THE EUROCODES - RESEARCH AND APPLICATION FOR CONCRETE STRUCTURES IN VIETNAM CONTEXT

TIÊU CHUẨN CHÂU ÂU - NGHIÊN CỨU VÀ ỨNG DỤNG CHO KẾT CẤU BÊ TÔNG CỐT THÉP TRONG ĐIỀU KIỆN VIỆT NAM

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Abstract: *Since 2018, it has been planned by the Vietnamese authorities for the preparation of a new system of the national construction codes and standards, of which the Eurocodes were recently taken into consideration to be systematically and gradually applied during the period from 2022 to 2030. Towards this orientation, significant attentions have also been paid and various number of studies on design of concrete structures to the Eurocodes have been conducted by Vietnamese researchers, which will be introduced in this paper to prepare for the comprehensive applications of the Eurocodes for concrete structures in Vietnam in the coming time when appropriable, especially the second generation of the Eurocodes will be expected to be also issued in coming years.*

Keywords: *concrete structures, design standards, Eurocodes*

Tóm tắt: *Từ năm 2018, cơ quan quản lý nhà nước của Việt Nam đã đề ra kế hoạch chuẩn bị cho một hệ thống mới về các tiêu chuẩn thiết kế và xây dựng, trong đó các tiêu chuẩn châu Âu (Eurocodes) gần đây đã được cân nhắc áp dụng một cách hệ thống và từng bước trong khoảng từ năm 2022 đến năm 2030. Định hướng này đã thu hút được sự quan tâm trong nhiều đề tài nghiên cứu của các nhà khoa học Việt Nam, trong đó có lĩnh vực thiết kế kết cấu bê tông cốt thép (BTCT) theo tiêu chuẩn châu Âu. Bài báo này giới thiệu một số đề tài được triển khai trong quá trình chuẩn bị cho việc áp dụng toàn diện tiêu chuẩn châu Âu cho kết cấu BTCT tại Việt Nam trong thời gian tới khi thích hợp, đặc biệt khi thế hệ thứ hai của Eurocodes dự kiến sẽ được ban hành trong những năm sắp tới.*

Từ khóa: *kết cấu bê tông, tiêu chuẩn thiết kế, tiêu chuẩn châu Âu*

1. Introduction of the Eurocodes

In the mid-1970s, in order to eliminate technical obstacles to trade within European countries, the Commission of the European Community decided on an action programme in the field of construction among which a set of harmonised technical rules for the design of building structures and construction works was initiated and an Eurocodes programme was conducted, leading to the first generation of European codes started in the 1980s. In 1989, it was decided that European Standard (EN - Europäische Norm) would be issued. By now, there have been considerable interests in the use of EN Eurocodes within and outside European Union (EU) and many countries have adopted or are in the process of adopting the Eurocodes. The Eurocodes may be used for the above purposes owing to the following reasons: (i) This is a complete set of design standards that cover in a comprehensive manner all principal construction materials, all major fields of structural engineering and a wide range of types of structures and products; (ii) This is also the most updated set of codes of practice; and (iii) They are flexible, offering the possibility for each country to adapt the Eurocodes to their specific conditions regarding climate, seismic risk, etc. through the Nationally Determined Parameters (NDP) - the open parameters that allow for national choices, for which countries can consider their own geographical, geological or climatic conditions, including different safety level requirements and construction traditions). NDP can also be adapted to the national approach and setup regarding risk and safety factors. The use of common or technically aligned standards supports the exchange of goods and services by increasing interoperability at a global level and contributes to the international dimension of European standardisation [1].

As shown in Figure 1, the current Eurocodes generations include a series of ten standards, namely, EN 1990 to EN 1999 (can also be referred to as EC0 to EC9) and provide common approach for the structural design of buildings and other civil engineering works and construction product including, geotechnical aspects, structural fire design and situations including earthquakes, execution and temporary structures.

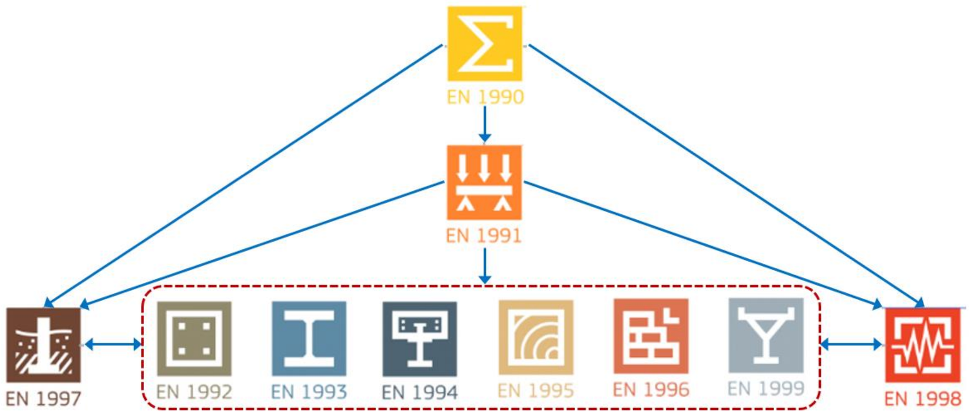

Figure 1. *The compositions of the current Eurocodes generation*

In Figure 1, EN 1990 (EC0) is for the Basis of Structural Design and plays the most important role in the set, of which EN 1991 (EC1) specifies Actions on Structures applied to the remaining standards. A group of six standards i.e. EN 1992, 1993, 1994, 1995, 1996 and 1999 (EC2, 3, 4, 5, 6 and 9) is for design of concrete, steel, composite, timber, masonry and aluminum structures, respectively. The two specific standards EN 1997 (EC7) and EN 1998 (EC8) are for geotechnical and seismic design, respectively.

Among the Eurocodes, EN 1992 (Eurocode 2 - EC2) applies to the design of buildings and other civil engineering works in plain, reinforced and prestressed concrete. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EC0 is concerned with the requirements for resistance, serviceability, durability and fire resistance of concrete structures. EC2 is divided into four parts, namely, EN 1992-1, EN 1992-2, EN 1992-3 and EN 1992-4, which were issued in 2004, 2005, 2006 and 2018 to deal with the design of concrete buildings, bridges, fastening and liquid retaining and containment structures, respectively. The first part includes two sub-divisions, namely, EN 1992-1-1 and EN 1992-1-2, which are for General rules and rules for buildings and General rules - Structural fire design, respectively. In BS EN, these two parts were updated in 2014 and 2019, respectively (Figure 2).

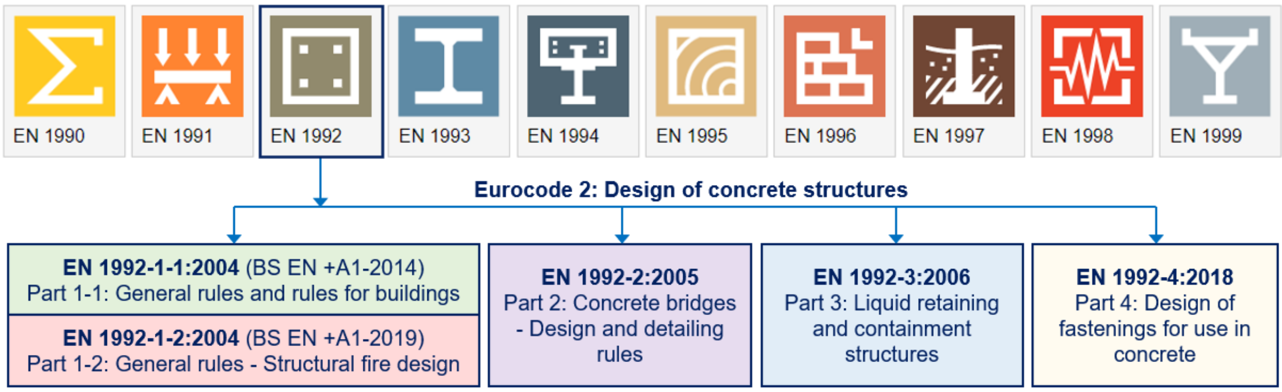

Figure 2. *EN 1992 for design of concrete structures*

EN 1992 is to be used in conjunction with EN 1990, EN 1991; other European Norms for construction products relevant for concrete structures; ENV 13670:2009 - Execution of concrete structures; EN 1997 and EN 1998 [1].

As concrete construction is of relatively dominant in Europe and worldwide, EC2 was scheduled to replace the corresponding individual national structural codes of European countries from April, 2010. In the United Kingdom, the British Standard BS 8110:1997 dealing with the design of concrete structures was replaced by the National Standard implementing Eurocode BS EN 1992-1-1:2004 and National Annex (NA to BS EN). As a result, all the public projects in England, Wales, and Northern Ireland must be specified using Eurocodes instead. By 2022, the European Union (EU) had introduced and shared knowledge and experience on the Eurocodes to Brunei Darussalam, Singapore and Malaysia to strengthen their national design standards and ensure safe and resilient structures. These ASEAN countries are at various stages of awareness regarding Eurocodes and their concepts. In Singapore, the Eurocodes have been widely adopted as national standards and EC2 has been applied for the design of concrete structures of public projects as a replacement of BS 8110 since 2015. Malaysia is the first ASEAN country to access to EU's Eurocodes Database. A number of the Eurocodes including selected parts of EC1, EC2, EC3, EC7 and EC8 have been already adopted in this country. Malaysia was also granted to access to the Eurocodes' NDP Database through the European Commission's Joint Research Centre (JRC). This milestone in the Eurocodes implementation for Malaysia provides access to a wealth of data and experience from many other countries. Access to the NDPs Database will assist in the national implementation of chosen Eurocode parts. In 2022, Eurocodes workshops were organised dedicated to relevant authorities in Brunei Darussalam with the primary objective is to respond to the training and capacity needs of these countries towards the increasing awareness of the benefits of using Eurocodes, its impact to the future of construction sector and implications of climate change, as well as facilitate their implementation as national design codes [1].

In Vietnam, together with other advanced international design standards for concrete from Russia (SP 52 and SP 63 [2,3]), the United States (ACI 318 [4]) and the United Kingdom (BS 8110 [5]), EC2 [6,7] has also been a considerable design code on concrete structures applied for projects since 2010. In February 2018, Decision No.198/QD-TTg was issued by the Prime Minister to approve the Scheme of completing the system of codes and standards of construction engineering within Vietnam territory. In Jun 2018, Ministry of Construction established the Executive Board of the scheme and issued Decision No.900/QD-BCDDTQ to promulgate the contents of Decision No.198/QD-TTg. In the documentary No.5456/BXD-KHCN dated on 11 November, 2020 sending to Ministry of Science and Technology, it was suggested by Ministry of Construction that the Eurocodes are to be considered as one of the options with the orientation of the Decision No.198/QD-TTg, of which 144 core design standards will be established by the deadline of 2030. Towards this development, a significant number of research and application (R&A) works on reinforced concrete structures have been conducted by Vietnamese researchers and will be introduced following timeline in the next section.

2. Local R&A of the Eurocodes for RC structures

In 2006, the Vietnamese standard for design of structures for earthquake resistance TCXDVN 375:2006 [8] was established on the basis of the acceptance of EN 1998 with complementing or replacing items having Vietnam characteristics. There are two parts in the standard: Part 1 - General rules, seismic actions and rules for buildings; and Part 2 - Foundation, retaining structures and geotechnical aspects. This can be considered as the ever first application of an Eurocode to Vietnamese practice in the field of construction. The standard was then renamed to TCVN 9386:2012 [9] and has been constantly used in practice to date together with TCVN 5574:2018 [10].

In 2010, the first text book for the design of reinforced concrete structures according to the Eurocodes was published in Vietnam [11], followed by a series of other Eurocodes text books as reference for Vietnamese students and practicing engineers.

In the period from 2008 to 2015, experimental studies were performed [12-17] and rational analysis approaches were proposed [17-20] by Singaporean and Vietnamese researchers in a series of publications on the calculation of reinforced concrete (RC) columns and composite slabs at ambient and fire conditions following specifications of EN 1992. The studies were conducted in Singapore, during the progress of this country to transform from BS 8110 to EN 1992 for official design of concrete buildings. Figure 3 illustrates an example of the research outcome, which is the extension of two EN 1992 methods for calculation of moment magnification at ambient, namely, method of nominal stiffness (MNS) and method of nominal curvature (MNC) to the fire condition [19].

Since 2015 in Vietnam, numerical and simplified analytical methods based on EN 1992 were continue to be proposed for uniaxial and biaxial bending RC columns simultaneously subjected to fire and restraints [21-23] (Figure 4). Besides, the fire behaviour of RC columns in multi-functional complex buildings [24] as well as the effects of concrete cover [25] and of concrete spalling [26] were also studied.

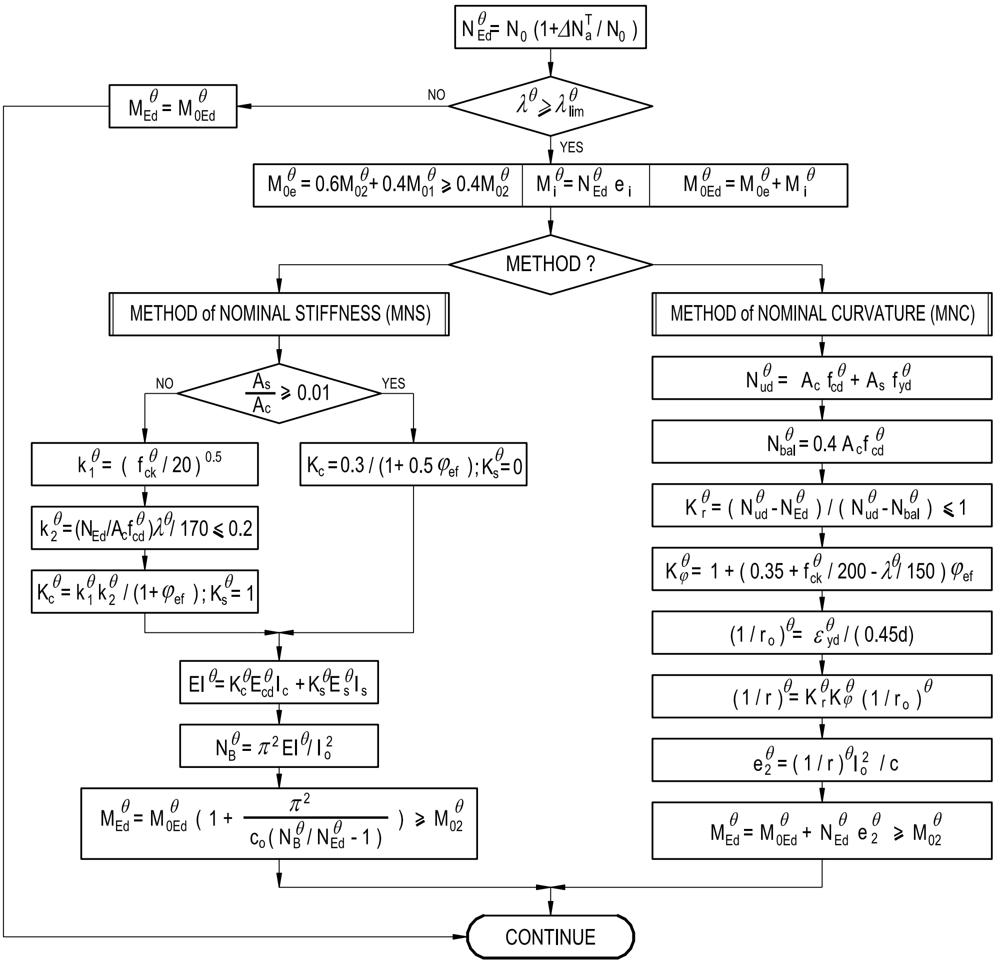

Figure 3. *Example of analytical study developed from the Eurocodes [19]*

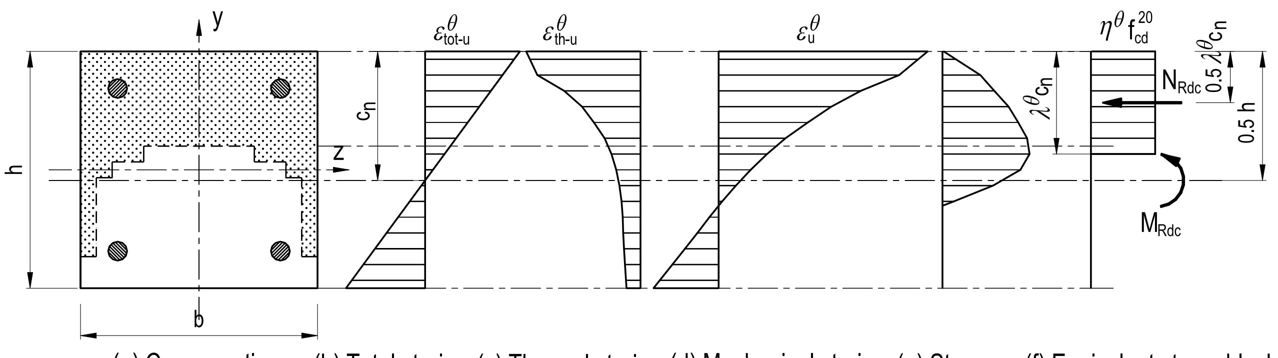

Figure 4. *Simplified analysis of column cross-section in fire to EC2 [21]*

In 2017, an experimental programme was conducted on RC beams from which the observations on flexural behaviour of the tested specimens were compared to calculation results of a number of design standards, including EN 1992 [27]. Then, the general principles and a number of calculation methods specified in the Eurocode EN 1992-1-2 of structural fire design for concrete structures, which can be applied to determine the flexural strength deterioration (FSD) coefficient of reinforced concrete (RC) beams when subjected to fire exposure following ISO 834 curve was performed [28]. Temperature-dependent mechanical properties of concrete and reinforcing steel, tabulated method and 500^{o}C isotherm method (among simplified calculation methods) were introduced and illustrated by design case studies. A calculation sheet was established to investigate the FSD of RC beams. It was explicitly shown that the FSD coefficient of RC beams is proportional to the beam cross-sectional dimensions and the distance from the beam surfaces to the centroid of longitudinal reinforcement (so-called axis distance), but is not significantly affected by concrete compressive strength.

In another study [29], post-tensioned (PT) girders were analysed together with other RC beams and columns in the frame to clarify the effects of the arrangement and number of prestressed cables on the internal forces distribution, strength, stiffness and deformation of the transfer PT girder as well as of the whole frame. Three PT design options to the Eurocodes were proposed in a reality worked example on a three-dimensional frame having seven storeys and a 15m-span transfer PT girder on the second floor to investigate the effects of the overall analysis. The analysis results showed that the solution of having only PT for the transfer girder is more reasonable in PT materials usage, whereas all the design criterion on strength and serviceability can still be satisfied. However, due to the detailing requirement of anchorage ends, the solution of distributing prestressed cables can also be applied efficiently not only for the transfer girder but also for other girders on the above floors [26].

In 2018, the contribution of concrete in composite structures were also studied in an experiment to determine *m-k* values for flat-decking composite slabs to EC4 [30-31] and in an analytical investigation of strength degradation of concrete encased steel composite columns at elevated temperatures based on the Eurocodes specifications [32]. In the same year, some overview analyses on the advantages and disadvantages in applying the related design standards of Russia [3-4], the United States of America [4], the European Union [6] and Vietnam [10] into the design practice for concrete buildings in Vietnam were performed in [33]. An overview comparison table on the mentioned standards was proposed and could be considered as a reference for the authorities in their planning on establishing the new Vietnamese design standard of concrete and reinforced concrete structures in the coming time. A number of analytical and experimental results were also given in an appendix for illustration.

In 2019, the Eurocodes system including design standard, product specification, product certificates, calculation principles based on failure criterion specified in the code, and a number of case studies were introduced to illustrate the design procedure for post-installed anchor solution of bolts into concrete was introduced [34]. It was shown that together with each bolt's strength, the concrete integrity under the actions of the whole group of bolts also plays an important role in the load bearing capacity of the connection. Besides, the anchorage length into concrete of the bolts shall be determined based on both safety and economical requirements instead of using an experiential parameter [34]. In this period of time, fire resistance of reinforced concrete slabs was also assessed using the simplified methods and ABAQUS numerical model according to EN 1992-1-2 [35,36].

In 2020, granular material pressure to reinforced concrete walls of cylindrical slender silos was studied analytically and experimentally according to the Eurocodes [37]. It was shown from the investigation that in Vietnam conditions, the friction coefficients between some granular materials and concrete surfaces obtained in local testing conditions are relatively closed to those specified by Eurocodes, American Concrete Institute and Russian code. This was one of the premises for the reference of international codes to build up Vietnamese national codes for designing RC silo structures [37].

In 2021, an experimental programme was conducted on the levels of material and structure of RC columns using fly ash [38], from which nonlinear material models were proposed [39] and analytical results were compared to those of a number of design standards including the Eurocodes [40]. In the same year, the effect of the new orientation of technical standard system following the Eurocodes on the training of civil engineers was also discussed in [41].

In 2022 and 2023, machine learning technology and neural network models were applied for validating the previous research outcome on the axis distance's influence on the flexural strength deterioration of reinforced concrete beams under ISO 834 fire [42] and for some other studies on RC structures at ambient and fire conditions [43-44].

Some images of experimental studies reviewed above are shown in Figure 5.

Together with the fundamental studies on EN 1992-1-1 and EN 1992-1-2 introduced in this article, many other research works have also been conducted by Vietnamese researchers from the Vietnam Institute for Building Science and Technology (IBST), Hanoi University of Civil Engineering (HUCE), Hanoi University of Architecture (HUA), etc. for the other parts of the Eurocodes, especially in the series of research projects in the framework of Decision No.198/QD-TTg granted by Ministry of Construction (MoC) and Ministry of Education and Training (MoET).

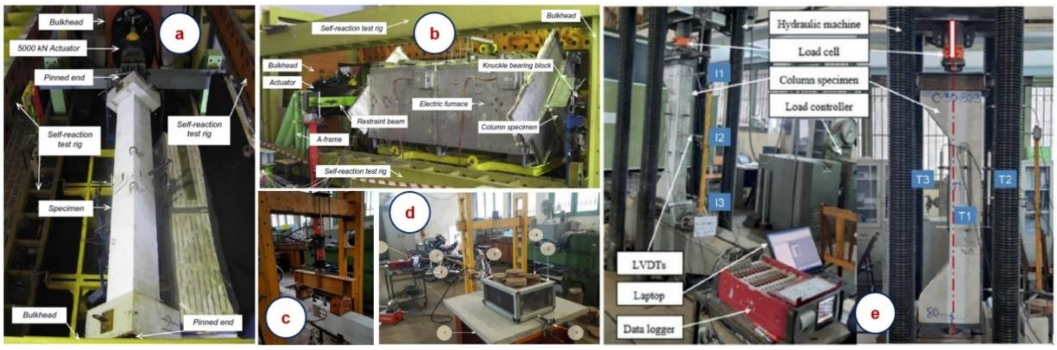

Figure 5. *Experimental studies for the Eurocodes validation*
Testing on (a) RC columns under biaxial bending [13] (b) RC columns under fire [12]
(c) RC beams [27] (d) Friction between materials and concrete [37] (e) RC fly ash columns [38]

3. The development of the Eurocodes for RC structures

The current generation of the Eurocodes results from a long and dedicated effort from the EU civil and mechanical engineering scientific and technical community who drafted the normative documents, developed and achieved various research projects aiming at clarifying several scientific and technical aspects to be finally approved. Long-term confidence in the codes is based on the ability of the structural Eurocodes to evolve in an appropriate manner in order to address the variety of new methods, new materials, new regulatory requirements and new societal needs developing. The structural Eurocodes are appraised so as to identify improvements to the existing suite to reflect the state of the art, and extend harmonisation by reducing the need for NDPs [1].

According to the European Commission [1], the timeline of events leading to the publication of the Eurocodes second generation is shown in Figure 6, in which the set-up of the Project Teams (PT) on the work programme started in 2015 and the publishing of the complete set of the Eurocode second generation is expected after 2026.

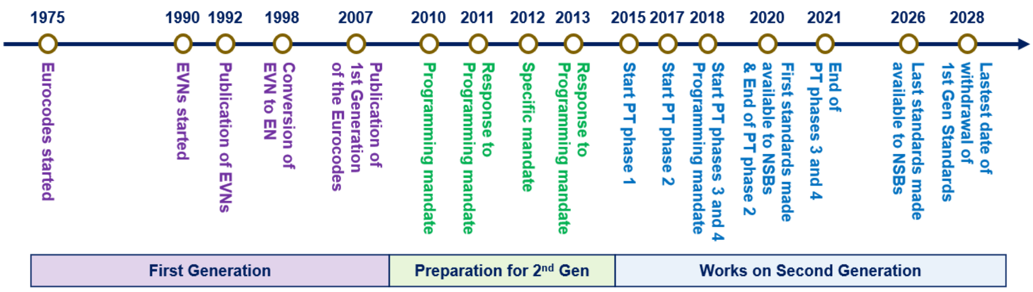

Figure 6. *Timeline for the Eurocodes second generation [1]*

The second generation of the Eurocodes incorporates improvements to the existing suite and extends its scope as shown in Figure 7, which shows that the new suite will ensure the standards remain fully up to date through embracing new methods, new materials, and new regulatory and market requirements, namely: (i) Promoting further harmonisation and improving the practical use of Eurocodes for daily calculations (ease-of-use) [45]; (ii) Introducing requirements for the assessment, re-use and retrofitting of existing structures; (iii) Strengthening of requirements for robustness; (iv) Developing a new Eurocode on structural glass; and (v) Advancing pre-normative work on fibre-polymer composite structures (FRP), tensioned membrane structures, and respective CEN technical Specifications (Figure 7).

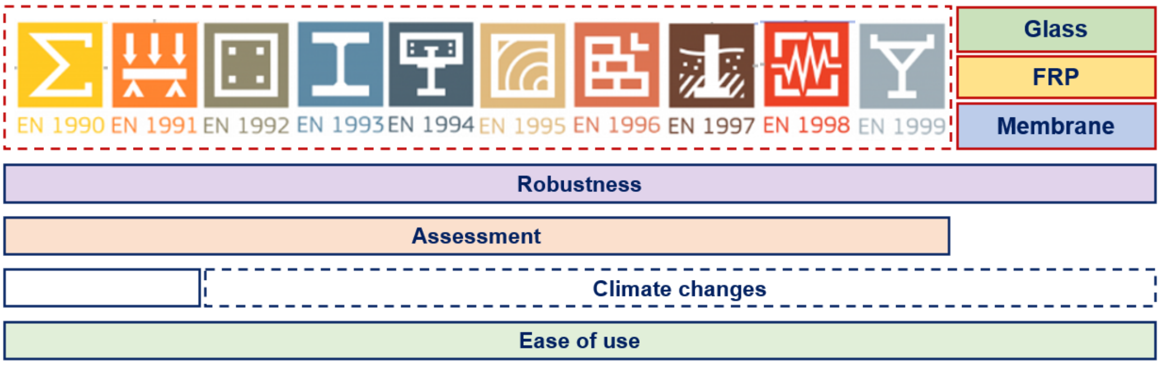

Figure 7. *Second generation of the Eurocodes [1]*

In the second generation of the Eurocodes, EN 1992 will also be improved with new contents and enhancements. In particular for EN 1992-1-1, the improvements will be made with the following key changes [45]: (i) Provisions for improved sustainability of concrete structures including Permitting reference age for concrete strength to be chosen up to 91 days to benefit from slow strength development of "green concretes"; Introducing Exposure Resistance Concept for durability assessment of concretes, suitable for common and new types of concrete such as "green concretes"; Introducing provisions for recycled aggregates concrete; Introducing provisions for assessment of existing structures; and Introducing provisions for adaptation of partial material factors for improved quality control and/or improved knowledge; (ii) Design rules which are based on physical models avoiding member specific rules, sufficiently comprehensive for existing structures but simplified for new construction; (iii) Commonly used design provisions are given in the main text, special design provisions which are used for less common structures or members are given in Annexes; (iv) Simple fatigue verification for all types of structures is given in Clause 10; detailed fatigue verification is given in Annex E; bridge specific fatigue verification provisions are given in Annex K; (v) Integration of bridge provisions from current EN 1992-2:2005 into future EN 1992-1-1, with few bridge specific rules given in Annex K; (vi) Integration of containment structures provisions from current EN 1992-3:2006 into future EN 1992-1-1, Annex D (cracking due to restraint) and Annex H (water tightness); and (vii) Re-define effective concrete strength f_{cd} such as to avoid different design provisions for grades up to 50 MPa and for grades above 50 MPa, and to simplify assumptions for strain and stress distributions in concrete compression zone.

The following new contents will be included in the scope of EN 1992-1-1 [45]: (i) Requirements assumed in design provisions and for specification of materials in Annex C serve as interface to product standards; (ii) Safety format for non-linear analysis procedures; (iii) Design of membrane-, shell-and slab type members; (iv) Durability design with performance-based approach for consideration of new types of cement and concrete (e.g. green concretes); (v) Coverage of new methods of anchoring reinforcing steel (U-bar, headed bar, post-installed bar); and (vi) Strength of confined concrete.

Enhancements of EN 1992-1-1 will be included for ease of use as follows: (i) Collect all partial action and material factors in easy to read table form in Clause 4; (ii) Keep only material properties needed for common design in Clause 5; properties for detailed design or less commonly used materials and requirements for products moved to Annex; (iii) Remove 122 NDPs and added 51 new NDPs (new items); (iv) Reduce volume of text corresponding to current version of EN 1992-1-1, EN 1992-2 and EN 1992-3 by 35%; (v) Provide comprehensive background document on design provisions; (vi) Shear and punching shear strength: comprehensive design model and formulae for detailed verification of new members without and with shear reinforcement; amendments for existing structures not complying with detailing rules of new construction; simplification of comprehensive model for quick check whether shear or punching needs detailed verification at all; (vii) Anchorage and lap length: tabulated data for anchorage length of bars stressed to design yield strength as a function of concrete strength; detailed formula for verification of anchorage and lap length as a function of stress in reinforcement, concrete strength, cover, confinement, bends/hooks, etc.; and (viii) Collect detailing rules for members in easy to read and compact table format [45].

Table 1. *Examples of ease-of-use for detailing rules in the Eurocodes second generation [45]*

	Description	Symbol	Requirement
1	Minimum longitudinal reinforcement, in those parts of the section where tension may occur	$A_{s,\min}$	12.2(2), see also 12.2(3), 12.2(6)
2	Minimum shear and transverse torsional reinforcement, when required. Minimum torsion reinforcement should be provided to the full perimeter including features not counted part of the thin wall section	$\rho_{w,\min}$	12.2(4)
3	Minimum bottom reinforcement at inner supports taking account of unforeseen effects at supports		$0{,}25A_{s,\text{req span}}$
4	Maximum longitudinal spacing of shear assemblies/stirrups	$s_{\max,l}$	$0{,}75d(1+\cot\alpha)$
5	Maximum longitudinal spacing of bent-up bars [a]	$s_{\max,bu}$	$0{,}6d(1+\cot\alpha)$
[a] These spacings are consistent with the shear model in 8.2.3. Where alternative models are used alternative spacing may be required			

For EN 1992-1-2, the improvements will be made with the following key changes [45]: (i) Harmonise the structure and table of contents of EN 1992-1-2 with other fire parts; (ii) Amend and improve simplified design methods; and (iii) Ensure consistency between tabulated design data, simplified and advanced design methods.

New contents will be included in the scope of EN 1992-1-2 as follows [45]: (i) Properties of steel fibre reinforced concrete at high temperature; (ii) Properties of recycled aggregate concrete at high temperature; (iii) Specific rules for avoiding and controlling spalling; and (iv) Simplified analytical formulae for determination of temperature profiles in members.

The following enhancements will be included for ease of use of EN 1992-1-2: (i) Reduce number of alternative application rules; (ii) Clarify the use and scope of tabulated data; (iii) Include simplified analytical formulae for determination of temperature profiles in members; (iv) Remove 14 NDPs and adding two new NDPs; (v) Reduce volume of text corresponding to current version of EN 1992-1-2 by about 30%; and (vi) Provide comprehensive background document on design provisions [45].

4. Discussions

It is shown in this paper that various fundamental studies have been conducted by Vietnamese engineers and researchers, especially for concrete structures, including experimental, numerical and analytical approaches for the behaviour as well as the analysis of RC elements under flexure and compression and validated with EN 1992 specifications.

However, there are still a number of pronounced challenges for the country to plan for a near future of 2030 of using the Eurocodes as a comprehensive set of design standards for concrete structures in particular and for other types of construction in general, especially in the context that the second generation of the Eurocodes with significant improvements are in a rapid progress of preparation and will be issued soon after 2026.

As highlighted by the Eurocodes Commission, all the Eurocodes-using countries should undertake research to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge. As a result, Vietnam should pool the national funding available for such research so that it can be used at community level to contribute to the existing technical and scientific resources for research, thus ensuring an ongoing increased level of protection of buildings and other civil works, specifically as regards the resistance of structures to earthquakes and fire. In addition, the international cooperation may be needed to support and shorten the preparation and application of the Eurocodes in Vietnam considering the local conditions of construction materials (concrete, rebars, etc.), climate (temperature, humidity, etc.), workmanship, as well as economical and technical factors in our country. It is also noted that when applying the Eurocodes into Vietnam conditions, they should be used in an appropriate manner with the input data for calculation specified by the Vietnam Building Codes. Besides, design manuals incorporating fundamental theory and practical instructions are also of importance to be soon published as a reference for Vietnamese researchers, lecturers, students and engineers to have good understanding so that they can be capable of applying the Eurocodes efficiently to construction activities in Vietnam.

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