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Concrete Model Code for Asia : Design

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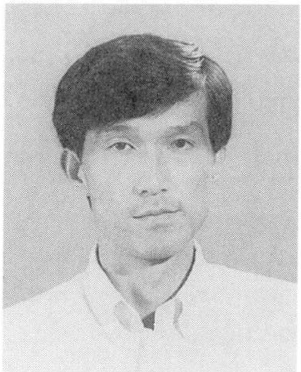

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Summary

The design part of the Asian Concrete Model Code is briefly introduced. The design part is based on the performance based design concept, which is a new generation of the design method for the 21st century. The design part consists of the Level 1, Level 2 and Level 3 documents. The Level 1 and Level 2 documents can be commonly applied to any structure and to any region. The Level 3 document is prepared in accordance with the Level 1 an Level 2 documents and provides the complete design process for particular structure or region.

1. Introduction

The Asian Concrete Mode Code (ACMC) was first published in January 1998[1]. ACMC contains three parts, namely Part I Design, Part II Materials and Construction and Part III Maintenance. This paper introduces the new concept and the main contents in Part I Design.

2. Outline of Design Part

2.1 Performance Based Design

The design part is drafted with the performance based design concept. The performance based design concept is the concept that clearly describes the required performance of the structure being designed. In ACMC the required performance is classified into the following three categories:

- Serviceability
- Restorability (or reparability)
- Safety

Serviceability is the ability of a structure or structural element to provide adequate services or functionality in use and not to cause unpleasant environment under the effects of considered actions. *Restorability* is the ability of a structure or structural element to be repaired physically and economically when damaged under the effects of considered actions. *Safety*, which is the most important performance, is then the ability of a structure or structural element to ensure no harm would come to the users and to people in the vicinity of the structure under any actions.

The concept of the limit state design is similar to that of the performance based design. The difference is that the former describes the limit state with rather engineering terms while the latter describes the required performance with rather non-engineering terms, which can be understood easily by the users and the society. For example, the crack limit state, which is a typical limit state, indicates allowable crack width. We, engineers, can understand the meaning of the allowable crack width, however the user, non-engineers, my not understand its meaning fully. In the performance based design serviceability is clearly described first. One of items listed under serviceability is aesthetics of a structure. The width and length of a crack are good indices to indicate whether the structure looks good or not. As a result, limits for crack width and length can be specified.

Each performance must be quantified by some index, so that its required level can be explicitly expressed. In ACMC the performance index, PI is introduced for quantification. The required level of the performance is called the "performance index required", PI_R, while the index of the performance that a structure or structural element possesses is called the "performance index possessed", PI_P. Each required performance is then examined by comparing PI_P with PI_R. Generally the performance index is chosen in such a way that the greater value of the performance index means the better performance. In this case the following formula should be satisfied.

$$PI_P > PI_R \qquad (1)$$

A typical example of PI_P and PI_R is the bending strength of an element and the maximum bending moment acting on the element respectively. The bending strength should be greater than the maximum bending moment. Another example is that PI_P is the maximum crack width caused by actions and PI_R is the limit of crack width for aesthetics. In this example the maximum crack width should be less than the crack limit, i.e. $PI_P < PI_R$.

By using the performance index, not only the examination of the required performance but also the evaluation of the performance possessed by the structure can be conducted. The examination only tells you whether the structure satisfies the required performance or not. The evaluation, however, tells you how good the performance the structure possesses. ACMC includes this concept as well. As a simplified method, the ratio, PI_P / PI_R can be used for the evaluation.

2.2 Level 1, 2 and 3 Documents

Each Part of ACMC consists of Level 1, Level 2 and Level 3 documents as shown in Fig. 1. The Level 1 document in Part I Design describes the basic concepts, such as the performance based design concept as described earlier. The Level 2 document has four chapters as follows:

- Design for Actions in Normal Use

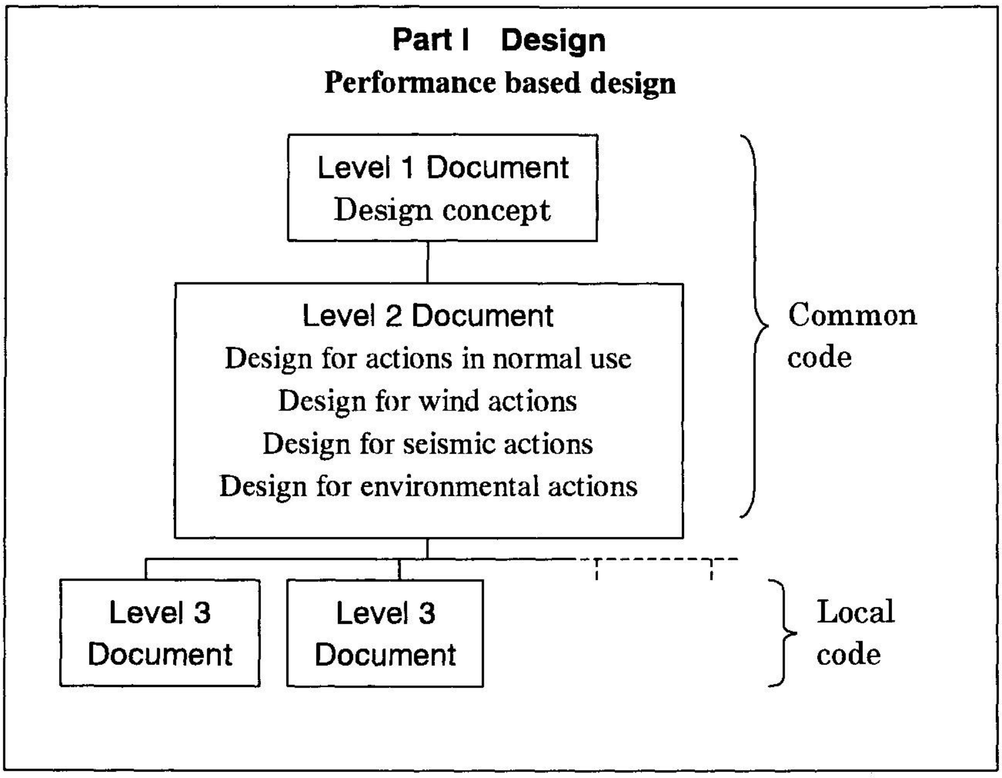

Fig. 1 Structure of Part I Design

- Design for Wind Actions
- Design for Seismic Actions
- Design for Environmental Actions

Four chapters are for different types of actions. Each chapter describes what kinds of performance should be examined and what are the performance indices. Even for the same performance the performance index may be different if the types of actions considered are different. Forces, such as axial force, bending moment, shear force and torsion are the performance indices for safety in the Design for Actions in Normal Use, while displacements are the performance index in the Design for Seismic Actions.

The Level 1 and Level 2 documents are codes for any types of structure in any region/country. However, there exist local conditions in each region and country, which may not be applied elsewhere. Some construction materials are not available due to economical and/or climatic reason. Also some types of structure and structural analysis may not be suitable due to economical reason and/or available technological level. The Level 3 document can consider all these local conditions. The contents in the Level 3 document should conform to those in the Level 1 and 2 documents, even though the details may be different. For this reason the Level 3 document is preferably prepared by the authority in each region and country. The Level 3 document can also solve the problem caused by the situation that there are variable codes for different types of structures, such as buildings and bridges. In a country like Japan and China the codes for buildings and for bridges are different. For example the design equations, such as that for shear strength are different. The design equation is the tool to calculate the performance index that only appears in the Level 3 document but not in the Level 1 and Level 2 documents. In this case preparation of both the Level 3 document for buildings and the Level 3 document for bridges is the solution.

3. Level 1 Document

The table of contents for the Level 1 document is as follows:

0. Notation
1. General
2. General Principles
3. Requirements
4. Materials
5. Actions
6. Analysis
7. Examination of Performance
8. Evaluation of Performance

Chapter 1 tells you that the scope of ACMC is all types of concrete structures as well as structural and nonstructural elements subjected to mechanical and environmental actions. It is described in Chapter 2 that structures should be designed, constructed and operated to maintain their performances in safety, economical restorability and serviceability. It goes on to say that in the design and construction of structures special considerations has to be made to protect the environment by avoiding any damage to the environment and by saving or recycling resources. Chapter 3 describes three required performances, serviceability, restorability and safety. Chapter 4 says that the material properties and models that are necessary for design analysis (or computation of the performance index) should be specified. The detailed specifications are provided in the Level 2 and Level 3 documents. Chapter 5 classifies actions into four groups, actions in normal use, wind actions, seismic actions and environmental actions. This classification is adopted in the Level 2 document. Chapter 6 suggests that a three-dimensional analysis with consideration of material and geometrical non-linearity and time effects is the best to be used. Simplified methods, such as one or two dimensional analysis, linear analysis and static analysis, which are used in most of the current practical cases, can be used with careful consideration of their accuracy. Chapters 7 and 8 explain how to examine and evaluate the required performance (see Sec. 2.1 of this paper for the details).

4. Level 2 Document

The Level 2 document contains 4 chapters for four different types of actions, namely (1) actions in normal use, (2) wind actions, (3) seismic actions and (4) environmental actions. Each chapter is for the case in which the corresponding actions are major actions and the effects of the other actions are negligible. For example in the chapters for other than environmental actions the effects of environmental actions are rather small because of moderate environment and/or because of the proper measure for protecting the structure.

The level 2 document provides all the items necessary for design. These items are common in any region and for any type of structure. However, the detailed descriptions may be different for different regions and different structure types and are provided in the Level 3 document. For example, it is said in the Level 2 document that the stress-strain relationship of concrete must be provided. No specific stress-stain relationship, however, is provided in the Level 2 document, which is provided in the Level 3 document instead.

Each chapter has identical table of contents, which conforms with that of the Level 1 document, as follows:

*.0 Notation
*.1 General
*.2 Requirements
*.3 Materials
*.4 Actions
*.5 Analysis
*.6 Examination of Performance
*.7 Evaluation of Performance
(*: 1 to 4)

4.1 Design for Actions in Normal Use

Actions in normal use are classified into three categories:

- Permanent loads
- Variable loads
- Accidental loads

Fatigue loads, which are repetitive loads and cause fatigue phenomena such as strength reduction and stiffness reduction, are among variable loads. For each load the intensity, duration and frequency need to be specified.

Materials to be described are concrete, reinforcement and materials at the interface between concrete and reinforcement. Reinforcement may be steel and continuous fibers, while the materials at the interface are those for filler, grouting and shear connector. The material properties of concrete and reinforcement necessary for design analysis are strength (static and fatigue), stiffness, time-dependent properties (creep, relaxation and shrinkage) and thermal properties (thermal expansion and conductivity). Material models, such as stress-strain relationship, may be provided instead of material properties. The most appropriate stress-strain relationship is a three dimensional one with consideration of the effects of loading history, such as rate, duration and cycles of loading. The stress-strain relationship for concrete should consider the situation after cracking as well, so that the mechanism at crack surface can be treated appropriately. Simplified stress-strain relationships may be used provided that their applicability has been confirmed. Instead of providing separate models for concrete, reinforcement and the interfacial material, models for the composite material consisting of concrete, reinforcement and the interfacial material may be provided.

The required performances and corresponding indices needed to examine the required performances are listed in Table 1.

Table 1 Required performances and performance indices

Required performances		Performance indices
Major items	Sub items	
Serviceability	Comfortable ride/walk	Acceleration, natural period, gap/step, pavement type
	Comfortable stay	Deformation
	Anti-vibration	Vibration level, natural period
	Anti-noise	Noise level, soundproof wall type
	Anti-odor	Substance density
	Anti-humidity	Humidity
	Aesthetics	Crack density, dirt density
	Shielding	Amount of substance/energy penetrating, crack width
	Permeability	Amount of substance/energy penetrating, porosity
Restorability		Axial force, bending moment, shear force, torsion, stress range
Safety		Axial force, bending moment, shear force, torsion, stress range

The required performances for serviceability are those to provide comfortable use of the structure, to avoid unpleasant environment around the structure and to keep necessary functions of the structure. Practically the performance indices for restorability and safety may be the same because the critical situations for restorability and safety are rather similar under the effects of actions in normal use. Generally the appropriate performance indices for both restorability and safety are either forces or stress ranges but not deformations/displacements. Deformations/displacements are good indices for wind and seismic actions. Stress ranges as the performance index are for fatigue loading. Restorability here is the ability to limit structural damage in such a way that no repair work is necessary. Under the effects of actions in normal use the force, the performance index, beyond which repair works are required and the force at the ultimate stage are only slightly different. Therefore, it has practically no meaning to specify the performance index possessed, PI_P for the force beyond which repair works are impossible economically and technologically. Under the effects of seismic actions, however, the performance index corresponding with the repairable state is meaningful (see Sec.4.3).

4.2 Design for Wind Actions

The main feature of this chapter for the design for wind actions is the description for actions and analysis. The characteristics of wind actions, such as wind speed and wind pressure, depend on the type of structures because the importance and design life of the structures are different. Structures are divided to consider appropriate return periods as follows:

- Extremely important structures and components
- Regular structures (including tall buildings) and components
- Small-scale, light residences and stores and the like
- Temporary facilities

For wind pressure evaluation structures are classified as follows:

- Normal, bulky and relatively stiff structures
- Tall and slender or flexible structures
- Irregular structures

Acceptable analyses for wind pressure evaluation are

- Equivalent static approaches based on tabulated coefficients
- Dynamic approaches based on the natural frequency and geometry of the structures
- Wind tunnel tests

Provisions for materials and examination of performance are essentially the same as those in the design for actions in normal use. The only exception is that displacements of the structure, such as inter-story drift for buildings, can be a performance index for restorability.

4.3 Design for Seismic Actions

The provisions for this chapter are to ensure the formation of a planned yielding mechanism in the structure. For the structures in which the yielding mechanism may not occur other design approaches should be applied.

The following three levels of earthquakes are considered for seismic actions:

- *Minor-to-moderate earthquake:* Earthquakes which may occur a couple of times during the lifetime of the structure
- *Severe earthquake:* Earthquakes which may occur once during the lifetime of the structure
- *Ultimate earthquake:* Earthquakes which is the strongest feasible for the site

The return period and intensity of the above earthquakes are different depending on the lifetime of the structure and the importance of the structure. If the structure is important like a nuclear power plant, an ultimate earthquake that may not occur at the particular site but somewhere may be chosen as the ultimate earthquake.

Nonlinear pushover analysis should be used. Nonlinear dynamic analysis may be used additionally to improve the accuracy of the analytical results. With confirmation of the reasonable accuracy in the analytical results simplified methods, such as linear analysis and plastic limit analysis, may be applied instead of the nonlinear pushover analysis. Material properties and models necessary for the design are essentially the same as those for the design for actions in normal use.

The performance index for all the required performances (serviceability, restorability and safety) is displacements of the structure. The maximum response displacement, which is the performance index required, PI_R, for each performance is calculated by taking one of the three levels of the earthquake as seismic actions. Serviceability is to ensure that the function of the structure is maintained and that members planned to yield do not yield. Reparability that ensures that members planned yield can be repaired economically and technologically is the basis to determine the performance index possessed, PI_P for restorability. It should also be ensured that members planned not to yield do not yield nor fail in shear. For safety PI_P should be chosen so that the significant loss of the load carrying capacity of the structure does not occur and that the integrity of the structure to support the loads acting after the earthquake event is maintained.

4.4 Design for Environmental Actions

The design for environmental actions is applied to the cases in which the effects of environmental actions are not negligible. In those cases the structure is designed for not only the environmental actions but also major actions to the structure, namely actions in normal use, wind actions or seismic actions.

Environmental actions that cause the material property change, usually the property deterioration, are as follows:

- Chloride ion penetration
- Carbonation
- Freezing and thawing
- Chemical attack
- Abrasion by cavitation and friction

Besides the material properties necessary for the design analysis under the effects of actions in normal use, wind actions and seismic actions (see Sec.4.1) there are other material properties necessary for the analysis of environmental effects. They are permeability, ion diffusibility and resitivities against chemical and physical attacks. The material properties, such as strength and stiffness are calculated with consideration of the environmental actions and the material properties for the environmental actions.

Durability grade is specified besides the required performances as shown in Fig. 2. Durability grade is the required durability level in the structure, which depends on the degree and frequency of remedial actions during the design service life, and is classified into the following three grades:

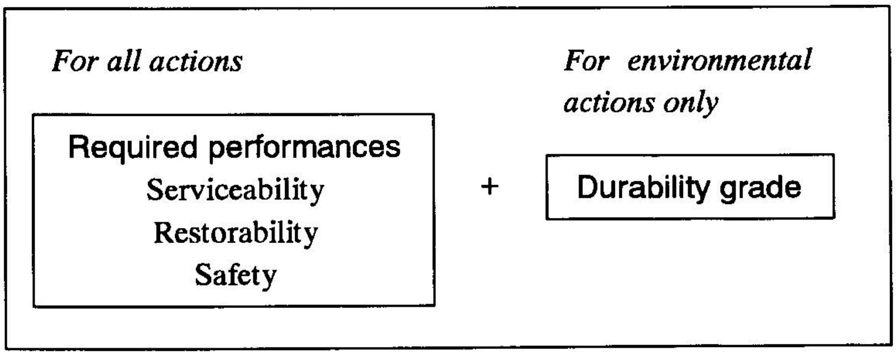

Fig. 2 Durability grade

- *Durability grade 1:* During the service life, the structure should maintain its required performances without any remedial actions
- *Durability grade 2:* During the service life, the structure should maintain its required performances with a couple of times of simple remedial actions
- *Durability grade 3:* During the service life, the structure should maintain its required performances with the regular remedial actions

The effects of environmental actions are considered in either of the following two ways:

(1) The performance index under the effects of the other actions that are actions in normal use, wind actions and seismic actions is calculated with consideration of the effects of environmental actions. This performance index is called as long-term performance index, *LPI.* The required performance is examined by comparing the long-term performance index possessed LPI_P with the long-term performance index required, LPI_R. The bending strength of a section calculated with consideration of the material property deterioration is a LPI_P, while the maximum bending moment calculated with consideration of the material property deterioration is a LPI_R. The LPI_R depends on the durability grade. In the case of the bending moment, LPI_R for the durability grade 1 is greater than or equal to that for the durability grade 2, and that for the durability grade 2 is greater than or equal to that for the durability grade 3.

(2) The required performance under the effects of actions other than environmental actions is examined according to the provisions in the design for the respective actions. And then the *deterioration index*, which is a kind of simplified performance index, is applied for the examination of the performance under the effects of environmental actions. The deterioration index possessed is compared with the deterioration index required. The deterioration index possessed is calculated as the material property deterioration. The deterioration index required depends on the durability grade. The deterioration index is provided for each type of deterioration as follows:

- *Chloride induced reinforcement corrosion:* The depth from concrete surface, where the concentration of chloride ions has reached the critical value to depassivate the reinforcing steel, and the amount of reinforcement corrosion
- *Carbonation:* The depth of carbonation and amount of reinforcement corrosion
- *Frost damage:* The depth of concrete damaged by freezing and thawing
- *Concrete corrosion due to chemical attack:* The damaged concrete area and depth, the loss in concrete strength, and the amount of reinforcement corrosion

For example, the depth from concrete surface, where the concentration of chloride ions has reached the critical value to depassivate the reinforcing steel is calculated as the deterioration index possessed. On the other hand the required depth for the critical value of the chloride ion concentration, which is the deterioration index required, is provided considering the durability grade. The required depths for the durability grade 1 is greater than or equal to that for the durability grade 2, which is greater than or equal to that for the durability grade 3.

5. Level 3 Document

Without the Level 3 document actual design for structures cannot be done. The Level 3 document contains the complete processes for the examination of each required performance, which are the necessary design equations and details. The Level 3 document acts like a design manual. It be prepared only for a particular type of structure or for a particular region/country. There can be many Level 3 documents.

The International Committee on Concrete Model Code (ICCMC) has been preparing some examples of the Level 3 documents as follows:

- Design for Actions in Normal Use based on a Japanese code[2)]
- Design for Actions in Normal Use based on the current Thai practice
- Design for Wind Actions based on the current Malaysian/Singaporean practice
- Design for Seismic Actions based on the current Thai practice
- Design for Actions in Normal Use (Punching Shear Strength in Reinforced and Post-tensioned Concrete Flat Plates with Spandrel Beams)

The first four are examples that are meant to be applied to a certain country(s), while the last example is only for examination of a particular required performance, safety, in which punching shear force is the performance index.

6. Conclusions

The design part of the Asian Concrete Model Code, Part 1 Design, is briefed in this paper. The main feature of Part 1 Design is as follows:

(1) Part 1 Design is written with the performance based design concept, which clearly indicates the required performance. The required performance is classified into serviceability, restorability and safety.

(2) Part 1 Design consists of the Level 1, Level 2 and Level 3 documents. The Level 1 document describes the main concept of design while the Level 2 document explains all the required performances with the corresponding performance index, which quantifies the performance for examination of the performances. The Level 3 document provides the complete examination processes of the required performance that are the design equations and details. The Level 1 and Level 2 documents are common to any structure and any region/country, however the Level 3 document may be applied to only particular structure and particular region/country.

(3) The Level 2 document contains four chapters, which are for design for actions in normal use, wind actions, seismic actions and environmental actions.

Acknowledgement

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prepared Chapters 2, 3 and 4 in Level 2 documents.

Reference

1) International Committee on Concrete Model Code: Asian Concrete Model Code – First Draft, ICCMC, January 1998

2) Japan Society of Civil Engineers: Standard Specification for Design and Construction of Concrete Structures, JSCE, 1996 (in Japanese)