Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 81 (1999)

Artikel: Design process of concrete structures by performance based design
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DOI: https://doi.org/10.5169/seals-61418

Design Process of Concrete Structures by Performance Based Design

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Summary

This paper deals with what the design process should be in the performance based design, and what we have to do near future to make the performance based design effective. At first the historical background of design method for concrete structures in Japan was briefly reviewed. Then, the current situation was discussed on the target of the working group which authors are involved in three aspects, (1) to make a comprehensive chart of design process, (2) to survey current technical means applicable to design and (3) to develop a rational evaluation method for the life cycle cost.

1. Introduction

The Concrete Committee of the Japan Society of Civil Engineers has established nine working commissions for making preparations for a coming new design code based on the performance criteria. The working commission of planning and design, one of the nine WCs, has three tasks. The first one is to make a comprehensive chart of design process of concrete structures under a performance based design code. The second is to survey current technical means applicable to design. In other words, the task is to survey what kinds of software can be commercially provided for the numerical solutions of specific design problems. The third is to develop a rational evaluation method of the life cycle cost of concrete structures.

Throughout the first year activity, the overall design charts were drawn for several concrete structures, such as highway bridge piers, railway bridge piers, box culverts and off-shore structures. The design charts involve the decision making part of planning, the verification process of structural performance and the inspection for maintenance. The demolition and recycle use of materials could be considered taking account of environmental effects. The design service life of structures must be the most important item of requirements. The quality of materials, the way of construction and the necessity of maintenance should be examined to assure the design service life. The design chart may reveal what should be studied more both in material properties and in structural behaviors.

The survey of numerical techniques shows that reliable softwares are limited to the static elasto-plastic behaviors of concrete structures. There are some programs which can treat the dynamic behavior of concrete structures including the elasto-plastic range. The reliability and the applicability, however, are still in progress. Much more efforts are expected to develop the analytical approaches of the deterioration process of concrete structures.

2. Background of Design Code in Japan

The standard specifications for concrete structures in Japan was firstly established in 1931 by the Japan Society of Civil Engineers (JSCE). At that time the elastic analysis was widely taken into account and the allowable stress design method was adopted in the standard. Since such a design code was very simple and not so many words were necessary in the standard, then, much attention was paid to construction practice. Although the standard specification has been reviewed and revised every five years since then, the allowable stress design method was kept effective as the basis of design for fifty-five years until 1986. During the period lots of technical innovation were made in many aspect, but major revision was mainly done in the part of construction practice in the standard. The revision in the design part was minor within the frame work of the allowable stress design method.

The research and discussion on the mechanical behavior of concrete structures have certainly been continued in the JSCE code committee. In particular, the survey and discussion on the ultimate strength design method started in 1969, and in 1975 the activity was extent to the limit states design method. After a long preparation for revision of the design standard, the limit sates design method was newly adopted in the JSCE Standard Specifications for Concrete Structures - Design Part - in 1986. The new standard has been reviewed and revised every five years. After the Great Hanshin Earthquake in 1995, a lot of effort were concentrated on examination of the mechanical behaviors of reinforced concrete structures under severe earthquakes. At the same time the discussion on the revision of seismic design code was actively conducted. The results were summarized in the new design code, the JSCE Standard Specifications for Concrete Structures - Seismic Design Part - in 1996.

The seismic design part, which is apart from the design part, is formulated by the new concept based on the performance criteria. The computer aided verification techniques, such as non-linear finite element analyses, should be fully utilized. This code is a forerunner of the performance based design code. Through the experience of making the seismic design part of the JSCE standard specifications, the JSCE concrete committee has decided to revise the whole part of the standard as the performance based design by 2006.

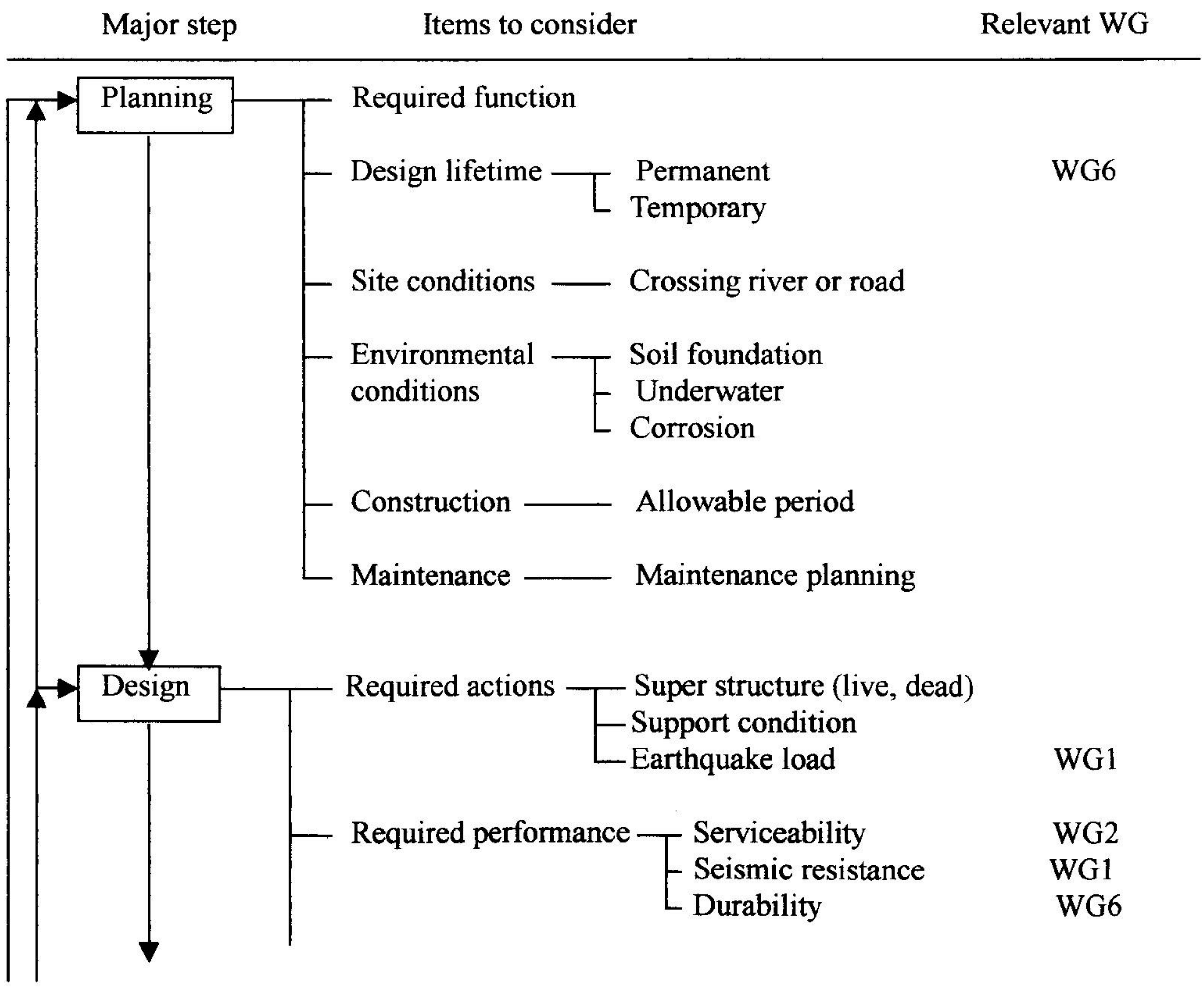
3. Flow Chart of Design Process

For proceeding the enormous works nine working groups were firstly set up in 1997, such as WGs on (1) Safety, (2) Serviceability, (3) Materials, (4) Construction practice, (5) Initial quality, (6) Durability, (7) Design process, (8) Quality assurance, (9) Maintenance and repair. Table 1 shows the list of working groups.

Table 1 Working groups

WG	Object	Content
WG 1	Safety	Ultimate capacity and seismic resistance
WG 2	Serviceability	Cracking, deformation, vibration etc
WG 3	Materials	Concrete, steel etc
WG 4	Construction	Construction practice
WG 5	Initial quality	Evaluation of initial quality of concrete
WG 6	Durability	Time-depending properties
WG 7	Design process	Flow chart of design process
WG 8	Quality Assurance	Materials and construction practice
WG 9	Maintenance	Maintenance and repair

The authors are involved in the WG7, and this report introduces the outline of the current activity of WG7. The mission of WG7 is to look over the whole design process and to harmonize the activity of each WG in the design process. To make the mission clear, it is requested for WG7 to draw the flow chart of design process taking some structures as examples. Each member in WG7 has been working to make examples of design process with different structures, such as highway bridge structures, railway viaduct structures, underground structures and marine structures. As an example the design process of highway bridge structure is shown below.



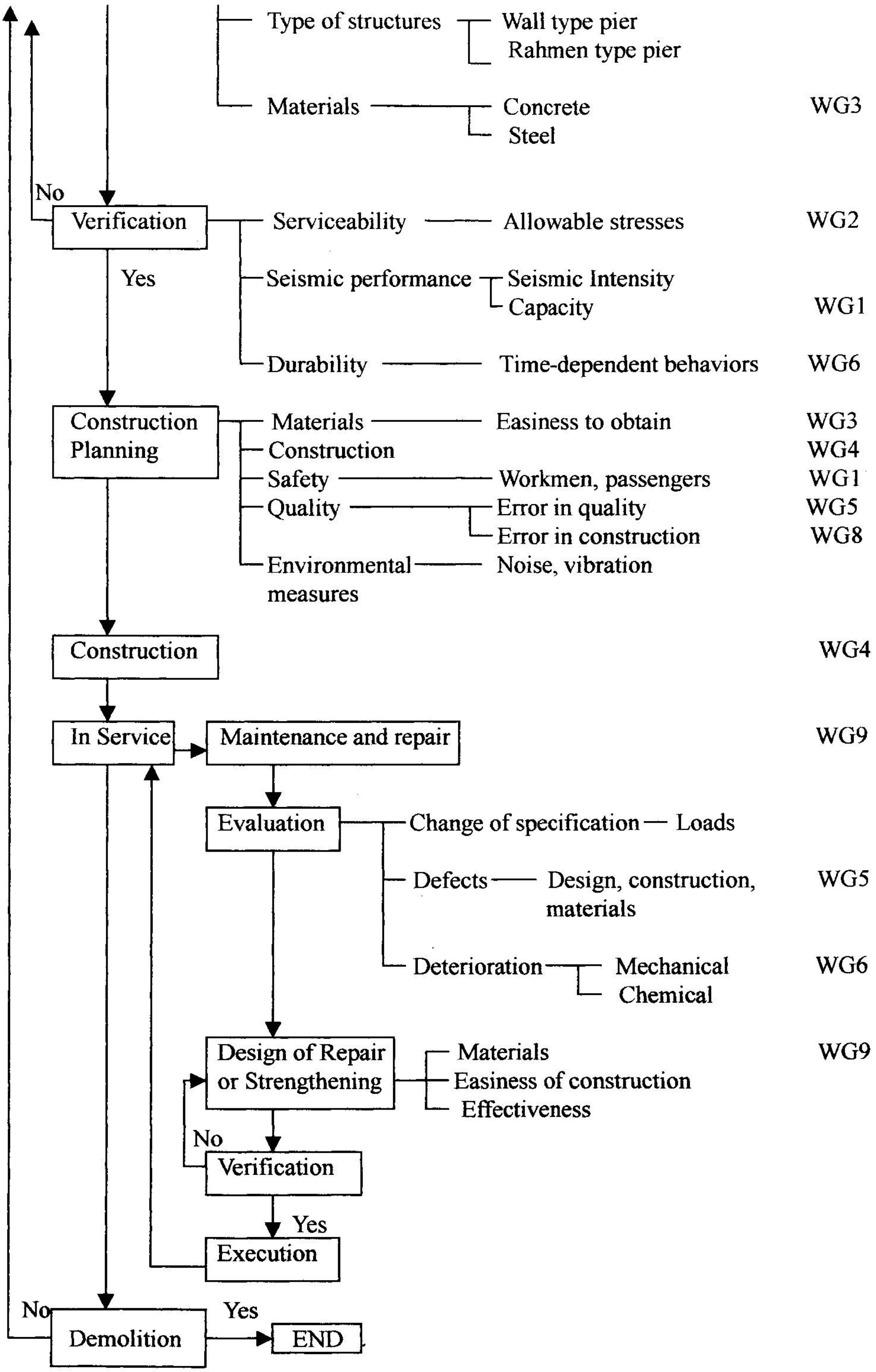


Fig.1 Flow chart of design process of bridge structure

4. Design Aids; available and required

Since the process of planning and design of structures requires a lot of works to do, many engineers must be involved in this process. The process should be divided into several units for effective execution, and the work of each unit may be done by an individual group. The group would be expected to be a specialist for a given work. In addition, so many empirical solutions have been adopted in different aspects of design. Then, what design engineers have to do first is to get used to how to use such solutions, and secondly to conduct many calculations. This situation of design process makes it quite difficult for design engineers to understand how their works influence the overall design.

In order to mitigate this situation, it is necessary to introduce new technology for reducing time consuming calculation works, and to indicate the design process clearly. The time consuming works always come from the verification process requiring so much calculations. Fortunately, recent innovation in computer engineering and the development of numerical technique make it possible to conduct enormous calculations in the verification process by computers. Table 2 shows some examples of what can be done by computer programs in Japan.

Table 2 Computer programs (examples)

Items	Programs
Planning	Determination of bridge span length Perspective simulation of road route Tracing of car movement in railway Determination to traffic lanes Etc.
Design	Overall design system for composite girders Overall design system for railway PC girders RC box girder bridges RC slabs PC rahmen type bridges Etc.
Structural behavior	Stability of slope, break water, etc Frame analyses – 2D, 3D Many types of FEM for various structures – 2D, 3D – linear, non-linear, – elastic, plastic Influence line for girders Sectional capacity Etc.
Seismic analysis	Dynamic response analysis – FEM – 2D, 3D – linear, non-linear, – elastic, plastic – combined of soil movement with underground structures FEM for soil foundation Calculation of natural period of structures Seismic design of RC piers Verification of capacity of RC piers Etc

Table 2 represents only some examples for bridge structures. There are many other computer programs utilized for design. The thermal stress analysis for massive concrete structures is one of the most extensively developed technology in Japan. These programs, however, need more refinement to get higher reliability. In particular, three dimensional analysis should be developed further more in any cases. Not only the analytical study but also the study of micro chemical and mechanical behavior of concrete should be proceeded to take account of the initial properties of concrete as well as the long term deterioration of concrete in design.

5. Necessity of Life Cycle Consideration for Structures

The key point of the performance based design lies in the performance of concrete structures in the life cycle. This gives benefits to both owners and designers of structures. Taking economical conditions into account, the owners can select the suitable condition of structure in the life time from several design alternatives. For example, one choice is to pay much money for obtaining the high quality at the initial stage, and no maintenance cost for the rest of life. The other choice is to pay less at the initial, and to consider maintenance cost later.

The benefit for designers or engineers is to enlarge the acceptance of new technology. The performance based design can reflect new technology quite easily and accept it in design without major changes of design rule. In addition, the consideration for the life cycle behavior of structure is indispensable to make a proper evaluation on the superiority of the initial high quality of structures even if it is expensive.

The members of WG 7 have just started to study how to develop an evaluation model of the life cycle cost of given structures.

6. Concluding Remarks

The most essential point of the performance based design lied in the verification technology. When we have a highly reliable and widely applicable analysis for a required performance, for example, a FEM for the flexural capacity of structural members, we can command the structural design at will. After constructing the frame work of design process, the WG 7 is now making some design examples by the new method with examining how effective the current verification techniques are.

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