each filler block type (block type 1 to 8)

Block type	1 [170]	2 [200]	3 [255]	4 [170]	5 [255]	6 [170]	7 [200]	8 [255]
Length of bottom shell (l_{bs})	505.0	500.0	502.0	409.0	410.3	406.3	401.7	405.3
Breadth (B)	203.7	198.7	196.7	194.3	195.3	221.7	231.0	220.7
Height (H)	104.3	139.7	199.3	124.0	194.3	118.0	139.0	197.3
Bearing width (b_w)	24.3	24.0	21.7	21.8	22.5	20.4	17.8	18.7
Thickness of top shell (t_{ts})	23.6	35.1	31.4	36.6	36.4	25.1	22.4	23.3
Thickness of bottom shell (t_{bs})	31.7	30.0	31.0	33.8	34.0	27.5	26.2	29.3
Thickness of vertical shell (t_{vs})	31.8	31.1	30.9	33.4	32.5	26.2	27.6	27.2
Thickness of vertical web (t_{vw})	32.0	34.1	29.0	32.3	33.1	23.6	22.7	21.8
Depth of rebate (d_r)	57.3	60.4	58.7	61.2	60.9	71.9	68.9	70.2
Effective span (l)	529.3	524.0	523.7	430.8	432.9	426.7	419.5	424.1
Effective depth (d)	76.6	107.1	168.1	88.8	159.1	91.7	114.7	171.0
Effective span/depth ratio	6.9	4.9	3.1	4.9	2.7	4.7	3.7	2.5

Table 5.6 continues: Effective span over depth ratio of each filler block type (block type 9 to 13)

Block type	9 [170]	10 [200]	11 [255]	12 [170]	13 [255]
Length of bottom shell (l_{bs})	451.7	451.0	451.7	411.0	408.7
Breadth (B)	188.7	190.3	189.7	197.0	195.0
Height (H)	117.3	142.0	190.7	124.3	194.7
Bearing width (b_w)	21.4	17.9	17.3	27.1	23.4
Thickness of top shell (t_{ts})	28.0	22.2	22.8	35.8	35.1
Thickness of bottom shell (t_{bs})	27.7	28.2	28.0	36.0	35.0
Thickness of vertical shell (t_{vs})	28.5	27.7	26.0	34.0	35.6
Thickness of vertical web (t_{vw})	27.4	30.0	25.7	33.6	35.7
Depth of rebate (d_r)	68.1	70.0	69.6	60.2	60.3
Effective span (l)	473.1	468.9	468.9	438.1	432.1
Effective depth (d)	89.5	116.8	165.3	88.5	159.6
Effective span/depth ratio	5.3	4.0	2.8	5.0	2.7

Table 5.7: Effective span over depth ratio form largest to smallest

Block type	1 [170]	4 [170]	6 [170]	9 [170]	12 [170]	2 [200]	7 [200]	10 [200]	3 [255]	5 [255]	8 [255]	11 [255]	13 [255]
Length of bottom shell (l_{bs})	505	409	406	452	411	500	402	451	502	410	405	452	409
Breadth (B)	204	194	222	189	197	199	231	190	197	195	221	190	195
Height (H)	104	124	118	117	124	140	139	142	199	194	197	191	195
Bearing width (b_w)	24	22	20	21	27	24	18	18	22	23	19	17	23
Thickness of top shell (t_{ts})	24	37	25	28	36	35	22	22	31	36	23	23	35
Thickness of bottom shell (t_{bs})	32	34	28	28	36	30	26	28	31	34	29	28	35
Thickness of vertical shell (t_{vs})	32	33	26	28	34	31	28	28	31	32	27	26	36
Thickness of vertical web (t_{vw})	32	32	24	27	34	34	23	30	29	33	22	26	36
Depth of rebate (d_r)	57	61	72	68	60	60	69	70	59	61	70	70	60
Effective span (l)	529	431	427	473	438	524	419	469	524	433	424	469	432
Effective depth (d)	77	89	92	89	88	107	115	117	168	159	171	165	160
Effective span/depth ratio	6.9	4.9	4.7	5.3	5.0	4.9	3.7	4.0	3.1	2.7	2.5	2.8	2.7

5.2.2.3 Part 3 – Theoretical models and analysis

Table 5.8: Dimensions and forces for modelling (refer to Figure 4-7 in Chapter 4)

Block type	1 [170]	4 [170]	6 [170]	9 [170]	12 [170]	2 [200]	7 [200]	10 [200]	3 [255]	5 [255]	8 [255]	11 [255]	13 [255]
Core centre spacing (Cs)	79	125	127	141	189	156	125	141	157	126	126	142	124
Effective depth (d)	77	89	92	89	88	107	115	117	168	159	171	165	160
Effective rebate depth (dr-eff)	41	44	58	54	42	45	56	56	43	44	56	56	43
Effective bearing width (bw-eff)	28	28	23	25	31	28	23	23	26	28	23	22	30
Design load	1.85	1.81	1.81	1.82	1.83	1.84	1.81	1.81	1.88	1.82	1.83	1.83	1.86
Minimum load	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75

Notes:

The design load = (average mass of the filler block type from test 1 (in kN) + 3.5 kN as per SANS 1879:2011) / 2.

The minimum load = 3.5 kN / 2 (the average mass of the filler block type is ignored or assumed to be almost equal to zero).

5.2.2.4. Analysis of models for member forces

Table 5.9: Forces and moments for Manufacture – A filler blocks

Block type	1				2				3			
	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}
Unit		kN	kN	kN.mm		kN	kN	kN.mm		kN	kN	kN.mm
Max. load	8	3.52	1.46	59.14	9	2.81	1.77	76	9	1.79	1.26	81.7
Min. load	8	3.33	1.38	55.97	9	2.67	1.69	72.4	9	1.67	1.18	76.13

Table 5.10: Forces and moments for Manufacture – B filler blocks

Block type	4				5			
	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}
Unit		kN	kN	kN.mm		kN	kN	kN.mm
Max. load	9	2.73	1.76	61.26	9	1.53	1.21	64.11
Min. load	9	2.63	1.7	59.13	9	1.47	1.16	61.58

Table 5.11: Forces and moments for Manufacturer – C filler blocks

Block type	6				7				8			
	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}
Unit		kN	kN	kN.mm		kN	kN	kN.mm		kN	kN	kN.mm
Max. load	9	2.57	1.9	61.37	9	2.04	1.62	59.83	9	1.37	1.37	64.15
Min. load	9	2.49	1.84	59.4	9	1.97	1.57	57.75	9	1.31	1.31	61.44

Table 5.12: Forces and moments for Manufacture – D filler blocks

Block type	9				10				11			
	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}
Unit		kN	kN	kN.mm		kN	kN	kN.mm		kN	kN	kN.mm
Max. load	9	2.98	1.93	68.58	9	2.24	1.66	67.26	9	1.57	1.42	71.56
Min. load	9	2.87	1.86	66.05	9	2.16	1.6	64.88	9	1.51	1.36	68.58

Table 5.13: Forces and moments for Manufacture – E filler blocks

Block type	12				13			
	Elem	Axial	Y-shear	M_{xx}	Elem	Axial	Y-shear	M_{xx}
Unit		kN	kN	kN.mm		kN	kN	kN.mm
Max. load	4	2.11	2.11	75.89	9	1.55	1.19	64.54
Min. load	4	2.01	2.01	72.61	9	1.46	1.12	60.73

5.2.2.5 Part 4 – Construction of filler blocks (Questionnaire 2)

Table 5.14: Responses around the construction of filler blocks

	Questionnaire 2: Filler Blocks							
	Question	Manufacturer	A	B	C	D	E
Background and general	1	Describe your background regarding your familiarity with the concrete masonry rebated filler blocks.	Manufacturer	No answer	Manufacturer	Sales consultant	No response
	2	How many years have you worked with concrete masonry rebated filler blocks?	17	15	23	5	No response
	3	How many beam and block projects have you completed on average per year?	250	85	380	50	No response
	4	How many beam and block projects that incorporated concrete masonry rebated filler blocks have you completed?	5000	No answer	8740	50	No response
	5	How many beam and block projects that incorporated expanded polystyrene rebated filler blocks have you completed?	1000	55	60	0	No response
	6	Do you belong to any statutory body such as the Engineering Council of South Africa, Master Builders, Concrete Society or any others?	No	No answer	No	Yes, Concrete Manufacturers Association	No response

Table 5.14: Responses around the construction of filler blocks, continued…

	Questionnaire 2: Filler Blocks						
	Question	Manufacturer	A	B	C	D	E
	7	Were you directly involved in designing the concrete masonry rebated filler blocks you use for your projects?	Yes, an engineer designed the filler block	Yes	No, an engineer designed the filler block	No, structural engineer	No response
	8	How often do you cast the batch of filler blocks per month?	12	No answer	22	1	No response
Manufacturing	9	What materials do you use for manufacturing these blocks?	Umngeni River Sand, 9.5 mm aggregates, Cement 42.5N, chemical additive and water	No answer	Umngeni River Sand, 9.5 mm stone and cement	River sand, 9.7 mm stone and cement	No response
	10	Please provide the names of any admixtures you use when manufacturing your blocks.	DGN Powermaster	No answer	None	Chryso Activator Plus	No response
	11	Do you do any integrity tests for the materials you intend purchasing to manufacture these blocks?	No, visual and handfeel	No answer	Yes, grading and cleanliness of sand	Yes, Sieve Analysis	No response
	12	Do you conduct any trial mix designs using the materials you use in your mix?	Yes, independent laboratory	No answer	Yes, we do trial test batches and test the blocks	Yes, production test run	No response

Table 5.14: Responses around the construction of filler blocks, continued…

	Questionnaire 2: Filler Blocks						
	Question	Manufacturer	A	B	C	D	E
	13	Do you make any filler block samples for testing prior to the bulk/batch production?	No	No answer	Yes	No	No response
	14	Do you do any in-house filler block testing to assess the strength of the blocks prior to selling to the public?	Yes	Yes	Yes	Yes	No response
	15	Our organization follows adequate curing procedures.	Agree	Agree	Agree	Strongly agree	No response
	16	For how many days do you cure your filler blocks?	7	14	7	7	No response
	17	What method do you use to cure these blocks?	Dry stacking and water spraying	Sun	The blocks are watered on day two	Natural air dry	No response
Design	18	Have you previously changed the design of your filler blocks because of poor structural performance?	No	No	Yes	No	No response
	19	Do you think the self-weight of your filler blocks can be reduced without affecting the strength?	Yes	Strongly disagree	Disagree	Disagree	No response
Production cost	20	Do you think the production cost of your filler blocks is badly affected by the selection of the materials you are using?	Neutral	Neutral	Agree	Agree	No response

Table 5.14: Responses around the construction of filler blocks, continued…

	Questionnaire 2: Filler Blocks						
	Question	Manufacturer	A	B	C	D	E
	21	Do you think the production cost of your filler blocks is badly affected by the actual design of your filler blocks?	Agree	Neutral	Agree	Agree	No response
Improvement	22	Do you think reviewing the design of your filler blocks could save you money in the long term?	Strongly agree	Strongly agree	Neutral	Agree	No response
	23	Do you think doing trial mix designs could significantly improve the structural performance of your filler blocks?	Agree	Strongly agree	Agree	Agree	No response
	24	Do you think educating your staff about the mix designs for concrete masonry blocks could have a significant positive effect in the production of your blocks?	Agree	Strongly agree	Agree	Agree	No response
	25	Do you think improving the curing process could significantly improve the strength of your filler blocks?	Agree	Agree	Agree	Agree	No response

Table 5.14: Responses around the construction of filler blocks, continued…

	Questionnaire 2: Filler Blocks						
	Question	Manufacturer	A	B	C	D	E
Improvement	26	Please give any comments/suggestions about the topic	NB: The filler block is only a void former. It is not a structural part of the slab. It only has to take a down point load of ± 200 kg to support the weight of labour and concrete. We suggest using scaffolding plank on top for heavier traffic	No answer	No answer	No answer	No response

5.2.2.6 Part 5 – Fire resistance of CMRFB

Table 5.15: Calculation of equivalent thickness (T_{efb})

Filler block type	Length of bottom shell (l_{bs}) mm	Breadth (B) mm	Height (H) mm	Gross volume (V_g) x 10^6 mm³	Number of voids	Thickness of vertical shell (t_{vs}) mm	Thickness of vertical web (t_{vw}) mm	Length of void (L_v) mm	Thickness of top shell (t_{ts}) mm	Thickness of bottom shell (t_{bs}) mm	Height (H_v) or Radius (R) mm
1	505.0	203.7	104.3	10.7	6						25.0
2	500.0	198.7	139.7	13.9	3	31.1	34.1	123.2	35.1	30.0	74.6
3	502.0	196.7	199.3	19.7	3	30.9	29.0	127.4	31.4	31.0	136.9
4	409.0	194.3	124.0	9.9	3	33.4	32.3	92.5	36.6	33.8	53.6
5	410.3	195.3	194.3	15.6	3	32.5	33.1	93.0	36.4	34.0	123.9
6	406.3	221.7	118.0	10.6	3	26.2	23.6	102.3	25.1	27.5	65.4
7	401.7	231.0	139.0	12.9	3	27.6	22.7	100.4	22.4	26.2	90.5
8	405.3	220.7	197.3	17.7	3	27.2	21.8	102.4	23.3	29.3	144.7
9	451.7	188.7	117.3	10.0	3	28.5	27.4	113.3	28.0	27.7	61.6
10	451.0	190.3	142.0	12.2	3	27.7	30.0	111.8	22.2	28.2	91.6
11	451.7	189.7	190.7	16.3	3	26.0	25.7	116.1	22.8	28.0	139.9
12	411.0	197.0	124.3	10.1	2	34.0	33.6	103.2	35.8	36.0	52.6
13	408.7	195.0	194.7	15.5	3	35.6	35.7	88.7	35.1	35.0	124.5

Table 5.15: Calculation of equivalent thickness (T_{efb}), continued

Filler block type	Volume of voids (V_v) 10^6 (mm³)	Percentage of voids (%)	Volume of solids (V_s) x 10^6 mm³	Equivalent thickness of filler block (Te_{fb}) mm
1	2.4	22.4	8.3	81.0
2	5.5	39.5	8.4	84.5
3	10.3	52.3	9.4	95.1
4	2.9	29.3	7.0	87.6
5	6.8	43.4	8.8	110.1
6	4.4	41.8	6.2	68.6
7	6.3	48.8	6.6	71.2
8	9.8	55.6	7.8	87.6
9	4.0	39.5	6.0	71.0
10	5.8	48.0	6.3	73.9
11	9.2	56.6	7.1	82.8
12	2.1	21.2	7.9	97.9
13	6.5	41.7	9.0	113.6

5.3 Third aim:

- Determine what constituted acceptable quality of a deliberately roughened precast concrete surface by conducting a survey to learn about the construction methodologies used by manufacturers. Site visits were undertaken to validate information given by the contractors (Figure 5-4, Figure 5-5 and Figure 5-6 and Questionnaire 3).

5.3.1 Integrity of the roughened surface

Also refer to appendix B and C for the photographs showing roughened surfaces.

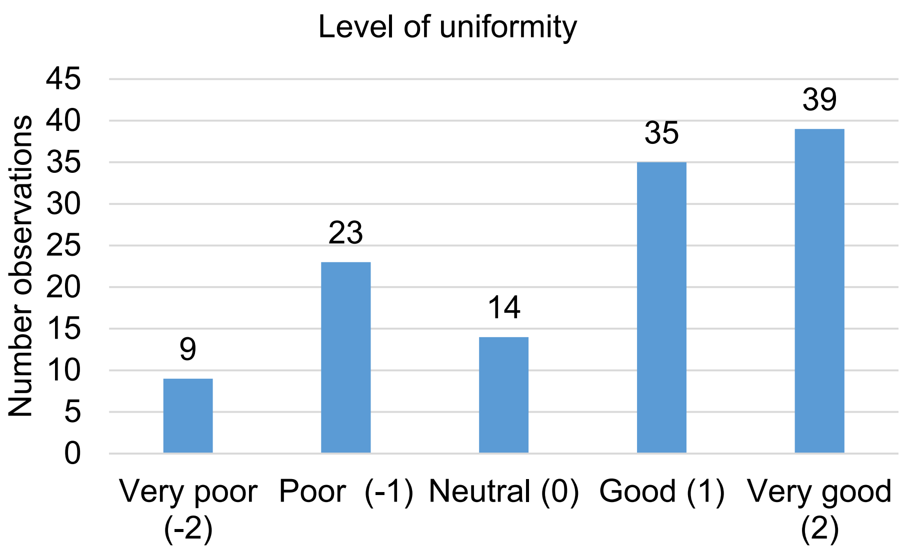


Figure 5-4: Level of roughness interface uniformity of precast ribs

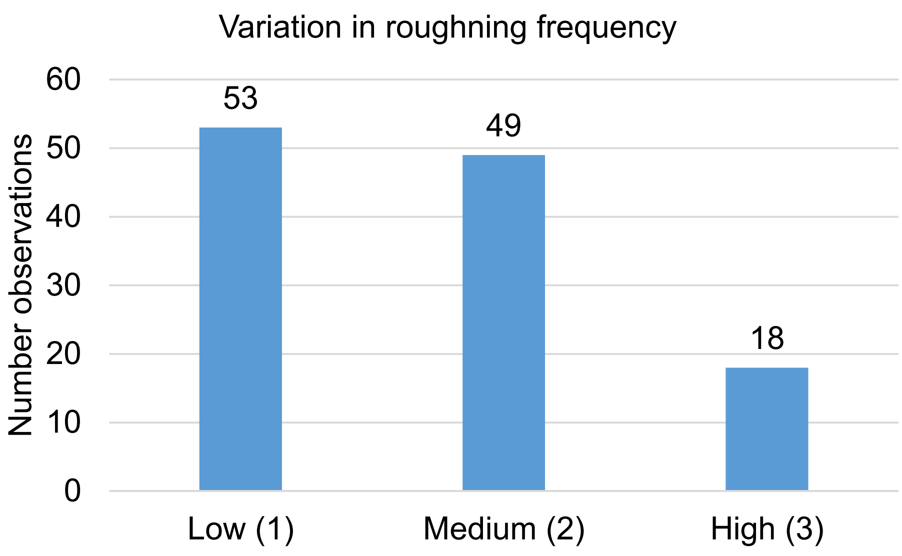


Figure 5-5: Variation in interface roughness frequency of precast ribs

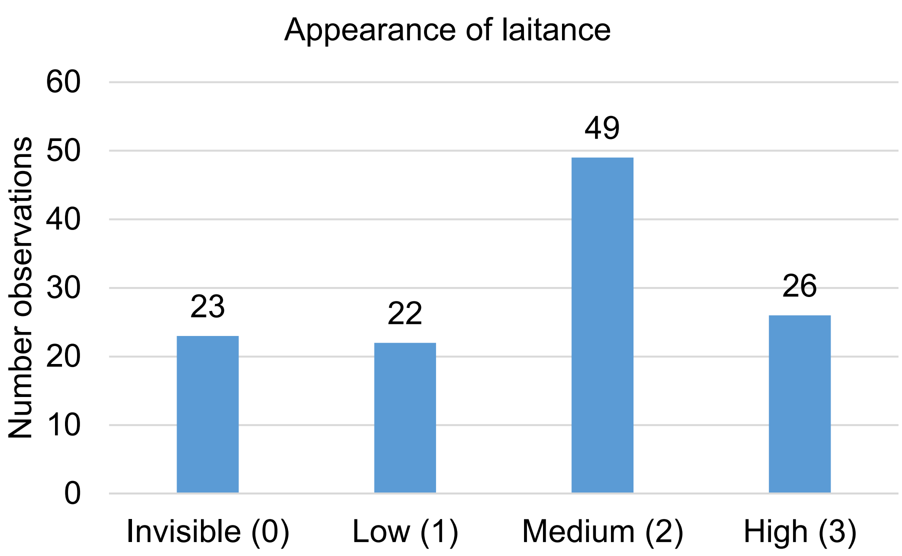


Figure 5-6: Appearance of laitance on the interface of precast ribs

5.3.2 Shear Interface (Questionnaire 3)

Table 5.16: Interview results for the construction of the surface of precast ribs

Question	Manufacturer	A	B	C	D	E
1	What tool do you use to deliberately roughen the surface of precast concrete beams/planks/ribs?	Strong Polypropylene Brush	No response	Rough brush	Use wood float finish instead of steel float finish	No response
2	Your tool provides a uniform precast concrete roughened surface	Neutral	Neutral	Agree	Agree	No response
3	Your tool provides a variation in the frequency of the concrete surface roughness	Agree	Neutral	Agree	Neutral	No response
4	The roughened interface of precast concrete often shows some formation of laitance concrete (a weak layer of aggregates and cement fines on a concrete surface)	Agree	Neutral	Strongly disagree	Disagree	No response
5	We always ensure that our precast rib is adequately roughened but to no specific measurable roughness	Agree	Agree	Agree	Agree	No response
6	Our organization complies with SABS 0100-1:2000 with respect to the roughening of the precast concrete surface	Neutral	Strongly agree	Agree	Agree	No response

Table 5.16: Interview results for the construction of the surface of precast ribs, continued…

Question	Manufacturer	A	B	C	D	E
7	Our organization ensures that the precast ribs have a surface roughness equal to or greater than 3 mm as specified by clause 4.3.4 of SANS 1879:2011.	Agree	Strongly agree	Agree	Agree	No response
8	How many minutes after casting concrete ribs do you begin the process of roughening the surface?	20 - 30 minutes	No response	5 - 10 minutes	Immediate	No response
9	How many people are in charge or skilled to roughen the concrete surface in your precast plant?	1	4	1	3	No response
10	Do you measure the roughness of the precast interface prior to selling it to the public?	Yes, visual inspection	Yes, laser equipment.	Measurements were done and we established we exceeded the 3 mm	No	No response
11	Do you provide any samples to the clients of the precast concrete surface roughness for the ribs you produce?	No	Yes	No	No	No response

Table 5.16: Interview results for the construction of the surface of precast ribs, continued…

Question	Manufacturer	A	B	C	D	E
12	Do you provide shear hooks/links/studs to resist the horizontal shear?	Yes, Bent 4 mm diameter pretensioned wires - inserted with hooks into concrete - tested with crowbar when cured	Yes	Yes, tests were done by Natal University where the ribs were tested with and without shear studs	Yes, no testing done	No response
13	Do you deliberately provide hooks/links/studs for handling purposes only?	No	Yes	No	Yes	No response
14	Did you often get any complaints/comments doubting the integrity of the precast concrete roughened surface for your ribs?	No	No	No	No	No response
15	Do you think a better tool should be designed for making a quality roughened concrete surface?	No, present tool adequate enough	No response	No, the rough brush is giving the required results.	No, the process we utilise is effective and efficient	No response
16	Do you think a code of practice should provide a reliable method to roughen the precast concrete surface?	Yes	Yes	No	No	No response

Table 5.16: Interview results for the construction of the surface of precast ribs, continued…

Question	Manufacturer	A	B	C	D	E
17	Please give any comments/suggestions about the topic	We have witnessed delamination when other suppliers and manufacturers have chosen the smooth surfaces with without indentation on top of beams	No answer	The University of Natal did some tests that established that a roughened surface on the concrete produced superior bonding than the sheer studs	No answer	No response

5.4 Fourth aim:

- Determine interfacial tensile bond strength through physical testing of deliberately roughened concrete ribs which are mainly used in special connections.

The summary of the Test 1 and Test 2 results is presented in Table 5.17 and Table 5.18 respectively. The self-weight of the cast in situ concrete topping/beam is not included.

5.4.1 Table 5.17: Interfacial tensile bond stresses (Test 1)

Beam	Average Surface Roughness Rz (mm)	Design Strength (N/mm²)	Casting date	Days tested	Cube strength at testing (N/mm²)	Tensile Force at Failure (kN)	Contact Area (mm²)	Tensile Stress (N/mm²)	Comment
A1	-5	30.0	23-Nov-13	10 (3-Dec-13)	25.6	6.9	26 250.0	0.26	
A2	-4					7.5		0.29	
A3	-4					3.9		0.15	
A4	-3							0.00	Recast
A5	-4					8		0.30	
A6	-3							0.00	Recast
A7	-3							0.00	Beam collapsed
A8	-2					2.4		0.09	
A9	-5							0.00	Recast
A10	-4					4.9		0.19	
A11	-4							0.00	Recast
A12	-4					7.1		0.27	
A13	-3							0.00	Recast
A14	-5					9.3		0.35	
A15	-3					3.6		0.14	
A16	-5					10.6		0.40	
A17	-2					7.6		0.29	
A18	-2					5.2		0.20	
A19	-4							0.00	Recast
A20	-4							0.00	Recast
A21	-6					7.9		0.30	
A22	-4					3.6		0.14	
A23	-3					9.1		0.35	

5.4.1 Table 5.17: Interfacial tensile bond stresses (Test 1), continued…

Beam	Average Surface Roughness Rz (mm)	Design Strength (N/mm²)	Casting date	Days tested	Cube strength at testing (N/mm²)	Tensile Force at Failure (kN)	Contact Area (mm²)	Tensile Stress (N/mm²)	Comment
A24	-3					6.2		0.24	
A25	-5					4.5		0.17	
A26	-4					2.5		0.10	
A27	-4					3.3		0.13	
A28	-3					5.2		0.20	
A29	-3	30.0	25-Nov-13	10 (3-Dec-13)	25.6	5.6	26 250	0.21	
A30	-5							0.00	Recast
A31	-4					9.2		0.35	
A32	-3					3		0.11	
A33	-3					5.8		0.22	
A34	-4					6.4		0.24	
A35	-4					9.1		0.35	
A36	-4							0.00	Recast
A37	-2					7		0.27	
A38	-4					3.4		0.13	
A39	-4					5.2		0.20	
A40	-5					11.6		0.44	
A41	-6					7.7		0.29	
A42	-3					5.7		0.22	
A43	-7							0.00	Recast
A44	-4					7.3		0.28	

5.4.1 Table 5.17: Interfacial tensile bond stresses (Test 1), continued…

Beam	Average Surface Roughness Rz (mm)	Design Strength (N/mm²)	Casting date	Days tested	Cube strength at testing (N/mm²)	Tensile Force at Failure (kN)	Contact Area (mm²)	Tensile Stress (N/mm²)	Comment
A45	-2					4.1		0.16	
A46	-3					2.6		0.10	
A47	-6					9.4		0.36	
A48	-4					2.5		0.10	
A49	-7							0.00	Recast
A50	-4					7.5		0.29	
A51	-5					4.8		0.18	
A52	-3					9.4		0.36	
A53	-3					5.6		0.21	
A54	-3					4.9		0.19	
A55	-5					6.2		0.24	
A56	-4					6.2		0.24	
A57	-3					7.2		0.27	
A58	-5					8.3		0.32	
A59	-4					4.9		0.19	
A60	7					6.3		0.24	

5.4.2 Table 5.18: Interfacial tensile bond stresses (Test 2)

Beam	Average Surface Roughness Rz (mm)	Design Strength (N/mm²)	Casting date	Days tested	Cube strength at testing (N/mm²)	Tensile Force at Failure (kN)	Contact Area (mm²)	Tensile Stress (N/mm²)	Comment
A1	-5	30.0	08-Dec-13	4 (12-Dec-13)	19.0	9.6	47 250	0.20	
A2	-4					9		0.19	
A3	-4					7.2		0.15	
A4	-3					3.6		0.08	
A5	-4					10.4		0.22	
A6	-3					2.6		0.06	
A7	-3							0.00	Beam collapsed
A8	-2					5.7		0.12	
A9	-5					5.3		0.11	
A10	-4					4.9		0.10	
A11	-4					3		0.06	
A12	-4					6.2		0.13	
A13	-3					3.7		0.08	
A14	-5					4.5		0.10	
A15	-3					4.7		0.10	
A16	-5					12		0.25	
A17	-2					7		0.15	
A18	-2					6.8		0.14	
A19	-4					2.1		0.04	
A20	-4					7.1		0.15	
A21	-6					4.3		0.09	
A22	-4	30.0	08-Dec-13	4 (12-Dec-13)	19.0	4.5	10 000	0.45	
A23	-3					5.6		0.56	

5.4.2 Table 5.18: Interfacial tensile bond stresses (Test 2), continued…

Beam	Average Surface Roughness Rz (mm)	Design Strength (N/mm²)	Casting date	Days tested	Cube strength at testing (N/mm²)	Tensile Force at Failure (kN)	Contact Area (mm²)	Tensile Stress (N/mm²)	Comment
A24	-3	30.0	12-Dec-13	4 (08-Dec-13)	19.0	4.8	26 250.00	0.18	
A25	-5					2.8		0.11	
A26	-4					3.1		0.12	
A27	-4					2.1		0.08	
A28	-3					5.2		0.20	
A29	-3							0.00	
A30	-5					5.1		0.19	
A31	-4					3.7		0.14	
A32	-3					1		0.04	
A33	-3					3.6		0.14	
A34	-4					3.1		0.12	
A35	-4					4.4		0.17	
A36	-4					4.2		0.16	
A37	-2							0.00	
A38	-4					1.8		0.07	
A39	-4					1.3		0.05	
A40	-5					14.3		0.54	
A41	-6					8.7		0.33	
A42	-3					5.3		0.20	
A43	-7					9.3		0.35	
A44	-4					6.2		0.24	
A45	-2					2.8		0.11	

5.4.2 Table 5.18: Interfacial tensile bond stresses (Test 2), continued…

Beam	Average Surface Roughness Rz (mm)	Design Strength (N/mm²)	Casting date	Days tested	Cube strength at testing (N/mm²)	Tensile Force at Failure (kN)	Contact Area (mm²)	Tensile Stress (N/mm²)	Comment
A46	-3							0.00	
A47	-6					9.5		0.36	
A48	-4					1		0.04	
A49	-7					7.5		0.29	
A50	-4					5.3		0.20	
A51	-5					4.5		0.17	
A52	-3					5.2		0.20	
A53	-3					1.1		0.04	
A54	-3					6.6		0.25	
A55	-5					7.1		0.27	
A56	-4					9.2		0.35	
A57	-3					5.6		0.21	
A58	-5					7.5		0.29	
A59	-4					4.9		0.19	

5.5 Fifth aim:

- Make an assessment by undertaking a basic comparison study between one local beam and block slab system that uses a shallow rectangular precast pretensioned rib to beam and block slab systems used in the United Kingdom.
- Propose a design for a precast pretensioned rib that spans up to 5 metres without temporary props.

The findings for the basic comparison study are presented in Chapter 6 in order to avoid redundancy here.

Chapter 6

Discussion of results

6.1 First aim

- Provide the users of beam and block slab systems with basic technical information about the possible ways to improve the efficiency and effectiveness in the design, manufacturing and construction of beam and block slab systems by undertaking an exploratory (pilot) study to better understand users of these systems concerns.

6.1.1 Introduction to the survey (Questionnaire 1)

The South African Institute of Civil Engineering (SAICE) Durban and Pietermaritzburg's, monthly newsletter 'OUTLOOK', which has more than 1000 recipients including at least 100 email-recipients, was used as the tool to get information to better understand users of these systems concerns. In spite of this effort, only 32 fully completed and valid responses were received. However, this is an ongoing challenge in South Africa when conducting questionnaire surveys.

About two thirds of respondents were consultants. This is good because the majority of comments given by consultants are influenced by the level of professional responsibility.

6.1.2 Technical contents of the survey

To summarize, 65.72% of the respondents admit to not having problems using the beam and block slab system in any class of building, if all fire regulations and minimum standards have been fulfilled. This is a positive sign in the construction industry; however a significant gap is still left for improving this suspended flooring system to become a more preferred alternative structural solution (question 5).

The structural integrity of the cast in-situ concrete topping appears to be satisfactory but not free from the issues relating to cracking and lack of compaction as a result of its shallow thickness (question 6).

There is significant division with regards to preference in using polystyrene over conventional infill and reliability associated with defects like cracking of normal sand-cement plaster (question 7, 8, 9 and 10).

Differences in opinions and uncertainty have been noted with regards to;

- Effectiveness of the surface shear interface resistance for standard precast pretensioned ribs (question 11).
- Fire resistance of 40- 60 mm cast in-situ structural topping (12), effectiveness in fire resistance of precast pretensioned ribs with a 15 mm concrete cover over the pretensioning wire (question 13) and effectiveness of normal sand-cement plaster in resisting and shielding heat to structural components (question 14).

60.00% of the respondents are concerned with the availability of necessary documentation (e.g. quality control test results etc.).

6.1.3 Address the concerns of the commenters

“Propping often inadequate” (commenter 1).

The majority of precast pretensioned ribs used in beam and block slab systems have a minimum depth of 60 mm and a minimum width of 65 mm as specified by SABS 0100-1 (2000: 56). The depth of precast ribs is affected by the spacing of temporary props. These ribs are normally used to build 150/170, 200 and 255 mm thick self-supporting flooring systems. Shallow ribs are generally unable to work without the provision of temporary props except when supporting construction loads over short spans (e.g. spanning over narrow passage walls).

The designer or manufacturer (or both) of a beam and block slab system should detail how temporary propping should be arranged, failing which the recommendation given by SANS 1879 (2011: 13) is assumed to be adequate and may be used. The code requires a maximum spacing of 1.8 m centres and levelled to a specified pre-camber, if necessary.

What has been noted with some inexperienced builders is that they tend to leave out the base plates at the bottom of props which result in concentrated loads (the leg of the prop punching through the ground) causing immediate settlements when construction loads are applied. Figure 6-1 shows a typical case.

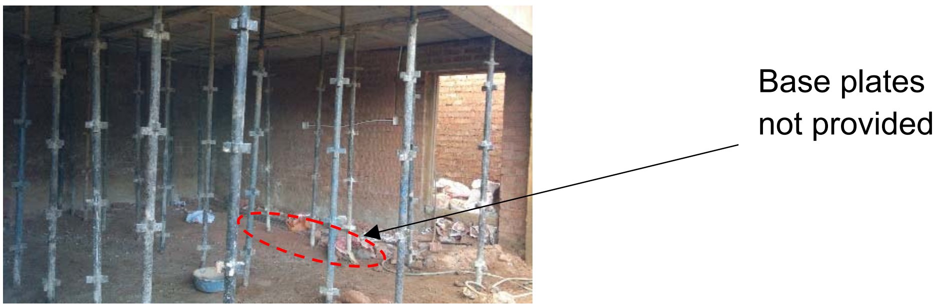


Figure 6-1: Temporary props for a typical beam and block slab system

"Fire resistance/rating not always addressed" (commenter 2).

According to SABS 0100-1 (2000: 6) there are three issues involved in this subject with regards to fire resistance:

The **first issue** is the preservation of structural/member strength which is linked to the reduction in the structural strength of the flooring system as a result of the increase in temperature. This is influenced by a number of other factors including the type of filler blocks used, which depends on whether or not it is concrete masonry or expanded polystyrene or rarely both (2000: 168).

The code recommends that a comparison should be made between the gross cross section of the solid materials to that of combustible materials (e.g. polystyrene filler blocks) and if found to be less than 50%, a soffit finish such as those listed in 2000: 170 may be used in order to increase the fire rating of the flooring system.

The **second issue** is the confinement of heat within the heated compartment. It is commonly agreed that a beam and block slab system with concrete masonry filler blocks have a better performance over the untreated or even treated expanded polystyrene filler blocks. Since the concrete masonry is incombustible, it acts as a shield. It reduces the intensity of heat radiation loaded onto the thin structural topping. This will further reduce the chances of explosive spalling of concrete topping thus preventing the progression of flames from one floor to the next. The use of expanded polystyrene filler blocks is not allowed on multi-storey buildings.

The **third issue** is the transmission of heat through the structural members. It is clear that the fire properties of concrete masonry units form an integral part of the fire rating of these suspended flooring systems and more in-depth technical knowledge is required to make people comfortable to use it especially in multi-storey buildings.

"Concrete pours sequence not considered when using polystyrene formers" (commenter 3).

First of all, it is important for the designer to acknowledge the method of implementation of a beam and block slab system and in conjunction with this, the builder should preferably advise on how they intend to carry out construction work.

At this stage, the designer can incorporate the implementation methodology and make necessary adjustments to suit the construction needs. This should also be done in accordance with SABS 0100-2 (1994: 31) in order to ensure that the structure remains composite. Clause 10.4.1 advises that “high quality workmanship is necessary when joints are being formed”. This includes both construction and unforeseen joints. In the case of the latter, the engineer may be required to inspect and approve the continuation of work.

“Vertical shear resistance not always addressed at flat soffit connections (extra steel, wire ties etc.)” (commenter 4).

The figure below describes a typical connection.

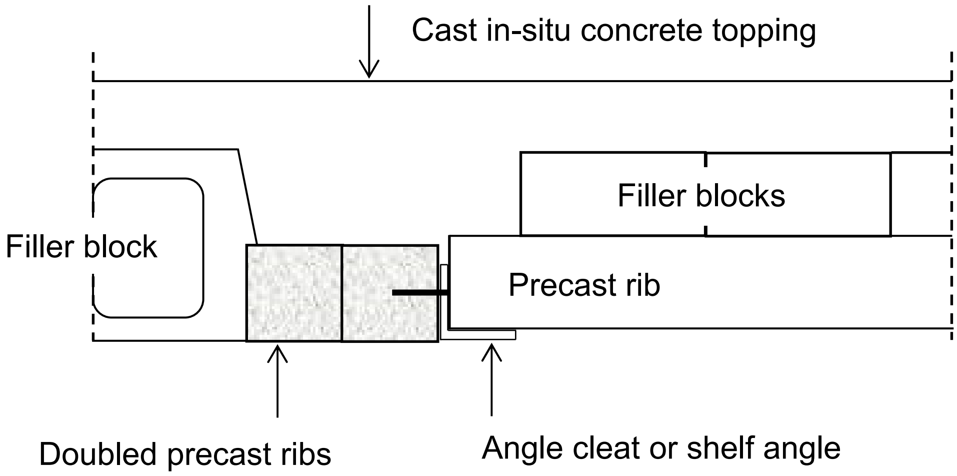


Figure 6-2: Connection detail of the change in the direction of the span

A photograph was taken on-site of a similar connection to that shown above. This is just to show the as-built connection and does not mean that the vertical shear was not addressed adequately in this connection.

Figure 6-3: The as-built connection of the change in the direction of the span

Such details do not always fall within the scope of the standard specifications for a particular beam and block slab system. Such details are common in application but differ from the loading perspective; hence, they need to be designed accordingly.

The design model (especially the loading path) needs to be a true model of the actual structural behaviour. It is preferred that such details are provided in the manufacturer's catalogue in order to alert the user to their feasibility and it must be clearly indicated that they need to be designed by a professional structural engineer or competent person.

The vertical shear design of a beam and block slab system should be in accordance with SABS 0100-1 (2000: 56). The rib(s) need to be assessed for an increased service and ultimate stresses since they are not often designed for such loading configurations (concentrated loads). SANS 1879:2011 does not give any recommendations for such details.

"Some systems more suited to domestic than commercial/industrial and vice versa" (commenter 5).

The design of a beam and block slab system is largely dependent on the loading condition (type of structural loading). The loads are normally uniformly distributed for domestic applications and concentrated loads are expected when these slabs are used for industrial applications. It is common that ribs without horizontal shear studs/links are used for domestic applications and those with latticed or shear links used for industrial applications.

"Safety during the inspection can be worrying (walking on ill-fitting blocks)" (commenter 6).

The person undertaking the inspection of a beam and block slab system needs to be alert to any potential danger(s) resulting from 'ill-fitting' blocks. This can be caused by manufacturing faults like the one shown in Figure 6-4 and Figure 6-5. The stone at the inside corner of the rebate (next to the tip of the pen) causes a reduction in bearing width of the filler block at the support.

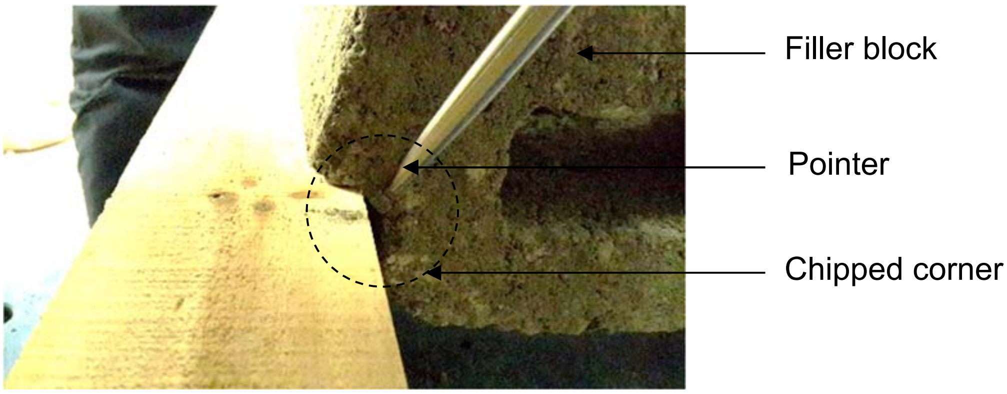


Figure 6-4: Typical picture of an 'ill-fitting' filler block

The next photograph shows the chipping through the entire face of the nib which reduces the bearing width of the filler block on the rib.

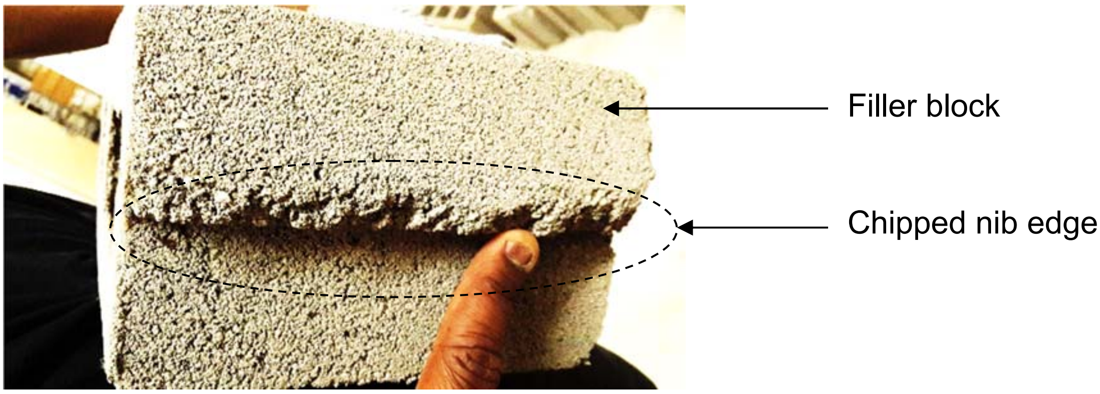


Figure 6-5: Typical picture of a filler block with a chipped nib edge

The graph below shows the variations in the bearing width of concrete masonry rebated filler blocks in mm recorded during Test 1. The SANS 1879 (2011: 13) specifies a minimum bearing width of 35 mm (Annex D, part D1). It is important to note that the majority of manufactures started producing these concrete masonry rebated filler blocks before this recommendation was made.

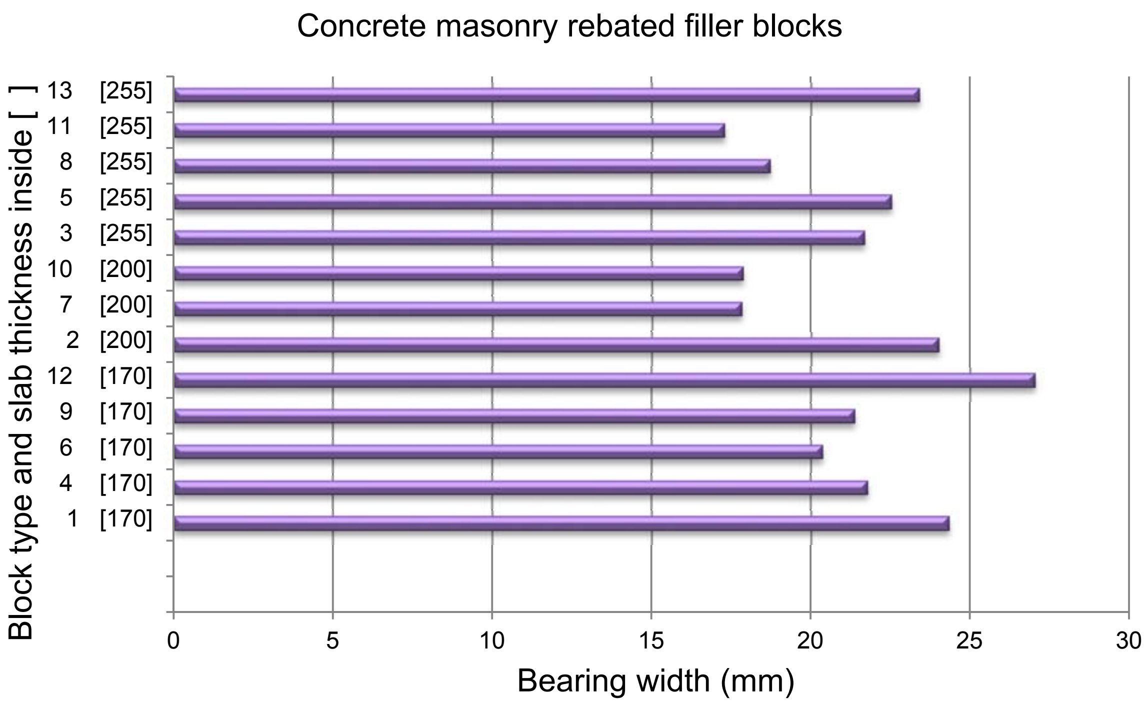


Figure 6-6: Bearing width of filler blocks measured in mm

Another alarming issue is the use of filler blocks with cracks. Cracks may be formed during the manufacturing process and some during transportation or mishandling. The figure below shows a filler block with a crack and honeycombing in the bottom shell. This particular block failed at the weak zone during Test 1.

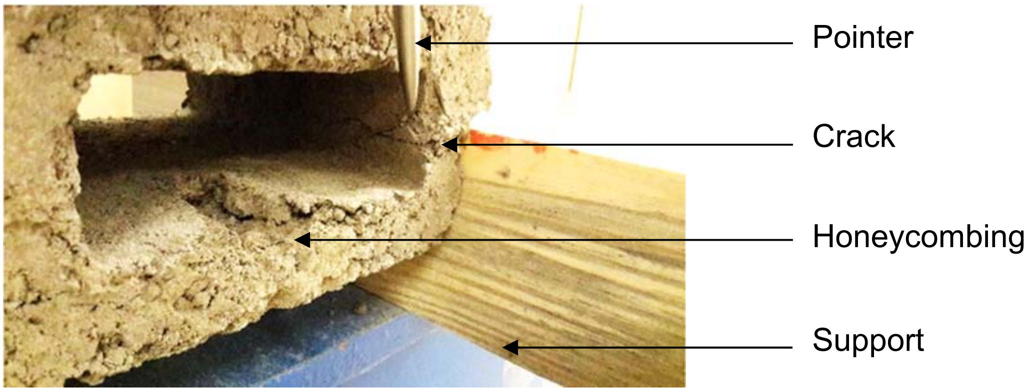


Figure 6-7: Filler block with a crack and honeycombing at the bottom shell

It is therefore advisable to take extra precaution when walking on these blocks on site. Some people reduce the chance of falling through by stepping on two blocks at a time or stepping above the vertical outer shell. The manufacturers and people using these filler blocks should avoid using blocks that do not fit properly or present some form of manufacturing defect (or both).

"The beam and block system is a faster alternative in building suspended slabs. I have used this system mostly in residential buildings with success. To avoid problems I issue the beam and block supplier/contractor details on how I want the planks to span and the position of spreader ribs and additional rebar. I approve the beam and block supplier's layout before construction commences, and this way there are no problems" (commenter 8).

It is always important to spend some time and provide all necessary details on the construction drawings in order to ensure that construction runs smooth.

“Horizontal shear strength between PC Rib and Cast In-situ concrete is increased if vibrated correctly and constructed properly” (commenter 9).

The guide to good practice given in Shear at the Interface of Precast and In-situ Concrete, by the FIB Commission on Prefabrication (1982: 16) places great emphasis on the surface treatment and the workmanship. A study by Vesa (1979 cited in the FIB Commission on Prefabrication 1982: 12) showed that adequate treatment of the surface prior to casting the in-situ topping is as important as the specified grade of undulation. Another study by Gustavsson (1980 cited in the FIB Commission on Prefabrication 1982: 12) also confirmed the above.

“Labour is in most cases not skilled to plaster the soffit of the poly-blocks” (commenter 10).

Technical skills have become very scarce in South Africa. This is a problem even when plastering common brick or masonry walls with normal sand-cement plaster. Plastering successfully on expanded polystyrene filler blocks requires skill and proper selection of materials.

“I have not worked with polystyrene void formers. I have used "Manufacturer X" in many instances and have their design literature which is adequate. Other slab systems such as “Manufacturer Y" and "Manufacturer Z" do not have adequate design literature but my designs get vetted by them or they do the design for which they take responsibility” (commenter 11).

It is important to provide all necessary information to the designer/client for them to make an informed decision prior to opting for a particular beam and block slab system.

"The fire resistance with regard to cover to the rib wires needs to be addressed" (commenter 12).

SANS 1879 (2011: 6) recommends that "the minimum cover over the reinforcement measured in accordance with 5.4 shall be 15 mm, or as required" (see A.1). 'A1' refers to the special requirements from the client or the nature of the building. Precast concrete construction should produce high quality concrete structural elements. It is therefore expected that the tolerance of concrete cover over reinforcement is smaller compared to concrete structural elements cast on site. The figure below shows an example of how the concrete cover can be physically measured at the edge of the rib where the wire is visible.

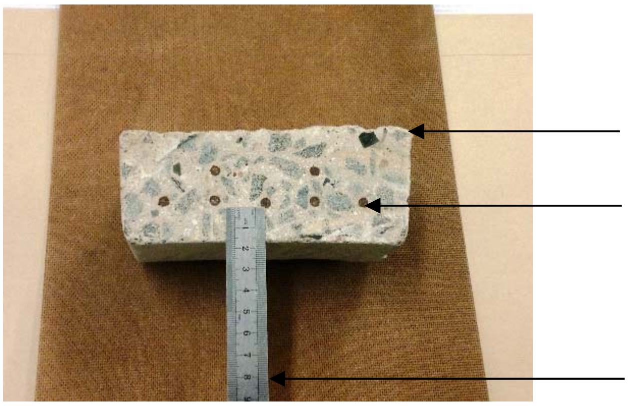


Figure 6-8: Typical precast rib showing a concrete cover over the wires

The concrete cover over pretensioned wires was measured from 120 precast pretensioned ribs (refer to Figure 6.9) by using a cover meter (non-destructive magnetic type) and the results are presented here. It should be noted that the deviations lead to either less or more concrete cover over the wires. Less cover could compromise the fire rating of the flooring system and the durability of the slab. Excessive cover affects the effective design depth of the slab which could result in reduced flexural strength, more deflection and sometimes even cracking which could further affect the durability of the structural member.

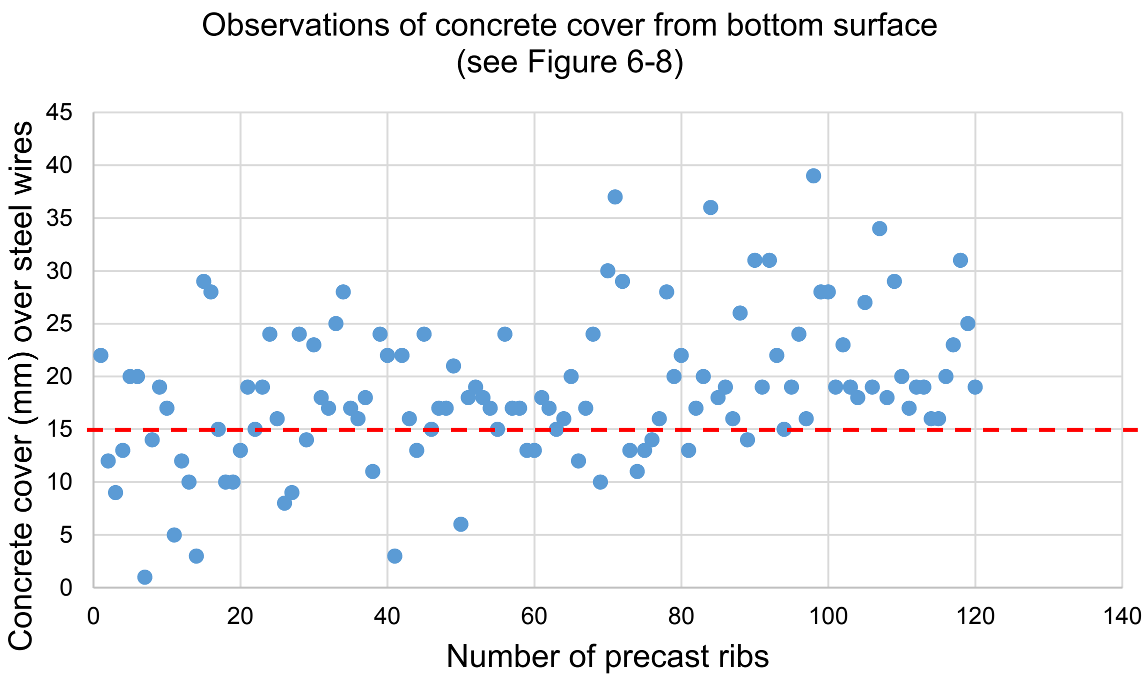


Figure 6-9: Concrete cover over pretensioned wires measured at the soffit of 120 precast pretensioned ribs

"Using polystyrene as form work for slabs has been extremely effective structurally and economically" (commenter 13).

The expanded polystyrene rebated filler blocks are much lighter than concrete masonry rebated filler blocks. The heavy concrete masonry filler blocks recorded in this study averaged 26 kg. The equivalent volume of the expanded polystyrene filler block would only have a total mass of 0.256 kg. This has a significant effect on the structural efficiency of the flooring system (strength/weight ratio).

It was later found that using the expanded polystyrene filler block is becoming more expensive than using concrete masonry filler blocks. Some manufacturers say polystyrene filler blocks are best if used on floor areas greater than 100 m².

“Need a code” (comment 14).

The two codes addressing beam and block slab systems directly are SANS 1879:2011 and SABS 0100-1:2000. This study also found that very few consulting engineers knew about the existence of SANS 1879:2011 for precast concrete suspended slabs.

“The design is very specific to loading layout. Concerns are raised with reference to future alterations / additions. Generally, we only use the system on shorter spans in lightly loaded residential structures - always with additional steel” (comment 15).

This is why it is important to keep all structural drawings safe as this helps in making viable decisions about future alterations.

6.2 Second Aim

- Investigate, by conducting a series of strength to weight ratio tests, how efficient or inefficient these filler blocks are.
- Examine the structural integrity with respect to the integrity of the manufacturing methodologies and the product thereof.
- Formulate a method to quantify the fire-resistivity of concrete masonry rebated filler blocks to the structural topping with respect to confining fire/flames from one floor to the next.

6.2.1 Activity 1 – Structural Efficiency

6.2.1.1 Introduction

Some manufacturers regard concrete masonry rebated filler blocks that sustain loads far above their design strength as strong and efficient. Heavy filler blocks loading far above the required strength are effective but not efficient. For example, when you divide the load at failure by the mass of the filler block, the higher the value, the stronger the filler block. The idea behind the ‘structural efficiency’ of filler blocks is discussed in detail in order to create a true reflection of how efficient/inefficient a particular filler block type may be with respect to its design load carrying capacity. In other words, the aim of this discussion is not to identify a manufacturer that makes the strongest block but to create an understanding behind the requirements necessary for a structural efficient filler block with respect to the load carrying capacity.

6.2.1.2 Important points to consider

The points listed below are a key to understanding the discussion:

- The structural efficiency (based on the failure load) should be equal or greater than the theoretical structural efficiency (based on the design load), but it is important to note that for the structural efficiency to be equal to theoretical structural efficiency, the failure load of the filler block as a result of the externally applied load should then be exactly 3.5 kN.
- The filler blocks bear on precast ribs with a spacing ranging from 560, 600, and 650 mm. This spacing is determined by the manufacturer of a beam and block slab system.
- All filler blocks for beam and blocks slab systems manufactured in South Africa should be able to support a construction load of 3.5 kN as mentioned earlier.
- All rebated filler blocks covered in this study are made from concrete masonry.

- Filler blocks are non-structural supports but they are used as temporary 'structural' supports for the construction loads.

6.2.1.3 The structural efficiency with respect to the load carrying capacity

Figure 6.10 presents different structural efficiencies for filler blocks produced by different manufacturers. It is seen from the graph that during Test 1, block type 1 had the highest structural efficiency followed by 9 and then 13. During Test 2, block type 9 had the highest followed by 13 and then 10. The manufacturers advised that the load carrying capacity of these filler blocks sometimes vary drastically and that has been confirmed. The self-weight of these filler blocks do not vary significantly from the values which are advertised by the manufacturers. There is no ideal value for the theoretical structural efficiency since the spacing of the ribs vary.

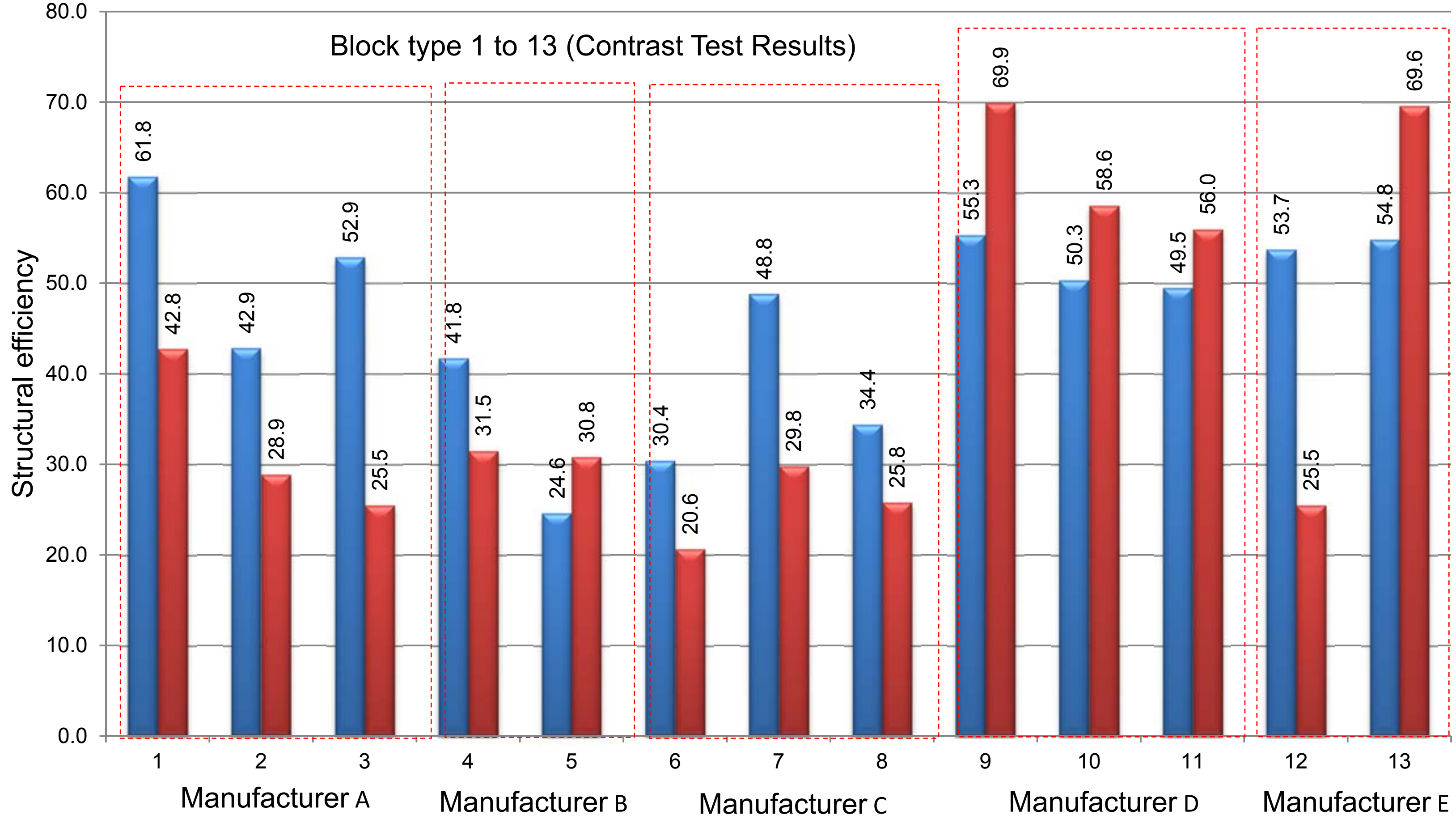


Figure 6-10: Structural efficiency of concrete masonry rebated filler blocks for manufacturer A, B, C, D and E

6.2.1.4 The benefit of higher structural efficiency

The values given in the graph simply indicate the ratio of the average failure load to the average mass of each filler block type. A higher value implies a higher load resistance. Thus, from a safety point of view, a block type with a higher value is safer to use compared to a one with a lower magnitude.

6.2.1.5 Drawbacks of higher structural efficiency

Although higher values are convenient from a safety point of view, they often come with extra cost resulting from the following:

- Excessive use of binder (e.g. cement).
- Spending more money on higher quality materials which then increase the cost of producing a 'non-structural' filler block.
- Increasing the physical strength of the filler block by adding more material.

One must always keep in mind that these filler blocks are non-structural (i.e. they can be removed once the slab is self-supporting). They are simply used as temporary supports ('structural support') for the construction loads (e.g. people working on the deck and the mass of wet concrete).

6.2.1.6 Theoretical structural efficiency

The theoretical structural efficiency for filler blocks is calculated by making the following assumptions:

- All filler blocks should fail at an externally imposed load of 3.5 kN exactly (356.78 kg).

- The theoretical structural efficiency of each filler block type is given by the ratio of 3.5 kN including the average mass of filler blocks divided by the average mass of the filler blocks.

The mass of the filler block governs its theoretical structural efficiency. All filler blocks are evaluated against a failure load of 3.5 kN. The theoretical structural efficiencies for all blocks are shown in Figure 6-11. There is no ideal value for the theoretical structural efficiency since the spacing of the ribs used by different manufactures vary.

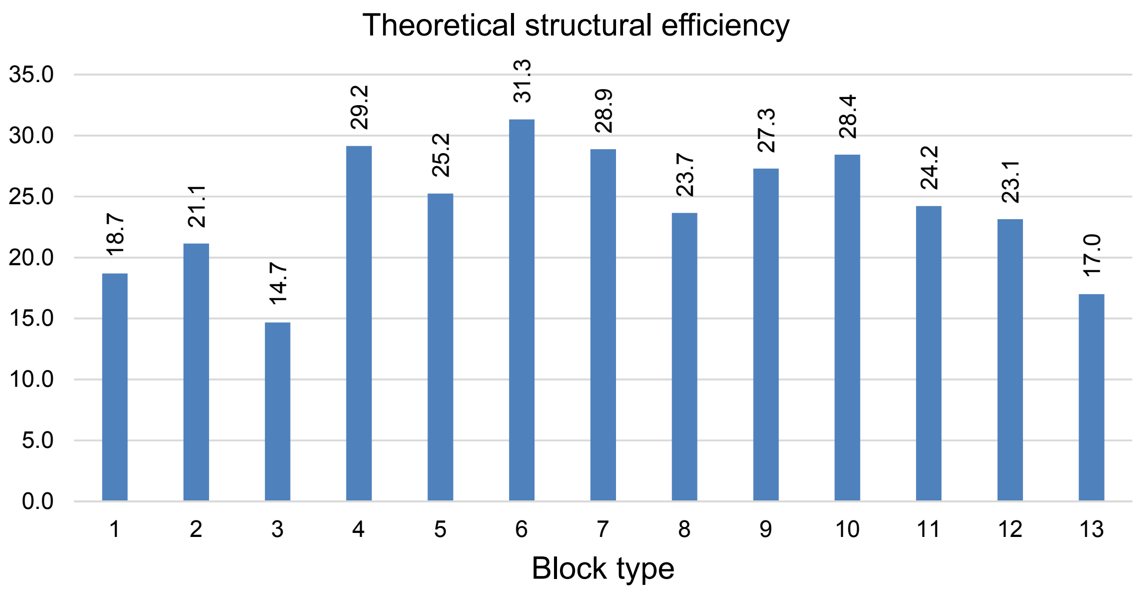


Figure 6-11: Theoretical structural efficiencies of filler blocks

It is important to note that the higher the value of theoretical structural efficiency, the lighter the filler block is.

6.2.1.7 Structural wastefulness (inefficiency)

The structural efficiency of concrete masonry rebated filler blocks can be determined by assessing the wastage of the load carrying capacity (i.e. over-design/over-strength).

This is calculated as a percentage of the structural efficiency minus the theoretical structural efficiency divided by the theoretical structural efficiency.

Minimal wastage yields an efficient design, hence a more 'structural efficient' filler block is produced with respect to the design load carrying capacity. On the other hand, higher the wastage yields an inefficient design, hence the less structurally efficient the filler block type is. Figure 6.12 presents the efficiency and deficiency/inefficiency percentage of the filler blocks.

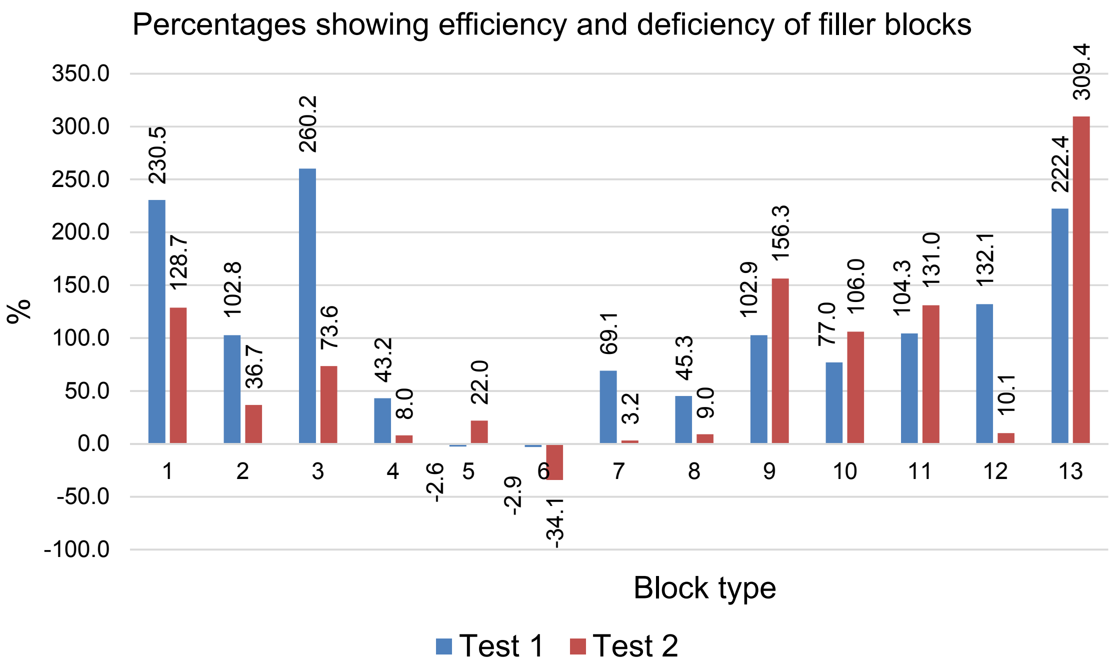


Figure 6-12: Structural efficiency and inefficiency of filler blocks

The values below the zero line indicate insufficient load carrying capacity. However, it should be remembered that some filler blocks are still designed for a construction load of 200 kg and not 356.78 kg as per the latest/new requirement of the code. To make sense of the values above the zero line, a factor of safety is used which is discussed in the next section.

6.2.1.8 Acceptable limits

A factor of safety corresponding to the standard deviation of the mean for the filler blocks tested over a reasonable period of time can be used. This will vary for every manufacturer. A safety factor of 1.5 is used as an example and applied to the construction load of 3.5 kN. The new theoretical structural efficiency is calculated based on the factored construction load (5.25 kN) following the procedure given in 6.2.1.6. The factored theoretical structural efficiencies are presented in Figure 6-13.

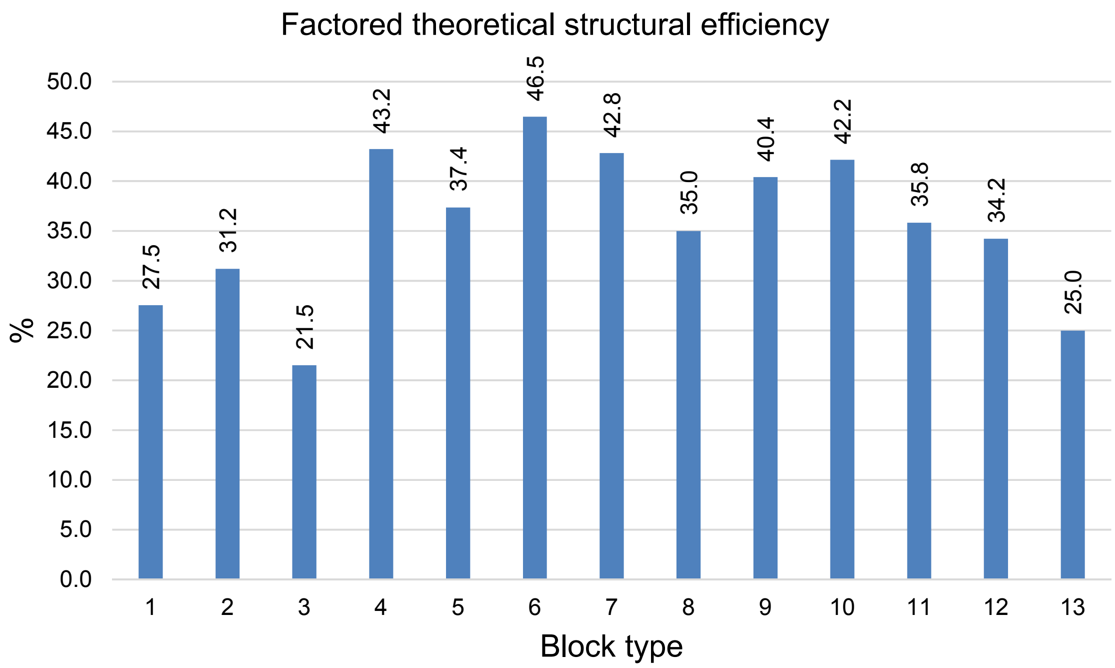


Figure 6-13: Factored theoretical structural efficiencies of filler blocks

The factored efficiency and inefficiency of filler blocks is shown in Figure 6-14.

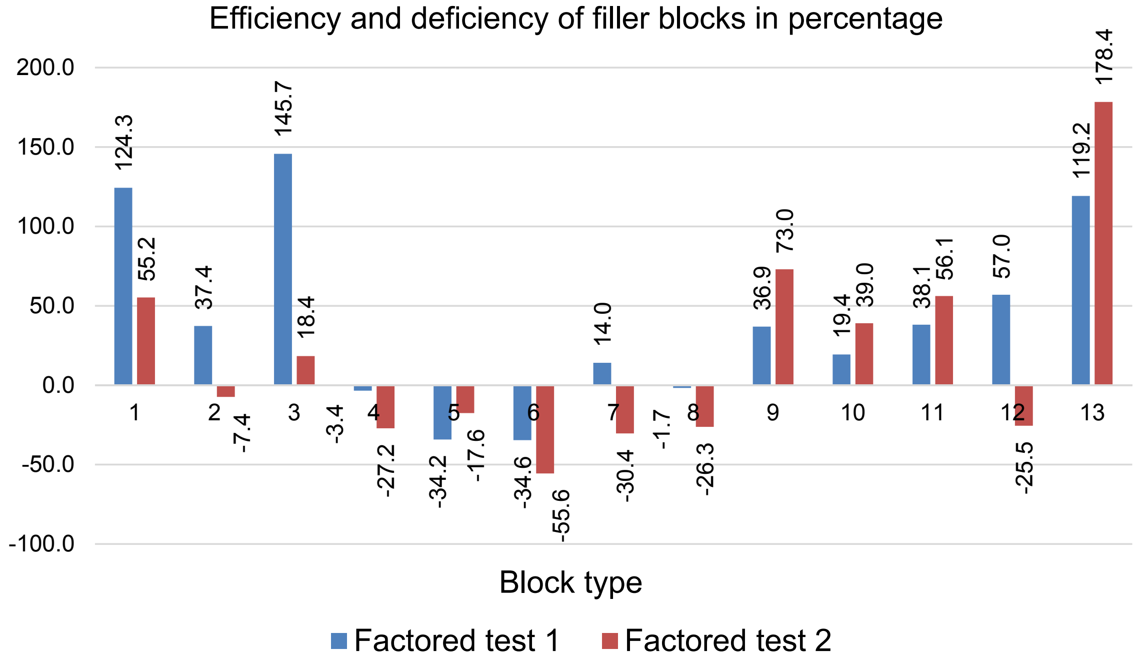


Figure 6-14: Factored structural efficiency and inefficiency of filler blocks

6.2.1.9 Wastage in filler blocks

It is important to note that absolute structural efficiency with respect to the load carrying capacity is achieved by making the structural efficiency equal to the theoretical structural efficiency. However, introducing a factor of safety such as 1.5 (or any suitable factor) allows leeway (allowing for uncertainty in the quality of the filler block). Therefore the structural efficiency of the filler block with respect to the load carrying capacity can be amplified on the basis of the factored theoretical structural efficiency. This can indicate if there is wastage or if the strength of the filler block is being compromised within reasonable safety margins as shown in Figure 6.15. Oversized filler blocks put more weight on the design of the ribs. This increases the cost of ribs as a result of higher strength required.

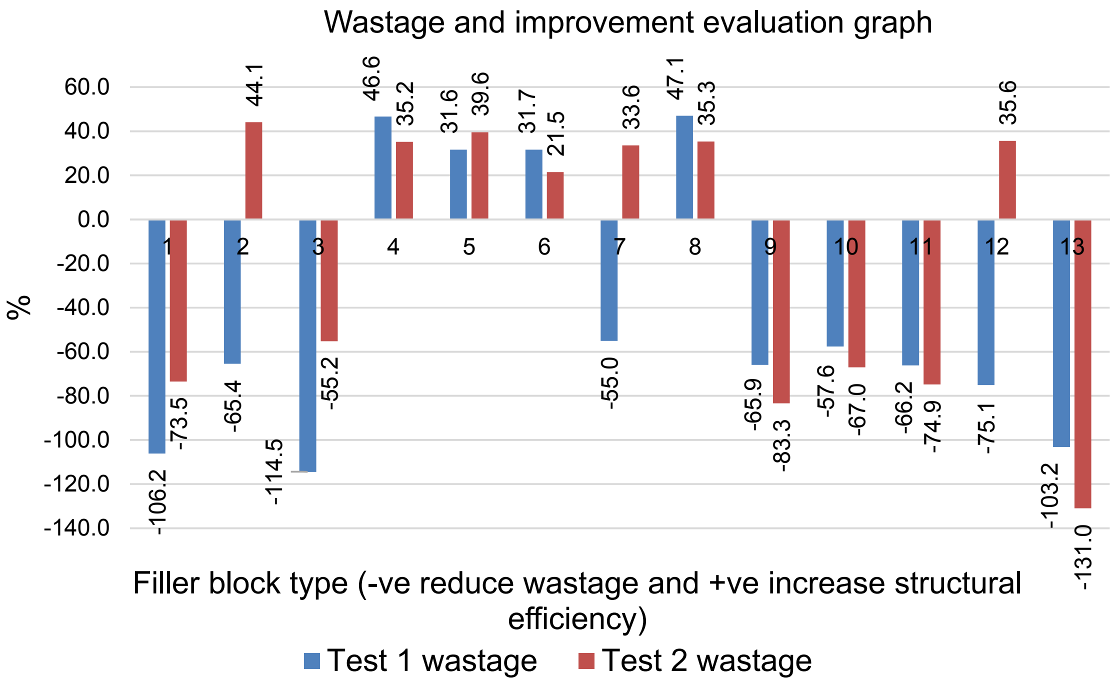


Figure 6-15: Wastage in filler blocks

6.2.2 Activity 2 – Structural Integrity

6.2.2.1 Part 1 – Naming the elements making up the filler block

Refer back to 4.3.3.2 in Chapter 4.

6.2.2.2 Part 2 – Categorizing the blocks

Another way of assessing whether or not the filler block is likely to be structurally efficient is by evaluating its effective span over effective depth ratio (refer to Figure 6-16). The geometric design of the block can cause it to experience excessive or minimal shear and axial forces including bending moments. Concrete masonry is good in compression but poor in tension. The magnitude and the nature of forces have an important role in the load carrying capacity of concrete masonry filler blocks.

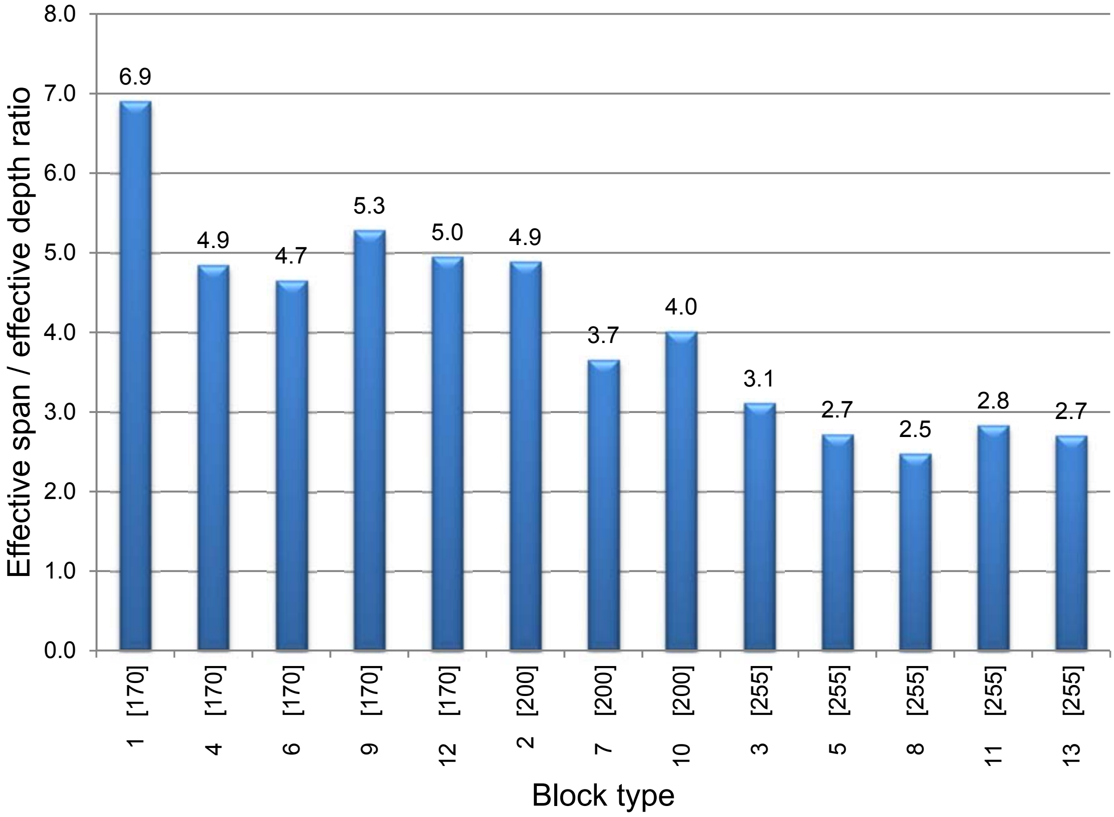


Figure 6-16: Effective span over effective depth ratio

There is a correlation between the magnitude of the forces generated in members of the filler blocks and the magnitude of the effective span over effective depth ratio as noted below:

Table 6.1: Comparison of axial forces and effective span over effective depth ratio

Slab thickness in mm	Effective span over effective depth ratio	Axial force (kN)	Comment
150/170	6.9 - 5.0	3.52 - 2.11	Highest
200	4.9 - 3.7	2.81 - 2.04	Medium
255	3.1 - 2.5	1.79 - 1.37	Lowest

6.2.2.2.1 Filler blocks for 150/170 mm thick flooring systems

Block type 1 is a cellular block type and does not fit exactly into this category because of its geometric design. All the other blocks are either double or triple core types. Table 6.2 shows the analysis inclusive and exclusive of the filler block type 1. The standard deviation around the mean excluding block type 1 is 0.26 compared to 0.89. Although both values are low, 0.26 reflects the true unbiased value. The effective span over effective depth ratio of 150/170 category is 4.98 (say 5). The advantage of block type 1 is that it can work for shallow overall slab thickness (e.g. 120 thick slabs). This filler block is the heaviest and demonstrated the highest load carrying capacity for this category.

Table 6.2: Statistics of effective span over depth ratio for the filler blocks used in 170 mm thick slabs

Statistics [170]		
	Including block type 1	Excluding block type 1
Mean	5.36	4.98
Std. Error of Mean	0.40	0.13
Median	5.00	4.95
Mode	4.70	4.70
Std. Deviation	0.89	0.25
Range	2.20	0.60

6.2.2.2.2 Filler blocks for 200 mm thick flooring systems

The standard deviation of 0.62 is low (refer to Table 6.3), but there were only three block types in this category and all varied significantly (refer to Figure 6.16). There is not much to be learnt from this unless the mean of 4.20 is compared to a value found using the relationship between the effective span over effective ratio for 150/170 mm and 255 mm thick flooring systems.

Table 6.3: Statistics of effective span over depth ratio for the filler blocks used in 200 mm thick slabs

Statistics [200]	
Mean	4.20
Std. Error of Mean	0.36
Median	4.00
Mode	3.70
Std. Deviation	0.62
Range	1.20

6.2.2.2.3 Filler blocks for 255 mm thick flooring systems

The standard deviation of 0.22 is low. The mean of 2.76 (say 2.8) is acceptable. The filler blocks are within the effective span over effective depth ratio.

Table 6.4: Statistics of effective span over depth ratio for the filler blocks used in 255 mm thick slabs

Statistics [255]	
Mean	2.76
Std. Error of Mean	0.10
Median	2.70
Mode	2.70
Std. Deviation	0.22
Range	0.60

6.2.2.2.4 General discussion

The evaluation of effective span over effective depth ratio of 150/170 mm and 255 mm thick flooring systems indicates consistency (with exclusion of block type 1 in the [150/170] category). It is therefore expected that the performance of the filler blocks within this category is not jeopardized by poor geometric design (i.e. effective span and effective depth) which in many cases are fundamentals to control the magnitude of member forces, such as the forces acting in the top shell, bottom shell, vertical shell(s) and vertical web(s). The effective span over effective depth ratio of 5 and 2.8 for the 150/170 mm and 255 mm filler blocks respectively can be taken as the norm.

6.2.2.3 Part 4 – Construction of concrete masonry rebated filler blocks (Questionnaire 2)

6.2.2.3.1 Introduction

Only two respondents appeared to be heavily involved in the construction of beam and block slab systems, casting more than 10 batches of filler blocks per month, completing at least 250 projects per year and 5000 projects completed (to date of the interview). Other manufacturers are less active. One respondent uses a lot of expanded polystyrene filler blocks and has completed at least 1000 projects. No respondent is a member of any statutory body that deals with issues specific or related to beam and block slab systems.

6.2.2.3.2 Manufacturing

All respondents use river sand, 9 mm stone, cement and water to make concrete masonry rebated filler blocks, sometimes with admixtures like DGN Powermaster and Chryso Activator Plus. Some manufacturers prefer to do integrity tests like a sieve analysis and cleanliness of the sand and some manufacturers assess by visual and hand feel. Trial mix designs are done by independent laboratories and some prefer to run a production test by physically testing the sample filler blocks. All manufacturers conduct in-house load carrying capacity tests prior to selling the filler blocks to the public. The curing procedure is conducted for a period of up to 7 days, and some manufactures cure in dry stacks that are sprayed with water.

6.2.2.3.3 Design

Only one respondent has changed the design of the filler block as a result of poor structural performance and only one believes that the self-weight of the filler block can be reduced without compromising the strength of the filler block. The majority of the respondents employed an engineer to design the filler blocks. The majority of the manufacturers make triple core type filler blocks.

6.2.2.3.4 Production cost

Half of the respondents believe that the production cost of the filler block is badly affected by the selection of the materials used to manufacture the block. The rest were unsure. The majority of the respondents believe that the production cost of the filler block is badly affected by the actual design of the filler block and only one is unsure.

6.2.2.3.5 Improvement

All respondents believed that doing the trial mix design, educating staff and improving the curing process would improve the design concept of the filler block with respect to the load carrying capacity. The majority of the respondents believe that reviewing the design of the filler block could save them money in the long term.

6.3 Third aim

- Determine what constituted acceptable quality of a deliberately roughened precast concrete surface by conducting a survey to learn about the construction methodologies used by manufacturers. Site visits were undertaken to validate information given by the contractors.

6.3.1 Integrity of the roughened/undulated surface

6.3.1.1 Level of uniformity

Uniformity of the deliberately roughened surfaces for beam and block slab systems is usually lacking. The uniformity of the roughened surface tends to depend on the width of the brush used to create the roughening.

The effects observed by the student during repetitive site visits to have cause the variation in uniformity are:

- Variation in viscosity of the top surface of green concrete where bleeding has occurred in some arrears.
- Cleanliness of the bristle of a broom used to roughen the top surface.
- Inconstancy in the physical pressure exerted by the person undertaking roughening. Inconstancy caused by the width of the casting bed where, at the far end the person needs to stretch the body compared to the closer edge where the body is more relaxed.

This confirmed a wide spread of categorised observations (very poor, poor, neutral, good or very good) in Figure 5-4 (Chapter 5).

6.3.1.2 Variation in roughening frequency

The actual cause of the variation in roughening frequency was not particularly observed during the site visits but it is assumed that some effects, if not all mentioned in 6.3.1.1 somehow make a contribution.

This confirmed a wide spread of categorised observations (Low, medium and high) in Figure 5-5 (Chapter 5).

6.3.1.3 Appearance of laitance

At almost all site visits where precast ribs were being cast, excessive vibration (i.e. exceeding 10 to 15 seconds in duration) was observed. Applying a vibrator without following any structured/purposeful pattern was also observed. This left spots where water and fines (e.g. sand and cement) moved to the surface to cause laitance. Stones settled within the concrete mixture causing a thicker layer of mortar and laitance at the top surface (a weak layer). There were no attempts to remove laitance by washing after 2 to 4 hours from compaction. Site observations showed that the actual process of roughening caused localized laitance. It should be noted that laitance can be removed by brushing the concrete while it is still green.

This also confirmed a wide spread of categorised observations (Invisible, Low, Medium and High) in Figure 5-6 (Chapter 5).

6.3.2 Shear interface (Questionnaire 3)

Apart from the observations made during some random site visits, the manufactures were given the opportunity to respond to Questionnaire 3 which dealt with the issues related to construction practice and integrity of precast ribs, which are discussed below:

The majority of respondents use a strong brush (polypropylene or other) from 5-10 or 20-30 minutes to roughen the green surface of precast ribs. There is only one manufacturer who applies a wood float finish immediately after casting. Half of the respondents agreed that the tool they use produced a uniform surface and a variation in roughness frequency. The other half is unsure.

Half of the respondents have only 1 person skilled to roughen the surface and the other half have 3 to 4 people. The number of people undertaking roughening can affect the quality of the surface roughness unless proper training is undertaken.

Only one manufacturer provides small rib samples to the clients showing the surface roughness. No manufacturer doubted the integrity of the roughened surface hence they all believe that the tool they use is adequate. In fact, half of the respondents agree that the code should provide a reliable way to roughen the surface and the other half believed that it should not.

The majority of respondents say that the roughening of their precast ribs complies with SABS 0100-1:2000 and SANS1879:2011 although this is not always measured. Half of the respondents measure the roughness, one by visual inspection and the other by laser equipment. The other half does not measure the roughness.

There is a difference of opinion with respect to the appearance of laitance but the majority seem to believe that this is not an issue.

Half of them provide steel hooks for handling only but all believe that these hooks also work/contribute in resisting the horizontal shear. Steel hooks actually have a minimal effect.

6.4 Fourth aim

- Determine interfacial tensile bond strength through physical testing of deliberately roughened concrete ribs which are mainly used in special connections.

6.4.1 Test 1 discussion

Figure 6.17 shows the relationship between interfacial tensile bond strength and surface roughness (R_z) at 10 days. The best fit curve shows a slight trend which suggests an increase in tensile bond strength as the surface roughness increases. There is clear evidence of high tensile bond strength even at low surface roughness. It is assumed that low surface roughness are those less than 3 mm and high surface roughness are those greater than 3 mm. Surface roughness above 5 mm shows higher values of tensile bond strength. The overall wide spread of the data suggests other influences causing the widening of this trend. This representation does not take into consideration the effects of the level of uniformity, the variation in roughening frequency and intensity of laitance concrete.

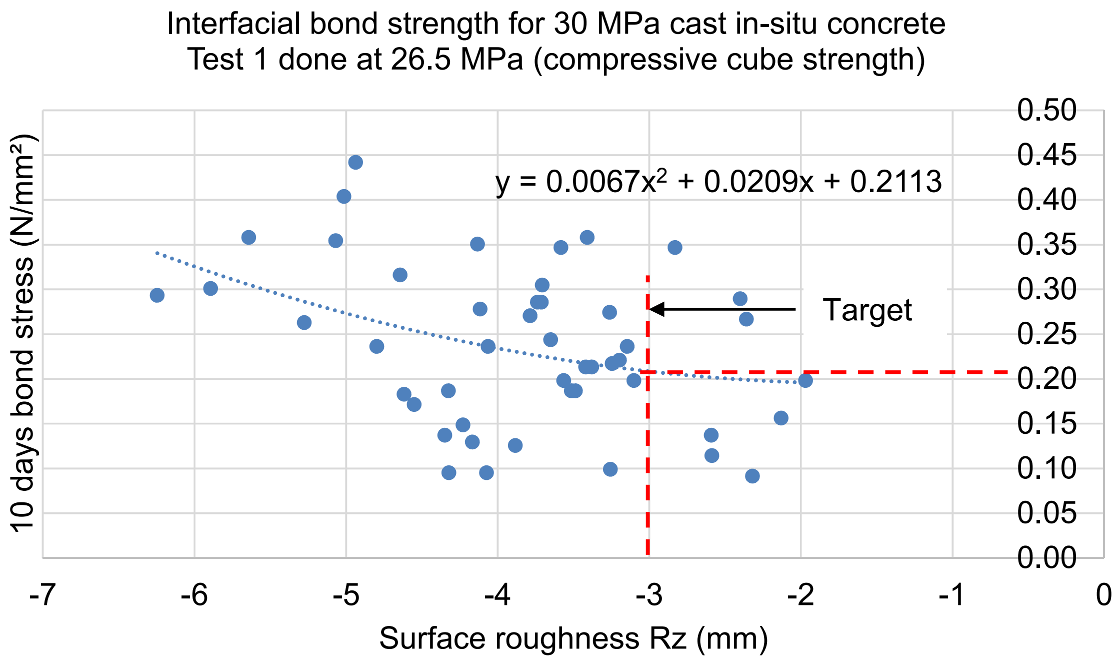


Figure 6-17: Interfacial tensile bond strength at 10 days for 30 MPa concrete

6.4.2 Test 2 discussion

Figure 6.18 shows the relationship between interfacial tensile bond strength and surface roughness (R_z) at 4 days. The best fit curve still shows a slight trend which suggests an increase in the tensile bond strength as the surface roughness increases. The low surface roughness (less than 3 mm) does not indicate higher tensile bond stresses. However, the high surface roughness shows a wider spread of achievable tensile bond stresses. This confirms other influences causing the widening of this inclining band. Again, this representation does not take into consideration the effects of the level of uniformity, the variation in roughening frequency and intensity of laitance concrete.

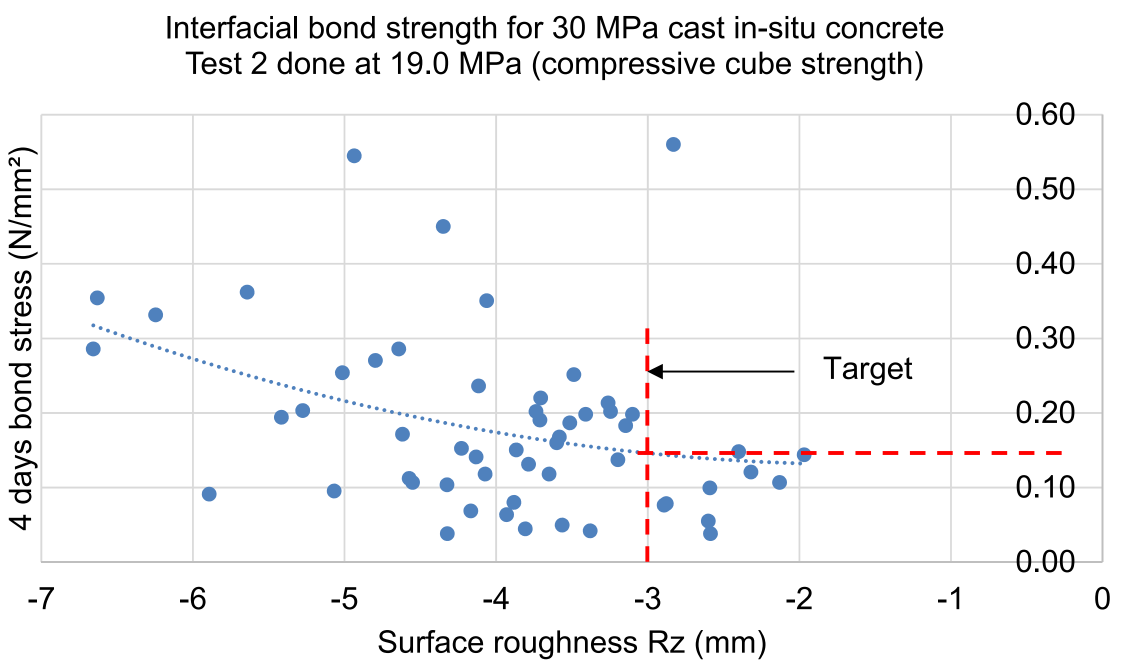


Figure 6-18: Interfacial tensile bond strength at 4 days for 30 MPa concrete

6.4.3 Overall discussion

There is low tensile bond strength developed in 4 days between precast surface and in-situ concrete. This is when the compressive strength of concrete during testing was 19.0 MPa (based on the compressive strength of concrete cubes). This strength is 2 MPa higher than 17 MPa when the temporary props can be removed. The self-weight of common (±150 mm wide x ±60 mm deep) precast rib hanging underneath the structural topping is generally too low to cause delamination. The delamination would require a contribution of other factors such as poor surface treatment and a contaminated surface. The surfaces with low roughness can still attain high tensile bond strength provided the surface treatment is carried out adequately.

6.5 Fifth aim

- Make an assessment by undertaking a basic comparison study between one local beam and block slab system that uses a shallow rectangular precast pretensioned rib to beam and block slab systems used in the United Kingdom.
- Propose a design for a precast pretensioned rib that spans up to 5 metres without temporary props.

6.5.1 Design, manufacturing and construction implications of using a shallow rectangular rib on the overall efficiency of beam and block slab systems

- The flexural design of precast pretensioned rib requires special consideration for the load effect as a result of temporary propping and the final design loads.
- The stresses induced by differential shrinkage resulting from the compressive strength of cast in-situ concrete (structural topping) being 10 MPa greater than that of pretensioned rib need to be checked but this is very often neglected because of the uncertainty about the exact time of casting.
- The precast pretensioned rib made from high early strength concrete required for early stress transfer in order to speed up the production process and, which is supposedly good in compression, ends up using pretensioned steel and the whole rib acting as a tension flange.
- Since the rib is shallow, the cast in-situ top flange and the web made from generally 25-30 MPa concrete forms a larger portion of the materials required for the flexural strength of the beam and block slab system.
- The strength of concrete masonry rebated filler blocks which is mainly used to support construction loads becomes a waste when the slab can support itself.

The physical strength tests of 13 types of CMRFB from five manufacturers in Durban proved that the filler blocks have the capacity and for some, far more, to resist the recommended construction load of 3.5 kN and can therefore be used as structural blocks with minor improvements.

6.5.2 Example of some features of shallow rectangular precast pretensioned rib

Table 6.5: Properties of shallow rectangular precast pretensioned rib

Manufacturer	Overall depth (mm)	Compressive strength (N/mm²)	Self-weight of rib (kg/m)	Centre to centre spacing (mm)	Effective span (m)	Imposed live load (domestic) (kN/m²)
A	60	40	21.6	650	4.30	1.5

6.5.3 Design, manufacturing and construction key benefits of using a deep inverted T-section precast pretensioned rib on the overall efficiency of beam and blocks slab systems

- The inverted T-section precast pretensioned rib can be made from high early strength concrete in order to accelerate the production process.
- If the height of the web is raised as much as possible, it can act as a compression member that is capable of providing enough flexural strength for the construction loads and final imposed live loads.
- If the above is achieved, the structural topping can be replaced by a non-structural topping and this will eliminate the following:
  - Risk of relying on composite action to achieve the flexural strength between the precast rib and cast in-situ structural topping.

- o Volume of cast in-situ concrete.

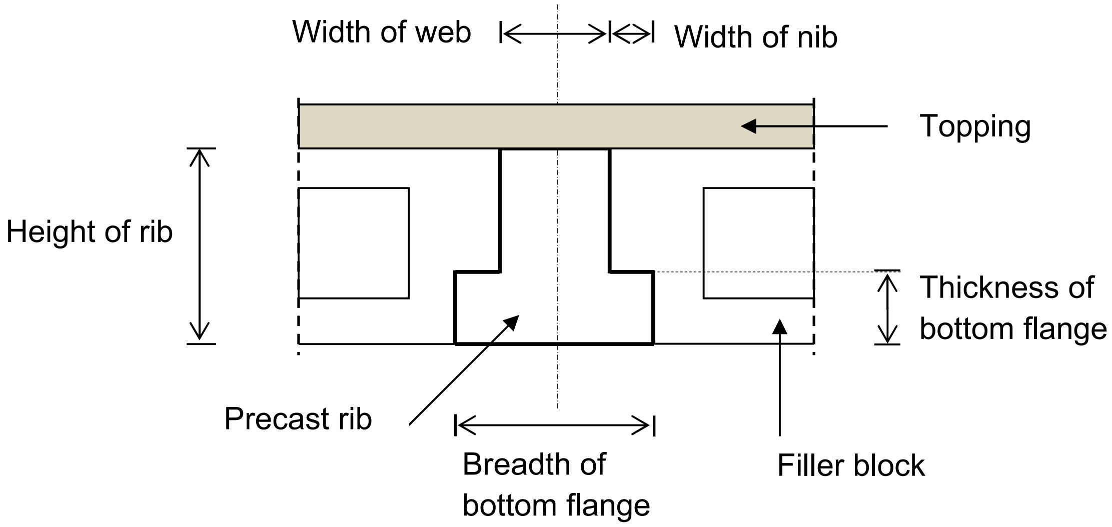


Figure 6-19: Beam and block slab system using precast inverted T-section rib

6.5.4 Pretensioned ribs used in the United Kingdom

An internet-based search by the student revealed that beam and block slab systems without temporary props are common in the United Kingdom. They are made from inverted precast pretensioned T-section ribs and span up to 4.51 m without temporary props. They are generally used with solid concrete masonry rebated filler blocks. However, their filler blocks are mainly structural and solid unlike hollow types that are common in South Africa. The properties of ribs supplied by three manufactures in the United Kingdom are compared to a rib common in South Africa (±150 mm wide x ±60 mm deep). The first three manufacturers (F, G and H) where randomly selected.

Table 6.6: Properties of inverted T-section precast pretensioned rib

Manufacturer	Overall depth (mm)	Compressive strength (N/mm²)	Self-weight of rib (kg/m)	Centre to centre spacing (mm)	Effective span (m)	Imposed live load (domestic) (kN/m²)
F	155	50	40.0	520	4.40	1.5
G	155	60	30.4	510	4.25	1.5
H	155	60	36.0	520	4.51	1.5

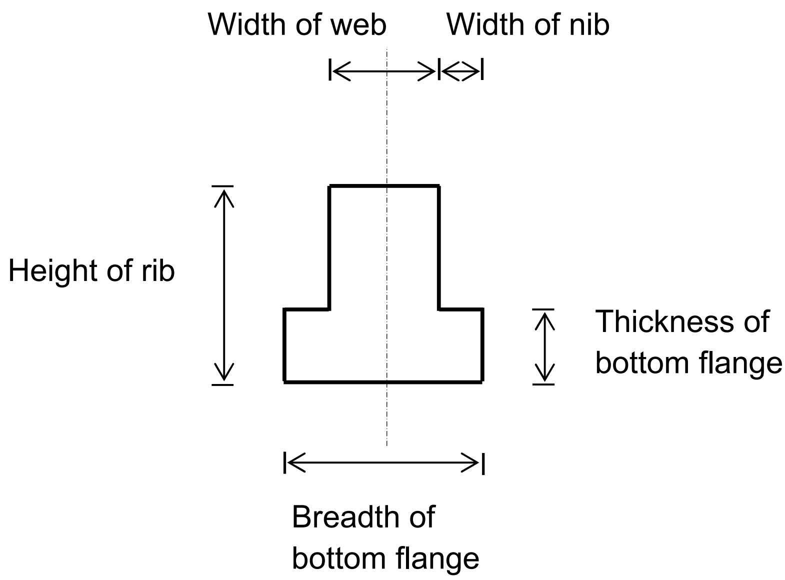


Figure 6-20: Precast pretensioned inverted T-section rib used in the United Kingdom

6.5.5 Review of key features

A basic review of the key features between a beam and block slab system with structural topping, non-structural blocks and rectangular shallow precast pretensioned ribs and that have non-structural topping, structural blocks and deep inverted T-section precast pretensioned ribs has been done and the following is noted:

- Using a deep inverted T-section rib can give a span of up to 4.51 m without the use of any temporary props. However, a closer spacing less than 560, 600 & 650 mm compared to that mentioned in Chapter 1 is necessary.
- Temporary props can be eliminated including soffit shutter or formwork.
- Requirement for horizontal shear resistance can be eliminated.
- More concrete cover can be provided as a result of sufficient depth of the section. This is beneficial for the durability in coastal areas and the fire resistance of a structural member.
- Effects of differential shrinkage can be eliminated.
- Lack of adequate vibration can be eliminated.
- There is a choice of casting a transfer beam by threading a steel bar of up to 16 mm diameter through a preformed hole.

Chapter 7

Conclusions

Beam and block slab systems offer a unique suspended flooring structural solution achieved by prefabricating ribs off-site and also by the use of prefabricated void formers or filler blocks to support the cast in-situ structural topping which later forms a series of T-beams, which are well known to be structurally efficient.

The overall structural efficiency and effectiveness of beam and block slab systems depend on the structural efficiencies and effectiveness of all components used to produce the flooring system as well as the construction methods used to manufacture those components and final assembly and construction of the flooring system.

The findings for each aim of the study are summarized below:

First aim

Provide the users of beam and block slab systems with basic technical information about the possible ways to improve the efficiency and effectiveness in the design, manufacturing and construction of beam and block slab systems by undertaking an exploratory (pilot) study to better understand users of these systems concerns.

The following conclusions can be drawn from Questionnaire 1;

- Most people are keen to use beam and block slab systems to any class of occupancy building if all fire regulations, and minimum standards are well within acceptable limits.

- In general, respondents do not prefer to use expanded polystyrene foam filler blocks over conventional filler blocks. However, it was noted in Questionnaire 2 that Manufacturer A had completed more than 1000 projects involving poly-blocks compared to Manufacturer B and C who had completed 55 and 60 respectively.
- Respondents are not reluctant to plaster expanded polystyrene foam filler blocks with a normal sand-cement plaster because of lack of information with regards to the construction methodology and reliability.
- There is doubt with regards to the effectiveness of 15 mm concrete cover over pretensioned steel in precast ribs when resisting fire and providing a durable structural component. The results shown in Figure 6 -9 indicated 35 precast ribs out of 120 (29%) that had a concrete cover over steel below 15 mm.
- People often rely on a normal sand-cement soffit plaster to provide additional fire protection to the main structural elements. If normal sand-cement soffit plaster contribute to fire rating, it must be proven to be able to withstand the design fire rating without peeling off within the required duration of time.
- The design, manufacturing and construction methodology of beam and block slab systems is not adequately documented and controlled, and the engineer is often not given adequate design information with regards to the concrete and steel strength and quality in order to confidently carry out design ratification for the whole structure.

Second aim

- Investigate, by conducting a series of strength to weight ratio tests, how efficient or inefficient these filler blocks are.
- Examine the structural integrity with respect to the integrity of the manufacturing methodologies and the product thereof.
- Formulate a method to quantify the fire-resistivity of concrete masonry rebated filler blocks to the structural topping with respect to confining fire/flames from one floor to the next.

The load tests done in Test 1 and Test 2 indicated that the filler blocks are effective (reaching and sustaining loads far in excess of the required). It should be remembered that Manufacturer A had been designing filler blocks for a construction load of 2 kN (200 kg) but still achieved an average failure load above 3.5 kN.

All filler blocks should be designed for a construction load of 3.5 kN as recommended by SANS1879: 2011. If this is adhered to, the theoretical structural efficiency will depend entirely on the self-weight of the filler block. Heavy filler blocks have lower theoretical structural efficiency and light filler blocks have higher theoretical structural efficiency. The filler blocks made from expanded polystyrene foam have the highest theoretical structural efficiency but are likely unable to support a construction load of 3.5 kN when cut to 200 mm widths which is equivalent to that of common concrete masonry filler blocks. When comparing poly-blocks to concrete masonry rebated filler blocks tested in the study, the average failure loads of 1.08 kN, 1.42 kN and 1.16 kN were achieved. This is significantly lower than the loads sustained by concrete masonry rebated filler blocks. However, poly-blocks are able to support a construction load of 3.5

kN when produced or cut to large lengths. Concentrated loads may punch through the expanded polystyrene foam. The inefficiency of concrete masonry rebated filler blocks can be determined by the structural wastefulness graph expressed as a percentage of the structural efficiency (based on the failure load) minus the theoretical structural efficiency (based on the design load of 3.5 kN) and all divided by the theoretical structural efficiency.

It was seen that some concrete masonry rebated filler blocks are structurally efficient and some are structural inefficient. It was noted in particular that concrete masonry filler blocks of cellular type are the heaviest and exert more dead load on the flooring system. However, they are useful to construct shallow beam and block slab systems that are 150 mm in depth or even less. This filler block is effective because they support way above the required construction load but are inefficient.

There is a correlation between the effective span over effective depth ratio of concrete masonry rebated filler blocks and the magnitude of forces and moments generated in members. However, more work is needed to develop the most effective and efficient structure (geometry) of concrete masonry rebated filler blocks. This will include theoretical design and analysis, building and physically testing models and practical consideration.

Questionnaire 2 indicated that all manufacturers perform in-house testing of concrete masonry rebated filler blocks. 84.62% of manufacturers use triple core filler block. These filler blocks only have vertical and horizontal members. The geometry or structure of the filler blocks require joint stiffness to resist loads.

The ability of beam and block slab systems to resist fire or shield flames (through thin structural topping) from progressing from one floor to the next can be determined by calculating the fire resistance of concrete masonry rebated filler blocks where the resistance is a function of the type of aggregates used to manufacture the filler blocks and their equivalent thickness. If the fire resistance of a filler block is equal or greater than fire resistance given in Table 46 of SABS 0100-1: 2000, then the fire progression from one floor to the next is not possible through structural topping. However, this method ignores the presence of small gaps between the filler blocks and other structural elements. The proposed method need to be tested at full scale since the filler blocks are used in the horizontal position compared to the vertical position in masonry walls.

Third aim

- Determine what constituted acceptable quality of a deliberately roughened precast concrete surface by conducting a survey to learn about the construction methodologies used by manufacturers. Site visits were undertaken to validate information given by the contractors.

The top surface of precast ribs that were deliberately roughened by bristles of a broom showed a significant variation in uniformity, appearance of laitance and roughness frequency. Although the broom is effective in providing a surface roughness (Rz) of 3 mm, it is not always efficient when considering factors like variation in uniformity, appearance of laitance and roughening frequency. SABS0100: 2000 and SANS1879: 2011 do not provide recommendations on how to deal with the variations in surface roughness and how much effect this has on the horizontal shear strength. Site observations showed that the roughening process causes localised laitance and no site evidence of removing laitance was observed.

Questionnaire 3 reflected that the majority of manufacturers prefer to use a broom to roughen the surface of precast ribs. There is no standard time set to begin the roughening process of precast ribs. However, the process generally begins 10 minutes after casting concrete. The roughness of the surface of the precast ribs is not measured according to the method specified by SANS 1879:2011. Manufacturers believe that the steel hooks used for handling provide horizontal shear resistance between the roughened surface of precast ribs and cast in-situ concrete. Steel hooks are often installed after casting concrete and do not have a longitudinal steel bar or wire restraining corners that are embedded inside concrete. For this reason, they should not be assumed to provide any structural strength other than for handling.

Fourth aim

- Determine interfacial tensile bond strength through physical testing of deliberately roughened concrete ribs which are mainly used in special connections.

Delamination tests undertaken of separating a roughened surface of precast ribs and cast in-situ concrete when reached a compressive strength of 19 MPa (which is close to 17 MPa) produced a tensile stress of 0.15 MPa for the surface roughness (R_z) of 3 mm. This tensile stress is adequate to support the self-weight of common precast ribs (±150 mm wide x ±60 mm deep) when temporary props are removed after the cast in-situ structural topping reached a compressive strength equal to or greater than 17 MPa as mentioned by Annex D (informative) of SANS 1879:2011. Further to this, the tensile interfacial bond strength of 0.21 MPa was reached when the cast in-situ concrete reached a compressive strength of 26.5 MPa (which is close to 25 MPa) for a surface roughness (R_z) of 3 mm. This stress may be low for the structural connections that need to rely on interfacial tensile bond.

Connections similar to that shown in Figure 6-3 and Figure 7-1 should be designed such that they do not rely on the tensile bond strength but through tie reinforcing bars taking the full tension or load causing delamination.

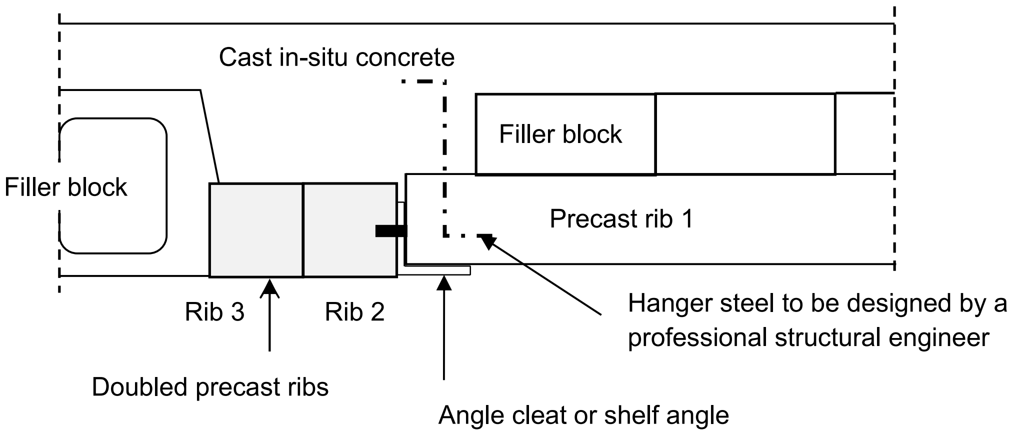


Figure 7-1: Alternative detail of a hanger steel

Fifth aim

- Make an assessment by undertaking a basic comparison study between one local beam and block slab system that uses a shallow rectangular precast pretensioned rib to beam and block slab systems used in the United Kingdom.
- Propose a design for a precast pretensioned rib that spans up to 5 metres without temporary props.

Beam and block slab systems used locally, especially in the Durban area are made from a ±150 mm wide x ±60 mm deep rectangular precast pretensioned concrete sections. They span between 1.5 to 1.8 m and require temporary propping. Inverted T-beams made from precast pretensioned higher strength concrete sections are very common in the United Kingdom. The ones cited in the study can span up to 4.51 m without providing temporary props.

Both types need to provide an area where the filler block can sit. Both systems are effective since they do what they are designed for but inverted T-beams are more efficient than rectangular ribs since they can eliminate completely the use of temporary props for spans up to 4.51 m. This feature can provide a more efficient construction method in low cost housing. Further research is required on designing an inverted T-beam by using high strength precast pretensioned concrete that can span up to 5 m without using temporary props.

Recommendations

Filler blocks

- Mix design and trial tests are necessary to save the costs of producing over-strength concrete masonry rebated filler blocks which costs money (thus inefficient).
- All manufacturers should indicate in their catalogues the type of aggregates used to manufacture the filler blocks and the equivalent thickness to enable the engineer to assess the fire resistance of the filler block with respect to its ability to shield fire or flames from progressing from one floor to the next.
- The figure below shows a model proposed by the student of a filler block that has triangulated members. This work is left for future research.

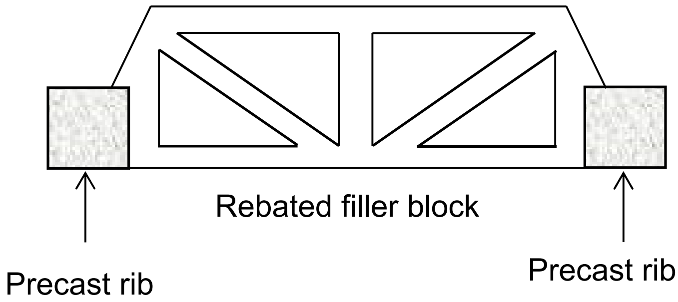


Figure 7-2: Proposed filler block

Precast ribs

It is recommended that manufactures use a hand tool with rigid spikes similar to the one shown in the figure below which has been used by contractors to roughen concrete roads or pavements. On-site monitoring is necessary in order to evaluate whether or not the proposed tool will be effective and more importantly improve the effectiveness of the roughening process. Future research should investigate the optimum time for roughening concrete.

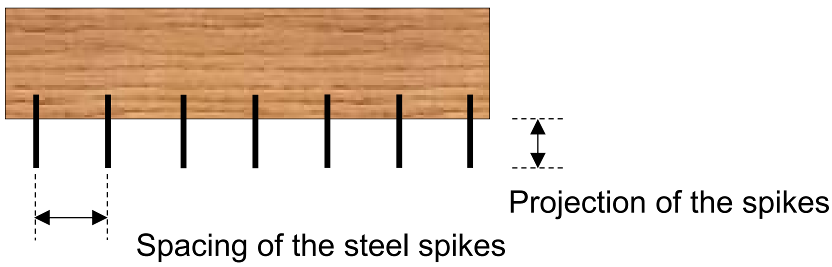


Figure 7-3: Proposed stiff roughening tool

The advantages of this tool are:

- Stiff spikes are capable of maintaining a constant horizontal distance between the grooves during the roughening process compared to the flexible bristles of a broom.
- They can also be pushed deep into green concrete to create a pronounced undulation without bending.

However, it should be noted that ~~a~~ skill is required to be developed in order to achieve reasonable or acceptable results and acquiring proper training, knowledge and understanding of the mechanics involved in the behaviour of newly cast in-situ concrete will improve the efficiency.

Special connections

All special connections must be designed by a professional structural engineer and tie bars provided to resist full tension force.

Proposed precast rib

Following the basic comparison study of the two systems in Chapter 6, trial dimensions presented in the table below were used to design a proposed precast pretensioned rib spanning up to 5 m without temporary props.

Table 7.1: Properties of inverted T-section precast pretensioned rib

Manufacturer	Overall depth (mm)	Compressive strength (N/mm²)	Self-weight of rib (kg/m)	Centre to centre spacing (mm)	Effective span (m)	Imposed live load (domestic) (kN/m²)
Trial specification	150	60	35.0	500	5.00	1.5

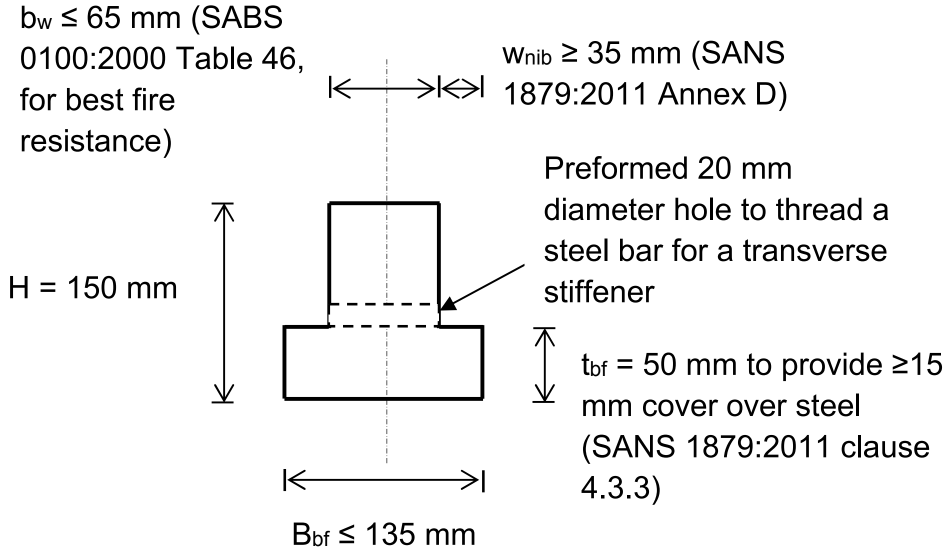


Figure 7-4: Technical detail of a proposed rib

Where,

- H - Overall height
- B_{bf} - Breadth of the bottom flange
- b_w - Breadth of web

- w_{nib} - Width of nib
- t_{bf} - Thickness of bottom flange

The technical detail of a typical beam and block slab system consisting of concrete masonry structural blocks and non-structural topping as recommended by the SABS code 0100-1 (2000: 55 and 56) is shown below.

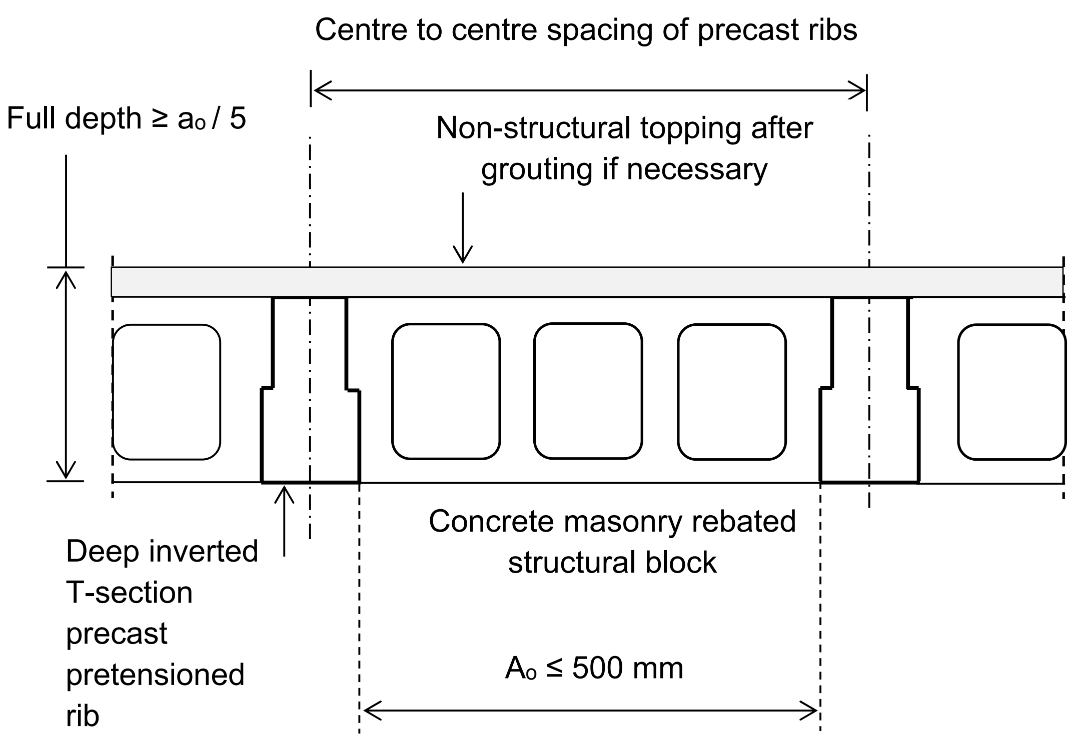


Figure 7-5: Technical detail of a proposed beam and block slab system

Where,

- A_o - Clear distance between ribs

This forms the foundation for future research of a precast rib that can be used for light loading application ranging from domestic to industrial use without temporary props.

Summary

The manufacturers of beam and block slab systems should take note of the following issues in order to improve efficiency and effectiveness of design, manufacturing and construction of beam and block slab systems:

With respect to filler blocks,

- SANS 1879:2011 recommends a design load of 3.5 kN for filler blocks
- SANS 1879:2011 recommends a bearing width of not less than 35 mm
- Undertake trial mix designs and test samples prior to batch production

With respect to precast ribs,

- SANS 1879:2011 recommends a concrete cover over pretensioning wire of not less than 15 mm
- Surface roughness should have good quality with respect to uniformity, similarity in frequency and be free of laitance
- If laitance forms, it should be removed
- Vibrators should not be kept in one spot for a long period of time to avoid the bleeding of concrete

General

Poor quality control and workmanship remain key issues to rectify in order to improve efficiency and construction of beam and block slab systems. Design information and any information pertaining to quality assurance should be made available to structural engineers who take final responsibility for the overall stability of the structure.

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Annexure A – Questionnaire 1

The following questions were posed to the respondents by Khuzwayo (2013: 93-95) through Questionnaire 1:

1. Were you involved in any design or work with a beam and block slab system in any of your projects? (Refer to Figure 11-1and 11-2): (yes or no).
2. Describe your background regarding your familiarity with the beam and block slab system: (consultants, manufacturers, contractors, architects and academics).
3. How many beam and block projects have you completed? (<10 or ≥10).
4. Do you belong to any statutory body such as the Engineering Council of South Africa, South African Institute of Architects, Master Builders or any others?: (yes or no).

For questions 5-15, the respondent had a choice to answer by stating, strongly agree, agree, neutral, disagree and strongly disagree.

5. Normally I have no problem using a beam and block slab system to any class of occupancy building if all fire regulations and minimum standards are within the acceptable limits.
6. A 40-60 mm cast in-situ structural topping has not shown any structural defects such as cracking and poor compaction as a result of design and construction methodology.

7. Normally I prefer to use polystyrene foam infill blocks rather than conventional infill blocks.

8. I have experienced some cracks in a normal sand-cement ceiling plaster when applied to conventional infill blocks probably because of the design and construction method.

9. I have not experienced any problems when plastering polystyrene foam infill blocks with a normal sand-cement plaster when applying a key-coat.

10. I do not plaster polystyrene foam infill blocks with a normal sand-cement plaster because of lack of information with regards to construction methodology and reliability.

11. The horizontal shear resistance between the top of a standard precast pretensioned rib and cast in-situ concrete topping raises doubts with respect to effectiveness.

12. The nominal thickness 40-60 mm of the structural topping raises doubts with respect to effectiveness when resisting heat.

13. The concrete cover ≥ 15 mm over the pretensioning steel in the precast ribs raises doubts with respect to effectiveness when resisting heat.

14. I have relied on a normal sand-cement soffit plaster to provide additional fire protection to main structural elements.

15. The design, manufacturing and construction methodology of a beam and block slab system is not adequately documented and controlled, and the engineer is

often not given adequate design information with regards to the concrete and steel strength and quality in order to confidently carry out design ratification for the whole structure.

Question 16 (below) was an open general question that allowed the respondent to give more feedback.

16. Please share with us any experiences, general comments and concerns with beam and block slab systems.

Figure 11-1: Typical detail of a beam and block slab system with conventional infill blocks

Figure 11-2: Typical soffit detail of a beam and block slab system with polystyrene foam infill blocks

Annexure B - Questionnaire 2

Background and general

1. Describe your background regarding your familiarity with the concrete masonry rebated filler blocks (refer to Figure 4-10 below): design-engineer, manufacturer, contractor etc.

Figure 4-10: Typical concrete masonry rebated filler block

2. How many years have you worked with concrete masonry rebated filler blocks?
3. How many beam and block projects have you completed on average per year? (e.g. 50 projects).
4. How many beam and block projects that incorporated concrete masonry rebated filler blocks have you completed?
5. How many beam and block projects that incorporated expanded polystyrene rebated filler blocks have you completed?
6. Do you belong to any statutory body such as the Engineering Council of South Africa, Master Builders, Concrete Society or any others? If yes, which?

7. Were you directly involved in designing the concrete masonry rebated filler blocks you use for your projects? (yes or no). If no, who designed it? (e.g. an architect) Do not mention the name.
8. How often do you cast the batch of filler blocks per month?

Manufacturing

9. What materials do you use for manufacturing these blocks? (e.g. Umngeni River Sand, 12 mm aggregates and cement etc.).
10. Please provide the names of any admixtures you use when manufacturing your blocks.
11. Do you do any integrity tests for the materials you intend purchasing to manufacture these blocks? (yes or no). If so, which?
12. Do you conduct any trial mix designs using the materials you use in your mix? (yes or no). If so, how?
13. Do you make any filler block samples for testing prior to the bulk/batch production? (yes or no).
14. Do you do any in-house filler block testing (refer to Figure 4-11 below) to assess the strength of the blocks prior to selling to the public?

Figure 4-11: Typical testing of a concrete masonry rebated filler block

15. Our organization follows adequate curing procedures (strongly disagree, disagree, neutral, agree or strongly agree).
16. For how many days do you cure your filler blocks?
17. What method do you use to cure these blocks?

Design

18. Have you previously changed the design of your filler blocks because of poor structural performance? (yes or no).
19. Do you think the self-weight of your filler blocks can be reduced without affecting the strength? (strongly disagree, disagree, neutral, agree or strongly agree).

Production cost

20. Do you think the production cost of your filler blocks is badly affected by the selection of the materials you are using? (strongly disagree, disagree, neutral, agree or strongly agree).
21. Do you think the production cost of your filler blocks is badly affected by the actual design of your filler blocks? (strongly disagree, disagree, neutral, agree or strongly agree).

Improvement

22. Do you think reviewing the design of your filler blocks could save you money in the long term? (strongly disagree, disagree, neutral, agree or strongly agree).
23. Do you think doing trial mix designs could significantly improve the structural performance of your filler blocks? (strongly disagree, disagree, neutral, agree or strongly agree).

24. Do you think educating your staff about the mix designs for concrete masonry blocks could have a significant positive effect in the production of your blocks? (strongly disagree, disagree, neutral, agree or strongly agree).
25. Do you think improving the curing process could significantly improve the strength of your filler blocks? (strongly disagree, disagree, neutral, agree or strongly agree).
26. Please give any comments/suggestions about the topic.

Annexure C - Questionnaire 3

1. What tool do you use to deliberately roughen the surface of precast concrete beams/planks/ribs?
2. Your tool provides a uniform precast concrete roughened surface (strongly disagree, disagree, neutral, agree or strongly agree).
3. Your tool provides a variation in the frequency of the concrete surface roughness (strongly disagree, disagree, neutral, agree or strongly agree).
4. The roughened interface of precast concrete often shows some formation of laitance concrete (a weak layer of aggregates and cement fines on a concrete surface), (strongly disagree, disagree, neutral, agree or strongly agree).
5. We always ensure that our precast rib is adequately roughened but to no specific measurable roughness (strongly disagree, disagree, neutral, agree or strongly agree).
6. Our organization complies with SABS 0100-1:2000 with respect to the roughening of the precast concrete surface (strongly disagree, disagree, neutral, agree or strongly agree).
7. Our organization ensures that the precast ribs have a surface roughness equal to or greater than 3 mm as specified by clause 4.3.4 of SANS 1879:2011 (strongly disagree, disagree, neutral, agree or strongly agree).
8. After how many minutes after casting concrete ribs do you begin the process of roughening the surface?
9. How many people are in charge or skilled to roughen the concrete surface in your precast plant?

10. Do you measure the roughness of the precast interface prior to selling it to the public? (yes or no). If yes, how?
11. Do you provide any samples to the clients of the precast concrete surface roughness for the ribs you produce? (yes or no).
12. Do you provide shear hooks/links/studs to resist the horizontal shear? (yes or no). If yes, who and how did you test their effectiveness?
13. Do you deliberately provide hooks/links/studs for handling purposes only? (yes or no). If yes, have you checked their ineffectiveness?
14. Did you often get any complaints/comments doubting the integrity of the precast concrete roughened surface for your ribs? (yes or no). If yes, from whom? (e.g. architect) Do not mention the name.
15. Do you think a better tool should be designed for making a quality roughened concrete surface? (yes or no). If no, why?
16. Do you think a code of practice should provide a reliable method to roughen the precast concrete surface? (yes or no).
17. Please give any comments/suggestions about the topic.

Annexure D1 – Surface profile for ribs A1 to A20 (mm)

Beam	Surface profile (mm)																					Average
A1	-7.2	-1.9	-6.4	-2.1	-7.7	-2.9	-6.0	-5.2	-6.3	-3.7	-7.0	-4.5	-7.3	-4.9	-6.9	-3.7	-7.0	-4.5	-6.4	-3.5	-6.2	-5.0	-5.28
A2	-7.4	-3.5	-4.7	-1.8	-3.5	-2.0	-3.6	-2.3	-3.8	-2.9	-7.4	-6.1	-8.0	-0.5	-6.2	-1.4	-3.7	-1.9	-0.1	-2.6	-6.6	-1.9	-3.71
A3	-6.2	-4.3	-1.7	-5.5	-4.7	-5.0	-5.2	-3.1	-5.8	-5.6	-3.9	-4.8	-4.0	-6.0	-3.4	-4.6	-3.2	-5.9	-1.4	-2.9	-4.2	-1.9	-4.23
A4	-2.0	-1.8	-2.3	-1.8	-3.4	-3.1	-3.3	-2.2	-3.2	-1.6	-2.7	-3.1	-3.4	-4.0	-2.6	-3.3	-4.6	-3.4	-3.2	-3.3	-2.5	-2.9	-2.89
A5	-4.1	-1.1	-4.8	-3.8	-4.7	-0.5	-4.4	-1.3	-3.4	-0.8	-5.1	-3.1	-6.8	-1.4	-4.3	-3.7	-4.9	-4.4	-5.8	-4.6	-2.3	-6.3	-3.71
A6	-2.2	-2.3	-3.4	-2.1	-1.9	-2.6	-2.3	-3.0	-2.8	-2.4	-3.0	-1.9	-3.0	-2.8	-3.2	-3.2	-3.0	-3.2	-2.2	-2.4	-2.3	-2.4	-2.60
A7	-3.4	-3.2	-1.8	-1.9	-0.9	-4.6	-2.3	-4.9	-5.9	-2.8	-3.3	-4.2	-1.8	-3.1	-1.2	-5.2	-3.7	-5.0	-1.0	-5.6	-3.4	-3.9	-3.31
A8	-2.3	-2.8	-2.6	-2.7	-2.6	-2.5	-2.4	-2.3	-2.4	-2.8	-2.3	-2.1	-2.3	-2.3	-2.1	-2.4	-2.4	-2.5	-2.4	-2.4	-0.1	-2.3	-2.32
A9	-5.3	-3.3	-4.0	-2.9	-5.3	-2.1	-4.8	-5.6	-4.6	-4.6	-3.7	-5.3	-3.2	-5.8	-4.1	-6.6	-2.3	-4.6	-3.9	-7.0	-5.1	-7.0	-4.57
A10	-5.3	-3.5	-4.1	-3.4	-4.5	-1.6	-7.7	-6.5	-7.7	-2.5	-6.1	-2.1	-4.2	-1.6	-5.0	-4.1	-5.6	-4.3	-5.5	-2.3	-5.1	-2.5	-4.32
A11	-1.9	-3.4	-2.9	-4.2	-4.0	-3.5	-3.6	-3.8	-4.6	-4.1	-3.8	-4.8	-5.0	-5.2	-5.4	-5.5	-3.3	-3.5	-3.8	-3.9	-1.4	-5.0	-3.93
A12	-4.1	-5.2	-5.8	-6.6	-3.3	-3.9	-1.7	-2.6	-0.1	-4.5	-3.4	-4.2	-4.2	-4.4	-4.4	-4.3	-3.9	-4.5	-5.2	-0.5	-4.1	-2.5	-3.79
A13	-1.6	-2.4	-1.7	0.6	-3.2	-3.5	-5.1	-2.9	-2.5	-2.4	-2.8	-5.4	-3.6	-4.2	-3.4	-1.9	-4.3	-3.2	-2.3	-2.7	-1.4	-3.7	-2.88
A14	-5.3	-1.2	-2.4	-4.2	-3.5	-6.5	-7.5	-2.6	-8.4	-5.7	-0.7	-1.0	-5.0	-7.5	-5.5	-8.2	-1.6	-5.7	-4.6	-8.7	-7.6	-8.2	-5.07
A15	-2.8	-2.0	-1.8	0.8	-2.4	-2.3	-2.9	-2.4	-3.0	-3.0	-3.7	-2.9	-3.3	-2.5	-3.0	-2.6	-1.8	-3.1	-2.9	-3.2	-2.8	-3.3	-2.59
A16	-3.9	-2.3	-5.9	-4.3	-5.0	-3.5	-6.0	-3.5	-6.4	-3.9	-4.7	-7.4	-2.1	-5.4	-4.4	-5.0	-6.7	-5.2	-7.4	-6.5	-6.9	-3.8	-5.01
A17	-2.2	-2.1	-2.2	-1.7	-2.6	-2.0	-1.6	-2.3	-2.7	-1.0	-1.9	-3.6	-2.4	-2.9	-2.2	-2.5	-1.7	-3.0	-2.2	-3.0	-3.2	-4.1	-2.40
A18	-2.3	-2.5	-2.3	-1.7	-2.4	-2.2	-2.2	-2.2	-1.5	-1.8	-1.9	-1.8	-1.7	-1.5	-1.8	-1.8	-2.2	-2.8	-1.9	-1.6	-1.9	-1.8	-1.97
A19	-2.1	-1.9	-2.1	-1.0	-1.8	-5.0	-3.0	-3.6	-4.0	-3.1	-4.3	-3.5	-3.7	-2.9	-2.4	-2.7	-4.2	-7.1	-6.6	-7.3	-7.2	-4.4	-3.81
A20	-3.3	-4.0	-3.2	-3.7	-3.5	-3.9	-3.7	-4.3	-4.2	-4.7	-4.6	-4.0	-2.2	-3.9	-3.1	-3.8	-4.0	-4.6	-4.0	-4.5	-4.0	-4.1	-3.87

Note: The surface profile was taken from a levelled arbitrary line above the roughened face of the rib (hence they are negative) between 100 to 120 mm segment.

Annexure D2 – Surface profile for ribs A21 to A40 (mm)

Beam	Surface profile (mm)																						Average
A21	-2.6	-2.4	-6.7	-4.9	-5.7	-6.9	-4.6	-7.9	-6.8	-7.9	-6.3	-8.2	-7.5	-7.7	-4.3	-4.3	-4.5	-5.8	-6.1	-5.3	-6.4	-6.8	-5.89
A22	-5.8	-5.6	-5.7	-3.4	-4.1	-4.0	-3.8	-4.1	-2.8	-4.4	-5.3	-5.0	-4.0	-6.6	-2.8	-4.0	-3.0	-2.4	-3.7	-4.2	-5.8	-5.3	-4.35
A23	-3.9	-2.8	-3.0	-3.4	-3.3	-3.2	-2.2	-2.6	-2.5	-2.9	-1.3	-2.5	-2.8	-3.1	-3.3	-2.0	-3.2	-2.4	-3.0	-3.4	-3.4	-2.1	-2.83
A24	-2.8	-3.4	-3.1	-3.2	-2.2	-2.4	-2.2	-2.5	-2.6	-2.6	-2.9	-2.8	-2.8	-3.6	-3.9	-3.6	-3.3	-3.4	-3.7	-3.9	-4.1	-4.2	-3.15
A25	-3.2	-5.8	-3.5	-7.8	-4.8	-6.3	-5.2	-3.0	-6.4	-2.2	-4.4	-4.1	-7.3	-6.4	-6.5	-4.1	-1.6	-3.3	-4.4	-2.1	-5.3	-2.7	-4.55
A26	-4.3	-4.1	-4.0	-3.6	-3.6	-3.4	-2.8	-2.8	-3.0	-2.9	-2.7	-3.4	-3.7	-4.9	-5.0	-6.4	-5.6	-4.7	-4.0	-4.2	-5.1	-5.5	-4.07
A27	-3.8	-4.8	-4.5	-3.8	-6.5	-4.6	-5.5	-4.8	-2.5	-4.6	-2.8	-3.6	-3.0	-3.7	-2.5	-6.0	-2.7	-3.3	-2.6	-4.0	-2.7	-3.3	-3.88
A28	-6.6	-3.9	-4.7	-3.1	-4.5	-1.1	-2.4	-2.4	-1.3	-1.4	-4.6	-1.8	-0.2	-2.8	-3.2	-3.0	-3.2	-3.4	-3.7	-3.7	-3.8	-3.6	-3.10
A29	-6.4	-3.5	-5.5	-2.8	-4.6	-2.7	-2.8	-4.4	-2.3	-1.3	-3.2	-2.8	-1.9	-4.0	-3.3	-3.6	-2.5	-3.6	-3.8	-2.5	-4.9	-3.0	-3.42
A30	-5.3	-3.9	-5.9	-4.4	-6.9	-1.7	-7.3	-1.2	-7.3	-4.2	-8.2	-5.0	-5.2	-3.8	-7.2	-5.5	-7.1	-6.1	-4.9	-8.8	-7.3	-2.1	-5.42
A31	-3.8	-1.7	-4.6	-2.0	-2.1	-3.5	-2.8	-3.4	-3.7	-5.7	-5.4	-5.4	-5.1	-2.5	-7.4	-5.1	-7.9	-3.4	-5.0	-1.4	-5.9	-3.4	-4.13
A32	-4.2	-2.9	-3.4	-4.1	-2.7	-2.6	-2.9	-3.2	-1.9	-1.6	-1.4	-1.7	-2.6	-2.6	-3.0	-2.4	-2.5	-2.6	-2.5	-1.5	-1.9	-2.8	-2.59
A33	-2.4	-2.6	-2.4	-3.0	-3.2	-3.4	-3.2	-2.9	-3.5	-3.4	-3.8	-4.0	-3.5	-3.4	-3.8	-3.5	-3.4	-3.5	-2.6	-3.4	-3.0	-2.7	-3.20
A34	-3.7	-3.1	-4.2	-4.0	-4.2	-4.7	-4.6	-4.1	-2.8	-3.6	-3.9	-4.0	-3.8	-3.2	-3.2	-3.8	-3.8	-3.0	-3.1	-3.3	-3.1	-3.3	-3.65
A35	-4.4	-2.2	-1.8	-4.3	-5.0	-5.0	-3.3	-3.0	-2.6	-4.0	-4.7	-4.1	-5.7	-3.5	-3.1	-4.1	-4.6	-4.0	-2.5	-3.0	-0.9	-3.1	-3.58
A36	-3.1	-0.9	-4.5	-2.2	-4.0	-2.5	-4.2	-5.1	-2.0	-5.4	-3.5	-5.2	-4.5	-5.3	-2.3	-4.6	-2.9	-3.8	-4.1	-2.7	-3.9	-2.6	-3.60
A37	-3.1	-3.0	-2.8	-2.9	-2.8	-2.6	-2.5	-2.2	-1.8	-2.6	-2.2	-3.0	-2.2	-1.7	-2.1	-2.3	-2.4	-2.2	-2.1	-1.7	-2.2	-1.7	-2.36
A38	-8.1	-3.5	-6.7	-4.0	-6.5	-4.0	-3.6	-4.3	-4.3	-4.1	-3.6	-3.9	-4.3	-3.7	-3.8	-3.3	-3.9	-3.7	-3.8	-3.0	-2.6	-3.4	-4.17
A39	-3.4	-3.4	-3.4	-3.8	-3.6	-3.8	-3.8	-3.6	-3.6	-3.4	-3.8	-3.7	-3.8	-3.3	-3.3	-3.3	-3.7	-3.5	-3.6	-3.7	-3.7	-3.3	-3.56
A40	-4.7	-2.9	-3.9	-2.9	-4.5	-5.2	-5.0	-5.6	-7.1	-3.5	-6.2	-2.0	-7.4	-4.4	-5.5	-4.2	-4.8	-5.3	-4.3	-6.6	-5.0	-7.7	-4.94

Note: The surface profile was taken from a levelled arbitrary line above the roughened face of the rib (hence they are negative) between 100 to 120 mm segment.

Annexure D3 – Surface profile for ribs A41 to A60 (mm)

Beam	Surface profile (mm)																					Average
A41	-4.2	-6.9	-3.7	-6.5	-3.9	-5.9	-2.9	-7.8	-6.1	-6.5	-4.1	-7.8	-6.2	-8.7	-7.9	-8.3	-2.3	-8.0	-12.0	-6.4	-7.7	-3.6	-6.25
A42	-2.9	-3.0	-2.5	-1.9	-1.5	-2.7	-3.0	-3.0	-3.2	-2.8	-2.5	-4.4	-3.2	-3.1	-3.3	-2.5	-3.8	-5.0	-5.2	-2.5	-3.9	-5.6	-3.25
A43	-6.9	-1.6	-6.6	-4.1	-5.1	-4.8	-9.8	-6.6	-6.1	-7.9	-7.4	-5.7	-8.5	-5.4	-7.4	-5.8	-9.1	-6.2	-8.4	-6.4	-9.6	-6.7	-6.63
A44	-2.5	-3.5	-2.8	-2.9	-2.1	-3.6	-3.8	-3.4	-4.1	-2.7	-5.8	-3.9	-5.7	-4.2	-5.1	-5.4	-4.8	-5.3	-3.7	-3.8	-7.5	-4.1	-4.12
A45	-1.4	-1.3	-1.8	-1.8	-2.1	-2.1	-2.0	-1.5	-1.0	-2.5	-2.6	-2.1	-2.7	-2.5	-3.2	-2.8	-3.3	-1.7	-2.0	-2.5	-1.5	-2.6	-2.13
A46	-3.2	-2.9	-2.7	-2.7	-2.8	-3.0	-3.2	-3.1	-3.5	-3.7	-3.7	-3.7	-3.7	-3.4	-1.9	-3.6	-3.9	-3.9	-3.1	-4.1	-3.2	-2.8	-3.26
A47	-6.8	-1.8	-5.2	-3.2	-5.5	-2.6	-8.8	-4.6	-8.7	-4.3	-6.5	-5.1	-5.4	-5.7	-8.4	-6.0	-9.2	-4.1	-6.7	-6.4	-6.6	-2.8	-5.64
A48	-2.5	-2.9	-3.2	-2.9	-3.1	-3.4	-3.4	-2.3	-6.0	-5.0	-8.6	-5.4	-5.5	-4.8	-5.3	-3.9	-5.2	-1.6	-4.0	-2.3	-8.5	-5.2	-4.32
A49	-6.7	-7.3	-6.1	-3.5	-6.6	-5.3	-8.5	-5.4	-9.1	-7.6	-8.6	-8.0	-8.7	-7.8	-0.6	-6.9	-3.1	-7.0	-6.1	-9.2	-6.6	-7.9	-6.66
A50	-3.5	-3.0	-3.5	-3.3	-3.2	-5.0	-5.4	-4.9	-3.3	-2.3	-4.4	-3.8	-4.6	-4.9	-1.6	-4.5	-4.6	-3.2	-4.8	-2.2	-3.6	-3.1	-3.74
A51	-6.9	-2.2	-3.8	-4.3	-2.8	-3.7	-2.4	-2.8	-4.6	-4.7	-3.8	-3.1	-3.2	-6.1	-7.3	-6.2	-5.3	-5.5	-6.1	-5.1	-5.4	-6.3	-4.62
A52	-2.3	-2.8	-2.9	-1.9	-1.9	-2.8	-2.5	-2.6	-2.2	-2.1	-4.0	-2.5	-2.8	-4.3	-2.0	-4.5	-2.4	-5.1	-3.1	-6.8	-6.7	-6.7	-3.41
A53	-2.7	-3.6	-2.9	-2.7	-2.9	-3.3	-2.7	-4.0	-2.8	-3.5	-4.7	-3.1	-5.3	-3.1	-4.5	-3.0	-5.0	-2.6	-3.5	-3.1	-2.7	-2.7	-3.38
A54	-4.4	-3.0	-3.1	-2.9	-3.3	-3.1	-5.9	-3.3	-2.7	-3.1	-4.6	-4.9	-3.1	-4.3	-3.5	-3.9	-3.8	-2.5	-2.5	-3.3	-1.1	-4.6	-3.49
A55	-4.7	-6.6	-5.5	-6.7	-4.5	-4.3	-2.1	-4.5	-3.4	-5.1	-3.8	-5.5	-4.3	-5.5	-3.9	-5.7	-3.8	-4.6	-5.5	-4.2	-6.3	-4.9	-4.80
A56	-3.7	-2.5	-3.4	-2.4	-1.8	-4.2	-2.8	-4.5	-3.0	-5.8	-4.7	-5.3	-2.0	-5.6	-3.7	-6.5	-4.0	-4.2	-4.8	-4.6	-4.9	-5.4	-4.06
A57	-3.4	-1.7	-0.6	-3.9	-2.7	-2.4	-3.4	-2.4	-4.1	-0.8	-3.1	-2.0	-4.0	-1.1	-3.1	-1.0	-4.8	-10.0	-3.1	-5.5	-3.3	-5.4	-3.26
A58	-4.7	-3.6	-5.3	-2.7	-4.9	-5.5	-2.9	-7.4	-2.4	-4.8	-2.9	-7.0	-5.4	-7.0	-6.4	-7.3	-3.8	-3.9	-2.6	-3.3	-3.0	-5.3	-4.64
A59	-3.0	-3.2	-1.7	-3.0	-4.0	-3.4	-4.0	-3.7	-4.0	-3.9	-4.5	-3.5	-3.7	-4.4	-4.5	-4.3	-2.4	-2.1	-4.1	-3.3	-3.0	-3.9	-3.51
A60	-6.5	-1.7	-4.7	0.2	-4.5	1.1	-4.5	2.4	-6.0	1.7	-2.9	2.0	-6.5	1.0	-7.2	0.5	-4.6	-0.4	-4.4	-4.3	0.6	-7.4	-2.54

Note: The surface profile was taken from a levelled arbitrary line above the roughened face of the rib (hence they are negative) between 100 to 120 mm segment.

Annexure D4 – Surface profile for ribs B1 to B20 (mm)

Beam	Surface profile (mm)																						Average
B1	-3.2	-2.5	-2.7	-2.5	-3.2	-3.6	-3.5	-2.1	-4.4	-3.9	-2.8	-3.2	-5.0	-5.0	-3.5	-4.3	-1.9	-4.4	-3.0	-4.3	-0.2	-4.4	-3.34
B2	-4.5	-4.9	-2.7	-3.4	-2.4	-3.4	-3.3	-3.7	-3.5	-1.8	-3.3	-2.6	-2.6	-2.8	-2.6	-2.1	-2.0	-2.2	-1.2	-0.8	-1.9	-2.4	-2.72
B3	-1.7	-1.6	-2.2	-2.7	-2.9	-2.7	-2.3	-2.4	-2.9	-2.4	-2.6	-2.8	-2.4	-2.9	-2.1	-2.3	-2.4	-2.5	-2.8	-2.1	-2.4	-1.6	-2.39
B4	-2.5	-2.4	-2.5	-2.6	-3.9	-4.4	-2.5	-4.3	-3.4	-5.7	-4.7	-4.1	-3.6	-3.2	-3.5	-3.0	-3.0	-3.1	-3.3	-2.4	-3.4	-3.5	-3.40
B5	-3.4	-4.0	-4.6	-3.6	-4.4	-4.3	-3.1	-3.7	-3.6	-2.9	-3.4	-4.8	-2.8	-4.0	-4.0	-3.6	-4.5	-4.5	-4.4	-4.8	-4.6	-4.8	-3.99
B6	-5.7	-6.4	-6.3	-5.9	-5.4	-4.7	-2.7	-6.4	-5.2	-4.7	-6.1	-1.4	-5.8	-3.2	-5.1	-3.1	-5.1	-4.3	-4.5	-4.0	-4.2	-3.8	-4.71
B7	-4.2	-3.0	-3.0	-3.7	-3.7	-4.1	-4.5	-3.6	-3.5	-2.8	-3.1	-4.0	-3.3	-3.5	-3.4	-3.9	-4.1	-2.7	-3.8	-3.7	-3.0	-3.2	-3.54
B8	-3.1	-3.2	-3.5	-3.2	-3.4	-3.5	-2.3	-3.4	-1.7	-3.5	-3.2	-3.4	-3.6	-3.0	-3.1	-3.0	-3.6	-3.1	-3.2	-2.4	-2.7	-2.2	-3.05
B9	-2.6	-2.8	-1.8	-2.0	-2.3	-2.2	-2.3	-2.3	-1.0	-1.7	-2.1	-2.7	-2.3	-2.1	-2.3	-2.2	-2.3	-2.4	-2.4	-2.2	-1.9	-1.2	-2.13
B10	-4.0	-1.8	-2.5	-3.8	-3.7	-4.6	-4.3	-4.8	-4.8	-4.9	-5.1	-4.9	-4.9	-4.5	-4.8	-5.8	-3.4	-4.4	-4.5	-7.6	-8.1	-5.1	-4.65
B11	-3.6	-3.2	-2.3	-2.7	-2.8	-3.2	-3.2	-3.2	-3.3	-3.2	-4.0	-4.4	-4.0	-3.9	-6.0	-5.9	-4.6	-5.4	-6.2	-6.2	-5.8	-5.1	-4.19
B12	-10.7	-10.8	-10.8	-8.0	-8.2	-8.7	-9.2	-9.4	-8.6	-9.1	-10.3	-11.2	-10.0	-10.3	-11.5	-12.9	-12.0	-11.0	-10.9	-11.0	-11.0	-11.4	-10.32
B13	-3.1	-3.0	-3.4	-3.4	-1.8	-3.2	-3.2	-2.7	-2.4	-2.4	-2.4	-3.1	-1.9	-3.2	-2.8	-1.2	-2.6	-2.5	-2.2	-2.2	-2.9	-2.0	-2.60
B14	-2.1	-2.9	-2.6	-2.7	-1.5	-2.3	-2.7	-2.0	-2.3	-2.5	-3.0	-2.3	-2.3	-2.0	-3.0	-2.4	-2.5	-2.8	-2.7	-1.9	-2.5	-2.3	-2.43
B15	-2.0	-1.9	-1.5	-2.6	-2.4	-2.6	-2.5	-2.4	-1.9	-2.1	-2.1	-2.1	-1.8	-2.5	-1.7	-1.6	-2.0	-1.5	-2.2	-2.2	-1.9	-2.2	-2.06
B16	-3.1	-3.6	-2.5	-2.2	-2.7	-2.7	-3.0	-3.6	-3.6	-3.7	-3.3	-3.8	-2.8	-2.4	-2.9	-2.8	-2.9	-3.1	-2.6	-2.2	-3.1	-2.7	-2.96
B17	-2.7	-2.5	-2.6	-3.2	-2.6	-3.1	-2.4	-3.4	-2.5	-2.4	-3.1	-3.2	-3.5	-3.3	-3.3	-2.4	-2.1	-1.4	-2.5	-1.8	-3.1	-4.0	-2.77
B18	-2.1	-1.8	-1.6	-1.8	-1.7	-1.6	-1.9	-1.8	-1.4	-1.6	-2.2	-2.0	-2.6	-1.6	-1.9	-1.2	-1.9	-1.5	-1.7	-1.7	-1.6	-1.4	-1.74
B19	-4.5	-4.2	-3.2	-3.4	-4.9	-3.9	-4.9	-5.5	-4.3	-6.0	-5.2	-6.2	-5.2	-4.4	-6.4	-6.3	-6.9	-5.2	-4.4	-3.6	-6.4	-5.9	-5.05
B20	-2.9	-2.3	-4.2	-3.5	-3.8	-3.0	-1.8	-2.1	-2.0	-2.3	-2.2	-2.1	-2.6	-2.4	-3.8	-2.4	-3.0	-1.8	-1.2	-1.8	-4.2	-1.6	-2.59

Note: The surface profile was taken from a levelled arbitrary line above the roughened face of the rib (hence they are negative) between 100 to 120 mm segment.

Annexure D5 – Surface profile for ribs B21 to B40 (mm)

Beam	Surface profile (mm)																					Average
B21	-4.3	-4.2	-4.0	-4.3	-5.3	-4.6	-4.0	-3.4	-3.9	-4.3	-4.2	-4.0	-4.6	-4.6	-4.5	-4.4	-4.2	-4.2	-4.3	-4.2	-3.9	-3.8	-4.23
B22	-2.3	-1.5	-2.4	-3.8	-3.0	-2.6	-6.8	-7.5	-7.7	-5.8	-4.0	-4.9	-5.7	-8.0	-8.0	-5.2	-4.4	-5.5	-5.5	-5.0	-5.6	-4.9	-4.99
B23	-3.5	-3.1	-2.6	-2.8	-1.7	-2.4	-2.9	-2.5	-3.0	-2.6	-2.6	-2.2	-2.1	-1.8	-2.6	-2.9	-2.4	-3.0	-3.2	-2.9	-2.5	-2.0	-2.60
B24	-5.4	-2.8	-5.7	-5.5	-4.1	-5.2	-5.4	-5.5	-5.6	-5.3	-5.3	-5.0	-5.3	-5.1	-5.4	-5.2	-4.2	-5.0	-5.1	-4.6	-5.0	-5.1	-5.04
B25	-4.2	-2.9	-5.0	-5.6	-3.3	-3.2	-6.2	-5.5	-3.6	-3.5	-3.4	-4.0	-2.5	-3.5	-3.6	-3.7	-3.4	-3.2	-3.6	-2.3	-2.2	-2.6	-3.67
B26	-5.1	-5.1	-4.9	-4.8	-4.8	-5.1	-4.3	-3.1	-5.2	-4.0	-4.7	-4.0	-3.9	-4.1	-3.6	-3.9	-3.6	-3.5	-3.9	-3.7	-4.0	-3.0	-4.18
B27	-4.0	-2.9	-4.7	-3.3	-3.6	-3.3	-3.4	-4.1	-3.4	-3.1	-3.2	-4.0	-3.7	-2.8	-3.3	-4.8	-3.1	-4.3	-3.3	-3.7	-4.1	-4.5	-3.66
B28	-4.6	-3.9	-4.4	-4.2	-4.4	-4.8	-3.7	-3.1	-4.2	-2.9	-3.1	-3.9	-2.8	-3.2	-3.3	-3.0	-3.6	-3.6	-3.0	-4.0	-3.4	-4.1	-3.68
B29	-4.0	-3.5	-3.8	-2.2	-3.1	-3.0	-3.4	-3.4	-3.6	-3.3	-3.7	-3.6	-3.2	-3.3	-3.3	-2.3	-3.4	-3.3	-3.5	-3.0	-3.2	-3.1	-3.28
B30	-3.6	-4.1	-3.0	-2.6	-3.2	-3.2	-3.5	-3.7	-3.4	-3.1	-3.1	-2.7	-4.0	-4.4	-4.2	-3.3	-2.7	-2.8	-3.4	-2.4	-4.2	-2.5	-3.31
B31	-4.5	-4.2	-8.3	-6.1	-4.7	-3.7	-4.2	-5.2	-6.7	-5.2	-4.5	-5.4	-4.5	-3.9	-4.1	-3.1	-4.0	-2.5	-3.3	-2.3	-4.1	-3.3	-4.45
B32	-6.1	-5.7	-6.3	-6.0	-5.7	-6.6	-6.7	-5.7	-5.5	-4.8	-2.6	-4.4	-1.7	-5.5	-4.5	-5.3	-3.5	-4.8	-4.4	-4.2	-4.3	-3.6	-4.90
B33	-4.3	-3.4	-3.0	-4.3	-4.6	-3.9	-2.1	-5.4	-4.0	-3.2	-4.7	-4.9	-4.7	-1.4	-3.5	-4.9	-2.2	-3.6	-3.5	-3.4	-1.7	-3.1	-3.62
B34	-3.9	-4.2	-3.1	-2.5	-3.6	-3.7	-3.5	-3.1	-3.2	-2.6	-2.2	-1.0	-0.8	-1.7	-3.4	-3.9	-3.5	-4.3	-4.3	-3.9	-3.6	-3.5	-3.15
B35	-3.4	-3.0	-2.9	-3.8	-2.9	-2.9	-2.3	-3.6	-4.0	-4.4	-3.7	-1.8	-2.3	-4.1	-4.1	-4.4	-4.4	-5.1	-4.2	-4.6	-1.7	-3.7	-3.51
B36	-5.3	-4.8	-6.4	-5.2	-2.9	-3.9	-5.0	-5.1	-5.9	-5.8	-5.8	-5.3	-4.4	-4.2	-5.0	-4.4	-4.1	-3.7	-3.4	-2.8	-3.4	-2.8	-4.53
B37	-5.9	-4.5	-4.9	-4.8	-5.0	-5.8	-5.6	-5.0	-6.9	-5.8	-5.3	-6.2	-6.5	-6.5	-6.5	-6.1	-6.1	-5.5	-5.1	-5.8	-5.6	-5.7	-5.69
B38	-3.6	-3.5	-3.5	-3.5	-3.5	-3.2	-3.4	-3.5	-3.1	-3.1	-3.3	-3.3	-3.2	-2.8	-2.0	-3.1	-2.8	-2.9	-2.6	-2.1	-2.2	-2.1	-3.01
B39	-4.8	-4.8	-6.9	-2.1	-2.3	-1.4	-2.3	-4.4	-4.4	-4.4	-4.0	-3.9	-3.9	-3.9	-3.6	-2.2	-2.3	-2.1	-1.9	-12.3	-5.6	-5.6	-4.05
B40	-10.5	-7.8	-8.0	-7.5	-5.8	-4.4	-3.8	-2.8	-2.5	-3.6	-3.4	-2.7	-2.8	-2.9	-3.9	-3.3	-3.3	-3.5	-2.9	-3.2	-3.3	-3.5	-4.33

Note: The surface profile was taken from a levelled arbitrary line above the roughened face of the rib (hence they are negative) between 100 to 120 mm segment.

Annexure D6 – Surface profile for ribs B41 to B60 (mm)

Beam	Surface profile (mm)																						Average
B41	-2.6	-2.7	-2.2	-0.4	-1.9	-2.2	-2.7	-1.8	-2.9	-3.9	-3.6	-4.1	-4.0	-3.9	-3.4	-3.2	-2.2	-3.5	-2.3	-1.7	-1.2	-2.3	-2.66
B42	-3.7	-3.9	-3.9	-3.2	-2.2	-2.1	-3.2	-2.0	-2.3	-3.7	-2.6	-2.6	-3.3	-3.2	-3.7	-3.2	-3.2	-3.3	-3.1	-1.9	-2.7	-2.8	-2.98
B43	-1.7	-2.5	-2.8	-1.1	-2.2	-2.3	-3.3	-4.3	-2.5	-2.2	-4.5	-3.2	-3.5	-3.4	-3.3	-2.8	-3.5	-3.1	-2.5	-4.2	-4.8	-3.8	-3.06
B44	-5.8	-2.4	-2.8	-4.3	-4.5	-3.0	-1.4	-3.2	-2.4	-2.7	-2.5	-3.2	-3.8	-4.8	-4.8	-5.6	-5.2	-4.6	-4.3	-6.1	-4.7	-4.1	-3.92
B45	-2.2	-1.9	-2.1	-2.5	-3.1	-3.0	-2.3	-2.9	-1.8	-2.1	-2.0	-1.8	-2.4	-2.7	-2.6	-2.0	-2.3	-1.6	-1.2	-1.7	-2.7	-2.9	-2.26
B46	-3.9	-5.4	-5.4	-4.5	-5.6	-6.9	-7.4	-7.3	-3.8	-5.6	-5.8	-5.3	-5.6	-5.1	-5.9	-5.9	-5.1	-4.8	-4.9	-5.5	-5.8	-6.4	-5.54
B47	-3.9	-4.1	-2.6	-0.6	-4.5	-4.7	-4.5	-2.5	-1.5	-1.6	-2.0	-2.2	-2.2	-2.4	-2.4	-2.7	-2.7	-2.6	-2.6	-2.0	-1.6	-1.3	-2.60
B48	-3.3	-3.7	-5.0	-4.5	-3.0	-2.3	-1.3	-4.1	-3.5	-2.0	-2.5	-3.6	-3.8	-1.7	-4.6	-3.2	-2.4	-4.1	-2.7	-3.5	-4.0	-3.0	-3.26
B49	-3.4	-3.7	-3.3	-3.4	-3.5	-3.8	-3.7	-3.7	-3.4	-3.8	-3.8	-3.4	-4.1	-4.0	-3.8	-3.3	-3.7	-3.3	-4.7	-4.7	-4.9	-5.0	-3.84
B50	-1.9	-1.2	-1.4	-2.4	-2.1	-2.0	-2.1	-3.1	-0.9	-1.6	-3.0	-2.7	-2.8	-2.8	-2.9	-3.0	-2.7	-2.4	-3.1	-2.9	-2.2	-3.0	-2.37
B51	-3.3	-3.0	-2.7	-3.5	-3.3	-3.8	-4.2	-3.8	-3.5	-3.4	-3.5	-3.3	-3.3	-3.5	-3.1	-2.9	-2.9	-2.4	-3.8	-3.0	-3.2	-3.0	-3.29
B52	-2.7	-2.9	-3.8	-3.9	-4.3	-4.6	-4.9	-5.1	-5.1	-5.1	-4.1	-4.4	-4.7	-3.9	-4.8	-3.8	-3.4	-3.8	-3.9	-3.8	-4.3	-3.7	-4.13
B53	-4.6	-3.4	-3.2	-5.4	-3.9	-5.2	-3.4	-5.1	-5.3	-6.2	-4.1	-4.2	-6.0	-6.0	-4.4	-5.0	-3.7	-3.3	-3.0	-4.5	-5.0	-4.4	-4.51
B54	-5.2	-5.3	-4.6	-5.0	-4.5	-4.7	-4.8	-4.6	-4.5	-4.2	-3.1	-3.9	-5.1	-3.7	-3.8	-3.7	-4.3	-4.1	-4.5	-3.8	-2.6	-4.9	-4.31
B55	-2.4	-2.3	-1.0	-1.3	-1.5	-1.5	-1.2	-1.8	-1.2	-1.9	-1.9	-1.8	-1.8	-1.3	-2.3	-2.3	-1.9	-1.2	-1.7	-1.8	-1.7	-1.8	-1.71
B56	-3.3	-1.8	-4.1	-5.8	-5.1	-4.7	-5.5	-5.4	-4.3	-4.4	-4.1	-3.9	-2.7	-4.8	-4.4	-5.7	-5.8	-3.4	-5.1	-3.3	-4.8	-5.0	-4.43
B57	-2.8	-3.0	-2.7	-2.9	-3.2	-3.9	-3.8	-4.0	-3.8	-4.2	-4.4	-4.9	-3.8	-4.1	-5.2	-4.5	-4.8	-3.1	-2.3	-2.2	-2.2	-3.0	-3.57
B58	-2.5	-2.8	-2.9	-3.6	-3.6	-3.7	-4.4	-4.3	-4.2	-4.9	-5.3	-4.8	-5.3	-4.8	-2.8	-2.9	-4.5	-5.3	-4.9	-3.9	-3.0	-3.3	-3.98
B59	-4.3	-4.6	-3.3	-3.3	-3.8	-3.3	-3.7	-2.9	-3.5	-3.0	-2.5	-3.4	-3.6	-4.5	-3.3	-3.3	-3.4	-3.5	-4.0	-3.8	-4.1	-4.2	-3.60
B60	-1.5	-6.2	1.3	-4.8	0.4	-6.7	-0.6	-4.8	0.5	-5.3	0.1	-4.2	-0.5	-3.6	0.5	-4.8	-0.3	-4.9	-0.5	-4.2	-1.2	-7.2	-2.66

Note: The surface profile was taken from a levelled arbitrary line above the roughened face of the rib (hence they are negative) between 100 to 120 mm segment.

Annexure E1 – Interface inspection for uniformity, frequency and laitance for beams A1 to A20

	Level of uniformity					Variation in frequency			Laitance			
Beam	Very poor (-2)	Poor (-1)	Neutral (0)	Good (1)	Very good (2)	Low (1)	Medium (2)	High (3)	Invisible (0)	Low (1)	Medium (2)	High (3)
A1					2		2			1		
A2				1		1				1		
A3					2	1				1		
A4		-1				1					2	
A5					2	1			0			
A6		-1					2		0			
A7					2			3	0			
A8				1		1					2	
A9					2	1				1		
A10				1				3		1		
A11				1			2			1		
A12				1			2		0			
A13				1			2			1		
A14					2	1			0			
A15					2	1			0			
A16					2		2		0			
A17					2	1			0			
A18					2	1			0			
A19				1				3		1		
A20					2	1			0			

Annexure E2 – Interface inspection for uniformity, frequency and laitance for beams A21 to A40

	Level of uniformity					Variation in frequency			Laitance			
Beam	Very poor (-2)	Poor (-1)	Neutral (0)	Good (1)	Very good (2)	Low (1)	Medium (2)	High (3)	Invisible (0)	Low (1)	Medium (2)	High (3)
A21				1			2			1		
A22			0					3			2	
A23					2	1			0			
A24			0					3		1		
A25				1				3			2	
A26		-1					2				2	
A27		-1					2				2	
A28			0				2				2	
A29		-1						3		1		
A30		-1					2		0			
A31		-1						3	0			
A32	-2						2				2	
A33					2	1			0			
A34					2	1			0			
A35				1			2				2	
A36		-1						3			2	
A37					2	1			0			
A38				1			2				2	
A39					2	1			0			
A40					2		2		0			

Annexure E3 – Interface inspection for uniformity, frequency and laitance for beams A41 to A60

	Level of uniformity					Variation in frequency			Laitance			
Beam	Very poor (-2)	Poor (-1)	Neutral (0)	Good (1)	Very good (2)	Low (1)	Medium (2)	High (3)	Invisible (0)	Low (1)	Medium (2)	High (3)
A41					2	1				1		
A42					2	1				1		
A43				1			2				2	
A44		-1				1					2	
A45				1		1					2	
A46			0			1					2	
A47					2		2		0			
A48		-1						3			2	
A49					2		2		0			
A50					2	1				1		
A51	-2							3		1		
A52					2		2		0			
A53			-1			1					2	
A54				1			2				2	
A55				1			2			1		
A56				1			2		0			
A57					2		2			1		
A58				1			2			1		
A59				1		1					2	
A60					2	1			0			

Annexure E4 – Interface inspection for uniformity, frequency and laitance for beams B1 to B20

	Level of uniformity					Variation in frequency			Laitance			
Beam	Very poor (-2)	Poor (-1)	Neutral (0)	Good (1)	Very good (2)	Low (1)	Medium (2)	High (3)	Invisible (0)	Low (1)	Medium (2)	High (3)
B1					2	1					2	
B2					2	1					2	
B3					2	1					2	
B4				1			2				2	
B5		-1					2				2	
B6			0			1					2	
B7			0			1					2	
B8				1		1					2	
B9					2	1					2	
B10	-2							3			2	
B11				1		1						3
B12	-2							3				3
B13				1			2				2	
B14					2	1					2	
B15					2	1					2	
B16					2	1					2	
B17					2	1					2	
B18					2	1					2	
B19					2	1					2	
B20				1			2					3

Annexure E5 – Interface inspection for uniformity, frequency and laitance for beams B21 to B40

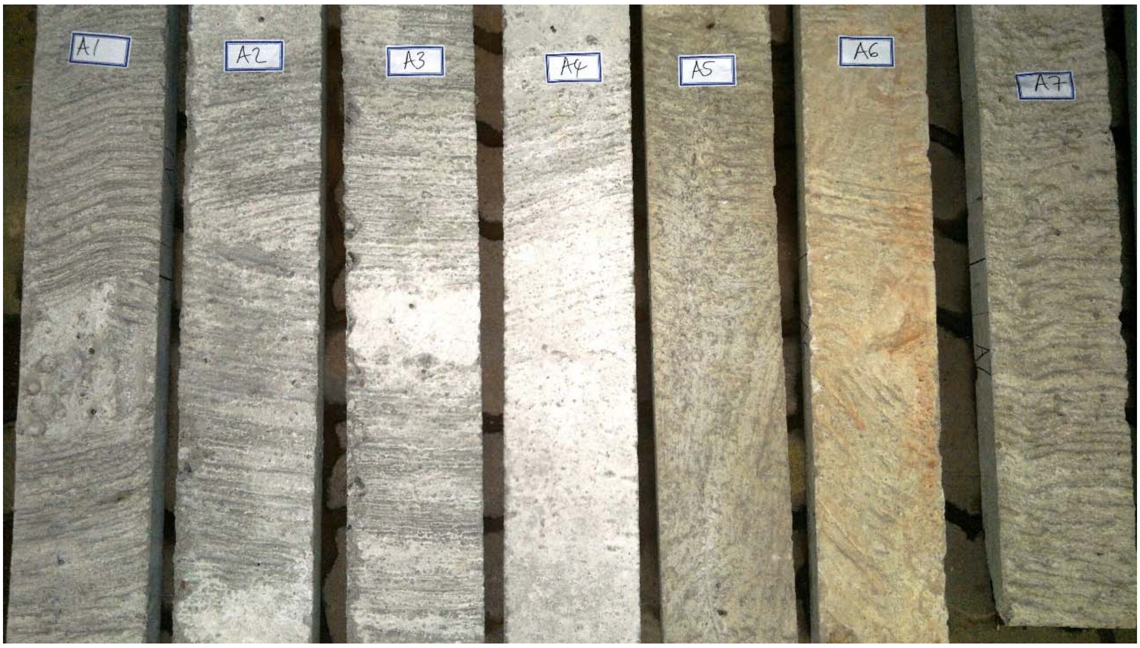
	Level of uniformity					Variation in frequency			Laitance			
Beam	Very poor (-2)	Poor (-1)	Neutral (0)	Good (1)	Very good (2)	Low (1)	Medium (2)	High (3)	Invisible (0)	Low (1)	Medium (2)	High (3)
B21			0				2					3
B22				1			2				2	
B23				1			2				2	
B24				1		1					2	
B25		-1					2				2	
B26			0			1					2	
B27			0					3				3
B28				1			2				2	
B29					2	1				1		
B30		-1					2				2	
B31				1			2				2	
B32	-2						2				2	
B33				1		1				1		
B34		-1				1						3
B35				1		1					2	
B36		-1					2				2	
B37				1		1				1		
B38		-1					2			1		
B39		-1					2				2	
B40	-2							3				3

Annexure E6 – Interface inspection for uniformity, frequency and laitance for beams B41 to B60

	Level of uniformity					Variation in frequency			Laitance			
Beam	Very poor (-2)	Poor (-1)	Neutral (0)	Good (1)	Very good (2)	Low (1)	Medium (2)	High (3)	Invisible (0)	Low (1)	Medium (2)	High (3)
B41	-2						2					3
B42	-2						2					3
B43				1		1						3
B44			0				2					3
B45				1			2					3
B46		-1					2					3
B47			0					3				3
B48				1			2					3
B49				1		1					2	
B50			0			1						3
B51					2	1						3
B52		-1				1						3
B53		-1					2					3
B54					2	1						3
B55			0				2					3
B56		-1						3				3
B57	-2						2					3
B58		-1						3				3
B59		-1					2					3
B60					2	1						3
Totals	9	23	14	35	39	53	49	18	23	22	49	26

Note: beam A60 and B60 were not available at the time of photograph

Annexure F1 – Interface profiles for beams A1 to A7



Annexure F2 – Interface profiles for beams A7 to A9

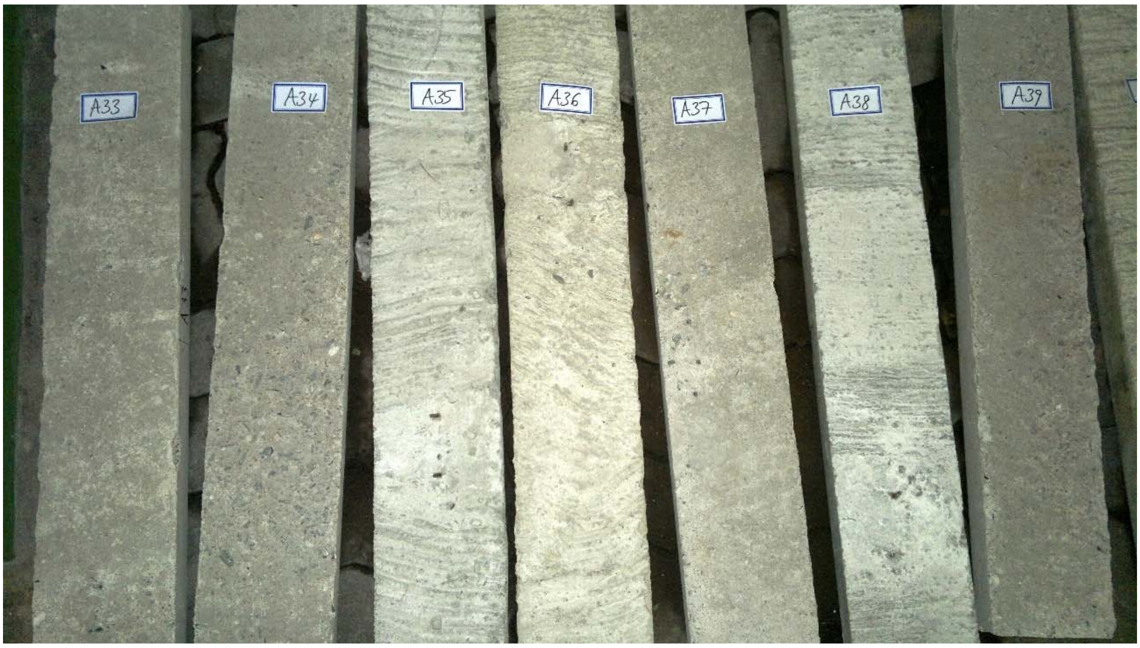
Annexure F3 – Interface profiles for beams A10 to A16

Annexure F4 – Interface profiles for beams A16 to A21

Annexure F5 – Interface profiles for beams A22 to A27

Annexure F6 – Interface profiles for beams A28 to A32

Annexure F7 – Interface profiles for beams A33 to A39



Annexure F8 – Interface profiles for beams A38 to A44

Annexure F9 – Interface profiles for beams A45 to A52

Annexure F10 – Interface profiles for beams A51 to A59

Annexure F11 – Interface profiles for beams B1 to B10

Annexure F12 – Interface profiles for beams B11 to B22

Annexure F13 – Interface profiles for beams B20 to B30

Annexure F14 – Interface profiles for beams B31 to B43

Annexure F15 – Interface profiles for beams B44 to B59

Annexure G – Mix 1 concrete cube test results

Casting Date	23-Nov-13		
Testing date	30-Nov-13		
Days Testing	**7**		
Sample No.	A1	B1	C1
Mass (kg)	2.375	2.385	2.412
Height (mm)	100	100	101
Width (mm)	101	101	100
Breath (mm)	102	103	102
f_{cu} (N/mm²)	27.6	25.3	24
Force at Failure (kN)	283.1	239.4	291.5
Average fcu	25.6		

Casting Date	23-Nov-13		
Testing date	07-Dec-13		
Days Testing	**14**		
Sample No.	G1	H1	I1
Mass (kg)	2.353	2.391	2.369
Height (mm)	100	100	101
Width (mm)	101	104	101
Breath (mm)	102	101	101
fcu (N/mm²)	27	24.4	29
Force at Failure (kN)	269.5	244	289.6
Average fcu	26.8		

Casting Date	23-Nov-13		
Testing date	03-Dec-13		
Days Testing	**10**		
Sample No.	D1	E1	F1
Mass (kg)	2.388	2.363	2.409
Height (mm)	100	100	100
Width (mm)	101	101	100
Breath (mm)	100	100	102
fcu (N/mm²)	25.4	25.5	26.4
Force at Failure (kN)	254	255.2	264.3
Average fcu	25.8		

Casting Date	23-Nov-13		
Testing date	21-Dec-13		
Days Testing	**28**		
Sample No.	J1	K1	L1
Mass (kg)	2.382	2.392	2.365
Height (mm)	101	101	100
Width (mm)	101	101	101
Breath (mm)	101	103	102
fcu (N/mm²)	34.7	27.3	27.8
Force at Failure (kN)	346.5	273.2	277.8
Average fcu	29.9		

Annexure H – Mix 2 concrete cube test results

Casting Date	08-Dec-13		
Testing date	11-Dec-13		
Days Testing	**3**		
Sample No.	A2	B2	C2
Mass (kg)	2.379	2.357	2.329
Height (mm)	102	99	100
Width (mm)	98	99	100
Breath (mm)	101	103	100
fcu (N/mm²)	22	16	14
Force at Failure (kN)	219.9	159.9	140.3
Average fcu	17.3		

Casting Date	08-Dec-13		
Testing date	18-Dec-13		
Days Testing	**10**		
Sample No.	J2	K2	L2
Mass (kg)	2.393	2.398	2.411
Height (mm)	100	100	100
Width (mm)	100	100	102
Breath (mm)	100	102	102
fcu (N/mm²)	22.2	31	23.9
Force at Failure (kN)	221.8	309.6	239.1
Average fcu	25.7		

Casting Date	08-Dec-13		
Testing date	12-Dec-13		
Days Testing	**4**		
Sample No.	D2	E2	F2
Mass (kg)	2.351	2.364	2.37
Height (mm)	99	100	100
Width (mm)	100	101	100
Breath (mm)	101	100	100
fcu (N/mm²)	22.6	16.8	17.5
Force at Failure (kN)	225.6	168.3	174.8
Average fcu	19.0		

Casting Date	08-Dec-13		
Testing date	22-Dec-13		
Days Testing	**14**		
Sample No.	M2	N2	O2
Mass (kg)	2.405	2.396	2.33
Height (mm)	101	102	100
Width (mm)	102	100	100
Breath (mm)	102	104	100
fcu (N/mm²)	27.4	31.6	28.3
Force at Failure (kN)	274	315.6	283
Average fcu	29.1		

Casting Date	08-Dec-13		
Testing date	13-Dec-13		
Days Testing	**5**		
Sample No.	G2	H2	I2
Mass (kg)	2.355	2.362	2.399
Height (mm)	100	100	100
Width (mm)	100	100	100
Breath (mm)	102	100	102
fcu (N/mm²)	22.6	14.6	21.2
Force at Failure (kN)	226.3	145.8	21.2
Average fcu	19.5		

Casting Date	08-Dec-13		
Testing date	05-Jan-14		
Days Testing	**28**		
Sample No.	P2	Q2	R2
Mass (kg)	2.386	2.393	2.399
Height (mm)	102	101	101
Width (mm)	100	100	100
Breath (mm)	102	102	101
fcu (N/mm²)	30.3	26.8	37.7
Force at Failure (kN)	303.3	267.6	376.7
Average fcu	31.6		