

Quality Assurance and Recommended Connections of Prestressed Hollow Core Slabs

Summary

Prestressed concrete slabs in the form of hollow core floors are the most widely used system of precast flooring in Malta. They have been used for nearly 30 years, starting off in a relatively modest way, the first slabs being 100mm and 200mm thick. Their use was mostly aimed for the terraced houses and apartment blocks. Since then much larger sections have been made available which make for more ambitious use and consequently more importance is to be attached to the performance of these elements and the structure as a whole.

Introduction

The performance of the finished product is dependant on:

- A. The quality of the product itself (Quality Assurance) and
- B. The manner in which it is used, i.e. the way the precast element is fitted in within the whole structure (Connections).

This paper will focus on these two aspects.

I believe that the following guidelines for a quality assurance programme should be made familiar to producers, civil engineers, building contractors and everyone connected with the building industry to ensure an improved quality product.

A. QUALITY ASSURANCE

1. FACTORY PRODUCTION CONTROL REQUIREMENTS

The management's policy and objectives should be for the commitment to quality. It should ensure that this policy is understood, implemented and maintained at all levels in the organisation.

Responsibility and Authority

The responsibility, authority and the interrelation of all personnel who manage, perform and verify work-affecting quality should be defined, particularly for personnel who need the organisational freedom and authority to:

- Initiate action to prevent the occurrence of product non-conformity
- Identify and record any product quality problems
- Initiate, recommend or provide solutions to quality problems through designated channels
- Verify the implementation of solutions
- Control further processing, delivery or installation of nonconforming product until the deficiency or unsatisfactory condition has been corrected

Management Representative of Factory Production Control (MRFP)

The manufacturer must appoint a person who should have appropriate authority, knowledge and experience of the production of the products to be responsible for conducting and supervising factory control procedures and ensuring that the requirements given in these rules are implemented and maintained. The representative should conduct and supervise that documentation needed for monitoring and controlling product conformity is made up, approved, established, maintained and adequately renewed, when required. He should, on behalf of the management, supervise that production control system according to documentation is implemented and maintained.

2. MANAGEMENT REVIEW

On a regular basis, at least once a year, the representative should present to the management a report from a review of the production control system, made to ensure the continuing stability and effectiveness of the system.

The review should be based on internal and external audits- including design reviews if applicable, and should be summed up at a meeting, where apart from the representative assigned persons from management and from sales and marketing, structural engineering, economy and operational divisions should attend. Reviews should be made on schedule and furthermore when needed.

The review should at least cover the following aspects:

- Results and assessment of internal and external audits
- Manufacturing problems
- Supplier problems
- Customers complaints
- Production control system development
- Training
- Trend analysis (including the cost of quality)
- Proposals for improvements and future developments

3. QUALITY SYSTEM

The manufacturer should establish, implement and maintain a documented factory production control system as a means of ensuring that the products conform to this standard, in a works quality manual.

In the Quality Manual the manufacturer should describe:

- The quality policy at the plant
- A list of specifications for properties of raw and constituent materials, concrete mix, steel bars and tendons, testing methods in standards etc. and how conformity to specifications should be verified by the suppliers.
- An organisational ‘ block scheme’, showing the structure of the quality-affecting organisation from top management position downwards. The responsibilities, authorities and duties of every position in the scheme should be clearly identified.

- A brief description of important steps in the production process, from design, preparation of the beds to storing outdoors, preferably in the form of a flow-chart. Reference should be made to written work instructions, or established manuals, standard methods

The following elements during the production process have to be considered when detailing procedures and instructions:

- If applicable, procedures for reviewing and approving incoming drawings and other manufacturing data, as to their confirmation by a responsible competent person, and their feasibility and adaptation for production.
- If applicable, procedures for in-house design control, including confirmation of drawings and other manufacturing data by an assigned competent person, and design verification measures.
- Procedures for production changes in relation to drawings and revisions of drawings.
- Safety measures
- Batching operations
- Preparation of beds
- Tensioning and anchoring
- Castings
- Curing
- Additional works on the slabs
- Inspection preceding detensioning
- Detensioning and cutting
- Identifying and marking of slabs on the bed
- Lifting and transport
- Storing
- Procedure for handling and processing rejected slabs
- Exchange information to and from the customer, on safety related matters, which may influence the procedure for lifting and placing on the building site

Additional inspecting and testing operations for consideration are:

- Receiving inspection and testing incoming constituent components from suppliers, to ensure their quality performance documentation conforms to the appropriate product specification.
- Selection and handling of concrete test specimens and of full-scale load test specimens
- Preparation and testing of the specimens, recording of test results
- Checking of slab ends, for strand slippage and imperfections
- Measuring of dimensions and of the positioning of the strands
- An inspection, calibration and testing scheme
- Documented procedures for control of nonconforming products, for corrective actions, for handling, storage, and delivery of products, for quality record.
- Documented procedures for training of personnel, with reference to records of training

4. INSPECTION AND TESTING

All necessary facilities, equipment and personnel should be available to carry out inspections, calibrations, measuring and tests. The manufacturer may subcontract parts of these activities, in which case he should make sure that the subcontractor will have the necessary facilities, equipment and personnel. It should always be the manufacturer's responsibility that inspection, measuring and testing will be carried out, even if subcontracted, and that the equipment will be controlled, calibrated and maintained, even if another party owns it.

The equipment should be used with regard to a known measurement uncertainty. This should be consistent with the required measurement capability traceable to National Standards.

Inspection and Test Status

As early as possible in the production process, the hollow core slabs should get an identity mark and be provided with labels and markings, indicating whether a product has

been accepted or not, according to test and inspections performed. Nonconformity of a product may be linked to an inspection or nonconformity report, or similar documentation. The further processing of the report and decisions on its use or prospective scrapping should be coherent to this information on inspection of the test status.

The information on inspection and test status should be maintained, and adequately revised. Throughout the production, to ensure that only products which have passed the required inspections and tests, and in due course have been reclassified or reworked, will be dispatched.

The authority within the organisation, responsible for the release of the conforming products, should be identified and documented in the quality manual.

Testing

For raw and constituent materials, and for concrete mix, standard testing methods should be used. A correlation or safe relationship between the tested property, according to standard, and another property, verified by the test method as desired, should be demonstrated and documented. The relationship should be founded on adequate preliminary tests and regression analysis. It should be examined at intervals, on the basis of relevant audit tests. The examination should also take place each time the production condition change. It should be carried out separately for every aisle in the factory, and the initial and repeated tests is based on samples adequately spread over the difficult production lines.

5. CONTROL OF NON-CONFORMING PRODUCTS

The manufacturer should establish and maintain procedures to ensure that products that do not confirm to these requirements in this standard are prevented from inadvertent use.

If the result of a test or inspection is unsatisfactory, the manufacturer is obliged at once to take the steps necessary to rectify the shortcoming. Constituent materials or slabs,

which do not comply with the standard requirements, are to be rejected, scrapped or treated specially, and be marked accordingly.

After rectification, adequate inspections and tests are to be repeated without delay if technically possible, as it is necessary that there is evidence that the defects have been overcome.

Where necessary and for the avoidance of consequential damages, defects should be notified to the customer in the event of products being delivered before sustaining test results are available.

Corrective Action

The manufacturer should establish and maintain procedures for:

- a) investigating the causes of nonconforming products and the corrective actions needed to prevent recurrence.
- b) analysing all processes, work operations, quality records and customer complaints to detect and eliminate potential causes of nonconforming products.
- c) initiate preventative actions to deal with problems to a level corresponding to the risks encountered.
- d) applying controls to ensure that corrective actions are taken and that they are effective.
- e) implementing and recording changes in procedures resulting from corrective actions.

6. HANDLING, STORAGE AND DELIVERY OF HOLLOW CORE SLABS

The manufacturer should establish and maintain procedure for handling, storage, loading and transportation of hollow core slabs.

Handling

The manufacturer should provide guideline notes that clearly outline the recommended safe method for efficiently lifting and processing the hollow core slabs in and around the working environment to prevent damage or deterioration.

Storage

The manufacturer should provide secure storage spaces to prevent damage or deterioration of the hollow core slabs, pending delivery.

Delivery

The manufacturer should provide a guideline method statement for the transportation of the hollow core slabs. The method statement should emphasise the importance of ensuring that slabs are securely supported and fixed during transportation.

The manufacturer should also make available written information on the safety measures necessary for lifting and placing the slabs on the building site. The manufacturer should pass the written safety information to a competent person who has been designated responsible for the erection of the slabs on that building site.

Every individual delivered slab should be definitely identifiable and traceable with regard to its production data. For this purpose the manufacturer should mark the products on the delivery documents so the relation to the corresponding quality records and other records required in this standard can be secured.

7. QUALITY RECORDS

The supplier should establish and maintain procedures for identification, collection, indexing, filing, storage, maintenance and disposition of quality records.

Quality records should be maintained to demonstrate achievement or the required quality and the effective operation of the quality system. Appropriate sub-contractor quality records should be an element of this data.

Actions taken when inspections or tests indicate that requirements are not met, should be recorded. Quality inspection and test records should be maintained to demonstrate achievement of the required quality and the effective operation of the quality system. Retention times of quality records should be established in writing with the purchaser. Quality records should be available for evaluation by the purchaser or his representative for an agreed period. Where quality records have been retained it is envisaged the period of time is to be not less than 15 years.

8. TRAINING OF PERSONNEL

The manufacturer should establish and maintain procedures for the training of all personnel activities affecting quality. Personnel performing specific assigned tasks should be qualified on the basis of appropriate education, training and or experience, as required. Appropriate records of training should be maintained.

9. INSPECTION, CALIBRATION AND TESTING

Clear control measures are considered necessary to assure the supplier that the hollow-core slabs as manufactured meet the specified requirements and that they satisfy Euro-code quality control objectives. The measures that are considered necessary consist of various inspections and tests which involve the assessment of test results for the following sub-divisions:

1. Calibration and checking of equipment

Batching plant

Stockpiles, bins, etc..

Weighing equipment, water meter, admixture dispensers

Hollow core manufacturing equipment

Casting beds

Stressing jacks

Measuring equipment

Casting machine

Sawing machine

Lifting and storing equipment

Laboratory testing equipment

Machines for compression, splitting and bonding tests

Gauged weights, scales, sieves and gauges

2. Testing and inspection of materials and components

Constituent materials for concrete

Cement, sand, aggregates, mixing water, admixtures

Concrete

Various tests incl. compressive and tensile strength, chloride content, w/c ratio, consistency.

Steel

Conformity of strands

3. Testing and inspection during production

Production

Casting beds

Strands

Anchoring

Casting

Additional operations before curing

Curing

Detensioning and cutting

4. Inspection and testing of finished slabs

Slabs before storage

Initial slippage of strands

Cross-section and length

Surfaces, slab ends

Drainage holes

Full scale slab

Load-bearing capacity

Shear test

5. Inspection during lifting and storing.

Having established the appropriate quality control system of the elements, one must ensure that this good quality hollow core slab is utilised properly and that it will fulfil its intended purpose as part of the whole structure. This brings me to the second part of this paper, namely connections.

B. CONNECTIONS

The stability of a structure utilising hollow core slabs as one of its main element depends among others, on the integrity of the connections. It is my experience that locally very little, if any, consideration is given to the detailing of the floor to floor and floor to wall connections. The practice is usually that the perit specifies a particular slab to take a particular load and then it is usually left for the contractor to lay the slabs in any way that he sees fit. This has given rise to a number of problems associated with bad detailing. One must bear in mind the behaviour of the prestressed hollow core slabs under different situations with respect to bending, shear, concentrated loads and load distribution through the joints amongst others.

Utilising hollow core slabs as statically determinate structural elements theoretically avoids absolutely any restraint whatsoever. However restraints sometimes result from certain practically unavoidable conditions rather than from intentionally imposed boundary conditions.

It is therefore generally accepted good engineering practice to utilise certain connection ties, in order to ensure a minimum acceptable bearing capacity required to withstand horizontal loadings or movements which could otherwise impair the structural stability.

To achieve such continuity, free displacements and rotations of the hollow core slabs have to be restrained at their supports. This creates additional hyper static secondary moments and axial forces, which should be duly incorporated in the design.

Providing a semi-monolithic connection between precast units will immensely improve the performance of the structural system in respect to transfer of horizontal loadings and safety against progressive collapse.

These include slab to wall connections where the slabs are exposed to fixation effects at the supports, connections at the joint, bond to joint concrete and the clamping effect of the walls under normal loads. Under these effects, tensile cracks can appear close to the support which can cause a serious problem of shear transfer capacity of the slab.

In precast concrete design, stability should be provided by the “stabilising elements” such as:

- Columns (in low buildings) rigidly fixed to the foundation
- Walls or load-bearing facade elements
- Cores (usually elevator shafts, stairwells etc...)

The rest of the structure is built around these “stabilising elements” which of course could also be prefabricated if sufficient repetition justifies their use. As the slabs span from one stabilising element to another, such as walls or beams (usually parallel to the façade), in-situ structural concrete topping is an option for ensuring diaphragm action of the floor. However this is time-consuming and slows down progress on site. Consequently with a view to executing projects using more prefabricated components, alternatives in detailing or a combination of both can be used. These include placing reinforcing bars in the cast-in-situ joints between slabs and corresponding elements protruding into the floor units. Other methods include breaking out parts of the cores and filling with concrete, introducing dowels, and welding of steel plates or reinforcement.

The following diagrams illustrate some examples, which can be utilised. These are sub-divided in:

- Hollow core slabs on Concrete Elements
- Hollow core slabs on Steel Members
- Hollow core slabs on Masonry

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Hollow core slabs on Masonry

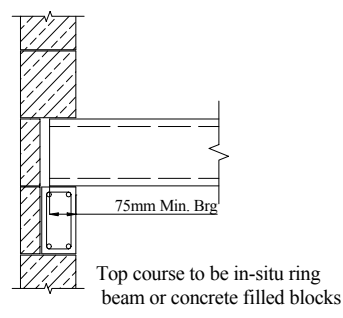


Fig. M1 Typical concrete block exterior wall bearing

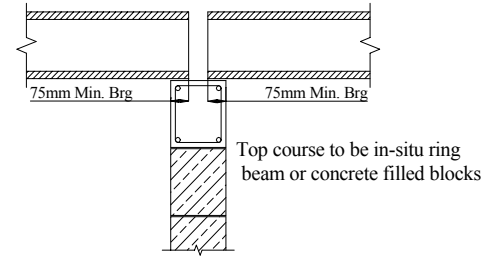


Fig. M2 Typical brick or concrete block interior wall bearing

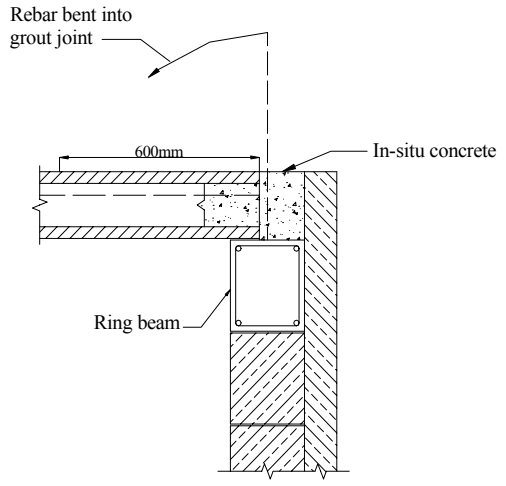


Fig. M3 Bearing on exterior wall

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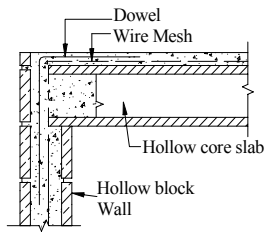


Fig. M7 Exterior wall

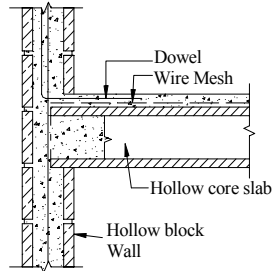


Fig. M10 Exterior wall

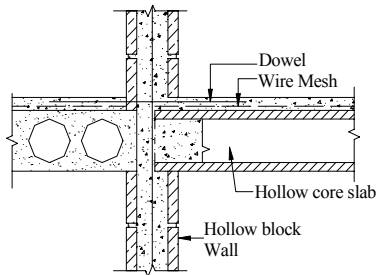


Fig. M8 Interior wall

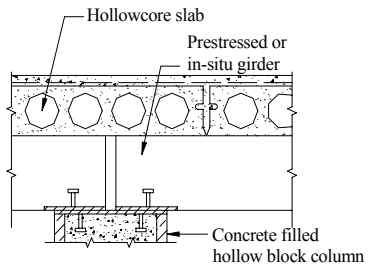


Fig. M9 Filled hollow block column

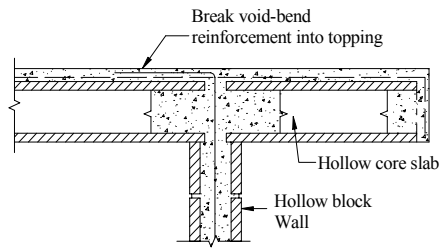


Fig. M11 Cantilever

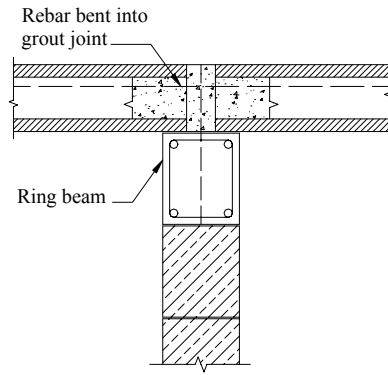


Fig. M4 Bearing on interior block wall (untopped)

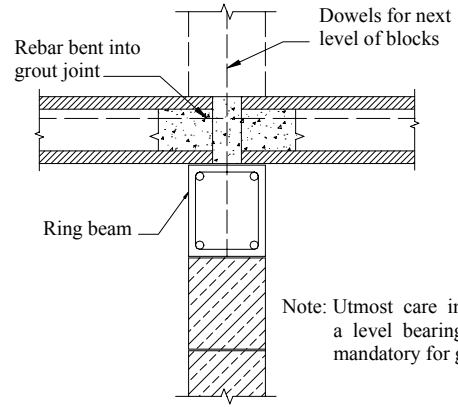


Fig. M5 Masonry bearing at multi-storey construction

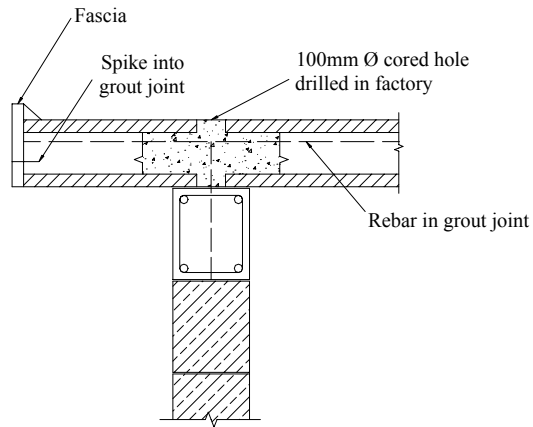


Fig. M6 Cantilever bearing situation

Hollow core slabs On Concrete

Rebar bent into slots
sawn into hollow core slabs
(bent out of keyway)

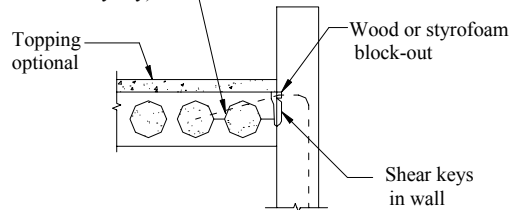


Fig. C1 Shear connection to concrete wall
(topped or untopped)

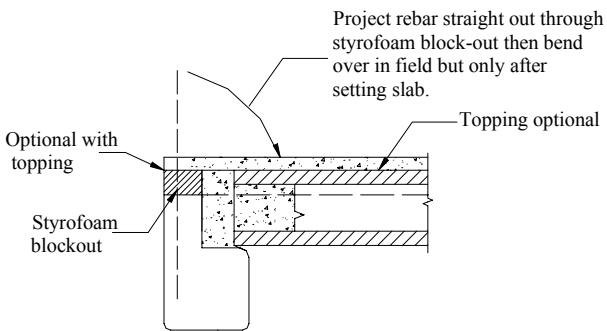


Fig. C2 Bearing on exterior concrete beam
(topped or untopped)

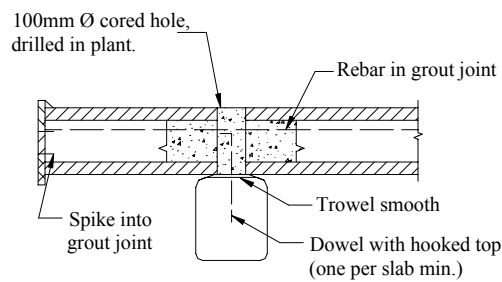


Fig. C3 Cantilever bearing situation

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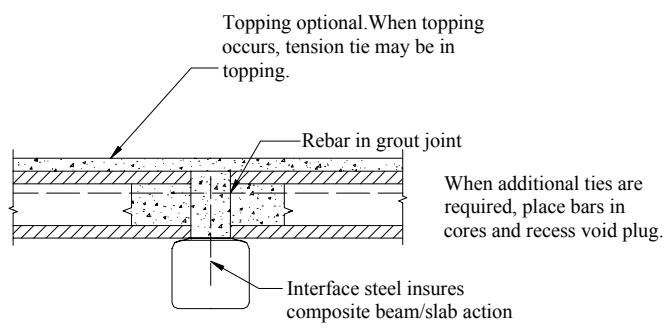


Fig. C4 Bearing on interior concrete beam (type 1)
(topped or untopped)

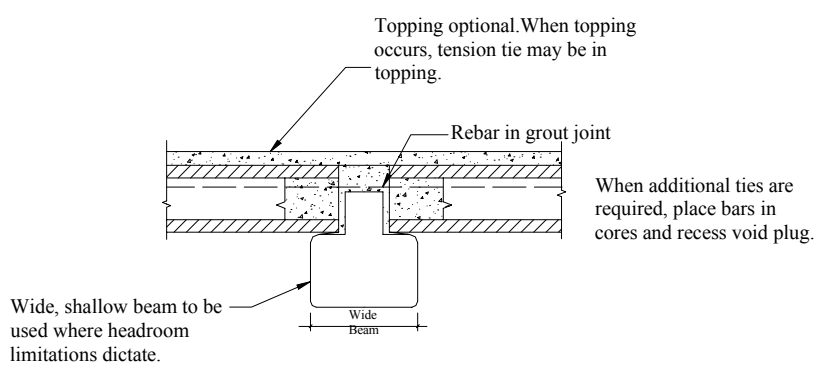


Fig. C5 Bearing on interior concrete beam (type 2)
(topped or untopped)

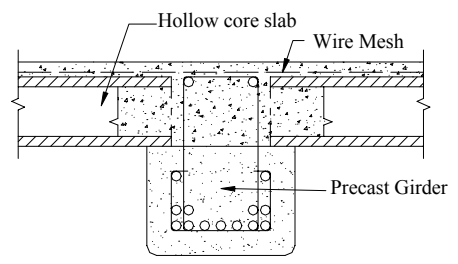


Fig. C6 Girder Support

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Hollow core slabs on steel

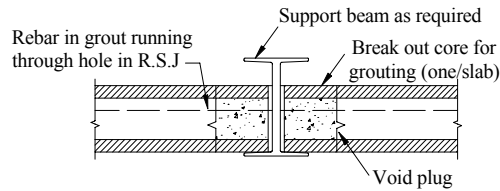


Fig. S1 Bearing on interior beam

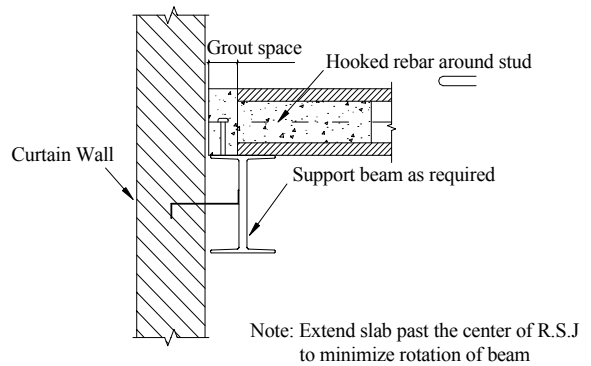


Fig. S2 Bearing on beam with exterior curtain wall

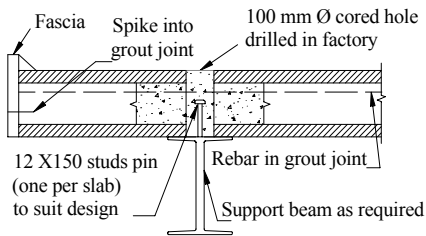


Fig. S3 Canilever bearing situation

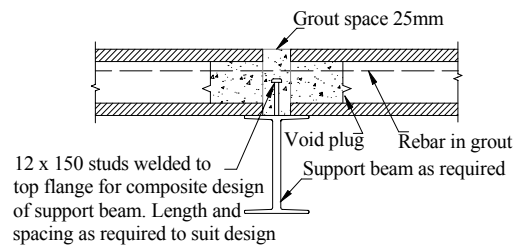


Fig. S4 Bearing on interior beam

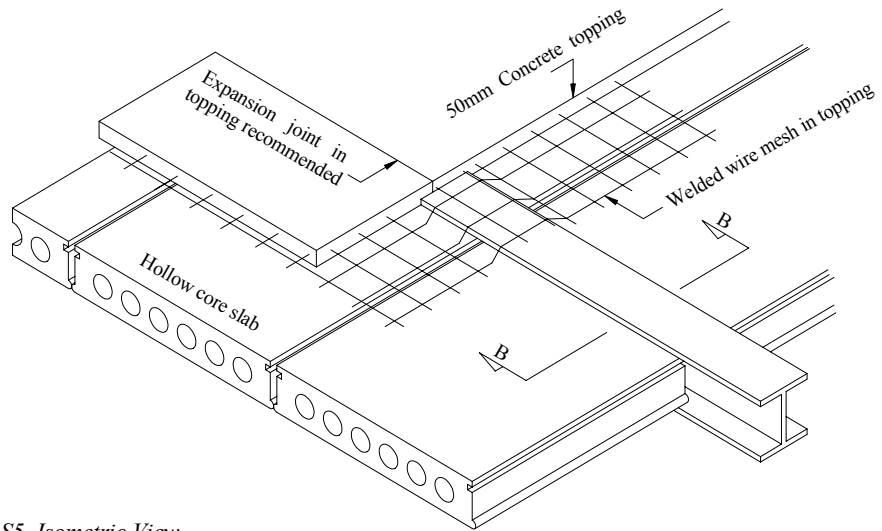


Fig. S5 Isometric View

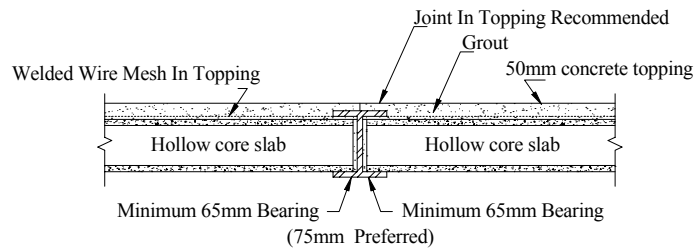


Fig. S6 Section B-B

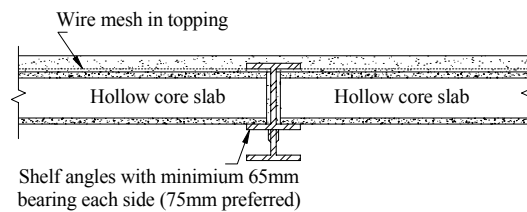


Fig. S7 Alternate section

Major openings

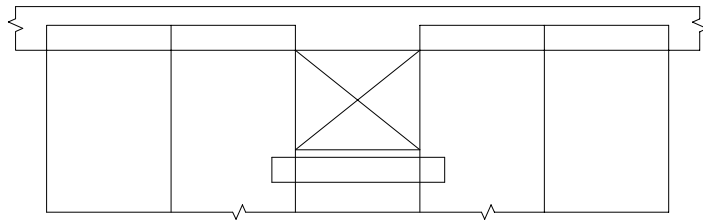


Fig. S8a Plan

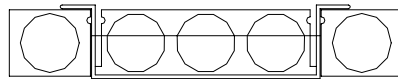


Fig. S8b Angle seat

Conclusion

Hollow core slabs enable a very efficient industrialised production. By ensuring that the slabs are produced under a strict quality assurance programme and that these are safely transported, erected on site and that proper detailing is ensured, a semi-monolithic structure is achieved with improved performance of the structural system with respect to fire resistance, safety against progressive collapse and transfer of horizontal loads.

