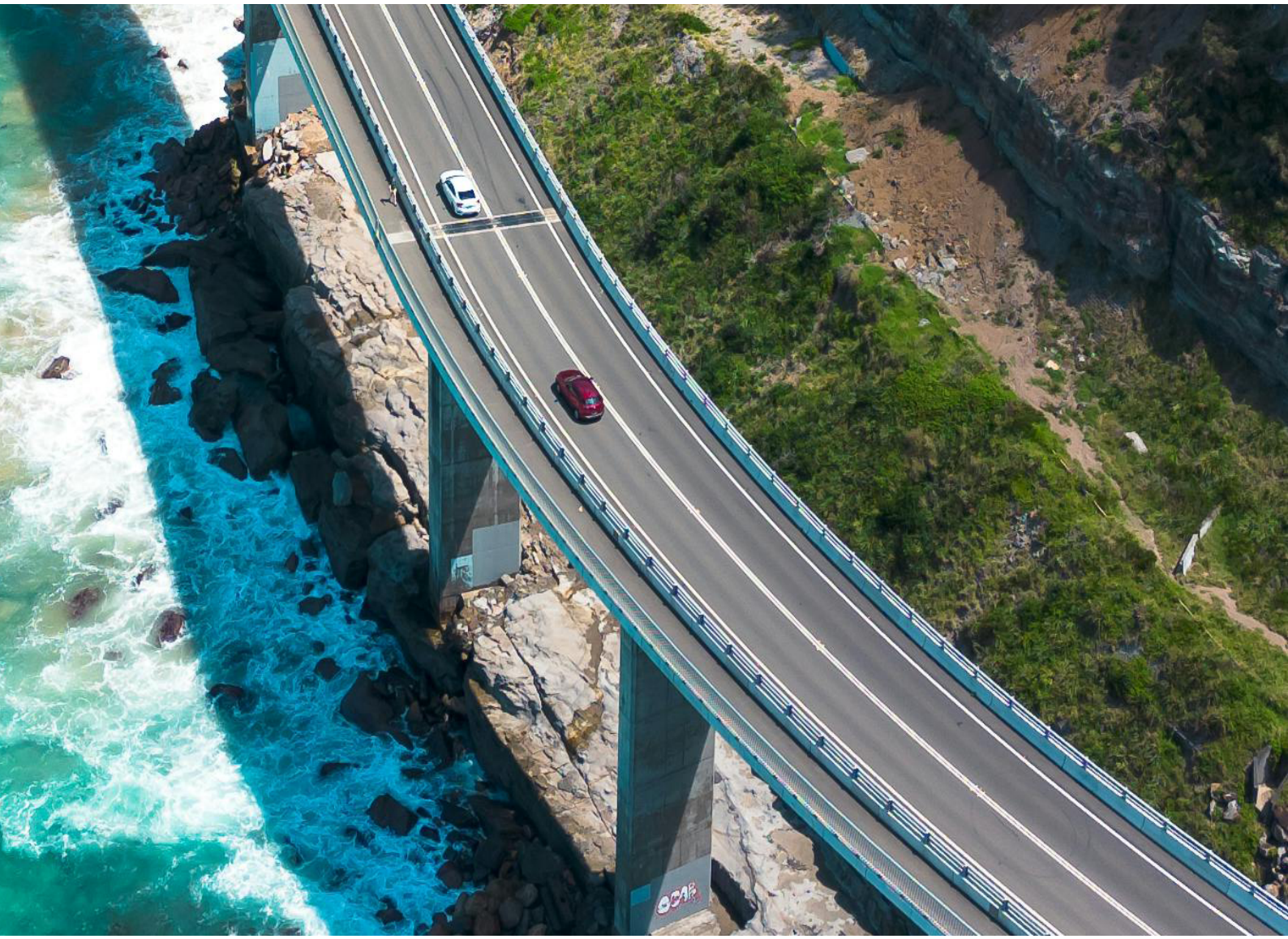
GUIDE

CEMENT CONCRETE & AGGREGATES AUSTRALIA

Guide to Long-span Concrete Floors



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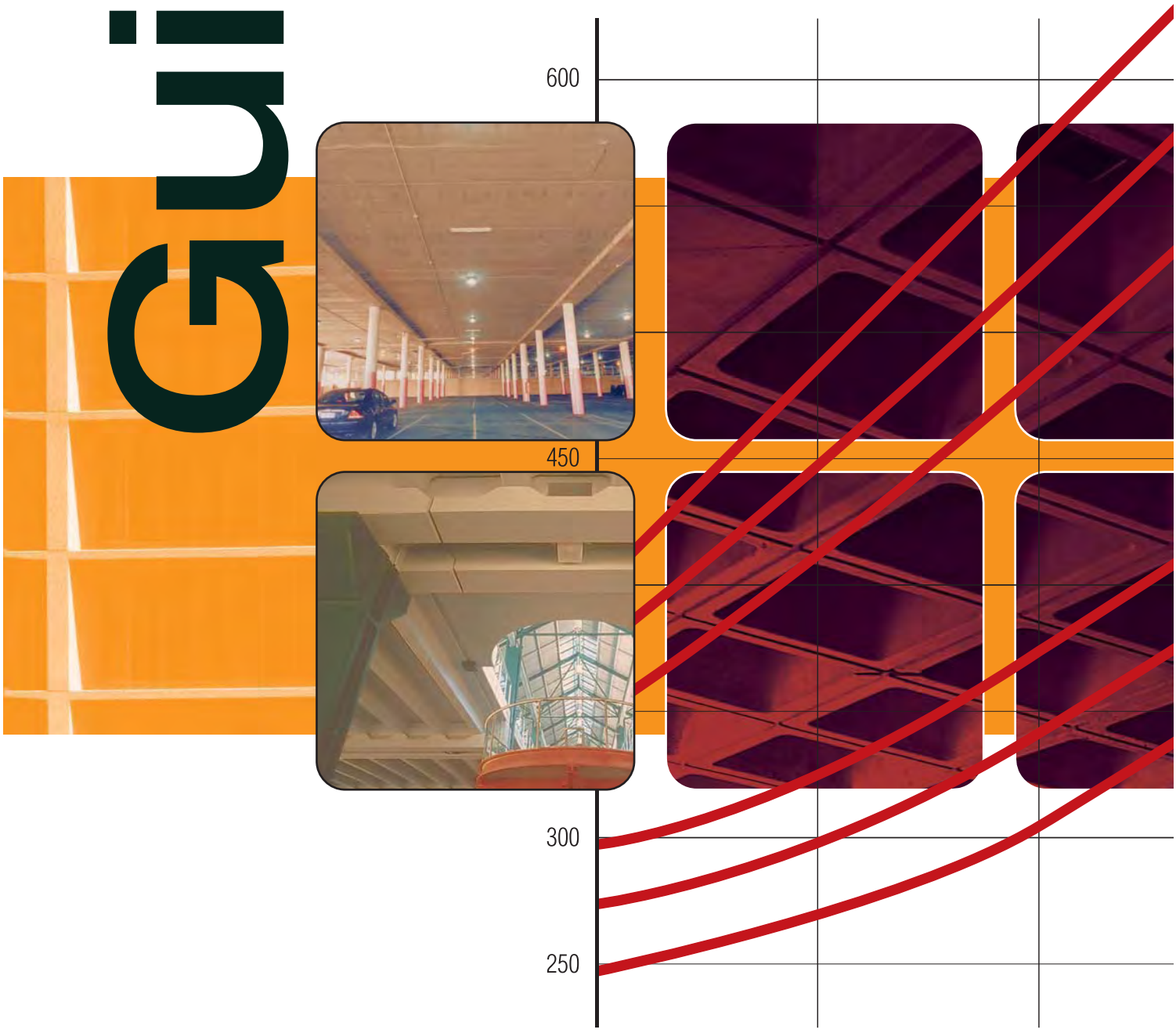

CEMENT & CONCRETE ASSOCIATION OF AUSTRALIA

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Cement and Concrete Association of Australia

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CEMENT & CONCRETE ASSOCIATION OF AUSTRALIA

The Cement and Concrete Association of Australia is a not-for-profit organisation established in 1928 and committed to serving the Australian construction community.

The Association is acknowledged nationally and internationally as Australia's foremost cement and concrete information body – taking a leading role in education and training, research and development, technical information and advisory services, and being a significant contributor to the preparation of Codes and Standards affecting building and building materials.

The Association's principle aims are to protect and extend the uses of cement, concrete and cement-based products by advancing knowledge, skill and professionalism in Australian concrete construction and by promoting continual awareness of products, their energy-efficient properties and their uses, and of the contribution the industry makes towards a better environment.

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Concrete floor systems offer the designer a wide variety of options from which to choose a floor system for a particular project. All of these systems incorporate the many advantages which concrete bestows. Most importantly it is a plastic material when fresh and can be moulded into any shape the designer chooses. Thus it imposes almost no restriction on the plan of the floor although individual systems may impose limitations. Further, concrete allows a variety of surface finish, colour and texture to be used. Concrete is non-combustible and possesses good insulating qualities, concrete floor systems can thus be designed to meet the requirements for fire resistance. Concrete is also a durable material and can easily be designed to meet the durability requirements for the particular exposure location, while the abrasion resistance of the floor surface can be adjusted to meet the most demanding requirements. This Guide concentrates on the structural design of the floor system and the designer should consult other manuals for advice on how to specify the concrete mix and construction practices to achieve the desired performance (see Bibliography).

The permission of the National Precast Concrete Association Australia to use material from its *Precast Concrete Handbook* in the section on precast floor systems is gratefully acknowledged.

The charts for the insitu floors have been prepared using the computer program RAPT version 5.41 as licensed by the Prestressed Concrete Design Consultants (PCDC) to the Cement and Concrete Association of Australia.

This Guide supersedes *Design Guide for Long-span Concrete Floors* (T36) published by the Cement and Concrete Association of Australia and the Steel Reinforcement Promotion Group in 1988.

Relevant Australian Standards

AS/NZS 1170.0	*Structural design actions – General principles*, Standards Australia, 2002.
AS/NZS 1170.1	*Structural design actions – Permanent, imposed and other actions*, Standards Australia, 2002.
AS/NZS 1170.2	*Structural design actions – Wind actions*, Standards Australia, 2002.
AS 1311	*Steel tendons for prestressed concrete – 7-wire stress-relieved steel strand for tendons in prestressed concrete*, Standards Australia, 1987.
AS 1366.3	*Rigid cellular plastics sheets for thermal insulation – Rigid cellular polystyrene – Moulded (RC/PS – M)* Standards Australia, 1992.
AS 1530.4 4	*Methods for fire tests on building materials, components and structures – Fire-resistance tests of elements of building construction*, Standards Australia, 1997.
AS 3600	*Concrete structures* Standards Australia, 2001.
AS 3610	*Formwork for concrete* Standards Australia, 1995.
	Supplement 2 *Formwork for concrete – Commentary* (including Amdt. 1) Standards Australia, 1996.
AS/NZS 4671	*Steel reinforcing materials*, Standards Australia, 2001.

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1 SCOPE

Concrete structures have, for many years, dominated the Australian multi-storey commercial and residential building scene. Landmark projects such as Sydney's MLC building and Melbourne's Rialto rank among the tallest reinforced concrete buildings in the world and testify to the skills of Australian designers, builders and tradesmen.

Traditionally, column spacings and floor spans in these buildings have been in the range of 6 to 9 metres, to both contain costs and simplify construction. However, recently there is an increasing preference by building owners and tenants for large floor areas with column-free space and spans from 9 to 16 metres. This has focused the interest of designers and builders on methods of reducing costs and speeding construction of long-span floors. For the purposes of this Guide, long-span floor systems are generally spanning greater than six metres for reinforced concrete systems or eight metres for prestressed systems. Some systems are effective below these arbitrary limits and their full range is included herein for completeness.

The aim of this Guide is to provide designers with an appreciation of the factors that should be taken into account in selecting a floor system for a particular building. A section on the major architectural considerations is followed by another on the major structural design considerations and one on construction considerations. These are followed by a description of the various floor systems, photographs/sketches of each showing the appearance of the soffit and a chart indicating the economical spans and load capacities to aid in their selection.

The Guide provides discussion on only the common factors to be considered in the choice of a floor system. Designers are responsible for identifying and designing for all the requirements specific to their particular project, eg attack by chemicals to be used in the manufacturing process to be carried out in the building or specific limits required on deflections or vibration.

It is emphasised that the graphs are not design charts but aids to enable designers to quickly identify appropriate floor systems to carry the applied loading for the desired span, and thus provide approximate dimensions for the preliminary design.

2 PROCESS OF FLOOR SELECTION

The process of selecting a floor system can be complex, covering architectural, structural and construction considerations and generally will involve several iterations or progressive refinements until the final choice is made and the detailed design can be undertaken. It encompasses a number of identifiable stages commencing with a conceptual design of the structure and ending in the completed design approved for construction. These stages can be summarised as:

Conceptual Design – when the space and usage requirements, the architectural appearance, the standard of quality and the broad requirements for the structure are defined. It will also consider how the structure will perform and how it is to be built. In addition, a preliminary cost estimate should be made to confirm that the project is economically viable. Usually, a number of alternative schemes will be evaluated and perhaps a couple chosen for further evaluation at the next stage.

Preliminary Design – when the client requirements for the project are refined and the chosen alternative schemes considered in more detail. In this stage, for each scheme being evaluated, the following aspects of the total structure have to be defined:

- Lateral load-resisting systems.
- Framing plans.
- Preliminary member sizes, including floor thicknesses. These may be based on span-to-depth ratios, the charts in this Guide or a preliminary structural design carried out to confirm proposed sizes.
- Control of volume change deformations and restraint forces.
- Connection concepts.

Approximate member sizes for the alternative designs are used to develop more-precise costing for each scheme to find the optimum solution. Planning application based on the preferred scheme is usually submitted and, if required, a more detailed cost estimate is prepared to confirm the project is on budget.

Final Design – when the client requirements are finalised and the chosen preliminary design scheme is fully analysed, designed and detailed for the whole design life, including construction and demolition, covering all limit states. Durability, fire resistance and other relevant design actions also have to be considered. At this stage, the project documentation, plans and specifications, etc are prepared and submitted for approval and, if required, a further cost check carried out.

The effect of loads, forces and deformations on the joints and the behaviour of the total structure under the various design actions should always be considered. Restraint, by loadbearing walls and columns under the slab, of volume-change deformation in floors, due to shrinkage or tensioning of the floor system, should always be considered otherwise significant cracking is likely to occur in the floor system and/or supporting elements.

For precast floors, the following may need to be considered during the design process:

- The design of the member during handling, transport and erection.
- The design of the structure during construction (sequence, support of individual members, bracing—including structural robustness required by AS/NZS 1170.0).
- The design of the completed structure.

3 ARCHITECTURAL CONSIDERATIONS

3.1 General

The numerous architectural considerations for any particular project range from space requirements for the various processes and activities to be carried out inside the building to the overall appearance of the building – both in isolation and in its context. By and large these are similar for floors of any span. The aspects considered herein are those that are significant or peculiar to long-span floors (ie floor-zone thickness, services, penetrations through the floor) and generally have a direct impact on the design of the floor system. Nevertheless, other aspects not considered herein may be controlling factors, eg a requirement on limiting vibration, facade treatment, etc.

The requirements for the surface finish on floors are no different to those for normal-span floors except perhaps for drainage gradients because of their sensitivity to deflection (see Section 4.3).

In most cases, the soffit finish is produced off formwork even for precast elements. If the soffit is visible in the completed building, the effect of the formwork and the pattern it makes on the surface needs to be considered. While the appearance of the floor structure when it is to be exposed to view is often decided by the architect, the structural designer must be aware of aesthetics and participate in achieving the desired appearance for the completed building. If the soffit is to receive a plaster coating, then consideration needs to be given to providing a suitable texture to the soffit. It is extremely difficult, if not impossible, to get plaster coatings to adhere to surfaces of high strength concrete that have a high density, eg surfaces of members cast against steel formwork.

3.2 Floor-zone thickness

The thickness of the floor zone is greater than the overall depth of the floor system. It includes the depth required for any floor finishes, set downs or set ups, falls, and the depth required to accommodate below-floor building services **Figure 1**. In modern buildings these often include air conditioning ductwork and fan coil units, ventilation and exhaust ducts, sanitary floor traps and waste pipes, stormwater waste pipes, hot and cold water, fire water and sprinklers, smoke detectors, data and electrical cabling, lighting and many other specialist services. Below these services there is usually a suspended ceiling (often a tile system to allow access to the services) supported on a tee bar system or similar with hangers to the floor over. Alternatively, an applied ceiling finish to the soffit of the floor can be used. The 'gravity' services of sewer and stormwater usually have precedence over other services as they must be laid to nominated falls.

Minimising the floor-zone thickness can provide a significant cost benefit. If there is a limit on the overall height of the building, it will maximise the number of storeys that can be provided. Alternatively, if the number of storeys is fixed, it will minimise the height – and therefore the cost – of all vertical elements. This is particularly significant for the external walls in which relatively high-cost materials will often be used.

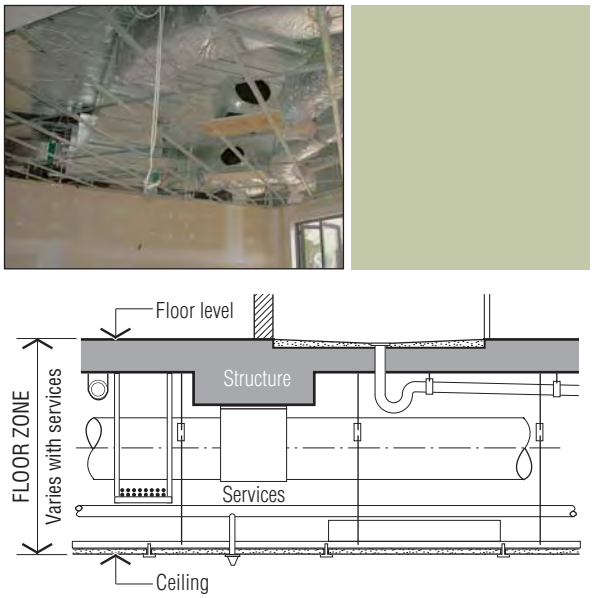


FIGURE 1: Typical floor zone

3.3 Services

Services need to move horizontally along and across the floor and vertically from floor to floor in a building without clashing. The architect, structural designer and the services designer should liaise closely to ensure that services such as ducts, cables and the penetrations for the services do not jeopardise the structural behaviour of the floor system or the operation of the building.

Electrical, data and telephone ducts are sometimes cast within the slab thickness. A single electrical duct does not reduce the slab capacity significantly.

FIGURE 2: Cables placed within a slab

However, two or more ducts tied to a reinforcing bar may significantly reduce its bond and effectiveness. Certainly the effect of a number of ducts brought to a central distribution point must be evaluated both structurally and from a fire-resistance requirement. Concentrations of service ducts should be identified at the design stage and appropriate design strategies used to accommodate them, eg locate service boxes into deepened areas of the slab **Figure 2**. Locating these ducts under a false floor above the structural slab will also avoid the problem.

Services located below the floor system may pose other problems of support and transverse distribution past or through intervening beams or bands. It is normal for the service contractor to support the services with light drilled fixings into the soffit of the floor within the cover zone. The location of heavy-duty fixings which extend beyond the cover zone or drilled, cut or cored holes or penetrations through the floor system should have approval of the designer to ensure that the structural performance is unimpaired. For example, a transverse duct with either dimension greater than, say, 0.25D through the web of a beam can significantly reduce its shear and/or its flexural capacity.

The designer may also have to nominate fixing zones and coring zones for services in prestressed and precast floor systems.

Vertical services are usually accommodated by providing penetrations through the floor structure. These are often in riser ducts in one location within the building – frequently adjacent to stairs, lift shafts, rear walls and the like. Incorporating services except small electrical conduits within concrete columns and walls should be avoided. Columns and walls are highly stressed elements and reducing the concrete cross-section available to carry the load may necessitate increasing the dimensions or the required concrete strength. Further, bringing the service duct through the reinforcing cage in a column, wall or footing will involve loss of support area and can involve having to modify the reinforcing cage. Later modification of the service due to changes over the life of the building is also difficult, while with water, waste water or sanitary drainage services, there is the potential for corrosion of the column reinforcement.

Set downs in the top of slabs are often required for bathrooms and toilets or areas open to the weather. These setdowns allow finishes such as floor tiles to be laid on the concrete to the required falls for drainage. In buildings such as hotels and hospitals, the extent of such setdowns can be significant. Set downs of 20–100 mm may be required and this will need to be allowed in the floor system design, in terms of both structural performance and fire rating.

The requirements for services will change with time quite apart from any change implicit in change of occupancy. Thus at the design stage consideration should be given to how future changes in the requirements for services are to be accommodated. The design should facilitate these future decisions even though they cannot be foreseen in detail. For example, incorporating an access floor on top of the structural slab provides a space where horizontal services can be relocated or updated as necessary. Similarly, marking the positions of prestressing cable ducts on the soffit of the slab by using plastic supports (or similar) to hold the ducts in the desired position means that future penetrations through the slab can avoid the cables with a high degree of reliability.

3.4 Penetrations

Large penetrations through a floor for major ducts, non-loadbearing stairs or lift shafts are part of the structural design of the floor system. Loads due to large non-loadbearing ducts, shafts, stairs and lifts and the loads of surrounding floor are usually carried by bands or beams around the perimeter of the penetration which in turn carry the loads back to the columns or adjacent beams.

Vertical services such as downpipes tend to be located adjacent to columns because columns provide lateral support and protection. However, from a structural point of view locating services adjacent to the columns is not ideal. At this location, the shear and moment are usually a maximum and there is therefore a concentration of reinforcing steel (and/or prestressing tendons) to provide the necessary flexural and shear strength. Furthermore, this may not be a desirable location for a rainwater downpipe from a flat roof as the column is likely to be a high point of a roof (the roof will tend to sag between columns). This may not be true for fully prestressed structures as the floor system will tend to hog between columns; however, the comment regarding high shear and moment still applies.

FIGURE 3: Services and penetrations through slabs

FIGURE 4: Services in a column

Vertical penetrations through floors over say 200 mm by 200 mm, or where many penetrations are anticipated, are best detailed on the design drawings. Consideration should be given to providing more penetrations or larger penetrations than those initially required, so as to provide space for later expansion of services. Generally, these penetrations will require to be designed to achieve the fire resistance required for the floor system or be enclosed in a fire-rated duct.

Beams and slabs can be designed to accommodate fairly large horizontal penetrations reasonably close to columns but these need to be designed and detailed on the drawings and their detailing not left to the service contractor. The possible rearrangement of the reinforcement layout to suit the service contractor should be avoided at all costs. Consideration should be given to reducing the depth of the beam or band locally by using a haunch, notch, etc to avoid penetrations. Upstand beams can sometimes be incorporated around service ducts to allow services to exit below the floors easily. Small horizontal penetrations up to say 50–100 mm in diameter can usually be accommodated in the middle third of a beam depth. However, this restriction may make it difficult to accommodate pipes needing falls – particularly where there are long horizontal runs. **Figures 3 and 4** show examples of various services and penetrations through slabs, beams and columns.

4 STRUCTURAL CONSIDERATIONS

4.1 General

The aim in the structural design of long-span floors is to provide a serviceable and economical floor structure. The floor must meet the client's needs as set out in the brief and also reflect community expectations for safety, amenity and environmental impacts.

A serviceable long-span floor is one that has sufficient strength to carry the permanent and imposed actions as well having adequate stiffness to limit deflection and vibrations. It must have the required resistance against fire, be durable, and be visually acceptable, if exposed to view. The floor may also have to resist actions other than vertical actions and meet other design criteria such as watertightness or chemical resistance.

The aspects of durability and fire resistance, while requiring careful consideration, are not peculiar to long-span floor systems and are not discussed herein. Similarly, while the appropriate specification of the concrete and the reinforcing materials will have a direct impact on the performance and long-term behaviour of the floor, this is no different to their impact on other concrete structures. Designers are therefore referred to the bibliography for further information on these aspects.

An economical long-span floor is one that optimises the material and labour costs. Minimum weight does not necessarily result in the lowest cost. Structural designers should review the design progressively as it proceeds to ensure the structural design is integrated with other aspects of the design of the building, eg building services, and no significant errors have been made. The accuracy of structural design theories, applied actions and material properties is such that there is no point in determining actions or member sizes to an excessive degree of accuracy.

The designer should have a feel for how the floor will work, understand how the actions will be resisted and where the forces will go. Importantly, designers should also consider buildability and other construction issues to ensure the floor can be built efficiently. It is also important that the designer reviews progressively and checks the drawings of the floor prior to construction to ensure that the intent of the design has been properly translated onto the drawings.

4.2 Strength

The design of long-span concrete floors has to conform to the requirements of the Building Code of Australia (BCA)[1] and the principles of design as contained in AS/NZS 1170 and AS 3600. In essence these follow limit-state design principles and require that:

- actions for each limit state are determined;
- the structure and its parts are analysed for the appropriate actions using the specified combinations of factored actions; and
- the structural responses under the above actions do not exceed the appropriate member or section capacity.

For example, for the design for the strength limit state the design strength of the section shall not be less than the design action effect (derived from the combination of factored actions), ie $R_d = \phi R_u \geq S^*$.

Generally, section dimensions and properties are estimated initially and the member analysed for the applied actions. Choosing appropriate dimensions is a matter of experience and using general sizing rules such as span-to-depth ratios or the charts in this Guide. The dimensions of the member are adjusted if the section is either under-strength or significantly over-strength, or if the serviceability or any other limit state is exceeded. The fundamental concept of the ductility of reinforced concrete structures has been re-emphasised in the most recent editions of AS 3600.

4.3 Deflection

Designers should appreciate that deflection is just as important as strength in the structural design of concrete floors, particularly in the design of shallow reinforced concrete floors systems. Special attention should be given to the proportioning of the floor system for deflection before the final design.

The rules for deflection control given in the current edition of AS 3600 incorporate some changes from those given in previous editions. Table 2.4.2 of AS 3600 suggests a limit of span/250 for the total deflection and states that this applies to the idealised frame as set out in AS 3600. For long-span floors these limits may not be appropriate. As an example, a 60-mm deflection in a 15-m span meets the span/250 rule but may be visually unacceptable and affect partitions and walls under. Designers need to carefully consider such effects and may need to design for a lesser deflection.

For two-way floor systems such as flat plates or flat slabs the deflection of the column strip may need to be limited to, say, 25–30 mm so that the deflection in the centre of the slab between the columns in the middle strip is not too high. Designers will need to consider if the column-strip deflection, an average of the column-strip and the middle-strip deflections or the maximum deflection in the centre of the slab between the columns is the controlling deflection. It is strongly recommended that the expected order of deflections be discussed with the architect, the client, and the user or owner of the building so that they understand what orders of long-term deflections may be expected and how this may affect the operation of the building. Excessive long-term deflections can lead to unserviceable floors and, in the extreme, the need for demolition.

Reinforced floors can be precambered to counteract the effects of long-term deflection but care is needed in applying such cambers. It is suggested cambering be limited to a maximum of half of the total deflection.

Architectural and other components, both under and over (eg partitions including deflection heads, glass walls, folding doors) can be affected by deflections, which can cause unintended load transfer to the walls below. Adequate allowance for these effects should be made, remembering that all elements above and below the floor will still be subject to the same long-term deflections irrespective of any cambers, except where the supporting floor is a slab on ground. Rigid walls (eg masonry) should have control joints to allow for such deflections and careful consideration should be given if supported on flat plate or flat slab floor systems. Wherever possible, rigid walls should be supported on a stiff floor system such as beam systems with limited long-term deflections.

The selection of the level of prestress and the load to be balanced are important in the design of prestressed slabs. The level of average prestress is typically in the range of 1.5–3.5 MPa. Generally, the load to be balanced is the permanent actions plus a proportion (often a small proportion) of the imposed actions. Care is needed in determining this proportion. Most prestressed concrete floors will have a net positive (upward) camber or hog at the time of transfer of prestress caused by the eccentricity of the prestressing force.

FIGURE 5: Cantilevered floor slabs

Many inherent variables affect camber and deflection, eg early stripping of formwork for insitu floors, incorrect back propping, time of release of prestress, time of erection and application of imposed actions for precast members, and relative humidity. Calculated long-term values should therefore never be considered any better than estimates. While detailed methods have been derived for predicting the long-term deflection of concrete members, the data on which they are based has a scatter of at least 15 to 30% using laboratory-controlled specimens.

4.4 Cantilevers

Cantilevers are often used for balconies and along the external edge of a building to balance the internal span and/or improve the shear capacity at edge and corner columns **Figure 5**. Regardless of the floor system chosen they always need careful consideration. Cantilevers are usually limited to a span of about 25 to 35% of the back span and should be supported by a stiff support such as a beam or column. They should not be supported off another cantilever at right angles. The deflection of a cantilever is sensitive to the rotation at the support. In particular, a long cantilever with a short back span may deflect down significantly or a short cantilever with a long backspan may deflect up significantly.

Where cantilevers, edges of floors and floors are exposed to weather, consideration will need to be made for set downs for finishes, falls for drainage and cover for durability, as well as the spacing and amount of reinforcement for crack control. With thin floors, such as flat slabs or flat plates, where cantilevers or the edges of the slab are exposed to view they will deflect between the column lines. This will possibly make the support of external walls difficult with differential deflections, and may result in an unacceptable visual profile along the edge of the structure even though it may be structurally adequate. Solutions include an edge beam or band beam or closely spaced supports or similar to stiffen the edge.

With some precast floor systems such as hollowcore, cantilever spans can be difficult to achieve and special consideration and consultation with the manufacturer should be made if these are required.

4.5 Vibration

AS 3600 does not prescribe any design criteria for the control of vibration. It merely requires that vibration be considered and appropriate action taken to ensure that vibration does not adversely affect the serviceability of the structure.

Aerobics, dancing and other rhythmic human activities have caused annoying vibrations in a number of buildings in recent years (particularly in cantilevers) in both insitu and precast construction. The two main factors behind these problems are resonance (where the natural frequency of the floor structure is equal to or close to a forcing frequency of the rhythmic activity), and the presence of other occupancies in the building such as offices or restaurants where people are sensitive to the vibrations generated. Where such activities are anticipated, the design team should obtain specialist advice.

4.6 Crack control

Concrete is a brittle material and even minor tensile strain will cause it to crack to some degree, in service. The various types of cracking are discussed in detail in *Durable Concrete Structures*[2].

Cracking may allow oxygen and moisture to reach the embedded steel, providing conditions where rusting of the steel can occur and spalling of the surface will result. A sufficient amount of closely spaced reinforcement limits the width of cracks, hence minimising the intrusion of water, and maintaining the protection of the steel. Prestressing may also be used to limit, or eliminate, cracking. High-quality concrete provides adequate corrosion protection for reinforcement for most conditions.

The structural and durability requirements of AS 3600 are based on a nominal crack width of 0.3 mm. Cracks that are not expected to exceed that width do not need repairing. Crack control for flexure in reinforced beams is based on the provision and adequate distribution of a minimum area of reinforcement. Restrictions are placed on either the bar diameter or the centre-to-centre spacing, depending on the tensile stress in the steel in critical tensile zones.

4.7 Check-list for structural design procedures

The structural design of concrete structures incorporating suspended long-span floor systems needs an appreciation of many factors and for these reasons must be carried out by a designer (usually a structural engineer) experienced in such design. The BCA provides a simplified and uniform set of regulations designed to establish essential construction standards for structural adequacy, fire resistance, public health and general amenity. The technical requirements of this code refer to AS 3600, as well as to other standards such as AS/NZS 1170.

In any structural design of floors, one designer should be responsible for the overall structural design including stability, robustness, movement joints, fire resistance and durability even if more than one designer is involved in the design process.

The following check list sets out the principal steps in designing a suspended concrete floor system to meet the requirements of the BCA and AS 3600. While it is written for insitu floors, a similar process applies for precast floors.

STEP 1 Member Arrangement

Determine a feasible arrangement for the suspended concrete floor system including slab thickness, band rib or beam sizes, supporting columns, walls, etc. The aim should be to arrive at a preferred option that is economical and structurally efficient. This may require preliminary design and assessment of two or more alternatives. Experience, the site constraints, the builder's or other preferences will sometimes dictate a solution.

STEP 2 Establish the Basic Design Criteria

- Occupancy of the structure (BCA)
- Fire rating (BCA)
- Sound transmission (BCA)
- Exposure classification and durability requirements (AS 3600)
- Any other special design criteria that may be required (eg heavy loads).

STEP 3 Floor System Sizing

Determine the minimum floor system thickness from Step 2 above, and with the chosen concrete strength and cover, use the span-to-depth ratios or charts in this Guide or other information available to the designer to determine the initial suspended floor system thickness.

STEP 4 Floor Thickness

Select a suitable overall thickness of floor system to satisfy expected deflection and which is equal to or greater than the thickness of the slab determined in Step 3. If the floor system is not thick enough then the designer will need to choose a greater thickness and repeat the design processes set out below until a suitable thickness is found.

STEP 5 Determine the Permanent and Imposed Actions (AS/NZS 1170)

This includes permanent and imposed actions as well as wind and earthquake loads where the floor system is part of the overall structural system.

STEP 6 Calculate Design Bending Moments and Shear Forces

Determine the design action effects at the critical sections in accordance with the strength requirements of AS 3600 for the chosen floor system.

STEP 7 Strength Design (AS 3600)

This requires detailed analysis of the floor system and detailed design including calculations and, if the floor system is not adequate for strength or if the flexural reinforcement or shear reinforcement is excessive, repeating the design from Step 4 until suitable sizes are determined. The final design calculations are usually required to be submitted to the local authority or checked and certified by others.

STEP 8 Calculate Deflection

Check the calculated deflection or the span-to-depth ratio using the simplified method in accordance with AS 3600 or by more-sophisticated analysis, or from manufacturer's information as appropriate. Estimate required camber, if any, or repeat the design from Step 4 if deflection is excessive until a satisfactory floor system thickness is found.

STEP 9 Complete Detailed Designs and Documentation

Complete the detailed calculations for all design aspects necessary for the particular project and finalise the documentation, ie drawings, specification, etc. It is important that the designer remembers that the documentation is the means of communicating the design intentions to the contractor/builder and it should be reviewed from this viewpoint before being issued. Guidance should be provided on how the structure is to be stabilised during erection of the elements until lateral stability is achieved by the completed structure. It may be necessary for the designer to describe the sequence for construction to ensure the design concept is not compromised and the structure remains stable during erection.

5 CONSTRUCTION CONSIDERATIONS

5.1 General

The considerations listed in this Section are general in nature and do not provide a checklist for all matters that need to be addressed. They should be supplemented by considerations specific to the particular project, eg the requirements for finish to floors, the proposed construction method, eg precast construction, and the location of the project.

In general, minimising the amount of labour on site, measures to minimise the construction period (or floor-to-floor construction time) and schedules that give early access for following trades and advanced occupation to part of the project will reduce the construction time, the holding charges and thus improve the economic viability of the project.

5.2 Formwork

Formwork for insitu concrete and propping of precast is a major consideration as it can directly affect the architectural appearance of the project and the construction cost and schedule. Formwork can be 50–75% of the direct cost of a floor. Generally, a specialist designer, employed by the contractor, will be responsible for formwork design. It will take into account the requirements of the specification and the construction process, eg construction loads, stripping, back propping, and specified finishes and formwork patterns **Figure 6**.

To simplify formwork, member sizes should be rationalised consistent with structural economy, eg band-beam widths of 1200, 1800 and 2400 mm will enable standard plywood sheets to be used. Similarly, drop panels in flat slabs should be dimensioned to suit plywood and timber sizes.

Because of the high cost of site labour, making soffit formwork on site is often avoided. Formwork is usually designed to have a number of reuses and to facilitate easy stripping and re-erection to keep the overall floor construction period as short as possible. Sophisticated table and flying forms have been used on multistorey projects, while, to minimise costs, precast floor units are sometimes preferred.

Early stripping of formwork and back propping allows early access to the floors by other trades. It also allows greater re-use of formwork and reduces the amount of formwork required. On the other hand, particularly for reinforced floors, if the formwork is removed too early and appropriate back propping and reshoring not carried out then the floor immediately below may carry most of the load before its design strength is fully developed. This may result in overstressing the floors and long-term deflection problems.

Back propping and reshoring of suspended floors in multi-storey construction can be a complex issue. In some circumstances the loads due to construction may exceed the design load of the floor as set out in AS/NZS 1170.2. As an example, a suspended floor over a reactive clay site with insufficient space for propping may have to carry the full construction load of the floor above. For further details on back propping see McAdam and Behan[3] and Beeby[4].

Prestressed floor systems will reduce stripping times compared to conventionally reinforced floor systems. Post-tensioned floors are usually fully stressed at 7 days allowing formwork to be stripped after this time. Reshoring and back propping, however, still need to be carefully considered.

FIGURE 6: Formwork is a major consideration in a project

5.3 Reinforcement

Reinforcement details should be as simple as possible to facilitate fixing, reduce the risk of errors and to simplify checking. Cogs and hooks should be limited to those that are essential. Mesh should be used where possible, while consideration should be given to using stock length bars for larger projects, and to using alternative bar sizes to distinguish column strips from middle strips. More information can be found in the *Reinforcement Detailing Handbook*[5].

Prefabricated cages and mats expedite reinforcement fixing, while standardising the layout to accommodate service ducts minimises problems likely to arise with arbitrary on-site adjustment of the layout to suit services. On larger jobs, consideration should be given to making a mock up of difficult areas to see if it is possible to simplify the reinforcement **Figure 7**.

In slabs, proprietary shear reinforcement should be used at columns instead of bent up bars and small ligatures which are difficult to fix and time consuming.

Mechanical splicing of reinforcement is the quickest method of developing continuity of the reinforcing bar across a construction joint without the need to damage the formwork or where lap splicing is not appropriate. A number of different splicing systems are available. The majority involve some form of threaded coupler that can be used to join two threaded bar ends together. However, designers should evaluate each coupler type to ensure that it will not significantly reduce the ductility of the reinforcement.

Post-tensioning should follow industry practice. Strand size commonly used in building work is 12.7 mm, either four or five in slab cables and seven in beams. This allows the use of lightweight jacks capable of stressing either individual strands or up to seven strands together. This eliminates problems associated with handling heavy jacking equipment within the confined areas of a floor deck. Use uniform recess sizes and dimensions for anchorages. Avoid interferences at intersection duct profiles especially at columns and slab corners. Consult a specialist post-tensioning company before finalising details.

FIGURE 7: Mock-up of complicated reinforcement details

5.4 Joints

Joints should be shown on the drawings as required by AS 3600, Clause 1.4.2. Construction joints should be shown on the drawings as it gives the builder/contractor an understanding of what joints need to be allowed for. They occur in slabs, columns, stairs and other structural elements. In vertical elements they are usually at the underside and/or topside of horizontal elements.

Where construction joints are exposed to view, designers should provide a rebate or similar to ensure they read as a straight line.

6 INSITU CONCRETE FLOOR SYSTEMS

6.1 General

There are many concrete floor systems from which the designer can select an economical and technically satisfactory solution.

Traditionally, concrete floor systems are reinforced using bars, fabric or using high-strength strand which is stressed. The action of prestressing with a straight or a draped cable in concrete enables the applied loads to be balanced by the uplift force so that practically no deflection results. This is a significant benefit in long-span floors as it eliminates the need to camber formwork or to provide deeper reinforced concrete sections.

In recent times, with the increasing popularity of partially prestressed concrete, the difference between normal reinforced concrete and traditional fully prestressed concrete has become less clear-cut. This approach combines prestressing's benefits of controlling deflection and cracking with the economy of reinforced concrete. For example, an economical floor system might comprise partially prestressed bands or beams (with both strand and reinforcement) in one direction combined with a normally reinforced slab in the other direction.

Even with a total prestressed system, bar reinforcement will be required for ductibility, crack control and for restraint at anchors and the like.

Spacing and location of columns and loadbearing walls need to be selected to provide the most economical structure and to meet spatial and other requirements. In the case of a multiple-use building such as a carpark, retail and residential, different column spacing may be required for each use, leading to transfer floors and transfer beams in some cases. Care should always be taken with the initial framing of a structure to ensure the most economical column and loadbearing wall locations are used. Slab spans in the past were often in the order of 8–9 m, but longer spans have been used in recent years.

With the trend towards longer spans, the criterion of stiffness has become more important, so that in practice the dimensions of the floor are determined by stiffness considerations rather than strength.

Longer span floors generally have a greater structural depth, higher self weight, possible problems with vibration and deflection, and increased cost. However, when taken as part of the overall cost of the structure these costs may be acceptable. In many cases the addition of a few strategically placed columns or loadbearing walls can significantly reduce the slab span. Sensible positioning of columns need not detract from the flexibility of floor areas. The cost to provide long-span column-free space may not be warranted in all cases.

For continuous spans, reducing the outer span to about 75–80% of the inner spans can minimise the need for deeper floor systems in the external spans. Similarly, cantilevers may be used to balance the inner span, but see comments on the use of cantilevers in Section 4.4.

Particular attention should always be given to the corners and the edges of the floor system where two-way behaviour of the slab is likely to occur (depending on the stiffness of edge beams and columns) and the effects of lack of continuity should be considered.

With all floor systems, careful consideration should be given to shrinkage of floors and shortening due to prestress. Both processes, and particularly the latter, will generate significant forces in the floor system if it is restrained by walls or stiff columns, especially if they are located near or at each end of the floor system and parallel to the direction of stressing. This in turn can lead to significant cracking and other problems. Techniques to overcome these problems include pour strips, slip joints and the like.

An examination of some of the common examples of concrete floor systems follows. These cover both single and multiple spans.

A quick selection of possible floors can be made from the chart in **Figure 8**. The preliminary design thickness can then be assessed from the particular chart for each floor system. Note that these floor thicknesses/beam depths should be used only as the basis for detailed design.

All of the charts in Sections 6.2 to 6.7 are based on a regular grid with equal or near-equal spans. They are for initial sizing and preliminary design only before carrying out the detailed design of the selected floor system. Detailed design should be carried out in accordance with the suggested design procedure set out in Section 4.7.

The following assumptions have been made in preparing the charts for insitu floors. Designers should satisfy themselves that the particular floor system they are designing meets these assumptions or make appropriate adjustments to the preliminary sizes to cover variations in the assumptions:

- For continuous spans there are 3 or more spans (in each direction for two-way systems) with a cantilever at each end so that equal or near equal deflections and bending moments are achieved in each span
- For a single span the floor spans one way from a core wall to a suitable edge beam or column. The core wall has been assumed to provide full continuity to the floor system
- Pattern loading is not considered for vertical loads. AS 3600 covers pattern loading when required
- Slabs are regular and do not have spans in orthogonal direction greater than 2 to 1
- Spans do not vary by more than 25%
- Uniform loads are applied to all spans
- Loads are in the range of 1.5 to 5.0 kPa, ie domestic to office type loadings.

Actual floor systems in buildings come in all sizes, shapes, and forms. There are so many variables to any floor system such as different spans, offset spans, cantilevers, and the extent of continuity, the effects of beams, columns and walls on the slab system, etc that it is difficult to cover all situations in a limited series of charts. With the range of sophisticated computer packages now available for concrete floor design, it is strongly recommended that once a floor system and initial sizes are chosen then a series of trial runs be carried out to determine the appropriate thicknesses and details as part of the preliminary design process.

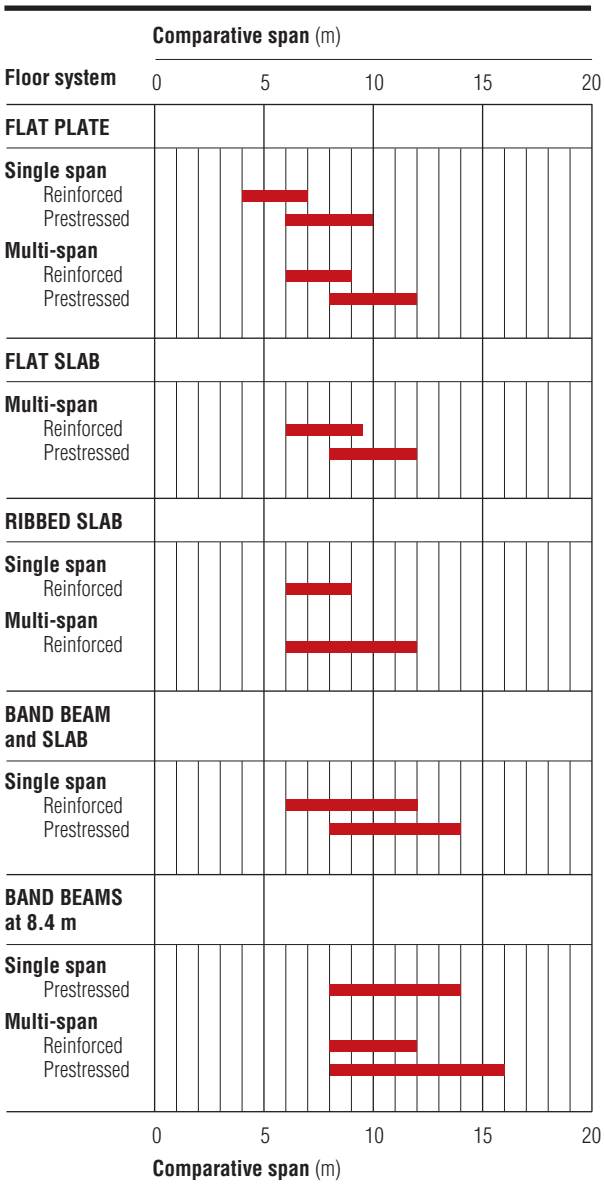


FIGURE 8: Quick selection guide for insitu floors

6.2 Flat Slab

A flat slab is a one-way or two-way system with thickenings in the slab at the columns and loadbearing walls called 'drop panels' **Figure 9**. Drop panels act as T-beams over the supports. They increase the shear capacity and the stiffness of the floor system under vertical loads, thus increasing the economical span range. This form of construction has become less popular in recent years because of the limit on economical spans of about 9.5 m for reinforced slabs and about 12 m for prestressed slabs. Reinforced flat slabs may need to be sensibly pre-cambered (not overdone) to control deflection.

The plan dimensions of the drop panels are a minimum of 1/3 of the span in the direction under consideration, usually rounded to the nearest 100 mm. The overall depth of the drop panel is typically taken as 1.75 to 2 times the depth of the slab, again rounded to suit timber sizes or the nearest 25 mm.

The principal features of a flat slab floor are a flat soffit, simple formwork and easy construction. The economical span 'L' of a reinforced concrete flat slab is approximately D x 28 for simply supported, D x 32 for an end span and D x 36 for an interior span. Prestressing the slab increases the economical span to D x 35, D x 40 and D x 45 respectively, where D is the depth of the slab excluding the drop panel.

FIGURE 9: Flat slab floor system

Advantages:

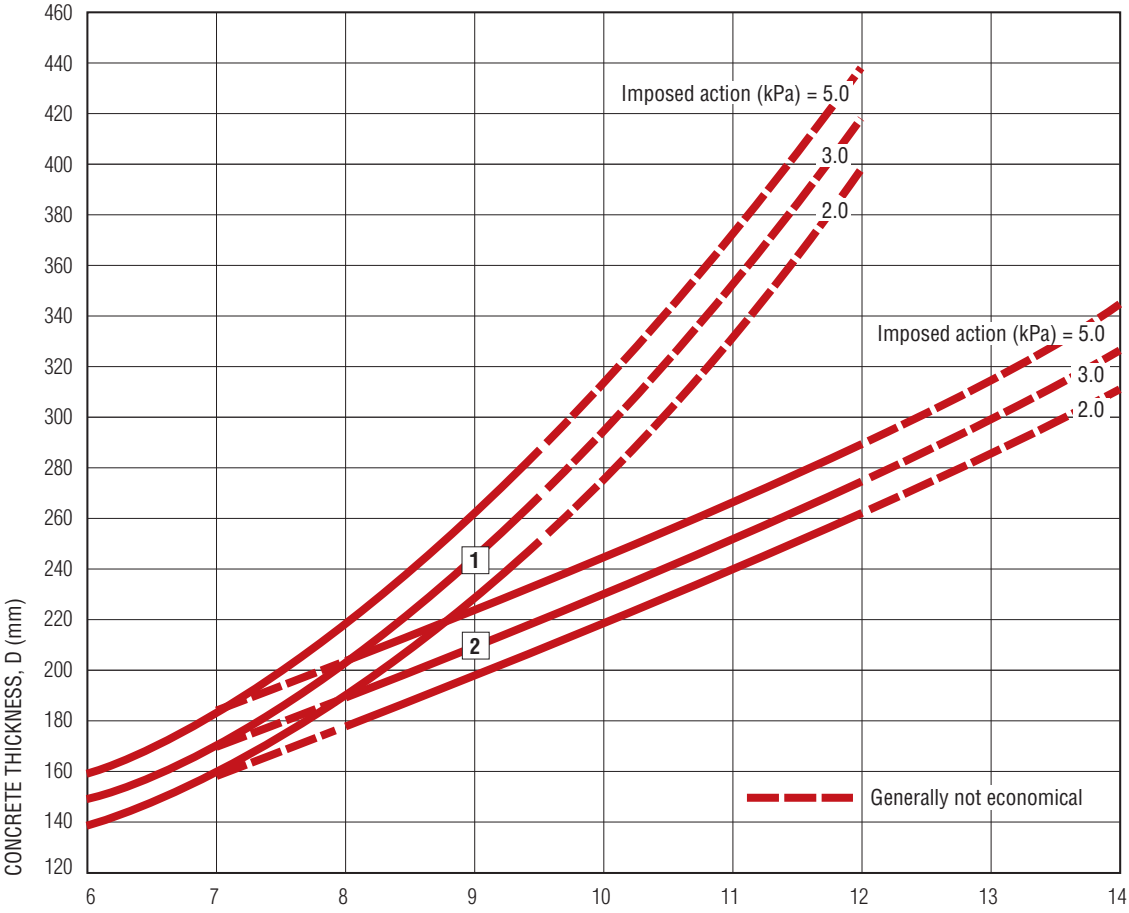
- Simple formwork
- No beams—simplifying under-floor services outside the drops
- Minimum structural depth
- Usually does not require shear reinforcement at the columns.

Disadvantages:

- Medium spans
- Generally not suitable for supporting brittle (masonry) partitions
- Drop panels may interfere with larger mechanical ducting
- Vertical penetrations need to avoid area around columns
- For reinforced flat slabs, deflection at the middle strip may be critical.

REINFORCED FLAT SLAB and PRESTRESSED FLAT SLAB

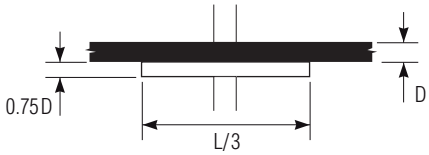
Multi-span



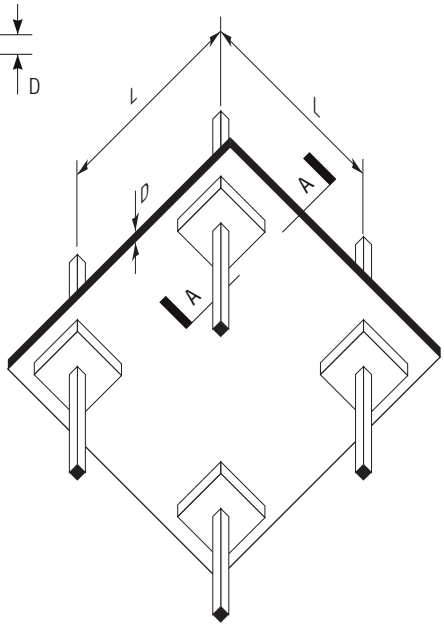
CURVES

1 Reinforced

2 Prestressed



SECTION A–A



NOTES:

1 For preliminary design and initial sizing only.

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

- a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed
- b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

5 For typical square grid, interior span only

6 With reinforced flat slabs, for spans over 9 m, while the deflection for column strips is less than span/250 the total deflection at mid-span is likely to exceed 25 mm

6.3 Flat Plate

A flat plate is a one- or two-way system usually supported directly on columns or loadbearing walls **Figure 10**. It is one of the most common forms of construction of floors in buildings. The principal feature of the flat plate floor is a uniform or near-uniform thickness with a flat soffit which requires only simple formwork and is easy to construct. The floor allows great flexibility for locating horizontal services above a suspended ceiling or in a bulkhead.

The economical span of a flat plate for low to medium loads is usually limited by the need to control long-term deflection and may need to be sensibly pre-cambered (not overdone) or prestressed. An economical span for a reinforced flat plate is of the order of 6 to 8 m and for prestressed flat plates is in the range of 8 to 12 m.

The span 'L' of a reinforced concrete flat-plate is approximately D x 28 for simply supported, D x 30 for an end span of a continuous system, to D x 32 for internal continuous spans. The economical span of a flat plate can be extended by prestressing to approximately D x 30, D x 37 and D x 40 respectively, where D is the depth of slab.

Advantages:

- Simple formwork and suitable for direct fix or sprayed ceiling
- No beams—simplifying under-floor services
- Minimum structural depth and reduced floor-to-floor height.

Disadvantages:

- Medium spans
- Limited lateral load capacity as part of a moment frame
- May need shear heads or shear reinforcement at the columns or larger columns for shear
- Long-term deflection may be controlling factor
- May not be suitable for supporting brittle (masonry) partitions
- May not be suitable for heavy loads.

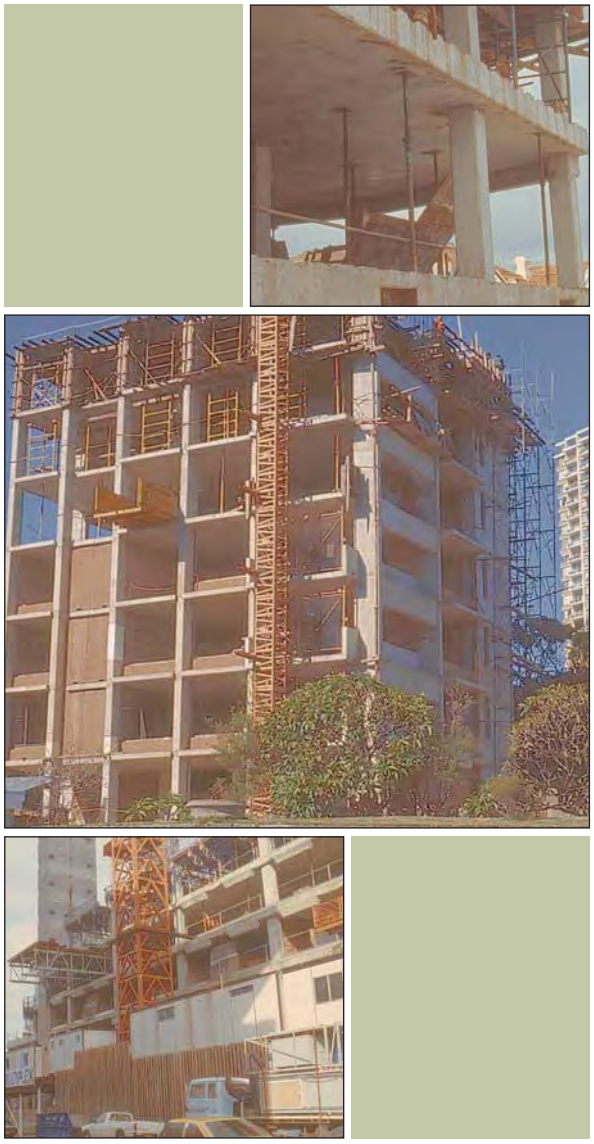
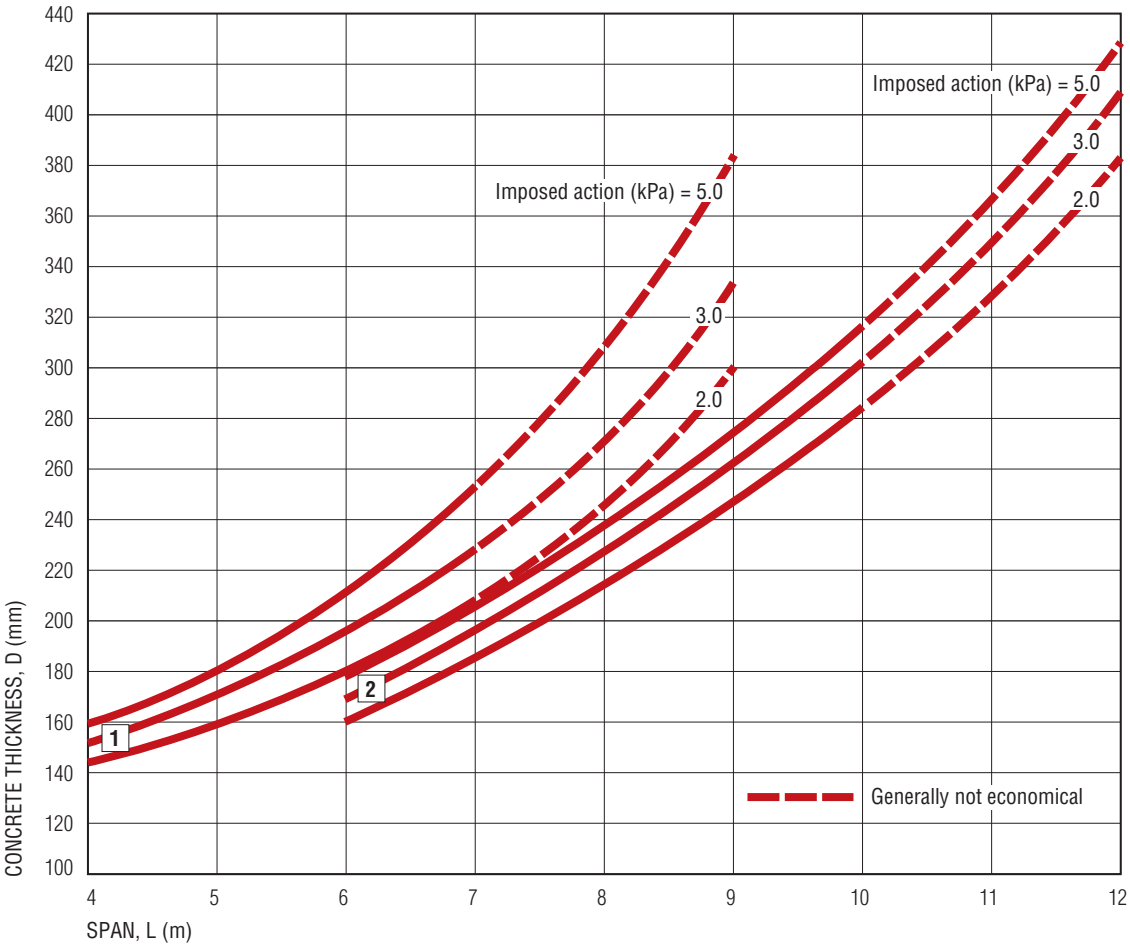


FIGURE 10: Flat plate floor system

REINFORCED FLAT PLATE and PRESTRESSED FLAT PLATE

Single Span



CURVES

1 Reinforced

2 Prestressed

NOTES:

1 For preliminary design and initial sizing only.

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

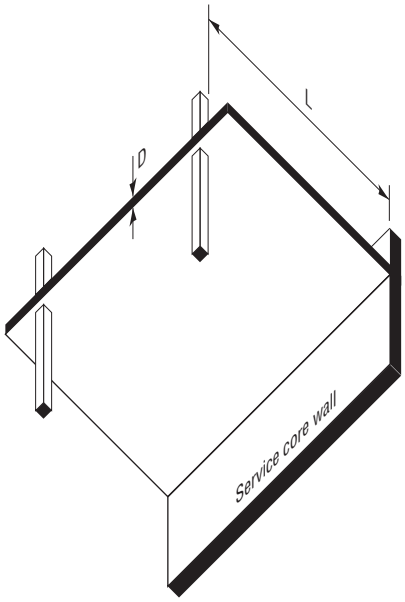
- a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed
- b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

5 Full continuity at the core wall assumed

6 Unsupported edges of floors may require stiffening for support of external walls and/or visual reasons

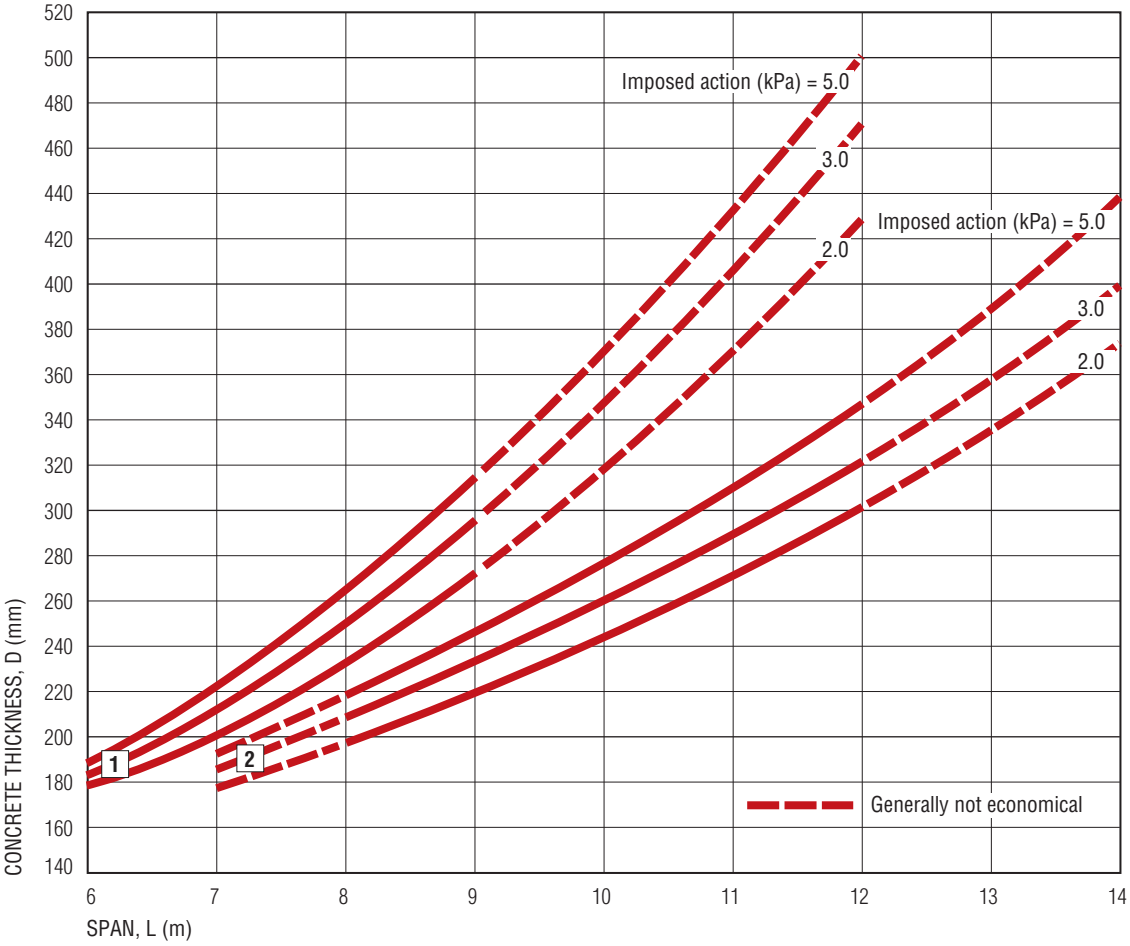
7 For larger spans, shear heads or reinforcement may be required at the columns

8 Deflection to be the lesser of span/250 or 35 mm



REINFORCED FLAT PLATE and PRESTRESSED FLAT PLATE

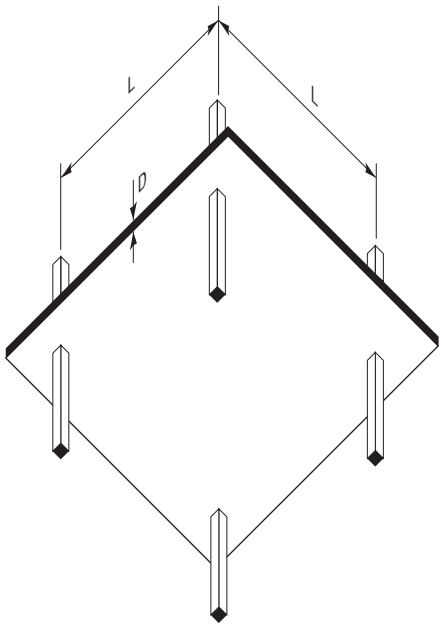
Multi-span



CURVES

1 Reinforced

2 Prestressed



NOTES:

1 For preliminary design and initial sizing only.

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

- a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed
- b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

5 For typical square grid, interior span only

6 Deflection to be the lesser of span/250 or 35 mm

6.4 Beam and Slab

This system consists of beams framing into columns and supporting slabs spanning between the beams **Figure 11**. It is a very traditional system. The relatively deep beams provide a stiff floor capable of long spans, and able to resist lateral loads. However, the complications of beam formwork, co-ordination of services, and overall depth of floor have led to a decrease in the popularity of this type of floor.

The traditional reinforced concrete beam-and-slab floor has an economical span 'L' of D x 15 for a single span and D x 20 for a multi-span, where D is the depth of the slab plus beam. The depth of slab between the beams can be initially sized using the span-to-depth ratios for a flat plate. Prestressing is not normally used with this system.

Advantages:

- Traditional effective solution
- Long spans.

Disadvantages:

- Penetrations through beams for large ducts difficult to handle
- Depth of floor
- Greater floor-to-floor height.

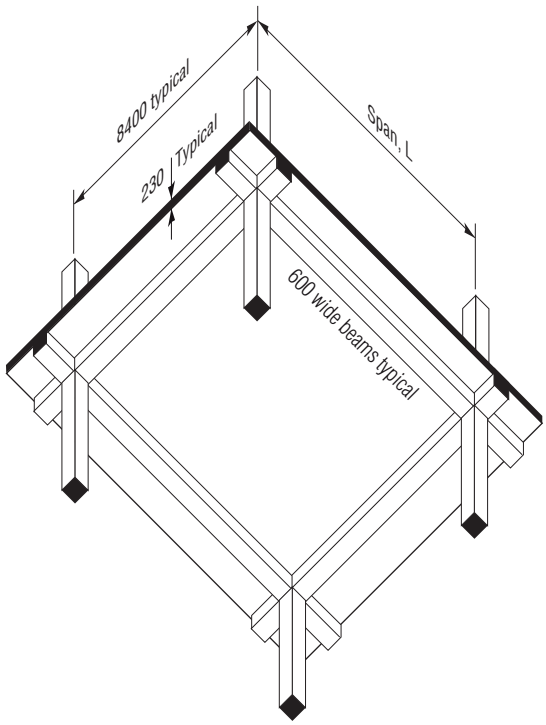


FIGURE 11: Beam and slab system

6.5 Ribbed (Waffle) Slab

Ribbed floors consisting of equally spaced ribs are usually supported directly by columns **Figure 12**. They are either one-way spanning systems known as ribbed slab or a two-way ribbed system known as a waffle slab. This form of construction is not very common because of the formwork costs and the low fire rating. A 120-mm-thick slab with a minimum rib thickness of 125 mm for continuous ribs is required to achieve a 2-hour fire rating. A rib thickness of greater than 125 mm is usually required to accommodate tensile and shear reinforcement. Ribbed slabs are suitable for medium to heavy loads, can span reasonable distances, are very stiff and particularly suitable where the soffit is exposed.

Slab depths typically vary from 75 to 125 mm and rib widths from 125 to 200 mm. Rib spacing of 600 to 1500 mm can be used. The overall depth of the floor typically varies from 300 to 600 mm with overall spans of up to 15 m if reinforced, longer if post-tensioned. The use of ribs to the soffit of the slab reduces the quantity of concrete and reinforcement and also the weight of the floor. The saving of materials will be offset by the complication in formwork and placing of reinforcement. However, formwork complication is minimised by use of standard, modular, reusable formwork, usually made from polypropylene or fibreglass and with tapered sides to allow stripping.

For ribs at 1200-mm centres (to suit standard forms) the economical reinforced concrete floor span 'L' is approximately D x 15 for a single span and D x 22 for a multi-span, where D is the overall floor depth.

The one-way ribs are typically designed as T-beams, often spanning in the long direction.

A solid drop panel is required at the columns and loadbearing walls for shear and moment resistance.

Advantages:

- Savings on weight and materials
- Long spans
- Attractive soffit appearance if exposed
- Economical when reusable formwork pans used
- Vertical penetrations between ribs are easy.

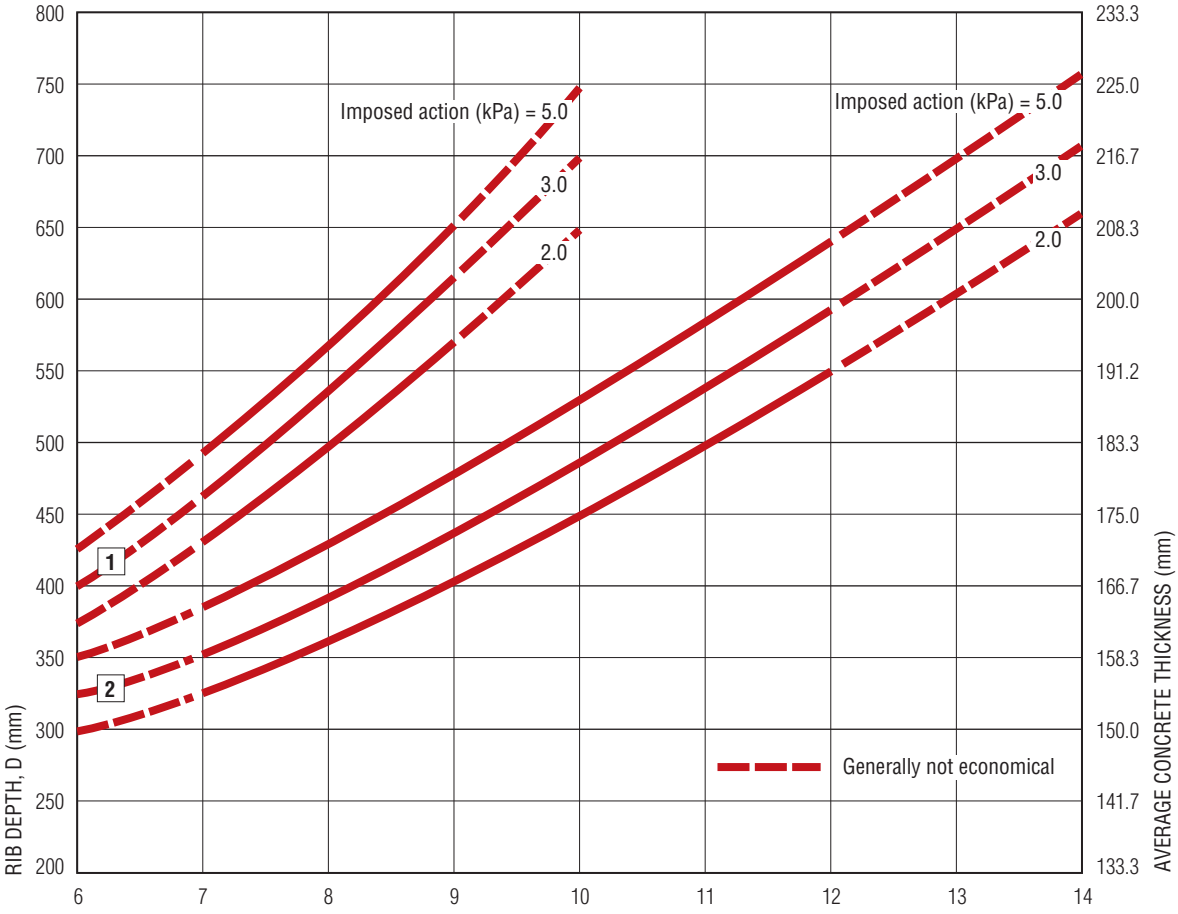
Disadvantages:

- Depth of slab between the ribs may control the fire rating
- Requires special or proprietary formwork
- Greater floor-to-floor height
- Large vertical penetrations are more difficult to handle.

FIGURE 12: Ribbed (waffle) slab supported directly by columns

REINFORCED RIBBED SLAB

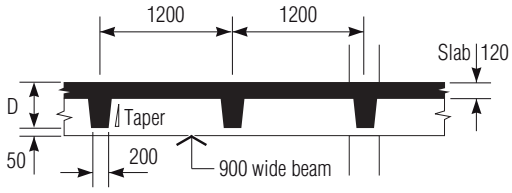
Single and Multi-span



CURVES

1 Single span

2 Multi-span



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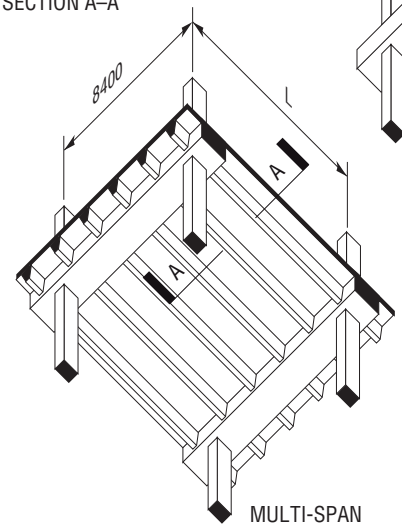
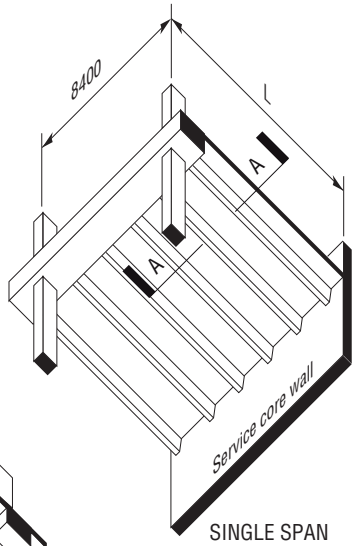


MULTI-SPAN



SINGLE SPAN

NOTES:

1 For preliminary design and initial sizing only.

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

- a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed
- b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

5 For single-span, continuity at core wall assumed. For multi-span, typical interior span assumed

6 Deflection of rib to be the lesser of span/250 or 35 mm

6.6 Band Beam and Slab

This system consists of a series of parallel, wide, shallow beams (known as band beams or thickened slab bands) with the floor slab spanning transversely between the bands **Figure 13**. The floor slab is designed as a continuous slab, with the shallow band beams carrying all loads from the slab. Band beams or thickened slab bands are a two-way slab system designed in accordance with Clause 7.5 of AS 3600 and are not treated as beams, except for shear under Clause 8.2 of AS 3600.

Band beams are commonly used for longer span structures often with the bands post-tensioned and the slabs reinforced. Sometimes, composite concrete/metal decking is used for the slabs, provided the slab spans are not too large.

The band beam has a relatively wide, shallow cross section which reduces the overall depth of floor while permitting longer spans similar to the traditional concrete beam. The concrete section simplifies both the formwork and services which can pass under the beams.

Advantages:

- Relatively simple formwork
- Shallow beams to allow services to run under the floor
- Minimum structural depth and reduced floor-to-floor height
- Long spans
- Good cost/time solution
- Allows the use of flying forms.

Disadvantages:

- Long-term deflection may be controlling factor and post-tensioning may be required
- May need service penetrations through beams which are difficult to handle.

In a single-span floor, the spacing of the band beams may coincide with the columns, or the bands may be more closely spaced to reduce the thickness of the slab spanning between walls or beams. For single-span reinforced concrete floors the economical span 'L' of the band beam is D x 20 to D x 22 depending on the width and spacing of the band beam, where D is the depth of the slab plus band beam. Prestressing the band beam gives economical band-beam spans in the range of D x 24 to D x 28. In a multi-span floor, the spacing of the band beams is fixed by the transverse spacing of the columns.

For initial sizing of the slab, the span-to-depth ratios from Section 6.3 can be used. For internal spans the slab thickness is based on the clear span between band beams, and for an external bay is from the edge of band to the column line of the external band. The depth of the band is typically 1.5 to 2 times the depth of the slab and the minimum economical span for a band beam is about 7–8 m.

In multiple spans using reinforced concrete, the economical slab of the band beam 'L' is approximately D x 22 for 1200-mm-wide band beams and D x 26 for a 2400-mm-wide beams at 8400-mm centres. Prestressing increases the economical span 'L' to D x 24 to D x 28 for similar beam widths. D is the depth of slab plus band beam in each case.

The maximum span for reinforced concrete bands should not normally exceed 12 m. Above this span, bands should be prestressed. The slab band width should be between band-spacing/3 to band-spacing/4 and, where possible, should be based on a module of a standard sheet of ply of 2.4 m x 1.2 m.

Vertical sides should be used if possible to simplify formwork. Sloping sides are sometimes used where bands are exposed to view or where the effective span of the slab needs to be reduced.

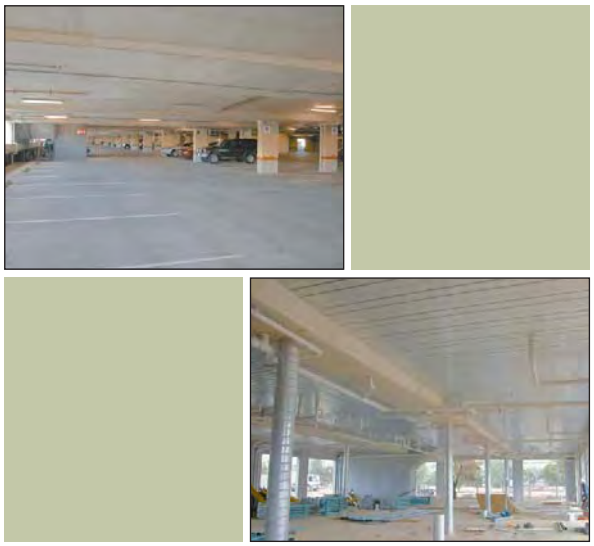
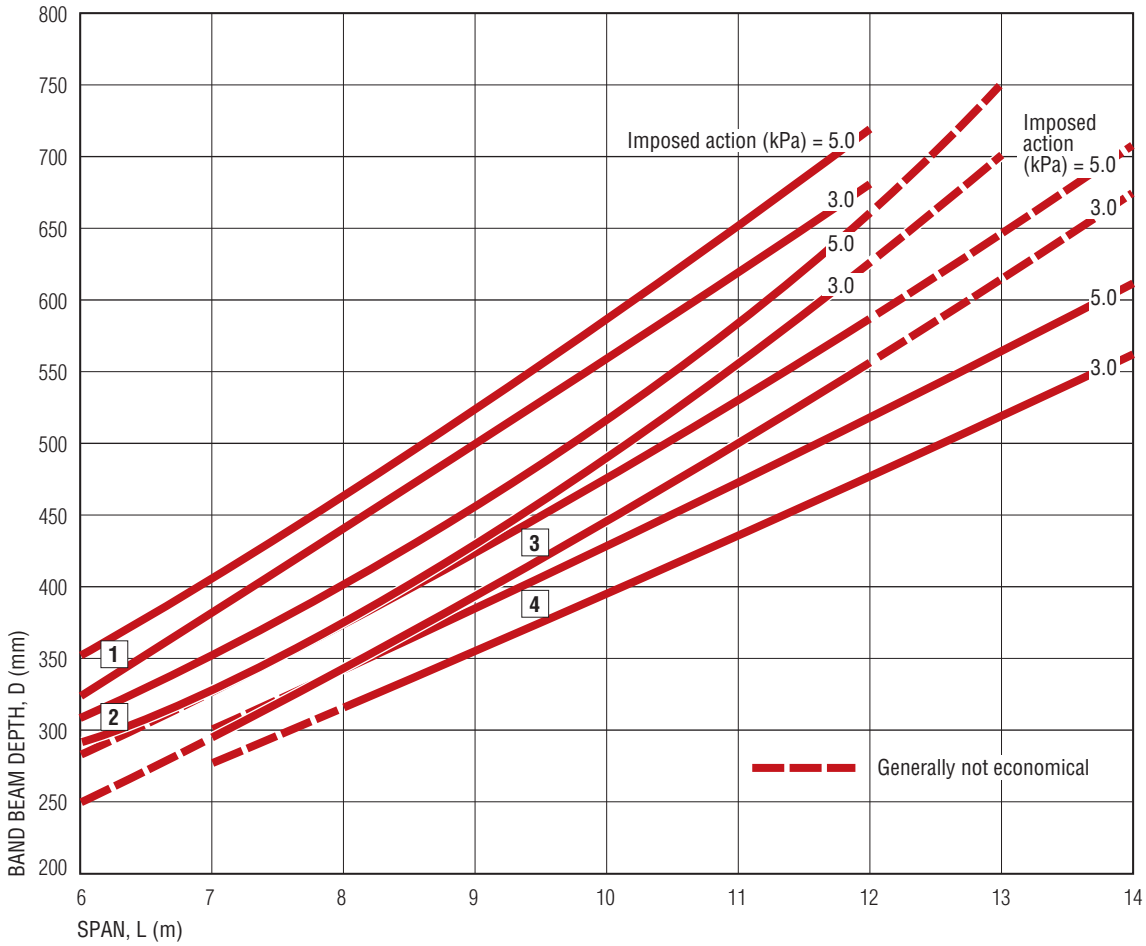
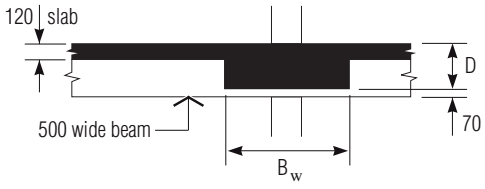


FIGURE 13: Band beam and composite/metal decking slab

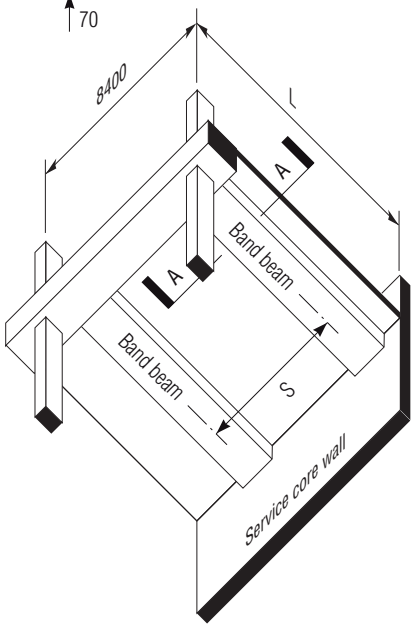
REINFORCED and PRESTRESSED BAND BEAMS and SLAB **Single Span**





SECTION A–A

CURVES		B_w	S
1	Reinforced,	600	4200
2	Reinforced,	1200	4800
3	Reinforced,	2400	6000
4	Prestressed,	1200	4000



NOTES:

1 For preliminary design and initial sizing only.

2 Imposed action of 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

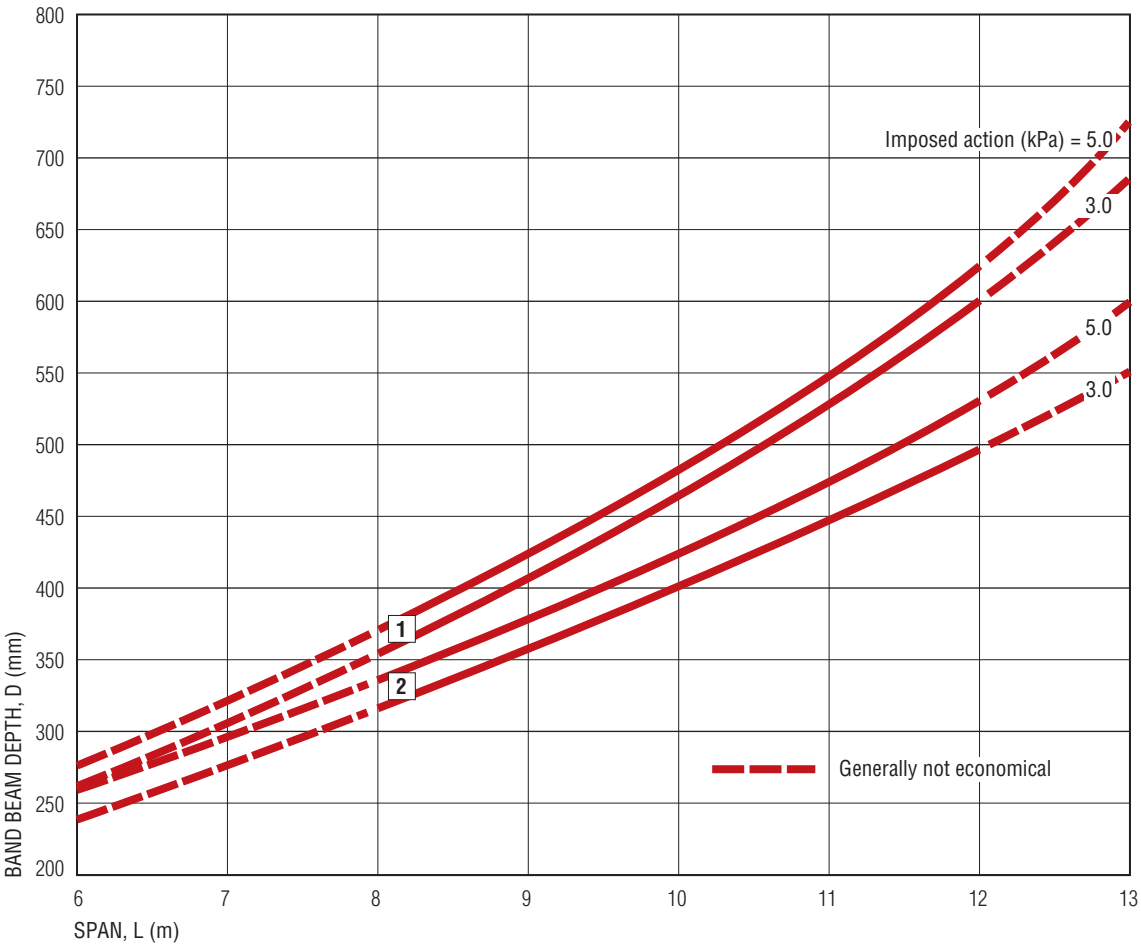
3 A 120/120/120 Fire Resistance Level assumed

4 For imposed actions of 3.0 kPa and 5.0 kPa, an additional permanent action (dead load) of 1.5 kPa has been included with the imposed actions (live load) when preparing this chart

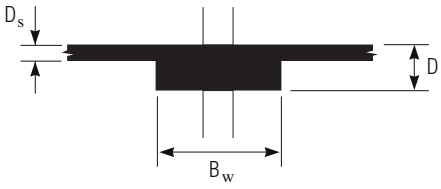
5 Continuity at core wall assumed

6 Deflection of band beam to be the lesser of span/250 or 35 mm

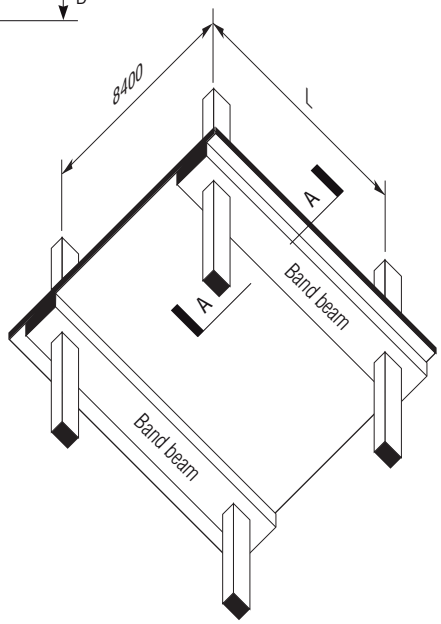
REINFORCED BAND BEAMS at 8.4 m CENTRES **Multi-span**



CURVES		B_w	D_s
1	Reinforced,	1200	200
2	Reinforced,	2400	170



SECTION A–A



NOTES:

1 For preliminary design and initial sizing only.

2 Imposed action of 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

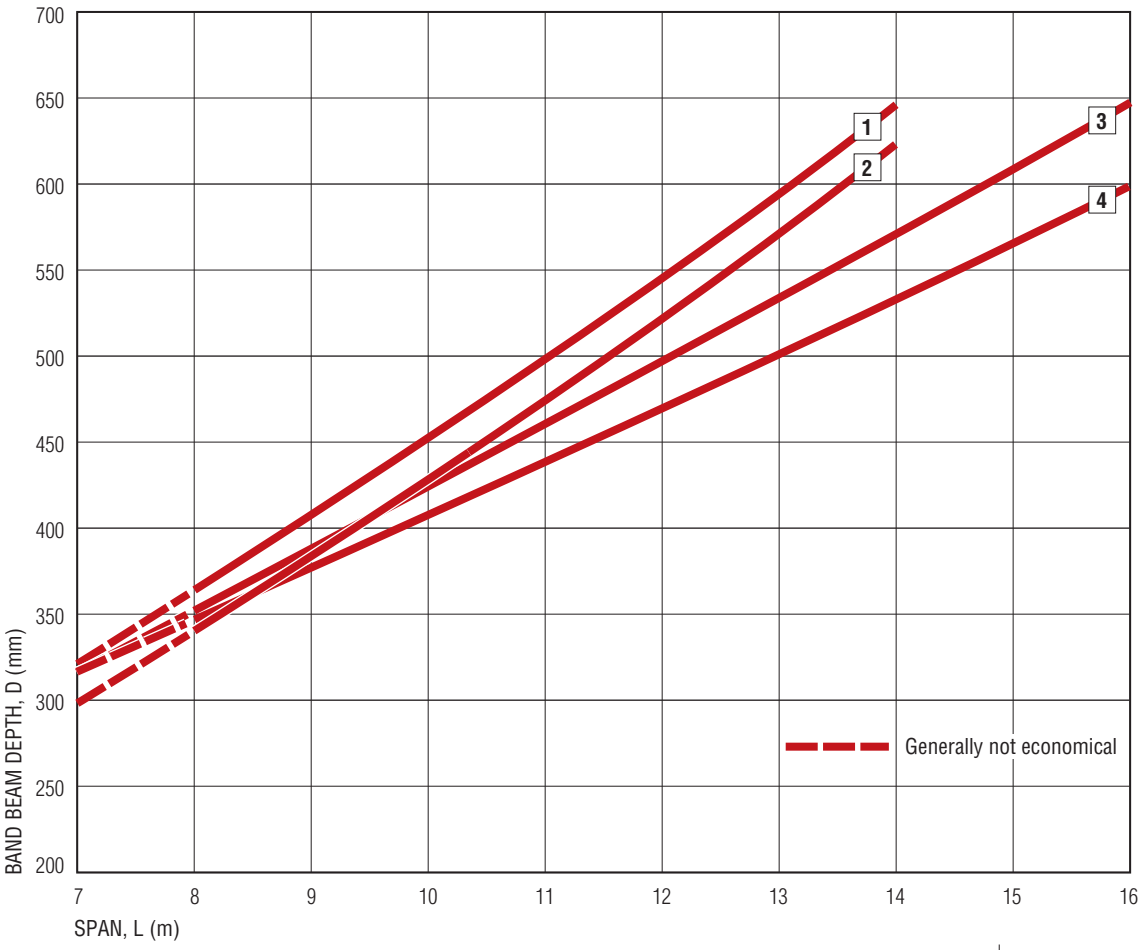
4 For imposed actions of 3.0 kPa and 5.0 kPa, an additional permanent action (dead load) of 1.5 kPa has been included with the imposed actions (live load) when preparing this chart

5 Typical interior span assumed

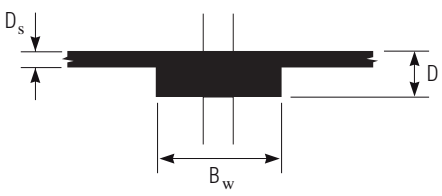
6 Deflection of band beam to be the lesser of span/250 or 35 mm

PRESTRESSED BAND BEAMS at 8.4 m CENTRES

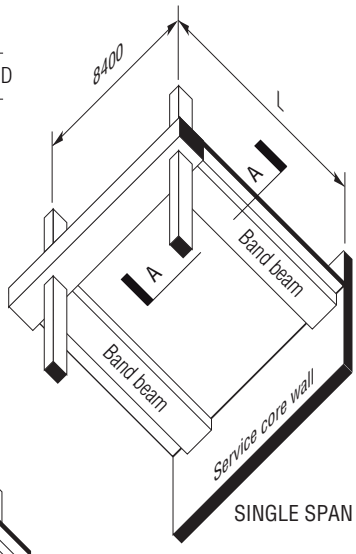
Single and Multi-span



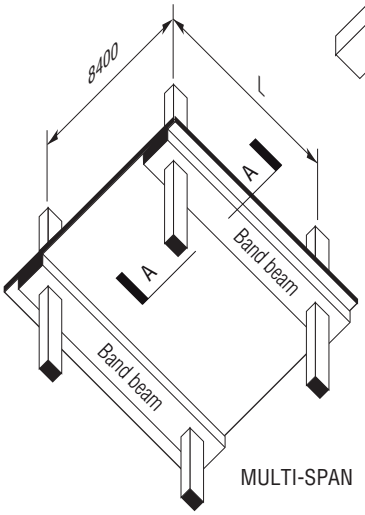
CURVES		B_w	D_s
1	Single span,	1800	160
2	Single span,	2400	150
3	Multi-span,	1800	160
4	Multi-span,	2400	150



SECTION A–A



SINGLE SPAN



MULTI-SPAN

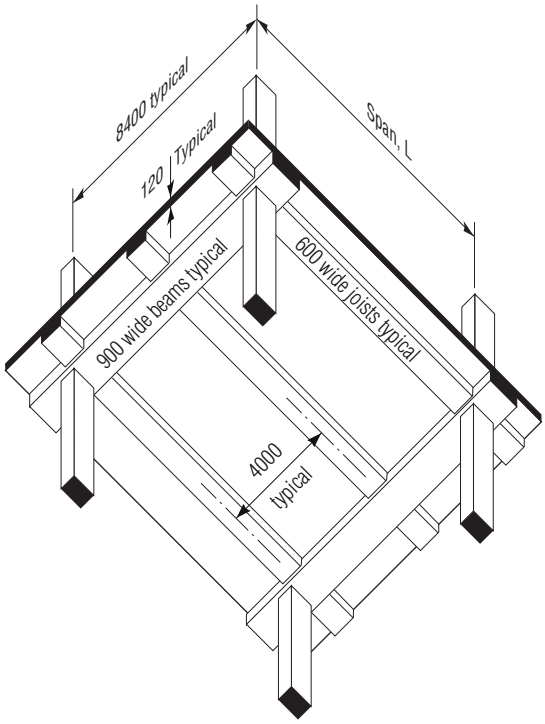
NOTES:

1. For preliminary design and initial sizing only.
2. Curves are for an imposed action of 5.0 kPa (typical for assembly areas without fixed seating) to which has been added a permanent action (dead load) of 1.5 kPa
3. A 120/120/120 Fire Resistance Level assumed
4. For single span, continuity at core wall assumed. For multi-span, typical interior span assumed
6. Deflection of band beam to be the lesser of span/250 or 35 mm

6.7 Slab and Joist

This system consists of a slab spanning between beams (which span between columns) and usually an intermediate joist in one direction.

Frequently, the slab thickness between the joists is controlled by requirements for fire-resistance. For example, a 2-hour fire resistance rating requires a 120-mm slab thickness, which is capable of spanning approximately 4 m. For this widely spaced rib or joist floor the economical span 'L' is D x 18 for a single span and D x 22 for a multi-span. Prestressing the joists permits the span to be increased to D x 24 and D x 28 respectively, where D is the depth of floor including the slab and joist.



Advantages:

- Thin slab panels possible
- Suits industrial structures
- Long spans
- Vertical penetrations between beams easily accommodated.

Disadvantages:

- More formwork
- Joists and beams intrude on services
- Depth of floor
- Greater floor-to-floor height.

7 PRECAST AND COMPOSITE FLOOR SYSTEMS

7.1 General

These systems consist of precast floor elements spanning one way onto either insitu or precast beams or precast beam shells or other suitable supports. The precast floor elements are usually simply supported before a topping concrete is placed to complete the system.

Precasting offers the advantages of off-site manufacture under factory conditions and fast erection on site. When combined with prestressing, additional benefits of long span and high load-capacity can be obtained. A number of different systems are available including:

- Hollowcore planks, either with or without a topping
- Composite flooring using precast permanent formwork panels
- Composite flooring using precast beam and infill
- Solid slabs either reinforced or prestressed
- Single and double T-beams.

Manufacturers will usually deliver precast concrete panels to the builder's time schedule, thus allowing panels to be lifted from the transport and placed directly into position. A quick selection of possible floors can be made from the chart in **Figure 14**. The preliminary design thickness can then be assessed from the particular chart for each floor system. Note that these floor thicknesses/beam depths should be used only as the basis for detailed design. Comprehensive information on precast floor systems can be found in the *Precast Concrete Handbook*[6].

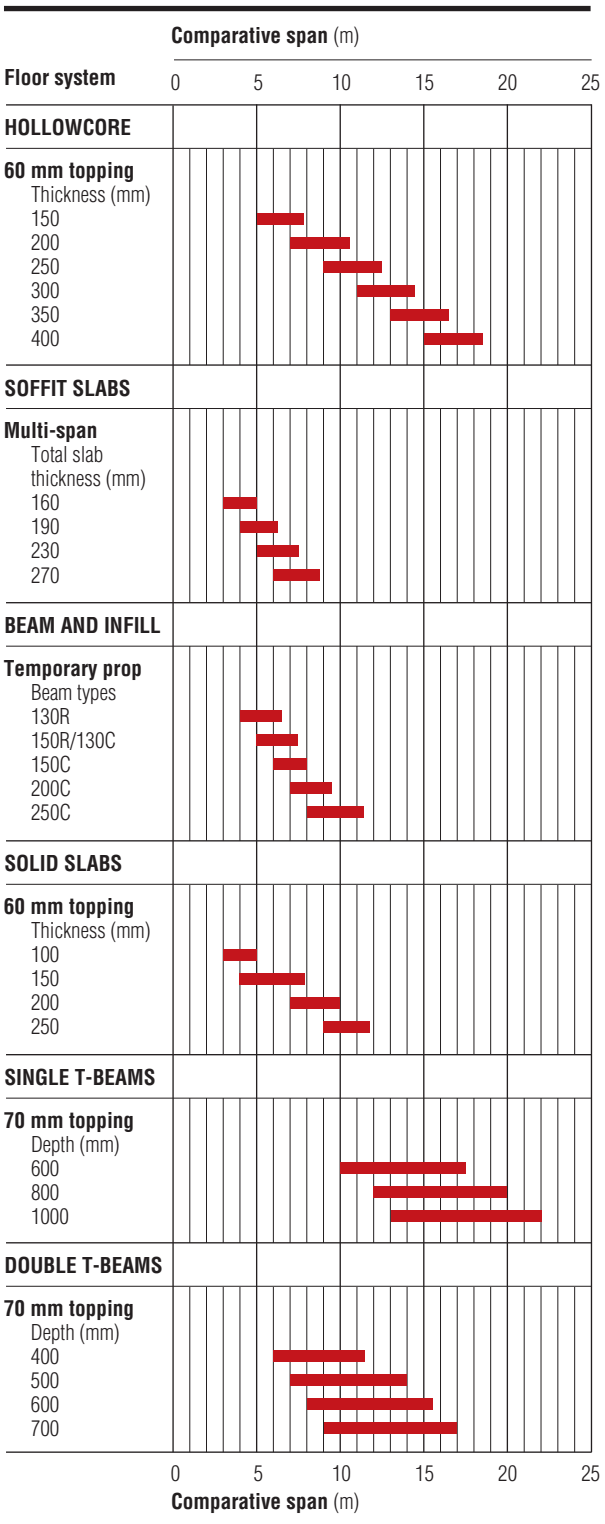


FIGURE 14: Quick selection guide for precast floors

7.2 Hollowcore

Hollowcore floor planks are precast, prestressed units produced on long-line casting beds using slide forming or extrusion methods **Figure 15**. During manufacture, cores are formed throughout the unit, reducing its self-weight. Planks are usually 1200-mm-wide, though some manufacturers can produce 2400-mm-wide units. These wider units may require increased crane capacity but offer greater speed of placement, less joints, grouting and sealing. Thicknesses vary from 150–400 mm in 50-mm increments. The thickness is determined by span, loading, fire rating and cover to reinforcement to satisfy exposure conditions. Profiled edges form shear keys between units.

The economical typical span for a precast hollowcore unit is approximately D x 30 to D x 35 where D is the depth of the precast unit plus topping. Where slenderness ratios fall between 35:1 and 45:1 panels should be checked for vibration-resonance effects. Spans exceeding 45:1 should not be used.

Planks may be used as plain sections or topped to give a composite unit. The topping increases plank capacity and fire rating. It provides a level surface or drainage falls and is recommended for most building work.

For economy, the structure should be dimensioned to accommodate the 1200- or 2400-mm modular plank width. If this is not possible, planks can be sawn longitudinally by the manufacturer, or partial-widths wet cast. Planks can be supplied with block-outs and cored holes to suit openings, services, etc. The permitted core-hole shape and number in a plank will vary with the depth and the particular proprietary forming machine.

Fire rating is a function of the effective concrete thickness and the concrete cover to strand. Fire rating can be increased by the addition of a concrete topping and cover increased by application of insulating material to the soffit. Comprehensive information on fire-resistance levels can be found in *Hollowcore Flooring Technical Manual*[7].

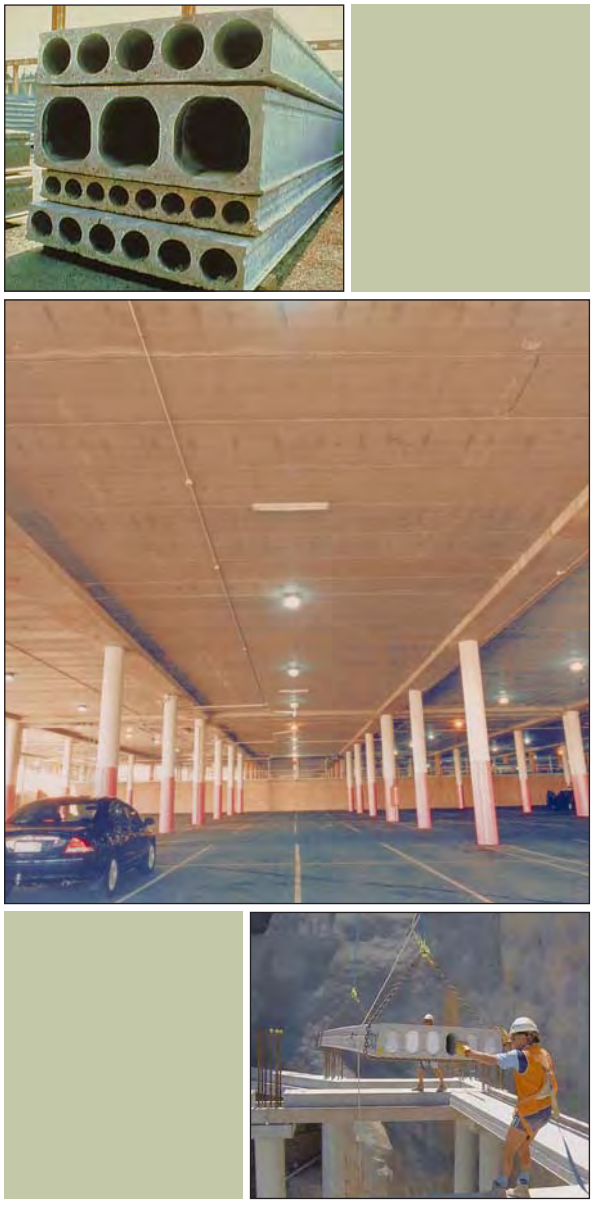
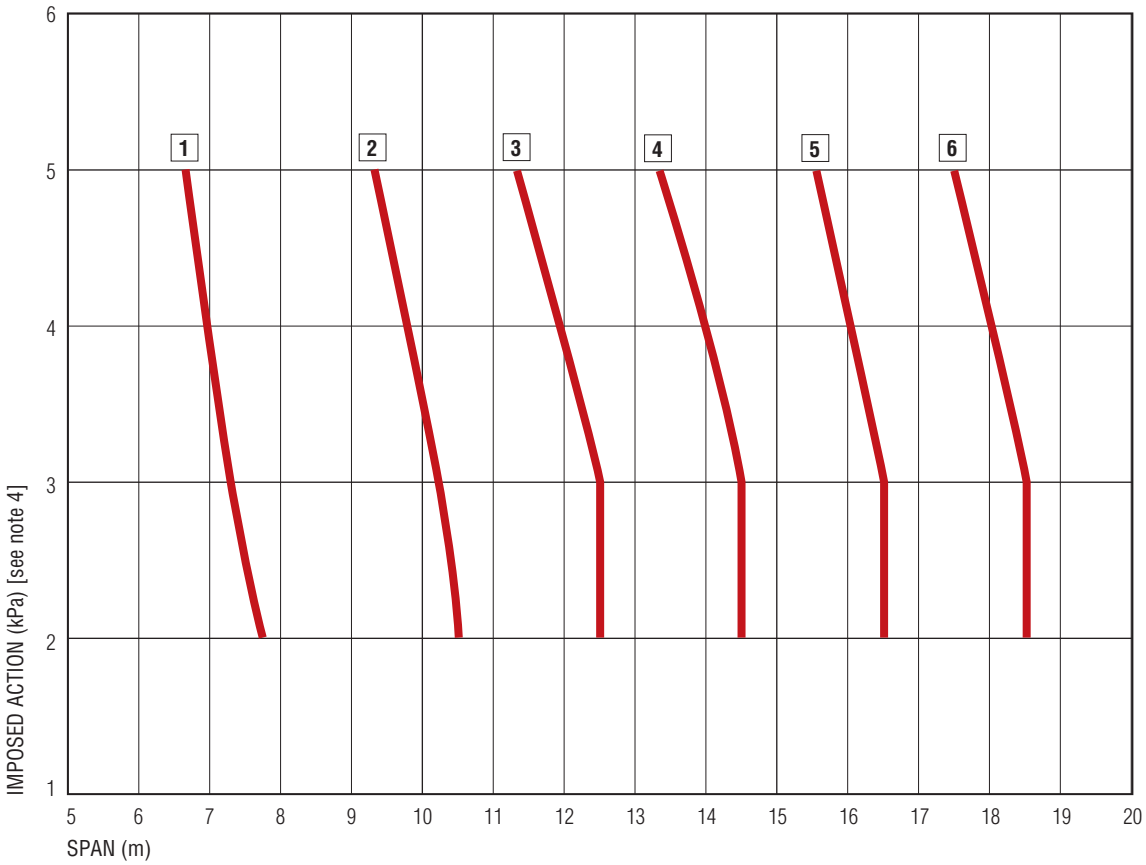


FIGURE 15: Hollowcore planks floor system

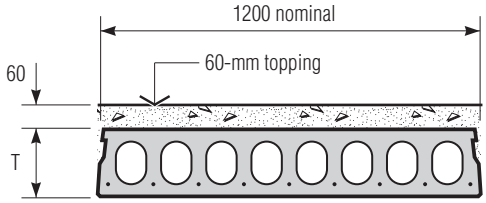
HOLLOWCORE PLANKS WITH 60-mm TOPPING

Single Span



CURVES

1. **150**/8-9.3/40
2. **200**/7-12.7/40
3. **250**/9-12.7/40
4. **300**/11-12.7/40
5. **350**/13-12.7/40
6. **400**/16-12.7/40



NOTES:

1. For preliminary design and initial sizing only. Refer to the specific manufacturer's design information for actual load capacities and design information for the chosen system
2. Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating
3. A 120/120/120 Fire Resistance Level assumed
4. The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:
   a. For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed
   b. For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

PLANK IDENTIFICATION

7.3 Permanent Formwork or Soffit Slabs

The system, known by several names depending on the manufacturer (eg *Transfloor*, *Humeslab*) incorporates precast concrete slabs, usually 55-mm-thick, with embedded reinforcement and trusses **Figure 16**. To complete the floor, an insitu concrete topping acts compositely with the precast panels.

For long spans, soffit slabs require temporary props for support until the composite section is able to carry the construction loads.

The bottom reinforcement embedded in the precast panel may consist of a layer of mesh, the bottom chords of the trusses and additional reinforcing bars as required by the designer. The trusses provide strength and stiffness for handling and transport, allow panels to support construction loads with a minimum of temporary propping, contribute to the top and bottom reinforcement, and act as bar chairs to support the top reinforcement.

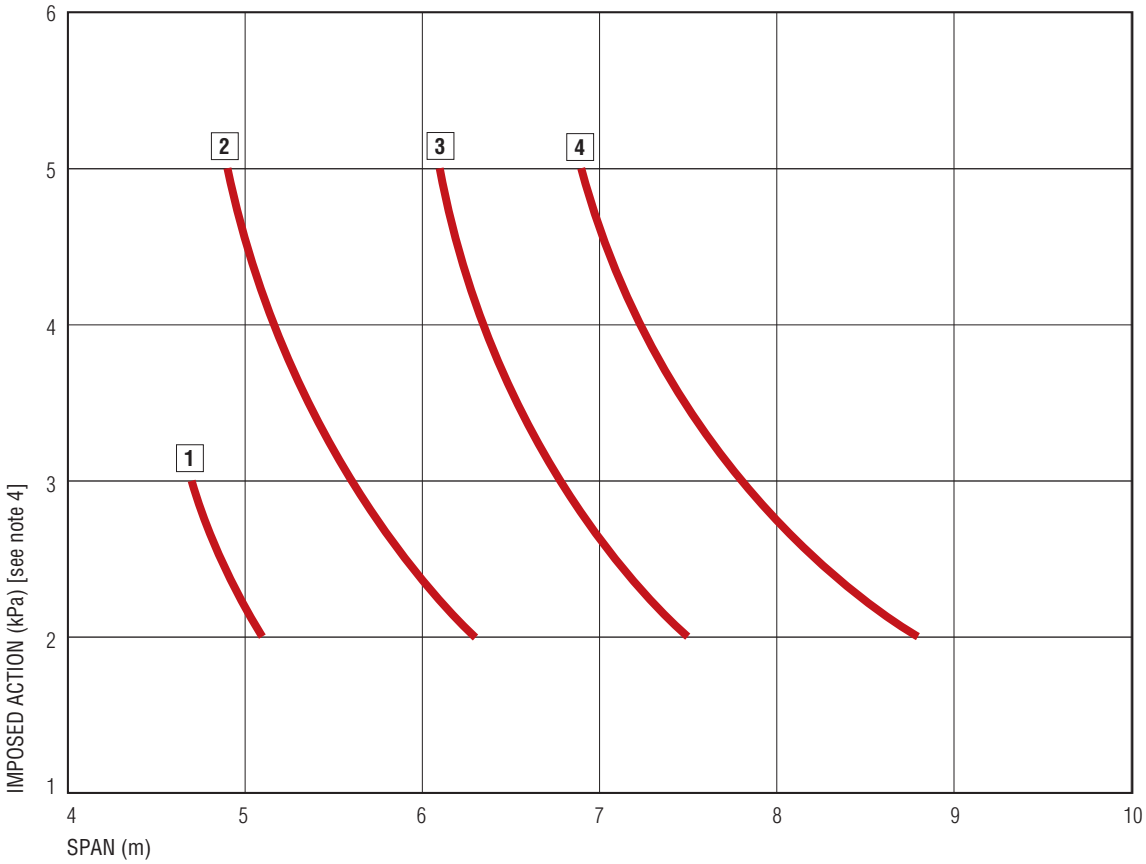
Polystyrene void-formers can be bonded to the top surface of the panel between the trusses in place of the insitu concrete, resulting in a significant reduction in the self weight of the finished slab and reducing the amount of insitu concrete required.

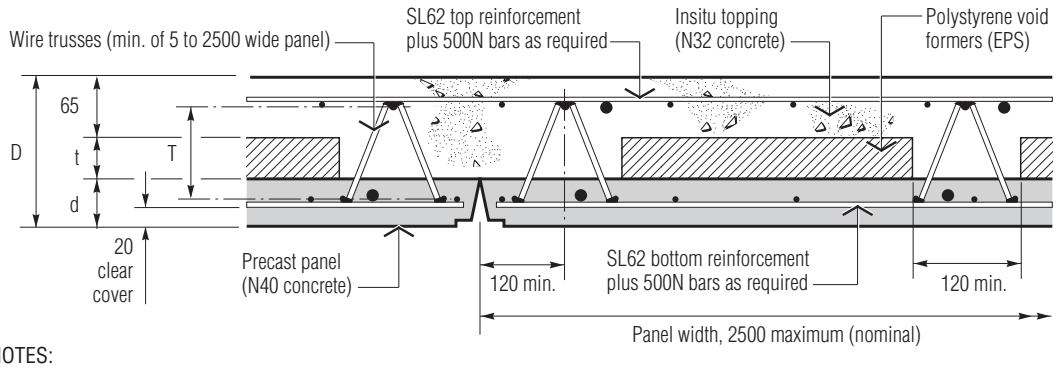
Since the product is cast in a steel mould using wet-mix process, considerable flexibility of plan shape is possible, while openings for stairs and major services may be cast-in. Small penetrations for electric wiring and plumbing can be cut on site. Keyways may be cut into the polystyrene for service runs.

The system imposes few restrictions on designers because there are no standard panel sizes. The length, width, thickness, plan geometry and reinforcement can be varied to suit the design requirements. The only restriction is transport limitations which generally limit maximum width to 2.5 m and maximum length to about 12 m. Special lifting frames are required for units over 8 m long.

FIGURE 16: Permanent formwork or soffit slabs

PERMANENT FORMWORK or SOFFIT SLABS **Multi-span**





NOTES:

1 For preliminary design and initial sizing only. Refer to the specific manufacturer's design information for actual load capacities and design information for the chosen system

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed

b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

Curve	Slab depth, D (mm)	Panel depth, d (mm)	EPS thickness, t (mm)	Truss height, T (mm)	Self-weight (kPa)	Top reinf. (kg/m^2)	Bottom reinf. (kg/m^2)
1	160	55	40	82	3.3	4.4	4.3
2	190	55	70	110	3.6	4.9	5.0
3	230	55	110	154	3.9	5.6	6.1
4	270	55	150	192	4.3	6.1	6.8

7.4 Composite Floors – Beam and Infill

The system, known as *Ultrafloor* and similar, comprises precast, prestressed concrete inverted T-beams, spaced apart with an infill material spanning between the flanges of the beams **Figure 17**. This assembly provides the strength to support the weight of the (subsequently placed) wet insitu concrete topping. After the insitu concrete has hardened, its compressive strength acts compositely with the tensile strength of the precast beams to efficiently carry the design loading on the floor.

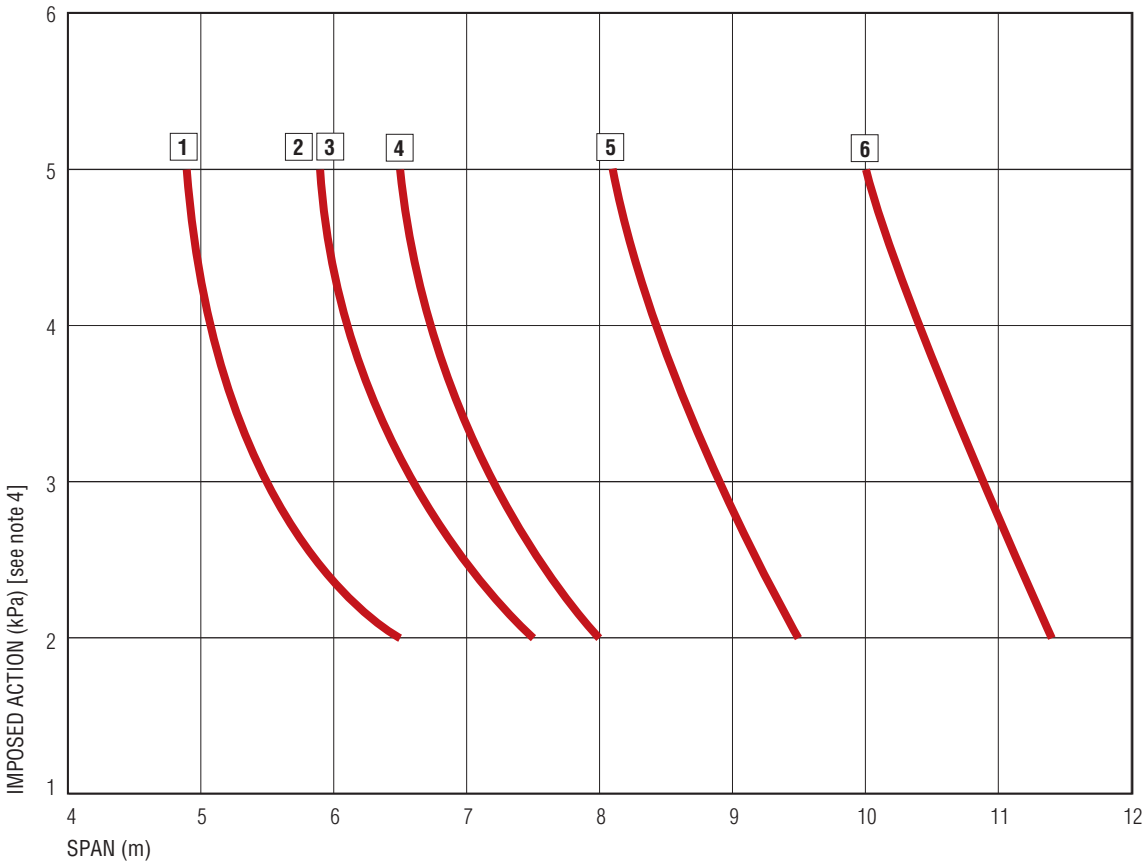
In longer spans, where the load of the fresh concrete would be critical, a row of temporary props can be placed under the centre of the beams during concreting. These remain in place for approximately three days until the prestressed beams are able to act compositely with the insitu concrete topping.

In addition to offering the well-established advantages of precast flooring, it has a number of further benefits, including ready accommodation of site tolerances and service penetrations (with adjustment of beam positions) and enhanced acoustic performance with appropriate detailing.

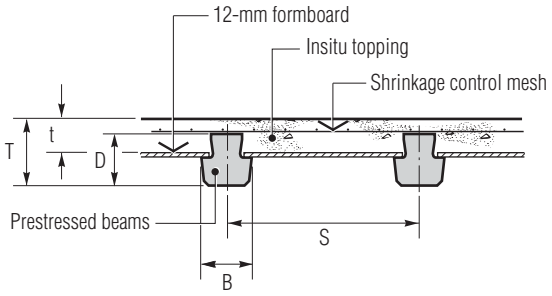
FIGURE 17: *Ultrafloor* composite floor system

COMPOSITE BEAM AND INFILL

Single Span (Temporally propped)



Curve	Beam	D (mm)	B (mm)	T (mm)	t (mm)	S (mm)	Selfweight (kPa)
1	130R	130	130	180	98	480	2.79
2	150R	150	130	200	88	480	2.98
3	130C	130	190	180	98	540	2.90
4	150C	150	250	200	88	600	3.34
5	200C	200	250	250	88	600	3.71
6	250C	250	250	300	138	600	4.89



NOTES:

1 For preliminary design and initial sizing only. Refer to the specific manufacturer's design information for actual load capacities and design information for the chosen system

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed

b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

7.5 Solid Slabs

Solid precast prestressed floor slabs are typically wet-cast on long-line beds in unit moulds or by hollowcore equipment using slipform or extrusion methods. The hollowcore equipment will set the width dimension, usually at 1200 mm. It is also possible to cast them on separate casting beds. A convenient module to suit the building layout may be selected when using unit moulds. The cross-section has similar shear key details to hollowcore planks. Thickness is usually 150, 200 and 250 mm. Units over 250 mm deep are likely to be too heavy for normal building purposes.

The slenderness should not exceed an L/D of 45. This may need to be limited to 30 to 35 for applications that are sensitive to vibration.

Solid slabs are chosen where:

- the loading results in high shear or there are heavy point loads;
- the environment is aggressive, for example in splash zones or where condensation may occur over water;
- high cover or special concrete is required;
- projecting reinforcement requires the units to be wet-cast, for example when used as a soffit beam to support hollowcore.

Prestressed units will develop hog, with inevitably some differential between adjacent units. Where this is a concern, an insitu topping can be used to provide a level floor (usually normal-class N32 concrete). A topping is recommended for most projects. A grouted shear key detail is required between planks to transfer local loads to adjacent units. Typically, 50% of local loading on a 1200-mm-wide plank is transferred to adjacent units through the shear keys.

Un-topped units require grouted joints for fire integrity, sound insulation and to prevent long-term differential movement between adjacent slabs. Topped units are not grouted separately, the width of the joint is selected to allow filling during the topping operation.

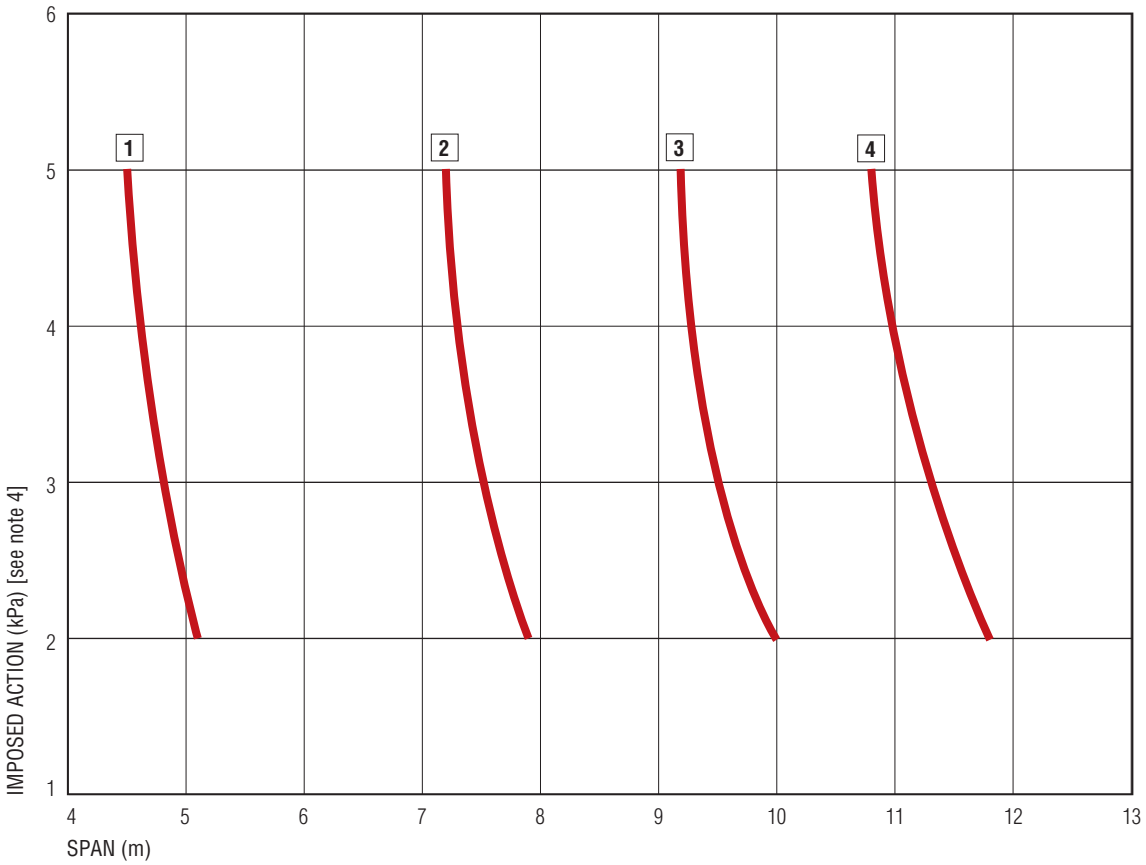
The length of support at the end of the slab will be dictated by circumstances. A bearing length of 80 mm is a normal minimum and, preferably, the length should be half the depth of the precast section. Plank lengths of less than 3 m may not develop the tensile capacity of the prestressing strand due to bond limitations. The critical section for shear usually occurs in the transmission zone of the strand.

In addition to service requirements, construction load conditions should be checked. These should include: live load on the precast unit; the topping weight plus live load on the precast section prior to developing composite action; and stacked materials on both the precast and composite sections, if this is likely to occur.

FIGURE 18: Lifting of solid slab unit

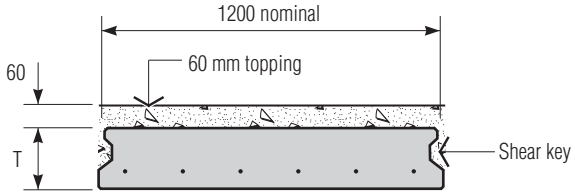
PRECAST PRESTRESSED SOLID SLABS WITH 60-mm TOPPING

Single Span



CURVES

1 **100**/8-9.3/40
2 **150**/7-12.7/40
3 **200**/9-12.7/40
4 **250**/11-12.7/40



NOTES:

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2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed

b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

SLAB IDENTIFICATION

FIGURE 19: Double T-beams

7.6 Single and Double T-Beams

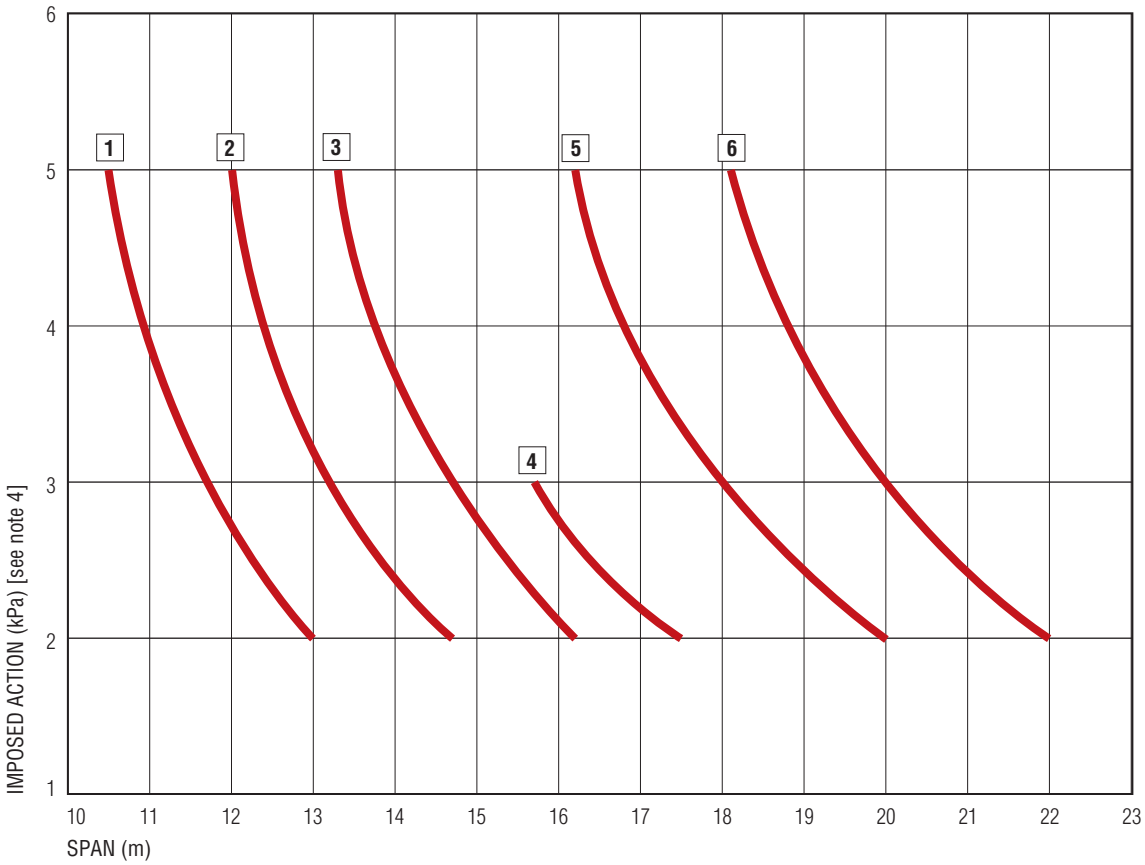
Single and double T-beams cover the span range beyond slab-type members such as hollowcore planks **Figure 19**. They are a very efficient structural shape. The typical range for double-tees is 12 to 24 m and single-tees from 15 to 30 m. Through the use of adjustable moulds, the depth, and to a lesser extent width, can be varied to suit the application. Beams are usually topped with a levelling or structural screed concrete on-site.

The units are cast on a long-line pretensioning bed with straight (preferred arrangement) or deflected strands. Long units are carried on articulated vehicles and site access must take account of this. Erection is normally by mobile crane and access for these vehicles will also have to be taken into account in the planning stage. Single and double T-beams are the basis for design of economical, fire rated structures where construction time, long spans or heavy loadings are important cost influences.

The economical span 'L' between supporting beams is approximately D x 15 to D x 20 (depending on the level of prestress) where D is the overall depth of the T-beam including topping.

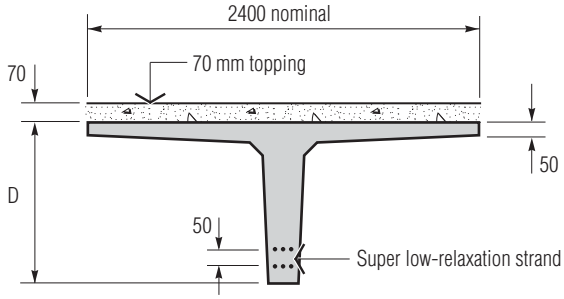
SINGLE T-BEAMS WITH 70-mm TOPPING

Single Span



CURVES

1. **600**/6-12.7/50
2. **800**/6-12.7/50
3. **1000**/6-12.7/50
4. **600**/12-12.7/50
5. **800**/12-12.7/50
6. **1000**/12-12.7/50



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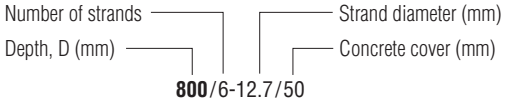
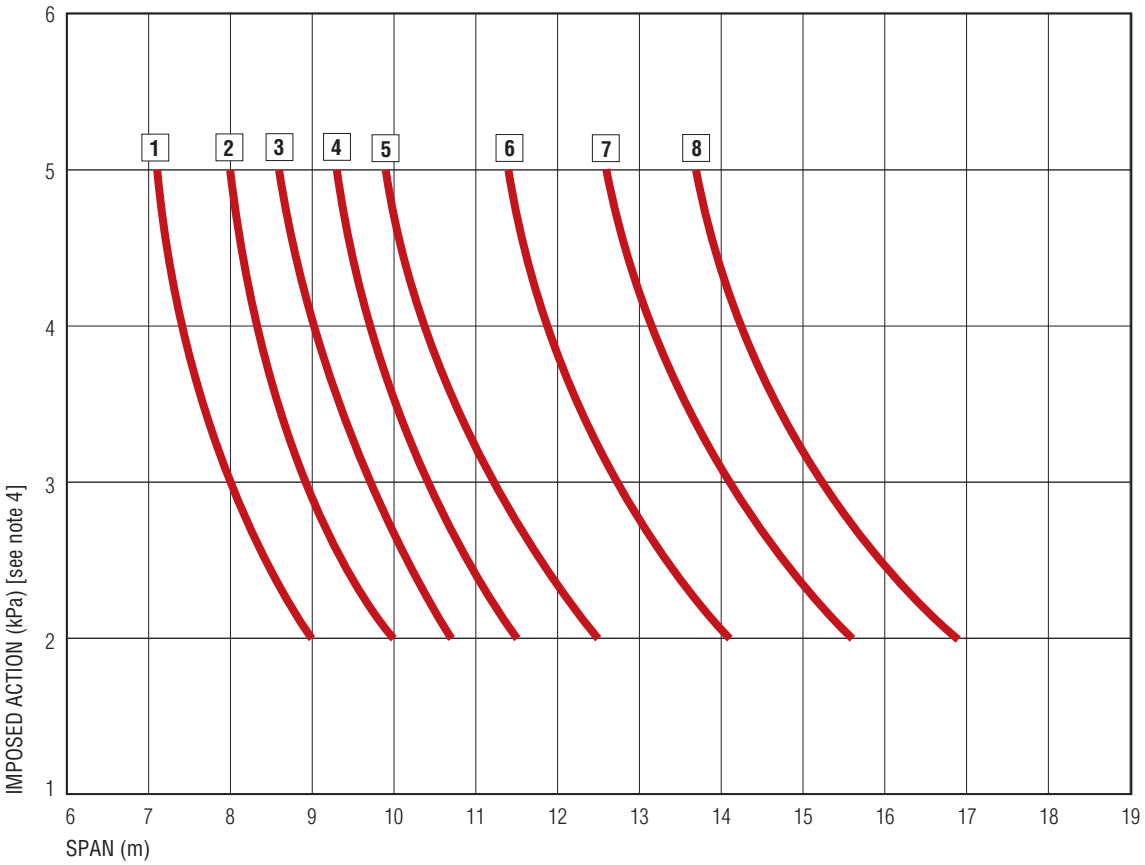
2. Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating
3. A 120/120/120 Fire Resistance Level assumed
4. The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:
   a. For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed
   b. For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

BEAM IDENTIFICATION



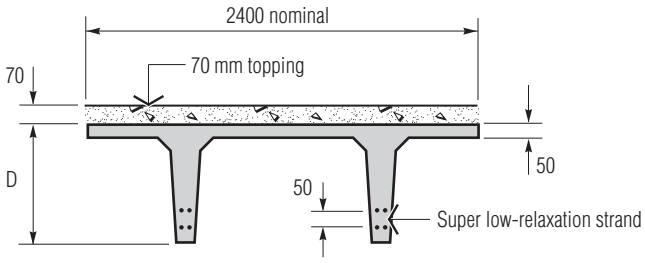
DOUBLE T-BEAMS WITH 70-mm TOPPING

Single Span



CURVES

1	**400**/4-12.7/50	5	**400**/10-12.7/50
2	**500**/4-12.7/50	6	**500**/10-12.7/50
3	**600**/4-12.7/50	7	**600**/10-12.7/50
4	**700**/4-12.7/50	8	**700**/10-12.7/50



NOTES:

1 For preliminary design and initial sizing only. Refer to the specific manufacturer's design information for actual load capacities and design information for the chosen system

2 Imposed action of 2.0 kPa typical for domestic etc, 3.0 kPa typical for offices etc and 5.0 kPa typical for assembly areas without fixed seating

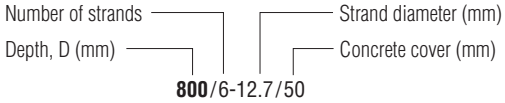
3 A 120/120/120 Fire Resistance Level assumed

4 The following additional permanent actions (dead loads) are included with the imposed actions (live load) when preparing this chart:

   a For imposed action of 2.0 kPa an additional permanent action of 0.5 kPa has been allowed

   b For imposed actions of 3.0 kPa and 5.0 kPa an additional permanent action of 1.5 kPa has been allowed

BEAM IDENTIFICATION



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