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Structural design of concrete to EC2 and GB50010-2010: a comparison

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Abstract. We mainly compares the differences and similarities in the design using the Chinese code GB50010-2010 (modified in 2015) and Eurocode 2. The paper focuses on the comparison of the two design codes in relation to the ultimate limit state (ULS) and serviceability limit state (SLS) as well as durability requirements. Also, the material specifications using both codes are discussed in relation to stress-strain curves, strength grades etc.

1 Introduction

The Chinese government invested over $50 billion to Belt and Road projects by March 2017[1], and 20% of this investment went to engineering sections[2]. Many countries adopt Eurocodes as their design standards for the plan of international project [3], in addition to European countries and UK for their own national local projects. Some Chinese companies working on international projects also use Eurocodes as a reference. However, due to the region differences the designs to Eurocodes and Chinese codes follow similar but different guidelines. In addition, Eurocode is considered as a relatively advanced design standard and is widely adopted (including Europe, and some countries in Africa and Asian). Hence, the comparison between the design standards using the two codes is of interest to practical engineers working for international projects. This paper provides a review of the concrete design to relevant codes in both China and Europe, with a focus on the comparison of the two standards in concrete structural design part (EN1992-1-1 & EN1992-2 for Eurocode and GB50010-2010 for Chinese Standard) [4]. An E-learning package is developed based on the research outcome. The package summarizes main differences between the two standards and the background logics.

2 Basic Information

2.1 Background Information of GB50010-2010

The GB50010-2010 is generally designed based on the requirement raised in the "Unified standard for reliability design of engineering structures" (GB 50153) and "Unified standard for reliability design of building structures "(GB 50068) [4]. The code of GB50010-2010 is designed towards two objectives. The first objective is to enforce the economic policies and national techniques for the design of concrete structures in China, and the second objective is to ensure the structures to be reasonable designed (in the first satisfy the safety requirements, and in the second design the structure economically), and hence satisfy the requirement of sustainable development [4-6]. In general, the code could be used to design the normal reinforced concrete, plain concrete and pre-stressed concrete structures used in civil and industrial buildings [4]. However, special concrete structures and lightweight aggregate concrete structures need extra considerations [4].

The GB50010-2010 includes eleven chapters and ten appendixes. The chapters are listed below: 1 General Provisions, 2 Terms and Symbols, 3 General Requirements, 4 Materials, 5 Structural Analysis, 6 Ultimate Limit States Design, 7 Checking of Serviceability Limit States, 8 Detailing Requirements, 9 Fundamental Requirements for Structural Members, 10 Prestressed Concrete Structural Members, 11 Seismic Design of Reinforced Concrete Structural Members [4]. Generally the detailed design requirements are concentrated from the third chapter to the eleventh chapters, and these parts will be quoted for the comparison against the Eurocode.

2.2 Background Information of Eurocodes

The Eurocodes consist of ten European standards specifying the structural design rules within the European Union (EU). These standards were developed by the European Committee for Standardisation according to the requirement from the European Commission[7]. Generally the Eurocodes is designed to pursuit three main objectives: a means to prove compliance with the requirements for mechanical strength and stability and safety in case of fire established by European Union law[8]. By March 2010 the Eurocodes are mandatory for the specification of European public works and are intended to become the

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standard for the private sector. The Eurocodes therefore replace the existing national building codes published by national standard bodies (e.g. BS 5950), although many countries had a transition period of co-existence. Additionally, each country is expected to issue a National Annex to the Eurocodes as a for a particular country (e.g. The UK National Annex).

Table 1. Eurocode Contents.

Standard ID	Name of the Code	Short
EN1990	Eurocode 0-Basis of Structural Design	EC0
EN1991	Eurocode 1-Action on Structures	EC1
EN1992	Eurocode 2-Design of Concrete Structures	EC2
EN1993	Eurocode 3-Design of Steel Structures	EC3
EN1994	Eurocode 4-Design of Composite Steel and Concrete Structures	EC4
EN1995	Eurocode 5-Design of Timber Structures	EC5
EN1996	Eurocode 6-Design of Masonry Structures	EC6
EN1997	Eurocode 7-Geotechnical Design	EC7
EN1998	Eurocode 8-Design of Structures for Earthquake Resistance	EC8
EN1999	Eurocode 9-Design of Aluminium Structures	EC9

Eurocodes is a set of codes, and during the design procedure each code usually needs to be cross referenced. Table 1 provides the ID of different Eurocodes. Within the Eurocodes, EC0, EC1, EC7 and EC8 are considered as general ones, which guide all structural design, and the rest of the codes are used for structures with specific construction materials [7, 9-11].

3 Comparison of Material Properties in GB 50010-2010 and EC2

3.1 Concrete

3.1.1 Comparison of Compressive Characteristic Strength

The Eurocode uses a two-index form denoting concrete strength such as C40/50, where the first number is the strength characteristic value of the concrete cylinder specimen with the size of $\phi 150mm * 300mm$, and the second is the strength characteristic value of the cube specimen with the size of $150mm * 150mm * 150\,mm$. The formulas within EC2 have adopted the cylinder compressive strength for design. The relationship between cylinder compressive strength and the equivalent cubic compressive strength is: $f_{ck} \approx 0.8 f_{ck,cube}$. The characteristic strength f_{ck} is defined as the value that guarantees 95% safety, which is the same in both codes. In GB50010-2010 the concrete strength is expressed by a single value, such as the C50, which represents the nominal compressive strength of $50\ MPa$ of the standard cube specimen with the size of $150mm * 150mm * 150\,mm$. GB50010-2010 also defines the axial compressive strength of the standard specimen with size of 150mm x 150mm x 300mm in prism shape as f_{ck} [12].

The comparison of the specimen type associated with their codes are provided in the Table 2. According to the table the specimens used within the two codes are similar. The main difference is GB50010-2010 does not include the design of concrete with high strength grade $f_{ck,cube} = 85, 95\ and\ 105\ (in\ MPa)$. Hence the Chinese standard mainly concentrate on the concrete with low to normal strength grades.

Furthermore, it is worthwhile to note that the definition of f_{ck} of the two codes are different, but if the specimen have same shapes, then similar compressive strength would be expected.

3.1.2 Compression of Compressive Design Strength

The design value of concrete compressive strength, tensile strength and the corresponding characteristic value given in EC2 are as follows:

$$f_{cd} = (\alpha_{cc} f_{ck})/\gamma_c \qquad (1)$$

where γ_c represents partial coefficient of the concrete strength, which is 1.5 for the permanent and the transient condition, and takes 1.2 for accidental circumstance; and α_{cc} represents the reduction coefficient considering the long-term effect and adverse effect to concrete, for compressive and bending condition this factor should equal 0.85 while in other conditions should equal 1.0.

Chinese standard has adopted a similar method to obtain the concrete design strength. However, the value of γ_c is slightly smaller than Eurocode. For the structural design, according to GB50010-2010 this factor should equal to 1.4 and for the bridge the road design according to JTG D62-2004 this value should equal to 1.45[4, 13].

If taking the α_{cc} as 1 and $\gamma_c = 1.5$, the design compressive value of the two standard is shown in Table 2.

According to the table, Chinese code has smaller design value while the specimen is same. Hence GB 50010-2010 is more conservative while the value of $\alpha_{cc} = 1$ and $\gamma_c = 1.5$ are adopted in the structures designed following EC2. However, if $\alpha_{cc} = 0.85$ are adopted, the design compressive values of the two standard would be close.

3.2 Rebar

The mechanical properties of rebar are also very important in reinforced concrete structures. Rebar not only provides tensile strength and compressive strength to the structure, but also make the structure satisfy the special requirements of deformation properties.

The dimensions and type of reinforcement defined in Chinese codes and Eurocodes are similar, but the strength are different. The steel bar defined in Chinese codes covers low, medium and high strength level, while the Eurocode do not have low strength level and pay more attention to the middle and high level reinforcements. In addition, under the same reinforcement level, the values of elastic modulus and steel characteristic yield strength in Chinese code and Eurocode are the same, and for the partial factor of reinforcement, the value of the European code is 4.17%, less than that in Chinese code[8].

Table 2. Standard Value of Concrete Cube Compressive Strength in MPa.

Strength Grade ($f_{ck,cube}$)		15	20	25	30	35	37	40	45	50	55	60	65	67	70	75	80	85	95
Code	EN	C12/15	C16/20	C20/25	C25/30	-	C30/37	-	C35/45	C40/50	C45/55	C50/60	-	C55/67	-	C60/75	-	C70/85	C80/95
	GB	C15	C20	C25	C30	C35	-	C40	C45	C50	C55	C60	C65	-	C70	C75	C80	-	-
f_{ck}	EN (from cylinder)	12	16	20	25	-	30	-	35	40	45	50	-	55	-	60	-	70	80
	GB(from prism)	10.0	13.4	16.7	20.1	23.4	-	26.8	29.6	32.4	35.5	38.5	41.5	-	44.5	47.4	50.2	-	-
f_{cd}	EN ($\alpha_{cc} = 1$, $\gamma_c = 1.5$)	8	10.67	13.33	16.67	-	20	-	23.33	26.67	30	33.33	-	36.67	-	40	-	46.67	53.33
	GB (known as f_c)	7.2	9.6	11.9	14.3	16.7	-	19.1	21.1	23.1	25.3	27.5	29.7	-	31.8	33.8	35.9	-	-
	Percentage Differences	11.11	11.15	12.02	16.57	-	-	-	10.57	15.45	18.58	21.20	-	-	-	18.34	-	-	-

3.2.1 Comparison of Rebar Strength

The rebar classification is specified in GB 50010-2010 for China and some detailed specification could be found in EN10080-2005 for Eurocode. The steel varieties and specifications are relatively close for the two codes[14].

One of the most important characteristic parameters of steel bar is its characteristic yield strength f_{yk} . EC2 defines the characteristic yield stress f_{yk} by the standard yield load divided by the section nominal area of the rebar. In addition, for the steel bar without obvious yield stress, the stress corresponding to 0.2% residual deformation can be used as the yield stress, which is similar to Chinese code. Figure 1 shows the typical stress-strain relationship curves of steel bars, and the steel normal strength are presented in the Table 3.

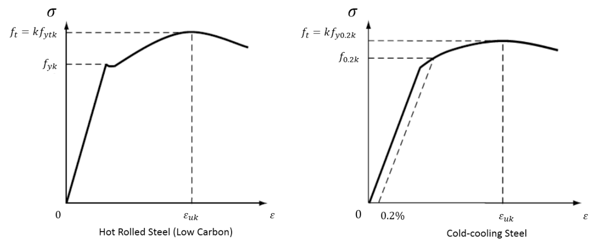

Figure 1. Steel bar stress-strain relationship.

According to the Table 3, GB 50010-2010 include low, medium and high strength rebar, while the Eurocode does not have low strength level rebar, the minimum strength specified in Eurocode is 400 MPa.

In addition, the design values of yield strength in terms of tension and compression for each rebar grade are the same for each code, except the highest grade in GB 50010-2010, see Table 3.

Table 3. Strength of Rebar.

Standard	Reinforcement Code	Diameter (mm)	f_{yk}	f_{yd}	$f_y{}'$
GB 50010-2010	HRB335 HRBF335	6-50	335	300	300
	HRB400 HRBF400 RRB400	6-50	400	360	360
	HRB500 HRBF500	6-50	500	435	410
EC2	B400		400	348	348
	B500		500	435	435
	B600		600	522	522

4 Comparison of Durability and Limit State in EC2 and GB50010-2010

Both Chinese code and Eurocode adopt the philosophy of limit state concept, with consideration of safety factors of loading and resistance[8]. The partial loading factors of Eurocode are higher than those adopted in GB500010-2010. [8] For the two codes, while the strength level of concrete is same, the value of concrete standard strength, elasticity modulus, design strength is higher than Chinese standard [8]. This section will present the durability and limit state design of the two codes.

4.1 Durability and Concrete Cover

In addition, the regulation of structural reinforcement and expansion joints in China contains more details. Comparing the control method of the load crack of the reinforced concrete member in Chinese-code and Eurocode, Chinese-code adopt the method of crack width checking to control the cracks, and Eurocode pays more attentions on crack control, including calculating the minimum steel area, restricting the stress imposed on concrete and the steel bar. The crack width calculation method of the two codes are similar[8].

4.1.1 Environment Code

Both codes require the design of concrete structures to consider the environment condition in order to keep the structure durable and economical. Based on EC2 and EN206-1, the environmental conditions are classified by exposure grade. Detailed charts are recorded in EN206-1 and EC2. The main environment is divided into six categories: 1. No corrosion or erosion risk. 2. carbonation corrosion. 3. Chloride Apparel 4. Chloride corrosion in seawater. 5. Freeze-Thaw denudation 6. Chemical erosion.

The concrete exposure environment is divided into seven categories in GB 50010-2010, but there is no specific description of each classification. Comparing the environmental categories of the two codes, the classification of the environmental categories of concrete structures by EC2 is more detailed than Chinese code.

4.1.2 Concrete Cover

The concrete cover requirement in Eurocode is based on the grade of concrete structure exposure and the environmental category, while in Chinese code is based the Environment category and concrete structural form.

EC2 defines the thickness of the concrete cover as the distance from the concrete surface to the nearest steel bar (including the associated links, distribution rebars etc.). The nominal thickness c_{nom} of the protective layer is defined as the sum of the minimum cover thickness c_{min}

and the allowable design error Δc_{dev} (which equlas to 10mm normally):

$$c_{nom} = c_{min} + \Delta c_{dev} \quad (2)$$

The associated exposure classes related to environmental conditions could be found in Table 4.1 of EN1992-1-1 :2004[15].

The structural classification of the c_{min} prescribed by EC2 is contained in EN10080[14]. In addition, the recommended concrete strength is S4 for structures with a design life of 50 years, and specific adjustments for different materials can be found in Table 4.3N of EC2, and the minimum structure class recommended by EC2 is S1.

Table 4. Values of c_{min} for reinforcement steel based on EN10080.

Structure Class	Environment Condition							
	X0	XC 1	XC 2/X C3	XC 4	XD 1/X S1	XD 2/X S2	XD 3/X S3	X0
S1	10	10	10	15	20	25	30	S1
S2	10	10	15	20	25	30	35	S2
S3	10	10	20	25	30	35	40	S3
S4	10	15	25	30	35	40	45	S4
S5	15	20	30	35	40	45	50	S5
S6	20	25	35	40	45	50	55	S6

Table 5. Minimum Cover Specified in GB 50010-2010.

Environment Categories	Slab, Wall, Shell	Beam. Column
I	15	20
II a	20	25
II b	25	35
IIIa	30	40
IIIb	40	50

For EC2, the minimum cover thickness c_{min} should meet the requirements of bonding and durability, which could be obtained from Table 4(for reinforcement steel based structure) and Table 4.3N of EC2 (for pre-stressing steel based structure). For GB 50010-2010， the cover thickness requirement of concrete structures with a life span of 50 years should satisfy the minimum requirements provided in the Table 5, and for the concrete structure with a design life of 100 years, the cover should be not less than 1.4 times of those in Table 5. Furthermore, if the strength grade of concrete is not more than C25, the thickness of the protective layer in the table should be increased by 5mm, the concrete cushion (blinding concrete) should be set on the reinforced concrete foundation, and the thickness of the concrete cover should be calculated from the top of cushion layer and should not be less than 40mm[4].

4.2 Limit State Design

Limit State Design (LSD) is a design method widely used in civil engineering. The partial factor of Eurocode is 3.33% larger than Chinese code[8]. In contrast to the non-load crack control clause of the Chinese-code and Eurocode, it is found that the Chinese standard structure is reinforced on both sides of the beam and inside the stirrup, while the Eurocode is on both sides and the lower part of the beam and outside the stirrup.

Both the EC2 and GB50010-2010 adopt limit state philosophy for design. Both codes divide the limit states into ultimate limit state and serviceability limit state. This section will compare the LSD of the two standards.

4.2.1 Comparison of Ultimate limit state (ULS)

The ULS concerns the safety of people, and/or the safety of the structure. In some circumstances (agreed for a particular project with the client and the relevant authority), the limit states that concern the protection of the contents should also be classified as ultimate limit states, as documented in EC0[7]. Specifically, Eurocode considers the following states as ULS:

(1) states prior to the structural collapse, which, for simplicity, are considered in place of the collapse itself

(2) loss of equilibrium of the structure or any part of it, considered as a rigid body[7];

(3) failure by excessive deformation, transformation of the structure or any part of it into a mechanism, rupture, loss of stability of the structure or any part of it, including supports and foundations[7];

(4) failure caused by fatigue or other time-dependent effects.

The limit states can be divided into EQU, STR, GEO and FAT A detailed explanation of the four limit states could be found in the provided references[7, 16, 17].

Errors and inaccuracies may be due to a number of causes. Firstly, design assumptions and inaccuracy of calculations. In addition, possible unusual increases in the magnitude of the actions. Thirdly, unforeseen stress redistributions. Fourthly, constructional inaccuracies. These cannot be ignored and are taken into account by applying a partial factor of safety during design[18].

Generally, permanent and variable actions will occur in different combinations, all of which must be taken into account in determining the most critical design situations for any structure. For example, the self-weight of the structure may be considered in combination with the weight of furnishings and people, with or without the effect of wind acting on the building (which may also act in more than one direction)[15]. In Eurocode, the actions are used in place of loadings/forces while in Chinese code loadings/forces are retained. The variable actions in Eurocode as well as Chinese code are divided into leading variable action and accompanying variable actions such as wind loading. However, in old British standard BS8110 there is no such division[19].

Yan Yalin[20] thinks the common load combinations under the STR based on Eurocode can be expressed by:

$$1.35 * Dead\ Load + 1.5 * Live\ Load \quad (3)$$

Xue Yingliang[21] thinks the common combinations under the STR based on Eurocode should be the maximum value of eq. (4) expressed as below：

$$\max\begin{cases}1.35 * Dead\ Load + 1.5 * \psi_{0,L} * Live\ Load \\ 1.35 * 0.85 * Dead\ Load + 1.5 * Live\ Load\end{cases} \quad (4)$$

According to EC0 Annex A, the selection between (3) or (4) should base on the specific national Annex. According to the British Annex, both equations are applicable.

Normally the result of (4) is smaller than of (3). The detailed reduction factor can be found in [22].

The ULS load in Chinese code can be obtained as:

$$1.2 * Dead\ Load + 1.4 * Live\ Load \quad (5)$$

The minimum and recommended values of variable actions/live load in EC2 and GB50010-2010 are provided in Table 6 for common civil buildings. As can be seen from the table, the recommended values of live load stipulated in EC2 are larger than the value of GB50010-2010, while some are less than GB50010-2010. However, it is hard to say which is safer according to the value provided in the table, because the basic national conditions of the two countries are different. For instance, the recommended live load value of teaching room for China is 2.5 $\mathrm{kN/m^2}$, which is higher than the value provided by EC2, due to the higher density of students in China than that in most Europe countries.

Table 6. Comparison of Recommended Live Load.

Standard	Usage Area						
	House	Teaching Room	Office	Canteen	Night Club	Stack Room	Hospital
EC2 min	1.5	1.5	2	2	4.5	7.5	1.5
EC2 Sug	2	2	3	3	5	7.5	2
GB50010-2010	2	2.5	2	2.5	4	5	2

Table 7. Load Combination.

Combination	Standard Code	
	EN1990:2002	GB50009-2012
Standard Combination	$\sum_{j\geq1} G_{k,j} + P + Q_{k,1} + \sum_{i\geq1} \psi_{0,i} Q_{k,i}$	$\sum_{j=1}^{m} S_{G_{jk}} + S_{Q_{1K}} + \sum_{i=2}^{n} \psi_{c_i} S_{Q_{ik}}$
Frequency Combination	$\sum_{j\geq1} G_{k,j} + P + \psi_{1,1} Q_{k,1} + \sum_{i\geq1} \psi_{2,i} Q_{k,i}$	$\sum_{j=1}^{m} S_{G_{jk}} + \psi_{f_1} S_{Q_{1K}} + \sum_{i=2}^{n} \psi_{q_i} S_{Q_{ik}}$
Quasi-permanent Combination	$\sum_{j\geq1} G_{k,j} + P + \sum_{i\geq1} \psi_{2,i} Q_{k,i}$	$\sum_{j=1}^{m} S_{G_{jk}} + \sum_{i=1}^{n} \psi_{q_i} S_{Q_{ik}}$
$G_{k,j}$, $S_{G_{jk}}$ represents the characteristic value of permanent load, P represents the relevant representative value of a pre-stress action $Q_{k,i}$, $S_{Q_{i,k}}$ represents the characteristic value of living load i. $\psi_{0,i}$, ψ_{ci} represents the combination factor for a variable action i, $\psi_{1,i}$, ψ_{fi} represents the frequency factor of a variable action i and $\psi_{2,i}$, ψ_{qi} represents the quasi-permanent variable action i.		

Table 8. Factors.

Standard	Symbol	Area					
		Flat	Balcony	Stairs	Market	Stages	Stacks
EN 1991:2002	ψ_0	0.7	0.7	0.7	0.7	0.7	**1.0**
	ψ_1	0.5	0.5	0.5	**0.7**	**0.7**	0.9
	ψ_2	0.3	0.3	0.3	**0.6**	**0.6**	0.8
GB 50010-2010	ψ_c	0.7	0.7	0.7	0.7	0.7	0.9
	ψ_f	0.5	**0.6**	0.5	0.6	0.6	0.9
	ψ_q	**0.4**	**0.5**	**0.4**	0.5	0.5	0.8
Note:the **bold** number represents the value of the relevant factor are different between the two codes, and the larger one is presented in **bold** format.							

The load combination used in the EN1990:2002 and GB50009-2012 are provided in Table 7. The Chinese-code and Eurocode have the same form of load combination.

Some common values of those factors introduced in Table 7 are provided in Table 8[23].

According to the Table 8, most values of the three factors for Chinese code and Eurocode are same. The minor differences between the two codes could easily be observed from the table. The maximum value difference is a quasi-permanent factor (ψ_2 for EN1991:2002 and ψ_q for GB50010-2010), which is $0.5 - 0.3 = 0.2$, and the other differences are 0.1. The two codes are quiet close in this part. However, it is hard to say which is safer according to those value provided in the table, because the basic national conditions of the two countries are different.

For permanent loads, the main components stipulated by the two standards are the self-weight of structure and decorations. For live load, the recommended value of live load stipulated in the two standards are similar. For the specific project the two codes might provide different values, but the difference should be small.

4.2.2 Comparison of Serviceability limit state (SLS)

According to the requirement of EC2, the checking of the limit state should be based on the following factors:

(1) The distortion that affects the appearance, user comfort or structural function (including mechanical or service functions), and distortion of surface finishing or non-structural component;

(2) The vibration that makes pedestrians uncomfortable or restricts the effectiveness of structural functions;

(3) The damage that adversely affects the durability, appearance, or structural function.

Based on the above factors, the EC2 stipulates the concrete structure should satisfy:

$$Ed \leq Cd$$

where：

Cd reflects the limiting design values of serviceability criterion (i.e. f_{Cd}, M_{Cd});

Ed reflects the design value of action effect in the serviceability criterion, determined based on the relevant combination (i.e. f_{Ed}, M_{Ed}).

In GB 50010-2010 related to SLS, the following describes the guidance.

(1) Deformation checking should be carried out for the components which need to be controlled.

(2) The tensile stress of concrete should be checked when the cracks are not allowed.

(3) For the members that are allowed to appear cracks, the stress crack width should be checked;

(4) For the floor structure with the requirement of comfort, the vertical natural frequency checking should be carried out.

Based on the above factors, the GB 50010-2010 stipulates the concrete structure should satisfy:

$$\mathrm{S} \leq \mathrm{C}$$

where:

S reflects the design value of action effect corresponding to the Ed in EC2 ;

C reflects the Limit design values, corresponding to the Cd in EC2.

The detailed deflection control requirement is provided in 7.4 of EN1992-1-1. The requirement is:

$$\frac{l}{d_{basic}} * F1 * F2 * F3 \geq \frac{l}{d_{Actural}} \quad (6)$$

The $\frac{l}{d_{basic}}$ involved is obtained by:

$$\frac{l}{d}=K\left[11+\frac{1.5\sqrt{f_{ck}}\rho_0}{\rho}+3.2\sqrt{f_{ck}}\left(\frac{\rho_0}{\rho}-1\right)^{1.5}\right] \quad for\ \rho\le\rho_0$$
$$\frac{l}{d}=K\left[11+\frac{1.5\sqrt{f_{ck}}\rho_0}{\rho-\rho'}+\frac{\sqrt{f_{ck}}}{12}\sqrt{\frac{\rho'}{\rho_0}}\right] \quad for\ \rho>\rho_0 \tag{7}$$

where K depends on the span type, equals to 1, 1.3, 1.5, 0.4 for simply support span, end span, interior span or cantilever span respectively.

The calculation of F1, F2, F3 could be found in[24]. The allowable deflection values for flexural members in GB50010-2010 is presented in Table 9.

For the deflection control, GB50010-2010 used a table while EC2 used some equations. Consider table normally based on conservative simplification, it seems equations given in EC2 could provide more precise result and more flexible.

Table 9. Allowable deflection in GB50010-2010.

Type of members	Limiting values of deflection
Crane girder: Manual-operated crane: Electric-operated crane:	 $l_0/500$ $l_0/600$
Roof, floor and stair members: When $l_0<7m$ When $7m\le l_0\le 9m$ When $l_0>9m$	 $l_0/200(l_0/250)$ $l_0/250(l_0/300)$ $l_0/300(l_0/400)$

The crack control levels and limit values of maximum crack width control stipulated in EC2 and GB50010-2010 is presented in Table 10 and Table 11 respectively:

Table 10. Crack control in EC2.

Exposure Class	Reinforced members and Prestressed members with unbonded tendons	Prestressed members with bonded tendons
	Quasi-permanent load combination	Frequent load combination
X0, XC1	0.4[1]	0.2
XC2, XC3, XC4	0.3	0.2[2]
XD1, XD2, XD3, XS1, XS2, XS3		Decompression
Note1:	For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to give generally acceptable appearance. In the absence of appearance conditions this limit may be relaxed.	
Note2:	For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads.	

Table 11. Crack control in GB50010-2010.

Environmental Categories	Reinforced concrete structures		Prestressed concrete structures	
	Crack control levels	$w_{lim}(mm)$	Crack control levels	$w_{lim}(mm)$
I	III	0.3(0.4)	III	0.2
II	III	0.2	II	0.1
III	III	0.2	I	-

From the two tables, the allowable maximum crack width of the two codes are 0.4 mm and depends on different conditions the requirement would vary. Generally the crack widths control of the two codes are close.

5 Case Study

In this section a rectangular beam flexure design example will be presented according to both code to present the main difference discussed above.

5.1 Problem Statement

A rectangular simply supported beam with a span of 6m is required in a project, the exposure condition is an open-air environment of non-severe cold or non-cold area. The cross section of the beam should be b*h=250mm*500mm. The material using is: concrete with $f_{ck,cube}=30\ MPa$, and reinforcement $f_{yk}=400\ MPa$. Design moment value is $300\ kNm$, the quasi-permanent moment is: $150\ kNm$. Calculate the longitudinal reinforcement area and check the deflection.

5.2 Chinese Code Solution

Flexure Design:

According to the description, the environment code is II_a. Minimum cover for beams is 25 mm. Assume 10 mm link and 20 mm main reinforcement then $a=25+10+\frac{20}{2}=45mm$, $a'=45mm$, $h_0=h-a=500-45=455mm$.

Check if the section required compression reinforcement:

$$\alpha_s=\frac{M}{\alpha_1 f_c bh_0^2}=0.4053>\alpha_{s,max}=0.384$$

need compression reinforcement

$$A_s'=\frac{M-\alpha_{s,max}\alpha_1 f_c bh_0^2}{f_y'(h_0-a')}=107\ mm^2$$

$$A_s=\frac{\alpha_1\xi bh_0 f_c}{f_y}+A_s'=2448\ mm^2$$

Deflection check:

Span equals to 6m, then the deflection limitation:

$[f]=l_0/200$.

According to the provided information:

Elasticity modulus of steel: $E_s=2*10^5 N/mm^2$

Elasticity modulus of concrete: $E_c=3*10^4 N/mm^2$

$$\alpha_E=\frac{E_s}{E_c}=6.67$$
$$\rho=\frac{A_s}{bh_0}=\frac{2447.6}{250*455}=0.0215$$
$$\rho'=\frac{A_s'}{bh_0}=\frac{107}{250*455}=9.4*10^{-4}$$
$$\rho_{te}=\frac{A_s}{0.5*bh}=\frac{2447.6}{0.5*250*500}=0.0206$$
$$\sigma_{sq}=\frac{M_q}{0.87h_0A_s}=\frac{150*10^6}{0.87*455*2447.6}=154\frac{N}{mm^2}$$
$$\psi=1.1-0.65*\frac{f_{tk}}{\rho_{te}\sigma_{sq}}=1.1-0.65*\frac{2.01}{0.0206*154}=0.8845$$
$$B_s=\frac{E_sA_sh_0^2}{1.15\psi+0.2+\frac{6\alpha_E\rho}{1+3.5\gamma_f'}}=4.877*10^{13}N\cdot mm^2$$
$$\theta=1.6+0.4\left(1-\frac{\rho'}{\rho}\right)=1.9825$$
$$B=\frac{B_s}{\theta}=2.46*10^{13}N*mm^2$$
$$f=\frac{5}{48}\frac{Ml_0^2}{B}=\frac{5}{48}\frac{150*10^6*6000^2}{2.46*10^{13}}=22.86mm$$
$$[f]=\frac{l_0}{200}=\frac{6000}{200}=30mm,\ \text{hence, } f<[f], OK$$

5.3 Eurocode Solution

Flexure Design:
In Eurocode, for the concrete of C25/30, $f_{ck} = 25MPa$. In order to compare with GB50010-2010, select same steel strength $f_{yk} = 400\ MPa$, hence $f_{yd} = 347.83\ MPa$. Then according to the environment, select 25 mm concrete cover. Assume the diameter of the links is 10mm.
The effective depth :

$$d = h - cover - \frac{\Phi}{2} - \Phi_{link} = 455mm.$$

$$\mathrm{K} = \frac{M}{f_{ck}(b)(d^2)} = 0.2319 > \mathrm{k}' = 0.167$$

need compression reinforcement
Lever arm z :

$$\mathrm{z} = \mathrm{d}\left[0.5 + \sqrt{0.25 - \frac{k'}{1.134}}\right] = 373.3 = 0.82\mathrm{d} < 0.95d$$

Thus:

$$\mathrm{A}_s' = \frac{(K - K')f_{ck}bd^2}{0.87f_{yk}(d - d')} = 588mm^2$$

$$\mathrm{A}_s = \frac{K' f_{ck}bd^2}{0.87f_{yk}Z} + A_s' = 2251mm^2 < 0.04Ac = 4550\mathrm{mm}^2$$

Deflection Check:
For simply supported beam, $\mathrm{K} = 1.0$

$$\rho_0 = \frac{\sqrt{f_{ck}}}{1000} = \frac{\sqrt{25}}{1000} = 0.005$$

$$\rho = \frac{\mathrm{A}_s}{bd} = \frac{2251}{250 * 455} = 0.0198 > \rho_0$$

$$\rho' = \frac{\mathrm{A}_s'}{bd} = \frac{588}{250 * 455} = 0.0052$$

Thus the basic $\frac{l}{d}$ equals to:

$$\frac{l}{d_{bas}} = K\left[11 + \frac{1.5\sqrt{f_{ck}}\rho_0}{\rho - \rho'} + \frac{\sqrt{f_{ck}}}{12}\sqrt{\frac{\rho'}{\rho_0}}\right] = 14$$

Consider the cross section is rectangular and span less than 7m, conservatively assume $\mathrm{A}_{s,prov} = A_{s,req}$ in this stage, thus:

$$\mathrm{F1} = 1.0,\ \mathrm{F2} = 1.0,\ \mathrm{F3} = \frac{A_{s,prov}}{A_{s,req}} = 1$$

$$\frac{l}{d_{act}} = \frac{6000}{455} = 13.19 < \frac{l}{d_{bas}} * \mathrm{F1} * \mathrm{F2} * \mathrm{F3} = 14,\ \mathrm{OK}$$

6 Conclusion

In this paper, the main issues related to concrete structural design are discussed and the similarities and differences of the EC2 and GB50010-2010 are studied. For the normal concrete structural design, the partial load factors in the two codes are different. For ULS, the partial load factors in EC2 is a little larger than the Chinese code. Considering the same strength concrete, Chinese code adopts a lower design value, so the two codes' final structure reliability should be relatively close. For SLS, GB50010-2010 gives a reference form, which provides the direct requirement of the deflection for different concrete specifications and structures. EC2, however, indirectly checks whether the span-depth ratio is satisfied based on equations provided, to control deflection. For SLS crack control, EC2 and GB50010-2010 are relatively close. From the given case study, the compressive reinforcement area obtained by GB50010-2010 is smaller than that of EC2, and the area of main reinforcement is larger than the result of EC2, and both $\mathrm{A}_{s,pro}$ could pass the deflection check in the two codes.

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