RETURN OF THE RIB

Ribbed slabs of all varieties offer many benefits for the whole-life performance of a building, write Jenny Burridge and Elaine Toogood

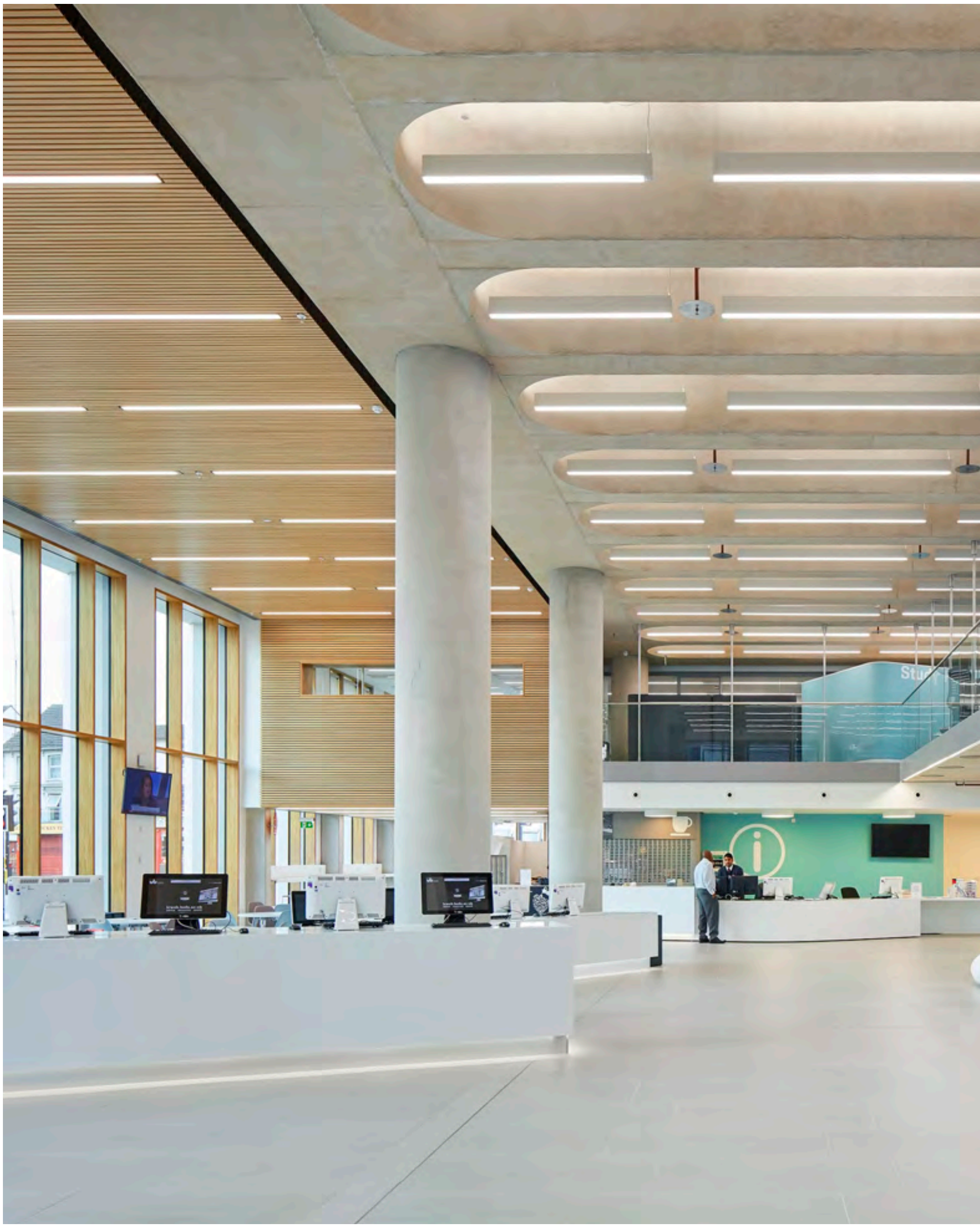


Photo: Hufton + Crow

Having been somewhat out of fashion for many years, the ribbed and waffle slabs built 50 years ago are now being refurbished to provide thermal mass and visually interesting soffits. Meanwhile new buildings are being constructed with ribbed slabs to enable longer spans, with less concrete and steel, and therefore lower embodied carbon.

Why specify ribbed slabs?

- **Material efficiency** Although ribbed slabs are deeper than flat slabs, the amount of concrete and reinforcement is considerably less, with a saving of about 20% in the volume of concrete and 10% in the weight of steel. This means smaller loads, resulting in slimmer columns and less extensive foundations. Ribbed slabs can also be post-tensioned, which reduces the concrete volume by a further 10%. They are more suitable for longer spans than flat slabs, and post-tensioned ribbed slabs can be used for much longer spans. It is possible to construct a 15m span with a depth of just 600mm (see figure 2, overleaf).
- **Visual interest** Where the soffit is exposed, a ribbed slab can add architectural interest. The coffers formed by the ribs can be used as the space for lighting and chilled beams.
- **Thermal mass** The potential of concrete to help stabilise internal temperatures is a frequent reason for leaving concrete walls and soffits exposed. Ribbed slabs enhance this by increasing the surface area of the soffit.
- **Vibration control** Ribbed slabs provide a stiffer floor than an equivalent flat slab and therefore reduce vibration from footfall or equipment.

Types of ribbed slab

There are different types of ribbed slab, but the terms "ribbed", "troughed" and "coffered" are used interchangeably by most architects and engineers. In the Concrete Centre book, Economic Concrete Frame Elements to Eurocode 2, we use "ribbed" to denote a one-way slab sitting on beams which are deeper than the ribbed slab. "Troughed" denotes a slab where the beams and the ribbed section are the same depth. "Coffered" tends to be used for a slab where the ribs are not as defined as in a typical ribbed slab, for example at Portcullis House in Westminster. A waffle slab is different to the typical ribbed slab in that the ribs run in both directions producing a soffit that looks like a waffle. These were very popular in the 1960s and 70s, the Barbican Centre in London being a well-known example. In this article, we use "ribbed" as the general term.

Structural design

A ribbed slab can be designed as a slab rather than individual beams provided that the ribs are spaced no more than 1.5m apart, the depth of the rib below the flange is no more than four times its width, and the flange is at least one-tenth of the clear distance between the ribs. The depth of the flange will normally be determined by the requirements of fire and acoustics.

Ribbed, troughed and coffered slabs are all designed as one-way slabs spanning onto primary beams. If troughed slabs are used – ie, the ribs and the beams are the same depth – the most efficient layout is 4:3 with the ribs spanning the longer distance. If the grid is not square, it is usually more efficient to span the longer direction with the ribs and the shorter direction with the primary beams. Shear at the column head is taken by the beam.

Waffle slabs are designed as two-way spanning slabs in a very similar way to flat slabs, splitting the slab into column and middle strips and designed for punching shear at column heads. The coffers for the waffle slabs will normally be left out

Visual ribbed concrete

As with any as-struck concrete, the formwork material used for ribbed soffits will influence the sheen and tone of the concrete surface. Any changes in material will therefore be visible, as will junctions between formwork elements. Addressing both issues in detail is fundamental to a successful outcome.

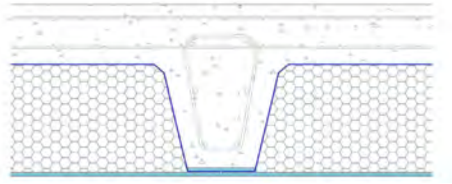
GRP offers the advantage of being moulded as a continuous shape to create the entire trough (including curved ends), reducing the risk of surface variation and the number of junctions required (see details, right). Placing of the folded edge is critical. Details 2 and 3 illustrate good details using MDO-faced ply pushing the junction to the aris where it can be sealed. The GRP gives the concrete a slightly reflective sheen which can be reduced if the mould is rubbed down, but in practice this is not very noticeable if confined to the insides of the troughs.

Correx-coated polystyrene can offer an acceptable surface, and is ideally scored to create a chamfered internal corner, reducing the risk of honeycombing. It comes in 1,200mm lengths, so taped joints will be visible and their workmanship must be controlled on site, as should the vertical termination to the trough. Detail 1 uses a ply insert to cover the ends of the Correx, usefully placing the junction at the arises. A sealed corner is likely to be neater.

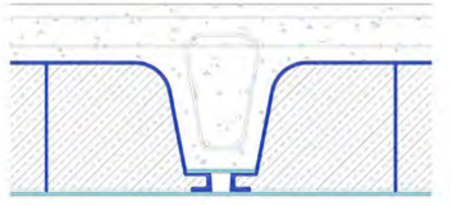
All ply inserts should be cut from the same board to provide a tight abutment between the strips and create the same surface tension, and nail fixings should be set out. Vertical concrete edges are not recommended for these proprietary moulds, with a draft of around 5° required to allow the trough form to be released. Tighter draft angles are possible but typically only for formwork designed to be dismantled on site, for example ply. Designers should consider the practicality of this when designing the section.

Other design tips include avoiding aligning the inside of a trough with a vertical wall. A step forward (as per detail 4) places the cold joint between wall and floor more sensibly in an internal corner. Also, deep troughs are less easily kept clean from debris on site, making it even more critical to tie reinforcement elsewhere.

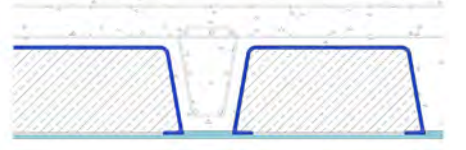
FIGURE 1: FORMWORK DETAILS FOR RIBBED SLABS



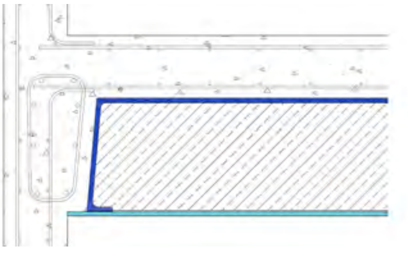
1 Typical cross-section of Correx-faced polystyrene void former. Ply covers joint between troughs. Ideal minimum draft angle 5°



2 Cross-section of detail with GRP void former and ply insert covering joints between trough sections



3 Cross-section of alternative typical detail with GRP void former and ply insert placed between trough sections



4 End section in GRP; profile is set forward of wall

Drawings: Cordek

around the column heads so that punching shear can be resisted.

Figure 2 (overleaf) shows the span-to-depth graphs for different forms of ribbed slabs under an imposed load of 2.5kN/m^2 (residential) and 5kN/m^2 (commercial).

Construction

Ribbed slabs are slower to build than flat slabs because both the formwork and the reinforcement are more complicated. They also tend to have exposed soffits so that the thermal mass benefits can be exploited; therefore more care should be used. Normally the formwork is constructed from a table form with the void formers fixed to the top. The void formers tend to be constructed from polystyrene or GRP. The choice of mould depends on the dimensions, the finish, the installation of the moulds, and intended reuse and repetition. Access and transport to site and positioning of the moulds will all impact budget and programme.

The ribs should always have an angle to the sides, rather than being vertical, to ease the stripping of the formwork. An angle of 4-5° (called the draft) is enough to make the demoulding much easier.

GRP moulds are the most expensive, but because they give the best finish and can be used more times before being replaced, they can also be the most cost-effective. They can give up to about 20 uses, if the contractor is careful. The release agent used on GRP moulds should be oil-based, as solvent-based release agents can damage them.

GRP moulds require a slight radius of 2-3mm on any change of direction so very sharp corners should be avoided. Otherwise the corner becomes a weak point and the mould will not be able to be reused. Joints between the moulds will appear as a line in the finished concrete, so it is worth discussing how best to express them with the formwork supplier.

GRP moulds are all bespoke. Previously there were standard sizes and moulds could be taken from project to project, but that is no longer the case. They can be made on a 13m x 6m pattern machine so 12m-long moulds are probably the largest available. The moulds are stiffened along the length by plywood ribs so that they can be transported and lifted into place. However, though they are moderately robust they do need to be stored carefully while not in use. Storage on site can be an issue with larger moulds.

Photo: Hufton + Crow

LEFT AND PREVIOUS PAGE The University of Bedfordshire library by MCW Architects. The long-span coffered slabs generate large areas of column free space at each floor

BELOW LEFT The bespoke moulds for the coffered slabs were made from GRP

BELOW RIGHT The location of each trough mould is expressed by the rectilinear joint lines and change in surface texture on the soffit at each end

Photos: Cordek

Polystyrene moulds offer a cheaper unit cost, and are available in three different finishes. For ribbed slabs, two are suitable: resin-coated and Correx-coated. The resin-coated moulds are not sufficiently robust to be used more than once; Correx-faced moulds can typically be used three to four times.

Correx cannot be formed around complicated surfaces, but can be curved in one direction, though the curving process results in small ridges on the concrete. Polystyrene moulds are smaller than GRP moulds and several would be needed to form one trough. The joints between the moulds are typically taped and will always be visible, so must be set out and installed carefully.

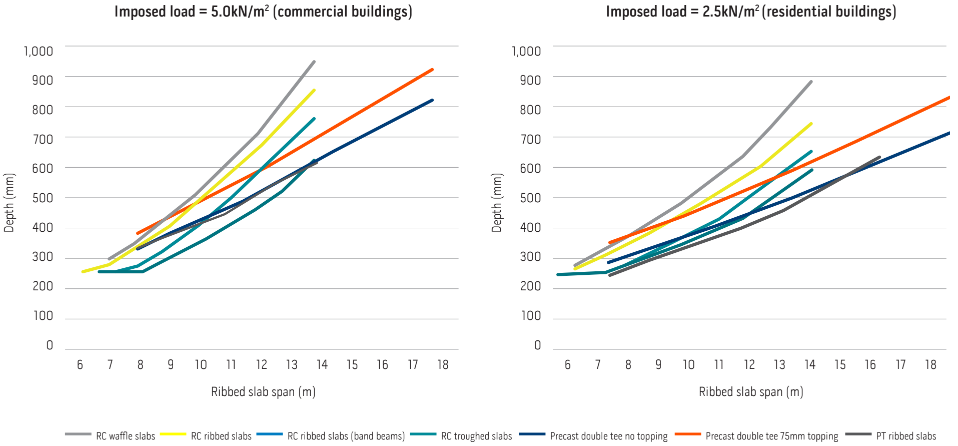
Trough forms can be created using timber formwork, such as MDO-faced ply. This type of formwork was used on the Judge Business School extension in Cambridge (CQ 264). These can be used for longer troughs or where the shape doesn't lend itself to prefabricated moulds.

Precast options

Ribbed slabs can also be precast, either as bespoke units or as standard double-T units. The formwork used for bespoke units would be similar in style to that used for in-situ ribbed slabs already described, but with the benefit of factory conditions to maintain and store the units. Transporting the units to site and placing them becomes a more important issue, and the weight of the units can determine the size of crane required.

With thanks to Simon Poole and Dan Ward of Cordek

FIGURE 2: SPAN-TO-DEPTH GRAPHS FOR DIFFERENT FORMS OF RIBBED SLABS UNDER DIFFERENT IMPOSED LOADS



Note: troughed slabs are set at a 4:3 ratio (ribbed slab:band beam) with the span shown being the ribbed slab span. All other span-to-depth ratios are for a square grid.

Source: Economic Concrete Frame Elements to Eurocode 2, published by The Concrete Centre