

New Challenges for Aluminium Structures: An Introduction

Structural applications of aluminium have grown considerably in the last decades. In transportation, the low mass weight, resulting in a high strength to weight ratio, makes aluminium a favourable material for aircrafts, high speed trains and ferries. In building and civil engineering, sometimes the low weight is determining the choice for aluminium, for example for movable bridges or helicopter decks on offshore platforms. However, more often other favourable properties such as corrosion resistance, easy shaping of profiles by extrusion, and aesthetics are of importance.

A condition for a successful structural application of aluminium is the availability of design rules. Several national standards do already exist, some of them even for decades, but with the release of 'Eurocode 9: Design of Aluminium Structures' a new challenge for structural aluminium applications exists on short term. Eurocode 9 is by far the most extensive and up-to-date standard compared to national standards of various European countries.

Aluminium and steel are different materials but design problems usually are similar. Aluminium differs from steel in its physical properties (low mass weight, stiffness and linear expansion) and in its mechanical properties (strength and elongation), the latter as a result of alloy hardening. A designer should make use of the advantages of aluminium – in particular its light weight, extrudability and corrosion resistance

– and find adequate solutions for the disadvantages such as its low stiffness, resulting in stability being a more predominant design aspect, and its lesser fatigue and fire resistance behaviour, when compared to steel.

Obviously, there are enough reasons to release a special issue of *Structural Engineering International* devoted to aluminium. This special issue starts with two papers surveying structural aluminium applications. Then the material is introduced. The subsequent papers are dealing with Eurocode 9 topics, both with static design as well as with fatigue. Then, papers concerned with topics like stability, composite structures, welded joints and sustainability are presented. The series is finalised by papers on recent structural applications for bridges and buildings.

The authors of the articles in this special issue on aluminium in structural engineering are acknowledged for their contributions to this issue, which may further enhance the application of aluminium in building and civil engineering structures.

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Structural Applications of Aluminium in Civil Engineering

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Summary

The Aluminium (Al) element was discovered 200 years ago. After an initial period of technological development, aluminium alloys were used in many structural applications, including the civil engineering field. The last decades have been devoted to analyse the structural behaviour of extruded and welded members by means of theoretical and experimental research. The achieved knowledge represents today the solid basis for modern codification. The present paper gives an overview of the contemporary developments in the design of aluminium alloy structures.

Basic Prerequisites

The success of aluminium alloys as constructional material and the possibility of a competition with steel are based on some prerequisites, which are connected to the physical properties, the production process, and the technological features.

In particular, it is commonly recognised that aluminium alloys can be

economical, and therefore competitive in those applications where full advantage is taken of the following prerequisites [1, 2, 3]:

Lightness

Low specific weight of aluminium alloys which is one third of steel, makes it possible to:

- simplify the erection phases;
- transport fully prefabricated components;
- reduce the loads transmitted to foundations;
- economize energy either during erection and/or in service;
- reduce the physical labour.

Corrosion Resistance

Formation of a protective oxide film on the surface makes it possible to:

- reduce the maintenance expenses;
- provide good performance in corrosive environments.

Functionality of Structural Shape

Extrusion process makes it possible to:

- improve the geometrical properties of the cross-section by designing a

shape which simultaneously gives the minimum weight, and the highest structural efficiency;

- obtain stiffened shapes without using built-up sections, thus avoiding welding or bolting;
- simplify connecting systems among different component, thus improving joint details;
- combine different functions of the structural component, thus achieving a more economical and rational profile.

Fields of Application

Competitiveness

The best application can be obtained in some typical cases, which are characterised in getting profit at least of one of the main basic properties: lightness, corrosion resistance and functionality [4, 5, 6]. The structural applications which best fit these properties in the field of civil engineering are the following:

- Long-span roof systems in which live loads are small compared with dead loads, as in the case of reticular space structures and geodetic domes covering large span areas, like halls and auditoriums.
- Structures located in inaccessible places far from the fabrication shop, for which transport economy and ease of erection are of extreme importance, like for instance electrical transmission towers, which can be carried by helicopter.
- Structures situated in corrosive or humid environments such as swimming pool roofs, river bridges, hydraulic structures, and offshore super-structures.
- Structures having moving parts, such as sewage plant crane bridges and moving bridges, where lightness means economy of power under service.
- Structures for special purposes, for which maintenance operations are particularly difficult and must be limited, as in the case of masts, lighting towers, antenna – towers, sign motorway portals, and so on.

The above groups mainly belong to the range of ‘civil engineering’, but a wider field of potential applications is the more general one of ‘structural engineering’.

Lightweight Structures

When structural weight is a fundamental issue, the utilization of aluminium

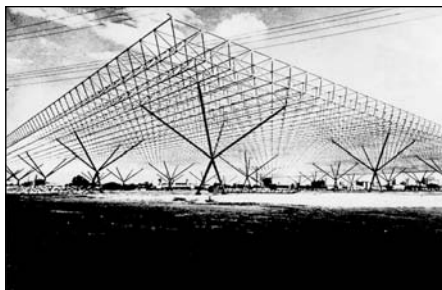


Fig. 1: The reticular space structure of the Interamerican Exhibition Center of Sao Paulo (Brazil)

can represent a valid alternative to steel. In addition, the complete absence of maintenance increases the advantages in particular for those structures situated in humid environments.

Several applications of reticular space structures can be found in South America (Brazil, Colombia, Ecuador). The historical background in this field is represented by a very spectacular space structure which has been erected for the Interamerican Exhibition Centre of Sao Paulo in Brazil in 1969 (Fig. 1), covering an area of about 67 600 m² with a mesh 60 × 60 m. The depth of the reticular layer is 2,36 m. It was entirely site-bolted on the ground, and later it was lifted at the final level of 14 m by means of 25 cranes located in the corners of the mesh, in the position of the actual supports. The weight of the reticular structure was 16 kg/m²; the number of bars was 56 820 and their total length one after another was 300 km. The erection time was extraordinarily quick (27 hours), by using a number of 550 000 bolts in 13 724 nodes. The materials were: aluminium alloys of 6063 and 6351 series T6 for cylindrical bars, Al 99,5 for trapezoidal sheeting and, galvanized steel bolts for connections. Very similar is the case of the International Congress Centre in Rio de Janeiro, where the same mesh 60 × 60 m has been used, covering a total area of 33 000 m² (Fig. 2).

Many significant applications are developed in Colombia, like the reticular structures for roofing swimming pools [7] (Fig. 3). Among many different applications, reticular systems covered by aluminium sheeting can be mentioned: the roofing of the Sport Hall of Quito, Ecuador (Fig. 4) and the Memorial Pyramid in La Baie (Quebec, Canada) (Fig. 5), for remembering the damage due to a flood in the 80's. The reticulated domes represent the most challenging application of aluminium alloys in the structural field, allowing



Fig. 2: The International Congress Centre of Rio de Janeiro (Brazil)

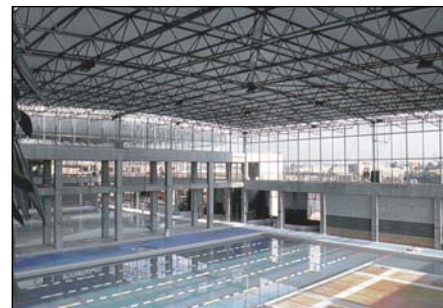


Fig. 3: Swimming pool roofing (Colombia)

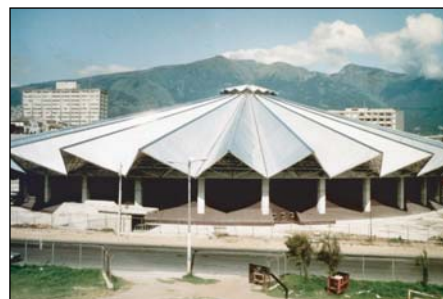


Fig. 4: Sport Hall of Quito (Ecuador)



Fig. 5: The Memorial Pyramid in La Baie (Quebec, Canada)

the realisation of important constructions (sporting arenas, exhibition centres, congress halls, auditoriums, etc). These applications are very interesting for the rapidity of erection, the connection systems, and the remarkable dimensions.

The first applications were: the ‘Dome of Discovery’ erected in London for the South Bank Exhibition during the Festival of Britain (1951), composed by three directional reticulated arches,

with a diameter of 110 m and 24 kg/m² weight and the geodetic dome erected for covering the “Palasport” in Paris, by using the Kaiser Aluminium system with 61 m diameter and 20 m height (1959). Both were like prototypes in their field: the largest and the first, respectively.

More recently, interesting structural systems for geodetic domes made of aluminium have been set-up in the United States, where ‘ad hoc’ systems are used both for roofing industrial plants with ecological purposes, and for large roofing of public buildings. A famous application is the ‘Spruce Goose’ dome, being the largest in the World with a diameter of 415 feet (Fig. 6). Many geodetic domes are used for industrial applications, like coal storage plants (Fig. 7).

A recent application of a reticular dome has been done in Rome during



Fig. 6: The “Spruce Goose” dome during erection (Long Beach, California)



Fig. 7: Aluminium domes for coal storage plant



Fig. 8: Geodetic dome in the Museum of ‘Mercati Traianei’ in Rome (Italy)

the restoration activity of the ‘Mercati Traianei’ Museum [8] (Fig. 8).

Low Maintenance Requirement

There are special structures having the function to support fixed elements, which are located at a given distance from the ground, the prevalent dimension being horizontal (e.g. portal frames for traffic signs) or, vertical (e.g. antennas, electrical transmission and lighting towers). For these structures, the elimination of maintenance represents a fundamental prerequisite. At the same time, the extrusion process can improve the geometrical properties of cross-sections in such a way to obtain the minimum weight and the highest structural efficiency. In addition, the lightweight of aluminium allows prefabricated systems, very easy for transportation and erection, giving rise to competitive solutions in comparison with other materials.

Many towers for electrical transmission lines have been erected in Europe. Two important aluminium towers have been erected in Naples. The first example is the tower for parabolic antennas of the Electrical Department of Naples erected in 1986. This design received the international award ‘Hundred Years of Aluminium’ [9]. The reason for choosing aluminium was basically its lightness (the tower has been erected on top of an existing reinforced concrete stair-case) and its corrosion resistance property (no problem of maintenance). Its height is 35 m from the top of the stair-case (in total about 50 m). It is composed of a cylinder with 1800 mm internal diameter and 20 mm thickness. The fabrication was shop-welded, by dividing the total height into three parts, which were field-bolted during the erection (Fig. 9a). The second example is the ‘Information Tower’ near the football stadium in Naples, which has been equipped with antennas and screens in order to follow the games from outside the stadium (Fig. 9b).

A field where the properties of aluminium play a determinant role is – the hydraulic applications (pipelines, reservoir). The case of the rotating crane bridges for large settling circular pools in water sewage treatment plants is a typical case (Fig. 10). In particular, the ‘corrosion resistance’ allows to eliminate any protection also in the presence of a corrosive environment, while the ‘lightness’ corresponds to energy

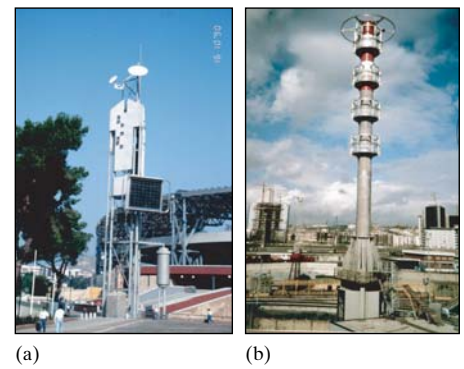


Fig. 9: Two aluminium alloy towers erected in Naples



Fig. 10: The sewage plant pool of Po-Sangone (Torino, Italy)

saving – during the operating phases of the plant [10].

It seems important to underline that nowadays offshore applications can be considered the main – future – trend for aluminium alloys. In fact, they offer to this industry enormous benefits in the form of cost savings, ease of fabrication, and proven performance in difficult and hostile environments.

Stair towers, mezzanine flooring, access platforms, walkways, gangways, bridges, towers and cable ladder systems can all be constructed in pre-fabricated units for simple assembly offshore, or at the fabrication yard.

Mobility and ease of installation are maintained even for large structural elements, such as link bridges and telescopic bridges .

Helidecks, have been made by using aluminium alloy since the early seventies, so they are now fully tried in heavy duty situations (Fig. 11).

Moreover, they are designed to be modular and have bolted connections, allowing quick erection and easy shipping, and handling. In addition, they offer weight reduction of up to 70% over steel, meeting the highest safety standards; and providing up to 12% cost saving [11].



Fig. 11: A structural off-shore application: helideck

Complete crew quarters and utilities modules, from large purpose-built modules to flexible prefabricated units, have been recently developed. The modules may be used singly, or assembled in a group to form multi-story complexes, linked by central transverse corridors and stair towers.

Crossing Structures

All kinds of bridges have been built using aluminium alloys. The Arvida Bridge in Quebec, Canada (1950) is the challenging prototype of a motorway bridge made of aluminium alloy. It was built according to the Maillart's scheme with a total span of 150 m, an arch of 87 m of span, and total weight of 200,000 kg (Fig. 12).

The technology of composite structures made of aluminium beams and concrete decks, has been also developed. Concrete-aluminium composite systems have been used in some bridges built since the sixties in the United States and later in France.

A prototype for a new floating bridge has been recently opened in The Netherlands for crossing water straits [12].

A new important field of application is the one of military bridges in which 'lightness' and 'corrosion resistance' play a fundamental role. At present, it is possible to reach 40 m of span with prefabricated elements – easy to transport and to erect. The main applications have been developed in Great Britain, Germany and Sweden. In Germany, a military bridge is produced composed



Fig. 12: Arvida bridge (Quebec, Canada)



Fig. 13: The German military bridge: erection phases



Fig. 14: The new Swedish military bridge [13]

of prefabricated units, easy to transport, and erect (Fig. 13).

In the new Swedish model (Fig. 14) the high-tech friction stir welding process was used [13].

The foot-bridge is a structural typology where aluminium alloys are successfully employed, owing to low live load. Additional advantages, thanks to 'lightness' are evident in the case of moving bridges. Examples of aluminium foot bridges can be found in France, Germany, The Netherlands, Italy, and in Canada.

Refurbishment of Bridges

A lightweight system for replacing damaged concrete bridge decks has been developed and used in Sweden, based on an orthotropic plate of aluminium hollow extrusions. This solution can be very competitive in many cases as an alternative to the conventional solutions. Weight reduction has made it possible to use the existing foundations and supports [11].

Conclusion

The above examples have clearly shown some of the situations – where the structural use of aluminium alloys gives a suitable and convenient solution. Summing up, it is possible to conclude in general that the main reasons

for switching from steel to aluminium are the following:

- lower weight;
- lower maintenance cost;
- longer life;
- recycling.

Under these conditions, a new challenge is open for aluminium alloys in the field of structural engineering.

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