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PERFORMANCE-BASED SEISMIC ENGINEERING:CONVENTIONAL VS. INNOVATIVE APPROACHES

Vitelmo V. BERTERO[1]

SUMMARY

After historical and critical reviews of the state of the art and of the state of the practice of ***Performance-Based Seismic Engineering (P-B SE)*** and the role and importance of ***Performance-Based Earthquake-Resistant Design (P-B EQ-RD)***, this paper briefly discusses a comprehensive approach for P-B EQ-RD of civil engineering facilities based on the use of energy concepts. The paper then attempts to answer the following questions: (1) Why do we need innovative approaches in ***Earthquake Engineering (EE)***? (2) What are innovative approaches? (3) When can such innovative approaches be efficiently used? (4) How have these approaches been applied in practice? and (5) What are the impediments to the implementation of such approaches? Based on the use of the energy balance equation, a flow chart classifying the different conventional and innovative systems is presented. From analysis of the pros and cons of the conventional and innovative approaches, it becomes clear that the use of innovative approaches will result in more efficient control of the damage to structures and nonstructural components. The main impediment for widespread application of these innovative approaches is the lack of, or the over-conservative requirements of, code provisions for the P-B EQ-RD and ***P-B EQ-Resistant Construction (P-B EQ-RC)*** for the use of such innovative approaches and available systems and techniques.

INTRODUCTION

Performance-Based Seismic Engineering: A Historical and Critical Review. The need for designing and constructing civil engineering facilities for predictable performance under all the different types of excitations to which they can be subjected during their lifetime has been discussed for a long time. In the 1960s, recognizing that structural failure generally occurs in successively more severe stages at successively less probable excitations, proposals were made that design should be done ideally following a comprehensive procedure by which the resistances of a structure to the various failure stages (performance levels) are correlated to the probabilities of the corresponding loads (excitations or hazard levels) so that the total cost, including the first cost and expected losses from all the failure stages, is minimized [Sawyer 1964]. The 1967 commentary of the ***Structural Engineers Association of California (SEAOC) Blue Book*** introduced what can be considered the general philosophy of the EQ-RD of buildings sheltering other than essential and hazardous facilities. Essentially, this philosophy states that the following three design objectives should be accomplished: (1) prevent nonstructural damage in minor EQ ground shaking which may occur frequently during the service life of the structure; (2) prevent structural damage and minimize nonstructural damage during moderate EQ ground shaking which may occasionally occur; and (3) avoid collapse or serious damage during severe EQ ground shaking which may rarely occur.

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[1] *Nishkian Professor Emeritus and Research Engineer of the Earthquake Engineering Research Center, University of Californi*

The above general EQ-RD philosophy is in complete accord with the concept of comprehensive design. In spite of the fact that in the 1970s a design methodology based on the two behavioral criteria (design objectives) of collapse and loss of serviceability was developed [Cohn 1972] and was proved to be feasible and practical for EQ-RD of ductile moment-resisting frames [Bertero and Kamil 1975, and Zagazeski and Bertero 1977], current

code design methodologies, at least in the U.S., even today fall short of realizing the goals and objectives of this philosophy. As described by Sharpe [1992], informal discussions among experts (practitioners and researchers) about practical procedures necessary to accomplish designs for predictable performance did not start until about mid-1988 when informal talks began between an ad hoc group of U.S. and Japanese experts.

The relatively limited levels of ***EQ Ground Motions (EQGMs)*** of the M7.1 Loma Prieta EQ in October 1989 caused more than $8 billion in direct damage. This economic loss was judged by the structural engineering profession and public policy makers as too large for this moderate event. Therefore in 1992, the SEAOC Board of Directors established the Vision 2000 Committee to develop a framework for the next generation of a performance-based seismic building code. After several meetings, this committee adopted a Mission Statement and developed a work plan for the committee [Sharpe 1992]. According to this plan, it was determined that a final document containing required EQ-RD provisions would be available by the year 2000. However, the work needed to prepare such a document did not start until about mid-1994. Japanese experts formulated their own plan for the development of a performance-based design approach [Yamanouchi 1992]. The formulated plans were discussed in the 1992 meeting of the U.S.-Japan ad hoc group. While all the previously mentioned informal activities took place, several Japanese and U.S. researchers were carrying out studies for the development of an improved EQ-RD methodology which, based on actual mechanical behavior (performance) of real buildings, would be more reliable than those that were available. In 1992, Connor and Wada presented a framework for performance-based design which was then applied to the development of a new technology for EQ-RD and EQ-RC that originally was denominated as ***Damage Tolerant Structures (DTS)*** [Wada et al. 1992] and later as ***Damage Controlled Structures (DCS)*** [Wada et al. 1999]. In 1992, Bertero, R. and Bertero, V. proposed a conceptual methodology which is in compliance with the worldwide accepted EQ-RD philosophy and is based on well established fundamental principles of structural dynamics, the mechanical behavior (performance) of the entire facility system, and comprehensive design. It takes into account from the very beginning of the iterative EQ-RD procedure the simultaneous demand for deformation, strength, and their combined effects on the demanded and supplied energy capacities of the entire facility system.

In January 1994, the M6.7 Northridge EQ occurred, resulting in losses estimated at more than $20 billion, i.e., more than twice the losses of the Loma Prieta EQ. Engineers and public policy makers alike determined that it is unacceptable to experience this magnitude of loss in these relatively frequent and moderate events. Faced with this problem and with the need to repair, rehabilitate (upgrade), and reconstruct many hundreds of buildings, the California Office of Emergency Services contracted with SEAOC to develop ***Recommendations for Performance-Based Design and Construction Procedures*** which could be used immediately. In one year the SEAOC Vision 2000 Committee developed recommendations for ***Performance-Based Seismic Engineering (P-B SE).*** The report of the SEAOC Vision 2000 Committee [1995] gives detailed discussions of what is understood by P-B SE and recommends a conceptual framework for achieving such P-B SE which encompasses the full range of issues to be addressed in the design, construction, and maintenance of buildings for predictable and controlled seismic performance within established levels of risk. This report includes a discussion of the following different approaches that can be applied to P-B EQ-RD: ***Comprehensive Design, Displacement, Energy, General Force/Strength, Simplified Force/Strength and Prescriptive Approaches.*** These approaches vary in complexity and applicability. These possible design approaches do not comprise an exhaustive list, but represent some of the more promising general design methods. It was highly recommended that each of the design approaches should incorporate the ***capacity design strategy*** [Paulay and Priestley 1992], particularly at the conceptual design and final design stages.

After making an overview of the main issues associated with development and implementation in practice of P-B SE (which requires development of reliable P-B SE code provisions), Bertero, V.V. [1997b] made a critical review of not only the SEAOC guidelines for new buildings but also of the published NEHRP Guidelines for the Seismic Rehabilitation of Buildings [FEMA 273 and 274 Reports, 1997] which is another published resource document on P-B SE with recommendations and/or guidelines which are expected to serve as primary resources for the engineering of new buildings and the seismic upgrading (rehabilitation) of existing hazardous buildings.

COMPREHENSIVE EQ-RD APPROACH FOR P-B SE

The conceptual methodology of the comprehensive EQ-RD approach, developed by Bertero, R. and Bertero, V. [1992], was slightly modified for P-B EQ-RD according to the recommended design objective matrix and the framework for P-B SE. This methodology takes into account from the beginning of EQ-RD procedure, the simultaneous demands (including torsional effects) for strength (C_Y), deformation (δ) and rate of deformation and their combined effects on the ***Energy Input*** (E_I), and on the demanded and supplied energy capacities of the entire facility system and on the acceptable damage at the different limit states associated with the desired performance levels, and with each of the EQGM design ones. The iterative procedure involved in the comprehensive design approach proposed of P-B SE is discussed in detail in Appendix B of the Vision 2000 report. Herein only a brief discussion of the conceptual overall EQ-RD follows.

Conceptual Overall EQ-RD of Entire Facility System. Once the minimum design performance objectives are selected [in accordance with the probable sources of potential seismic hazards and the desired performance (damage)levels] and the site suitability for the construction and maintenance of the desired facility are established the design process of the entire facility system can be started. This process is an iterative one that is carried out in three phases: ***Conceptual Overall Design; Numerical Preliminary Design; and Numerical Final Design and Detailing.***

Definition of Conceptual Overall EQ-RD. Conceptual Overall EQ-RD is the avoidance or minimization of problems that can be created by the critical combination of the seismic effects with other probable excitations, using the physical understanding of the dynamic behavior of the entire facility system rather than numerical computations. Conceptual overall design of the facility system involves not only the choice of overall shape (configuration) and size of the facility, but also the selection of the structural layout, the structural system, the structural material, the type of nonstructural components (particularly those that could become unintentional structural components), and the foundation system. Although there is no universal ideal building and structural configuration, certain basic principles of EQ-RD can be used as guidelines to select adequate configurations, as well as efficient structural and foundation types and systems, nonstructural components, and their respective materials. Lists and discussions of the existing guidelines for the conceptual overall EQ-RD of entire building systems have been given by the author in previous publications [SEAOC Vision 2000 Committee, 1995 and Bertero, V. 1997a]. Herein a brief discussion is given of the guideline involving the use of energy concepts. This guideline can be stated as *"Selection of the structural system to be used in the preliminary EQ-RD and the final sizing and detailing of the structural members should be based on (or consideration should be given to) the application of energy concepts through the use of the energy balance equation."* The balance equation is:

$$E_I = E_E + E_D \qquad [1a]$$

$$E_I = E_K + E_S + E_{H\xi} + E_{H\mu} \qquad [1\,b]$$

where E_I is the energy input at the foundation of the building due to the EQGMs, E_E is the stored elastic energy, E_D is the dissipated energy, E_K is the kinetic energy, E_S is the strain energy, $E_{H\xi}$ is the energy dissipated through hysteretic damping and $E_{H\mu}$ is the energy dissipated through hysteretic plastic deformation.

Importance of applying energy concepts for EQ-RD. Comparing the energy balance equation (1) to the following one used in designs and called the *Design Equation*,

$$\textit{DEMANDS} \leq \textit{SUPPLIES} \qquad [2]$$

it becomes clear that E_I can be considered to represent the demands, and the summation of $E_E + E_D$ represents the supplies. Equation (1a) points out clearly to the designer that to obtain an efficient seismic design, the first step is a good estimate of E_I for the critical ***EQGM***. Then the designer has to analyze whether it is possible technically and/or economically to balance this demand with only the elastic behavior of the structure to be designed, i.e., with just E_E , or whether it is convenient to attempt to reduce E_E by dissipating as much as possible the effects of E_I using E_D . As revealed in Equation (1b), there are three ways to increase E_D : one is to increase the energy dissipated through hysteretic damping, $E_{H\xi}$, by increasing the linear viscous damping ratio, ξ; another is to increase the plastic hysteretic energy, $E_{H\mu}$, and the third is a combination of increasing $E_{H\xi}$ and

$E_{H\mu}$. At present, it is common practice to just try to increase $E_{H\mu}$ as much as possible through inelastic (plastic) behavior, i.e., through the use of the ***Deformation Ductility Ratio***, **μ**, which implies damage to structural members throughout the structure. Only recently has it been recognized that it is possible to increase $E_{H\mu}$ and $E_{H\xi}$ significantly and control damage of the entire facility system through the use of ***Energy Dissipation Devices (EDDs)*** inserted at properly determined locations throughout the facility. Increasing E_D by increasing $E_{H\xi}$ rather than increasing $E_{H\mu}$ has the great advantage that it can provide control of the structure's behavior throughout all of its limit states, i.e., for impending collapse, safety, functional and service performance levels. Increasing $E_{H\mu}$ by just increasing **μ** will not improve behavior at the service limit state.

If it is technically or economically impossible to balance the required E_I by E_E alone or through $E_E + E_D$, the designer has the option of attempting to decrease the E_I to the structure. This can be done through ***seismic Base Isolation Techniques (BIT). A combination of controlling (decreasing) E_I by seismic BIT and increasing E_D using EDDs, is very promising strategy for achieving not only efficient EQ-RD but also more reliable EQ-RC***. As will be discussed later, for reliable and efficient use of ***Innovative Controlling (or Protective) Systems (ICSs)*** (which has already been used successfully in certain areas of engineering) in the P-B SE of civil engineering facilities, the clear understanding of the above energy concepts and use of the energy balance equation (Eq. 1), are a must. Furthermore, the computation of the elastic and inelastic spectra for the E_I and other types of energy involved in the energy balance equation of the EQGMs is one of the most promising ways of estimating the damage potential of these EQGMs, and therefore a reliable way to establish the different EQ design levels that need to be considered in the design performance objective matrix.

Comments on the Importance of Conceptual Overall Design and on the Needs for Developing Comprehensive Integrated Guidelines for Attaining an Efficient (Optimal) EQ-RD of the Entire Facility System. The importance of a proper conceptual overall design has been discussed by the author in the above previous publications, by Krawinkler [1996], and by other authors. Although the Vision 2000 Committee Report contains certain guidelines to good EQ-RD of new buildings, and the FEMA 273 and 274 Reports (1997) give some isolated hints on the use of different strategies and techniques for the rehabilitation of existing buildings, theses resource documents, do not provide comprehensive integrated guidelines for attaining an efficient (optimal) conceptual overall EQ-RD of the entire building system. Thus, there is a need for developing such guidelines. Now the question is "How can these needed comprehensive integrated guidelines be developed?" In his paper [1997b], the author has discussed in detail how this can be done. Summarizing, it is the author's opinion that this can be done by:

First, conducting a critical review of the already existing guidelines regarding the use of not only traditional or conventional technologies, but also the use of new technologies for controlling the seismic response of civil engineering facilities, as is indicated in the flowchart of Figure 1, which also illustrates how it is possible to implement energy concepts (through the use of energy balance equation) using different methods (software) and different devices (hardware) which are classified under the following two main groups of methods, *Conventional and Innovative Approaches (or Systems);*

Second, adding new guidelines regarding the advantages and disadvantages not only of these two main group approaches, but also of each of the different systems, elements, and components that are currently available in the field for implementation of these approaches, and particularly relating these advantages and disadvantages with the type of time histories of the EQGMs ***(which can vary from a severe pulse to a pure harmonic)*** and their critical combination with the other possible excitations that are expected to act simultaneously;

Third, to develop guidelines using the results of existing studies and/or new studies *based on stochastic structural response*. This is needed to improve the reliability of EQ-RD and EQ-RC. Emphasis should be given to the results of stochastic studies on the importance of designing buildings with large overstrengths, ductilities, and redundancies, and their interdependence.

INNOVATIVE RESPONSE-CONTROLLING SYSTEMS FOR EQ-RD OF NEW FACILITIES AND UPGRADING OF EXISTING FACILITIES

Why Do We Need Innovative Approaches for P-B SE? Why not use only conventional approaches? To answer these questions, it is convenient to discuss the pros and cons of both approaches.

Conventional Approaches. As indicated in Fig. 1, one of these approaches would be to design and construct facilities that will absorb elastically the effects of the Input Energy E_I , i.e., $E_I = E_E$, from the expected EQGMs, including the ***Maximum Credible (capable or considered) EQGMs (MCE).*** Technically this is the simplest approach, because linear elastic methods of analysis and design can be used. However, for most standard facilities it will lead to an economically unacceptable solution. Thus, conventional EQ-RD practice permits that standard facilities be designed so that under severe EQGMs they are capable of dissipating large amounts of E_I through $E_{H\mu}$ that can occur at certain critical regions of the facility's structure. The key issues with this approach are: ***first*** to select reliably where the critical regions will be located; and ***secondly*** to dimension and detail these critical regions so they can dissipate sufficient energy, $E_{H\mu}$, so the facility can be designed for inertia forces significantly lower than those required for behaving elastically. In analyzing advantages and disadvantages of this approach, it has to be kept in mind that the $E_{H\mu}$ results in damage of the critical regions where the inelastic deformations occur (***the larger the μ, the larger the damage***). Even though the application of the Capacity Design Strategy can help significantly in controlling the location of the critical regions, there are still some serious difficulties with this, particularly in highly redundant structures and in prediction of the real hysteretic behavior. As illustrated in Fig. 1, in the case of a ***Moment-Resistant Frame (MRF)*** structure, the critical regions are usually located in the beams near or adjacent to the beam-column joints and at the bottom of the first story columns. Because of the large variation of the real mechanical characteristics of the structural materials with respect to the nominal values specified in the codes, it is very difficult to locate the critical regions, to determine the length of these regions, and thus to carry out their proper detailing. Furthermore, even if the critical regions are properly detailed in the drawings, some of the details are very difficult to carry out reliably in the field. Thus, it is not surprising to find in experiments that the hysteretic behavior of the critical regions start to degrade prematurely and that this phenomenon increases significantly with the repetition of cycles with reversals of inelastic deformations. This degradation is very difficult to predict because its high sensitivity to the quality control of the materials and their real detailing, i.e., workmanship in the field, so it is very difficult to control the real performance for the entire facility. Furthermore, to achieve significant $E_{H\mu}$ in the critical regions of a structure usually requires large ***Interstory Drift (ID)***, which results in substantial damage to nonstructural elements and contents.

Protection of Nonstructural Components and Building Contents. This is one of the more difficult issues to address in EQ-RD, particularly using conventional design methods. The issue is very often ignored and when addressed, can be very expensive to incorporate in conventional design. There are two primary mechanisms that cause nonstructural and content damage. The first is related to ID and the second to floor accelerations. Some structural engineers argue that to minimize nonstructural and content damage it is convenient to use stiff buildings because they reduce IDs, while others argue that because stiff buildings produce high floor accelerations the solution is the use of flexible buildings which reduce floor accelerations. However, flexible buildings have much higher IDs, and this accentuates damage to components that are sensitive to ID. Clearly what is needed is a design concept that will result in a reduction of both IDs and floor accelerations.

Innovative Approaches: Response Control or Protective Systems. As a consequence of all the difficulties in controlling the response (performance), particularly in controlling the $E_{H\mu}$ of structures designed and constructed using conventional approaches, ***innovative means of controlling the dynamic response of civil engineering facilities when they are subjected to significant EQGMs have been recently proposed.***

What Are Innovative Approaches? Innovative approaches to solve the problems of seismic engineering to civil engineering facilities are based on the addition of special mechanical devices to their conventional structural systems, with the main objective of improving the control of their seismic performance [floor accelerations and deformations (displacement and particularly ID and plastic deformations)] either by controlling the $\mathbf{E_I}$ to a significant part of these facilities and/or by minimizing or even eliminating its damaging effects by controlling the E_D (particularly the $E_{H\mu}$) demand on the traditional primary structural members. By controlling these types of energy demands and energy supplies, it is possible to control the ***Interstory Drift Indexes (IDI)*** and to lower the accelerations, and thus not only to control the damage to the primary structural members but also to reduce the damage to the nonstructural components, equipments, and contents of these facilities. This control (reduction) of the damage to the entire facility system is the main reason why these innovative approaches are usually also called ***protective approaches*** and the systems and devices used are called ***protective systems and devices.***

Classification And Definition Of Innovative Control Or Protective Systems For Seismic Effects.

Classification. As is indicated in the flow chart of Fig 1, the different systems that are available for control of the seismic response of civil engineering facilities, can be grouped under the following classification: ***Seismic Isolation Systems; Passive Energy Dissipation Systems; Active Systems; Hybrid Control Systems; and Others.*** This classification is practically the same as that adopted by ATC 17-1 [1993].

Definitions. ATC-17-1 [1993] has adopted the following ***System Definitions:***

Seismic Isolation Systems (SISs) *decouple building and bridge structures from the damaging components of EQGMs. Such systems require the structure to be supported on discrete isolators which detune the structural system and add substantial damping. Examples include elastomeric and sliding devices.*

Passive Energy Dissipation Control Systems (PEDCSs) *add damping to structures in such a way as to significantly reduce response to EQs. Examples include: viscoelastic dampers; hydraulic, metallic-yielding and friction devices; and lead extrusion systems that are installed within the structural framing system.* The author prefers to replace the phrase ***"add damping"*** in this definition with ***"add EDDs."***

Active Control Systems *provide seismic protection by imposing forces on a structure that counter-balance EQ induced forces. Inherently more complicated than SIS or EDDs, they include computer-controlled actuators that activate bracing or tuned-mass dampers located within the structure.*

Hybrid Control Systems *are usually a combination of active and passive systems. Reduced power demands and improved reliability are the main system features. Passive systems include a combination of SISs and/or EDDs.*

When Can Such Innovative Approaches Be Efficiently Used?The above strategy of controlling the dynamic response by adding mechanical devices is not new: it has been applied in many other branches of engineering. As has been pointed out in the pertinent literature, some of these applications include shock absorbers for vehicles, equipment vibration isolators, pipe restraints and snubbers, shock isolation devices to mitigate blast effects, and mass damping systems to control wind-induced vibration in buildings. However, relatively few of these devices have been applied specifically to control the seismic response. Only in recent years have there been some significant advances in the refinement of available mechanical device hardware and in the development of new ones for application to the *EQ-RD* and *EQ-RC* of new civil engineering facilities and for seismic upgrading of existing ones, particularly bridges, viaducts and buildings. Although the final decision to use this innovative strategy and to select the most efficient mechanical device hardware must be made on a case by case basis, in order to make an appropriate decision, both client and designer must recognize the principle features offered by an appropriately designed innovative system. Principle features offered by SISs, PEDCSs, and hybrid passive control systems have been discussed in detail by several authors in the pertinent literature and have been reviewed and summarized by the author [Bertero 1997a]. Although SISs have been used efficiently, i.e., have been proved to be a cost effective means of providing appropriate levels of seismic performance for civil engineering facilities since the early 1970s, and EDDs have also been used in the 1970s and 1980s as element of seismic isolation systems for enhancing energy dissipation in rubber isolation systems, the application of these devices was discontinued in the late 1980s in favor of the use of lead-rubber and high damping rubber isolators. However, more recently, particularly after the 1994 Northridge and 1995 Kobe EQs, consideration of the effects of forward rupture directivity on near-fault EQGMs, i.e., severe pulse-type EQGMs, prompted engineers in the U.S. and Japan to return to the use of EDDs in an attempt to mitigate their effects, particularly on medium rise and tall buildings. Recent studies [Wada et al. 1999, and Anderson et al. 1999] have shown that, for the EQ-RD of new high rise buildings as well as for the seismic upgrading of existing medium to high rise buildings, although the use of a conventional approach could be technically feasible, it will be economically unacceptable. Thus, at present the practical solution seems to be the use of EDDs.

How Have the Innovative Approaches Been Applied in Practice?

Applications of SISs to Buildings. In 1998 in the U.S., the total number of isolated buildings was 44 (24 new and 20 upgraded). At present in the city of Berkeley, California, SISs are being used in two new buildings under construction and in two existing buildings that are being seismically upgraded. These buildings are located less than 1 km from the Hayward Fault. Discussion and illustration of the design of new buildings and of the upgrading of existing buildings will be offered during the oral presentation of the paper. In Japan, the first building project using SISs was approved in 1980. As of January 1993 the total number of base isolation was 67, and as of January 1995 the number exceeded 75. At present, the number of projects, including those already constructed, those under construction, and those approved, exceeds 550.

Application of EDDs to Buildings. Although until now in the U.S. there have been relatively few applications of ***EDDs*** and most of the applications have been in the retrofitting of existing facilities in Japan in recent years, particularly after the 1995 Kobe EQ, the use of ***EDDs*** in the design of tall buildings is getting significant attention to attain what has been called ***DTS*** or ***DCS*** [Wada et al. 1999]. In a July 1998 U.S.-Japan workshop, it was reported that in Japan more than ***135 DTS*** buildings had been constructed using EDDs.

FUTURE DIRECTIONS IN THE DEVELOPMENT AND USE OF INNOVATIVE APPROACHES IN PERFORMANCE-BASED SEISMIC ENGINEERING

General Remarks Regarding Acceptance of Innovative Approaches. There is an increasing worldwide acceptance of innovative approaches to EQ-RD and EQ-RC. This is particularly true in cases of the use of SIS and EDDs. As pointed out by Kelly [1997] and Naeim and Kelly [1999], in the case of the use of BIT, initial skepticism that was so prevalent in the U.S. in the 1980s (when elastomeric systems were initially proposed) is no longer evident. Newer approaches are being developed which have led to a variety of SISs based on different mechanisms and materials. A discussion of the main reasons for the observed increase in acceptance of SISs and EDDs in P-B SE is presented in Bertero [1997a]. One of the main reasons why innovative strategies and techniques have become very attractive is that the devices used for implementation have been used and tested successfully in other branches of engineering. These devices are fabricated under thorough and rigorous manufacturing processes, inspection procedures, and testing necessary to ensure quality device production. These devices are tested not only before their installation but they can be inspected, maintained, re-tested, modified and replaced (if they have been damaged) at a relatively lower cost than the repair and/or seismic upgrade of the critical regions (plastic hinges) where the energy is dissipated in the case of conventionally designed facilities. Despite the observed increase in acceptance of isolation and energy dissipation technologies, and the significant advances in our knowledge through recent research, in practice the widespread application of these technologies in the U.S. is still impeded. Why? A brief discussion regarding the impediments follows.

What are the Impediments to the Widespread Implementation in Practice of the Innovative Approaches? As pointed out by the author [1992, 1997a and b], the improvement of our knowledge through research and development of new technologies and methods for improving performance control of civil engineering facilities when subjected to the effects of EQs is not enough to control the seismic risks: this should be followed by the formulation and strict implementation in the field of simple but reliable seismic code provisions which incorporate new improvements and/or developments. Thus, for proper use of existing isolation and energy dissipation technologies, there is a need to have reliable seismic code provisions and standards for technical activities involved in the use of these innovative technologies when used in civil engineering facilities. Until 1991, there were no building code provisions regulating the EQ-RD, EQ-RC, and maintenance of SISs and EDDs for new civil engineering facilities, or the seismic upgrading of existing facilities. Although in its 1991 edition, UBC introduced provisions for the EQ-RD and EQ-RC of new buildings using SISs, the requirements contained in the present provisions are over-conservative. Thus the author strongly believes that even at present the main impediment for widespread application of existing innovative isolation and energy dissipation technologies is the lack of code requirements for EQ-RD based on the use of EDDs and the over-conservative requirements of the code provision for EQ-RD and EQ-RC of isolated facilities when their requirements are compared with those used in the design and construction of traditional structural systems.

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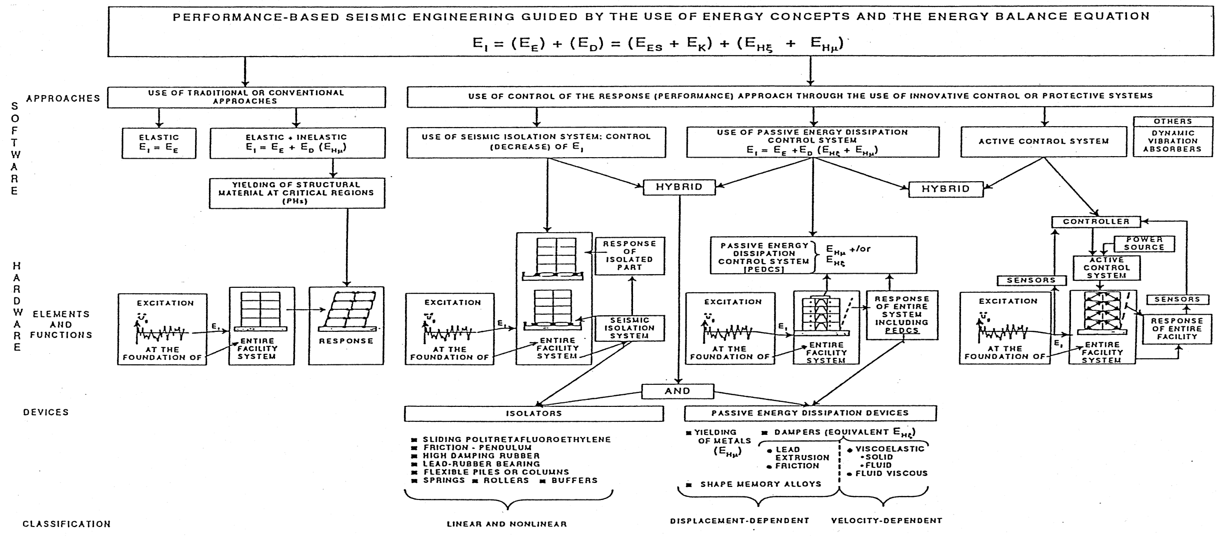

Figure 1. Flow chart of the approaches for P-B EQ-RD