Standard Specifications for Steel and Composite Structures

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Japan Society of Civil Engineers

NISHIKAWA Kazuhiro
Chairman, Committee on Steel Structures

NAGAI Masatsugu
Chairman, Subcommittee on Standard Specifications for Steel and Composite Structures

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はじめに

土木学会鋼構造委員会は、1971 年、土木工学における鋼材および鋼・合成構造に関する研究、調査を行い、学術・技術の進展に寄与することを目的として発足した。社会基盤を整備するための技術そのものが総合工学的であるため、鋼構造委員会の活動が学術・技術の進展に寄与してきたことは目立ちにくいものの、鋼構造物に要求される性能については時代の要請を常に意識してきた経緯がある。その意味で、技術の開発と技術の標準化を同時に行うこと、すなわち、鋼構造物を造ることと同時に技術規準を整備することが大切である。委員会の発足以来、多くの小委員会活動が技術規準類の整備に直接的あるいは間接的に関係してきたことがその証左である。

近年、技術規準類の国際化が図られ、技術規準の性能規定化が注目されている。性能規定化においては、透明性・説明責任の向上、コスト・環境負荷の縮減、品質・性能の確保などが基本要件である。鋼構造委員会では、世界の趨勢に遅れることなく、最新の技術を規準に盛り込むことを目標に、鋼構造物と合成構造物に関する統一的な学会規準を作成することを決めた。今回発行する鋼・合成構造標準示方書は、限界状態設計法に基づく性能照査型設計法として、鋼構造委員会で作成した始めての示方書である。欧米の技術規準が世界標準を目指している中で、この時期に性能照査型の標準示方書を完成させたことは大変意義深いと考えている。

このような標準示方書が全編完成した暁には、鋼構造の最新技術の現状のみならず、今後研究すべき箇所が明らかになり、鋼構造委員会が全力を挙げて目指すべき方向が明確になると思われる。社会基盤整備の中で、鋼構造物の果たす役割は今後とも大きい。このたび発刊する鋼・合成構造標準示方書はその役割の一端を担えるものと確信している。

最後に、標準示方書の作成を企画・運営された鋼・合成構造標準示方書小委員会の長井正嗣委員長ならびに山口栄輝幹事長をはじめとする標準示方書小委員会の委員各位、示方書の各編を担当された部会長ならびに幹事長をはじめとする部会委員各位に心からの謝意を表する次第である。また、示方書の内容について終始忌憚のないご意見をいただいた鋼構造委員会の委員各位に心からのお礼を申し上げる。

2007 年 3 月吉日

土木学会鋼構造委員会
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序

土木学会鋼構造委員会では、「鋼構造物設計指針 PART A 一般構造物」、「鋼構造物設計指針 PARTB 合成構造物」を 1987 年に出版している。

1988 年、鋼構造委員会の中に終局強度研究小委員会 (委員長　倉西　茂) が設けられ、終局強度に関わる研究成果の整理が行われた。その成果が鋼構造シリーズ 6「鋼構造物の終局強度と設計」として 1994 年に出版されている。これをベースとして鋼構造物設計指針 PART A の改定作業が鋼構造物設計指針小委員会 (委員長　西野文雄) により行われ、1998 年に第 2 版が発刊の運びとなっている。1994〜1997 年の 4 年間にわたり、終局強度研究小委員会に設けられた合成構造物の終局強度分科会 (主査　中井　博) において合成構造物の終局強度と設計に関する調査、研究が行われ、その成果をベースに PART B 第 2 版の改訂出版が行われた。当時、世界の趨勢は限界状態設計法へと大きく舵を取っており、極めてタイムリーな取り組みであったと考える。しかし、今、世界は限界状態設計法がグローバルスタンダードであり、北米、ユーロ圏では、限界状態設計法に基づく独自のコードがほぼ完成状態にある。以上のような世界情勢とともに、設計の自由度向上、構造の性能向上、競争力アップのために、従来の仕様規定型から性能照査型設計へのシフトが強く求められるようになっている。

このような変革の状況の中、鋼構造委員会では、2000 年に鋼構造物の性能照査型設計法に関する調査特別小委員会 (委員長　市川篤司) が発足し、グローバルスタンダード対応の、鋼構造を対象とした新しい設計フォーマットの姿、雛形の作成に着手し、その成果として、2004 年に委員会報告書「鋼構造物の性能照査型設計体系の構築に向けて」が出版された。この時点で、鋼構造委員会は、次世代のグローバル化対応設計フォーマットの基礎を構築したとの認識に至った。これを受ける形で、2004 年、鋼・合成構造標準示方書小委員会 (委員長　西村宣男) が発足し、最新の研究成果、知見の盛り込み、次世代対応の日本のプレゼンスを示す競争的な設計基準、すなわち性能照査限界状態設計法の作成に着手した。本標準示方書は、「総則編」、「構造計画編」、「設計編」、「耐震設計編」、「施工編」、「維持管理編」の 6 編で構成され、今回は、「総則編」「構造計画編」「設計編」を合本した形での出版となる。

本標準示方書は、合成桁ならびに合成桁とは切り離せない床版を扱う鋼・合成構造標準示方書である。合成桁は競争的な形式として世界に広く認識かつ多用されている構造であり、21 世紀のグローバルコンペティションを乗り切るには、この重要分野での日本のプレゼンスを示し、オリジナリティのある基準を独自に整備すること急務であるとの認識に基づくものである。そのため合成桁については、EC、AASHTO の設計条項の併記とあわせて我が国独自の研究成果を取り込んでいる。鋼桁の終局強度については、基本には「設計指針 PART A」を踏襲した形となっているが、照査式を部分係数法のフォーマットに書き改めるとともに性能照査規定型の記述としている点が特徴である。もとより、実構造物の設計にはその構造物の建設主体が認証した準拠すべき設計基準があり、それに準拠しなければならないことは言うまでもない。一方で、新構造に取り組む場合、準拠すべき基準が存在しない場合、また一層の性能向上、競争性のアップを目指した新しい設計手法の開発にあたり、本標準示方書が資することを祈っている。

最後になりましたが、出版にあたり、執筆を担当された委員各位に対し厚く御礼申し上げます。また、貴重なご意見、ご指摘を頂いた鋼構造委員会委員並びに鋼・合成構造標準示方書小委員会委員に対して厚く御礼申し上げます。杉山俊幸委員 (総則部会部会長)、市川篤司委員 (構造計画部会部会長)、依田照彦委員 (設計部会部会長) また、池田学幹事長 (構造計画部会)、野上邦栄幹事長 (設計部会) には具体的な作業の取り纏めにあたり、山口栄輝幹事長 (小委員会) には全体進行にあたり多大のご尽力を賜りました。重ねて厚く御礼申し上げます。

2007 年 3 月

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**：幹事

Part I General Principles

Standard Specifications for Steel and Composite Structures
【 General Principles 】

Contents

Chapter 1 General

1.1 Fundamental Philosophy

The fundamental philosophy of these specifications is that performance verification methods shall be applied to all of the structural planning, design, construction, and maintenance of steel and composite structures with full observance of engineering ethics at every stage.

【commentary】

1.2 Composition

These specifications comprise the following six volumes: General Principles, Structural Planning, Design, Seismic Design, Construction, and Maintenance.

【commentary】

1.3 Scope

These specifications shall be applied to the structural planning, design, construction, and maintenance of steel structures, composite girders, and composite columns. This scope is described as ”steel and composite structures” herein.

【commentary】

1.4 Design, Construction, and Maintenance Documents

(1) Design documents, drawings, construction procedure documents, maintenance documents, and all other relevant documents shall include a statement to the effect that compliance with relevant regulations has been fulfilled at every stage of structural planning, design, construction, and maintenance. These documents also shall be lodged.

(2) Design documents, drawings, construction procedure documents, maintenance documents, and all other relevant documents shall be presented in an appropriate manner that satisfies the requirements for official information and/or documentation. In the absence of specific requirements, the documents should be based on rules such as the Japanese Industrial Standards.

【commentary】

1.5 Terminology

The terminology used in these specifications is outlined in Table 1.5.1.

Table 1.5.1 Meaning of terms

Meanings of descriptive words and clauses	General examples for descriptive words and clauses
【Requirement】 something that must be satisfied according to these specifications	∼ shall (be) ∼ should (be) ∼ is to (be)
【Recommendation】 the most commendable choice among several alternatives	∼ shall preferably (be)
【Possibility】 one acceptable alternative	∼ may (be)

【commentary】

1.6 Skills and Responsibilities of Engineers

(1) Engineers who take part in the structural planning, design, construction, and maintenance of steel and composite structures shall be experts in the relevant field.

(2) Engineers who take part in the structural planning, design, construction, and maintenance of steel and composite structures should preferably be persons certified in the relevant field by public agencies.

(3) Engineers who take part in the structural planning, design, construction, and maintenance of steel and composite structure shall be responsible for ensuring public safety and benefit, preservation of the environment, other public interests.

(4) Engineers who take part in the structural planning, design, construction, and maintenance of steel and composite structure shall be accountable for both decisions made and performance-based verification evidence.

【commentary】

1.7 Structural Planning and Design Stage Reviews

Appropriate reviews should preferably be carried out in order to ensure that the technology and quality of the structural planning and design meet the requirements.

【commentary】

1.8 Terms and Definitions

Terms commonly used in these specifications are defined below.

(1) General terms relating to structural planning, design, construction, and maintenance

1) Performance-based design method: a design method in which there is no restriction on structural type and materials, design method, or construction method. The only requirement is that the designed structure meets the performance requirements. Specifically, it is a design method in which the specified performance of the structure is assured at each of the structural planning, design, construction, and maintenance stages once the objectives and functions of the structure have been clearly defined. That is, the performance of the structure is specified so as to fulfill its function.

2) Regulation-based design: a design method in which the structure or structural members are designed based on specific design codes that specify suitable procedures, such as design calculations, structural materials, and their sizes.

3) Deemed to satisfy regulations: regulations in which one or more solutions that are deemed to satisfy the performance requirements are illustrated. These regulations may be adopted in cases where the method of verifying structural performance is not necessarily specified. These regulations specify structural materials and their sizes, procedures such as design calculations that are empirically regarded as correct, and other factors.

4) Reliability-based design method: a design method in which the possibility of a structure/structural member reaching the limit state is estimated based on probabilistic theory.

5) Limit-state design method: a design method in which a limit state to be verified is clearly specified and partial-factor design is adopted as the verification format. The partial-factor design format is classified as a Level 1 verification format from the reliability-based design viewpoint. Strictly speaking, partial-factor design is not equivalent to limit-state design, although the two are sometimes regarded as equivalent in Japan.

6) Partial-factor design format: a design format incorporating certain partial factors in order to take into account uncertainties or scatter relating to actions, geotechnical parameters, structural member size, structural analysis method, etc.

7) Life-cycle cost: the total cost of structural planning, design, construction, maintenance, and demolition of a structure; in other words, the total amount invested over the complete life cycle of the structure.

8) Design working life: the assumed period for which a structure fulfils its intended purpose without major repair and within the scope of the initially established maintenance plan. Design working life is determined at the design stage. Initially planned regular inspections and repairs are continued throughout the design working life.

9) Durable lifetime: the period between entering service and the point in time at which the performance of the structure falls below requirements due to fatigue, corrosion, material deterioration, or other factors and the structure reaches its limit state.

10) Objective: a common expression of the reason for building the structure. It is often desirable for the objective to be expressed with the word 'client' or 'user' as the subject of the sentence.

11) Basic requirements: needs to be met relating to the basic use and function of structure, environmental conservation, and work safety. Requirements relating to size/space and

activities such as design and construction must be implemented based on the relevant laws.

12) Function: the role that a structure has to play in accordance with the objective.

13) Review: a process carried out by an authorized third-party institution in order to determine whether the design process, from determination of the objective to verification, is proper or not.

14) Authorization: the final determination by the third party brought in to perform a review.

15) Certification: the act of the third party institution issuing a certificate once the structural design is determined to be proper.

(2) Terms relating to performance

1) Performance: the behavior that the structure has to demonstrate in order to meet the objective or requirements.

2) Required performance: the performance that the structure has to demonstrate in order to meet the objective.

3) Performance item: the itemization of required performance. For each performance item, a verification index is set. The index generally includes a specified limit state.

4) Performance level: the level of performance that is required of each structure. Performance level is determined for each required performance depending on its necessity.

5) Safety: ability of a structure to protect the lives and assets of users and third parties.

6) Serviceability: ability of a structure to perform such that allowed degrees of user-experienced displeasure or unease are not exceeded.

7) Durability: ability of a structure or structural element to resist deterioration caused by repeated variable action and/or environmental action. In the case of steel and composite structures, corrosion of steel members caused by environmental action, fatigue phenomena caused by repeated variable action, and deterioration of concrete member materials and strength are considered.

8) Restorability: ease with which a structure can be restored to its originally specified performance level after undergoing assumed actions that lead to deterioration of its performance level.

9) Social and environmental compatibility: a measure of how a structure not only contributes to sound social, economic, and cultural activities but also minimizes stress on the surrounding social and natural environment.

10) Workability: a measure of how safe and assured construction work is during fabrication and erection.

11) Initial soundness: the requirement that a structure performs, upon completion, in line with the level intended at the design stage.

12) Maintainability: the ease of maintenance of a structure.

(3) Terms relating to limit state

1) Limit state: a state in which the structure or structural element no longer meets the required performance.

2) Safety limit state: a state resulting in collapse or other similar form of structural failure due to excessive deformation, displacement, vibration, or similar. The safety limit state is used as the limit state associated with structure safety. The term is often referred to as the "ultimate limit state" and so is used in the Seismic Design volume.

3) Serviceability limit state: a state that corresponds to conditions beyond which the specified service requirements for the structure or a structural element are no longer met. The serviceability limit state is used as the limit state associated with the serviceability

of a structure.

4) Repair limit state: a state in which continued use of a structure damaged by expected action is possible after repairs using currently available repair methods, carried out at reasonable cost, and carried out within a reasonable period. The repair limit state is used as the limit state associated with ease of repair. In the Seismic Design volume, the term "damage limit state" is used in place of "repair limit state".

5) Fatigue limit state: a state in which a structure or structural member suffers fatigue or failure as a result of repeating variable action. Fatigue limit state is used as the limit state corresponding to the fatigue durability of a structure.

(4) Terms relating to verification

1) Performance verification: activities performed in order to verify that the designed structure satisfies all of the performance requirements. When the limit-state design method is adopted, the judgment entails comparing response values S with the limit values of performance R.

2) Verification index: index used to express a performance item as a physical quantity. Verification indices are used in performance verification.

3) Response value (Demand) S : physical quantity representing the response of the structure to an action.

4) Limit value of performance (Capacity) R : allowable limit of physical response to a corresponding structural response. This value is determined based on the required performance level.

5) Statistical characteristic value: a value corresponding to the a priori specified fractile of the statistical distribution of a random variable such as a material property or action. The expected value and the mode of a random variable are regarded as statistical characteristic values.

6) Optimization: the process of obtaining an optimal solution such that the objective function, including required performance, performance item, etc. as subordinate variables, becomes a minimum or maximum under restraint conditions.

7) Partial factor: a factor assigned to each design value in order to consider its uncertainty. Five partial factors are generally used: an action factor, a material factor, a structural analysis factor, a structural member factor, and a structure factor.

8) Structure factor: a factor that takes into account the importance of the structural, social, and economic effects that failure of the structure would have.

(5) Terms relating to actions

1) Action: any effect that leads to deformation, displacement, constraint, or deterioration of a structure or structural element.

2) Load: an assembly of mechanical forces directly acting on a structure. The forces are converted from actions through the analytical model. A load is used as an input datum for design calculations of the stress resultant, stress, displacement, and so on.

3) Design value of action: a value obtained by multiplying the action factor by the characteristic value of the corresponding action.

4) Direct action: an assembly of concentrated or distributed mechanical forces acting on a structure.

5) Indirect action: the cause of deformations imposed on the structure or constrained in it.

6) Environmental action: mechanical, physical, chemical, or biological action that may cause deterioration of the materials constituting a structure.

7) Permanent action: action that is likely to act continuously throughout the design work-

ing life and for which variations in magnitude with time are small compared with the mean value.

8) Variable action: action for which the variation during the design working life is not negligible in relation to the mean magnitude and is not monotonous.
9) Primary variable action: one or one set of variable actions considered as the primary influences when load combinations are taken into account in performance verification work.
10) Secondary variable action: an action considered secondary among the variable actions and that is additive to the combination of primary variable action and accidental action.
11) Accidental action: action that rarely occurs on a structure over the design working life but which may cause serious damage if it does happen to occur.
12) Action modifying factor: a factor for converting the standard or nominal value of action into a characteristic value.
13) Action factor: a factor that takes into account the unfavorable deviation of statistical characteristic values of action, uncertainty relating to the action model, changes in action characteristics during the design working life, the influence of action characteristics on the relevant limit state of the structure, variations in environmental action, and so on.

(6) Terms relating to structural materials

1) Characteristic value of material strength: a value corresponding to an a priori specified fractile of the statistical distribution of material strength. The statistical distribution is determined based on statistical data obtained from standardized material strength tests.
2) Standard value of material strength: a value of material strength adopted in structural design specifications/standards other than "Standard Specifications for Steel and Composite Structures".
3) Material strength modifying factor: a factor for converting the standard value of material strength into a characteristic value.
4) Material factor: a factor that takes into account unfavorable deviation of statistical characteristic values of material strength, differences in material properties between experimental specimens and the real structure, the influence of material properties on the relevant limit state of the structure, changes in material properties over a given reference period, and so on.
5) Design value of material strength: a value obtained by dividing the characteristic value of material strength by the corresponding material factor.

(7) Terms relating to calculation of response value

1) Factor for structural analysis: a factor used to take into account the accuracy of structural analysis methods applied in the calculation of the stress resultant and similar, uncertainties relating to the modeling procedure used for the structure, and so on.
2) Design value of response: a value obtained by multiplying the factor for structural analysis by the response value. The response value is calculated by multiplying the values of actions by their corresponding action factors.

(8) Terms relating to calculation of limit value of performance

1) Structural member factor: a factor that takes into account the accuracy of structural resistance analysis methods applied in the calculation of load-carrying capacity, variations in structural member size, the importance of the role of the structural member, and so on.
2) Design limit value of performance: a value obtained by dividing the limit value of per-

formance by the structural member factor. The limit value of performance is calculated by using the design values of material strength.

【Commetary】

Chapter 2 Basis for Structural Planning, Design, Construction, and Maintenance

2.1 Purpose of Structural Planning, Design, Construction, and Maintenance

The most suitable type of steel and composite structure is selected and an outline of its dimensions is determined at the structural planning stage. Thereafter, the structure shall satisfy the required performance in all areas such as safety, serviceability, durability, restorability, social and environmental compatibility at every stage of design, construction, and maintenance throughout its design working life.

【commentary】

2.2 Verification of Performance

(1) At every stage of structural planning, design, construction, and maintenance, the required performance of a steel or composite structure shall be determined. In general, safety, serviceability, durability, restorability, and social and environmental compatibility are required to form part of the required performance.

(2) At the design stage, the performance level shall be demonstrated against each performance item corresponding to the relevant required performance. Performance verification shall be carried out for every performance item.

(3) In the performance verification of steel and composite structures, verification indices and their corresponding limit values of performance shall be determined first. Then, in general, a check as to whether the structural response value obtained through an appropriate numerical analysis method is less than or equal to each limit value of performance is carried out.

(4) Experimental confirmation or compliance with regulations relating to structural type, structural materials, etc. may be substituted for the verification method described in (3) above.

(5) At the structural planning and design stages, verification shall be performed such that the response value is less than or equal to the limit value of performance throughout both the construction period and the structure's working life. Specific verification methods are illustrated in the Structural Planning volume, the Design volume, and the Seismic Design volume.

(6) At the end of the construction stage, the just-completed structure shall meet the required performance as considered in its design. Specific verification methods are illustrated in the Construction volume.

(7) During the working life of a structure, an appropriate inspection or examination regime and suitable countermeasures against damage shall be selected so as to ensure that the required performance is satisfied. Specific verification methods are illustrated in the Maintenance volume.

【commentary】

2.3 Performance Level and Importance of Structure

Performance level shall be determined for the required performance corresponding to safety, serviceability, durability, restorability, and social and environmental compatibility. Performance level shall depend on the importance of the structure.

【commentary】

Part II Structural Planning

Standard Specifications for Steel and Composite Structures
【 Structural Planning 】

Contents

Chapter 1 General

1.1 Scope of Structural Planning

A structure shall fulfill its intended purpose, satisfy the conditions set by applicable laws and regulations, and be economic efficient. It shall also exhibit adequate safety, serviceability, durability, seismic safety, post-earthquake serviceability and restorability, social and environmental compatibility, and maintainability. Compliance with these requirements should be ensured through the structural planning process, in which an appropriate form and type of structure is selected and an outline, including major dimensions, should be developed.

【Commetary】

1.2 Considerations in Structural Planning

The structural planning process ensures that a structure fulfills its intended purpose and conforms to applicable laws and regulations. Economic efficiency, safety, serviceability, durability, social and environmental compatibility, maintenance, earthquake influence, and workability should be considered in the structural planning also considers. During the structural planning process, there shall be adequate consideration and comparison of alternative forms and types of structure.

【Commentary】

1.3 Supplementary Considerations in Structural Planning

In addition to the considerations prescribed in 1.2 above, the construction period and ground conditions shall be taken into account.

【Commentary】

Chapter 2 Constraints and Prerequisites in Structural Planning

2.1 Constraints Imposed by Laws and Regulations

Applicable laws and regulations shall be properly considered in the planning of a structure. If other structures impose restrictions, adequate consultation with related organizations shall be held, in addition to satisfying applicable laws and regulations.

【Commentary】

2.2 Prerequisites for Performance Verification

Prerequisites such as actions to be supported and design working life shall be considered from the structural planning stage of a new structure.

【Commentary】

Chapter 3 Economic Efficiency

3.1 General

Economic efficiency shall be taken into account in selecting the form and type of structure, and calculating the major dimensions.

【Commentary】

3.2 Methodology

Economic efficiency shall be considered in terms of initial cost and life-cycle cost.

【Commentary】

Chapter 4 Safety

4.1 General

Safety shall be considered in selecting the form and type of structure and in calculating major dimensions.

【Commentary】

4.2 Methodology

Safety shall be considered in accordance with Part 3, Chapter 6 ”Demand for Safety and Verification”.

【Commentary】

Chapter 5 Serviceability

5.1 General

Serviceability shall be taken into account in selecting the form and type of structure and in calculating major dimensions.

【Commentary】

5.2 Methodology

Serviceability shall be considered in accordance with Part 3, Chapter7 ”Required Serviceability Performance and Verification”.

【Commentary】

Chapter 6 Durability

6.1 General

Durability shall be taken into account in selecting the form and type of structure and in calculating major dimensions.

【Commentary】

6.2 Consideration of Fatigue Resistance

In principle, a type of structure that is properly considered for fatigue resistance shall be selected in consideration of durability.

【Commentary】

6.3 Consideration of Corrosion Resistance

In principle, specific methods of corrosion protection that offer adequate resistance shall be selected in consideration of durability.

【Commentary】

6.4 Consideration of Resistance to Material Deterioration

In principle, materials that have adequate resistance to deterioration shall be selected in consideration of durability.

【Commentary】

Chapter 7 Social and Environmental Compatibility

7.1 General

In selecting the form and type of structure, social and environmental compatibility shall be taken into account in principle.

【Commentary】

7.2 Consideration of Landscape

Landscape shall be properly considered in the consideration of social and environmental compatibility.

【Commentary】

7.3 Consideration of Noise and Vibration

Noise and vibration shall be properly considered in the consideration of social and environmental compatibility.

【Commentary】

7.4 Consideration of Environmental Impact Reduction

Reduction of environmental impact of the structure through effective resource utilization shall be properly considered in the consideration of social and environmental compatibility.

【Commentary】

Chapter 8 Maintenance

8.1 General

In selecting the form and type of structure, maintenance shall be taken into account so as to ensure that the intended performance is maintained after the start of service.

【Commentary】

8.2 Consideration of Potential Future Problems

Potential problems with the future maintenance of the structure shall be considered from the structural planning stage.

【Commentary】

8.3 Consideration of Maintenance Facilities

Maintenance facilities for the structure shall be considered from the structural planning stage.

【Commentary】

Chapter 9 Earthquake Influence

9.1 General

If earthquakes will have a dominant influence on the structure, their effects shall be considered in selecting the form and type of structure and in calculating the major dimensions.

【Commentary】

9.2 Selection of Seismic-Resistant Structural Type

In selecting the form and type of structure, local topography, geology, and ground conditions shall be considered as well as the structure's location. A type of structure that offers adequate seismic safety, post-earthquake serviceability and restorability under the prevailing conditions shall be selected.

【Commentary】

9.3 Consideration of Seismic Safety, Post-earthquake Serviceability and Restorability

(1) In order to consider seismic safety, post-earthquake serviceability and restorability, prospective earthquake motions and the importance of the structure shall be defined.

(2) Appropriate seismic performance shall be determined in accordance with the prospective earthquake motions and the importance of the structure, as determined in (1) above.

(3) The seismic safety, post-earthquake serviceability and restorability of the structure shall be ensured in compliance with the seismic performance requirements given in (2).

【Commentary】

Chapter 10 Constructability

10.1 General

In selecting the form and type of structure, workability shall be taken into account.

【Commentary】

10.2 Consideration of Workability during Shop Fabrication

The study of workability shall in principle include consideration of workability during shop fabrication.

【Commentary】

10.3 Consideration of Workability during Erection

The study of workability shall in principle include consideration of workability during on-site erection.

【Commentary】

Part III Design

Standard Specifications for Steel and Composite Structures
【 Deisgn 】

Contents

Chapter 1 General Provisions

1.1 Scope

This Design volume of the Standard Specifications for Steel and Composite Structures ("Specifications") describes the standard procedure for performance verification in the design of steel structures and composite girders ("steel and composite structures"). The Specifications also describe the structural details of the structure to be verified. The design step of verifying the effects of a large-scale earthquake (L2 earthquake) is described separately in the Earthquake-Resistant Design volume.

【Commentary】

1.2 Terms and Definitions

1.2.1 Commonly used terms

(1) General terms relating to design

1) Performance-based design method: a design method in which there is no restriction on structural type and materials, design method, or construction method. The only requirement is that the designed structure meets the performance requirements. Specifically, it is a design method in which the specified performance of the structure is assured at each of the structural planning, design, construction, and maintenance stages once the objectives and functions of the structure have been clearly defined. That is, the performance of the structure is specified so as to fulfill its function.
2) Regulation-based design: a design method in which the structure or structural members are designed based on specific design codes that specify suitable procedures, such as design calculations, structural materials, and their sizes.
3) Deemed to satisfy regulations: regulations in which one or more solutions that are deemed to satisfy the performance requirements are illustrated. These regulations may be adopted in cases where the method of verifying structural performance is not necessarily specified. These regulations specify structural materials and their sizes, procedures such as design calculations that are empirically regarded as correct, and other factors.
4) Reliability-based design method: a design method in which the possibility of a structure/structural member reaching the limit state is estimated based on probabilistic theory.
5) Limit-state design method: a design method in which a limit state to be verified is clearly specified and partial-factor design is adopted as the verification format. The partial-factor design format is classified as a Level 1 verification format from the reliability-based design viewpoint. Strictly speaking, partial-factor design is not equivalent to limit-state design, although the two are sometimes regarded as equivalent in Japan.
6) Partial-factor design format: a design format incorporating certain partial factors in

order to take into account uncertainties or scatter relating to actions??, geotechnical parameters, structural member size, structural analysis method, etc.

7) Life-cycle cost: the total cost of structural planning, design, construction, maintenance, and demolition of a structure; in other words, the total amount invested over the complete life cycle of the structure.
8) Design working life: the assumed period for which a structure fulfils its intended purpose without major repair and within the scope of the initially established maintenance plan. Design working life is determined at the design stage. Initially planned regular inspections and repairs are continued throughout the design working life.
9) Durable lifetime: the period between entering service and the point in time at which the performance of the structure falls below requirements due to fatigue, corrosion, material deterioration, or other factors and the structure reaches its limit state.
10) Objective: a common expression of the reason for building the structure. It is often desirable for the objective to be expressed with the word 'client' or 'user' as the subject of the sentence.
11) Function: the role that a structure has to play in accordance with the objective.
12) Review: a process carried out by an authorized third-party institution in order to determine whether the design process, from determination of the objective to verification, is proper or not.
13) Authorization: the final determination by the third party brought in to perform a review.
14) Certification: the act of the third party institution issuing a certificate once the structural design is determined to be proper.

(2) Terms relating to performance

1) Performance: the behavior that the structure has to demonstrate in order to meet the objective or requirements.
2) Required performance: the performance that the structure has to demonstrate in order to meet the objective.
3) Performance item: itemization of required performance. For each item, a verification index is set. The index, generally, includes a specified limit state.
4) Performance level: the level of performance that is required of each structure. Performance level is determined for each required performance depending on its necessity.
5) Safety: ability of a structure to protect the lives and assets of users and third parties.
6) Serviceability: ability of a structure to perform such that allowed degrees of user-experienced displeasure or unease are not exceeded.
7) Durability: ability of a structure or structural element to resist deterioration caused by repeated variable action and/or environmental action. In the case of steel and composite structures, corrosion of steel members caused by environmental action, fatigue phenomena caused by repeated variable action, and deterioration of concrete member materials and strength are considered.
8) Restorability: ease with which a structure can be restored to its originally specified performance level after undergoing assumed actions that lead to deterioration of its performance level.
9) Social and environmental compatibility: a measure of how a structure not only contributes to sound social, economic, and cultural activities but also minimizes stress on the surrounding social and natural environment.
10) Workability: a measure of how safe and assured construction work is during fabrication and erection.

11) Initial soundness: the requirement that a structure performs, upon completion, in line with the level intended at the design stage.
12) Maintainability: the ease of maintenance of a structure.

(3) Terms relating to limit state

1) Limit state: a state in which the structure or structural element no longer meets the required performance.
2) Safety limit state: a state resulting in collapse or other similar form of structural failure due to excessive deformation, displacement, vibration, or similar. The safety limit state is used as the limit state associated with structure safety. The term is often referred to as the "ultimate limit state" and so is used in the Seismic Design volume.
3) Serviceability limit state: a state that corresponds to conditions beyond which the specified service requirements for the structure or a structural element are no longer met. The serviceability limit state is used as the limit state associated with the serviceability of a structure.
4) Repair limit state: a state in which continued use of a structure damaged by expected action is possible after repairs using currently available repair methods, carried out at reasonable cost, and carried out within a reasonable period. The repair limit state is used as the limit state associated with ease of repair. In the Seismic Design volume, the term "damage limit state" is used in place of "repair limit state".
5) Fatigue limit state: a state in which a structure or structural member suffers fatigue or failure as a result of repeating variable action. Fatigue limit state is used as the limit state corresponding to the fatigue durability of a structure.

(4) Terms relating to verification

1) Performance verification: activities performed in order to verify that the designed structure satisfies all of the performance requirements. When the limit-state design method is adopted, the judgment entails comparing response values with the limit values of performance.
2) Verification index: index used to express a performance item as a physical quantity. Verification indices are used in performance verification.
3) Response value (Demand) S: physical quantity representing the response of the structure to an action.
4) Limit value of performance (Capacity) R: allowable limit of physical response to a corresponding structural response. This value is determined based on the required performance level.
5) Statistical characteristic value: a value corresponding to the a priori specified fractile of the statistical distribution of a random variable such as a material property or action. The expected value and the mode of a random variable are regarded as statistical characteristic values.
6) Optimization: the process of obtaining an optimal solution such that the objective function, including required performance, performance item, etc. as subordinate variables, becomes a minimum or maximum under restraint conditions.
7) Partial factor: a factor assigned to each design value in order to consider its uncertainty. Five partial factors are generally used: an action factor, a material factor, a structural analysis factor, a structural member factor, and a structure factor.
8) Structure factor: a factor that takes into account the importance of the structural, social, and economic effects that failure of the structure would have.

(5) Terms relating to actions

1) Action: any effect that leads to deformation, displacement, constraint, or deterioration

of a structure or structural element.

2) Load: an assembly of mechanical forces directly acting on a structure. The forces are converted from actions through the analytical model. A load is used as an input datum for design calculations of the stress resultant, stress, displacement, and so on.
3) Design value of action: a value obtained by multiplying the action factor by the characteristic value of the corresponding action.
4) Direct action: an assembly of concentrated or distributed mechanical forces acting on a structure.
5) Indirect action: the cause of deformations imposed on the structure or constrained in it.
6) Environmental action: mechanical, physical, chemical, or biological action that may cause deterioration of the materials constituting a structure.
7) Permanent action: action which is likely to act continuously throughout the design working life and for which variations in magnitude with time are small compared with the mean value.
8) Variable action: action for which the variation during the design working life is not negligible in relation to the mean magnitude and is not monotonous.
9) Primary variable action: one or one set of variable actions considered as the primary influences when load combinations are taken into account in performance verification work.
10) Secondary variable action: an action considered secondary among the variable actions and that is additive to the combination of primary variable action and accidental action.
11) Accidental action: action that rarely occurs on a structure over the design working life but which may cause serious damage if it does happen to occur.
12) Action modifying factor: a factor for converting the standard or nominal value of action into a characteristic value.
13) Action factor: a factor that takes into account the unfavorable deviation of statistical characteristic values of action, uncertainty relating to the action model, changes in action characteristics during the design working life, the influence of action characteristics on the relevant limit state of the structure, variations in environmental action, and so on.

(6) Terms relating to structural materials

1) Characteristic value of material strength: a value corresponding to an a priori specified fractile of the statistical distribution of material strength. The statistical distribution is determined based on statistical data obtained from standardized material strength tests.
2) Standard value of material strength: a value of material strength adopted in structural design specifications/standards other than "Standard Specifications for Steel and Composite Structures".
3) Material strength modifying factor: a factor for converting the standard value of material strength into a characteristic value.
4) Material factor: a factor that takes into account unfavorable deviation of statistical characteristic values of material strength, differences in material properties between experimental specimens and the real structure, the influence of material properties on the relevant limit state of the structure, changes in material properties over a given reference period, and so on.
5) Design value of material strength: a value obtained by dividing the characteristic value of material strength by the corresponding material factor.

(7) Terms relating to calculation of response value
   1) Factor for structural analysis: a factor used to take into account the accuracy of structural analysis methods applied in the calculation of the stress resultant and similar, uncertainties relating to the modeling procedure used for the structure, and so on.

(8) Terms relating to capacity of structural member
   1) Structural member factor: a factor that takes into account the accuracy of structural resistance analysis methods applied in the calculation of load-carrying capacity, variations in structural member size, the importance of the role of the structural member, and so on.
   2) Design capacity of structural member: a value obtained by dividing the capacity by the structural member factor. Capacity is calculated by using the design values of strength materials.

1.2.2 Terms used in this Design volume

(1) Primary member: a member whose failure would directly lead to loss of stability and/or function and failure of the whole structure.

(2) Secondary member: a member that fulfills a secondary function and whose failure would not directly lead to loss of stability and/or function nor failure of the whole structure.

(3) Structural detail: a design method agreed in response to a part that cannot be designed by applying a design calculation method and/or to a request made regarding construction to be considered at the design stage. A structural detail is a necessary condition for guaranteeing appropriate prior conditions for the design calculations.S

【Commentary】

1.3 Notation

The following notation is defined for this specification. Only general notation is given.

(1) Action, sectional force, capacity and stress

F_k	Characteristic value of action
F_d	Design action
M	Bending moment
M_{sd}	Design bending moment
$M_1,\ M_2$	End moment
M_E	Lateral torsional buckling moment
M_u	Flexural capacity
M_{rd}	Design flexural capacity
M_y	Yield moment
M_p	Full plastic moment
$N,\ P$	Axial force
$N_u,\ P_u$	Axial capacity
N_{sd}	Design axial force
$N_{rd},\ P_{rd}$	Design axial capacity
$N_Y,\ N_y$	Yield axial force
V	Shear force
V_{rd}	Design shear capacity
T	Torsional moment

T_{sd}	Design torsional moment
T_{rd}	Design torsion capacity
$P_E,\ P_e$	Euler buckling load
f_k	Characteristic value of material strength
f_d	Design material strength
f_{yk}	Characteristic value of tensile yield strength
f_{yd}	Design yield strength
f_{uk}	Characteristic value of tensile strength
f_{ud}	Design tensile strength
f'_{yk}	Characteristic value of compressive strength
f'_{yd}	Design compressive strength
f_{vyk}	Characteristic value of shear yield strength
f_{vyd}	Design shear strength
σ	Normal stress
τ	Shear stress
σ_{rd}	Design local buckling strength
τ_{rd}	Design shear strength
σ_{cr}	Buckling stress
τ_{cr}	Shear buckling stress
$\sigma_E,\ \sigma_e$	Euler buckling stress
σ_r	Residual stress
σ_u	Ultimate stress
$\sigma_Y,\ \sigma_y$	Yield stress

(2) Displacement and strain

$u,\ v,\ w$	Displacement in x, y, z direction
ε	Axial strain
ε_y	Yield strain
γ	Shear strain
ε_{st}	Starting hardening strain
E	Modulus of direct elasticity
G	Modulus of rigidity
E_{st}	Initial strain hardening coefficient
ν	Poisson's ratio

(3) Geometrical values

A	Cross-sectional area
A_e	Effective cross-sectional area
$D = \dfrac{Et^3}{12(1-\nu^2)}$	Bending stiffness of plate
$L,\ \ell$	Member length
I	Geometrical moment of inertia
$I_{\omega\omega},\ C_\omega$	Bending torsional constant
J	St.Venant's torsional constant
$R = \dfrac{b}{t}\sqrt{\dfrac{\sigma_Y}{E}\dfrac{12(1-\nu^2)}{\pi^2 k}}$	Width-thickness ratio parameter
W	Sectional modulus
Z	Plastic sectional modulus
r	Radius of rotation (radius of gyration of area)
ℓ_e	Effective buckling length

ℓ_e/r	Slenderness ratio
b_e	Effective width of plate
t	Plate thickness
$\alpha = a/b$	Aspect ratio of plate (ratio of long side to short side)
k	Buckling coefficient
γ	Relative stiffness of stiffener
$\lambda = \dfrac{\ell_e}{r}\dfrac{1}{\pi}\sqrt{\dfrac{\sigma_Y}{E}}$	Slenderness ratio parameter

(4) Verification

$S,\ R$	Response value, Limit value (Resistance)
$S_d,\ R_d$	Design response value,Design limit value (Design resistance)
γ_i	Structural factor
γ_a	Structural analysis factor
γ_f	Action factor (load factor)
γ_b	Structural member factor
γ_m	Material factor

【Commentary】

1.4 Basis of Design

1.4.1 Purpose of design

Steel and composite structures shall be designed so that they satisfy the required performance in all areas such as safety, serviceability, restorability, durability, and social and environmental compatibility throughout their design working life.

【Commentary】

1.4.2 Verification of performance

(1) During design, the performance required for steel and composite structures shall be defined clearly. Generally, required performance shall be established in the areas of safety, serviceability, restorability, durability, and social and environmental compatibility .

(2) During design, a performance level shall be specified for each performance item and the performance level shall be verified for each performance item.

(3) In general, verification indexes and limit states for the indexes shall be established. The performance of the structure shall be verified such that the response calculated by appropriate numerical analysis does not exceed the limit states.

(4) For any verification not carried out by the method in (3) above, verification through experimental methods or adherence to specifications relating to structure details and materials can be considered a suitable means of performance verification.

(5) In verifying performance, it shall be verified that the response value does not exceed the limit value at any time during the construction period and the design life.

【Commentary】

1.4.3 Verification method

(1) Verification shall be based on the partial factor method on the basis of reliability theory and, as a standard design procedure, it shall be based on the limit-state design method.

(2) In general, verification shall be based on design responses to design actions, design limits as determined by design material strengths, and individual partial factors. The performance of the structure shall, in general, be verified using Equations (1.4.1) and (1.4.2):

$$\gamma_i \frac{S_d}{R_d} \leq 1.0 \tag{1.4.1}$$

$$\gamma_i \frac{\sum \gamma_a \cdot S(\gamma_f \cdot F_k)}{R(f_k/\gamma_m)/\gamma_b} \leq 1.0 \tag{1.4.2}$$

where, R_d : design resistance
f_k : characteristic value of material strength
γ_m : material factor
γ_b : structural member factor
$R(\cdots)$: function for calculating limit value of structure from material strength
S_d : design response
F_k : individual characteristic value of action
γ_a : structural analysis factor
γ_f : action factor corresponding to each action (load factor)
$S(\cdots)$: function for calculating response value of structure from action
γ_i : structural factor

(3) During design, a verification shall be carried out for every limit state that can be considered.

【Commentary】

1.4.4 Partial factors

(1) Partial factors in a verification shall be determined based on the concept given in (2) and (3).

(2) The material factor, structural member factor, structural analysis factor, and action factor shall be determined in consideration of 1) unfavorable deviations from characteristic values, 2) uncertainties in computational accuracy, and 3) discrepancies between design and practice with respect to actions or structures and materials.

(3) The structural factor shall be determined as per the provisions of Section 1.5 below.

【Commentary】

1.4.5 Modification factors

(1) The specification provides for two modification factors, namely a material modification factor and an action modification factor.

(2) The action modification factor shall be defined for converting a specified or nominal action value into a characteristic action value.

(3) The material modification factor shall be defined for converting a specified value of material strength into a characteristic value of material strength.

【Commentary】

1.5 Structural Factor

Structural factor γ_i shall be determined according to structural importance and also the social and economical impact of the structure reaching its limit state.

【Commentary】

Chapter 2 Actions

2.1 General

(1) In the design of steel and composite structures, actions expected to act on a structure during the construction period and during the design working life shall be determined according to the required performance.

(2) Actions are all causes of deformation, displacement, constraint, and deterioration of a structure or structural member, as indicated below.

- Direct action: an assembly of concentrated or distributed mechanical forces acting on a structure.
- Indirect action: the cause of deformations imposed on the structure or constrained in it.
- Environmental action: mechanical, physical, chemical, or biological action that may cause deterioration of the materials constituting a structure.

(3) A load is defined as an assembly of mechanical forces acting directly on a structure. These forces are converted from actions through the analytical model. A load acts as an input datum for design calculations yielding the stress resultant, stress, displacement, and so on.

【Commentary】

2.2 Kinds of Actions

(1) In the design of steel and composite structures, actions shall be properly determined in correspondence with the verification items and the relevant structural members.

(2) Actions are classified into three classes according to their characteristic occurrence frequency, duration, and fluctuation, as defined below.

- Permanent action: action that is likely to act continuously throughout a given reference period and for which variations in magnitude with time are small compared with the mean value.
- Variable action: action for which the variation in magnitude with time is neither negligible in relation to the mean value nor monotonic.
- Accidental action: action that is unlikely to occur with a significant value on a structure over a given reference period and which may cause a serious damage to a structure if it does happen to occur.

(3) Actions are classified into three classes according to the characteristics response of a structure to them, as defined below.

- Static action: action that does not cause significant acceleration of the structure or structural members.
- Dynamic action: action that may cause impulse acceleration or other significant acceleration of the structure or structural members.
- Repeating action: action that may result in fatigue damage.

【Commentary】

2.3 Combinations of Actions

In a typical case of structural design, the combinations of actions shown in Table 2.3.1 shall be considered. In a case where an unusual combination of actions might be anticipated, action combinations aside from those listed in Table 2.3.1 may be taken into consideration according to the judgment of the responsible chief engineer.

Table 2.3.1 Combinations of actions

Required performance	Combination of actions
Safety	Permanent actions+Primary variable actions+Subsidiary variable actions Permanent actions+Accidental actions+Subsidiary variable actions
Serviceability	Permanent actions+Variable actions
Durability	Permanent actions+Variable actions

【Commentary】

2.4 Action Values

2.4.1 General

(1) The values of permanent actions and primary variable actions that are considered when verifying safety against structural failure or collapse may be statistical characteristic values obtained as an a priori specified fractile of construction period and design lifetime largest or smallest value probability distribution. The accidental action value may be taken to be the previously occurring largest value. The value of subsidiary variable action shall depend on which action combination is taken into account.

(2) The action value considered when verifying serviceability shall be the value expected to be observed frequently during the construction period and the design working life. This value shall be determined depending on the required performance and the relevant action combination.

(3) The value of action considered when verifying durability shall be determined by taking into account the variability of action during the design lifetime.

【Commentary】

2.4.2 Dead load

(1) The dead load shall be the action caused by the weight of the structural elements and ancillary facilities themselves.

(2) The characteristic value of dead load shall be calculated by reading off the dimensions of structural members precisely and by evaluating the unit weight of the structural materials properly.

【Commentary】

2.4.3 Earth pressure

Earth pressure shall be determined according to the required performance by considering the type of structure, structural rigidity, and type of subsoil.

【Commentary】

2.4.4 Prestressing force

(1) In a case where prestress is to be introduced into the structure, both the prestressing force immediately after the prestress is applied as well as the effective prestressing force after losses shall be considered in design and these values shall be determined according to the required performance.

(2) If a statically indeterminate force is caused by prestress, it shall also be considered properly.

【Commentary】

2.4.5 Live load

The live load shall consist of the moving load of vehicles, railway loading, and sidewalk loading (including crowd loading). It shall be determined according to the required performance by considering the load variations.

【Commentary】

2.4.6 Impact load

The stress imposed by the live load shall be incremented to account for impact effects. The dynamic influence of vehicles moving over the structure shall be considered as one kind of impact. The value of the impact load shall be determined according to the required performance in consideration of the structure's span, design characteristics, etc.

【Commentary】

2.4.7 Flowing water pressure

(1) The value of flowing water pressure acting on a structure shall be determined according to the required performance in consideration of the type of structure and the shape of the structural members.

(2) When designing structures on which flowing water may act, the dynamic influence of the flow water shall be taken into consideration.

【Commentary】

2.4.8 Hydrostatic pressure

The value of hydrostatic pressure shall be determined according to the required performance by properly taking into consideration fluctuations in water level and the size of the structure.

【Commentary】

2.4.9 Buoyancy or uplift

(1) The value of buoyancy or uplift shall be determined according to the required performance by properly taking into consideration the pore water and fluctuations in water level.

(2) Buoyancy or uplift shall be assumed to act in the vertical direction and the severest case of uplift shall be assumed.

【Commentary】

2.4.10 Wind load

(1) The value of wind load shall be determined according to the required performance by properly taking into consideration the wind characteristics of the construction site, the type of structure, the shape of structural members, etc.

(2) Flexible structures or structural members, in particular, shall be designed in consideration of dynamic deformation or stress resulting from wind because they may be considerably influenced by wind vibration.

【Commentary】

2.4.11 Snow load

In the design of structures that are constructed in areas that receive snowfall, the value of snow load shall be determined according to the required performance by taking into consideration the snowfall characteristics and maintenance procedures.

【Commentary】

2.4.12 Braking force and acceleration force

Braking forces and acceleration forces act on a structure when vehicles and trains slow down or accelerate. The values of these forces are determined according to the required performance by properly taking into consideration the types of vehicles or trains and the characteristics of the structure.

【Commentary】

2.4.13 Centrifugal force

A structure carrying curved tracks shall be designed to withstand centrifugal force. The value of centrifugal force shall be determined according to the required performance by properly taking into consideration the type of train and the characteristics of the structure.

【Commentary】

2.4.14 Longitudinal load imposed by long welded rail

Where long welded rails are laid on a railway bridge, the mutual force resulting from differences between the behavior of the rails and the bridge under temperature changes shall be treated as a longitudinal load imposed by the long rails. The value of this longitudinal load shall be determined according to the required performance by considering the type of bridge, its length, the track type, the arrangement of bearings, etc.

【Commentary】

2.4.15 Lateral train load and transverse wheel thrust

A train crossing a bridge imposes a lateral load while the wheels cause a transverse thrust. The values of these forces shall be determined properly according to the required performance.

【Commentary】

2.4.16 Wave pressure

The value of wave pressure shall be properly determined according to the required performance by considering the type of structure, its shape, the water depth, and the wave characteristics.

【Commentary】

2.4.17 Erection-related force

Structures are generally designed in consideration of the structural system in place at completion, but this may differ from the system of load support during erection. The forces arising during erection shall be properly taken into consideration according to structural conditions during erection and erection procedure used.

【Commentary】

2.4.18 Collision force

A collision force might be imposed by a user of the structure, as in the case of a vehicle collision, by a third party as in the case of a ship impact, or through a natural phenomenon such as impact by driftwood, etc. The anticipated value of the collision force shall be determined according to the required performance in consideration of the location of the structure.

【Commentary】

2.4.19 Concrete shrinkage

(1) The characteristic value of concrete shrinkage shall be determined in consideration of the materials used, environmental conditions, the size of structural members, etc.

(2) In the design of statically indeterminate structures such as rigid frames and arches, concrete shrinkage may have a uniform effect on the cross section of the structure.

【Commentary】

2.4.20 Effect of concrete creep

(1) The characteristic value of concrete creep shall be determined in consideration of the materials used, environmental conditions, structural member size, concrete age at application of

stress, etc.

(2) In the design of statically indeterminate structures such as rigid frames and archs, concrete creep may have a uniform effect on the cross section of the structure.

【Commentary】

2.4.21 Effect of temperature changes

(1) The effect of temperature changes shall be determined according to the required performance by taking into consideration the type of structure, environmental conditions, the size of structural members, etc.

(2) The characteristic value of temperature change shall be determined as a rise and fall in temperature from an a priori specified temperature. In the design of statically indeterminate structures, temperature change may have a uniform effect on the cross section of the structure.

(3) In the case of a structure in which the temperature difference between structural members or between portions of the structure is not negligible, such differences shall be taken into account.

(4) In order to ensure a safe-side design, the characteristic value of temperature change when calculating the structure's stress resultant shall preferably be different from that used in determining the deformation of the structure.

【Commentary】】

2.4.22 Effects of displacement of supports and differential settlement

(1) Where displacement of a structure's supports and/or differential settlement is anticipated and if the effects of such movement on the structure might be significant, their effects shall be determined according to the required performance in consideration of the type of structure and subsoil conditions.

(2) The characteristic values of displacement of a structure's supports and/or differential settlement shall be determined carefully as they may have a considerable effect on the size and shape of structural members.

【Commentary】

2.4.23 Effect of earthquake

(1) Earthquake motion and all actions resulting from earthquake motion shall be considered in the seismic design of a structure.

(2) In taking account of the direction of earthquake motion, it is preferable that two perpendicular directions on the horizontal plane be considered not independently rather than simultaneously. If necessary, earthquake motion in the vertical direction shall be considered according to the dynamic characteristics of the structure.

(3) Two classes of earthquake motion shall be used in verification, as follows.

① Level 1 earthquake motion that has a relatively high probability of occurring during the working life of the structure.

② Level 2 earthquake motion that is strong and has a relatively low probability of occurring during the working life of the structure.

(4) The worst-case effect of earthquake motion on the structure shall be determined by considering seismicity around the site of construction, characteristics of the hypocenter and propagation of earthquake motion, amplification characteristics depending on subsoil conditions at the site, etc.
(5) Generally, a time-history acceleration wave of earthquake motion shall be used for verification.

【Commentary】

2.4.24 Effect of airborne salinity

If required performance is determined in consideration of airborne salinity, the worst-case effect over the structure's working life shall be assumed by considering the site location, the materials used, etc.

【Commentary】

2.4.25 Effect of exhaust gases

In designing a structure located where traffic jams are common, the effect of exhaust gases shall be considered by taking into account traffic flow volumes and transportation system management.

【Commentary】

2.4.26 Effect of carbon dioxide concentration

If necessary, the effect of carbon dioxide (CO_2) concentration shall be considered as it might affect the neutralization of concrete.

【Commentary】

2.4.27 Effect of acid concentration

The worst-case effect of acid concentration on the structure over its design working life shall be determined by considering the site location, materials used, etc.

【Commentary】

2.4.28 Effect of drying and wetting

The effect of repeated drying and wetting shall be considered in the case that a structure is subject to extremely frequent dry-wet cycles, since cracks leading to deterioration of concrete members may result.

【Commentary】

2.4.29 Effect of sunshine

In the case that a steel structure has a required performance relating to painting for which the effect of sunlight is considered, the worst-case effect of sunshine over the design working life shall be determined by considering the site location, materials used, etc.

【Commentary】

2.4.30 Effect of freezing

In a case where repeated freezing and thawing might cause severe cracking in concrete members, the effect of freezing shall be considered properly.

【Commentary】

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2.4.31 Effect of fire

In a case where there is a possibility of the structure being exposed to high temperatures such as in a fire, their effects shall be considered properly.

【Commentary】

2.5 Action Factors

(1) An action factor is used to take into account any unfavorable deviation of the statistical characteristic value of an action, uncertainties relating to action modeling, changes in action characteristics over a given reference period, influence of action characteristics on the relevant limit state of structure, variations in environmental action, and so on. The actual design value of each action shall be obtained by multiplying the action value as defined in 2.4 by its corresponding action factor.

(2) Where combinations of actions are taken into consideration, the action factors described in (1) above shall be modified by a reduction factor in consideration of the probability of the simultaneous occurrence of multiple actions according to the judgment of the responsible chief engineer.

【Commentary】

Chapter 3 Materials

3.1 General

3.1.1 Fundamentals of material physical properties

Regarding basic physical properties, the materials used in steel and composite structures must satisfy the following requirements:

(1) Adequate strength and deformability, or toughness
(2) Resistance to change or deterioration in quality during the working life
(3) Minimum impact on the environment
(4) Minimum impact on human beings and animals/plants

【Commentary】

3.1.2 Required properties of materials

(1) The materials used in steel and composite structures must have properties that are sufficient to meet the required performance.
(2) Material properties must be described using measurable physical quantities and be consistent with the calculation model.

【Commentary】

3.2 Structural Steel

3.2.1 Required steel properties

(1) The mechanical properties, chemical composition, shape, and dimensions of structural steel must satisfy the structure's required performance.
(2) Structural steel conforming to standards such as ISO and JIS and that has a long history of use in past projects is deemed to satisfy requirement (1). Such material can be used once conformity with the standards is confirmed through inspection certificates.

【Commentary】

3.2.2 Selection of steel type

(1) The type of steel used for a steel or composite structure must be selected according to the required material properties, which depend on the stress state where used, environmental conditions at the site, corrosion protection method, construction method, and so on. The properties of interest include strength, ductility, toughness, chemical composition, shape, size, and surface characteristics.
(2) A variety of types of steel is available depending on the requirements of quality control, workability, labor-saving, etc.. The selected material shall be demonstrated to have properties

that satisfy the objective through an appropriate procedure such as testing.

【Commentary】

3.3 Concrete

(1) The strength, ductility, and workability of concrete must be of specific quality suitable for construction.
(2) Ready-mixed concrete shall conform to JIS A 5308 in principle.

【Commentary】

3.4 Value of Material Properties for Design

3.4.1 General

(1) The quality of steel or concrete is expressed not only in terms of tensile or compressive strength but also through other material properties such as strength, deformation, heat, durability, or water tightness according to design needs. Appropriate consideration must be given to the influence of loading rate on strength and deformation properties.
(2) The characteristic value of material strength, f_k, should be selected such that most test values fall above it.
(3) Design material strength, f_d, is given by the characteristic value of material strength, f_k, divided by the partial factor for the material, γ_m.

【Commentary】

3.4.2 Structural steel

(1) Strength
  1) The characteristic values of tensile yield strength, f_{yk}, and tensile strength, f_{uk}, should be determined based on values obtained through tensile tests.
  2) The guaranteed value shall be taken as the characteristic value, f_{yk} and f_{uk}, for a material conforming to a standard such as ISO or JIS. In general, the nominal value of cross sectional area shall be used for design calculations.
  3) The characteristic value of compressive yield strength, f'_{yk}, shall be considered to be equal to that of tensile yield strength, f_{yk}.
  4) In general, the characteristic value of shear yield strength shall be obtained using Equation (3.4.1).

$$f_{vyk} = \frac{f_{yk}}{\sqrt{3}} \tag{3.4.1}$$

(2) Fatigue strength The characteristic value of fatigue strength shall be determined based on fatigue tests in which type of steel, shape, size, welding process, residual stress, fabrication errors, the histogram of applied stress range, and environmental conditions are taken into consideration.

(3) Stress-strain curve

1) An appropriate stress-strain curve should be determined according to the objective of the examination.

2) In verification for safety, the stress-strain curve shown in Figure 3.4.1 can be used.

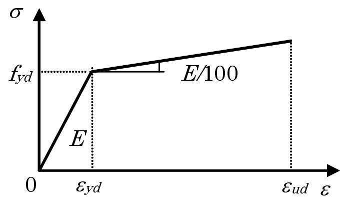

Fig.3.4.1 Stress-strain curve of steel

(4) Young's modulus

1) In principle, Young's modulus of the steel shall be determined through a tensile test conforming to a standard such as JIS Z 2241.

2) Young's modulus of steel can be generally taken as 205kN/mm^2.

(5) Poisson's ratio

Poisson's ratio of steel can be generally taken as 0.3.

(6) Coefficient of thermal expansion

The coefficient of thermal expansion of steel can be generally taken as 1×10^{-5}/℃.

【Commentary】

3.4.3 Concrete

The strength, stress-strain curve, Young's modulus, Poisson's ratio, and the other material properties of the concrete shall be determined through tests.

【Commentary】

3.5 Partial Factors for Materials

The partial factors for materials shall be properly determined in consideration of adverse variations in strength from characteristic values, variations between properties in specimens and actual structures, the influence of properties on limit states, changes in properties with time, and differences between real characteristic values and values assured by standards such as ISO and JIS.

【Commentary】

Chapter 4 Structural Analysis

4.1 General

(1) The structural analysis carried out must be relevant to the verification method used.
(2) It is important to note that structural analysis may not be always an appropriate means of verification.

【Commentary】

4.2 Structural Analysis Factor

(1) The value of the structural analysis factor, γ_a, shall be decided by taking account of various uncertainties, such as those involved in the structural analysis method and the structural model.
(2) In general, the structural analysis factor, γ_a, may be set to 1.0 in the case of linear analysis.
(3) In the case of nonlinear analysis, the relevance of the analysis method shall be verified first and then an appropriate value of structural analysis factor, γ_a, decided.

【Commentary】

Chapter 5 Structural Member Resistance

5.1 General

(1) The design resistance of structural members, as used in the verifications specified in Chapters 6∼10, shall be obtained by dividing the characteristic value of member resistance by the material partial factor.2

(2) The characteristic values of member resistance shall be determined using the characteristic values of material strength.

【Commentary】

5.2 Partial Factor for Uncertainty in Resistance

The partial factor for uncertainty in resistance (structural member factor) shall be determined in accordance with the formulas for calculating member resistance, while also taking into consideration uncertainty in the calculation method, the influence of member size variance, and the importance of the member (the influence of a member reaching the limit state on the structure as a whole).

【Commentary】

5.3 Steel Member Resistance

5.3.1 Tensile resistance

The tensile resistance of structural members shall be taken as the smaller of the values calculated by equations (5.3.1) and (5.3.2).

$$N_{rd} = \frac{A_g f_{yd}}{\gamma_b} \tag{5.3.1}$$

$$N_{rd} = \frac{A_n f_{ud}}{\gamma_b} \tag{5.3.2}$$

where, N_{rd} : design tensile resistance of the member
A_g : gross area of the cross section to be verified
A_n : net area of the cross section to be verified
f_{yd} : design yield strength
f_{ud} : design tensile strength
γ_b : structural member factor

【Commentary】

5.3.2 Compressive resistance

The compressive resistance of steel structural members in the axial direction shall be taken as the smaller of the resistance value for the strong axis and the weak axis calculated on the basis of the buckling curve in consideration of factors such as structural member imperfections, eccentric loading, residual stress, and variance in the yield strength in the cross section as well as the local buckling strength of plate elements constituting the member.

【Commentary】

5.3.3 Bending resistance

5.3.3.1 Classification of cross section

Structural members are classified as follows according to the maximum width-thickness ratio of the sectional element subject to bending or combined compression and bending (that is, the member's resistance to local buckling):

(1) Compact section: sections that may develop a plastic moment resistance

(2) Non-compact section: sections in which the stress in the extreme compression fiber of the steel, assuming an elastic distribution of stresses, may reach the yield strength, but local buckling is likely to prevent development of a plastic moment resistance

(3) Slender section: sections in which local buckling will occur before the yield stress is reached in one or more parts of the cross section.

【Commentary】

5.3.3.2 Bending resistance

The bending resistance of steel structural members shall be determined based on the nominal bending resistance corresponding to the classification of cross section, taking into account the influence of initial deflection and residual stress as well as elastic lateral-torsional buckling.

【Commentary】

5.3.4 Shear resistance of web

The shear resistance of the webs shall be determined properly in consideration of factors such as the constraining effect of flange and stiffeners, initial deformation, and residual stress due to welding.

【Commentary】

5.3.5 Local buckling resistance

(1) The local buckling resistance of plates supported at both ends or at one edge and of stiffened plates subject to compression shall be determined in consideration of factors such as boundary conditions and initial imperfections due to welding, including initial deformation and residual stress.

(2) Plates supported at both ends or at one edge and stiffened plates in locations with particular ductility requirements shall be of dimensions that guarantee the required ductility.

【Commentary】

5.4 Resistance of Steel Pipes

(1) The tensile resistance and compressive resistance of steel pipes shall be determined according to the provisions in 5.3.1 and 5.3.2.

(2) The bending resistance of steel pipes shall be determined on the basis of local buckling resistance against compressive stress in the axial direction, bending stress, or a combination of the two stresses.

(3) The shear resistance of steel pipes shall be determined in consideration of factors such as boundary conditions, initial imperfections due to welding, including initial deformation and residual stress, and whether the pipe is stiffened with rings or diaphragms.

【Commentary】

5.5 Resistance of Cables

The design resistance of cables shall be taken as the value calculated by equation (5.5.1).

$$N_{rd} = \frac{A_n f_d}{\gamma_b} \tag{5.5.1}$$

where, N_{rd} : design resistance of cables
f_d : design strength of the material
A_n : nominal cross sectional area of the cable
γ_b : structural member factor

【Commentary】

Chapter 6 Demand for Safety and Verification

6.1 General

(1) Safety shall be verified in consideration of all actions that might arise during the erection period and the design working life.
(2) Structural safety and public safety shall be the performance items verified to meet the safety requirement.
(3) An appropriate limit state shall be established for each performance item and safety shall be verified against the limit states of all performance items.

【Commentary】

6.2 Performance Requirement for Safety

6.2.1 Structural Safety

Steel and composite structures shall satisfy the requirements for load-carrying and displacement/deformation capacity and also shall be stable under the actions given in Chapter 2.

【Commentary】

6.2.2 Public Safety

The public shall be protected from any possible hazard that a steel or composite structure might pose throughout its service life.

【Commentary】

6.3 Verification of Structural Safety

6.3.1 Verification of load-carrying capacity

The verification of load-carrying capacity shall entail ensuring that the design action effect is smaller than the design member capacity.

【Commentary】

6.3.1.1 Verification of load-carrying capacity of members in framed structure

The load-carrying capacity of a structural member in a framed structure shall be verified for all applicable cases among the following:

(1) axial force
(2) bending moment
(3) combined axial force and bending moment

(4) shear force or a combination of shear force and torsional moment
(5) combined axial force, bending moment, and shear force
(6) biaxial stress in the above five cases when significant

【Commentary】

6.3.1.2 Verification of load-carrying capacity of plate

(1) The load-carrying capacity of a plate shall, in principle, be verified for normal stress and shear stress using the following equations. These stress components shall be obtained from forces and/or moments acting in the cross section.

$$\gamma_i \frac{\sigma}{\sigma_{rd}} \leq 1.0 \tag{6.3.1}$$

$$\gamma_i \frac{\tau}{\tau_{rd}} \leq 1.0 \tag{6.3.2}$$

where, γ_i : structural factor
σ : maximum normal stress in the cross section
σ_{rd} : design strength
τ : maximum shear stress in the cross section
τ_{rd} : design shear strength

(2) The load-carrying capacity of a plate shall be verified for all applicable cases among the following:
1) in-plane forces
2) out-of-plane forces
3) combined in-plane and out-of-plane forces
4) stiffened plate subjected to in-plane forces
5) a steel pipe subjected to a combination of forces in the transverse section

【Commentary】

6.3.2 Verification of Displacement/Deformation Capacity

A member required to have a particular displacement/deformation capacity shall be verified to ensure that the displacement/deformation due to actions will not exceed the limit state.

【Commentary】

6.3.3 Verification of Stability

(1) The stability of a structure with regard to rigid-body motion shall be verified for all possible transitional directions and rotations.
(2) The stability of a structure shall be verified by ensuring that the strongest action acting on the whole structure or part of the structure will not exceed its capacity.

【Commentary】

6.4 Verification of Structural Safety by Nonlinear Structural Analysis

Structural safety may be verified by evaluating the ultimate load-carrying capacity of the whole structure by nonlinear structural analysis.

【Commentary】

6.5 Verification of Structural Safety through Experiment

Structural safety may be verified by evaluating the effect of actions such as cross-sectional forces, stress and displacement, or load-carrying capacity experimentally.

【Commentary】

Chapter 7 Required Serviceability Performance and Verification

7.1 General

(1) Steel and composite structures must remain serviceable under the actions specified in Chapter 2 throughout their in-service period.
(2) Performance items related to serviceability include vehicle operating performance, train operating performance, and pedestrian comfort according to how the structure is utilized.
(3) Serviceability shall be verified for the limit state established for each performance item by setting proper verification indices representative of the performance item, except in cases where use of the structure is restricted or where the structure is rendered unusable due to meteorological conditions or earthquakes.

【Commentary】

7.2 Required Performance for Serviceability

7.2.1 Vehicle operating performance

Steel and composite structures shall be designed to provide safe passage of vehicles and to avoid undesirable psychological reactions among passengers in vehicles under the expected actions and meteorological conditions.

【Commentary】

7.2.2 Train operating performance

Steel and composite structures carrying railway tracks shall be designed to provide smooth passage of trains and to avoid undesirable psychological reactions among train passengers under the expected actions and meteorological conditions.

【Commentary】

7.2.3 Pedestrian comfort

Structures shall be designed to avoid undesirable psychological reactions among pedestrians under the expected actions and meteorological conditions.

It is recommended that structures be designed to provide safety and accessibility for all users, including the elderly and handicapped.

【Commentary】

7.2.4 Other Considerations for Users

Non-structural aspects of structures, including aesthetics and water-tightness, shall also be designed to avoid undesirable psychological reactions among users under the expected actions and meteorological conditions.

【Commentary】

7.3 Verification of Serviceability

7.3.1 Verification of vehicle operating performance

Vehicle operating performance under normal, wet, windy, and winter conditions shall be verified in principle as specified below.

(1) Verification of vehicle operating performance under normal conditions Performance requirements for vehicle operating performance under normal conditions shall be road surface soundness, stiffness, and operating visibility. Assessments shall be as follows.
Road surface soundness: Road surface flatness and friction coefficient shall meet a specified criterion for each item.
Stiffness : Deformation due to live load shall not be greater than a specified criterion.
Operating visibility : Visibility shall be the minimum required for the design velocity.

(2) Verification of vehicle operating performance under wet conditions
Vehicle operating performance under wet conditions shall be verified by confirming that the surface drainage system has a capacity be greater than a predetermined level of rainfall.

(3) Verification of vehicle operating performance under windy conditions
Vehicle operating performance under windy conditions shall be verified by confirming that the wind velocity over the structure is less than the specified criterion or that a speed limit dependent on wind velocity is imposed.

(4) Verification of vehicle operating performance under winter conditions Vehicle operating performance under winter conditions shall be verified by confirming that the floor slab selected is less prone to icing or that anti-freezing measures are adopted.

【Commentary】

7.3.2 Verification of train operating performance

The train operating performance and ride comfort of steel and composite structures that carry railway tracks shall, in principle, be verified under normal conditions as specified below.

(1) Verification of train operating performance under normal conditions
Train operating performance under normal conditions shall generally be verified by confirming that structure displacement as determined through static analysis is less than a criterion determined from the viewpoint of an operating safety limit.

(2) Verification of ride comfort
Ride comfort under normal conditions shall generally be verified by confirming that structure displacement as determined through static analysis is less than a criterion determined from the viewpoint of a ride comfort limit.

【Commentary】

7.3.3 Verification of pedestrian comfort

Pedestrian comfort under normal conditions shall, in principle, be verified in terms of pavement soundness, walking-induced vibration, and visibility as specified below.

(1) Verification of pavement soundness
Pavement soundness shall be verified by confirming that flatness is assured, slip resistance coefficient is within a range of a vibration index, and gradient is not greater than a specified criterion.

(2) Verification of walking-induced vibration
Walking-induced vibration shall be verified by confirming that vibration velocity and acceleration, which may affect walking comfort, are not greater than criteria specified for the natural frequencies of the structure or that the natural frequencies are outside the range of resonance.

(3) Verification of visibility
Pedestrian visibility shall be verified by confirming that visibility is not less than a specified criterion and that there is a large enough variation in brightness to allow discrimination of guidance block edges and stairway steps.

【Commentary】

7.3.4 Other considerations for verification

Other considerations for users shall be verified in principle using appropriate indices and related criteria.

【Commentary】

Chapter 8 Required Durability Performance and Verification

8.1 General

(1) Steel and composite structures must continuously maintain the required level of performance under the expected actions throughout the design working life.
(2) Performance verification items related to the durability of steel and composite structures include fatigue resistance, corrosion resistance, resistance to material deterioration, and maintainability.
(3) Verification of fatigue resistance, corrosion resistance, resistance to material deterioration, and maintainability must involve the setting of adequate indices representing performance item and verification of the limit state established for each item.

【Commentary】

8.2 Required Durability Performance

8.2.1 Fatigue resistance

Steel and composite structures must never suffer fatigue failure due to repeated loading during the design working life. Namely, the design must take into account fatigue resistance such that no steel member cracks or fails even if a crack is initiated and then propagates.

【Commentary】

8.2.2 Corrosion resistance

Steel and composite structures must maintain the required level of mechanical performance and function even if steel corrosion takes place under the expected environmental actions throughout the design working life. No failure of a steel member is allowed.

【Commentary】

8.2.3 Resistance to material deterioration

Steel and composite structures must maintain the required performance level with respect to material deterioration throughout the design working life.

【Commentary】

8.2.4 Maintainability

Ease of repair must be considered against time-dependent degradation of members due to fatigue, corrosion, and material deterioration throughout the design working life.

Ease of maintenance, covering repair and inspection, after entry into service must be considered.

【Commentary】

8.3 Verification of Durability

8.3.1 Verification of fatigue resistance

8.3.1.1 Verification of fatigue under repeated loading

The verification of fatigue under repeated loading must in principle involve using the following method. If another adequate verification method is available, it may be applied. Verification of fatigue under wind loading shall be in accordance with 8.3.1.2.

(1) It must be confirmed that no welded joints of low fatigue strength or for which quality control is difficult are used in fabricating steel members.

(2) For steel members, it must be confirmed whether the maximum stress range resulting from repetition of expected actions throughout the design working life is less than the fatigue limit (cut-off limit).

(3) In a case where the maximum stress range is greater than the fatigue limit (cut-off limit) under the expected actions throughout the design working life, it must be confirmed that the cumulative fatigue damage is less than the threshold value for fatigue failure.

(4) In verifying the fatigue of concrete members, it must be confirmed that serviceability and mechanical performance are maintained under the expected actions throughout the design working life.

【Commentary】

8.3.1.2 Verification of fatigue under wind loading

Verification of fatigue under wind loading must in principle involve confirming that the wind velocity at which vortex-induced vibrations arise is greater than the design wind velocity or the amplitude of vortex-induced vibrations is less than a threshold value. If another adequate verification method is available, it may be applied.

【Commentary】

8.3.2 Verification of resistance to steel corrosion

Verification for resistance to steel corrosion must in principle involve using the following method. If another adequate verification method is available, it may be applied.

(1) In a case where the corrosion protection method consists of a surface coating such as paint, it must be confirmed that the specific coating selected is suitable for the particular corrosive environment.

(2) In a case the corrosion protection method is anything except natural weathering of the steel or a surface coating, it must be confirmed that the specific corrosion protection method selected is suitable for the particular corrosive environment.

Regarding corrosion of steel reinforcement in concrete, it must be confirmed that the concrete carbonation depth and the chloride ion concentration remain below the threshold values for the occurrence of steel corrosion.

【Commentary】

8.3.3 Verification of resistance to material deterioration

Verification of resistance to material deterioration must in principle involve using the following methods. If another adequate verification method is available, it may be applied.

(1) It must be confirmed that concrete has the required frost resistance by determining the dynamic elastic modulus and mass loss in freezing and thawing tests.

2) Regarding concrete corrosion due to chemical attack, it must be confirmed through accelerated tests, atmospheric exposure tests, or another adequate verification method that concrete deterioration does reach a tangible level or affect the required level of performance.

3) It must be confirmed that concrete has the required resistance to the alkali aggregate reaction (ASR).

4) In a case where a surface coating is applied to concrete, the waterproofing effect of the coating must be confirmed in consideration of maintenance planning.

【Commentary】

8.3.4 Verification of maintainability

Verification of maintainability must in principle involve determination at the design stage of ease of maintenance, including inspection and repair, throughout the design working life. If another adequate verification method is available, it may be applied.

【Commentary】

Chapter 9 Required Social and Environmental Compatibility Performance and Verification

9.1 General

(1) Steel and composite structures shall maintain their social and environmental compatibility under the actions specified in Chapter 2 throughout the construction and in-service periods.
(2) Performance items related to social and environmental compatibility include social compatibility, economic rationality, and environmental compatibility.
(3) Social and environmental compatibility shall be verified with respect to the limit state established for each performance item by setting a proper performance index representative of each performance item. However, in cases where there are difficulties in setting and verifying such limit states for social and environmental compatibility, society and environmental compatibility shall be verified by optimizing each performance item.

【Commentary】

9.2 Required Social and Environmental Compatibility Performance

(1) Steel and composite structures shall be designed to provide the functions required according to their importance.
(2) Steel and composite structures shall be designed to be safe and functional and to minimize both construction cost and life-cycle cost.
(3) Steel and composite structures shall be designed to avoid adverse effects on the surrounding social and natural environments resulting from vibration and noise, to minimize environmental impacts, such as CO2 emissions, throughout their life cycle, and to offer an aesthetic that does not provoke undesirable psychological reactions in people nearby.

【Commentary】

9.3 Verification of Social and Environmental Compatibility

9.3.1 Verification of social compatibility

Social compatibility shall be verified by confirming that the performance index representative of each performance item satisfies the limit-state requirements established for that performance item in consideration of the importance of the steel or composite structure.

【Commentary】

9.3.2 Verification of economic rationality

Economic rationality shall be verified by confirming that the life-cycle cost（LCC）of a steel or composite structure is minimized or that the life-cycle utility (LCU), including social, economic, and cultural utilities, is maximized. However, in a case where it is impossible to satisfy these conditions, economical rationality shall be verified by optimizing LCC or LCU.

【Commentary】

9.3.3 Verification of environmental compatibility

Environmental compatibility shall be verified by confirming that performance indices for vibration and noise, which might adversely affect the surrounding social and natural environments, environmental impacts such as CO_2 emissions, and landscape are less than the specified criteria. However, in a case where it is impossible to satisfy these conditions, environmental compatibility shall be verified by optimizing each performance item.

【Commentary】

Chapter 10 Structural Members in General

10.1 Structural Members

All structural members shall be designed with the simplest possible structure for convenience in fabrication, transportation, site erection, examination, painting, maintenance, repair, etc. Examination of critical stage of members is given in Chapter 6.

【Commentary】

10.2 General

10.2.1 Secondary stress

Secondary stresses in a structural member resulting from eccentricity, node rigidity, sudden sectional changes, floor girder deflection, floor framing deformation related to variations in member length, deflection under self-loading, etc. must be designed to be as small as possible.

【Commentary】

10.2.2 Stress concentration

Stress concentration must be considered in design where it influences notch sections or structural discontinuities in a structural member.

【Commentary】

10.2.3 Alternately stressed structural members

A structural member that is subjected to alternating compressive and tensile stresses must be designed for safety under each stress.

【Commentary】

10.2.4 Minimum plate thickness and corrosion

(1) The minimum thickness of a steel plate is assumed to be that which ensures no change occurs during processing, transport, and site erection and that allows for damage to the section by corrosion, wear, etc.

(2) Where a corrosion allowance [margin] is allowed, the plate thickness assumed in verifying safety shall be the original thickness reduced by this margin.

【Commentary】

10.2.5 Curved members

When a curved structural member is designed as a straight member, it is necessary to thoroughly examine any additional stresses added by the curvature.

【Commentary】

10.2.6 Dynamic wind-resistant design of structural members

Wind-induced vibration may arise in the following types of structural members as well as in bridge girders, so the need for dynamic wind-resistant design must be examined.

- Towers of cable-stayed bridges and suspension bridges
- Cables of cable-stayed bridges and hangers of suspension bridges
- Arch bridges and truss bridges with large slenderness ratios
- Pillar-shaped members with especially large slenderness ratios, such as lighting pillars

【Commentary】

10.3 Frame Members with Axial Tensile Force

10.3.1 Slenderness ratio of members

The maximum slenderness ratio of a tensile member shall be below a maximum value determined in consideration of structural characteristics.

【Commentary】

10.4 Frame Members with Axial Compression Force

10.4.1 Width-thickness ratio of plate subjected to compressive stress and stiffened plate

The maximum width-thickness ratio of a plate subjected to compressive stress or a stiffened plate is assumed to be determined in consideration of steel type and position of the plate. The strength of a plate subjected to compressive stress or a stiffened plate is given in Chapter 5 ”Strucutral Member Resistance”.

【Commentary】

10.4.2 Perforated plate

The minimum thickness of a perforated plate subjected to compressive stress shall be determined in consideration of the distance between welding lines and the distance from a welding line to a hole.

【Commentary】

10.4.3 Influence of eccentric bending moment

The influence of eccentric bending moment shall be considered when angle steel, T-steel, etc. is fitted on only one side of a gusset plate.T

【Commentary】

10.4.4 Slenderness ratio of structural members

The slenderness ratio of a compressive member shall be below the maximum width-thickness ratio determined in consideration of the characteristics of the structure.

【Commentary】

10.5 Frame Members with Bending

10.5.1 Width-thickness ratio of plate subjected to compressive stress and stiffened plate

The maximum width-thickness ratio of plate subjected to compressive stress or a stiffened plate is assumed to be determined in consideration of the type of steel and the position of the plate.

【Commentary】

10.5.2 Effective section

In calculating deflection, statically indeterminate force, etc., bending rigidity is defined in terms of effective section corresponding to the effective width of the flanges.

【Commentary】

10.5.3 Overlapping flange

Where a cover plate overlapping another plate acts as a flange, the detailed structure shall take into consideration 1) welding properties and stress flow, 2) stress distribution in the girder, 3) fatigue, etc..

【Commentary】

10.5.4 Effective section for shear forces

The effective section bearing shear forces shall be determined appropriately according to the sectional shape of the member.

【Commentary】

10.6 Steel Pipes

10.6.1 Radial thickness ratio

The maximum radial thickness of steel pipes shall be determined in consideration of local buckling. The strength of steel pipe members is given in ”5.5 Steel Pipes Strength”.

【Commentary】

10.6.2 Stiffened member

Steel pipe members shall have a structure that resists buckling or local transformation caused by shear and torsion.

【Commentary】

10.6.3 Node structure

Nodes and shoes, which bear concentrated loading, shall be of a structure that resists local transformation and transmits stress smoothly.

【Commentary】

10.6.4 Curved tube

When curved tubes are used, safety against additional stresses arising in curved sections and local buckling must be determined.

【Commentary】

10.6.5 Steel pipe connections

(1) Connections between steel pipes shall be of a design that ensures stress transmission, resists local transformation, and secures sufficient strength.

(2) Axial connections of steel pipes shall be direct joints using high tensile bolts or welds. However, if the performance demanded in Chapter 11 ”Joints” can be satisfactorily assured, flange joints are acceptable.

(3) In connecting a steel pipe to a structural member with a different axis, a gusset joint or branching joint shall be used.

【Commentary】

Chapter 11 Joints

11.1 General

Joints shall be of a design that remains safe for all actions anticipated during erection and throughout the design working life.

【Commentary】

11.2 Joint Safety Requirements

Requirements relating to the load-carrying capacity and deformation of joints shall be specified adequately so as to ensure the safety of the structure under the influence of all actions anticipated during erection and throughout the design working life.

【Commentary】】

11.3 Verification of Joint Safety

The safety of joints shall be verified by means of the following methods to confirm that the requirements of 11.2 are met during erection and throughout the design working life.

(1) Load-carrying capacity
It must be confirmed that the resistance of joints is sufficiently greater than the actions applied during erection and throughout the design working life to ensure the required load carrying capacity.

(2) Deformation
Standard procedure is to confirm that joint deformation during erection and throughout the design working life under all anticipated actions is less than the deformation requirements in consideration of required deformation capacity and also sufficiently below the safe degree of deformation.

【Commentary】

11.4 General Principles for Joints

11.4.1 Member joints

Structural details of joints between members shall be designed so as to satisfy the following requirements.

(1) Smooth transfer of load
(2) Avoidance of eccentricity
(3) Avoidance of undesirable stress concentration

(4) Avoidance of undesirable residual stress and secondary stress

【Commentary】

11.4.2 Mixed welded, high-strength bolted, and bolted connections

Where there is a mix of welded, high-strength bolted, and bolted connections, the propriety of such joints shall be judged in consideration of the load-transfer mechanism.

【Commentary】

11.5 Welded Connections

11.5.1 Requirements

(1) Welded connections that transfer load shall not be subject to failure under all actions anticipated during the design working life and should transfer forces securely and smoothly between members/elements.

(2) Weldability shall be taken into consideration.

【Commentary】

11.5.2 Safety verification of welded connections

(1) The safety verification of welded connections that transfer load shall be confirmed such that their resistance exceeds all actions and does not fall far below the resistance of the weld material and the member itself.

(2) Verification of weldability shall be confirmed through due consideration.

【Commentary】

11.5.3 Size of fillet welds and geometry and dimensions of welded connections

(1) The size and minimum effective length of each fillet weld shall exceed each the required design value in every case. The size of a fillet weld, taken as the heat-affected zone, shall be minimized.

(2) The geometry and dimensions of welded connections shall be designed in consideration of smooth load transfer, avoidance of undesirable secondary stress and deformation, and fatigue.

【Commentary】

11.6 High-Strength Bolted Connections

11.6.1 Requirements for safety of high-strength bolted connections

The requirements for the safety of high-strength bolted connections shall be specified such that the requirements given in 11.2 are satisfied.

【Commentary】

11.6.2 Safety verification of high-strength bolted connections

The safety of high-strength bolted connections shall be verified in accordance with 11.3.

【Commentary】

11.6.3 Design characteristic values for verification of connection safety

Design characteristic values for the verification of connection safety shall be specified appropriately in consideration of the load-transfer mechanism and the verification method used.

【Commentary】

11.7 Structural Details of High-Strength Bolted Connections

11.7.1 Bolts, nuts, and washers

(1) Friction-type connections

Properties of bolt, nut, and washer materials used for friction-type connections shall comply with those specified in JIS B 1186 (Japanese Industrial Standards). Further, bolts, nuts, and washers shall have sufficient resistance to delayed fracture. Appropriate axial force shall be applied at installation and the force shall not decrease significantly during the service life.

(2) Bearing-type connections

Standards for bolts, nuts, and washers used for bearing-type connections shall be as specified in JSS II 01-1981 (Japanese Society of Steel Construction Standards).

(3) Tension-type connections

Properties of the bolt material used for tension-type connections shall comply with those specified in JIS B 1186 (Japanese Industrial Standards). Further, bolts shall have sufficient resistance to delayed fracture. The appropriate axial force shall be applied at installation and the force shall not decrease significantly during the service life.

【Commentary】

11.7.2 Holes for bolts

The size of holes for bolts shall be determined in consideration of the corresponding load-transfer mechanism for the connection type as well as workability.

【Commentary】

11.7.3 Bolt length

(1) Bolts must be long enough to deliver firm contact force between the contact surfaces.

(2) Bolt threads in bearing connections shall not extend into the shear plane.

【Commentary】

11.7.4 Bolt spacing

The minimum bolt spacing shall be larger than the spacing required to allow tightening. The maximum spacing should not exceed the local buckling and corrosion-prevention requirements.

【Commentary】

11.7.5 End and edge distance

The minimum distance from the end or edge of a member to the centre of a bolt hole shall be larger than the value required to ensure that there is no end or edge failure because of tearing prior to bolt failure. The maximum distance from the end or edge of a member to the centre of a bolt hole shall not exceed the corrosion prevention requirements.

【Commentary】

11.7.6 Minimum number of bolts

At least two bolts are required per connection. Where a connection is subject to shear force, two rows of bolts, meaning a minimum of 4 bolts in total, are required.

【Commentary】

11.7.7 Filler plates

(1) In the case of friction connections where plates of different thicknesses are connected, filler plates should be installed to fill the design gap.

(2) Where it is impossible to install a filler plate, the slip resistance of the connection shall be reduced by means of an appropriate method.

(3) In choosing the thickness and material grade of the filler plate, corrosion prevention and protection from rust shall be considered in addition to the load-transfer mechanism.

【Commentary】

11.7.8 Angled and round washers

In a case where the bolt axis is not perpendicular to the surface of the connected member, or if the surface of the connected member is not flat, care shall be taken not to impose undesirable bending stress on bolts and washers.

【Commentary】

11.8 Bolted Connections

11.8.1 General

(1) Regular bolted connections shall be adopted in cases where there is no need for high-strength bolted connections.

(2) The standard use of bolted connections is for bearing-type or tension-type connections where

there is no axial force on the bolt.

【Commentary】

11.8.2 Bolts, nuts, and washers

The standard bolts, nuts, and washers used in bolted connections shall be as specified in JIS B1180, JIS B1181, and JIS B1256, respectively.

【Commentary】

11.8.3 Structural details

Structural details of bolted connections should be determined appropriately in the same way as those of high-strength bolted connections.

【Commentary】

11.9 Pin Connections

(1) Structural members joined by pin connections shall not move at the point of connection. Further, nuts should be secured to prevent pins coming loose. The influence of wear on rotation at the pin and pin-hole shall be minimized.
(2) Pin design shall include consideration of wear loss to the pin cross section.
(3) In designing a member with a hole for a pin, the safety of the connection shall be verified in consideration of the stress concentration adjacent to the hole.

【Commentary】

Chapter 12 General Considerations for Framed Structures

12.1 Scope

This chapter applies to the design of framed structures such as trusses, rigid frames, arches, and suspension structures.

【Commentary】

12.2 Member Section Design

12.2.1 General

The design of members comprising a framed structure is given in Chapters 5∼ 9 and Chapter 10.

【Commentary】

12.2.2 Design of truss members

12.2.2.1 Composition of sections

(1) Regarding sectional composition, the centroid of the section shall by preference be designed to line up with the center of the section as well as to fit in the frame line.

(2) In combining plates to form the section, joints shall be designed not only with right-left symmetry but also with up-down symmetry.

(3) Chord members carrying compressive forces, end pillars, diagonal braces at the intermediate supports of a continuous truss and similar members shall have a box section or π-shaped section in principle. The slenderness ratio relating to the radius of gyration of area about the vertical axis (out of truss plane), is smaller than the one of horizontal axis (in truss plane).

(4) In a box section, the cross-sectional area of plates oriented parallel to the truss plane shall in principle be more than 40% of the gross cross-sectional area.

【Commentary】

12.2.2.2 Effective buckling length of compression members

(1) In the truss plane

The effective buckling length of members can be taken to be the frame length.

(2) Out of truss plane

The effective buckling length of members can be taken to be the distance between support points when the member is supported effectively by out-of-plane components and in-plane components.

【Commentary】

12.2.2.3 Combined compression material

The combined compression materials consisting of the sectional steel and other members shall be designed as follows.

(1) Slenderness ratio of combined compression materials
The slenderness ratio in both strong and weak axes of combined compression materials shall be computed by a suitable method.

(2) Shear force according to buckling of combined compression materials
Every part of combined compression materials shall be designed to bear a shear force amounting to 2

(3) Structural details of combined compression materials
Structure details of combined compression materials shall be provided as appropriate.

【Commentary】

12.2.2.4 Member with direct load

When a load acts to the place besides nodes, bending moment will happen except axial force in the member. This is valued appropriately in consideration of itself.

【Commentary】

12.2.3 Design of rigid frame members

12.2.3.1 Effective buckling length

The out-of-plane and in-plane effective buckling lengths of frame members shall be computed by a suitable method.

12.2.3.2 Members with axial compression forces and bending moments

The method of safety examination for members subjected to combined axial compression forces and bending moments is given in Chapter 6.

12.2.3.3 Examination of composition of bending, axial forces, and shear forces

The method of safety examination for members subjected to bending, axial forces, and shear forces is given in Chapter 6.

12.2.3.4 Influence of foundation structure

The influence of rotation and relative movement of the foundation must be considered in the design.

【Commentary】

12.2.4 Design of arch members

12.2.4.1 Effective buckling length

The out-of-plane and in-plane effective buckling lengths of arch members shall be computed by a suitable method.

【Commentary】

12.2.4.2 In-plane load-bearing ability of arches

Arch members shall be designed as members subjected to combined axial compression forces and bending moments.

【Commentary】

12.2.4.3 Out-of-plane buckling of arches

The out-of-plane buckling of arches must be checked using a suitable method.

(1) Structures consisting of one main arch or two main arches (where the two main arches are smaller than the span) must be checked for safety against out-of-plane buckling.

(2) Out-of-plane buckling must be checked under the most dangerous loading conditions.

(3) The lateral structure and sway bracing of arches shall be designed according to the regulations given in 12.4.

【Commentary】

12.2.5 Calculation of effective buckling length by eigenvalue analysis

The effective buckling length of a member can be calculated by applying elastic eigenvalue analysis to the total structural system, as given by equations(12.2.1) and (12.2.2), if 12.2.2.2, 12.2.3.1, and 12.2.4.1 do not apply.

$$|K_E + \kappa K_G(N_i)| = 0 \tag{12.2.1}$$

$$\ell_{ei} = \pi\sqrt{\frac{(EI)_i}{\kappa N_i}} \tag{12.2.2}$$

Here, K_E : elasticity rigidity matrix of infinitesimal displacement theory.

K_G : geometric rigidity matrix in standard state

κ : eigenvalue

ℓ_{ei} : effective buckling length of member i (m)

$(EI)_i$: Bending rigidity of material of member i (kNm^2)

N_i : design axial force of member i obtained by structural analysis (kN)

【Commentary】

12.3 Checking of Overall Structure

The safety of framed structures such as trusses, rigid frames, and arches shall be checked not only in terms of each member and joint but also in terms of the whole structure.

【Commentary】

12.4 Constraint in Horizontal Direction

There shall be adequate rigid lateral structures and sway bracing structures to ensure stereoscopic functioning of trusses and arches.

【Commentary】

12.5 Maximum Camber

2.5 Maximum Camber

The maximum camber can be manufactured for structures with its completed shape inspected when assembled.

【Commentary】

12.6 Substructure Members

Members that have the characteristics of substructures, such as base portions of rigid-frame pillars, shall be designed in consideration of providing adequate design load capacity, corrosion prevention, and transfer of forces to foundations.

【Commentary】

12.7 Torsion on Iron Towers

Transmission line towers and other steel pillars subjected to torsion caused by unequal tension of strung wires shall be designed to withstand the torsion.

【Commentary】

Chapter 13 Plate Structures

13.1 General

(1) This chapter applies to the design of plate structures. Plate elements and stiffened plate elements should be designed according to Chapters 6 and 10. A structure that can be considered a frame structure shall be designed according to Chapter 12.

(2) The structural analysis of special structures to which this chapter does not apply shall be carried out under rational loading and support conditions.

(3) Structural details and both of loading and support conditions for structural analysis should be followed design engineer.

【Commentary】

13.2 Effective Width

The stress and flexural stiffness of girders and beams subjected to bending moments shall be calculated in consideration of the influence of shear lag by accounting for effective width.

【Commentary】

13.3 Steel Girder Web

A steel girder web subjected to both in-plane bending and shear loading can be expected to exhibit post-buckling strength. The influence of welding distortion, manufacturing stress, transportation, and construction should be considered in the design of the steel girder web.

【Commentary】

13.4 Out-of-Plane Loading or Combined Out-of-Plane and In-Plane Loading

(1) In stiffening a steel plate subjected to out-of-plane loading, the arrangement and stiffness of the stiffeners shall be defined such that both deflection and stress do not exceed limit values. The loaded safety performance of the stiffeners themselves shall be verified.

(2) In stiffening a steel plate subjected to combined out-of-plane and in-plane loading, the loaded safety performance shall be verified against each loading individually and the combined loading.

【Commentary】

13.5 Other Plate Structures

A rectangular plate structure of uniform shape and thickness shall be designed according to Chapter 6. Other plate structures shall be designed with careful attention to their particular mechanical characteristics.

【Commentary】

13.6 Load Concentration Points

Points of load concentration, such as supports, shall be designed by verifying safety under the concentrated loading.

【Commentary】

13.7 Beam-to-Column Connections

At beam-to-column connections, stress shall be transferred smoothly between beam members and column members. Further, beam-to-column connections shall be designed with careful attention to stress concentrations in the vicinity.

【Commentary】

13.8 Panel Connections

Panel connections shall be of the simplest structure possible to smoothly transmit membrane forces between panels. Further, in designing the structural details of panel connections, consideration shall be given to ease of connecting members and ease of maintenance work, such as inspection, drainage, cleaning, and so on.

【Commentary】

13.9 Cross Beams, Cross Frames, Lateral Bracing, and Diaphragms

13.9.1 General

(1) The structural details of steel girders shall be designed such that shape and stiffness of the structure are maintained and lateral loading is transmitted to the supports.

(2) Load concentration points in steel girder and truss structures shall be designed such that the shape of the structure is maintained and concentrated loads are properly transmitted.

(3) The geometric properties of cross frames and lateral bracing shall be designed in consideration of both structural rigidity and ease of construction.

(4) If all of the following criteria are met, the slenderness parameter of the member can be

designed according to the criterion given in Chapter 10,

- the bridge structure can be considered a plane structure with respect to the main girder or main structure.
- cross frames or lateral bracing do not act as principal members.
- cross frames or lateral bracing are installed as truss members.

【Commentary】

13.9.2 Cross beams

In a case where the slab is supported on several main girders, cross beams at the supports or load-distribution cross beams shall be fitted between the main girders.

【Commentary】

13.9.3 Cross frames

(1) At the supports of a deck bridge, end cross frames shall be fitted between the main girders or main structural members.

(2) Cross frames responsible for load distribution shall be designed as principal members.

(3) The cross frames of a skew bridge should be placed with careful attention to the analytical procedure and the production and construction process.

(4) If all of the following criteria are satisfied, the cross frame count can be reduced:

- structural rigidity is ensured for the whole structure such as in the case of a reduced main girder bridge
- the responsible design engineer has verified structural safety.

【Commentary】

13.9.4 Lateral bracing

(1) The structural details of a steel girder shall be designed to ensure lateral loading is transferred to the supports.

(2) If all of the following criteria are satisfied, the amount of upper lateral bracing can be reduced:

- the bridge is a deck bridge
- the orthotropic deck or concrete slab is connected to the main girder
- horizontal motion of the main girder is restrained.

【Commentary】

13.9.5 Diaphragms

(1) Diaphragms shall in principle be placed as follows.

- angled in a skew direction in the supporting part of a skew girder bridge
- perpendicular to the main girder in the intermediate section of a skew girder bridge.
- perpendicular to the main girder in a curved girder bridge.

(2) An opening, or manhole, shall be installed in the diaphragm if necessary.

【Commentary】

Chapter 14 Slab Design

14.1 General

14.1.1 Structural scope

This chapter applies mainly to designed slabs under out-of-plane actions.

【Commentary】

14.1.2 Design action

The design actions as stipulated in Chapter 2 shall be considered in the design of a slab to cope with variable actions such as a live load.

【Commentary】

14.1.3 Analytical procedure

(1) The analytical model shall be developed through the choice of an appropriate modeling range under appropriate boundary conditions.

(2) In principle, the slab part shall be extracted as a board structure in the analysis. Depending on the purpose of the verification, the slab shall be modeled as having a large influence on the stress state at the verification point.

(3) In modeling each structural member, an appropriate element shall be chosen in consideration of its structural characteristics.

(4) The value of each material physical property shall be made an appropriate value reflecting its behavior.

(5) The evaluation of the analytical results shall be based on the modeling conditions as appropriate.

【Commentary】

14.2 Safety

14.2.1 Safety of slab

(1) The slab shall be able to carry the load safely and directly, transmitting it to the supports.

(2) The slab shall be designed so as to secure safety with respect to the two performance items that follow.

① Safety in carrying the load directly

② Safety as the main structural member

【Commentary】

14.2.2 Out-of-plane shear

(1) Under out-of-plane shear, the slab shall be completely safe against punching shear at the loading point.
(2) Under out-of-plane shear, the slab shall be safe against shear at the supports.
(3) In the case of change of stress transmission mechanism, the safety of slab shall be considered under the influence of cyclic loading.

【Commentary】

14.2.3 Out-of-plane bending

(1) Under out-of-plane bending, the slab shall be completely safe against the appropriate calculated out-of-plane bending.
(2) In the case of according to proposed out-of-plane bending equation, it shall be necessary to note the coverage, the analytical condition, and accuracy and to carry out an appropriate correction if necessary.

【Commentary】

14.2.4 In-plane forces

(1) Under in-plane forces, the slab shall be safe with respect to functioning as part of the main structure. It shall also be safe against earthquake, wind, and temperature changes.
(2) When under in-plane forces caused by deformation of the slab supporting girder, the safety of the slab shall be considered of its influence.

【Commentary】

14.2.5 Safety verification of slab

The safety of the slab shall be verified in consideration of pre-determined factors. At minimum, the verification of slab safety should be evaluated as follows.
(1) General Part
(2) Overhanging part (Support point and Base of handrail)
(3) Girder end
(4) Opening

【Commentary】

14.3 Serviceability

14.3.1 Serviceability of slab

The serviceability of the slab shall be verified using three performance items as follows.
(1) Deformation of slab
From the point of view of users, the slab shall perform without deformation so as to provide safety and comfort for pedestrians and traffic.

(2) Vibration of slab
The slab shall perform without improper vibration under cyclic loading.
(3) Drainage of slab
The slab shall drain quickly, without water pooling on the slab surface.

【Commentary】

14.3.2 Serviceability verification of slab

According to section 7.3 ”Verification of Serviceability”, the serviceability of a slab should be verified using the following performance items.

(1) Deformation of slab
Deflection under live load and condition of the slab surface shall be within limits.
(2) Vibration of slab
The slab shall not resonate at the frequency of passing trucks.
(3) Drainage of slab
The slab shall drain quickly without water pooling on the slab surface.

【Commentary】

14.4 Fatigue Resistance

14.4.1 Fatigue resistance of slab

(1) The slab fatigue resistance under cyclic loading (live load and wind load) shall be assured for the whole of the design working life.
(2) The verification of slab fatigue resistance shall clarify the failure mechanism and examine the respective influence of out-of-plane shear and out-of-plane bending.
(3) The verification of slab fatigue resistance shall be based on the appropriate specifications for fatigue strength.

【Commentary】

14.4.2 Fatigue due to out-of-plane shear

(1) The slab shall exhibit durability against out-of-plane punching shear fatigue caused by wheel loading.
(2) The slab shall exhibit durability against out-of-plane shear fatigue around it’s the supports.

【Commentary】

14.4.3 Fatigue due to out-of-plane bending

(1) The slab shall exhibit durability against out-of-plane bending.
(2) Slab connection components shall exhibit durability against stress caused by out-of-plane bending.

【Commentary】

14.4.4 Influence of water

(1) A waterproof layer should be used to protect against infiltration of water from the slab surface, which could damage the fatigue resistance of the slab.
(2) If a waterproof -layer is not used, the slab fatigue resistance shall be verified in consideration of the influence of water on the slab.

【Commentary】

14.5 Corrosion Resistance and Resistance to Material Deterioration

The materials used for the slab of a steel or composite structure shall exhibit sufficient corrosion resistance and resistance to material deterioration.

【Commentary】

14.5.1 Resistance to steel corrosion

Steel components of the slab shall exhibit corrosion resistance.
(1) steel corrosion
(2) corrosion of steel used in the concrete

【Commentary】

14.5.2 Resistance to concrete deterioration

Concrete components of the slab shall exhibit sufficient resistance to material deterioration.
(1) Damage due to alkali-aggregate reaction
(2) Damage due to frost
(3) Damage due to Chemical action

【Commentary】

14.6 Slabs of Various Types

A slab shall be appropriately designed and then constructed in the field so as to perform as required with respect to each performance item.

【Commentary】

14.6.1 Reinforced concrete slab

An RC slab shall be designed such that it satisfies each performance item. Performance shall be considered as satisfied through the observing of appropriate structural details.
(1) Slab thickness

(2) Connection to main girder
(3) Execution precision
(4) Reinforcement at girder end

【Commentary】

14.6.2 Pre-stressed concrete slab

A PC slab shall be designed such that it satisfies each performance item taking into account construction by pre-casting or post-casting. Performance shall be considered as satisfied through the observing of appropriate structural details.

(1) Slab thickness
(2) Connection to main girder
(3) Connection between slabs
(4) Reinforcement at girder end

【Commentary】

14.6.3 Steel-concrete composite slab

A steel-concrete composite slab shall be designed such that it satisfies each performance item. Performance shall be considered as satisfied through the observing of appropriate structural details.

(1) Slab thickness
(2) Shear connector
(3) Reinforcement at girder end

【Commentary】

14.6.4 Orthotropic steel deck

An orthotropic steel deck shall be designed such that it satisfies each performance item. Performance shall be considered as satisfied through the observing of appropriate structural details.

(1) Thickness of steel deck
(2) Effective width

【Commentary】

Chapter 15 Design of Composite Girders

15.1 General

This chapter applies to steel-concrete composite girders forming a concrete deck connected to a steel section via shear connectors.

【Commentary】

15.2 Resistance of Composite Girder

15.2.1 Classification of cross sections

(1) For the calculation of bending resistance, cross sections of composite girders are classified in the same way as those for steel sections, as defined in Chapter 5: (a) compact, (b) non-compact, and (c) slender.

(2) Where a steel compression flange is effectively restrained from buckling by a concrete flange attached using a shear connector, the section may be classified in accordance with the width-thickness ratio of the compressive web plates.

(3) A composite girder under negative bending moment or a steel compression flange that is not restrained from buckling should be classified in accordance with the classification of steel sections defined in Section 5.3.3.1.

【Commentary】

15.2.2 Design bending resistance

The design bending resistance of a composite girder shall be determined by an appropriate method in consideration of the cross section classification of the compact, non-compact, or slender section.

【Commentary】

15.2.3 Verification of bending moment

The bending moment of a composite girder shall be verified using the following:

$$\gamma_i \frac{M_{sd}}{M_{rd}} \leq 1.0 \tag{15.2.1}$$

where, M_{rd} : design bending moment

M_{sd} : design bending resistance

γ_i : structural factor

【Commentary】

15.2.4 Shear resistance

The design shear resistance of a composite girder is equal to that of the steel girder used in the composite girder.

【Commentary】

15.2.5 Verification of shear

At the safety limit state, the section shall satisfy the following:

$$\gamma_i \frac{V_{sd}}{V_{rd}} \leq 1.0 \tag{15.2.2}$$

where, V_{rd} : design shear resistance , V_r/γ_b
V_{sd} : design shear moment
γ_i : structural factor

【Commentary】

15.2.6 Verification of combined bending and shear

When a bending moment and vertical shear act on a composite girder simultaneously, the combined action of the two resultant forces shall be considered.

【Commentary】

15.3 Structural Analysis and Resultant Force

Linear elastic analysis is the basic analytical method for structural design of composite girders. In the case of continuous composite girders, tensile cracking may take place in the concrete slab near an internal support. Accordingly, resultant forces should be calculated in consideration of the reduction in stiffness caused by this cracking. When the resistance to bending moment is expected to be the full plastic bending moment, attention must be paid to the redistribution of the resultant forces due to plasticity.

【Commentary】

15.4 Shear Connectors

15.4.1 General

(1) Shear connectors shall be verified to satisfy the requirements of each performance item.
(2) Shear connectors shall be designed at both the safety limit state and the fatigue limit state to ensure proper performance throughout the design working life.
(3) Shear connectors shall have sufficient deformation capacity to redistribute horizontal shear force between the concrete deck and the steel element. The redistribution of horizontal shear force is assumed at at the safety limit state.

(4) When two or more different types of shear connector are used within the same span of a beam, account shall be taken of the effect of any difference in the shear force-slip relationships.

【Commentary】

15.4.2 Type of shear connectors

(1) Shear connectors are the devices provided at the interface between the steel element and the concrete deck to resist interface shear.
(2) In principal, shear connectors should be mechanical devices that join the steel and the concrete. However, other types of shear connector may be used as long as their safety has been verified in the proper way.

【Commentary】

15.4.3 Ultimate limit state for shear connectors

The safety and durability of shear connectors shall be verified at the safety limit state and the fatigue limit state, respectively. The ultimate load is applied to verify the safety limit state, while the service load is used in verifying the fatigue limit state.

【Commentary】

15.4.4 Verification at safety limit state

At the safety limit state, the shear connectors shall satisfy both of the following requirements:

$$\frac{1}{1.1}\left(\gamma_i \frac{q_{sd}}{q_{rd}}\right) \leq 1.0 \qquad (15.4.1)$$

$$\gamma_i \frac{Q_{sd}}{Q_{rd}} \leq 1.0 \qquad (15.4.2)$$

where,
q_{sd} : horizontal design shear force per unit length
q_{rd} : horizontal design shear resistance per unit length
Q_{sd} : total horizontal design shear force over longitudinal length where the size, type, and spacing of shear connectors are constant
Q_{rd} : total horizontal design shear resistance of shear connectors provided over the length
γ_i : structural factor. For a standard structure, taken to be $\gamma_i = 1.0$.

【Commentary】

15.4.5 Verification at fatigue limit state

At the fatigue limit state, shear connectors shall satisfy the following requirement:

$$\gamma_i \frac{V_{sd}}{V_{rd}} \leq 1.0 \qquad (15.4.3)$$

where, V_{sd} : horizontal fatigue shear range of an individual shear connector
V_{rd} : horizontal fatigue resistance range of an individual shear connector
γ_i : structural factor

【Commentary】

15.4.6 Design resistance of shear connectors

This clause is applicable to (1) headed stud connectors, (2) perfobond ribs, and (3) block dowels. Other types of shear connector can be used provided that the design resistance has been appropriately determined through experiment or other methods.

15.4.6.1 Design resistance of headed stud connectors

(1) The design resistance of headed stud connectors should be determined using appropriate methods in consideration of the casting direction of the concrete.
(2) Where headed stud connectors are subject to tensile force in addition to shear force and the influence of the tensile force is not negligible, a more accurate method that takes account of the tensile force shall be used.
(3) Where the headed stud connectors are arranged in groups, the influence of the grouped arrangement shall be taken into consideration by an appropriate method.

【Commentary】

15.4.6.2 Design shear resistance of perforated bonds

(1) The design shear resistance of shear connectors using perforated steel plates shall be evaluated in a suitable way that distinguishes between a transverse reinforcing bar running through a perforation and no transverse reinforcing bar.
(2) The shear resistance of a perforated steel plate should be greater than that of a shear connection with a perforated bond.

【Commentary】

15.4.6.3 Design shear resistance of block connectors

The design shear resistance of a block connector using perforated plates shall be evaluated in the proper way.

【Commentary】

15.4.7 Effect of steel girder plasticity on horizontal shear force

If the design bending moment exceeds the yield moment at the safety limit state, the effect of steel girder plasticity on horizontal shear force should be considered in the design of shear connectors.

【Commentary】

15.5 Detailing of Shear Connectors

15.5.1 Headed stud connectors

(1) The standard shank diameter shall be 19 mm or 22 mm. Reference should be made to JIS B 1198 "Headed stud connectors" for material properties, types, shapes, and proportions.
(2) The maximum spacing of headed stud connectors in the direction of the shear force shall be determined such that the required performance of the shear connectors is satisfied while also taking into account buckling of the flanges of the girders and other undesirable behavior.
(3) The minimum spacing of headed stud connectors shall be determined such that the required performance as the shear connectors is satisfied while also considering work execution and the prevention of harmful cracks in the slab.
(4) The distance between the edge of a headed stud connector and the edge of the girder flange shall be greater than 25 mm.
(5) In composite twin I-girder bridges or other similar types of bridge, headed stud connectors should be arranged in consideration of the transversal force and the tensile force in addition to the shear force.
(6) In the cross-section of the slab near the headed stud connectors, sufficient safety shall be assured against the shear force acting on the headed stud connectors.
(7) The shear holes in the precast slab shall be appropriately detailed in consideration of work execution in order to avoid local failure.

【Commentary】

15.5.2 Perforated-plate dowels

1. The thickness of the perforated plate and the diameter of the reinforcing bar running through the perforation shall be determined properly.
2. The diameter of the perforation shall be determined by considering bleeding and compaction of the concrete.
3. The maximum longitudinal center-to-center spacing of two adjacent perforations shall be determined so as to satisfy the required performance of the shear connectors.
4. The design shall include sufficient concrete cover at the perforated plate.
5. If two or more perforated plates are installed in parallel, sufficient transverse spacing shall be allowed.
6. Details of the perforated plates shall be determined with due consideration of fatigue.

【Commentary】

15.5.3 Block connectors

1. In a block connector with a hoop, if the hoop is diagonally welded to the block, the angle between the hoop and the steel flange shall in principle be 45 degrees.
2. The standard thickness of steel pate used in shear connectors shall be at least 16 mm and the diameter of a hoop should be at least 16 mm.
3. No shear connector shall be used that effects a wedge action on the concrete deck.

【Commentary】

15.6 Verification of Crack Width in Composite Girders

In a concrete slab subjected to a negative bending moment, the crack width due to composite action with a steel girder w_{md} and crack width due to local bending of the concrete deck caused by the wheel load w_{bd} shall satisfy the following:

$$\gamma_i \frac{w_{md}}{w_a} \leq 1.0 \tag{15.6.1}$$

$$\gamma_i \frac{w_{bd}}{w_a} \leq 1.0 \tag{15.6.2}$$

where, w_a : design critical value of crack width
γ_i : structural factor for standard structures $\gamma_i = 1.0$

【Commentary】

15.7 Effective Width of Concrete Deck for Composite Girders

For composite girders, effective width of the concrete deck shall be assigned in consideration of appropriate limit states.

【Commentary】