# SAFETY ANALYSIS

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## Contents



## Summary

Basic principles for assurance of safety and functionality of structures are stated, on which design concept and frameworks are formulated. It is emphasized that various types of uncertainties must be taken into consideration in order to attain quantitative evaluation of structural safety in design practice, and consequently reliability based design with appropriate performance functions is required worldwide. International design standard, the 1998 ISO/FDIS2394, is taken up as a common basis for defining design rules relevant to the construction and use of the wide majority of buildings and civil engineering works.



## 1. Design Principle

In design of structures, primarily emphasis is placed on the assurance of safety and functionality commonly of buildings and civil engineering works, marine structures, mechanical instruments, automobiles, aircrafts, etc. Minimum construction cost without extravagance and harmony of a structure with the environment are also required as the prerequisite criteria in design. However, sufficient safety against various modes of failure among many other criteria is the most essential requirement. If limited to buildings and civil engineering works, safety requirement is the most important matter, since they are built fixed on the earth and are exposed inevitably to various natural hazards such as earthquakes or wind turbulence during the life time. The safety of a structure is measured by the safety margin of structural resistance capacity to acting loads, both of which involve various types of uncertainties, typically such as deviation of material strength or unpredictable intensity and occurrence of earthquake load. Consequently, we can in no way attain the absolute safety and always allow some degree of acceptable risk in design.

In structural design, we consider two limit states for a structure to be designed. One is called an ultimate limit state beyond which the structure no longer satisfies the design performance requirements associated with collapse, or other similar forms of structural failure, and the other is called a serviceability limit state which corresponds to conditions beyond which specified service requirements for a structure or structural elements are no longer met. Typical examples for an ultimate limit state are loss of equilibrium of a structure or a part of the structure, considered as overturning and attainment of the maximum resistance capacity of the structure such as fatigue, corrosion or excessive deformations, etc.

Serviceability limit states include local damage like cracking, unacceptable deformations which may reduce the working life of a structure and excessive vibrations which cause discomfort to people, etc. In the design, these states are expressed in the form of mathematical expressions, namely a performance function or a design evaluation equation or a limit state function. These mathematical expressions are necessary since the evaluation of safety is conducted numerically for a structural model and a load model. Then, design is defined based on performance functions by such an engineering process as to retain safety within the allowable risk during a specific reference period, where the two limit states usually consist of plural states dependent on types of structures respectively.

## 2. Uncertainties for Structural Systems and Acting Loads

As stated, there are many kinds of uncertainties involved in design. If there is no uncertainty, the safety margin is not necessarily taken into consideration in the evaluation of structural performance. To specify the nature of uncertainties and to reflect it properly on design lead to appropriate safety analysis. Uncertainties are classified into four categories, namely probabilistic uncertainty, statistical uncertainty, model uncertainty and human error uncertainty.

Probabilistic uncertainty is uncertainty which is inherent to probabilistic nature such as deviation of material strength, and this uncertainty can not be eliminated even if data are accumulated. Thus, the quantitative evaluation of this uncertainty can only be done by using probability theory. Statistical uncertainty is uncertainty due to inaccuracy of distribution and parameters estimated from limited numbers of sample data. Model uncertainty comes from the gap between modeling simplification and the reality. Human errors are presumably involved in design and construction, but must be eliminated by appropriate actions such as a measure by total quality control during the stage of design and construction plus maintenance.

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## Bibliography

ISO/FDIS 2394. (1998). General principles on reliability for structures. [This is the final draft international standard, ISO, which constitutes a common basis for defining design rules relevant to the construction and use of the wide majority of buildings and civil engineering works.]

SEAOC. (1995). Vision 2000 – A Framework for Performance-based Design of Buildings. Volumes 1-4. Structural Engineers Association of California, Sacramento, CA, USA. [This is a recommendation report for long term development of performance- based design methods focused on the concepts of capacity design and a comprehensive design methodology.]

## Biographical Sketch

**Masaru Hoshiya** was born on October 23, 1937. He received B.S. in Civil Engineering, University of Tokyo, in 1963
M.S. in Civil Engineering, University of Pennsylvania, in 1966, and Ph. D. in Civil Engineering, Stanford University, 1969**.** He was a Bridge Design Engineer with Hitachi Ship Building Co., Osaka during1963-1968, Assistant Professor, Dept. of Engineering Mechanics and Science, Virginia Polytechnic Institute and State University during1969 – 1971, Associate Professor, Dept. of Civil Engineering, Musashi Institute of Technology, Tokyo, during 1971-1977, and is presently Professor, Dept. of Civil Engineering, Musashi Institute of Technology, Tokyo since 1977.His research interests are in the areas of (1)Structural Reliability and Risk Management, (2)Random Vibration, and (3)Structural Identification and Control and has many publications in these.