CHAPTER 2 BASIS OF DESIGN

2.1 General

At the stage of design of the structure, the following issues are to be determined with due consideration of overall economy.

a) structural details including the shapes and sizes of members,

b) details of reinforcement,

c) specifications of concrete and reinforcement to be used,

d) construction method – cast-in-place or precast, and,

e) maintenance method

Throughout the design life of the structure, appropriate steps shall be taken to ensure that the required performance in respect to safety, serviceability, environmental suitability, and aesthetics, is satisfied.

[Commentary] Verification methods for the structural characteristics are described in this Specification and the Standard Specifications for Concrete Structures "Seismic Design". The performance retained in the structure may change over time due to environmental condition, etc. The examination, whether this time dependent variation can be neglected or not, i.e. the examination for durability, such as carbonation, steel corrosion due to intrusive chloride ion, freeze-and-thaw, alkali-aggregate reaction, and water tightness is laid down in Chapter 2 of the Standard Specifications for Concrete Structures "Materials and Construction" (Fig. C2.1.1). In addition, because resistance to steel corrosion depends on crack width determined by structural detailing and cover depth, as well as quality of concrete, the verification method for it is described in this Specification and comprehensive examination method is integrated with the durability verification in Chapter 2 of the Standard Specifications for Concrete Structures "Materials and Construction".

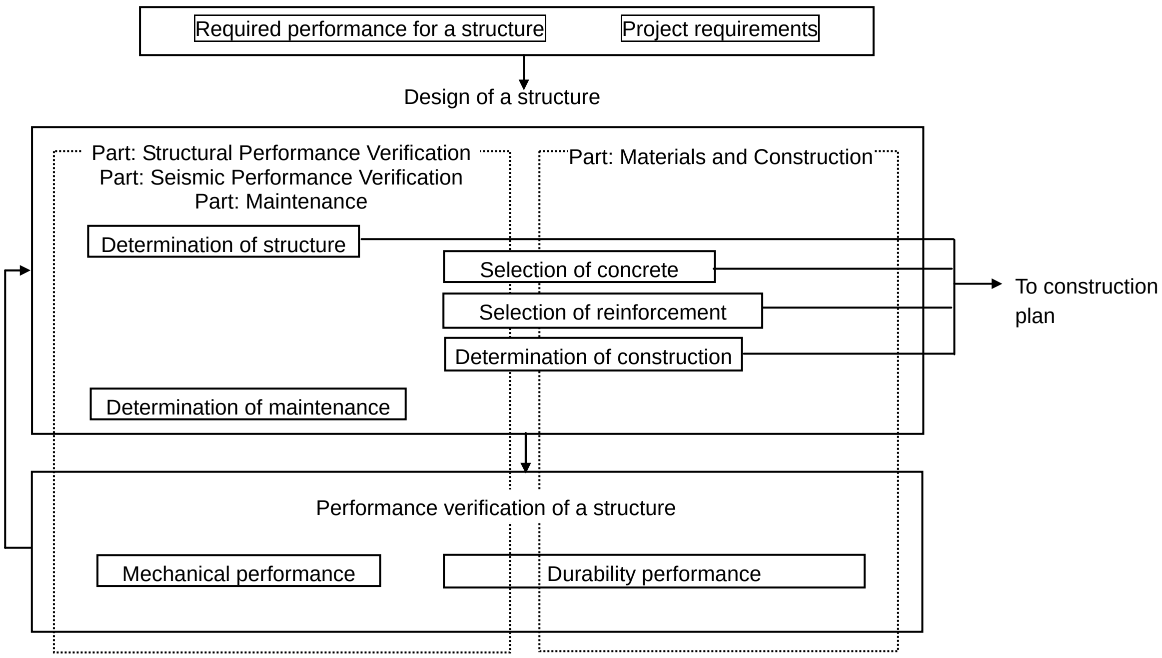

Fig. C 2.1.1 The stage of design work

The serviceability and safety of a structure depend on structural details, such as shapes and sizes of members, arrangement of reinforcement, and mechanical properties of materials, which are specified in this Specification and the Standard Specifications for Concrete Structures "Seismic Design". However, structural details, such as shapes and sizes of members and arrangement of reinforcement, also have a strong bearing on the verification of constructability and durability. Therefore, the preliminary consideration with this Specification is needed to make the overall design work rational.

After a concrete structure is completed, repair, strengthening or any improvement is difficult in general. Therefore, it is important that sufficient investigation is carried out at the design stage, and an estimate of the possible future events is made. Also, the ease of maintenance activity should be kept in mind when deciding the dimension of the members. Standard Specifications for Concrete Structures "Maintenance" gives other details for the basis of maintenance of concrete structures.

2.2　Design life

The design life of a structure shall be determined in consideration of required service period of the structure, maintenance methods, environmental conditions, required durability of the structure and economy.

[Commentary] For design of a structure, it is necessary to indicate the design life with wide consideration to the purpose of the structure, economically determined period over which the structure is required to be in service, environmental conditions in the neighborhood of the structure, and demanded durability of the structure. Generally, the longer design life is specified, the higher durability and fatigue resistance performance will be required.

2.3　Prerequisite of verification

When conducting the performance verification of a structure, it is assumed that the general structural details laid down in this Specification are satisfied, and that the provisions in the following sections or chapters of the Standard Specifications for Concrete Structures "Materials and Construction" – Chapter 2 (durability verification), Section 3.2 (standard construction method), and, Chapter 5 (standard constructability) – are met.

[Commentary] The methods for performance verification described in this specification is based on mechanics of structures and materials, which generally have some conditions such as deformational consistency of concrete and reinforcement and local states of stresses. Thus, general requirements for structural detailing are specified to realize these assumptions. Otherwise, accuracy of the verification reduces and scope for application is restricted. If verification methods would be more applicable in future, fewer requirements on structural detailing would be enough.

For verifying safety and serviceability of a structure, variation of performance over time during the design life of the structure should be considered. However, if a structure meets the requirements of durability as laid down in Chapter 2 of the Standard Specifications for Concrete Structures "Materials and Construction", safety and serviceability verification may be carried out without explicitly considering the time-dependent deterioration of constituent materials. Hence, it is necessary to assume safety margin by estimating possible deviation of member dimensions, accuracy of bar arrangement and varying mechanical properties of materials. In this Specification, the safety margin is considered by presuming the standard construction methods and constructability of fresh concrete. When construction methods and requirements are determined in practice, these are determined according to the Standard Specifications for Concrete Structures “Materials and Construction” to realize equivalent or better quality of concrete than that has been assumed in this Specification.

2.4 Verification principles

(1) In principle, performance verification of a structure shall be carried out in such a way that limit states according to required performance of the structure are determined in regard to the entire structure or each constituent member during construction and design life, and that the structure or structural member with the structural details such as shape, size, bar arrangement is examined not to reach the limit state.

(2) The limit states are classified into the ultimate limit state, serviceability limit state, and fatigue limit state.

(3) The examination at the limit states should be carried out using the characteristic values of material strengths and loads and the safety factors specified in Section 2.6 of the present Specification.

(4) Examination for safety due to seismic loads, residual performance and difficulty of restoration after earthquake shall be carried out in accordance with provisions of the Standard Specifications for Concrete Structures “Seismic Design”.

[Commentary] (1) As a principle of this Specification, required performances of a structure should be set clearly at first. Thereafter, an equivalent limit state corresponding to each requirement should be specified. When a structure, or a part of it, reaches a certain limit state, its serviceability may suddenly lose, or it may even reach failure in some cases. Then, the structure cannot perform its function nor meet the requirements because of various defects. In such cases, performance verification of the structure may be done by examining the limit state. In setting a limit state, an index representing the state of a structure, member or material should be selected, and then a limit value set in accordance with the required performance. Verification is done by examining if a calculated response under given actions exceeds the limit values or not. The limit values should be set taking into account reliability of the analysis method and the model employed in calculating the response value.

In the case that a total structural system is not simple, consisting of several structures, a process with a possibility that the structural system does not meet the requirements is selected. Required performance is set for each constituent structure, and thereafter, limit state may be set for each element in each structure. In this case, the procedure to determine the limit state should be shown in a hierarchy way. Recommendations listed in Chapter 1 in this Specification, which show a series of procedures from embodiment of required performance to determination of the limit state of member, can be referred to.

(2) In the Specification, three limit states are defined as the ultimate limit state, the serviceability limit state and fatigue limit state, based on the difference of methods for examination.

The ultimate limit state is associated with the load carrying capacity of the structure or member. Some typical examples of the ultimate limit states are given in Table C2.4.1. An examination for the failure of the member should be carried out by comparing the member force and its capacity by selecting appropriate cross sections.

Table C2.4.1 Examples of the ultimate limit state

Ultimate limit state for	Conditions
Rupture of section	Rupture of critical sections of structural members.
Stability	Loss of stability of the whole or a part of the structure as a rigid body by overturning or other motions.
Displacement	Loss of load carrying capacity of the structure due to large displacement.
Deformation	Loss of load carrying capacity of the structure due to excessive deformation by plastic deformation, creep, cracking, and differential settlement.
Mechanism	Transformation of the structure into a mechanism

The serviceability limit state is associated with normal use or durability of the structure. Table C2.4.2 shows examples of actual conditions for the different serviceability limit states. In the case of cracking, crack width and its allowable value should be used as indices.

Table C2.4.2 Examples of the serviceability limit state

Serviceability limit state for	Conditions
Cracking	Impairment of appearance, durability, or water and air tightness of the structure.
Deformation	Excessive deformation, which is not suitable for normal use.
Displacement	Excessive displacement, which does not impair stability and equilibrium, but is not suitable for normal use.
Local damage	Local damage, which is not suitable for normal use of the structure.
Vibration	Excessive vibration, which is not suitable for normal use, or produces uneasiness.
Source of vibration	Vibration, which propagates to surrounding structures through foundation and produces discomfort

The fatigue limit state is associated with the fatigue failure of the structure or member subjected to repeated loads. Although the fatigue limit state is somewhere included in the ultimate limit state, this Specification defines separately due to the following reasons;

(i)As fatigue strength varies corresponding to the number of loading cycles, the examination for fatigue is different in nature from that for failure of cross sections at the ordinary ultimate limit states by member forces.

(ii)The load and the safety factors associated with fatigue are different from those of the ultimate limit state.

Verification items and the actions specified in these Specifications are summarized in Table C2.4.3.

Table C2.4.3 Verification items and the conditions for actions

Verification for,	Conditions	In accordance with,
Serviceability	Serviceability limit state under normal load + environmental condition	Chapter 7 of the present specification
Safety	- Ultimate limit state under the maximum static load - Fatigue limit state under the cyclic load	- Chapter 6 of the present specification - Chapter 8 of the present specification
Seismic	Limit state associated with safety, function and reparability under seismic action	Standard Specifications for Seismic Design and Construction of Concrete Structures
Durability	Limit state associated with material deterioration under normal load + environmental condition	Chapter 2 of Standard Specifications for Concrete Structures "Materials and Construction", and Chapter 7 of the present specification

2.5 Calculation of member forces and cross sectional capacities

(1) In principle, the function to calculate the member force shall earn the mean value of it, when loads and stiffness of members or materials are actual values.

(2) In principle, the function to calculate the cross sectional capacity shall earn the mean value of it when material strengths are actual values.

[Commentary] Here given is a principle for functions to calculate member forces and capacities. When a new method for calculating the capacity of member cross section is proposed by new findings, the equation shall conform this principle, that is to relate most expected mean values. In addition, it is required to offer the appropriate member factor γ_b associated with accuracy of the equation or reliability of the analytical value.

2.6 Safety factors

(1) Safety factors are material factor, γ_m, load factor, γ_f, structural analysis factor, γ_a, member factor, γ_b, and structure factor, γ_i.

(2) Material factors, γ_m, shall be determined considering the unfavorable deviations of material strengths from the characteristic values, the differences of material properties between test specimens and actual structures, effects of material properties on the specific limit states, and time dependent variations of material properties. The values of the factors may be determined according to Sections 3.2.1, 3.2.2, 3.3.1 and 3.3.2.

(3) Load factors, γ_f, shall be determined considering unfavorable deviations of loads from the characteristic values, uncertainty in evaluation of loads, effect of nature of loads on the limit states, and variations of environmental actions. The values of the factors may be determined according to Section 4.3.

(4) Structural analysis factors, γ_a, shall be determined considering the uncertainty of computational accuracy in determination of member forces through structural analysis. The factor, γ_a, may be taken as 1.0.

(5) Member factors, γ_b, shall be determined considering the uncertainties in computation of capacities of members, seriousness of dimensional error of members, and the importance of members on the entire structure when it (the member) reaches a certain limit state. The value of the member factor, γ_b, is determined corresponding to each equation for member capacities.

(6) Structural factors, γ_i, shall be determined considering the importance of the structure, as determined by the social impact when the structure would reach the limit state. The factors, γ_i, may be in between 1.0 and 1.2.

[Commentary] (1) Examination of safety for the ultimate limit state on failure of member cross section employs five safety factors – two of them, γ_f, and γ_a, are related to the design member forces, another two, γ_m and γ_b, are associated with design capacities of member cross sections, and the other, γ_i, indicates structural safety in comparison of the design capacity with the design force. The concept of these safety factors can be applied for other limit states. Fig. C2.6.1 shows a process for performance verification using the different appropriate safety factors described in this Specification and the Standard Specifications for Concrete Structures "Materials and Construction"

(3) The value of load factor, γ_f, may depend upon the type of the load, the limit state concerned and characteristics of member forces. It should be noted that the maximum load does not always create the critical condition, but in some structures, the minimum applied load may become primary in design.

(4) The function to calculate the member force should earn the mean value of it in principle according to section 2.5. The possible error of the function is considered by γ_a.

(5) The importance of the member should be judged from its role in the entire structure, in a manner that primary members are more important than secondary ones. The factor, γ_b, may be used to control the safety levels of flexural and shear failure modes separately, and to control failure of a certain member in a structure. The function to calculate the cross sectional capacity should earn the mean value of it in principle according to section 2.5. The reliability of the function is considered by γ_b.

(6) The structure factor, γ_i, which is associated with the importance of the structure, should account for the impact of violation of the limit state on the society. This impact could be in view of dissater mitigation and the cost of reconstruction or repair.

Standard Specifications for Concrete Structures-2002, “Structural Performance Verification”

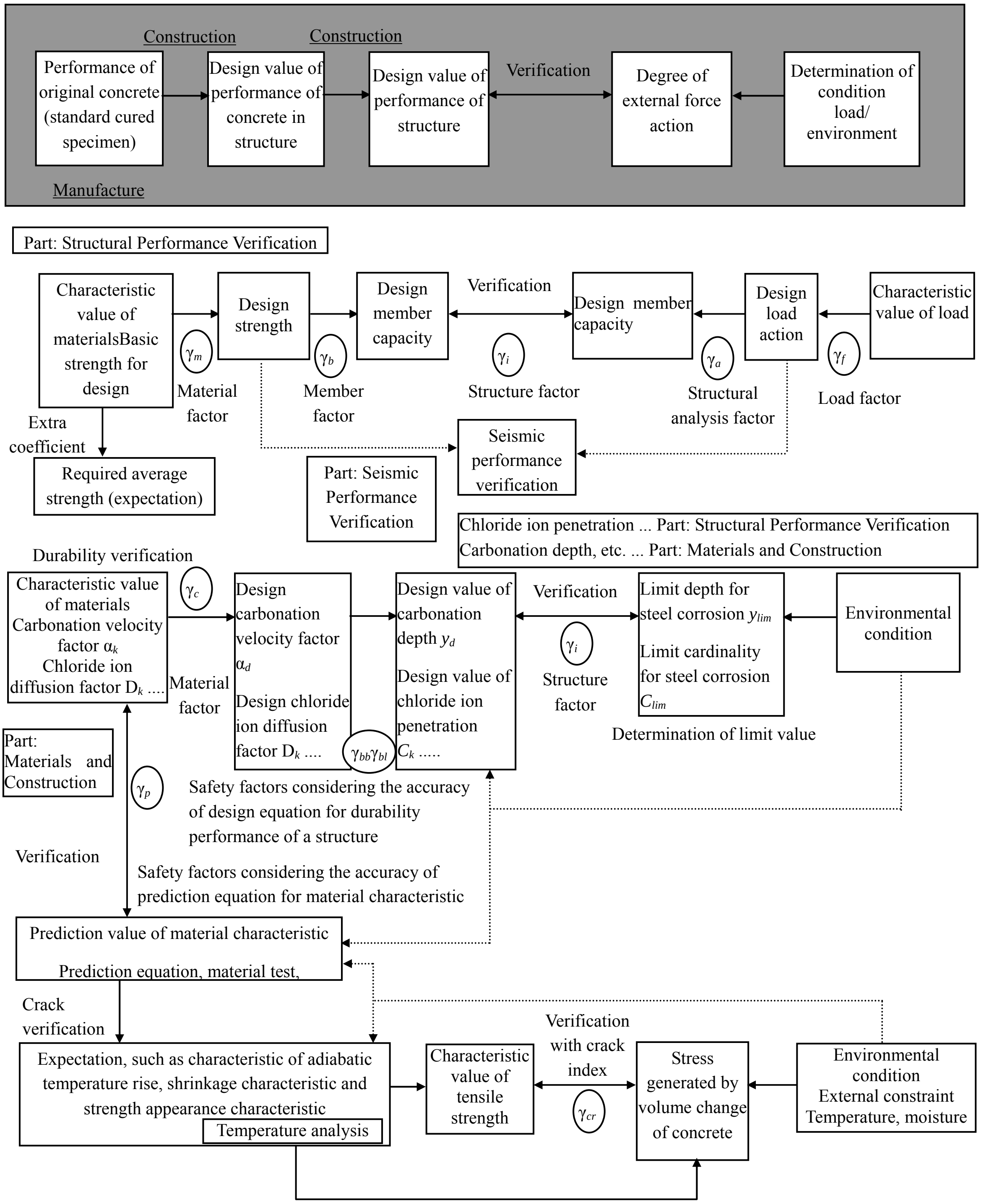

Fig. C2.6.1 Safety factors for verification of structural performance and durability