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# A Historical Perspective on the Belfast Truss Roof

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## Introduction

In recent publications on the history of structures, the term "Belfast Truss" has come to mean any wooden bowstring girder with latticework cross-bracing, regardless of the bracing arrangement. Strictly speaking, the term refers to a wooden bowstring girder in which the diagonal bracings connecting the upper curved bow and the lower straight cord are arranged always to meet in a right angle at the regularly spaced purlins on the bow.

It was probably the development of large medieval churches and associated tithe barns which provided the impetus to the development of timber structural roof forms without intermediate support. These consisted of timber, load carrying elements or trusses supporting a slate or sheet-copper or lead roof. As the industrial revolution took hold, manufacturing processes became concentrated into large units and a need for bigger industrial buildings, with clear floor areas, arose. Initially the medieval roof forms were utilised but, as spans increased, so did the size of timbers required for the individual members making up the trusses. Some relief came from the use of more complex truss forms but there was a clear need for a lighter and cheaper form of construction capable of bridging large spans.

In the first half of the nineteenth century, the development of the gas industry resulted in the production of high quality roofing-felts which could be laid on timber decking to produce a water-proof roof. This form of construction reduced significantly the dead load of the roof compared with slates or similar materials. The barrel roof-form, first recorded in the 1860s and later known as the Belfast truss roof, was widely used for industrial buildings up to the First World War (Fig. 1). During this period, its use held up well against other materials, but with steel trusses becoming more widely

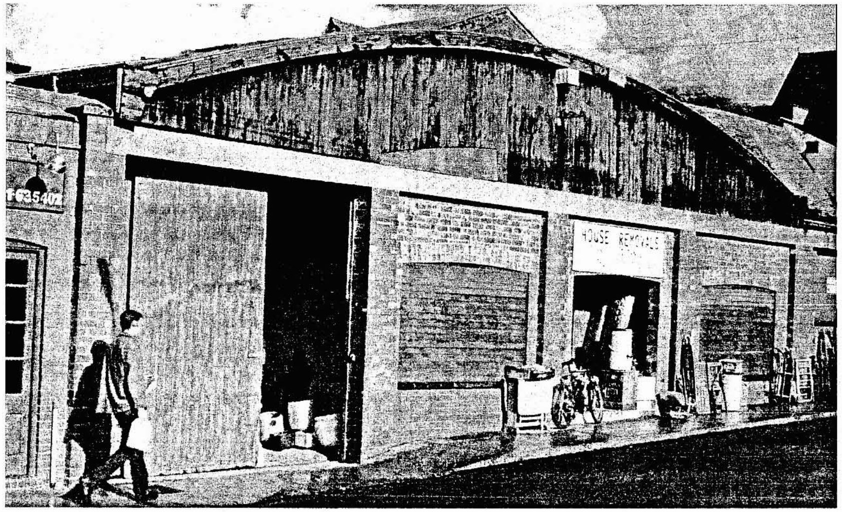


Figure 1 Typical building with a Belfast truss roof at Waterford, Ireland (photo: R. Gragg).

available, for example in aircraft hangers from 1918, its use declined. However, it continued to be used for moderate spans throughout the 1930s.

The use of the truss form was recommended during the Second World War but the wide availability of curved corrugated-iron for buildings such as the Nissen hut meant that few examples were constructed. Developments in laminated and gang-nailed trusses from the 1960s saw limited use as, by then, methods of covering large areas in concrete, steel or aluminium had been developed.

## Early Roof Forms

Early roof forms were of pitched construction, which form lends itself to the placing of roof slates or thatch.[1-4] Simple roofs using a couple or cruck developed by the addition of a collar or a collar and tie, doubling the span, and by c.1200 the collar, bolt and tie, or scissors truss had increased spans to 35 feet. The Mansard roof (from mid 1500s), or the kingpost truss, used from 1230, gave a similar order of span. The queen-strut, probably one of the most common trusses used in early industrial buildings with spans up to about 55 feet, was used in the Queen's House, 1528, and Horham Hall, 1575, and widely thereafter. More complex arrangements brought spans up to 70 feet.

A parallel development in church architecture was the hammerbeam truss, but even the addition of an arch between the hammerbeams and the pitch only served to increase the span from some 30 feet to some 50 feet.

In the early nineteenth century, Sir Robert Steppings built 100 foot span, timber, braced portal-frame roofs over naval slipways. However, the exact cost of construction is uncertain and, by c.1840, metal trusses were being used instead. There is some evidence that the braced-portal roof was weak at certain joints in the bracing[5].

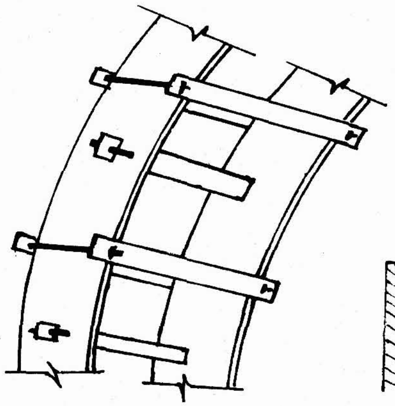

Figure 2A Philibert Delorme frame, made up of small parts, showing method of pinning.

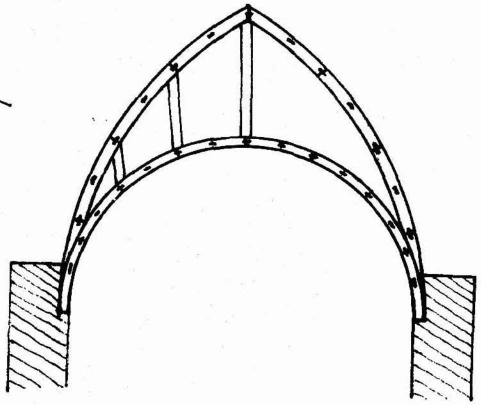

Figure 2B Suggested arrangement of Delorme's double roof frame.

## Barrel Roofs

The possibility of using a barrel, as opposed to pitch, roof was suggested by Philibert Delorme as early as 1561[6]. The Delorme system represents an early use of modules. His "frames" (Fig. 2A) consisted of two semi-circular members held apart by ties. Each semi-circle was built up from two layers of wooden pieces, 3-4 feet long, laid with joints alternate.





The first reported use of the system was for a span of 64 feet but spans of up to 90 feet were claimed. However, there were problems with the laying of roof tiles to a curve, especially for small spans, and it was recommended that an additional rib be placed above the structural elements to carry the tiles (Fig. 2B). Many early churches adopted such a roof form, but with a straight-sided upper rib.

In the sixteenth century, the possibility of using a braced truss made to a curve was explored by Palladio but how widespread was its use is not clear. Braced arches in timber were used on some bridges: see Fig. 3 which is based on the Old Walton bridge[7]. The bracing in this example has a similarity with the later Belfast truss.

In 1819, in a roof at the Libourne Barracks at Marac, Bayonne, France, the lower element of the Delorme arrangement was replaced by a series of planks bound together (Fig. 4)[8]. No doubt this was easier to construct, but no increase in span was achieved thereby. The form was later modified with

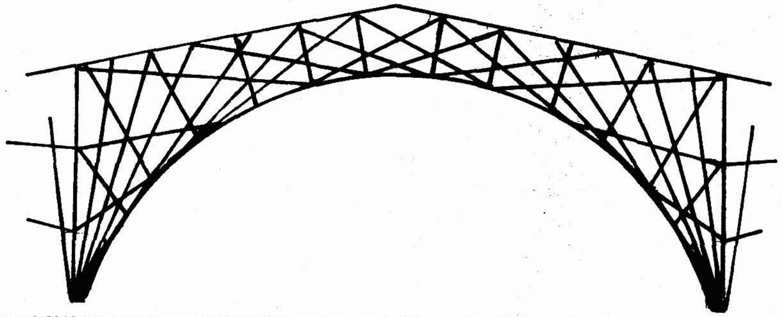

Figure 3 Old Walton Bridge on the River Thames: the central of three arches (deck not shown).

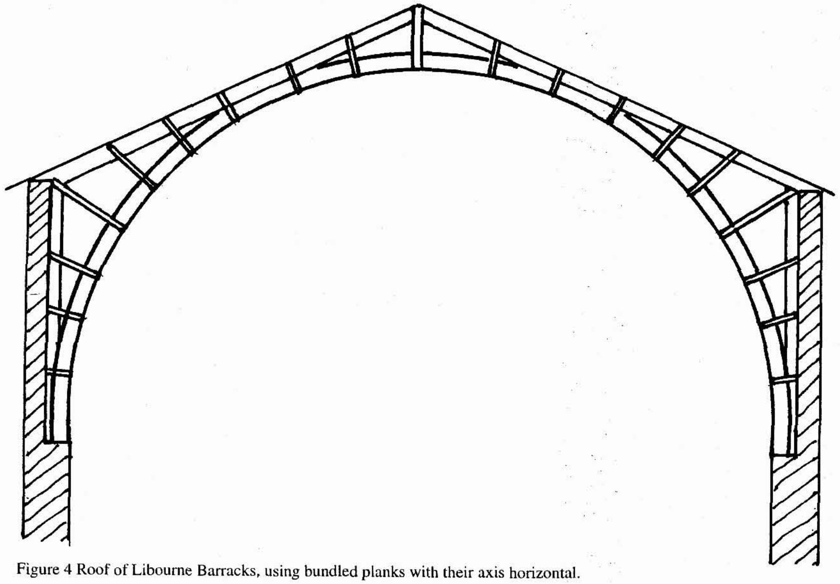

Figure 4 Roof of Libourne Barracks, using bundled planks with their axis horizontal.

the planks being set vertically, when it was known as a plank-truss roof. The fine example built in 1869 for the Great Hall of the County Down Asylum has a span of 46 feet[9]. With the advent of felts suitable for use on barrel roofs, the upper pitched element was removed, leaving what was called a bent-rip truss, but this was found to be suitable only for small spans. Built up forms of plank truss were also tried but spans achievable were again small, some 30 feet[10].

This type of construction was not without some risk. Bundled, laminated planks set as a stretched bow were used for the first King's Cross railway station roof in 1852, but the walls started to move out. The arrivals side was re-roofed in iron in 1869-70 and the departures side in 1885-7[11].

The desirability of having a curved roof-form for the laying of felts resulted in several arrangements being developed in which the curve was placed above the pitch, with spacers being inserted to form the required curve. One such form is illustrated in Fig. 5. However, this type of construction could, at best, be described as a compromise and a proper method for producing curved roofs was clearly needed.

It will be seen that all of the roof forms discussed so far have a limit of about 60 feet span, except perhaps, for Stepping's arrangement and the Delorme system. Part of the difficulty in increasing the span arose due to the dead weight of a pitched, slated, roof and part arose because of the need for unjointed main truss members of a much larger size as spans increased. This latter problem would nowadays be addressed by using laminated timber or glue-strengthened joints. Current Northern Ireland building regulations, for example, allow the maximum span of 40 feet for a solid single-span roof-beam to be raised to 100 feet for laminated construction of the same cross-sectional area[12]. However, in the mid nineteenth century this was not an option and, instead, it was to be the development of the Belfast truss roof which allowed for the ready increase of clear spans to 100 feet (although a maximum of 150 feet was claimed).

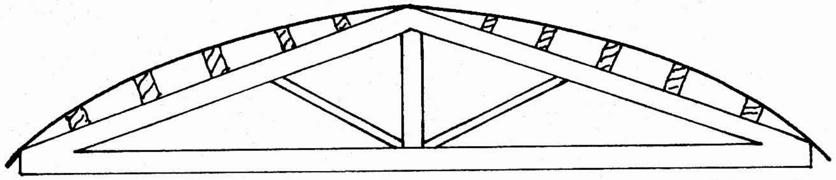

Figure 5 Barrel vault carried by spacers off a kingpost truss.

### History of the Belfast truss

The first known reference to a curved wooden felted roof supported on bowstring girders is found in The *Dublin Builder* for 1866[13], also repeated in other journals. The advertisement inserted by the Belfast firm of felt makers, M^c^Tear & Co, includes an engraved illustration, which shows a building where the trusses have bracings radiating from points below each end of the truss (Fig. 6). Later these foci were standardised at one half-span down and the design was subsequently carried in textbooks into the 1930s.

A proposed detailed series of Irish County Directories was never finished, but that for County Antrim was published in 1888 and that for County Down in 1886. These are well illustrated with engravings depicting various factories and other industrial premises, which show that many were then using a barrel roof-form. Also in the Antrim directory is an advertisement by a second Belfast felt supplier, Anderson & Co. The illustration for this advertisement shows a truss with parallel bracings equally spaced across the truss, a form described in the text as "a lattice work truss" (Fig. 7). At this time neither McTear nor Anderson were talking of "Belfast Trusses". The earliest known reference to a cheap form of roof "as used in Belfast" dates to 1900[14].

In 1896, the paint shop at the works of Charles Burrell & Son at Thetford in Norfolk burnt down. The






Figure 6 Typical advertisement by the felt makers M^c^Tear and Co. showing Belfast truss roof (from *The Country Gentleman's Catalogue*, 1894).

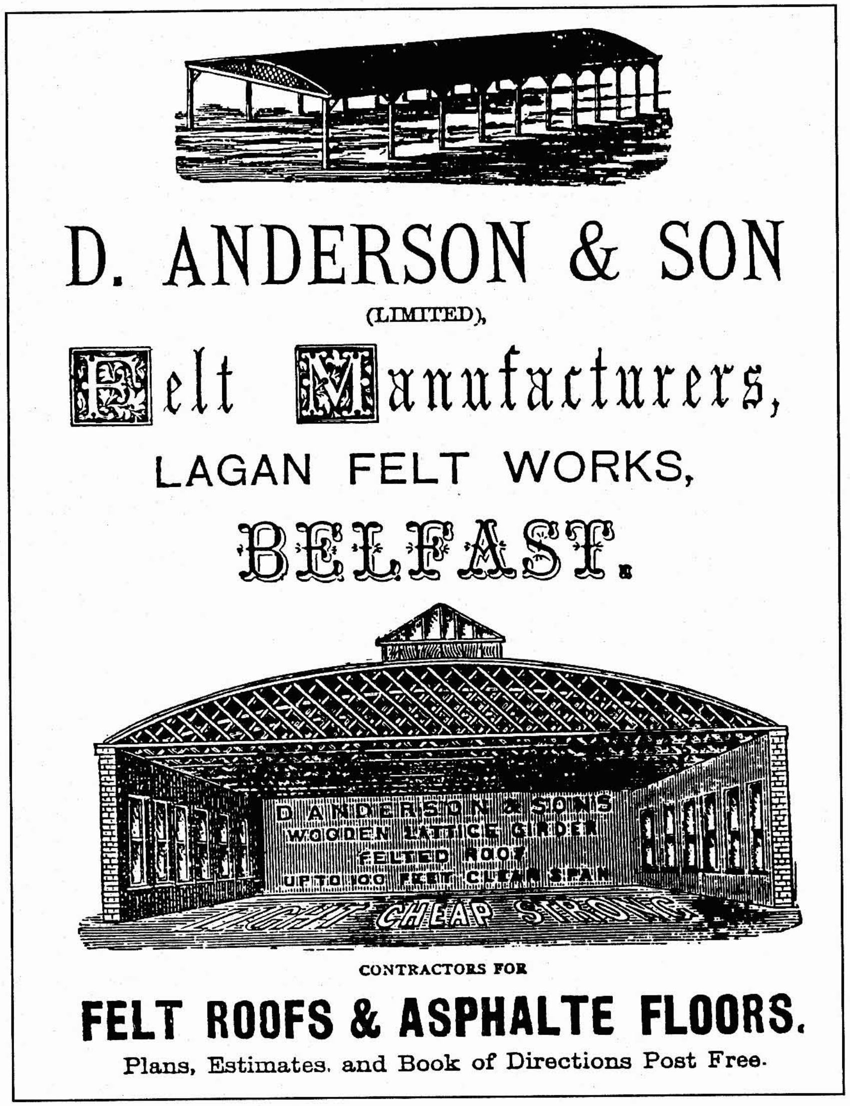


Figure 7 Advertisement by the Belfast felt supplier, Anderson and Co. (from *The County Antrim Directory*, 1888).

replacement building was roofed in bowstring trusses stamped BELFAST. Close-up photographs show that the trusses are of Anderson's second arrangement, with the bracing meeting every purlin in a right angle, the line of bracing across the truss varying, giving a "fan-like" appearance to it. Burrells were told that this was a prototype truss and it thus appears to be the first recorded example of a true Belfast truss.

A letter exists in the Science Library of the Queens University of Belfast, dating from about 1905, reporting on load tests carried out for Andersons by the Belfast firm of architects, Young and McKenzie. No reason is given for undertaking the tests nor the truss form tested. However, after this date, Andersons promoted "the Belfast roof" and it seems reasonable to infer that it was the fan-like bracing arrangement which was load tested.





**Structural Perspective**

It may be assumed that the change in bracing arrangement made by Anderson & Co, was considered to have had some structural benefit. The street directory shows that McTear & Co ceased to trade in about 1908. However, several other companies are known to have constructed and supplied Belfast roofs subsequently and all but one used Belfast trusses to the new arrangement.

It is noticeable that all of the structural forms mentioned so far differ from a conventional bow-string truss in that the pairs of bracings meet on the top bow, rather than the bottom cord. The roof was completed by close spaced light purlins supporting a timber decking, on which the roof felt was directly laid. By arranging that the braces meet on the top bow of the truss, it was possible to ensure that each purlin was supported on two braces. This cannot be achieved if the bracings meet at the bottom cord.

There is, however, no obvious benefit in a fan bracing over a parallel arrangement, unless this was conceived to give better structural stability against a wind load on the side. Wind tunnel tests undertaken in the School of Civil Engineering of the Queen's University do show an asymmetric load pattern over the roof due to wind. However, the stresses do not appear to be sufficiently significant as to require a change in bracing arrangement, although this may not have been known by Andersons in 1905. Model and computer tests both suggest that the member stress in the bracings is very low, except, perhaps, near to the supports, and this would suggest that their lay-up arrangement is largely unimportant.

The School has undertaken full scale tests[15] which, when taken with the Young and McKenzie results, suggest a failure load of approximately 40 pounds per super-foot regardless of span. This is probably more a function of Anderson's table of suggested member sizes, which increase with span, rather than a function of the truss *per se*.

Known failures of Belfast trusses are rare. The commonest problem encountered has been due to water ingress causing rot at the ends of the truss. However, this is a redundant structure and examples with rotted timbers have been seen still in service. Splicing of new timbers to replace rotted parts has also been successfully undertaken.

It cannot now be confirmed why a fan bracing arrangement was considered to be more suitable than a parallel arrangement. However, if the purlin joint is considered on a very simplistic level to act as a pin, then it is conceivable that two braces each meeting the purlin at 45 degrees (the Anderson arrangement) could be considered as necessary to ensure that an equal load be carried in each brace. It appears, therefore, that the fan arrangement of the Belfast truss may be simply a reflection of a lack of structural understanding on the part of the designers in 1905. Once this design was found to work, there would be little incentive to change it.

**Making a Truss**

Anderson's literature gives step-by-step instructions on how to make a truss. The curved bow and lower cord are formed of at least two boards with the braces in between and this means that the truss can be easily constructed on its side. One bow member is curved inside a row of pegs replicating the purlins, the rise being usually one sixth or one eighth of the span. These pegs have to be equally spaced, placed tangentally to the bow and accurately sized in area. The cord member is notched to take the bow and the joint nailed. The bracing timbers are accurately cut at their end to 45 degrees and set against the pegs. All joints are nailed. When all of the braces are in, the second bow/cord timbers are added and the pegs removed. A sole-plate completes the truss. The braces protrude above the bow and predetermine the purlin size and position. The weakness is at the end notched-joint and the truss is often strengthened here by solid sheeting, using double braces in one direction or by the use of metal straps.

It will be seen that the whole accuracy of the truss lay-up depends on the accurate placing of the pegs and the end cutting of the brace members; small errors here would magnify along the length of the brace affected. This build-up method of construction allows for the use of small section timbers of low grade.

**Why BELFAST?**

Belfast developed rapidly during the nineteenth century so that, by 1901, the port was more important than Dublin. Much of this growth was due to the development of the linen industry and many houses were built to accommodate the factory workers. Much factory building also tok place. The Belfast roof was rarely used for housing and a holiday home in the Mourne mountains is the only known house, purpose-built with such a roof, remaining. It was, however, quite widely used by industry. Apart from cost, the Belfast roof was considered to have one major advantage over other forms of pitched or barrel roof – it was considered to provide a warm surface. This was especially important for finishing processes in hot steamy atmospheres, when condensation dripping from a cold roof could spoil the end product.

There was a well-established history of timber construction in Belfast, especially in boat building from 1791. Although iron boat building developed from 1853, timber continued to be used for the many small boats built. An industrial base was perforce established in Belfast for the making of ship sheathing-felts. The manufacture of roofing felts would form a logical progression. Two factors would have contributed to this in Belfast. Firstly, the indigenous textile industry would have provided the fabric base at a low price. Secondly, a consequence of the growth of Belfast was a considerable increase in gas production, which, until the 1890s, was totally from coal. A production of 10 million cubic feet of gas annually in 1828, when the works opened, had reached 50 by 1845, 100 by 1855 and well over 1,000 by 1895[16]. A by-product of this gas production would have been a good local supply of coal tar and bituminous paints.

Northern Ireland had many factories in, for example, textile and paper manufacture, with Belfast roofs covering the various finishing processes. Although Ireland was lacking in certain building materials, especially good quality slate and large timbers and all metal products, which had to be imported, there was a sufficiency of building stone and brick. It may therefore seem surprising that the Belfast roof was not used more widely on other brick buildings. One reason why timber and slate continued in use in these circumstances might be due to the additional fire risk of a tar-felted roof. Fire was a considerable risk and, by 1813, fireproof textile mills were being built in part of England[17].

Ireland used to be rich in timber but by 1800 much of the natural forest had been cleared. The Public Records Office of Northern Ireland has a list of import duties proposed in 1813 and this includes for 300 tons of logwood (at 3d./ton or 1.25p./ton), 10,000 tons of timber square (at 2d./ton or 0.83p./ton) and 200,000 tons of plank or deal at 6d./120 ton or 2.5p./120 ton). A study of the maps for Belfast port shows that a timber pond had been established (for boat building) by 1847. The 1872 map shows ponds six times as large on the opposite river bank, while that of 1893 shows extensions to these one-and-a-half times larger again. Clearly a large trade in log timber had been established, initially from the Baltic countries (Memel pine) but later more pine was to come from north America. It has been suggested that the barrel roof-form developed partly in an attempt to utilise the off-cuts from this timber trade.

Further impetus for the development of a light, cheap, roof form in Ireland may have arisen from the important agricultural sector especially following the development of various model farms.





**Competition with Other Materials**

There was competition at an early stage from other materials. In 1877, the concrete toll-house to the Axemouth bridge in Devon, was built with a barrel roof, although later photographs show the roof felted[18]. Also in 1877, an article illustrating a range of buildings for a model farm shows round-roofed buildings constructed of concrete (presumably in mass), but this idea does not seem to have been widely taken up[19]. In any event, spans achievable in mass concrete were probably small.

A simple tied bow in wrought iron was used in a workshop erected beside Limerick graving dock, probably dating from when that opened (1873)[20]. Its construction was similar to a timber bent-rib truss although which came first is unclear. The covering over the 17 foot span trusses is in corrugated iron, perhaps original, discharging to big gutter sections carried on brick pinths on the iron stone-wall head-plate beam. Reference has also been made to a longer span steel bow-string truss over the Afton Downs sheep shearing shed (Australia), also covered in corrugated iron and which may date to 1887[21]. In 1912, steel lattice girders were available in a size sufficient to allow the construction of a lightweight roof over Wolborough service reservoir (Newton Abbot). However, no systematic study of the development of light metal trusses in this period seems to have been undertaken.

By the early 1890s, the Enniskillen newspaper, *The Impartial Reporter*, was regularly carrying an advertisement for an all-metal hay-shed, hundreds of which, it was claimed, had been successfully built. That such a design had reached what may be regarded as a rural backwater, County Fermanagh, suggests a widespread distribution of such structures and some, apparently to this design, are still to be found throughout Ireland. Corrugated iron hay sheds had appeared in Ulster by 1903[22]. Despite this competition, the Belfast roof held its own until after the First World War. The need to expand the home-defence air-services rapidly with the arrival over Britain of German bombers led to many hangers being built with Belfast roofs after 1916, with spans of up to 100 feet (Fig. 8). Those built all in timber were sold off by the Air Ministry in 1919-20, but quite a number with brick sides continued to give service for many years, and some still exist[23]. Buildings with such roofs were also to be found

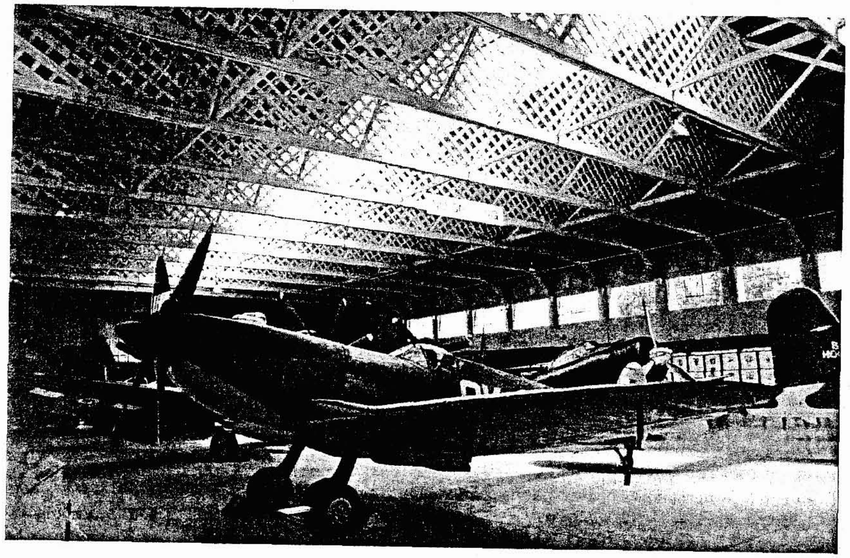

Figure 8 Belfast truss used in a First World War hangar at Duxford, Cambridgeshire (photo: S. Gilbert).

at certain factories, which required additional space to undertake war-work, especially aircraft construction[24]. However, wooden-roof hanger construction basically had no future. The Belfast truss general purpose hanger was already too small for the large experimental RAF bombers appearing in 1919. Further, in a privately produced history *McAlpine Contracts*, dating from about 1921, the photograph of the hanger built at Turnbury c.1918 appears to show a metal truss. Thereafter, increasing span requirement led to metal roof forms, initially based on Lamella construction in steel[25].

Despite the abandonment of hanger construction in timber after 1919, the Belfast roof continued to be actively promoted for small and medium sized roof spans[26]. Based on such surveys as have been undertaken in Northern Ireland, the buildings most commonly constructed in the 1930s were garages, farm out-sheds, in builder's yards and for some railway buildings (both for goods storage and platform awnings). Until the last 15 years or so, many remained, but the number is declining as problems with rot (often due to lack of maintenance) set in. Such buildings, often in poor order, may still be found throughout Britain: at least ten examples have been listed, notably the hangers at Hooton Park Airfield in Cheshire of c.1917.

Another location where timber roofs held out against other forms was at sea ports. The ready availability of small sized timber made the Belfast roof ideal for port buildings and many were constructed. Harland and Wolff's photographic records show that Belfast's shipyards in the 1920s and 1930s were almost entirely made up of buildings with Belfast roofs (Fig. 9). These lasted until the advent of the building dock when large ship-sections prefabricated under cover rendered them too small, and almost all have now gone.

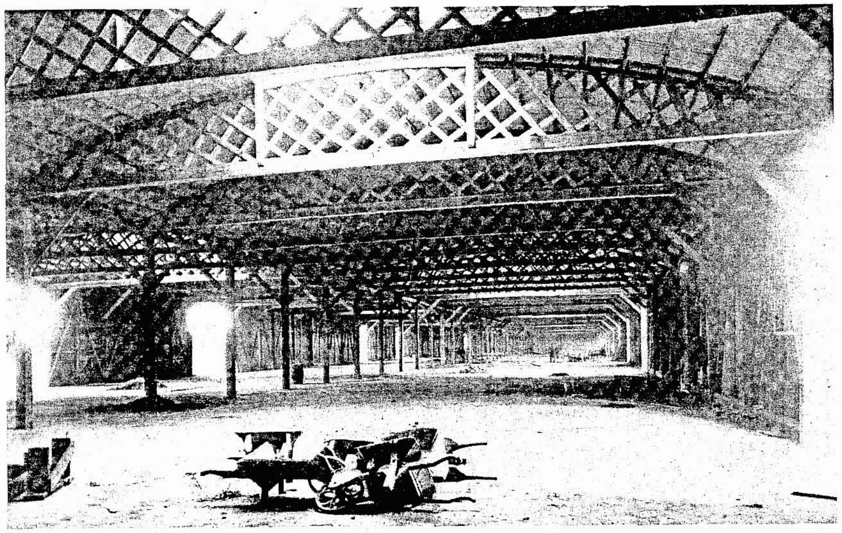

Figure 9 Internal view of a transit shed at Belfast Docks, c.1917 (photo: Grahams of Dromore).

The speed of construction for the Belfast roof could, on occasions, have advantages over other forms of roof construction. When the Glasgow factory of the American *Singer Sewing Machine* Company was burnt down in 1906, a replacement building had to be erected quickly in order to allow production to recommence without significant labour layoff and a Belfast roof of 3,400 square yards was built in just four days. Indeed, one US visitor was heard to ask for details of the "Built Fast" roof[27]!





**Later Use**

It is known that some temporary buildings were constructed with Belfast roofs. One was built for the laying of the foundation stone of Parliament Buildings in Belfast in 1928[28]. An earlier photograph of the signing of the Ulster Covenant (in the Ulster Museum, Belfast) shows a Belfast roof, but it is not clear whether this was erected for the occasion or if an existing site was used. A construction photograph relating to the large concrete railway viaducts built in 1932-4 north of Belfast shows a temporary shelter with a Belfast roof covering part of the batching plant.

The relatively easy construction techniques needed for the Belfast roof made it ideal for less technologically advanced governments and its design was carried in the Ministry of Works handbook used in the former British colonies for some years[29] (Fig.10). The design was also taken up in USA where timber buildings are more common.

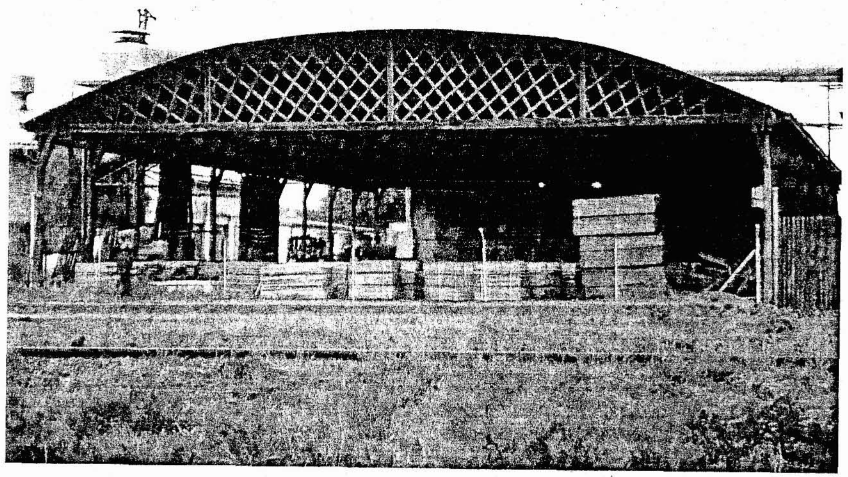

Figure 10 Building in South Africa erected using advice from a Ministry of Works Handbook.

Although the Belfast truss was recommended for reuse during the Second World War[30], when it was noted that "this (form) is particularly important at present as it utilises short lengths of timber", only one quoted use for it has been located, and this in a bastardised form. Here, the cords were set inside the bracings, which lay in one direction on one face and in the other on the opposite face[31].

Variations in timber truss design were promoted, mostly in north America, after the War (see Table 1) and some moves were made to introduce into the United Kingdom a bowstring truss in laminated timber, with a series of simple V braces split by a vertical[32]. Although a good example is to be seen in Sunderland docks, in the long term, timber construction could not hope to compete with modern light-weight structural roofs, built, for example, in aluminium, and the Belfast truss is now given in most contemporary text books as being an archaic constructional form[33].

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| Item | Span | Reference |
|---|---|---|
| Undersling bow, V and vertical braces. | ? | *Civil Engineering,* April 1958 |
| Laminated timber, V and vertical braces. | 40 ft. | *Civil Engineering,* October 1948, p592 |
| Same form. | 56 ft. | *Municipal Engineering,* (Supp.) 24.1.69, S159 |
| Same form but with shear connectors. | 150 ft. | *Civil Engineering,* December 1940, p352 |
| With K bracing. | 200 ft. | *Civil Eng. & PWR,* February 1957, p199 |
| Laminated arches. | 205 ft. | Ibid, p 197. |

**Table 1. Details of some modern timber bowstring trusses.**

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28. Shown in official pamphlet guide *Parliament Buildings, Stormont* (Belfast, 1985).
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33. When making the Belfast truss, the bracings are laid and nailed face to face, with spacers at the bottom cord. However, each layer is pinched in by half of its thickness so that the braces lay side-by-side at the top bow. Two lay-ups have been seen which attempt to prevent this need to pinch in the braces (although given the light loads these members carry, pinching-in probably presents no structural difficulty).
First are trusses with braces which meet at both the bottom cord and at the top bow. Only one crossover is possible, at mid height. Spans seen are not large. Secondly are trusses in which the two timbers making up the top bow have been separated. One is set between the braces at the top and one at mid height. Spacers may be inserted at other crossover points. One of the timbers making up the bottom cord is also placed between the layers of braces, which now all lie vertical. Evidence about these trusses is limited, but may suggest that this arrangement is weaker than the Belfast truss. Neither of these truss forms seem to have a specific name.