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Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF
FLOORS AND ROOFS USING PRECAST
DOUBLY-CURVED SHELL UNITS

(First Revision)

UDC 69-024/025 [624-074-4] : 691-81 : 69-001-3



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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF FLOORS AND ROOFS USING PRECAST DOUBLY-CURVED SHELL UNITS

(*First Revision*)

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Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF FLOORS AND ROOFS USING PRECAST DOUBLY-CURVED SHELL UNITS

(First Revision)

0. FOREWORD

0.1 This Indian Standard (First Revision) was adopted by the Indian Standards Institution on 29 May 1984, after the draft finalized by the Building Construction Practices Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Precast doubly-curved shells have been in use for the past few years as roofing and flooring elements. These shell units are effectively used for replacing the solid RCC slabs. They may be used in conjunction with precast joists or battens or planks or as waffle shells by providing *in situ* ribs in two directions. This type of construction has many advantages over the conventional RCC slabs being lighter in weight and saves reinforcing steel and concrete. It is also suited for use as workshop floors and loading platforms carrying heavy uniform loads. It eliminates the use of shuttering fully and scaffolding partially. The sizes of the shells are chosen depending upon handling facility available.

0.3 This standard was first published in 1971. The present revision incorporates the modifications, necessary as a result of experience gained during the use of this standard. The important changes incorporated cover thickness of edge beam, and details of erection of masonry mould for precasting.

0.4 In the preparation of this standard, assistance has been rendered by the Structural Engineering Research Centre, Madras who have supplied valuable technical information.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with

IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard covers the details of construction of floors and roofs built with precast funicular shells.

1.1.1 A brief outline for the design of precast shell is also given.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Bearing — The surface on which the precast shells or the precast planks rest for their support.

2.2 Dry Filling — Unbonded materials used for filling and levelling up haunches. These may be in the form of sand, coal ash, brickbats or any other approved materials.

2.3 Edge Beam — The beams provided along with periphery of the shell to stiffen the shell.

2.4 Fixed Casting Platform — A level platform built in masonry and finished smooth with mortar or cement rendering.

2.5 Funicular Shells — This is a thin doubly-curved shell of a shape which is purely in compression in most of the parts of the shell except near the edge beams. The shape of the shell gives purely compressive stresses under uniform loads and its shape is defined by the equation :

$$\nabla^2 z = - \frac{w}{N}$$

where

z = height of the shell ordinate,

w = uniform load per unit area of plan projection, and

N = allowable compressive stress.

$$\nabla^2 z = \frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2}$$

when

x, y are ordinates.

*Rules for rounding off numerical values (revised).

2.6 Haunches — The area in cross-section of the floor or roof between the top level of the finished floor and the exterior surface of the shell units.

2.7 In-Situ Flange — The structural concrete cast *in situ* along with ribs of the intergrid shell or on top of the precast planks, battens, beams or open web joists.

2.8 In-Situ Ribs — The portion between two shell units formed by placing the precast units apart to form the web of the joist or the intergrid shell.

2.9 Intergrid Shell — Floors or roofs formed with precast shell units placed to form webs in both directions and filled to a level above the crown of the shell giving flat finished top surface. The ribs in both directions will have the same level and height.

2.10 Movable Casting Platform — A level platform built in timber plywood or steel to support the sagging fabric used for precasting the shells.

2.11 Precast Battens or Beams — Precast reinforced concrete or prestressed concrete beams either in the form of inverted 'T' or 'I' or rectangular sections used for carrying the precast shells.

2.12 Precast Planks — Precast reinforced concrete members of 60 to 100 mm thickness with requisite reinforcement to carry the loads from the shells.

2.13 Rise — The vertical distance between the springing line and the crown of the shell measured on the inner face of the shell.

2.14 Sagging Fabric — The woven fabric used as the mould for the shell to cast itself. The fabric may be in the form of cloth, canvas, or hessian.

2.15 Shell Size — This shall be the outside to outside dimensions of the sides of the shell in case of rectangular and square shells. In case of circular or other shapes of shells, dimensions shall be across the diagonals outside to outside.

2.16 Web Thickness — The thickness of the web of *in situ* concrete laid between two precast shell units.

3. NECESSARY INFORMATION

3.1 For the efficient design and construction of doubly-curved shell units for floors and roofs, detailed information with regard to the following is necessary :

- a) Total area to be covered by the scheme;
- b) Individual room size or column grids;

- c) Supporting elements, namely, framed structure or load bearing walls and their dimensions and restrictions, if any, to their arrangements;
- d) Level at which the floor or roof should be finished;
- e) Treatment of junctions of the floor and roof with the walls or parapets;
- f) Provision to be made in the roof with regard to slope for the purpose of drainage;
- g) Provisions for fixing of services, ceiling, etc; and
- h) Openings to be left in the floor or roof.

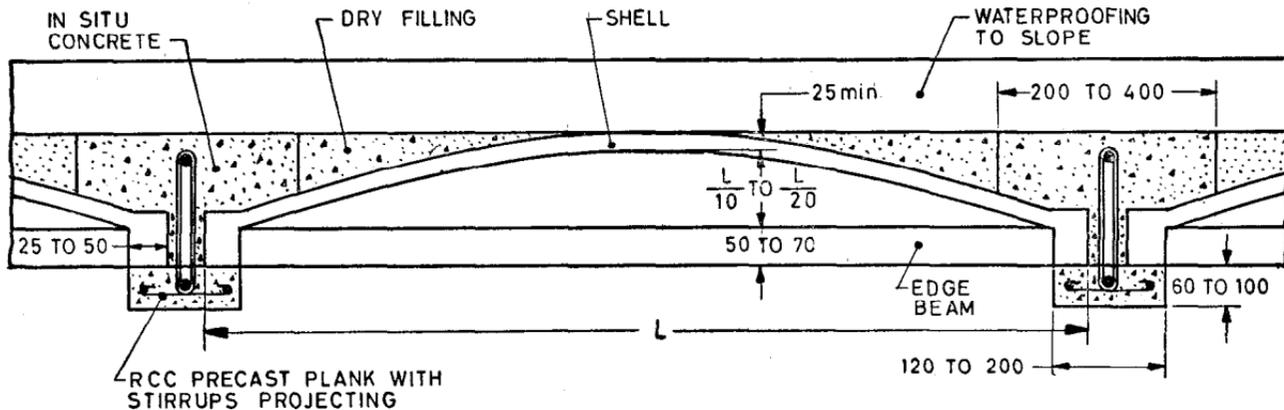
3.2 All the information as in **3.1** is to be made available to those who are responsible for the design and construction of the scheme. Necessary drawings and detailed instructions for the work shall be given.

3.3 Arrangements may also be made for proper exchange of information between the designer, builder and user at all stages of construction of the project.

4. DESIGN CONSIDERATIONS

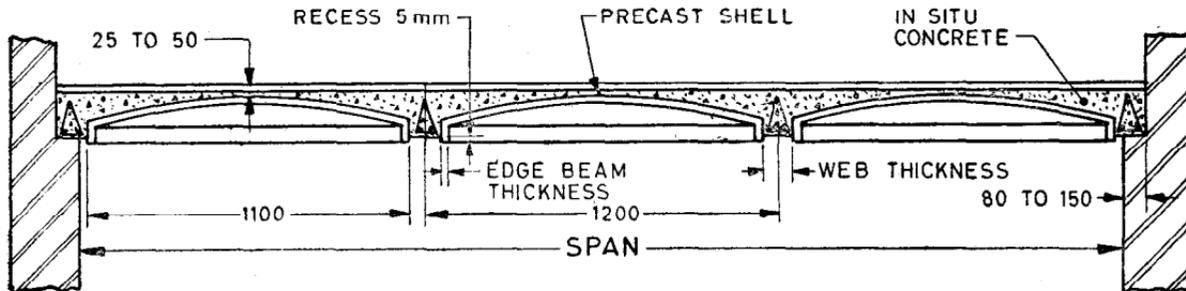
4.1 General — The doubly-curved shell units for floors or roofs may be used in one of the following patterns :

- a) Precast shell units supported on prefabricated beams or battens made in reinforced concrete, prestressed concrete, steel or timber. When concrete beams or battens are used, they may be designed either to carry the entire load without props or as propped tensioned flanges with *in situ* concrete poured between the haunches to form compression flange later. In this pattern of construction, the supporting elements and the shell units will be at different levels in the two directions. A typical detail of the scheme is shown in Fig. 1.
- b) Precast shell units kept supported on staging to form waffles in two directions. The haunches with reinforcement placed between the shell units are concreted up with structural concrete and made to a level of 20 to 50 mm (depending upon span) above the crown of the shell. The scheme finished in this pattern will have ribs in both directions in the room or column grid and they will be at the same level. Recess in the rib may be given to effect discontinuity in the ceiling pattern for the purposes of architectural treatment. A typical detail of the scheme is shown in Fig. 2.



All dimensions in millimetres.

FIG. 1 TYPICAL DETAILS OF PRECAST SHELL UNITS AND PRECAST PLANKS



All dimensions in millimetres.

FIG. 2 AN INTERGRID SHELL

4.2 The following Indian Standards shall be referred for designing the supporting elements, concrete mix, etc:

Reinforced concrete	—	IS : 456-1978*
Prestressed concrete	—	IS : 1343-1980†
Structural steel	—	IS : 800-1962‡
Structural timber design	—	IS : 883-1970§
Loading	—	IS : 875-1964
Composite construction	—	IS : 3935-1966¶

4.2.1 The minimum thickness of the shell shall be 25 mm and the sizes of shell shall be of modular dimensions.

4.2.2 The thickness of the webs in the precast supporting elements or rib in the intergrid pattern of shell shall be a minimum of 70 mm.

4.2.3 Unless otherwise specified, the precast shells shall be made of concrete grade M-15. The maximum size of the aggregate for the concrete shall not exceed 8 mm or 1/3 of the thickness of shell, whichever is more. The workability of the mix is to be assured as small thicknesses are being cast.

4.2.4 The minimum reinforcement in the edge beams of the shells shall be one 6 mm diameter mild steel bar.

4.2.5 The minimum reinforcement in the *in situ* concrete shall be governed by the provisions in IS : 456-1978*.

4.2.6 The minimum thickness of edge beam shall be 25 mm in normal condition and 35 mm in corrosive atmosphere. A typical detail of edge beam in corrosive atmosphere has been shown in Fig. 3.

5. PRECASTING

5.1 Precasting of the doubly-curved shell units may be carried out by any one of the methods given in 5.1.1, 5.1.2 and 5.1.3.

*Code of practice for plain and reinforced concrete (*third revision*).

†Code of practice for prestressed concrete (*first revision*).

‡Code of practice for use of structural steel in general building construction (*revised*).

§Code of practice for design of structural timber in building (*third revision*).

||Code of practice for structural safety of buildings: Loading standards (*revised*).

¶Code of practice for composite construction.

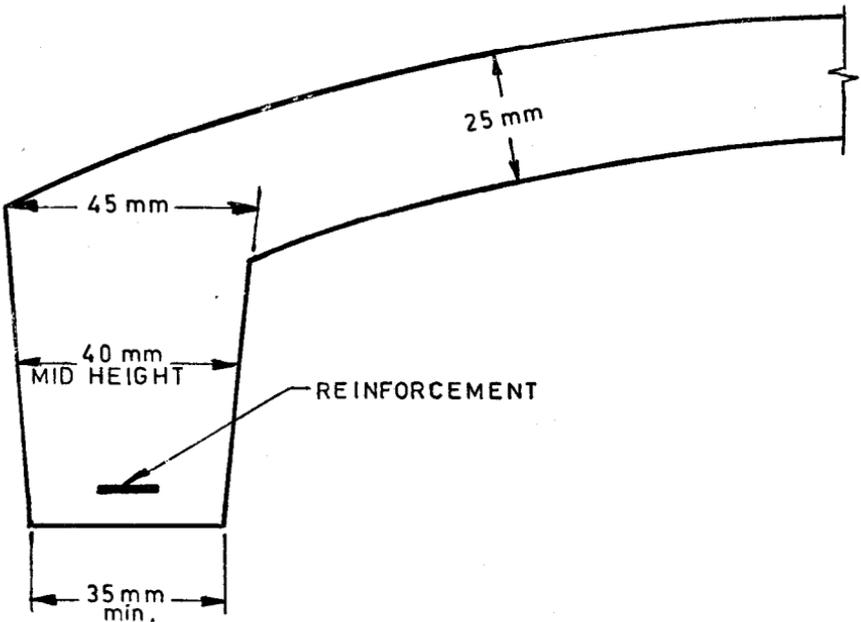
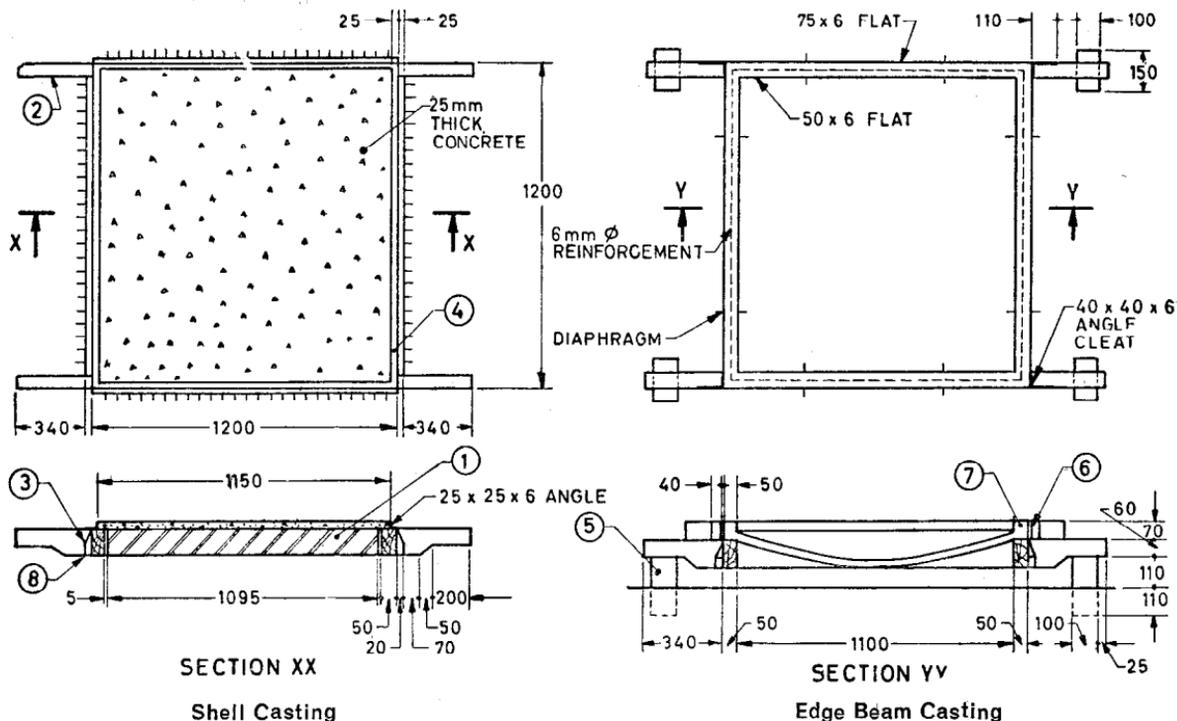


FIG. 3 DETAILS OF EDGE BEAM IN CORROSIVE ATMOSPHERE

5.1.1 Sagging Fabric Mould

- a) Frame for casting the shell unit (see example given in Fig. 4) shall be fabricated.
- b) A level platform in masonry or timber shall be built up.
- c) A square frame with hessian, canvas or cloth stretched and tucked to it shall be placed over a masonry platform so that the inside surface of the frame snugly fits into the outside of the platform. The fabric is thus fully supported from sagging. A frame equal to the shell thickness shall be set up on the platform. Concrete of the specific mix shall be poured inside the frame and compacted. The mould shall next be lifted off the platform and supported at 4 corners. The hessian sags and the shell gets itself cast (see Note). Ensure that shell is finished smooth as for ceiling finish.
- d) The mould for the edge beam shall be next set up. The reinforcement cage shall be placed in position and the edge beam concreted.



- 1 Masonry platform
- 2 Main frame 1 200 × 1 200 mm out to out
- 3 Hessian, tucked to headless nails
- 4 Shell frame 1 150 × 1 150 mm inside

- 5 Blocks from support
- 6 Edge beam mould outer 1 200 × 1 200 mm inside
- 7 Edge beam mould inner 1 100 × 1 100 mm out to out with fillets as shown
- 8 Headless nails

All dimensions in millimetres.

FIG. 4 EXAMPLE OF A FRAME FOR CASTING A SHELL UNIT

- e) The edge beams shall be demoulded 3 hours after casting.
- f) The shell should be inverted and cured in the normal way 24 hours after casting.

NOTE — The extent of sag and tension in the fabric may be regulated within the prescribed limits by two to three trial castings.

5.1.2 Masonry Mould

- a) The surface of the shell cast by itself adopting the method given in 5.1.1 is defined by the equation given in Table 1 for various plan shapes. For any desired raise of the shell of rectangular or square plan the ordinates on various points can also be calculated using approximate formula:

$$z = \frac{z_{Max}}{a^2 b^2} (a^2 - x^2) (b^2 - y^2)$$

where

z = vertical ordinate at point x, y ;

z_{Max} = maximum central rise which may be

$$\frac{L}{10} \text{ to } \frac{L}{20} \quad (L = \text{shell size});$$

$a = \frac{1}{2}$ length of the shell;

$b = \frac{1}{2}$ width of the shell; and

x, y = the co-ordinates of the grid point from the origin, which is taken as the centre of the shell unit.

The ordinates thus obtained shall be set off from a level platform and the surface concreted and finished smooth.

- b) The finished surface shall be coated with oil, grease or any other releasing agents.
- c) Outer mould for the edge beams shall be set up.
- d) The designed reinforcement for the edge beam shall be placed between the outer edge beam mould and the masonry platform built up.
- e) Concrete of the specified mix shall be laid in the edge beam and over the shell mould. The thickness over the shell mould equal to the designed thickness of the shell shall be controlled by thickness gauges. The shell is thus cast in the erect position. Ensure that finished concrete is rough enough to bond with screed concrete.
- f) The edge beam mould should be released 3 hours after casting.

- g) The shell should be lifted off the mould using levers at the four corners 24 to 48 hours after casting. Longer time up to 72 hours may be necessary in cold climates (below 25°C) as also when pozzolana cement is used. In using levers ensure that the levers are operated only on one side at a time and never at the end at diagonals.
- h) The shell should be kept stacked and cured in the normal way. The stacking of the shells may be done one above the other supported at four corners only, in piles of 8 to 10 shells.
- j) Shell units up to 1.5 m in size may be handled manually. Shells heavier than this will need the help of hoisting equipment and appliances. For small size shells where handling is done manually, provision of lifting hooks are not necessary.

5.1.3 Mechanized Process

- a) The mechanized process may be normally adopted when the size of the shell exceeds 1.5 m and where reinforcement is provided in the body of the shell.
- b) Surface of the shell may be calculated using the equations given in 5.1.2.
- c) The ordinates thus obtained shall be laid out to form a steel, timber, or plastic mould. The mould for the shell and the inner surface of the edge beam may be fabricated as a monolithic block.
- d) A level platform 600 to 1 000 mm above the ground level shall be made in timber or RCC with openings equal to the size of internal dimensions of the shell unit. Four to five openings may be provided in platform.
- e) The fabricated mould shall be mounted on a trolley with jacking arrangements for lifting and lowering the mould to the level of the casting platform.
- f) The trolley may be positioned below the opening and the mould raised to the appropriate levels. The outer edge beam mould shall then be positioned over the casting platform. The designed reinforcement in the edge beam and in the shells, if any, are then placed.
- g) Concrete of the specified mix shall be laid in the edge beam and over the shell mould. The thickness over the shell mould shall be controlled by thickness gauges. The shell is thus cast in the erect position.
- h) Outer edge beam mould may be released 3 hours after casting. Twenty-four to forty-eight hours after casting the shell, the mould may be lowered and the cast shell is left on the platform for a further period of 24 to 48 hours.

TABLE 1 EQUATION OF SHELL SURFACE FOR VARIOUS PLAN SHAPES

(Clause 5.1.2)

No.	GROUND PLAN	EQUATION TO THE SURFACE
1.		$z = \frac{16 wa^2}{N\pi^3} \sum_{n=1,3,5,\dots}^{\infty} \frac{1}{n^3} (-1)^{\frac{n-1}{2}}$ $\left(1 - \frac{\cosh \frac{n\pi y}{2a}}{\cosh \frac{n\pi b}{2a}} \right) \text{Cos } \frac{n\pi x}{2a}$
2.		$z = \frac{16 wa^2}{N\pi^3} \sum_{n=1,3,5,\dots}^{\infty} \frac{1}{n^3} (-1)^{\frac{n-1}{2}}$ $\left(1 - \frac{\cosh \frac{n\pi y}{2a}}{\cosh \frac{n\pi}{2}} \right) \text{Cos } \frac{n\pi x}{2a}$
3.		$z = \frac{w}{2N} \frac{a^2 b^2}{a^2 + b^2} \left(\frac{x^2}{a^2} + \frac{y^2}{b^2} - 1 \right)$
4.		$z = \frac{w}{4N} (x^2 + y^2 - a^2)$
5.		$z = \frac{w}{2N} \left[\frac{1}{2} (x^2 + y^2) - \frac{1}{2a} (x^2 - 3xy^2) - \frac{2}{27} a^2 \right]^2$

NOTE — The explanation to the symbols given in this table is the same as in 2.5 and 5.1.2.

- j) The mould may then be moved to the next opening in the casting platform and set for the casting of the next shell. The shells thus cast may be lifted off the casting platform after 48 to 96 hours after casting.
- k) Lifting hooks shall be provided at corners of the shell within the edge beam thickness.
- m) The shell may then be kept stacked and cured in the normal way.

6. CONSTRUCTION

6.1 The construction of the floor or roof using the doubly-curved shell units shall be carried out in accordance with **6.1.1** to **6.1.3**.

6.1.1 *Precast Battens and Precast Shell Units*

- a) The supporting elements either as load bearing walls or beams shall be finished to the bearing level of the precast elements.
- b) The precast concrete supporting elements or timber or steel joists shall then be placed at the appropriate levels with proper mortar pad bearing over the walls or beams.
- c) The battens or joists should be propped at points mentioned in the design.
- d) The shell units shall then be placed spanning the battens or joists with proper mortar pad bearing.
- e) The shells thus positioned leave space between edge beam equal to web thicknesses to be concreted along the length of battens or joists. In the other direction, between two shell units, only dry mortar packing be provided.
- f) The necessary reinforcement in the compression flange and for continuity over supports shall now be placed.
- g) The *in situ* compression flange for the battens or joists are then poured to the designed level and width. The haunches and uneven surface now left may be filled with dry filling to the level of the crown of the shell. This dry filling may be replaced by lean concrete, if desired.
- h) On attaining strength for the *in situ* compression flange, props shall be removed.
- j) The floor or roof is now ready to receive finishes and water-proofing.

6.1.2 Precast Shells in Intergrid Pattern — When precast shells are used in floor or roof in intergrid pattern, the procedure to be followed shall be as follows:

- a) Erect staging and place shuttering planks for the bottom of the ribs at the spacing of edge beam of shells.
- b) The staging and the shuttering planks shall be levelled to the designed level.
- c) If recess is provided in the ribs for architectural reasons, strips of planks or plywood shall be nailed along the ribs in two directions over the shuttering planks for the ribs.
- d) The precast shell units shall then be positioned in the grid pattern. The reinforcement designed for the ribs shall be tied and placed with proper covers. The distribution reinforcement and torsion bars are also laid over the shells and tied up to the rib reinforcement. The necessary triangular stirrups in webs are also tied up.
- e) Concrete of the specified mix shall then be poured in the ribs and over the shells to the designed level. Compaction of the concrete shall be done with vibrators.
- f) The surface of the shell units at the top shall be made as rough as possible, while precasting them, to ensure perfect bonding between the *in situ* concrete and the shell units.
- g) After the normal curing, staging and shuttering planks may be removed. The floor or roof is now ready to receive the finishes and waterproofing.

6.1.3 When the shell units are used in intergrid pattern on spans above 12 m, the depth of the ribs may demand their being cast in two stages. This is because the casting of edge beams of the shells along with the shell units might lead to fabrication problems as casting of thin edge beams of over 250 mm depth for the shell units may be difficult. In such cases regular side shuttering shall be provided for the ribs up to a level from which the shell edge beams will make up the total depth of the rib. In the process described in 6.1.2, the edge beam of the shells themselves form the side shuttering for the ribs.

6.1.4 Openings

6.1.4.1 It is not desirable to puncture openings in the precast shell units. However, if position of openings are known in advance, necessary provision may be made in the shell units while precasting. Such openings may be made in the shell with proper stiffening by adding reinforcement around the opening.

6.1.4.2 When the openings are to be made in intergrid shell pattern, procedure as in **6.1.4.1** may be followed. If large number of openings are required within one grid, this grid may be replaced by solid reinforced concrete instead of the precast shells, with suitable openings duly strengthened by adding reinforcement.

6.1.5 *Waterproofing*

6.1.5.1 Waterproofing treatments as provided for in reinforced concrete slabs may be provided for the floors or roofs built with doubly-curved shell units (*see* IS : 1346-1976* *and* IS : 4365-1967†). Special care should be taken for the treatment of junctions with walls.

6.1.6 *Thermal Insulation* — The thermal insulation normally provided for reinforced concrete slabs may also be provided for floors or roofs built with doubly-curved shell units.

6.1.7 *Floor Finishes* — Floor finishes, such as granolithic concrete flooring, mosaic tiles or terrazzo floors may be laid directly over the floors built with doubly-curved shell units.

6.1.7.1 In finishing the ceiling of the floor or roof using doubly-curved shells, the joints between precast elements shall be neatly finished with cement paste or mortar. Small air holes on the surface of the shell units shall also be finished with lime or cement paste before painting. No raking of surface shall be done to receive plaster on the inside of the shell or its edge beam.

7. INSPECTION

7.1 The inspection shall be done to avoid any bad construction which may result in one or more of the defects given in Table 2 in the floors or roofs.

*Code of practice for waterproofing of roofs with bitumen felts (*second revision*).

†Code of practice for application of bitumen mastic for waterproofing of roofs.

TABLE 2 DEFECTS IN FLOORS AND ROOFS

(Clause 7.1)

Sl No.	STAGE	PARTICULARS OF INSPECTION	TYPE OF LIKELY FAILURES
(1)	(2)	(3)	(4)
i)	Precasting	The compacting of concrete and position of reinforcement to be inspected. Stretching of the sagging fabric should be such that the sag in all the shells in one lot has a tolerance of not more than ± 3 mm. The lifting or inversion of shells should be done carefully. They should always be kept in such a way that their four corners are at the same level.	Cracking, lack of finish
ii)	Staging and props	Staging and props provided should not sag. More so, in the case of the scheme using precast battens of joists.	The interaction between compression and tension flange will be defective if the battens or joists sag during concreting of the flanges.
iii)	Bearing of the joists and shell units	The shells and joists should be positioned in perfect level and made watertight to prevent leakage of cement slurry from <i>in situ</i> concrete.	Bad concrete and bad ceiling finishes.

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SHRI G. K. MAJUMDAR	Hindustan Prefab Ltd, New Delhi
SHRI H. S. PASRICHA (<i>Alternate</i>)	
SHRI B. V. B. PAI	Concrete Association of India, Bombay
SHRI P. SRINIVASAN (<i>Alternate</i>)	
SHRI R. RAJAPPA	Tata Consulting Engineers, Bombay
DR M. RAMAIAH	Structural Engineering Research Centre (CSIR), Madras
SHRI Z. GEORGE (<i>Alternate</i>)	
SENIOR DEPUTY CHIEF ENGINEER (BLDGS)	Public Works Department, Government of Tamil Nadu, Madras
EXECUTIVE ENGINEER (PLANNING) (<i>Alternate</i>)	
SHRI K. S. SRINIVASAN	National Buildings Organization, New Delhi
SHRI SASHI KANT (<i>Alternate</i>)	
SUPERINTENDING ENGINEER (B & R)	Public Works Department, Government of Andhra Pradesh, Hyderabad
SURVEYOR OF WORKS, MADRAS CENTRE CIRCLE	Central Public Works Department, New Delhi

