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Recommendations for Design and Construction of Concrete Structures Using Stainless Steel Bars (draft)

June, 2009

Japan Society of Civil Engineers

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Member (2007 and 2008 F.Y.)

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Recommendations for Design and Construction of Concrete Structures Using Stainless Steel Bars (draft)

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Chapter 1 General

1.1 Scope

(1) These Recommendations (draft) provide general standards for the special requirements applicable to the design and construction of concrete structures using stainless steel bars.

(2) Concrete structures using stainless steel bar shall be designed and constructed with due consideration of the characteristics of the stainless steel bars.

(3) Specifications not provided for in these (draft) Recommendations shall conform to the Standard Specifications for Concrete Structures published by the Japan Society of Civil Engineers (hereinafter referred to as the Specifications.)

[Commentary]

(1) Reinforced concrete, when appropriately designed and constructed using appropriate materials, is highly durable and used widely in fabricating the main structural members making up the social infrastructure. However, the performance of a reinforced concrete structure may decrease substantially in a highly corrosive environment where chloride ions are present in large quantity. Examples of vulnerable infrastructure include waterfront and offshore structures, road bridges on which antifreezing agents are applied, and storage tanks for water containing a high concentration of chloride ions.

Stainless steel forms a passive film of chromium oxide that is highly resistant to corrosion, so the use of stainless steel bars in concrete can enhance the durability of a structure in a highly corrosive environment.

These (draft) Recommendations specify requirements for the aspects of design and construction that need special consideration when using stainless steel bars in structures affected by chloride ions as mentioned above.

(2) The characteristics of the stainless steel bar used, such as the stress-strain relationship and corrosion resistance, vary according to the type of stainless steel bars. Accordingly it is important to fully understand the characteristics of the stainless steel bars when designing and constructing concrete structures using stainless steel bars.

(3) These (draft) Recommendations conform to the general Specifications. Further, aside from special requirements specific to the design and construction of concrete structures using stainless steel bars given in these Recommendations, the common requirements for concrete structures shall conform to the Specifications. It should be noted that the Specifications are updated as technology advances so therefore it is recommended that, in principle, the most up-to-date version of the Specifications be applied.

1.2 Definitions

These (draft) Recommendations adopt the following definitions.

Stainless steel bar:	Stainless steel deformed bar for reinforced concrete prescribed by JIS G4322
SUS304-SD:	Austenitic stainless steel bar meeting the standards prescribed by JIS G4322
SUS316-SD:	Austenitic stainless steel bar meeting the standards prescribed by JIS G4322
SUS410-SD:	Ferritic or martensitic stainless steel bar meeting the standards prescribed by JIS G4322
Carbon steel bar:	Deformed bar as prescribed by JIS G3112 "Steel bars for concrete reinforcement"

[Commentary]

Stainless steel bar:

Generally, the term stainless steel refers to a steel containing 10.5% or more of chromium and 50% or more of iron. The high chromium content gives the steel high corrosion resistance. The stainless steel bars described in these (draft) Recommendations are deformed bars for concrete reinforcement as prescribed by JIS G4322. The Recommendations prescribe the following three types of stainless steel bar according to chemical composition: SUS304-SD, SUS316-SD, and SUS410-SD.

SUS304-SD:
SUS304-SD includes the following steel grades: SUS304 (18%Cr-8%Ni) and SUS304N2 (18%Cr-8%Ni-0.2%N), i.e. SUS304 with added nitrogen.

SUS316-SD:
SUS316-SD includes the following steel grades: SUS316 (16%Cr-10%Ni-2%Mo) and SUS316N (16%Cr-10%Ni-2%Mo-0.2%N), i.e. SUS316 with added nitrogen.

SUS410-SD:
SUS410-SD includes the following steel grades: SUS410 (12%Cr) and SUS410L (12%Cr-Low C), i.e. SUS410 with reduced carbon content.

Chapter 2 Stainless steel bars

2.1 Quality of stainless steel bars

The stainless steel bars shall conform to JIS G4322 "Stainless steel bars for concrete reinforcement."

[Commentary]

Stainless steel bars are manufactured by hot-rolling stainless steel in such a manner as to produce bars of the same shape as carbon steel bars. Stainless steel is an alloy containing 10.5% or more of chromium by mass ratio. Its high corrosion resistance is provided by the thin oxide (passive) film of chromium that forms on the surface of the steel.

The standards provide for many grades of stainless steel alloy containing different elements in various proportions according to required corrosion-resistant performance, mechanical properties, and other characteristics. These (draft) Recommendations cover only stainless steel bars manufactured from the following three grades of stainless steel as prescribed by JIS G4322 "Stainless steel bars for concrete reinforcement": austenitic SUS304-SD and SUS316-SD, and ferritic or martensitic SUS410-SD. Because the level of corrosion resistance required of stainless steel bars varies with the type and importance of a structure, the environment in which it is built, and the locations in which stainless steel bars are used, these (draft) Recommendations in the main narrow down the available types of stainless steel bar with different levels of corrosion resistance to the three above-mentioned types. These are also listed in Table C2.1.1, which gives the characteristic features of these stainless steels. Stainless steel bars are manufactured from general-purpose stainless steel with a proven track record and with verified performance when used as stainless steel bars.

SUS304-SD: Stainless steel bar manufactured from SUS304, i.e. the basic steel alloy most widely used as stainless steel, or enhanced-strength SUS304N2 obtained by adding nitrogen to SUS304

SUS316-SD: Stainless steel bar manufactured from SUS316, i.e. a more corrosion-resistant steel alloy obtained by adding molybdenum to SUS304, or enhanced-strength SUS316N obtained by adding nitrogen to SUS316

SUS410-SD: Stainless steel bar manufactured from SUS410, i.e. chromium stainless steel with a controlled alloy content, or SUS410L with low carbon content

Stainless steel bars manufactured from steel grades other than those listed above are not covered by these (draft) Recommendations because their mechanical performance when used in concrete members and their corrosion resistance performance when embedded in concrete have not been verified. However, structures may be designed and constructed with other types in conformance with these (draft) Recommendations if the required performance of the stainless steel bars has been verified in accordance with these (draft) Recommendations.

Table C2.1.1 Types and strength classes of stainless steel bars

Type designation	Strength classes	Corresponding steel grades
SUS304-SD	295A	SUS304 (austenitic) SUS304N2 (austenitic)
	295B	
	345	
	390	
SUS316-SD	295A	SUS316 (austenitic) SUS316N (austenitic)
	295B	
	345	
	390	
SUS410-SD	295A	SUS410L (ferritic) SUS410N (martensitic)
	295B	
	345	
	390	

2.2 Design values of materials

2.2.1 Strength

(1) Characteristic values of yield strength, f_{yk}, and tensile strength, f_{uk} of stainless steel bars may be used as the lower limit values of the JIS. The cross-sectional area of a stainless steel bar used in the examination of the limit state may be generally equal to the nominal cross-sectional area.

(2) A material factor, γ_s of stainless steel bars may be used as same as that of carbon steel bars.

[Commentary]

(1) Generally, when a stainless steel bar is subject to a tensile stress, it undergoes plastic deformation without a clear yield point appearing, as shown in Figure C2.2.1. For this reason, its yield strength may be defined as the 0.2% offset yield strength (stress at a residual strain of 0.2%). According to tension tests on stainless steel bars, although SUS304-SD and SUS316-SD tend to exhibit a large yield region ranging from the yield point to the tensile strength point, the characteristic values of yield and tensile strength of stainless steel bars, including also SUS410-SD, are about equal to or slightly larger than the lower limit values given in the JIS. Accordingly, characteristic values of yield and tensile strengths of stainless steel bars may be used as the lower limit values of the JIS.

(2) The quality of stainless steel bars is considered to be about the same as that of carbon steel bars. Accordingly, a material factor on the limit state of stainless steel bars may be used as that of carbon steel bars.

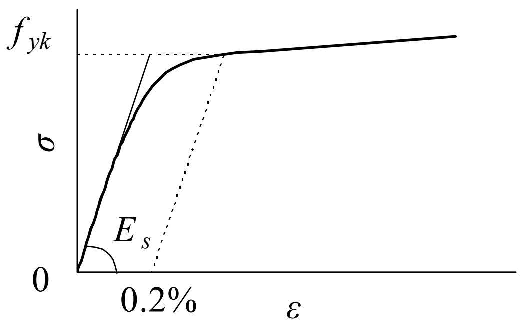


Figure C2.2.1 Definition of yield strength of stainless steel bars

2.2.2 Fatigue strength

The design fatigue strength, f_{srd}, of a stainless steel bar may be generally determined from Equation (2.2.1) as a function of fatigue life, N, and the stress, σ_{sp}, of stainless steel under a permanent load.

$$f_{srd} = 190 \frac{10^a}{N^k} \left(1 - \frac{\sigma_{sp}}{f_{ud}} \right) \Big/ \gamma_s \qquad (\text{N/mm}^2) \qquad (2.2.1)$$

with $N \leq 2 \times 10^6$

where:

f_{ud}: design tensile strength of the stainless steel bar as determined from a material factor of 1.05

γ_s: material factor of the stainless steel bar, which may be generally taken as equal to 1.05

(i) a and k shall, as a general rule, be determined through a test.

(ii) In case that the fatigue life does not exceed 2x10^6 cycles, a and k may be generally equal to the values given by Equation (2.2.2.)

$$a = k_{of}(0.81 - 0.003\phi)$$
$$k = 0.12 \qquad (2.2.2)$$

where:

ϕ: diameter of the stainless steel bar (mm)

k_{of}: coefficient for the shape of lug on the stainless steel bar, which generally be taken as equal to 1.0.

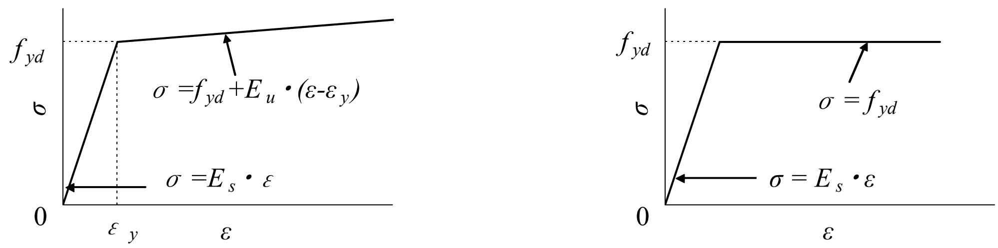
[Commentary]

The results of fatigue tests on stainless steel bars given in Reference Volume I Chapter 1.4 are nearly equivalent to the values determined from the fatigue strength Equation (2.2.1) as presented in the Specifications (Design) for SUS410-SD and are larger than the values determined from Equation (2.2.1) for SUS304-SD and SUS316-SD. Accordingly, the design fatigue strength of a stainless steel bar may be determined from Equation (2.2.1) regardless of the steel type.

2.2.3 Stress-strain curve

(1) An appropriate shape shall be assumed for the stress-strain curve of a stainless steel bar in accordance with the purpose of each examination.

(2) For an ultimate limit state, the idealized stress-strain curves shown in Figure 2.2.1 may be used in general, depending on the steel type and the specified value of yield strength.



(a) Incremental bilinear model (SUS410-SD295)

(b) Bilinear model (Other than SUS410-SD295)

Figure 2.2.1 Idealized stress-strain curves for a stainless steel bar

[Commentary]

(1) Generally, the stress-strain curve for a stainless steel bar reflects the characteristics of a material that undergoes plastic deformation without exhibiting a clear yield point, although it does vary with the type of a stainless steel bar and its strength properties. The stress at which a stainless steel bar undergoes plastic deformation is in most cases about 80% or more of the yield strength. Based on this understanding, an appropriate stress-strain curve shall be assumed in consideration of the purpose of the examination and the properties of the materials.

(2) According to the results of tension tests on stainless steel bars, steel types SUS410-SD295 exhibit notable strain hardening and increased stress beyond the elastic limit. For this reason, the incremental bilinear model (a) is assumed for the stress-strain curve for SUS410-SD295. For steel types other than SUS410-SD295, the stress-strain curve can be approximated by a model having a yield plateau, which is close to the curve for a carbon steel bar. For this reason, the bilinear model (b) may be used for the stress-stain curve. The test results are given in Reference Volume I Chapter 1.

The degree of elongation of SUS304-SD and SUS316-SD bars is slightly greater than that of carbon steel bars while that of SUS410-SD is comparable to carbon steel, so the degree of elongation of stainless steel bars may be taken as equal to that of carbon steel bars. However, when using the incremental bilinear model (a), the tensile load to which a stainless steel bar is subjected may become excessive. With this in view, it is desirable to limit the range of tensile strain of a stainless steel bar in examining the ultimate limit state to about $20{,}000 \times 10^{-6}$ or less.

2.2.4 Young's modulus

The Young's modulus of a stainless steel bar shall in general be equal to 200 kN/mm^2.

[Commentary]

According to the results of tensile tests on stainless steel bars, Young's modulus typically does not exceed 200 kN/mm^2. (Refer to Reference Volume I Chapter 1.) However, because variations in Young's modulus have little effect on the calculation results in general, for example when calculating the stress in the cross section and the deformation of a member, Young's modulus can be taken as comparable to that of a carbon steel bar. In cases where very precise calculations of member deformation are necessary, it is recommended to use a value of Young's modulus obtained from test results.

When the incremental bilinear model shown in 2.2.3 (a) is used for the stress-strain curve of a stainless steel bar, the stress increment ratio, E_u, in the strain hardening region may be taken as equal to about 5 kN/mm^2.

2.2.5 Coefficient of thermal expansion

The coefficient of thermal expansion of a stainless steel bar may in general be equal to that of concrete.

[Commentary]

The coefficient of thermal expansion of a stainless steel bar varies with the steel grade, being about 17.3x10^{-6}/°C for SUS304-SD, 16.0x10^{-6}/°C for SUS316-SD, and 10.0x10^{-6}/°C for SUS410-SD. These values are comparable to or slightly larger than that of concrete. (Refer to Reference Volum**e** Chapter 1.3.) Within the range of ordinary rises/falls in temperature, however, the effect of any difference in the coefficient of thermal expansion between concrete and stainless steel bars on the behavior of a concrete structure is considered small. Therefore, the coefficient of thermal expansion of a stainless steel bar may in general be treated as equal to that of concrete. However, for a member subject to particularly large temperature changes, the effect of the difference in coefficients of thermal expansion needs to be taken into consideration.

Chapter 3 Structural performance verification of structures

3.1 General

(1) Structures in which stainless steel bars are used as reinforcement shall maintain the required performance throughout their design service life.

(2) As a general rule, the verification of the resistance of stainless steel bars to corrosion shall be carried out in accordance with this chapter.

[Commentary]

Structures and structural members must maintain sufficient structural performance to suit the intended use throughout their design service life. The required performance measures include safety, comfort in use, water-tightness, serviceability, aesthetic appearance, and durability under environmental influence. Stainless steel bars have mechanical properties almost similar to those of carbon steel bars. Accordingly, indices of safety, such as cross-sectional capacity, and indices of serviceability, such as stress, cracking, displacement, deformation, and amplitude, may be calculated in the same manner as for structures and structural members using carbon steel bars.

Stainless steel bars are more resistant to corrosion than carbon steel bars, but the degree of resistance varies with the steel grade. Therefore, a verification of the resistance of stainless steel bars to corrosion shall, as a general rule, be carried out by the method described in this chapter.

3.2 Examination of cracking

(1) An examination shall be carried out to verify that cracking of the concrete does not impair the intended use of the structure, including its function and aesthetic appearance. This examination may be conducted by confirming that the width of cracks developed on the structure does not exceed the limit value of crack width below which the structure maintains the required performance.

(2) The limit value of crack width of members using stainless steel bars shall be set appropriately according to the required performance of the structure.

(3) The limit value of crack width of members using stainless steel bars may in general be determined from Table 3.2.1 according to the concrete cover thickness, c, and the type of a stainless steel bar. However, Table 3.2.1 shall in principle be applicable to concrete cover thicknesses, c, of not more than 100 mm.

Table 3.2.1 Limit value of crack width of members using stainless steel bars

Type of stainless steel bars	Limit value of crack width
SUS304-SD	0.5 mm
SUS316-SD	0.5 mm
SUS410-SD	0.005*c* or 0.5 mm, whichever is smaller

(4) The flexural crack width of members using stainless steel bars may be calculated by a method similar to that used for carbon steel bars.

[Commentary]

(1) Generally, the crack that develops in concrete structures is considered to be a cause of degradation in durability, water-tightness, and air-tightness due to steel corrosion, as well as excessive deformation and impaired aesthetic appearance.

(2), (3) Stainless steel bars are more resistant to corrosion than carbon steel bars and do not corrode easily even if corrosive agents such as chloride ions penetrate into the concrete through cracks. Accordingly, from the viewpoint of controlling steel corrosion, there is no need to control the crack width such that it is a minimum as in the case of carbon steel bars. However, if the crack width becomes excessively wide and seawater comes in direct contact with stainless steel bars in concrete, the stainless steel bars will be more likely to corrode.

Limit values of crack width are specified in Table 3.2.1 based on above situation. SUS304-SD and SUS316-SD, which are defined in JIS G4322 "Stainless steel bars for concrete reinforcement" are highly resistant to corrosion and therefore their limit value of crack width is set at 0.5 mm. The reason why the limit value is set is that a test using a cracked test specimen confirmed that corrosion barely occurs even if the crack width is up to 0.5 mm (Reference Volume II Chapter 5) and that if the crack width exceeds 0.5 mm, the pH in the crack drops and the stainless steel bars come into direct contact with salt water, which increases the possibility of corrosion. SUS410-SD, which is defined in JIS G4322 "Stainless steel bars for concrete reinforcement" is relatively less resistant to corrosion than SUS304-SD and SUS316-SD, and the fact was verified experimentally. For this reason, the limit value of crack width is set to be 0.005*c* for SUS410-SD. The value 0.005*c* is the limit value in typical environments specified by the Specifications (Design), which is applicable as the limit value of crack width of SUS410-SD under more severe corrosive environments than carbon steel bars.

If the crack width needs to be limited from the viewpoint of structural function and serviceability, such as to preserve aesthetic appearance and water tightness, the limit value of crack width needs to be determined in the same manner as when using carbon steel bars.

(4) It has been experimentally verified that the width of flexural cracks in a reinforced concrete member using stainless steel bars can be evaluated by the equation (C 3.2.1) given in the Specifications (Design), as in the case of carbon steel bars. (See Reference Volume I Chapter 1.5.)

$$w = 1.1 k_1 k_2 k_3 \{4c + 0.7(c_s - \phi)\} \left[\frac{\sigma_{se}}{E_s} + \varepsilon'_{csd} \right] \qquad \text{(C 3.2.1)}$$

where:

k_1: coefficient representing the effect of the surface profile of the stainless steel bars on crack width, which may in general be taken as equal to 1.0

k_2: coefficient representing the effect of concrete quality on crack width, given by equation (C 3.2.2)

$$k_2 = \frac{15}{f'_c + 20} + 0.7 \qquad \text{(C 3.2.2)}$$

f'_c: compressive strength of concrete (N/mm^2), which may in general be taken as equal to the design compressive strength, f'_{cd}

k_3: coefficient representing the effect of the number of layers of tension stainless steel bars, given by equation (C 3.2.3)

$$k_3 = \frac{5(n+2)}{7n+8} \qquad \text{(C 3.2.3)}$$

n: number of layers of tension stainless steel bars

c: thickness of concrete cover (mm)

c_s: center-to-center spacing between stainless steel bars (mm)

ϕ: diameter of a stainless steel bar (mm)

ε'_{csd}: value accounting for the increase in crack width due to the shrinkage and creep of concrete

σ_{sc}: increase in stress of a stainless steel bar from the state in which the stress of the concrete in the position of the bar is zero (N/mm^2)

The examination of shear and torsion cracks of members using stainless steel bars may also be carried out in the same manner as for carbon steel bars.

3.3 Corrosion verification of stainless steel bars

3.3.1 General

(1) It shall be confirmed that concrete structures in which stainless steel bars are used maintain the required performance throughout their design service life.

(2) A verification of the resistance of the stainless steel bars to corrosion due to the penetration of chloride ions and chemical attack shall be carried out in accordance with this chapter.

(3) A verification of the resistance of stainless steel bars to corrosion due to carbonation is not necessary. However the effect of carbonation on corrosion due to the penetration of chloride ions, if any, shall be confirmed.

[Commentary]

(1), (2) Even in a case where stainless steel bars are used, the durability for concrete structures, which are prescribed under Verification of Durability (Chapter 8) of the Specifications (Design), shall, as a general rule, be satisfied. The corrosion of steel due to the penetration of chloride ions is a primary cause of durability degradation in the case of structures such as marine structures and road structures subjected to the effect of an antifreezing agent in the winter. Chemical attack, including acid attack, is another primary cause of durability degradation in the case of structures such as sewerage facilities and structures in hot spring zones. When stainless steel bars are adopted as the countermeasure, or one of the countermeasures, used to resist steel corrosion and chemical attack, the effective and rational approach is to design the structure in such a way as to maximize the advantages of the stainless steel; that is, taking into full account their corrosion resistance. To this end, of the possible methods of verifying the corrosion of stainless steel bars due to the penetration of chloride ions, verification in terms of the threshold chloride ion concentration (below which corrosion does not occur) is prescribed in this chapter separately from the Specifications (Design).

(3) Concrete carbonation is a phenomenon in which the pH of the pore solution evolves from alkaline to neutral primarily through reaction with carbon dioxide from the air. Carbonation alone does not cause corrosion of stainless steel bars, since a passive film that is stable in a neutral solution forms on its surface. Accordingly, if no chloride ions exist around the stainless steel bars, it is no need to carry out a verification of carbonation.

The verification of corrosion due to the penetration of chloride ions assumes that the threshold chloride ion concentration for stainless steel bars, C_{lim}, does not decrease during the service life. However, C_{lim} decreases if the concrete around the stainless steel bars is carbonated. Therefore, if there is any penetration of chloride ions, the effect of carbonation on the corrosion due to chloride ions shall be confirmed.

3.3.2 Verification for the resistance of stainless steel bars to corrosion due to the penetration of chloride ions

(1) The required performance of structures in which stainless steel bars prescribed by JIS G4322 "Stainless steel bars for concrete reinforcement" are used shall not be degraded as a result of corrosion of the stainless steel bars due to the penetration of chloride ions.

(2) If the threshold chloride ion concentration for stainless steel bars, C_{lim}, is not exceeded by the assumed chloride ion concentration on the concrete surface, C_0, (that is, if $C_{lim} > C_0$), the verification for the resistance to corrosion may be omitted.

(3) The verification for the resistance to corrosion of the stainless steel bars due to the penetration of chloride ions may be conducted by confirming that the ratio of the design chloride ion concentration at the surface of stainless steel bars, C_d, to the threshold chloride ion concentration for the stainless steel bars, C_{lim}, multiplied by the structure factor, γ_i, is not more than 1.0.

$$\gamma_i \frac{C_d}{C_{lim}} \leq 1.0 \tag{3.3.1}$$

where:

γ_i: structure factor, which may in general be taken as equal to 1.0, with a value of 1.1 recommended for important structures

C_{lim}: threshold chloride ion concentration for stainless steel bars, which may, in general, be determined using Table 3.3.1

C_d: design chloride ion concentration at the surface of the stainless steel bars, which may in general be calculated from Equation (3.3.2)

$$C_d = \gamma_{cl} \cdot C_0 (1 - erf(\frac{0.1 \cdot c_d}{2\sqrt{D_d \cdot t}})) \tag{3.3.2}$$

where:

C_0: assumed chloride ion concentration at the concrete surface (kg/m^3), which may in general be determined from Table C3.3.2 for coastal structures where chloride ions are wind-borne from the sea

c_d: design thickness of concrete cover used for the verification (mm)

t: service life against the penetration of chloride ions (year)

γ_{cl}: safety factor that takes into account variations in the design chloride ion concentration at the surface of the stainless steel bars, C_d, which may in general be taken as equal to 1.3, with a value of 1.1 in cases where self-compacting concrete is used

D_d: design diffusion coefficient of chloride ions in concrete (cm^2/year), which may in general be calculated from Equation (3.3.3)

$$D_d = \gamma_c \cdot D_k + \eta \cdot \left(\frac{w}{l}\right) \cdot D_0 \tag{3.3.3}$$

where:

γ_c: material factor for concrete, which may in general be taken as equal to 1.0, with a value of 1.3 recommended for the top surface. The coefficient may be taken as 1.0 throughout if there is no difference in quality between the existing structural concrete and the standard curing specimens.

D_k: characteristic value of diffusion coefficient of chloride ions in concrete (cm^2/year)

η: coefficient of the effect of the movement of chloride ions and of cracks in the concrete, which may in general be taken as equal to 1.0 when stainless steel bars are used

D_0: constant representing the effects of the movement of chloride ions and of cracking in concrete (cm^2/year), which may in general be taken as equal to 200 cm^2/year

w/l: ratio of crack width to crack interval, as per the Specifications (Design) 8.3.7

where erf(s) is an error function and is represented by $erf(s) = \frac{2}{\pi^{1/2}} \int_0^s e^{-\xi^2} d\xi$

Table 3.3.1 Recommended value of critical chloride ion concentration for stainless steel bars C_{lim}

Types of stainless steel bar	Recommended value of threshold chloride ion concentration kg/m^3
SUS304-SD	15
SUS316-SD	24
SUS410-SD	9

(4) Where combined with carbon steel bars, the verification for resistance to corrosion of the carbon steel bars shall be carried out.

[Commentary]

(2) The threshold chloride ion concentration, C_{lim}, is represented by the total chloride ion concentration per unit volume of concrete. The recommended value of which is listed in Table 3.3.1 by type of stainless steel bars. The threshold chloride ion concentration for stainless steel bars is affected by pH. The recommended value is based on the pH of ordinary concrete, i.e. 12.5. If the threshold chloride ion concentration for stainless steel bars, C_{lim}, is not exceeded by the assumed chloride ion concentration on the surface of concrete, C_0, ($C_{lim} > C_0$), it is very unlikely that the stainless steel bars will corrode. For this reason, if $C_{lim} > C_0$, the verification of the corrosion resistance of the stainless steel bars may be omitted.

(3) The performance verification of a structure for the resistance to corrosion of stainless steel bars due to the chloride ion penetration may be conducted by confirming that the concentration of chloride ions on the surface of the concrete is not higher than the threshold chloride ion concentration for the stainless steel, in accordance with the Specifications (Design). In the case of stainless steel bars, the verification does not include defining the occurrence of cracking on the concrete surface resulting from steel corrosion due to chloride ion penetration as a limit state. The reason for this is to take into account the fact that stainless steel is highly resistant to corrosion but it may suffer a form of local pitting corrosion.

The concentration of chloride ions accumulated at the surface of the stainless steel bars due to the chloride ion penetration over the design service life may be estimated from the solution of Fick's diffusion equation, as shown by Equation (3.3.2).

The concentration of chloride ions on the surface of concrete used for the calculation of Equation (3.3.2) may be determined from Table C3.3.2 for coastal structures where chloride ions are wind-borne from the sea. The concentrations in Table C3.3.2 are in conformance with the Specifications (Design). For structural members not in the splash zone but in the atmospheric zone, the verification may be implemented by regarding the members as being in an environment near the shoreline.

When an antifreezing agent is disseminated to ensure traffic safety in the winter, the chloride ion concentration, C_0, on the surface of the concrete may locally exceed the value listed in Table C3.3.2. It is recommended that the appropriate chloride ion concentration on the surface of the concrete be determined by taking into account whether Equation (3.3.2) is applicable, the results of surveys conducted on existing structures (including the value of chloride ion concentration on the surface of the concrete), and the frequency with which the antifreezing agent is applied.

The design diffusion coefficient, D_d, of chloride ions in cracked cover concrete may be calculated from Equation (3.3.3), which is based on the concept of averaging the contribution of uncracked concrete to the movement of chloride ions and the effects of cracks on the movement of chloride ions, in accordance with the Specifications (Design). Coefficient η in Equation (3.3.3) is the term that compensates for the effects of cracks. The Specifications (Design) define $\eta = (w/w_a)^2$, with $\eta = 1.0$ when the crack width, w, is equal to the limit value, w_a. That is, the function is determined such that it is advantageous to limit the crack width to less than the limit value. For stainless steel bars, the limit value of crack width can be set larger than in the case of carbon steel bars. For this reason, as a simple safety measure, the coefficient, η, is made constant at the maximum value, 1.0, in calculating the diffusion coefficient.

Table C3.3.2 Chloride ion concentration on the concrete surface, C_0 (kg/m^3)

		Splash zone	Distance from shore (km)				
			Near shoreline	0.1	0.25	0.5	1.0
Area with a high content of air-borne salt particles	Hokkaido, Tohoku, Hokuriku, Okinawa	13.0	9.0	4.5	3.0	2.0	1.5
Area with a low content of air-borne salt particles	Kanto, Tokai, Kinki, Chugoku, Shikoku, Kyushu		4.5	2.5	2.0	1.5	1.0

The value of C_0 in the vertical direction may be determined by regarding a height of 1 m above sea level as equivalent to a distance of 25 m from the shoreline.

(4) When a stainless steel bar comes into contact with a carbon steel bar, macro-cell corrosion due to the contact between different metals may occur and cause the carbon steel bar to corrode rapidly. However, the results of accelerated tests in which a stainless steel bar was placed in contact with a carbon steel bar within concrete mixed with 1.2 kg/m^3 of chloride ions (i.e. the threshold chloride ion concentration for carbon steel bars) in an autoclave indicate that there is no effect of acceleration of corrosion to carbon steel bar by the stainless steel bar (Reference Volume I **2.6**). It is assumed from this that stainless steel bars barely give the influences to the corrosion of carbon steel bars if the concentration of chloride ions in the concrete does not exceed the threshold chloride ion concentration for carbon steel bars, 1.2 kg/m^3.

Accordingly, even where stainless steel and carbon steel bars come into contact with each other, there is no durability problem if the verification of durability of the carbon steel bars at that location is conducted in accordance with the Specifications (Design) and the results of the verification satisfy the requirements.

3.3.3 Verification for the resistance of stainless steel bars to corrosion due to chemical attack

In cases where stainless steel bars are employed as a measure to protect concrete from very severe chemical attack, the effects of the remedial measure shall be evaluated by an appropriate method with a maintenance plan in view.

[Commentary]

Chemical attack is a degradation phenomenon in which dissolution or deterioration of concrete is caused through contact with corrosive substances or in which concrete cracking or spalling of the cover concrete is caused by volumetric expansion resulting from the reaction of corrosive substances that penetrate the concrete with the chemical constituents of the cement or steel. Generally, in consideration of required performance, structural type and importance, degree of difficulty of structure maintenance, and environmental conditions, concrete should not suffer deterioration due to contact or penetration by corrosive substances nor should the effect of chloride ions reach the steel. However, if the chemical attack is very severe, it may be difficult to guarantee resistance to chemical attack only by making the concrete cover resistant. In such cases, it is sometimes practical and rational to take other measures, such as coating the concrete surface to control chemical attack and using stainless steel bars to control steel corrosion. It should be noted that, although the use of stainless steel bars does not directly control the deterioration of concrete due to chemical attack, it does have the potential, in new structures, to deliver not only improved durability but also simplified maintenance during the in-service period. This includes eliminating the need to replace stainless steel bars when repairing the concrete cover.

In carrying out verification for resistance to chemical attack, it is desirable to set an appropriate limit state and conduct a quantitative verification. However, at the present time, there is insufficient knowledge to specify a quantitative evaluation for functional impairment caused by deterioration of concrete due to contact with or penetration of corrosive substances as well as for the resistance of stainless steel bars to corrosion due to chemical attack. Accordingly, it is necessary to evaluate the effects of using stainless steel bars in such cases based on reliable data.

Chapter 4 General structural details

4.1 General

General structural details aside from those specified in this chapter shall conform to the Specifications (Design).

[Commentary]

Stainless steel bars are verified as being more resistant to corrosion than carbon steel bars. Further, various tests have verified that stainless steel bars and reinforced concrete made using stainless steel bars have mechanical properties comparable to carbon steel bars and reinforced concrete made with carbon steel bars. Accordingly, in the design of concrete structures using stainless steel bars, structural details should be considered in essentially the same manner as when designing with carbon steel bars, except for the details specified in 4.2 "Concrete cover" and 4.3 "Splices."

4.2 Concrete cover

(1) The thickness of concrete cover shall be determined by taking into account the strength of the bond between stainless steel bars and concrete, durability, and fire resistance. Because the strength of the bond and fire resistance in the case of stainless steel bars are comparable to the values when carbon steel bars are used, the thickness of concrete cover required to meet these performance measures may be set in conformance with the Specifications (Design).

(2) The thickness of concrete cover to be determined from a durability point of view shall meet the requirements of the verification regarding durability in Chapter 3 and shall be not less than the minimum thickness of concrete cover specified in the Specifications (Design).

[Commentary]

(1) The performance requirements for the cover concrete over stainless steel bars are not different from those of concrete over carbon steel bars. Commercially available stainless steel bars are of similar shape to carbon steel bars and the bond strength of stainless steel bars is comparable to that of carbon steel bars. Judging from the mechanical properties of available stainless steel bars, fabrication errors, including bending, are also comparable to those in the fabrication of carbon steel bars. Accordingly, the thickness of concrete cover required to meet these performance requirements may be determined as in the case of carbon steel bars.

(2) Stainless steel bars are more resistant to corrosion than carbon steel bars and offer advantages in applications in corrosive environments. In such environments, the thickness of concrete cover is determined in accordance with the durability verification specified in Chapter 3. When the thickness of concrete cover is particularly thin, situations where the preconditions of the verification are not satisfied may occur. For example, unexpected cracking or deterioration of the cover concrete may happen.

Therefore, even if the durability verification indicates that the thickness of concrete cover can be decreased, the minimum thickness shall be not less than that specified in the Specifications (Design).

4.3 Splices

(1) As a general rule, a method of splicing that has been experimentally verified shall be used as mechanical splice of stainless steel bars.

(2) When lapped splices are used for stainless steel bars, the location and length of the splices may be determined in a similar manner to those for carbon steel bars.

(3) As a general rule, welded or gas-pressure welded splices shall not be used with stainless steel bars.

[Commentary]

(1) It is necessary to confirm that mechanical splices used for stainless steel bars meet the performance requirements in accordance with the Recommendations for Design, Fabrication and Evaluation of Anchorages and Joints in Reinforcing Bars [2007]. In this case, durability, as well as the strength characteristics, of the mechanical splices needs to be confirmed. One type of mechanical joint for which performance has already been verified is the mortar-grouted sleeve joint using a stainless steel sleeve (Reference Volume I Chapter 1). The stainless steel sleeve should be of quality comparable to or better than that of the bar material.

(2) The bond between stainless steel bars and concrete is dependent on the lugs on the surface of the bars and can be evaluated in a similar manner as for carbon steel bars. The length of lapped splices specified in the Specifications (Design) may be taken as the length of lapped splices. In this case, consideration needs to be given to the use of stainless steel wire in connecting stainless steel bars to each other so as not to impair durability.

(3) Stainless steel bars are also used widely for welded structures. However, the resistance of the welds to corrosion may be affected depending on the welding methods, materials, conditions, and procedures used. There are a greater number of important considerations to obtain good weld properties with stainless steel than with carbon steel. For this reason, splices between stainless steel bars shall not, as a general rule, be welded. The same goes for gas-pressure welded splices.

Chapter 5 Construction

5.1 General

Requirements for construction aside from those specified in this chapter shall conform to the Specifications (Construction).

[Commentary]

Various tests have verified that concrete made using stainless steel bars exhibits mechanical performance comparable to that of concrete made with carbon steel bars. Further, stainless steel is a highly durable material and stainless steel bars can be handled similarly to carbon steel bars in all construction phases. Accordingly, construction requirements aside from those specific to stainless steel bars as specified in 5.2 shall conform to the Specifications (Construction) just as for carbon steel bars.

5.2 Reinforcement work

5.2.1 Reinforcement work of stainless steel bars

(1) Stainless steel bars may be bent similarly to carbon steel bars.

(2) Bent stainless steel bars shall not be straightened.

(3) As a general rule, stainless steel bars shall not be welded.

[Commentary]

(1) It has been experimentally verified that the material properties of stainless steel bars, such as corrosion resistance, are not impaired even if they are bent in a similar manner to carbon steel bars, as provided for in Reference Volume II Chapter 2. For this reason, stainless steel bars may be bent similarly to carbon steel bars.

(2) This requirement is prescribed to avoid impairing the properties of the stainless steel if bent steel bars are straightened. If unavoidable, it is permitted to straighten a bent carbon steel bar by appropriately heating it. However, there is insufficient data about such straightening of stainless steel bars. For this reason, the straightening of stainless steel bars is prohibited.

(3) For the reasons described in 4.3, stainless steel bars shall not be welded as a general rule. If stainless steel bars do have to be welded, it is necessary to carefully examine the effects of the welded stainless steel bars on the structure, including its durability, and weld the stainless steel bars based on welding management methods that conform to Reference Volume II Chapter 2 "Welding of stainless steel."

5.2.2 Placing of stainless steel bars

(1) Stainless steel bars shall be tied to each other firmly using stainless steel wires not less than 0.8 mm in diameter.

(2) As a general rule, tie bars to be used for the placing of stainless steel bars shall have a corrosion resistance comparable to or greater than that of the stainless steel bars themselves.

[Commentary]

(1) Stainless steel bars are highly resistant to corrosion and often used in corrosive environments. If annealed iron tie wires, as used to tie carbon steel bars, were to be used for stainless steel bars, the iron tie wires would corrode before the stainless steel bars. This would have an adverse effect on the aesthetic appearance and durability of the structure. For this reason, a material having a corrosion resistance comparable to or greater than that of the stainless steel bars shall be used when tying them.

(2) As with (1) above, if tie bars corrode before the stainless steel bars, there will be adverse effects on the aesthetic appearance and durability of the structure. For this reason, tie bars used with stainless steel bars shall have a corrosion resistance comparable to or greater than that of the stainless steel bars themselves.

Chapter 6 Inspections

6.1 General

Requirements for the inspection of stainless steel bars aside from those specified in this chapter shall conform to the Specifications (Construction).

[Commentary]

The inspection of structures made using stainless steel bars is similar to that in the case of carbon steel bars and shall conform to the Specifications (Construction), excepting the inspection items that need special attention when using stainless steel bars, such as the acceptance inspections for stainless steel bar quality, bending and placing, and the splicing of stainless steel bars.

6.2 Acceptance inspection for stainless steel bars

(1) There shall be an inspection prior to construction to ensure that the stainless steel bars delivered to the construction site are of the selected type and strength class.

(2) The on-site acceptance inspection for stainless steel bars shall conform to Table 6.2.1 as standard.

Table 6.2.1 On-site acceptance inspection of stainless steel bars

Items	Testing and inspection methods	Timing	Acceptance criteria
Quality items prescribed by JIS G4322	Confirmation based on manufacturer's test data or the method prescribed by JIS G4322	When delivered	Conform to JIS G4322

[Commentary]

To confirm that the stainless steel bars delivered to the construction site are of the type and strength class on which the design of the structure is based, an advance inspection is necessary before carrying out construction work.

Generally, stainless steel bars are delivered to the construction site in a bundle to which an inspection certificate, type symbol, nominal designation, manufacturer (or manufacturer code), and other details are affixed. The recommendation is to verify that the type and strength class of the delivered stainless steel are as prescribed, that the diameter of the stainless steel bars be measured with a vernier caliper, and that the bars are visually inspected. In addition, it is important to confirm using the manufacturer's performance test report that the material (including chemical composition, mechanical properties, and corrosion resistance), shape, dimensions, and weight have passed inspections according to JIS G4322.

6.3 Reinforcement work

(1) In inspecting the bending and placing of stainless steel bars, it shall be verified that the stainless steel bars have not been straightened or welded, and that tie wires and tie bars of corrosion resistance comparable to or greater than that of the stainless steel bars have been used.

(2) It shall be checked that stainless steel bars are spliced in appropriate positions by the appropriate method.

[Commentary]

(1) Because stainless steel bars are bent and placed similarly to carbon steel bars, inspection items except those that need special attention when using stainless steel bars shall conform to the Specifications (Construction).

As well as checking the points that need special attention when stainless steel bars are used, it is also important to check the layout of stainless steel bars for any mistakes in structures where both stainless and carbon steel bars are used.

If the inspection shows that the bending or placing of stainless steel bars is improper, the problems shall be corrected appropriately. In this case, also, bars must not be straightened.

(2) In inspecting splices between stainless steel bars, it shall be confirmed that stainless steel bars are spliced using a method for which the performance has already been verified. In addition, in checking the splicing of stainless steel and carbon steel bars, it is especially important to confirm that the splices are in the right positions.

Chapter 7 Construction records

7.1 General

(1) During construction, construction records shall be kept of the processes used for concrete work, manufacturing and construction conditions, curing methods, weather conditions and air temperature on the day of construction, and the results of quality control and inspections. Of these records, the necessary data shall be selected and retained as the construction records. The type of stainless steel bars used, the type of carbon steel bars used in combination with the stainless steel bars, and the thickness of concrete cover over stainless and carbon steel bars shall be recorded in detail.

(2) Requirements for construction records aside from those specified in this chapter shall conform to the Specifications (Construction).

[Commentary]

(1) Construction records serve as a basis for the maintenance of structures and the advancement of technology. They include:

(i) Records of the quality of the concrete: mix proportion, materials, results of quality control and inspection, name of ready-mixed concrete plant, and others

(ii) Records of concrete work: work volume, construction method, date, time of concrete placement, air temperature, humidity, pump model, pumped distance, feed pipe diameter, concrete pump operating company, number of workers and construction organization, curing method and period, and others

(iii) Results of material inspections: results of acceptance tests for concrete (including slump, air content, strength of test specimen, chloride ion content), results of acceptance tests for steel reinforcement, the type of stainless steel bar in particular

(iv) Results of inspection for the thickness of concrete cover: the thickness of concrete cover over stainless and carbon steel bars, when used in combination

(v) Results of inspection for structural concrete: includes the results of estimation of concrete strength by the rebound hummer, and others

(vi) Results of work progress inspection: includes the results of examination of cracking, if it occurs

(vii) Presence/absence of initial defects and repairs: cold joints, honeycombing, and others

(viii) Other special notes: details of changes regarding the quality of concrete and construction, and others

In addition to the construction records, the major specifications of the structure, design documents, the scheme of execution, in-process and completion inspection reports, and others are necessary and need to be retained for the maintenance of the structure. The records need to be arranged and retained in a manner that makes them easy to reference for maintenance.