Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 3 (1948)

Artikel: Corrugated concrete shell structures

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DOI: https://doi.org/10.5169/seals-4040

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Constructions de toits plissés en béton armé

Schalenkonstruktion in Beton mit gewellter Oberfläche

Corrugated concrete shell structures

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General data

Much has been done towards the simplification and standardization of centering and scaffolding of concrete shell structures, but judged by their relatively rare application, the economic results of the improvements have not proved quite satisfactory. The production of such shell structures has been, and probably will remain, the responsibility of specialised designers and contractors. During the war, the available labour was mostly unskilled; the use of timber and steel had to be reduced to a minimum. Simpler types and methods of construction had therefore to be employed and the concrete shell roofs with flexible moulds are one of the results of the simplification.

These roofs are constructed in the following way : Tubular scaffolding or pre-fabricated steel ribs, are erected at given spacings to follow the exact curvature of the future shell. A covering of jute fabric is then stretched over the steel skeleton and fixed to it so as to form a tight skin of the exact shape of the designed shell. The fabric is wetted and a thin layer of mortar, say $\frac{1}{2}$ in, is applied. This is followed by further layers and the roof is brought up to the required thickness. The scaffolding is then removed and re-erected for the next building.

In some types of roofs the sagging of the fabric between the steel ribs is prevented by stretching it tightly and by shrinking the fibres before the application of the grout. In other types of roofs the fabric is deliberately allowed to sag between the steel ribs to a given amount. After the application and hardening of the concrete the shell roof has therefore a definite corrugated shape.

Such buildings have been erected in various shapes : part-cylinders, truncated cones and corrugated barrels. The type which has found the

widest application is the corrugated shell arch. Photograph 1 shews the first of a number of such structures which recently have been erected for agricultural purposes in Eire. The shells are of 60 ft span, 30 ft rise, 2 in thickness and of lengths up to 200 ft. They are of catenary cross section and are corrugated in the length of the building. Each of their cross sections is a true arch, the buildings being carried on strip foundations at 60 ft centres.

To construct such a building (see photograph 2) two plain strip foundations are placed, one under each springing. A light pre-fabricated tubular steel falsework is erected : the ribs of the falsework are shaped exactly to catenary curves and they have timber backing; they are assembled on the ground, raised into position, and braced by a few straight tubular runners and diagonals. Their spacing is equal to the width of the corrugations and amounts to 8 ft for the 60 ft span of the building.

Over the falsework is stretched a sheet of fabric which is fastened to the timber backing on the ribs. It is made up of material 8 ft wide and sewn into one sheet to cover the part of the building for which the falsework is erected. Having been stretched and secured the fabric is wetted and liberally coated with liquid grout just ahead of the rendering. Portland cement rendering is then applied in two or three coats to make up to the desired thickness of 2 in, whith a layer of transverse and longitudinal reinforcements between the coats. The fabric sags under the weight of the rendering and forms the corrugations of the roof, which are 2 ft deep at the crown decreasing to 9 in depth at the springings.

Two days after the last coat has been applied the first few steel ribs are dismantled and re-erected to construct the next bays and to lengthen the building. The fabric which formed the flexible mould for the concrete remains in place and forms the internal finish of the building.

These buildings have been developed from similar structures erected during the War in U. K. and abroad to serve as barracks, stores, canteens and for similar purposes. They were of 20, 30 and 40 ft span and contained no reinforcement whatsoever.

Joints and ridge piece

Expansion joints are formed across the arch at the crests of the corrugations at intervals not exceeding 36 ft. They are filled with bituminous mastic.

In some buildings a tie bar is inserted in the ridge of the roof and embedded in a continuous concrete section to prevent the gradual creeping of the arch rings separated by the joints. This bar or tube is coated in bitumen to prevent its adhesion to the concrete. It is fitted with washers and nuts at each end and is tightened up when the concrete of the roof has set and hardened.

Opes and endwalls

Dormer windows, sky lights and side doors are easily provided for ordinary requirements. The width of any ope should, however, not exceed

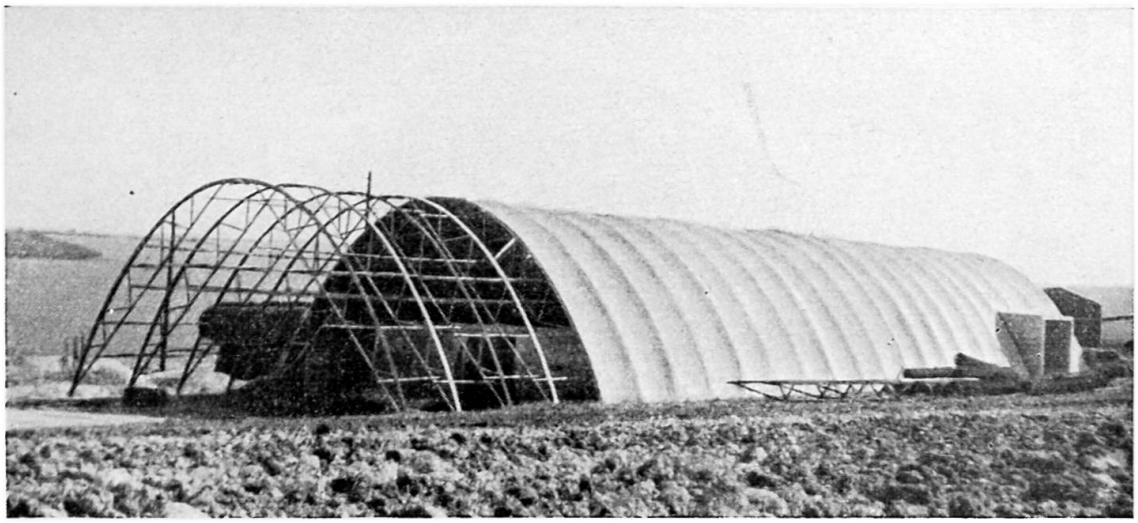

Fig. 1.

two bays of the corrugations and one whole arched ring (bay) should be left intact between any two opes.

The ends of these buildings may be constructed in brick or blocks in the conventional manner, but care must be taken that the brickwork does not bear against the shell. At least one inch of lime mortar, not gauged in cement, should be used to make the joint. In some cases, the ends have also been built in corrugated shell construction, in domed form, similar to the main barrel of the arch and utilising the same falsework. These domed ends have been found to be at least as economical as brick ends, while providing additional floor space and stability

Scaffolding and Staging

The scaffolding used at present is of tubular steel with standard couplers and fittings, as widely employed in Great Britain and U. S. To reproduce the exact shape of the shell, the skeleton consists of a few curved ribs which are pre-fabricated in the shop, and of straight tubes and couplers which are available locally. The timber backing of the ribs is recoverable, together with the steel ribs.

To form the staging simple tubular cripples are placed over the hessian against the supporting ribs and scaffold boards are laid between them. The cross pieces and the length of the cripples are arranged to permit staging at approximately 4 ft intervals in height.

Flexible moulds

Jute textile used for this purpose is generally made of Indian jute of great strength and can resist considerable tensile stresses induced in the early stages before the concrete has set.

The fabric used may be jute, coir, sisal or burlap. A good standard

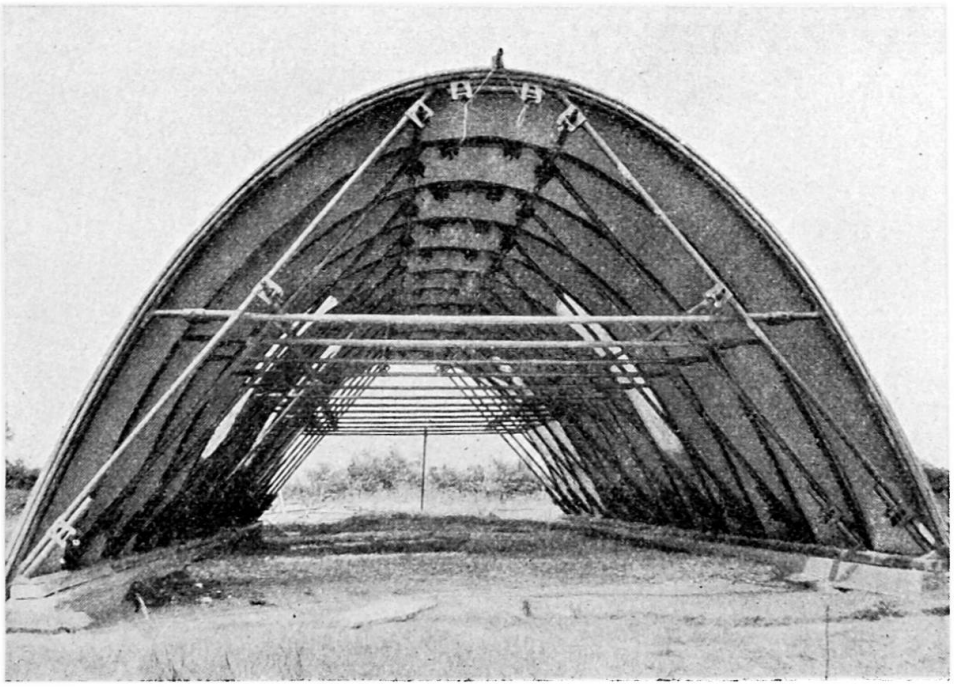

Fig. 2.

fabric is « 10 oz chested hessian ». The hessian is of fairly open mesh so that the slurry will penetrate through the material and form a good key for plastering if such internal finish is required. When entirely encased in concrete the hessian, with its high tensile strength, forms a continuous reinforcement or a toughener of the thin concrete shell. Often, however, a more closely woven fabric is employed which forms a warm and absorbent internal finish.

Concrete shell

The rendering is gauged 1 : 3 and each coat should be well floated to give good density. The sand should be of good concreting quality, on the coarse side, and the cement ordinary Portland. As the work is exposed to the atmosphere on both sides, and is very thin, ample precautions must be taken against rapid drying : it must be kept thoroughly wet for several days.

The roof surface may be finished as preferred by rendering, rough casting, splatter dashing or pebble dashing. It is not advisable to leave the surface of the roof smooth. If it can be done, the rough cast should be applied several weeks after the concreting of the roof when the greatest part of shrinkage has already taken place. Some of the buildings have been finished by an external bituminous coating serving also as camouflage.

When the falsework is removed for subsequent use, the hessian fabric forms the finish on the internal surface. When singeing it with a painter's lamp this provides a suitable surface for decorations. Ceilings may be hung from the roof by providing hooks anchored in the concrete shell.

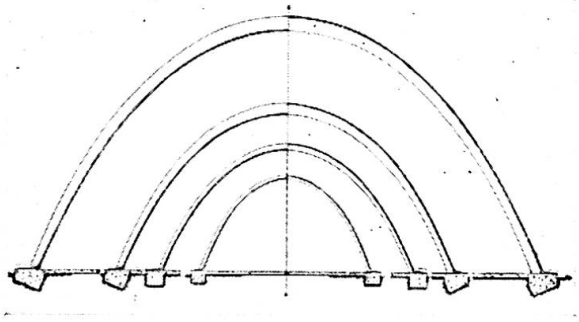

Fig. 3.

Span	Width of floor	Height inside corrugation	Width 6 ft above floor level	Cubical content per lin. ft	Thickness of concrete shell	Height of scaffolding	Ratio of span to height	Width of corrugation	Depth of corrugation at crown	Depth of corr, at springing	Overall ehight
ft	ft-in	ft-in	ft-in	cu-ft	in	ft-in	—	ft-in	—	in	ft-in
20	19-6	10-11	13-7	142	1¼	11-3	1.78	3-0	4	3	11-5
30	29-4	14-6	23-3	282	1½	15-0	2.00	4-6	6	4	15-2
40	39-0	19-0	33-0	500	2	20-0	2.00	6-0	12	8	20-2
60	58-0	28-6	51-9	1090	2	30-0	2.00	8-0	18	9	30-2
80	77-0	30-0	70-0	1530	2½	32-0	2.50	9-0	24	12	32-3

TABLE I. — *Dimensions of corrugated concrete shells*

For the dimensions of corrugated concrete shells see drawing and table I.

Properties

The hessian used as the supporting means for the concrete remains in place firmly adhering to the rendering. This hessian finish is warm and absorbent, and it is only in the most unfavourable circumstances, involving a high dew point and bad ventilation, that condensation has been found to take place in buildings erected in U. K.

All these buildings are single-skin structures. Wherever heat insulation is of paramount importance a lining of some kind should be fixed inside. If the upper portion of the building is not required for storage or for ventilation purposes, a suspended ceiling will raise the insulation of the roof to a degree required for dwellings or similar buildings in this country. In corrugated shell structures double skins may be provided by placing bitumastic blocks at frequent intervals on the crests of the corrugations of the hardened shell, stretching another sheet of hessian over the blocks and applying rendering to this sheet in the described manner. The cavity between both skins considerably improves the insulating qualities whether they refer to heat or sound.

The buildings are highly fire resisting, and proof against rats and other vermin which is of great importance when they are used for agricultural purposes.

The watertightness of the material is attributed to the fact that it is built up in thin layers, and as each layer is trowelled great density and absence of flaws results.

The relative toughness of the thin concrete shell is partly due to the presence of the fibre reinforcement and probably also due to the building up of the material in layers each of which is allowed to set and shrink before the next is applied.

Design and tests

The corrugated barrel shells are designed as ordinary arch roofs to suit the line of thrust for dead weight and superimposed loads. Dead weight and evenly distributed loads produce pure compression in the shell. The horizontal vault thrust is taken by the strip foundations. The stiffness of the structure, however, is not obtained by the thickness of the arch but by the depth of the corrugated shell. The depth of the corrugation is produced by the sagging of the fabric under the weight of the concrete.

The preliminary design is usually made by the analytical calculation of a few sections. The final design is made by graphical methods, whereby the line of thrust for asymmetrical loads is kept within the core of the corrugation. The compressive stress in the concrete due to dead weight does not exceed 100 lb per sq. in. For wind loads occurring in this country, no steel reinforcement is required up to spans of 40 ft with a span-rise ratio of 2.00. For greater spans a few light reinforcing bars are required in the crests and the valleys of the arched shell. Wire netting or other suitable mesh should always be provided in the shell to deal with shrinkage stresses.

The stability of these buildings has been investigated by loading tests by the Building Research Station, London. The deflections of buildings of 20 ft span under the proof load of the highest wind to be expected were negligible. Under $1\frac{1}{2}$ times the proof load there were no visible effects. Under double the proof load the maximum deflection was less than 1/10 in. The stability of the tested buildings was therefore considered to be entirely satisfactory.

Labour

The building processes necessary for the construction of these shell roofs consist of three simple operations :

1. The erection and removal of the re-usable falsework;
2. The stretching thereon of a light sheet of fabric and tacking it in position;
3. The application of successive coats of rendering on inclined surfaces.

Such roofs have been erected entirely with unskilled labour under the supervision of one skilled foreman.

Applications

Most of the shell structures described in this Paper have been erected as temporary structures under emergency conditions. They have been used for a variety of purposes : military barracks, canteens, stores, garages, etc. Several types have been subjected to test loads : both stability and weather-proofness have proved to be satisfactory. One of the principal assets of these buildings is that the materials required, concrete and hessian, do not encroach upon the needs of other building schemes.

At present these shell structures are being erected mostly for agricultural purposes, general purpose buildings, cow-sheds, garages and stores. A multi-span adaptation of the corrugated barrel shell is obtained by means of internal columns and lintols which carry the springings of two neighbouring barrels. Such buildings cover large floor areas with a minimum of obstruction.

Acknowledgement

The corrugated concrete shell structures described in this Paper have been designed and erected by J. H. de W. Waller, M. Inst. C. E. and the Author.

Résumé

Une disposition adéquate des échafaudages et des coffrages permet d'augmenter l'économie des constructions de toitures plissées en béton armé. Ce sont les conditions économiques résultant de la guerre qui ont amené une conception simplifiée quant aux coffrages. Ce mémoire traite de ceux-ci et notamment des coffrages pour toitures ondulées raidies par des nervures métalliques.

Zusammenfassung

Durch eine geschickte Projektierung der Gerüste und Schalung kann die Wirtschaftlichkeit von Schalenkonstruktionen in Beton erhöht werden. Die Kriegsverhältnisse bedingten eine Entwicklung, welche zu vereinfachten Schalenformen führte. Diese werden im vorliegenden Beitrag behandelt unter besonderer Berücksichtigung von Schalentypen mit gewellter Oberfläche, die durch Stahlrippen ausgesteift und mit einer biegsamen Haut überdeckt werden.

Summary

Concrete shell structures suffer from the disabilities that the cost of moulds and scaffolding is high and that they require considerable skill in erection. The impact of war has led to the development of simplified forms of shell roofs which form the subject of the Paper and has produced, among others, corrugated shell types constructed on steel ribs with flexible covering.

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