Research and Development of Performance-Based Design and Engineering System in Japan

Hiroyuki Yamanouchi[1)]
Hisashi Okada[2)]
and
Masaomi Teshigawara[3)]

Abstract

This paper describes a framework on performance-based structural design and engineering system that should be realized in the future, and introduces a current activity that is underway toward the new structural design/engineering system, at the Building Research Institute (BRI) in cooperation with many professional communities related to building structures.

Introduction

The current structural design methods are based on either strength or ductility, or otherwise the both of a structure. Thus, overall structural performance including others than strength and ductility has not yet become conscious in the mind of not only a structural engineer but also a researcher. Namely, the global structural performance before and after structural design is not always clearly described by a structural engineer. For instance, looking at the structural performance against a specified level of seismic forces, a structural engineer cannot say the expected performance such as remaining inter-story drift, damage degree of non structural elements and lifelines, reparability and so on. This situation is strongly owing to the current prescriptive design codes that bind a structural engineer without design flexibility.

The current design codes do not clearly require target structural performance, whereas design procedures and rules are definitely and prescriptively specified as code provisions. Therefore, under this inflexible system, the performance of a designed structure cannot be clearly predicted and described even by a structural engineer who designed the structure. Furthermore, structural design itself has become "calculation" just to keep restrictively the prescriptive specifications under code provisions.

In the future design system, on the contrary, the target or objective structural performance should firstly be defined as a clear picture, and then in order to attain the performance, a structural engineer may choose an appropriate design method and procedure. Thus, the most important thing toward the future design system is to facilitate a new design system including codes, where a structural engineer can determine target performance and realize it by choosing an appropriate design procedure. It is not until this is realized that a structural engineer can clearly explain the objective and expected performance of a structure designed by him or her to a client.

Structural Performance

The performance of a structure is not limited to structural safety; the word of structural performance has even wider concepts. That is, the concepts includes every structure-related performance; safety, reparability, durability, human comfort, maintainability, constructibility, aesthetics and so on. Furthermore, performance against various actions such as loads and forces should be taken into account. The basic definition and description materials of structural performance have already been proposed by the author elsewhere (1).

1) Director, Department of Research Administratiion and Management
2) Associate Director for Composite Structure, Department of Structural Engineering
3) Head of Structure Div., Department of Structural Engineering

Performance-Based Codes and Specification Codes

In recent years, structural technologies of building structures are making a rapid progress. For instance, various technologies such as new structural materials, base isolation and response control devices/systems have been developed.

However, the current codes for building structures in Japan cannot match new structural materials and systems, since they are regulated for conventional structural materials and methods and most of them are of specification types that specify, in detail, materials to be used, sizes and spacing etc., in most cases with numerals.

Therefore, it becomes necessary to convert structural codes from current specification types into performance-based types that prescribe objective performance to be accomplished in designed structures, and to allow structural engineers broad ways in selecting new structural materials and methods for achieving the required performance.

BRI/MOC Action Toward New System

Considering significant needs for a new design and engineering system on the basis of performance, the Building Research Institute, Ministry of Construction, has initiated a three-year National Comprehensive R&D Program entitled " New Structural Engineering System" since the fiscal year of 1995, in coordination with structure-related communities such as those of structural engineers, contractors, industries, academy and so on.

The most critical mission of the Program is to show possible ways to a new structural design and engineering system where a structural engineer can clearly explain the objective and expected performance of a building structure designed by him or her. For this, a lot of issues must be studied, discussed and solved; as a result of preliminary studies for formulating the Program, the major subjects to be dealt with in the Program have been identified, and the committees for the action have been organized, as shown in Table 1.

In this Project, we are examining the following two technical subjects:

1. Develop performance based structural design system. Here, we examine not only seismic performance but also other performances related to building structures,
2. Convert specification codes into performance codes in the Building Standard Law,

and furthermore, social issues related to structural engineering are being dealt with as follows:

3. Propose a menu of social systems which can effectively support performance-based design and engineering in terms of qualification of structural engineers, building confirmation procedures, quality assurance of design and so on.

As shown in Table 1. we have organized a Synthesizing Committee (Chairman is Prof. T. Okada of Shibaura Institute of Technology). This Committee steers and manages this comprehensive project. Under the Committee, we settled three Technical Committees. The tasks of the Technical Committees are as follows:

<u>Technical Committee 1</u>: Evaluation of Performance (Chairman: Prof. H. Akiyama of the University of Tokyo)

The Committee is examining the concepts of performance of structures, definitions of performance, measures of performance, loads and forces and their design levels.

(1)The Structure Performance Evaluation System

The structure Performance Evaluation System is shown in fig.1 . In the frame of (1) in fig.1, " Basic Structure Performances" which are primarily required for the building structure are extracted. In the frame (2), each detailed performance which is limit state for each object of evaluation are described in general expression. The kinds of loads or external forces in the frame (3), and their sizes in the frame (4), are set along with setting of the frame (1) " Basic Structure Performance " and the frame (2) " Performance Evaluation Items and Basic Required performance ". To this point of the first stage, the condition which the structure should be in, and the loads or the external forces which affects it are set in general expression.

In the second stage, the relation between the loads or the external forces and the basically required performance is set in engineering expression. " Quantitative Definition of the Sizes of Kinds of Loads and External Force " is done in the frame (5). The response value (kind) of performance to evaluate against these loads and external forces , and the limit value which satisfies performance are set in the frame (6) " The Principle of Performance Evaluation".

In the frame (7) " Evaluation or design Method " , the methods to realize " The Principle of Performance Evaluation " are developed with engineering judgment or some design criteria. The response value of performance to evaluate and the limit value to satisfy the performance set in the frame (6) " The principle of Performance Evaluation ", should promote the renewal of the conventional evaluation method, following to the development of social fulfillment and the advancement of evaluation technology. Accordingly, detailed performance evaluation or design methods established by current knowledge are only exemplified in order to renew easily or select practically.

(2)Basic Structure Performance

Safety, Restoration and Serviceability are itemized. Each of them corresponds to security of human lives and properties, and the function and habitability respectively. Table 2 describes the purpose and the contents of these basic structural performance.

(3)Performance Evaluation Items and Basic Required Performance

Required limit states (should-be conditions) for each basic structural performance to each evaluated objects are itemized and described in general expression. They are general definition (explanation) on the performance to evaluate. In table 3, safety limit for safety performance, damage control limit for restoration performance, and serviceability limit for serviceability performance are set. In the left column of table 3 the items to be evaluate are enumerated. These are structural frame, structural member, non-structural member, equipments/machines, fixture, and soil. Structural member and non-structural member might be arrange into one term of part of building. For example safety limit of structural frame states that non-destruction that affects human life should avoid. And in the safety limit of the part of building, a part of building should not drop off, or scatter.

(4)Kinds of Loads and External Force

Normal time (fixed or live loads, force such as buoyancy, negative friction, each pressure, water pressure etc.), abnormal time of snow, wind, earthquake , others (force such as temperature stress, special earth or water pressure etc.) should be considered. Basic structural performance should be kept against these loads and external forces.

(5)Sizes of Loads and External Force

They are fixed corresponding to the basic structure performance. Three level of these and their combination might be set corresponding to the three basic performances; safety, restoration, and serviceability.

(6)Quantitative Definition of the Sizes of Kinds of Loads and External Force

The background and the setting method to define the size are mainly determined in engineering expression.

(7)The Principle of Performance Evaluation

The engineering definition is made for performance to evaluate. In table 4, not only force, but displacement, energy, and acceleration, velocity, all of response value will be used for evaluating structure performance. In all response values, what kind of response value is used should be determined. It means that structure performance is defined by engineering values. Limit value to satisfy performance are the engineering expression on structure performance.

(8)The Evaluation or the Design method

Practical methods for evaluating the structure performance and designing the performance-based building are necessary to be developed with some engineering judgments (engineering criteria). The response value of performance to evaluate and the limit value to satisfy the performance set in (6) " The principle of Performance Evaluation ", should promote the renewal of the conventional evaluation method, following to the development of social fulfillment and the advancement of evaluation technology. Accordingly, detailed performance evaluation or design methods established by current knowledge are only exemplified in order to renew easily or select practically.

(9)Research items

The following items are considered as necessary research and development subjects.
1) The relation between damage degree and deformation of each member, energy, representative deflection to check.
2) The relation between damage degree and deformation of the whole building, energy and damage distribution along building height.
3) The engineering condition of fracture.
4) The background study to determine the level of loads and external forces.
5) Practical methods for evaluating the structure performance and designing the performance-based building adopting the latest research and developing technology.
6) Monitoring the performance of building, especially after earthquake.

Technical Committee 2: Target Performance Level (Chairman: Prof. Y. Aoki of the Tokyo Institute of Technology)

The main purpose of the Committee is to clarify the recognition and the requirements of owners and users for building structures, and to investigate desirable performance items and levels of building structures from the side of the society. At present (in 1996-1997), as the important subjects, the Committee are collecting and arranging the research data to clarify the performance levels and investigating the methodology to determine the performance levels.

(1) Calibration Working Group
This working group clarifies the performance levels of the building structures according to the present design standards, and examines whether the buildings by the new performance-based structure design standards have equivalent performance levels to the present buildings.
(2) Back Ground Risk Working Group
Safety levels required for building structures are investigated by comparing seismic risks with various kinds of risks existing in human daily lives, considering the characteristics of the risks.
(3) Feasibility Study Group Related to Performance Levels
This study group investigates the recognition and the requirements of owners and users for building structures by questionnaires etc. and their analyses, and the methodology to determine performance levels in a theoretical manner.

Technical Committee 3: Social System (Chairman: Dr. Yano of Nikken Sekkei Inc.)

The purpose of this Committee is to propose a menu of ideal social systems matching the purpose of performance-based design and engineering. Thus, the Committee deals with the problems on design review system, qualification of structural engineers, role of building officials and so on.

In 1995, we began with gathering information on past surveys to gain a better understanding on all elements related to the social system issues, including structural design, construction supervision, building confirmation and inspections, the "kentikushi" system (the qualification system of building engineers in Japan), design codes and regulations. At the next step, we put in order the findings and prioritized problems and issues which must be studied.

On the other hand, in April of 1996 it was officially decided by MOC that the Building Standard Law of Japan should be converted into that based on performance. Considering this change of policy, the Committee has also begun to deal with social systems preferable under the "new performance-based building standard law" that will be realized in a few years, in order that the future law will function smoothly and efficiently. In November of 1996, the Social System Committee established two Working Groups on 1) the survey of the Current Conditions of Social System(WG 1) and 2) the study on desirable Social Structure(WG2).

The contents of the examinations in the Committee and WGs are described below in more detail:

(1) Consideration on the concept of "social system" and its constituent elements(Committee),
(2) Surveys by questionnaire to structure engineers in order to grasp a gist of problems incorporated in the current states and to consider possible solutions toward desirable social systems(WG1),
(3) Identification of issues inherently involved in the "construction process relating to structural performance," which should also be supported by the social systems(WG2), and
(4) Study of ideal social systems compatible with performance-based design and engineering(WG2).

Need For International Coordination/Cooperation

In accomplishing a new structural design world in each country, it is hoped that international harmony and consistency in the conceptual framework on the new system will be attained considering the progressing borderless world. For this aim, an "international committee" is under consideration to be formed in the BRI National Program.

Partly for an initial step of the above action, a Japan-U.S. Workshop on Seismic Building Codes (Performance Based Seismic Engineering of Buildings) was held at the Earthquake Engineering Research Center, University of California, Richmond, CA. The main objectives of the workshop were:
1) to discuss the adequacy and efficiency of present Japanese and U.S. seismic codes in light of the experience derived from recent (1985-1995) significant earthquakes (particularly the 1994 Northridge and the 1995 Kobe earthquakes), and from studies conducted in the last ten years, and to identify problems whose solutions need improvement,
2) to discuss what can be done to improve present seismic code approaches, with particular attention to the interim recommendations for engineering procedures that the Vision 2000 Committee of the SEAOC has recommended for obtaining buildings with predictable and defined performance; and
3) to discuss the development of a work plan and the organization that will be needed to formulate the basic concepts and framework that can be used in Japan and the U.S. to develop practical seismic code regulations whose applications will result in facilities whose seismic performance will be predictable with a reasonable degree of confidence under the different types of earthquake ground motions that can occur during their service life.

The resolutions and recommendations of the Workshop are fully introduced in Appendix. The recommendations of the Workshop should be thought very significant to break through current blocked situations in the structural design/engineering world and to make progress in international harmony related to a future structural engineering system based on performance.

Just one year after the 1995 Hyogo-Ken-Nanbu Earthquake, and two years after the 1994 Northridge Earthquake, the Seventh U.S.-Japan Workshop on the Improvement of Structural Design and Construction Practice was held. At that time we held a special meeting with some members of SEAOC and ATC to discuss the international coordination and cooperation as the second step. In this meeting, the recommendation was re-affirmed and the following items were recommended.

1) Each side should establish a balanced high level policy/coordination committee with no more than seven members plus ex-officio members from participating governmental agencies.
2) Formal cooperation should be continued between Japan and U.S. Next meeting should be held as soon as possible after formation of the high level committee : preferably within six months from this meeting.

References

(1) H. Yamanouchi, 1992, "An Approach to Performance-Based Design System," the 5 the U.S.-Japan Workshop on the Improvement of Building Structural Design and Construction Practices, ATC-JSCA Joint Workshop, San Diego, Sept. 8-9.

Table 1 R/D Project for Performance Based Design

Development of Performance Based Structural
Design System in Japan

Three-year Project from 1995 Fiscal Year

Main Subjects

- Develop Performance Based Structural Design System
  (Not only seismic performance but also other performance)
- Convert specific code to performance code inBuilding Standard Law
- Propose Social System for Performance Based Code

Pre-study of Performance Based Design from 1992 in cooperation with the Kozai Club (Non-profit corporation consisting of steel makers)

Organization of R/D Project on Performance
Based Design System in Japan

Technical Committee

Convener: Professor Okada: Tokyo Univ.

Sub Committee 1

Evaluation of Performance

Convener : Professor Akiyama : Tokyo Univ.

Concept of performance of structure
Definition of performance
Measure of performance

Design seismic action, design loads and so on,

Under this sub committee, there are some Working Groups.

Sub Committee 2

Object Performance Level

Convener : Professor Aoki: Tokyo Institute of Tech,

Opinion of clients and users of buildings
Importance category of buildings
Acceptable risk and so on.

Sub Committee 3

Social System

Convener : Dr. Yano: Nikken Sekkei

Construction procedures
Design review
Qualification of engineers
Role of building officials and so on.

An International Committee (under consideration)

Table 2 Basic Structure Performance (required performance)

1) Safety
The purpose to request performance : To avoid hazard which directly affects human lives inside and outside of the buildings. (security o f human lives)

The contents to evaluate performance : To prevent fracture appropriately regarding safety on structure frames, members, interior and exterior finishing materials.

2) Restoration
The purpose to request performance : To secure the repairing ability to the damagecaused by the outer stimuli to the buildings.

The contents to evaluate performance : To control deterioration and damage degrees on structure frames and members, interior and exterior finishing materials, utensils and foundation in he light of repairing ability

3) Serviceability
The purpose to request performance : To secure serviceability (function) and habitability of the buildings

The contents to evaluate performance : To eliminate harmful deformation or vibration on structure frames and members, interior and exterior finishing materials, facilities and foundation in the light of serviceability

Table 3 Evaluated Objects and Fundamental Performance

Perform. / Objects	Safety Limit (keep of Human Life)	Damage Control Limit (keep of Properties)	Serviceability Limit (keep of Function)
Structural Frame	Non-destruction*1 to human life	*within* Assigned Damage	Non-Harmful*2 Def. or Vib. for normal use
(Structural Members)	Non-destruction*1 to human life	*within* Assigned Damage	Non-Harmful*2 Def. or Vib. for normal use
Non-structure Members	Non-Destruction*1, Drop, Scatter to human life	*within* Assigned Damage	Non-Harmful*2 Def. or Vib. for normal use
Equipments / Machines	Non-Overturn, Drop, Movement by deformation or vibration of structural frames or members	*within* Assigned Damage by deformation or vibration of structural frames or members	Non-Harmful*2 Def. or Vib. of structural frames or members for normal use of equipments / machines
Fixture	Non-Overturn, Drop, Movement by deformation or vibration of structural frames or members	*within* Assigned Damage by deformation or vibration of structural frames or members	—
Soil	Non-destruction*1 (decrease of support ability or change*3 of soil)	*within* Assigned Damage (decrease of support ability or change*3 of soil)	Non-Harmful*2 Change*3 for normal use of buildings or traffic

<Supplement>

(*1) destruction : unbalanced state of energy, force or deformation in static or dynamic response
(*2) harmful : available without interferance in the usual usage
(*3) change : landslide, movement, deformation, decrease of stiffness (ex. by liquilifaction), gap, crack of soil

Table 4-1 Basic Structural Performance : Safety

Principal of Performance Evaluation : Failure that affects human life is evaluated in the term of force, deflection and energy.

Action / Performance item	Permanent (P) D. L. etc	Snow (S)	Wind (W)	Earthquake (E)	Others temp. etc
1) Failure of structural frame	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$ $E_r<E_c$ $I_r<I_c$	$Q_r<Q_c$ $\delta_r<\delta_c$ $E_r<E_c$ $I_r<I_c$	$Q_r<Q_c$ $\delta_r<\delta_c$
2) Failure of structural members (column, beam, floor, wall, roof, foundation, pile etc)	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$ $E_r<E_c$	$Q_r<Q_c$ $\delta_r<\delta_c$ $E_r<E_c$	$Q_r<Q_c$ $\delta_r<\delta_c$
3) Failure or drop off of non-structural member	$Q_r<Q_c$	$Q_r<Q_c$	$\delta_r<\delta_c$ $A_r<A_c$	$\delta_r<\delta_c$ $A_r<A_c$	$Q_r<Q_c$ or $\delta_r<\delta_c$
4) Drop off, overturn of equipment	$Q_r<Q_c$	—	$A_r<A_c$ $V_r<V_c$	$A_r<A_c$ $V_r<V_c$	— —
5) Drop off, overturn of contents	$Q_r<Q_c$	—	$A_r<A_c$ (fix) $V_r<V_c$ (loose)	$A_r<A_c$ (fix) $V_r<V_c$ (loose)	— —
6) Failure of soil	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$	$Q_r<Q_c$ $\delta_r<\delta_c$

Q : force, stress, δ : deflection, E : energy, I : index, A : acceleration, V : velocity
suffix c : criteria(limit value), suffix r : response
[ ] : evaluation method has been temporarily provided.

Table 4-2 Basic Structural Performance : Damage Control

Principal of Performance Evaluation : Damage control limit determined by the economic and technical point of view is evaluated in the term of force, deflection and energy.

Action / Performance item	Permanent (P) D, L etc	Snow (S)	Wind (W)	Earthquake (E)	Others temp. etc
1) Damage of structural frame	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$ $E_r < E_c$ $I_r < I_c$	$Q_r < Q_c$ $\delta_r < \delta_c$ $E_r < E_c$ $I_r < I_c$	$Q_r < Q_c$ $\delta_r < \delta_c$
2) Damage of structural members (column, beam, floor, wall, roof, foundation, pile etc)	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$ $E_r < E_c$ $I_r < I_c$	$Q_r < Q_c$ $\delta_r < \delta_c$ $E_r < E_c$ $I_r < I_c$	$Q_r < Q_c$ $\delta_r < \delta_c$
3) Damage of non-structural member	$Q_r < Q_c$	$Q_r < Q_c$	$\delta_r < \delta_c$ $A_r < A_c$	$\delta_r < \delta_c$ $A_r < A_c$	$Q_r < Q_c$ oc $\delta_r < \delta_c$
4) Damage of equipment	$Q_r < Q_c$	—	$A_r < A_c$ $V_r < V_c$	$A_r < A_c$ $V_r < V_c$	— —
5) Damage of contents	$Q_r < Q_c$	—	$A_r < A_c$ (fix) $V_r < V_c$ (loose)	$A_r < A_c$ (fix) $V_r < V_c$ (loose)	— —
6) Damage of soil	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$	$Q_r < Q_c$ $\delta_r < \delta_c$

Q : force, stress, δ : deflection, E : energy, I : index, A : acceleration, V : velocity
suffix c : criteria(limit value), suffix r : response

Table 4-3 Basic Structural Performance : Serviceability

Principal of Performance Evaluation : Deflection or vibration that affects normal usage is evaluated in the term of force, deflection, vibration and velocity.

Performance item \ Action	Permanent (P) D. L. etc	Snow (S)	Wind (W)	Earthquake (E)	Others temp. etc
1) Deflection or vibration of structural frame	$\delta r < \delta c$	$\delta r < \delta c$	$\delta r < \delta c$	$\delta r < \delta c$	$\delta r < \delta c$
	$f r < f c$	$f r < f c$	$f r < f c$	$f r < f c$	$f r < f c$
2) Deflection or vibration of structural members (column, beam, floor, wall, roof, foundation, pile etc)	$\delta r < \delta c$ $Q r < Q c$	$\delta r < \delta c$ $Q r < Q c$	$\delta r < \delta c$ $Q r < Q c$	$\delta r < \delta c$ $Q r < Q c$	$\delta r < \delta c$ $Q r < Q c$
	$f r < f c$	$f r < f c$	$f r < f c$	$f r < f c$	$f r < f c$
3) Deflection or vibration of non-structural member	$Q r < Q c$	$Q r < Q c$	$\delta r < \delta c$ $A r < A c$	$\delta r < \delta c$ $A r < A c$	$Q r < Q c$ oc $\delta r < \delta c$
4) Deflection or vibration of equipment	$Q r < Q c$	—	$A r < A c$ $V r < V c$	$A r < A c$ $V r < V c$	— —
5) Deflection or vibration of soil	$Q r < Q c$ $\delta r < \delta c$	$Q r < Q c$ $\delta r < \delta c$	$Q r < Q c$ $\delta r < \delta c$	$Q r < Q c$ $\delta r < \delta c$	$Q r < Q c$ $\delta r < \delta c$

Q : force, stress, δ : deflection, f : vibration, A : acceleration, V : velocity
suffix c : criteria(limit value), suffix r : response

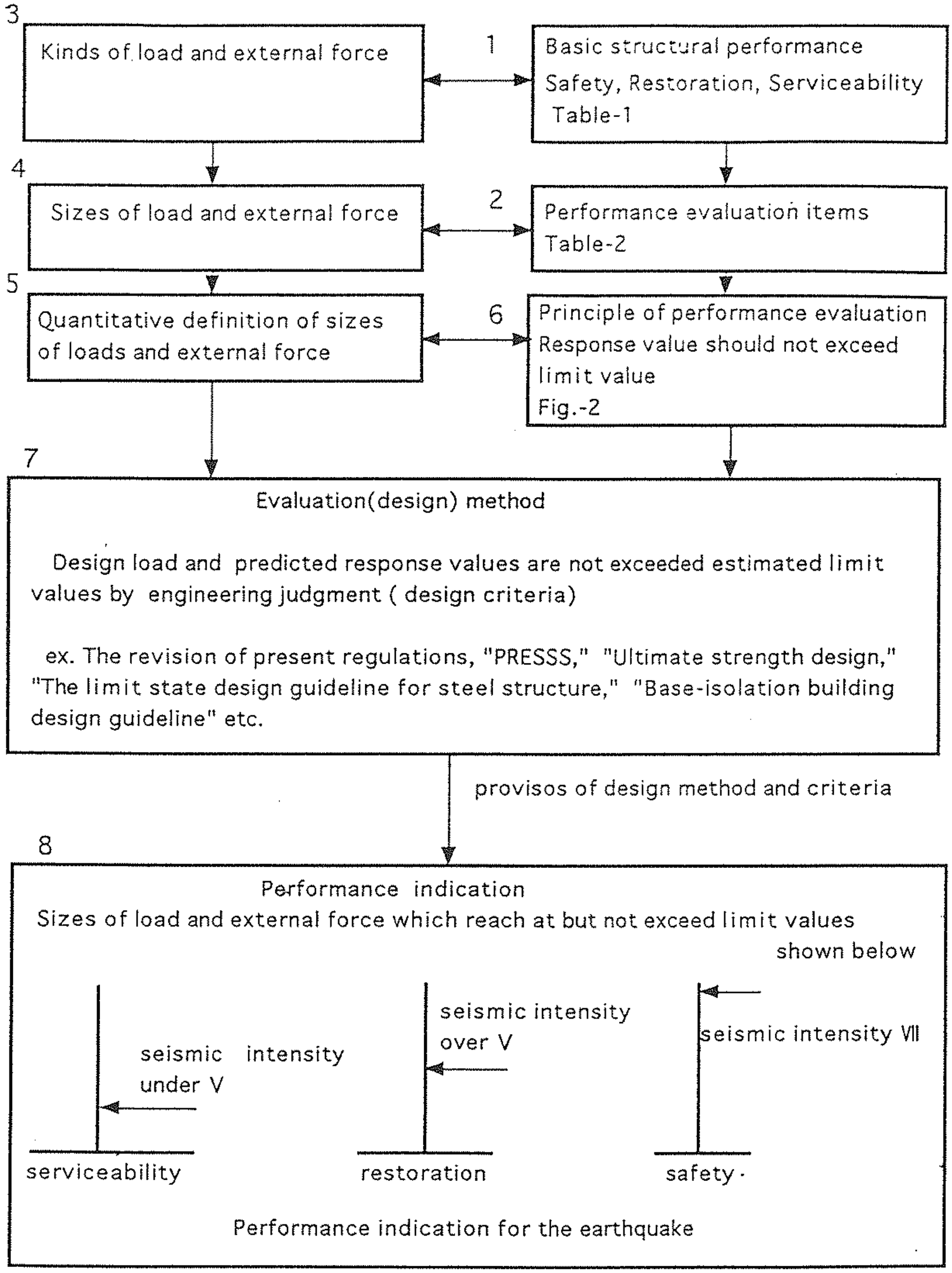

Fig. --1 EVALUATION SYSTEM OF STRUCTURE PERFORMANCE