and nonstructural components. This is the best way to avoid creating complex problems (soil-structure interaction, foundation movements, torsional effects, etc.). When these restrictive regulations are not followed, the code needs to specify that simple code procedure should be complemented with dynamic, linear and nonlinear procedures, which should be subjected to peer review.

PROBLEMS INVOLVED IN EQRD. From the flow diagram of general aspects involved in EQRD shown in Fig. 7, it is clear that seismic codes should regulate:

(1) selection of building sites, siting restrictions, land use, and building site suitability analysis;
(2) establishment of design EQs, EQRD criteria, and design methodology;
(3) restrictions and/or guidelines regarding proper selection of building configuration, foundation, structural layout, structural system, structural material and nonstructural components;
(4) estimation of demands on a structure and its content at the different levels of design EQs;
(5) estimation of the supplied capacities to a structure;
(6) analysis of the performance of a designed structure under different established levels of design EQs.

As stated earlier, review of the research results on the importance and effects of these general aspects of EQRD of structures indicates that the principal issues that remain to be resolved for improving such design are related to the following three basic elements: **EQ input, demands on the structure,** and **supplied capacities to the structure.** After a brief review of how seismic codes in the U.S. have been developed and have attempted to resolve the above issues, this lecture will focus on the first of these, the EQ input element, which involves the following interrelated issues: **design EQs, design criteria, and selection of design methodology.** The importance of proper establishment of the design EQs is summed up as **the need to know against what we have to design the structure.** As discussed earlier, while the design EQ is conceptually that motion which will drive the building to its critical response, the application in practice of this simple concept meets serious difficulty because of the great uncertainties in predicting the dynamic characteristics of future EQGMs and the variations in the critical response of a specific structural system according to the various limit states that could control the design. Therefore, design EQs depend on the design criteria. Design criteria should reflect in a transparent way the general philosophy of EQRD, which has been well established and is accepted world-wide. However, as will be discussed below, current code design methodologies fall short of realizing the goals of this philosophy [2, 8].

General Philosophy of EQRD. The general philosophy of EQRD of buildings sheltering other than essential and hazardous facilities was introduced in the U.S. in the commentary of the 1967 edition of the SEAOC Blue Book [17].

Except for a more precise wording of the principles involved in such a philosophy, these general principles are practically the same as those stated in the commentary of the 1988 edition of the SEAOC Blue Book [17], which are the following:

1. Prevent nonstructural damage in minor EQ ground-shakings, which may occur frequently during the service life of the structure;
2. prevent structural damage and minimize nonstructural damage during moderate EQ ground-shakings, which may occasionally occur;
3. Avoid collapse or serious damage during severe EQ ground-shakings, which may rarely occur

Ideal Philosophy of EQRD. Recognizing both that the acceleration and deformations that can be developed during the response of building systems to severe and even to moderate EQGMs are very high, and that there are many uncertainties in the estimation of demands and supplies, the ideal philosophy should attempt to realize all of the objectives of the above general philosophy by providing all the needed stiffness, strength, and energy dissipation capacity that can be accomplished with the minimum possible extra cost in initial construction and the slightest possible sacrifice of architectural features compared with the building as designed for just gravity loads.

The above general philosophy is in complete accord with the concept of comprehensive design. However, current code design methodologies fall short of realizing the goals and objectives of this philosophy.

Although the commentary on the SEAOC recommendations [17] states that structures designed in conformity with these recommendations should, in general, be able to accomplish the objectives of the above general philosophy, **in fact these recommendations are primarily intended to safeguard against major failure and loss of life, and not to limit damage, maintain functions, or provide for easy repair. In few words, current code design methodology is based on a one-level design EQ.** Moreover, the SEAOC commentary states, **"the protection of life is reasonably provided but not with complete assurance."** To summarize, the primary goal of the U.S.

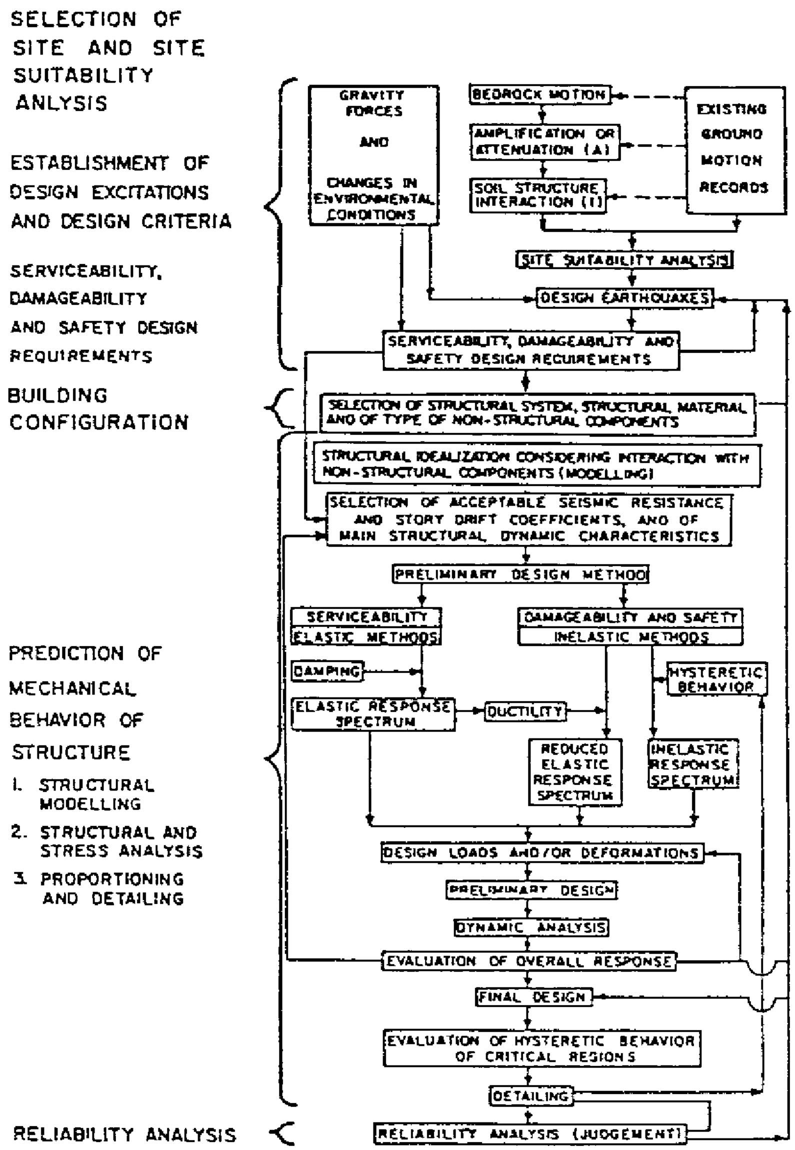

Fig. 7 FLOW DIAGRAM OF GENERAL ASPECTS AND STEPS INVOLVED IN EQRD

seismic provisions is the protection of life. **The secondary goal is to reduce (not eliminate) property damage.** The questions that need to be answered are: **(1) does the application of current seismic code provisions accomplish the above goals?**; and **(2) are these goals sufficient?** Before attempting to answer these questions, it is convenient to review the philosophy of building codes, particularly seismic codes, and to review the history and development of these codes.

U.S. Building Codes and Standards. Building codes in the U.S. are primarily technical legal requirements adopted by government agencies, specifying **minimum standards** for the design, manufacture, installation and use of building materials and components.

Code Philosophy. Although the primary function of a building code is to **provide minimum standards to assure public safety**, it usually has other objectives also. For example, the intention of the Uniform Building Code (UBC) [18] is clearly stated in its Section 1.02:

> The purpose of this code is to provide minimum standards to safeguard life or limb, health, properties, and public welfare by regulating and controlling the design, construction, quality of

materials, use and occupancy, location and maintenance of all building and structures within this jurisdiction and certain equipment specifically regulated therein.

In view of the above code purpose, it is not surprising that the SEAOC has established a seismic code philosophy that is in accordance with the above purpose of building codes. **Thus, the basic philosophy of the SEAOC seismic code and most of the other seismic codes, has been to protect the public in and about buildings from loss of life and serious injury during major EQs.** However, some owner-sponsored codes have gone further than this. For example, already in 1967, Chapter 21, Title 24 of the California Administrative Code related to the design and construction of public school buildings included, as its added purpose, the protection of property; i.e., this code is interested in minimizing damage as well as protecting the occupants. In 1975, Titles 17 and 21 of the administrative code related to the design and construction of hospitals and public school buildings include, as their added purpose, the protection of property. At present, Title 24 of the California Administrative Code regarding hospitals has the additional purpose that hospitals remain operational after an EQ.

History of Seismic Design Codes. The 1980 edition of the Structural Engineers Association of California (SEAOC) Blue Book [17] describes the history of EQ codes in California. Table 1 summarizes the history of seismic design codes and their provisions in the U.S. [13 (1982)].

The first EQ design requirements appeared in the 1927 edition of the Uniform Building Code [18]. Although these provisions were never put into effect in any city, they required all buildings over twenty feet in height, except non-fire-protected steel frame and wood frame buildings, to be designed for a lateral force applied at each floor level and at the roof level generally parallel to the two main axes of the structure. The force required was a percentage of the total dead and live loads, with the exception of buildings with a live load not over 50 pounds per square foot, for which only a percentage of the dead load was required. Structures on soils with a bearing value of two or more tons per square foot were to be designed for 7.5% of their vertical loads, and those with lesser soil-bearing value and those on piles were to be designed for 10% of their vertical loads.

When seismic requirements first appeared in building codes and were put into effect, practically nothing was known about EQ engineering. The 1933 Los Angeles Building Code, for example, merely stated that a building should be designed to withstand a steady horizontal thrust equal to 8% of its weight, in effect treating EQ forces in the same way it treated wind pressures. During recent years, the understanding of EQ engineering problems, and hence of seismic design, has undergone remarkable development. In the U.S., this was made possible largely by research after World War II on military protective structures, and after 1960 by the EQ engineering research programs in the U.S. as well as in Japan and other countries.

Building codes by which ordinary buildings are designed have also developed impressively, so that they are now much better suited to guide realistic design against EQ forces. Clearly, present methods of EQRD in the U.S. represent an outstanding improvement over methods available 20 or even ten years ago, particularly in regard to sizing and detailing of the superstructures of ordinary buildings. To elaborate on this, it is convenient to recognize that seismic code provisions can be classified into the following two main groups.

1. **Earthquake-Resistant Criteria.** This group covers the basis for design and the specifications of the minimum lateral forces and related effects (estimation of seismic demands), and will be discussed in more detail below.
2. **Material Code Specifications.** This group regulates sizing and detailing of the structure.

In the last two decades there have been tremendous improvements in the code specifications for the sizing and detailing of structural members and their connections and supports. Figure 8 illustrates the changes in the spacing of ties in the EQRD of RC columns. Although the importance of providing the structure with large **ductility** was recognized already in the 1959 SEAOC-recommended requirements, special provisions regarding the design of RC EQ-resistant structures first appeared in the 1971 edition of the ACI Code [19]. Because the amount and detailing of transverse reinforcement for achieving high ductility demands depart somewhat from the requirements of the ordinary practice in RC design and construction, the cost is higher for EQRD. This higher cost has caused some concern and the complaint that there may have been too much emphasis on creating ductility for ductility's sake [15]. This has also raised the following valid question: **"How do we design less ductile structures which are sufficiently reliable against earthquakes?"**

Regarding these complaints and questions, the lecturer believes that ductility requirements should not be relaxed in seismic design, at least until the results of new and reliable research and developments become available to justify such relaxation. **These stringent requirements for sizing, and particularly for detailing, have been the blessing of current code seismic design procedure.**

TABLE 1 -- HISTORY OF SEISMIC DESIGN CODES IN THE UNITED STATES

Date	Code or Provisions
Post-1906	San Francisco rebuilt to 30 psf wind
1927	First seismic design appendix in Uniform Building Code: V=CW (C=0.075 to 0.10)
1933	Los Angeles City Code: V=CW (C=0.08) - First reinforced seismic code
1943	Los Angeles City Code: V=CW [C=60/(N+4.5)] - N greater than 13 stories
1952	ASCE-SEAONC ($C=K_1/T_1$) (K_1=0.015-0.025)
1959	SEAOC V=KCW, $C=0.05/(T)_{1/3}$
1974	SEAOC V=ZIKCSW
1976	UBC V=ZIKCSW
1977	ATC-3 Tentative Recommendations $V=C_sW$, $C_s=1.2\ A_v\ S/RT \leq 2.5\ A_a/R$
1988	SEAOC $V=ZIC\ W/R_w$, $C=1.25\ S/T^{2/3} \leq 2.75$ $C/R_w \geq 0.075$

NOTE: *W=weight of building, V=base shear, T=period of vibration, N=number of stories, C,K,Z,I and S=numerical coefficients (C was originally a seismic design coefficient, but in codes later than 1943 a numerical coefficient dependent on T; Z=dependent on the zone in a seismic risk map; I=occupancy importance factor; and S=site-structural resonance or soil-profile coefficient), C_s=seismic coefficient, A_v=effective peak-velocity acceleration, A_a=effective peak acceleration, R=response modification factor, and R_w=numerical coefficient (called system quality factor)*

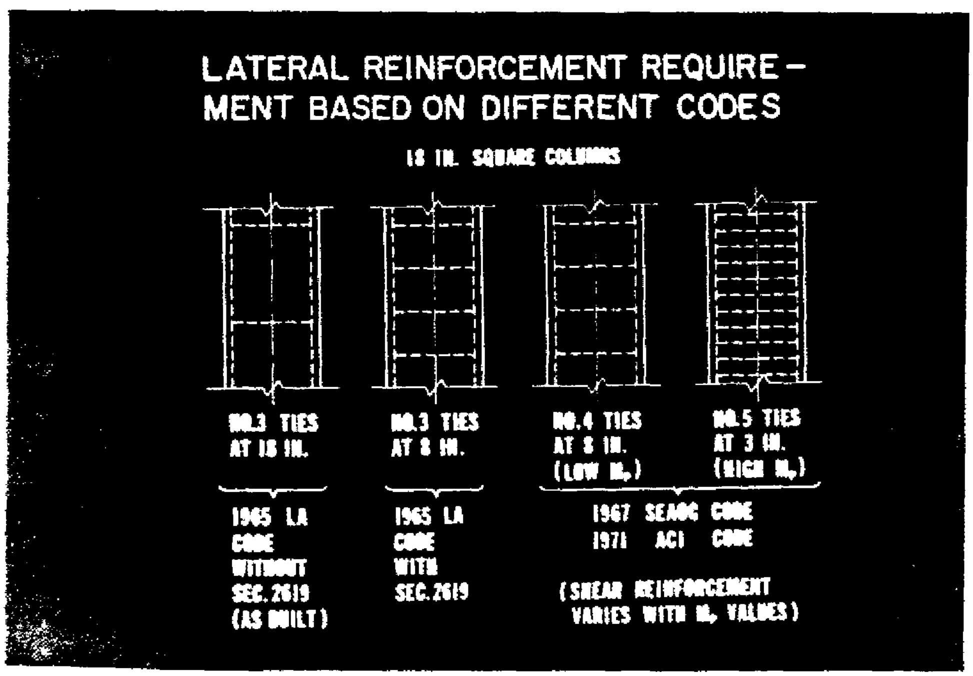

Fig. 8 ILLUSTRATION OF THE CHANGES IN CODE LATERAL REINFORCEMENT REQUIREMENTS

There are many uncertainties involved in the estimation of the demands and supplies in EQRD procedure As discussed below, the present code specifications for estimating seismic lateral forces and their effects are far from reliable. Thus, the reliability of present code EQ-resistant methodology is questionable. It is for this reason that **the lecturer believes that stringent sizing and detailing requirements, rather than complex numerical analyses conducted to comply with code formulae for estimating demands, have permitted many buildings to survive recent moderate-to-severe EQGMs.**

U.S. Code Earthquake-Resistant Design Criteria: Estimation of Demands. There are several sources of uncertainty in the estimation of demands. They can be grouped into two categories: (1) specified seismic forces, and (2) methods used to estimate response to these seismic forces.

(1) **Estimation of Seismic Forces.** For regular buildings, the lateral seismic forces can be derived as follows.
(a) Base Shear:

$$V = C_s W = \frac{C_{sp}}{R} W \tag{5}$$

where V is base shear, C_s is defined as the design seismic coefficient, W is the weight of the reactive mass (i.e., the mass that can induce inertial forces), C_{sp} is the seismic coefficient equivalent to a linear elastic response spectral acceleration, S_a, ($C_{sp}=C_sR=S_a/g$), and R is the reduction factor.
(b) Distribution of Base Shear over the Height of the Structure:

$$V = F_t + \sum_{i=1}^{n} F_i \tag{6}$$

where F_t is concentrated force at the top and represents the effects of higher modes (whiplash effect) and:

$$F_i = \frac{(V-F_t)w_i h_i}{\sum_{i=1}^{n} w_i h_i} \tag{7}$$

is the force at level i (usually the floor level, w_i is the portion of W located at or assigned to level i. and h_i is the height above the base to level i.

(2) **Estimation of Structural Response to Seismic Forces.** Structural response can be estimated using linear elastic analyses, either directly using the above statically equivalent lateral forces (Eqs. 6 and 7), or multiplying them by load factors, depending on whether the design will use allowable (service) stress or strength method.

The uncertainties involved in the estimation of base shear and its distribution over the height of the structure, as well as the reliability of the procedures and values specified by present U.S. seismic codes, have been discussed in detail in Refs. 5, 6 and 8.

A review of the history of how the values for the base shear resistance (Table 1) have been computed clearly shows that the equation recommended for its evaluation has become more and more sophisticated and requires more and more empirical numerical coefficients. However, what is really surprising is that the code requirement for base shear resistance remains practically the same as the first seismic code in 1927, and has even been reduced. as is shown by comparing Tables 1 and 2. This is surprising, because the building technology of the 1930's was quite different from the present one, and resulted in buildings with significantly lower overstrength.

As indicated in Tables 1 and 2, SEAOC introduced significant changes in their code recommendations in 1988 by adopting some of the 1977 ATC-3 recommendations. The new SEAOC recommendations have been adopted in the 1988 UBC [18]. Although these recent codes and recommendations recognize the severity of seismic hazard for different seismic zones in the U.S. and incorporate modern seismic design philosophies and approaches, they continue to place too much emphasis on designing for a yielding strength capacity which is the same as, or even lower than, that which resulted from applying the provisions of the first U.S. seismic code regulations in 1927.

The lecturer has recently analyzed present trends in EQRD and construction of buildings in the U.S. and has made the following observations.

(1) Recent code recommendations recognize the probable occurrence of very severe EQGMs at a given site

located in a region of high seismicity (high intensity and long duration of EQGMs). In spite of this fact and the significant changes in building construction technology, there has been very little change in the overall seismic coefficient for which buildings must be designed.

(2) The code continues to place too much emphasis on strength design based on fictitious seismic forces and linear elastic analyses of their effects.

(3) Because of economic pressures, designers try hard to comply with just the code minimum requirements for strength.

(4) The development and use of computer programs based on optimal design of members of a structure will lead to final designs with very little overstrength with respect to the code- required minimum strength.

(5) The use of very light and weak nonstructural elements (walls, partitions, claddings, etc.) which, furthermore, are built in such a way that their performance will not interfere with the deformation of the structure, results in buildings whose strength and stiffness are just those of the bare structural system.

TABLE 2 -- COMPARISON BETWEEN:

(1) EXPRESSIONS FOR THE EFFECTIVE SEISMIC COEFFICIENT, $C_s=V/W$, SPECIFIED BY THE 1985 UBC, THE ATC-3 AND THE 1988 SEAOC RECOMMENDATIONS;

UBC	ATC	SEAOC
ZIKCS	$\frac{1.2\ A_v\ S}{RT^{2/3}}$	$\frac{ZIC}{R_w}$
$C=\frac{1}{15\sqrt{T}}$		$C=\frac{1.25\ S}{T^{2/3}}$
$\frac{ZIKS}{15\sqrt{T}}$	$\frac{1.2A_v\ S}{RT^{2/3}}$	$\frac{1.25ZIS}{R_w T^{2/3}}$

(2) THE VALUES OF C_s FOR DUCTILE MOMENT-RESISTANT SPACE FRAMES, DMRSF, IN REGIONS OF HIGH SEISMIC RISK.

	UBC	ATC	SEAOC
	(K=0.7)	(R=8)	(R_w=12)
	$\frac{0.51\ S}{12\sqrt{T}}$	$\frac{0.060\ S}{T^{2/3}}$	$\frac{0.042\ IS}{T^{2/3}}$
	For I = 1 and T = 1 sec.		
V	0.045 S	0.060 S	0.042 S
Vu	0.063 S	0.060 S	0.059 S

All of the above developments and trends result in the construction of buildings with very little overstrength beyond the minimum code-required strength. **There is an urgent need for calibration of the real strength and stiffness of buildings that have been designed and constructed according to present codes. There can be no improvement in the EQRD of new buildings, in seismic performance evaluation of existing buildings, or in vulnerability assessment and upgrading of hazardous buildings, if there is no improvement in predicting stiffness, strength, and energy absorption and dissipation capacities of real building systems (soil-foundation-superstructure and nonstructural components).**

In recent years there has been an increasing amount of research on design concepts based on probabilistic approaches. This activity has resulted in a re-examination of past data, a close analysis of design concepts, and a formulation of design provisions to make the latter more logical for practitioners. Much remains to be done to apply such research to assessments of seismic risk, particularly in areas of low seismic activity, and to adapt such research to practical design and construction.

Comparison of Current Seismic Code Provisions. There are many seismic codes and recommended seismic provisions in the U.S. The lateral force requirements of the U.S. seismic codes are compared and discussed in Ref. 20. Analysis of comparisons of U.S. codes with the present seismic codes of Europe, Chile, Japan, Mexico D.F. and New Zealand makes clear that there are some significant discrepancies among the seismic provisions of the current codes. It is believed that this is a consequence of the fact that seismic codes, of necessity, are generalized