

## Introduction and Objectives

The Building Industry Consultative Council (BICC) has decided to set structural design standards and methodologies as one of its priorities. As a first attempt at setting quality design methods, the design of a typical local three-storey residential construction lying between common party walls has been chosen.

A plan and sectional layout of the proposed design example is included here. An open plan basement with overlying living quarters on the ground floor and a bedroom quarters on the first floor has been chosen as the common design requirement in such circumstances. A methodology for the structural design of such an example necessitates addressing the following:

- 1) Choice of material types and availability of their structural and mechanical properties;
- 2) Choice of static load (action) types based on International Standards;
- 3) Robustness;
- 4) Consideration of dynamic (seismic) loading (actions) particularly in detailing;
- 5) Serviceability and water retention;
- 6) Design to recognized international standards;
- 7) Detailing to a recognized international standard;
- 8) Presentation of design to a recognized international standard;

For the following example, the following assumptions have been made:

The site is free, excavated and lies between two existing third party developed properties.

The site foundation material is basically un-fissured, local limestone of a bearing capacity of at least 1,500 kN/m<sup>2</sup>

Masonry design compressive strength is 2.5 N/mm<sup>2</sup> made of globigerina limestone blocks and British Standard Class 4 mortar in the horizontal and vertical joints of a wall.

All structural concrete is grade C25.

All main steelwork is high yield with a maximum design strength of 410 N/mm<sup>2</sup>.

Mild steel (where specified) shall have a minimum design strength of 250 N/mm<sup>2</sup>.

Properties of proprietary products such as prestressed slabs shall be obtained from the supplier.

## Publication Aims

The design of a typical three-storey residential unit employing local construction methods is here attempted in order to highlight the use of International Design Standards and clear structural design methodologies when applied to the particular case of a typical local structure. The aim of the publication is not to portray a standardised cook-book type of approach, nor to replicate the numerous foreign texts outlining member by member design approaches, but rather to highlight possible ways of designing such a structure according to recognised standards, while highlighting possible dangers in the design of such structures. This is necessary because due to local construction practices the design of such a structure, although appearing at first glance to be simple, cannot always rely on 'deemed to satisfy rules' and 'rules of thumb', but requires a clear design methodology with the corresponding calculations and detailing requirements, particular to the local scenario.

In order for a structure to serve its purpose, it must be safe against collapse and be serviceable in use. Calculations alone do not produce a safe, serviceable and durable structure. Other factors such as the suitability of the materials, quality control and supervision of the workmanship are equally important.

The adoption of a limit state design approach allows for the fact that a structure may become unsatisfactory through a number of ways which all have to be considered independently against defined limits of satisfactory behavior. One therefore accepts the fact that there is an inherent variability in loads, materials and methods of design and construction which makes it impossible to achieve complete safety against any possible shortcoming. By providing sufficient margins of safety, one attempts to ensure an acceptable probability that the structure will perform satisfactorily during its intended life.

The design of a structure can be tackled in various ways and can sometimes employ a wide variety of differing assumptions between one method and another. Some assumptions while not one hundred percent accurate, can however lead to the design of a safe and economic structure. In the design example attempted below, this can be seen through the varying approaches one can adopt, at least two different approaches in this case. However a word of note is due here, a design method might be more accurate than another one, but the requirements of more lengthy calculations might not justify the extent to which it is more accurate.

The design example based on the above and depicted on the attached drawings shall be addressed with the application of a clear methodology.

In simple cross-wall construction the allocation of floor loads to the supporting walls is relatively straightforward. However with complex wall arrangements the

problem becomes more difficult and considerable differences in estimated wall loads can arise according to the assumptions made.

### **Method 1**

All loads carried by the reinforced concrete slabs shall be distributed to its supports using yield line theory pathways. This procedure involves the subdivision of the floor areas into triangles and trapeziums and the allocation of the loads from these areas to the appropriate walls. With a simple rectangular slab this is simple and reasonably accurate overall, however the presence of a complicated plan layout can lead to rather lengthy calculations. This methodology is based on the assumption that slab bending inevitably distributes loads in proportion to its aspect ratio irrespective of possible directionality of slab reinforcement.

### **Method 2**

All loads carried by the reinforced concrete slabs shall be distributed to its supports as dictated by the directionality of the reinforcement. This methodology, while clearer in load path assumptions, might sometimes require that the non-loadbearing walls be finished with soft, non-loadbearing materials at their contact positions with the said slab, such as polystyrene.

### **A Note on Arching Action**

Composite action between reinforced concrete beams and overlying masonry is well documented and has been extensively researched. It can lead to significant economies in material requirements. However a certain amount of conditions must be met in order for arching and/or composite action to be safely taken into account in the design of a structure. A very careful assessment of the deformations in the structure would be necessary in order to properly assess the loads to be carried in the transfer beam. One must also point out that whilst composite action can be confidently relied upon in beams of limited span and of a secondary nature its safe use as the primary system of support in structure is questionable without adequate tests geared for the local industry, especially when used together with prestressed precast planks of variable spans.

When arching/corbell action of the masonry and composite action between the planks and the masonry is taken into account, a redistribution of the loads is obtained with significant reductions of the load actions on the prestressed planks. These actions require a good knowledge by the designer before they can be considered. The following factors should be kept in mind :

- a) As arching action is developed within the wall, vertical stresses are heavily concentrated towards the supports. Arching action reduces the bending moments in the supporting beams, but high compressive forces are generated near the ends of the infill walls and cracking of the wall should be checked.
- b) Arching action behaviour has been found to occur in walls having a ratio of height to length greater than about 0.6.
- c) Composite action between overlying masonry walls and underlying masonry walls has traditionally assumed that the beam is shored during the construction of the overlying wall. This would imply that prestressed planks would have to be shored as well presenting us with substantial problems in the plank design.
- d) Openings close to the supports destroy complete arching action over the full span.

However when the experienced designer deems that arching action can be safely relied upon, one has to ensure that the detailing adopted on the construction site shall be such as to allow arching action of the masonry construction. Such detailing shall assume strict supervision of 'keying-in' of the masonry wall construction. 'Mursalli' (interlocking of masonry blocks at corners) or other approved modes of tying, 'inkulmar' (horizontal key details in each course along the height of the masonry wall) and bond stones are essential requirements.

### **A Note on the Load Distribution of Hollow Core Prestressed Slabs**

Another problem which we face with our local construction practices is then the load distribution on the hollow core prestressed slabs. Much research has been carried out on this subject yet this usually pertains to bridge decks and isolated loads. Once again local designers are somewhat left in the dark on the correct method of load distribution especially when we encounter the complex load fields as occurs in our local construction.

When a simply supported slab field is loaded by uniformly distributed loads, each slab unit deflects similarly so an individual slab unit can be treated as a one way slab, which is affected by the load acting on the slab unit. The situation is different when a slab field is subjected to concentrated loads such as line or point loads. Because slab units are connected by grouted joints and transverse ties, members adjacent to loaded slab are also forced to deflect and so the effect of a concentrated load is distributed to a wider area than the directly loaded slab unit.

It cannot be sufficiently overstressed that load distribution depends on how well the lateral displacement of the slabs in relation to each other is restricted. This is why the lateral displacement of the units must be restricted by means of the reinforcement in the transverse joints which give the necessary forces perpendicular to the joint when the adjacent elements tend to separate. The required resistance of the transverse tie reinforcement should be at least equal to the total vertical shear forces which have to be transmitted across the longitudinal joints.

This effectively means that the traditional bearing beam that is termed the 'sulletta' in local construction should not be used just as a spreader beam but should be used as a ring beam whereby the tie reinforcement present in this member is continued throughout on plan, respecting the tension lap rules of normal reinforced concrete construction.

Transverse load distribution should be considered only if:

- a) Good quality grout in joints.
- b) Lateral displacement between adjacent units is limited by means of adequate and continuous transverse tie reinforcement. The completed floor should be provided with transverse tie beams designed and arranged according FIP recommendations.

If these are not met, the load distribution should be considered impossible and every element should be designed for all the loads acting directly on that element and assuming zero transfer across the longitudinal joints.

The design of these type of floors when subjected to concentrated loads involves one of two scenarios. Either using simple deemed to safety rules or more complicated analytical methods. In the simplistic case the concentrated load is assumed to be distributed over an effective width equal to the total width of 3 precast units, or over a width equal to 0.25 of span on either side of the loaded area. This is identical to the requirements of BS8110. However the latter also states that in some forms of construction e.g. long span wide units, these limits may be inappropriate and more detailed considerations would have to be made. Where a reinforced concrete topping is used then the above limit is increased to a total of 4 planks.

When this type of simple distribution is not sufficient more complicated analytical calculations or graphs are used specific to each type of construction. It is interesting to note however that FIP recommendations give graphs only for bending moment and not for shear.

## Conclusion

Adoption of methodology shall be at the discretion of the Perit. Preference can only be specific to the particular design problem and site conditions under consideration by the Perit. Notwithstanding, it is also assumed that the Perit is to consult specialist advice when this is considered necessary.

In addition, it is also assumed that the structure has been checked not only for vertical load conditions but also for lateral stability as required by the various codes of practice. Detailing for 'robustness' and 'serviceability' should be an essential ingredient to a complete structural design methodology.

The 'Perit' must also assess the capacity of the pre-stressed slab design to obtain contribution from adjacent slabs in resisting loads (actions) in bending moment and shear. Proper assessment of the quality of the loads resisted together with supplier's data shall be necessary to establish and complete a design methodology.

