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The Second Generation Eurocode 9 †

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Abstract: The paper summarizes the main results achieved in the context of CEN Mandate M/515 for amending and extending existing Eurocodes with regard to Eurocode 9 (EC9) on Aluminium Structures (EN1999). The revision process led to introducing additional structural typologies (bridging, roofing and a composite of aluminium–concrete), new connection types, new materials and a new buckling material class and to defining improved buckling curves accordingly. This resulted in the addition of several new annexes to the main text. The new items were mostly planned for Part 1-1, including general upgrading, updating and simplifying, with some new additions where necessary. NDPs were reduced from 89 to 49. A general improvement of editorial aspects was obtained as well.

Keywords: CEN; Mandate M/515; Eurocode 9; Aluminium Structures; New Generation Eurocodes

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1. Introduction

In the early 1990s of the 20th Century, the CEN/TC 250/SC9 Committee devoted to Eurocode 9 (shortened as EC9) on the Design of Aluminium Structures was settled under the chairmanship of F.M. Mazzolani and activity soon started for drafting the general part, ENV1999-1-1, of the code. A parallel action was undertaken for the parts dealing with fire (ENV1999-1-2) and fatigue (ENV1999-2). At the beginning of the 21st Century, after the achievement of the ENV stage, in order to meet the need of the European Aluminium Industry for a specific codification dealing with cold-formed members and shell structures, two additional parts were developed, leading to the definitive layout of EC9 (EN1999), consisting of five parts:

- EN1999-1-1 Design of Aluminium Structures: General structural rules;
- EN1999-1-2 Design of Aluminium Structures: Structural fire design;
- EN1999-1-3 Design of Aluminium Structures: Structures susceptible to fatigue;
- EN1999-1-4 Design of Aluminium Structures: Cold-formed structural sheeting;
- EN1999-1-5 Design of Aluminium Structures: Shell structures.

The new parts, 1-4 and 1-5, were introduced because of the wide use of both thin gauge members and shell structures in civil as well as in industrial fields, including, in particular, transportation and storage applications. In addition, it appeared quite strange that such topics, widely covered in EC3 though, were not considered in EC9 at all. The first EN version was approved in 2007 and then revised in 2009 [1]. A few years later (2011), a similar document was issued by the Italian National Research Council (CNR), dealing with Aluminium Structures [2]. In 2015, the European Committee for Standardization (CEN) officially started the "Mandate M/515 EN—European Commission Mandate for amending existing Eurocodes and extending the scope of structural Eurocodes", paving the way to the publication of the Second Generation Eurocodes. Stakeholders, including structural design companies, the scientific community, industry associations and engineers, were deeply involved [3,4], supported by the European Commission and its Joint Research Centre (JRC). In this framework, the preparation of both new standards and new parts of existing standards was foreseen, with the purpose of updating the performance requirements,

while improving the user friendliness of Eurocodes at the same time. In this context, issues emerged in the first years of application of Eurocodes that have been fixed in this new generation of codes. Mandate M/515 EN ended in 2022. At the moment, CEN/TC 250 defines a detailed publication schedule showing when Enquiry and Formal Vote ballots will be launched. The Second Generation EC9 was formally and unanimously voted for in December 2022, whereas all other Eurocodes are expected to be officially available by 2025. The main results of the activity carried out in the framework of Mandate M/515 EN with regard to Eurocode 9 are reported hereafter.

2. The Main Features of Second Generation EC9

2.1. General

After the first version issued in 2007, the Second Generation EC9 was above all intended to enlarge the application field of the code rather than to correct the relatively few flaws pointed out by the users during the first years of trial. For this reason, improvement in the text was mostly achieved through the accomplishment of the main targets of Mandate M/515 EN, namely the reduction in the number of Nationally Determined Parameters (NDPs); the improvement in the user friendliness of Eurocodes, without reducing their applicability; the incorporation of recent studies, research and experience relevant to innovation in design and construction; and the development of auxiliary guidance documents to facilitate feedback from stakeholders and practitioners. In the case of Eurocode 9, the new items were mostly planned for Part 1-1, not neglecting important maintenance operations for the other parts, Parts 1-2, 1-3, 1-4 and 1-5, including upgrading, updating and simplifying, with some new additions where necessary. The Nationally Determined Parameters (NDPs) were reduced from 89 to 49. The revision process led to introducing additional structural typologies (bridging, roofing and a composite of aluminium–concrete), new connection types, new materials and a new buckling material class (Class B), an intermediate between the previous classes and to defining improved buckling curves according to the new material classes. This resulted in the addition of several new annexes to the main text. A general improvement in editorial aspects has been achieved as well.

2.2. EN1999-1-1 General Structural Rules

This document is the first of the five parts of EN1999 and gives basic design rules for structures made of wrought aluminium alloys, while giving limited guidance for cast alloys. It is also the largest and most comprehensive document of Eurocode 9; it covers the majority of structural problems (Figure 1), and provides generic design rules intended to be used with the other parts, EN1999-1-2 to EN1999-1-5. In its final version, it is supplemented by 22 annexes, most of which are informative, which cover a large number of specific topics associated with aluminium structural typologies and related technology.

During the execution of Mandate M/515 EN, the document was somewhat revised on the basis of the comments and proposals of amendments coming from the users. The whole of these remarks, alongside with the necessity to enlarge the general outreach of the code, also led to incorporating a number of new topics, namely the introduction of new material (alloy EN-AW 5383); introduction of additional structural typologies (bridging, roofing and a composite of aluminium–concrete); introduction of a new buckling material class (Class B), an intermediate between the previous classes, with the corresponding new buckling curves for an initial bow of both L/1000 and L/500 (Figure 2); improvement in and addendum of the rules for the equivalent T-Stub in tension (Figure 3); introduction of new connection types (FSW, bolt channels and screw grooves) (Figure 4); and addition of out-of-plane loading on stiffened plating.

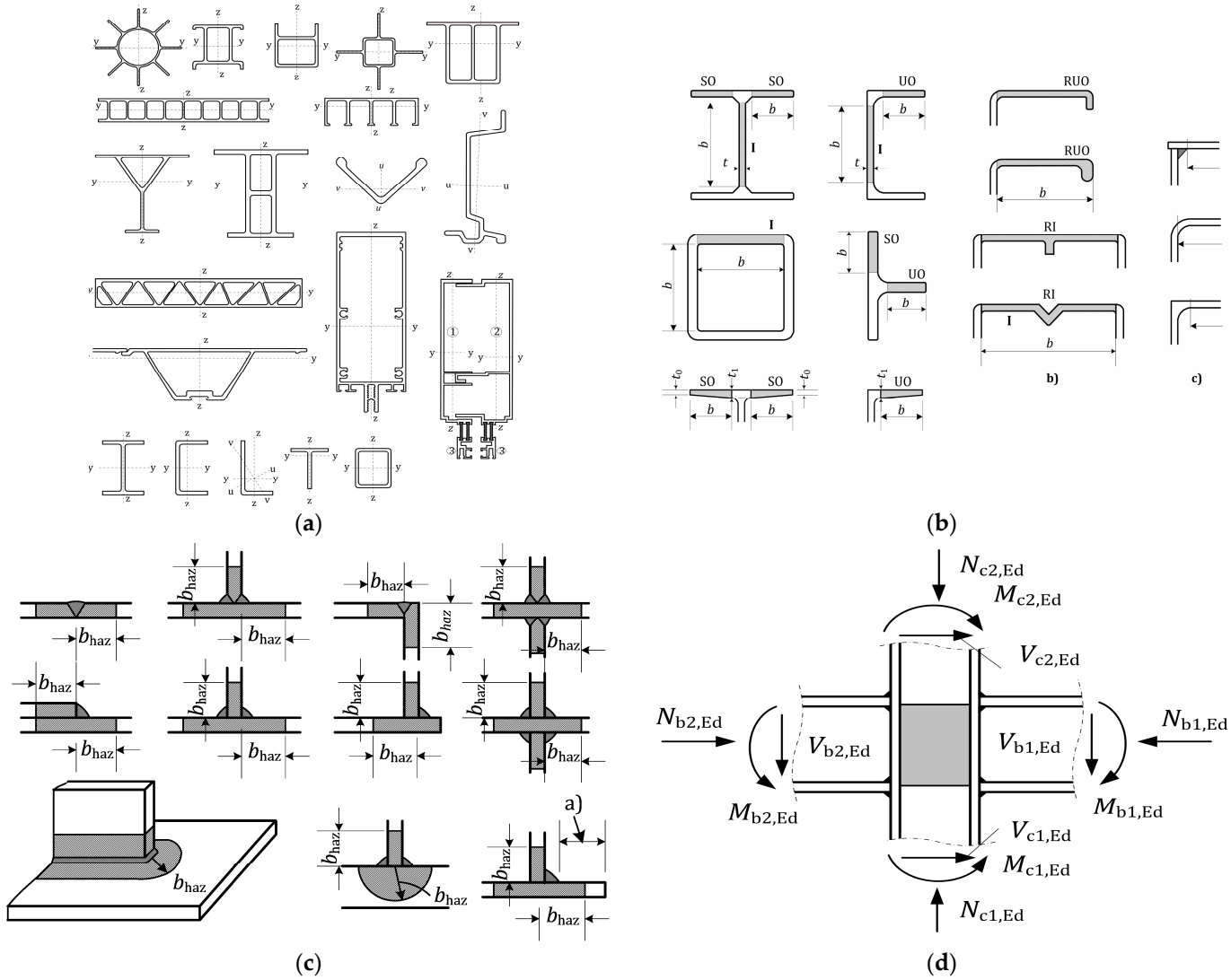

Figure 1. Typical topics dealt with in EN1999-1-1: (**a**) types of extruded sections; (**b**) classification of cross-sections; (**c**) welded connections; (**d**) structural joints.

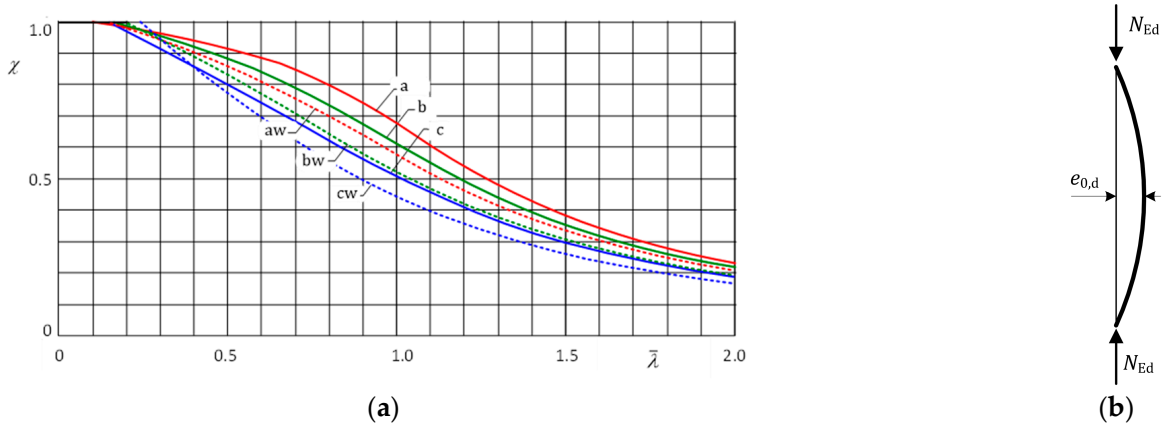

Figure 2. The new buckling curves given in EN1999-1-1 (**a**) for members under axial compression; (**b**) definition considering new material Class B and the presence of welds.

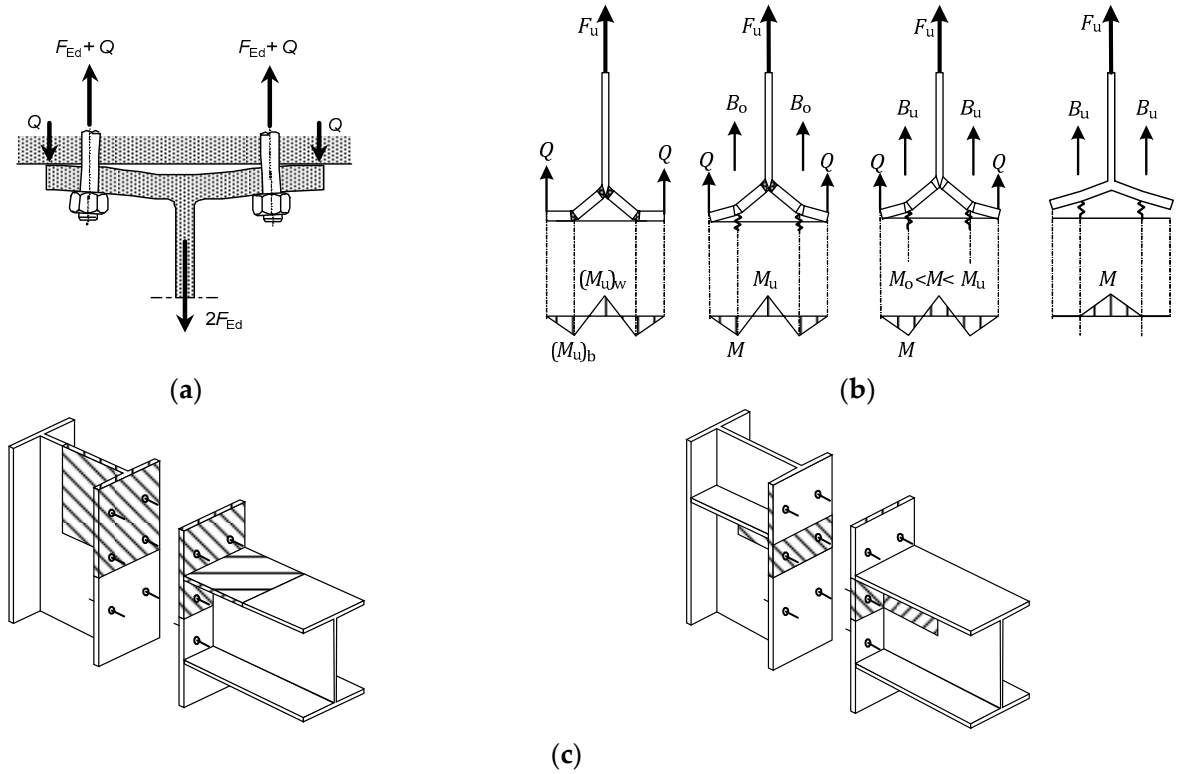

Figure 3. Modelling of T-Stub as given in EN1999-1-1: (**a**) the T-Stub in tension; (**b**) collapse mechanisms of tensioned T-Stub; (**c**) the T-Stub model extracted from real joints.

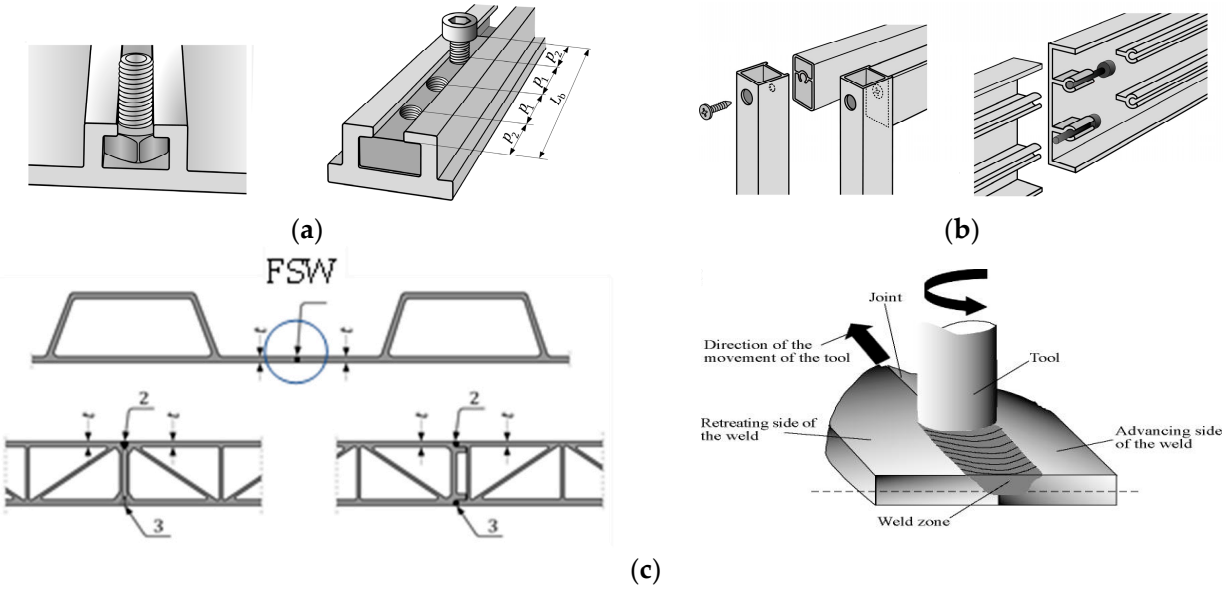

Figure 4. New types of connection allowed for in EN1999-1-1: (**a**) bolt channel; (**b**) screw groove; (**c**) friction stir welding (FSW).

At the same time, a number of new annexes were added, dealing with specific subjects such as bridges (Annex S) (Figure 5); lattice space roof structures (Annex T) (Figure 6); composite aluminium concrete beams (Annex U) (Figure 7); modified buckling conditions (Annex V); determining the extent of HAZ from hardness tests (Annex Q) and weld studs connected using arc stud welding with tip ignition (Annex R). In this context, new connection systems were included in the code in order to exploit the special features of

aluminium products. Friction stir welding (FSW), an innovative welding system patented by The Welding Institute in Cambridge (UK), allows for the making of long welded joints without the use of fillet material, with a high productivity and a very good fatigue behaviour. Joints relying on bolt channels and screw grooves were added in order to enhance the prerogatives of extruded profiles using particular joining systems. Likewise, some of the new annexes were added because of the great relevance of some structural categories in both construction of new works and refurbishment of existing ones. Aluminium bridges (Annex S) are designed as either permanent or temporary structures with outstanding applications in both civil and military transportation fields. Also, composite aluminium–concrete beams were profitably used in the refurbishment of some historical bridges in order to reduce the load on existing masonry piers. Last but not least, the importance of lattice space structures (Annex T) has been recognized in the construction of large span roofs, as shown with a large number of examples all around the world.

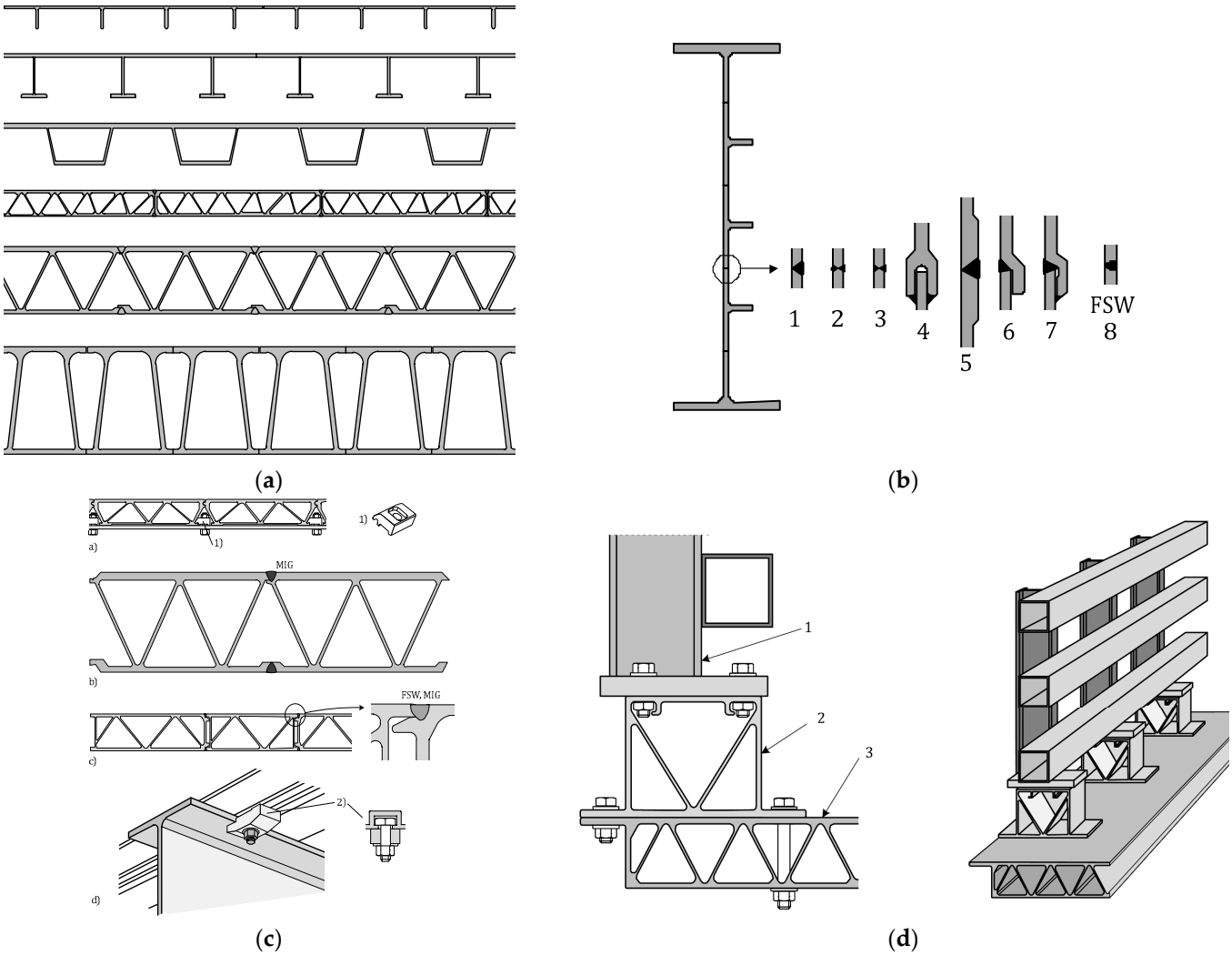

Figure 5. New details of bridges dealt with in Annex S of EN1999-1-1: (**a**) extruded decks; (**b**) deep girders; (**c**) details of splices of deck section; (**d**) connection of traffic barrier to aluminium deck.

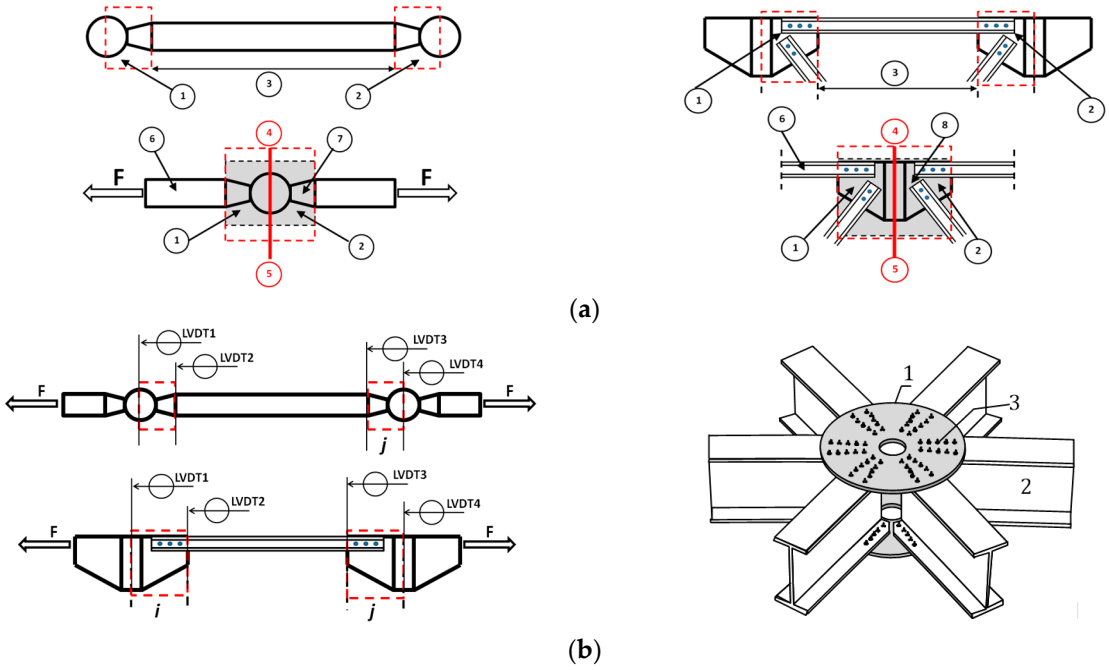

Figure 6. Details of lattice space roof structures dealt with in Annex T of EN1999-1-1; (**a**) definition of joint and connection; (**b**) testing of a complete connection-to-member sub-assemblage.

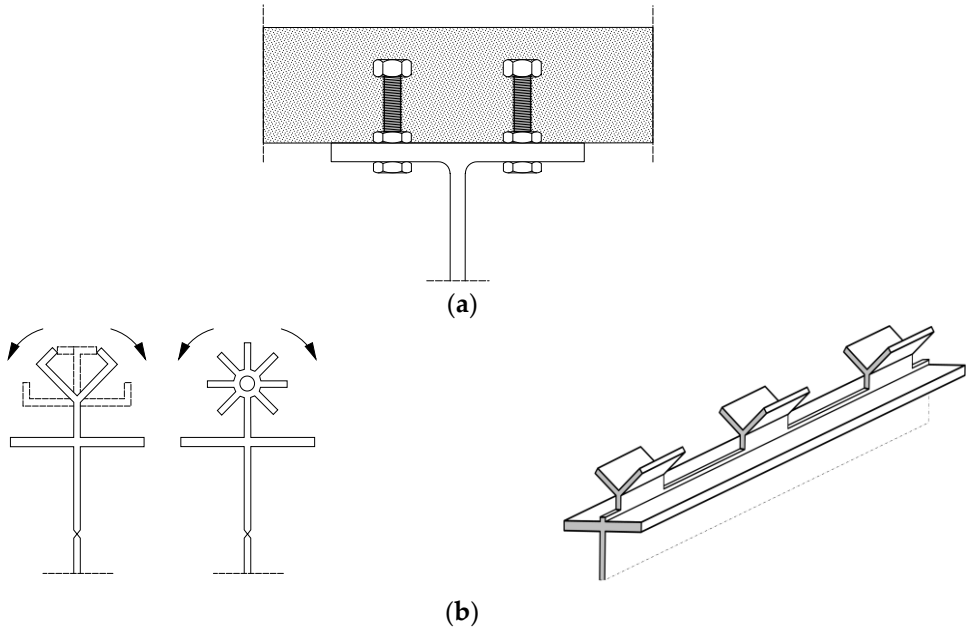

Figure 7. Composite aluminium–concrete beams (Annex U of EN1999-1-1): (**a**) connection with bolts; (**b**) special connectors with extrusion.

2.3. EN1999-1-2 Structural Fire Design

As for all Eurocodes, Part 1-2 of EC9 is devoted to fire design. For this reason, this part has been developed with the contribution of the Horizontal Group Fire (HGF) of CEN/TC250, having the task of coordinating the Fire Part of all Eurocodes (EN199x-1-2). No significant modifications have been included in the content of EN1999-1-2, rather just light changes with respect to the old version, which include some reorganization of the text and its coherence with other Eurocodes (EN199x-1-2 and EN1991); improvement in some figures; updating of many symbols according to Eurocodes related to other structural

materials (EN199x-1-2) and Eurocode 1; improved clarity and consistency; as well as harmonization of existing contents according to the new template provided with HGF.

2.4. EN1999-1-3 Structures Susceptible to Fatigue

The major changes introduced into Part 1-3 dealing with Fatigue Design are mostly concerned with improving clarity and scope. This led to some reorganization of the text and its coherence with the general part, EN1999-1-1; improvement in some figures; improvement in detail categories for fillet-welded joints between members; and improvement in detail categories for bolted joints. At the same time, friction stir welding was included into relevant joint types, including them in the scope and adding new detail categories for members with FSW.

2.5. EN1999-1-4 Cold-Formed Structural Sheeting

Together with Part 1-5, this part was written for the first time during the preparation of the EN version issued in 2007. No great changes have been made in the Second Generation Eurocode. Among the new contents of Part 1-4, there are just (Figure 8) new general rules for cold-formed profiles (not only profiled sheeting); new rules for a static overlapping system of sheeting with a single or double overlap; new rules for trapezoidal sheeting with side overlaps; and clarification of behaviour of the diaphragm at the end of building.

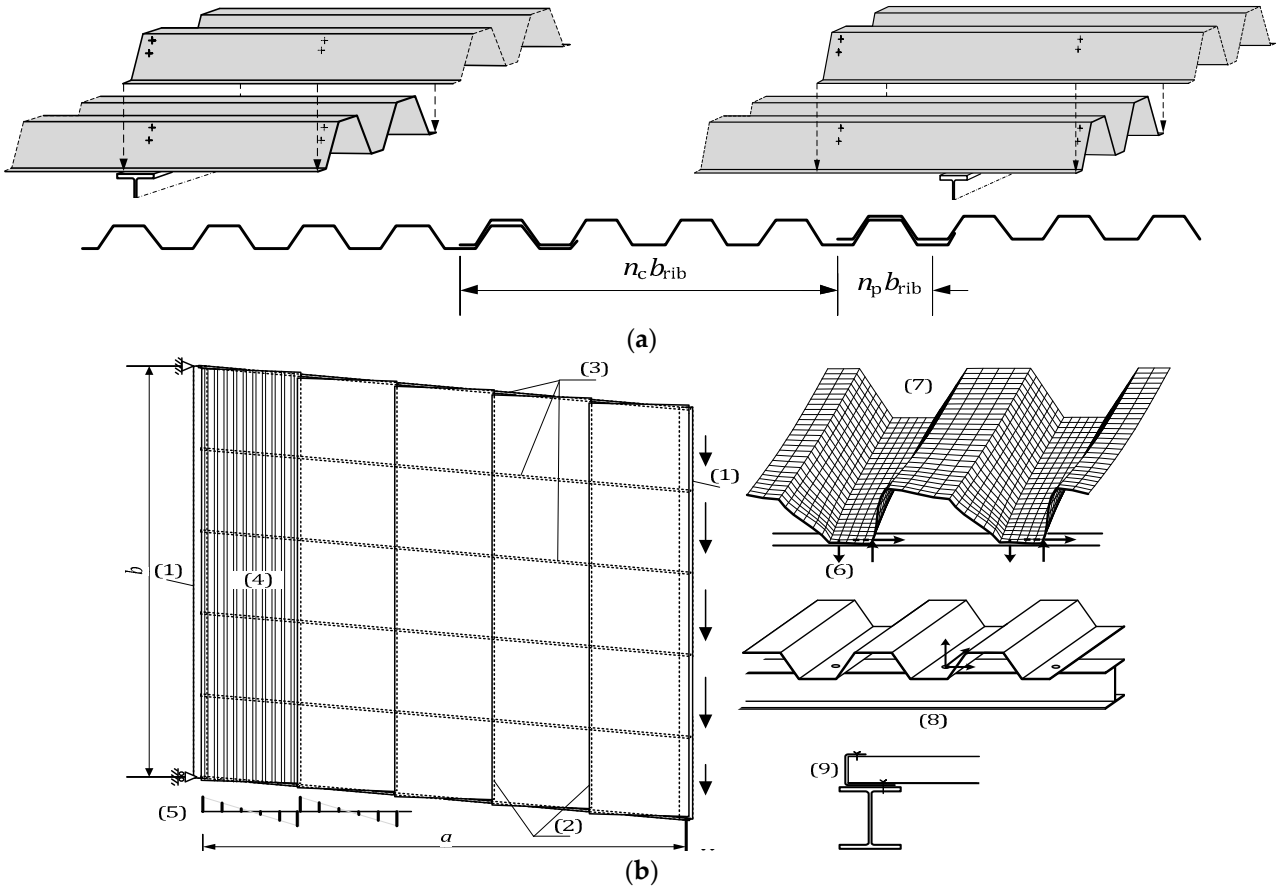

Figure 8. New topics dealt with in EN1999-1-4: (**a**) trapezoidal sheeting with side overlaps; (**b**) diaphragm at the end of building.

2.6. EN1999-1-5 Shell Structures

Minor changes have been made in the content list of EN1999-1-5, whereas major changes have been carried out in Annex A dealing with buckling formulae for cylinders, cones and spheres (Figure 9). In this context, a new more accurate formulation has been

introduced for imperfection reduction factors given in Annex A, related to unstiffened and stiffened shells under an axial load, circumferential pressure and shear, including the case of axial compression with coexistent internal pressure. This improvement, proposed after an ad hoc comparison with the corresponding buckling curves of steel shells, has led to a better fitting of buckling curves against benchmarked available data, also considering the addition of a new material class in EN1999 (Class B, an intermediate between A and C). This resulted in an improved consistency with the corresponding document of EC3 (EN1993-1-6).

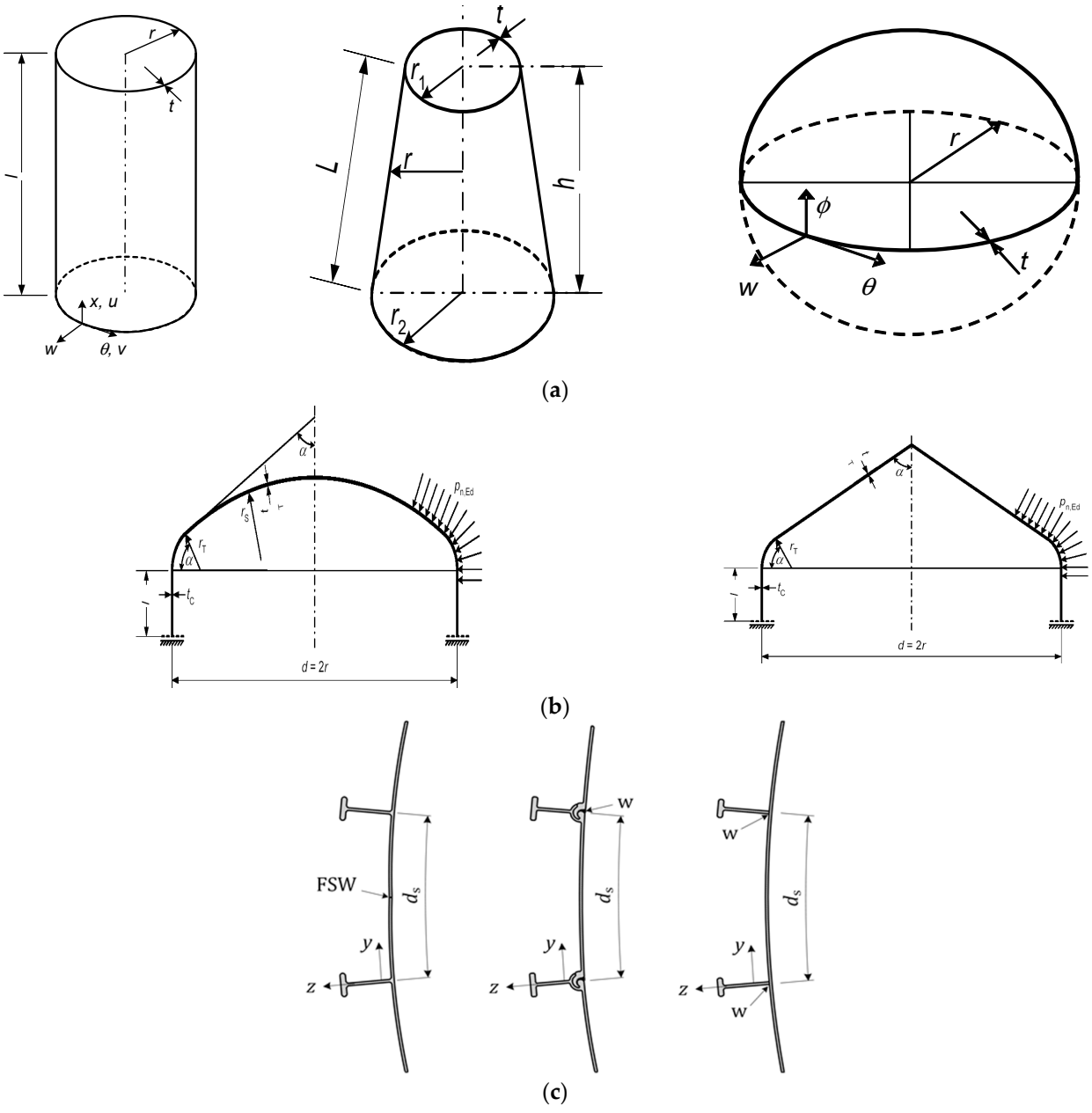

Figure 9. Topics dealt with in EN1999-1-5: (**a**) cylindrical, conical and spherical shells; (**b**) tori-spherical and tori-conical shells; (**c**) stiffened shells.

3. Conclusions

Until the beginning of the Eurocode era, the only code dealing with Aluminium Structures available at the European level was the ECCS European Recommendations for Aluminium Alloy Structures published in 1978 [5]. This document faced the most relevant topics in the state-of-the-art of the time on Aluminium Structures [6], leaving

some important subjects uncovered though. Since its first EN issue in 2007, Eurocode 9 has marked a valuable development in codification on Aluminium Structures for civil and industrial applications. A number of topics involving Aluminium Structures (e.g., cold-formed sheeting, shell structures, etc.) have been for the first time included into codification accepted at the European level. The whole of the contents of EC9 in its latest version enables the full design, execution and monitoring of all relevant structural typologies making use of aluminium and its alloys. The activity related to EC9 at the European level also triggered an important action at the national level, stimulating the preparation of corresponding documents, such as the one referred to in [2]. As an accomplishment of CEN Mandate M/515, started in 2015, in December 2022, the final draft of the Second Generation EN1999 was unanimously approved for publication by the European Member States. Its official publication took place in March 2023 [7]. The New Generation EC9 embodies a further extension and refinement of the previous version, including additional structural typologies (bridging, roofing, a composite of aluminium–concrete, etc.) alongside with many changes, making the code more effective and user-friendly. In March 2023, A. Mandara took over from F.M. Mazzolani as the Chair of CEN/TC250/SC9. EC9 enters a new stage of maintenance and feedback from users.

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Conflicts of Interest: The authors declare no conflict of interest.

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