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U.S. national program on seismic repair and retrofit of structures

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ABSTRACT

A five-year national research program in the U.S.A. on seismic repair and retrofit of structures initiated in 1990 is described in this paper. The objective is to promote closer ties between research and practice by facilitating the transfer of knowledge and rehabilitation techniques through a concentrated effort leading to the development of design guidelines and performance standards applicable to the needs of U.S. practice. The first year's projects implemented are reported and future priorities indicated. Procedures and mechanisms for coordinating this multidisciplinary and multi-investigator program are described.

INTRODUCTION

Recent damaging earthquakes that have occurred in the United States (Whittier-Narrows 1987, Loma Prieta 1989) and around the world (Mexico 1985, Chile 1985, Armenia 1988, Iran 1990, and the Philippines 1990) once again attest to the importance of earthquake-resistant design in the mitigation of potential property damage and life loss. The acute economic impact ($25 billion) and large number of casualties (20,000 deaths) which resulted from building damage and collapse in Mexico City during the 1985 Michaocan earthquake (Magnitude 8.1) constitute documentary evidence of the intense impact that a major seismic event could have on urban environments. In the U.S., the smaller October 1989 Loma Prieta earthquake (Magnitude 7.1) in the Santa Cruz Mountains of California gave further notice of the vulnerability of urban communities to seismic events with 72 deaths and a cost of about $10 billion in direct and indirect damages.

Over the last decade considerable research has been done in the United States and abroad on various aspects of seismic repair, strengthening, retrofit, and rehabilitation of existing, hazardous structures. During post-earthquake reconstruction periods, structures are typically repaired or strengthened to improve their seismic load capacity and performance. On other

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occasions, in anticipation of future earthquakes, the seismic rehabilitation of an existing building may occur on a voluntary basis. Knowledge and technology have been advanced as a result of all these efforts. However it has also been apparent that the pace of application and implementation of research results in reducing the vulnerability of existing structures is falling somewhat short of expectations in the U.S. In reality, it is admittedly clear that the problem of designing repair and retrofit schemes for existing buildings is more complex than the design process for new construction. Problems involved in rehabilitation of structures can be approached through a 3-step process as indicated in Figure 1: (1) vulnerability estimate, (2) behavior analysis, and (3) options and decision making.

In late 1989 the Earthquake Hazards Mitigation Program of the National Science Foundation decided that it was timely to address this critical situation by initiating a concentrated research program on a national scale to: (1) integrate the existing body of knowledge, and (2) carry out additional research as required to develop practical engineering measures for immediate implementation to safeguard seismically vulnerable existing structures throughout the entire U.S.

This paper describes the purpose and objectives of the NSF coordinated research program specifically initiated for the seismic repair and rehabilitation of existing structures. The program was publicly announced through a formal program initiative that was distributed nationally to researchers, design professionals, and academicians in January 1990 soliciting research proposals. The formal NSF announcement of this program initiative was issued as NSF Document 90-23, entitled "Repair and Rehabilitation Research for Seismic Resistance of Structures".

TECHNICAL BACKGROUND

As a background to the program initiative, a brief discussion of the technical problems involved is made in this section. Along with these discussions, an attempt is also made to assess the current state of knowledge and practice. These assessments will provide certain clues to new research and development efforts needed to deal with those problems.

Reliable Evaluation of Seismic Vulnerability

The current state-of-the-practice for seismic vulnerability evaluation of buildings is represented by the ATC-14 methodology (1987) which was developed over a 5-year study supported by NSF. This methodology was subsequently adopted by FEMA as reports FEMA-175 and 178. The essential features of the ATC methodology are: (1) it is based on life-safety hazard consideration, (2) buildings are classified into fifteen model types and typical weak-links of the building in question are identified from records of past seismic performance of similar buildings, and (3) standard code-consistent procedures for new design are used to guide the evaluation of the building's capacity vs. demand on the level of structural elements.

Limitations and Remaining Problems

It is apparent that the current knowledge base and practice suffer from several limitations and a number of studies to resolves these problems should be made to improve the situation.

These limitations are:

(1) Fifteen buildings classification types may not be sufficient. A more broadened classification approach, as suggested by Gavlin, et al (1989) which considers the structural framing system types in terms of lateral force resistant sources and their functions might be more appropriate;

(2) Linear elastic procedures, via use of elastic spectra, for assessing local element demands do not adequately address situations involving inelastic load distributions and interaction effects. Limited state analysis, using more refined analytical models which take into account all critical failure mechanisms, systems interaction, and uncertainties in modeling, etc. will improve the evaluation (Aktan, 1990);

(3) Economic consequences as a result of various degrees of damage, i.e., the damageability patterns due to loss under moderate seismic actions are also important factors;

(4) Field methods for evaluation of the current state of materials and buildings i.e., the capacity of the building whether or not it had undergone previous earthquake motions, such as nondestructive tests (NDT) might provide valuable tools in practice as compared with methods based purely on mathematical modeling and analysis. Such NDT methods might include ultrasonic tests, radars with image processing techniques, etc. for detection of fractures, cracks, yielding, and non-structural damages.

The above highlight but a few deficiencies in the current knowledge base for seismic redesign or upgrade as reflected in the state-of-the-art practice. To improve our ability to deal with such urgent problems, particularly for seismic regions in the Central and Eastern U.S. where seismicity as well as design/construction types are vastly different from the West Coast, a broad based effort covering building inventory, behavior (vulnerability) evaluation, and upgrade techniques based on sound engineering measures and cost benefit analysis is clearly needed. The NSF program initiative was developed behind such a technical background. To focus its effectiveness, efforts are concentrated on development of generally applicable engineering measures only, including design techniques and engineering details for typical or common situations.

NSF PROGRAM ON SEISMIC REPAIR AND RETROFIT

Program Description

The purpose of the NSF program initiative is to promote closer ties between research and practice by facilitating the transfer of knowledge and techniques through the development of engineering design guidelines or manuals applicable to U.S. practice. To foster the transfer of information, collaborative efforts combining researchers and design professionals are encouraged. Although not mandatory for participation in the program, this clearly stated support of collaborative and coordinated efforts was aimed toward practical engineering solutions based upon the integration of existing techniques and new research results.

The fundamental objectives of this new NSF program initiative were established to:

- Provide technical information for the realistic evaluation of the vulnerability of existing structures for various levels of seismic excitation, and
- Develop and document cost-effective construction techniques for repairing or strengthening structures identified as hazardous in seismic events.

To achieve these objectives, research proposals were encouraged to study key problems identified for immediate study as high priority items in the following topic areas:

- Performance evaluation of existing structures and foundations.
- Load-transfer mechanisms.
- Retrofitting criteria and techniques.
- Problems and solutions applicable to seismic zones on a nation-wide basis.
- New materials, methods, systems, and devices for seismic retro-fitting, and their design, manufacture, fabrication, and field installation.

Levels of Financial Support

The program is established as a long-term effort in which approximately $2.5 million is made available to the earthquake hazard mitigation research community over the period of five years. The approximate distribution of funds over the program's duration will average $0.5 million in each of the fiscal years 1990 through 1994 contingent on the quality of the proposals submitted in response to the program announcement.

Research Parameters

The research to be supported under this program announcement is intended to generate innovative, practical approaches and techniques which can be used to increase the seismic safety of existing structures. Proposals which involve only the repackaging of existing methods, manipulation of existing data, or investigation of approaches that are limited to incremental improvements to the existing state of practice are being discouraged. Other NSF resources, under the standard process established for submittal of unsolicited research proposals, are still available for the study of the safety and design of new structures.

Structures designed without seismic provisions or with older provisions utilizing the following materials appear to represent the greatest hazard: (a) unreinforced masonry infill walls or bearing wall systems, (b) ordinary concrete structures (including structures using tilt-up systems), (c) ordinary steel structures with non-seismic connection design, and (d) precast concrete structures. In addition, special attention is to be given to buildings of high occupancy and structures housing critical emergency services and/or toxic materials. Research in hazard reduction techniques is being encouraged to address the problems associated with these existing building types. One of the first steps in the existing building rehabilitation process is to determine the actual strength of the existing structure in order to establish the anticipated seismic performance level of the rehabilitated building system.

The coordinated research program is intended to utilize input from practicing engineers to assure that the research data acquired are applicable to current problems and that the technologies developed may be transferred rapidly and efficiently. It is expected that this coordinated seismic study program will provide design professionals with the necessary guidance in selecting analytical design procedures for establishing the seismic resistance of older existing structures that, in turn, will lead to economic and cost-effective upgrade measures. The fundamental goal is to facilitate the development of nationally applicable design recommendations for the reduction of earthquake hazards posed by existing structures.

The following areas of interest, within the topic areas listed above, were provided to prospective researchers as prototype examples noteworthy of study. These topics, however, were not intended to limit the scope of proposals from potential investigators:

- Performance evaluation of existing structural or nonstructural systems at various levels of seismic excitation.
- Performance characteristics of retrofitted or strengthened members and/or structural systems.
- Interaction of new and existing systems.
- Techniques and procedures involving materials, devices, or systems which provide significantly improved earthquake response performance.
- Foundation retrofitting techniques.
- Application of intelligent systems such as high-tech sensors and/or computerized performance monitoring/control systems.
- Cost effectiveness of proposed schemes.
- Program coordination, information exchange and technology transfer.

Research Coordination

One important feature of this program is that all projects underway are fully coordinated in terms their progress, information exchange, etc., so that collectively the final research products can be delivered as intended. All projects are expected to contribute directly to the development of a comprehensive technical summary document including design requirements and details for engineering practice. To achieve this purpose a program coordinator was selected by NSF based on technical depth and breadth in the overall subject areas of research. The program's development process will involve this coordinator in the organization of joint meetings and other effective means of communication to discuss research progress and technical exchange of information among all investigators.

Through specific exercises the coordinator will monitor the necessary information flow resulting from the research work so as to insure that needed technical materials are obtained for the final summary document. The first coordination meeting of all U.S. researchers involved in seismic repair and rehabilitation studies is scheduled for February 15, 1991, in Salt Lake City, Utah, during the 1991 Annual Meeting of the Earthquake Engineering Research Institute (EERI).

The coordinator for the seismic repair and rehabilitation program is Professor James O. Jirsa of the Ferguson Structural Engineering Laboratory, The University of Texas at Austin.

Project Selection

In response to the repair and rehabilitation program announcement, NSF received during the initial year (1990) a total of 56 proposals, of which ten proposals were collaborative research projects developed jointly between respective universities and professional engineering design offices. All proposals were evaluated by a panel of seven peer reviewers appointed by NSF under the standard review process with each proposal receiving a minimum of three reviews. Of the 56 proposals received, a total of nine were recommended for multiple (2-3) year funding during the first fiscal year 1990 at a total budget of $580 thousand. Five of these nine proposals funded represented collaborative research projects in joint association with respective universities and professional engineering design offices.

Repair and rehabilitation research proposed for study by these nine projects include the following general topic areas:

1. Strengthening and repair of non-ductile reinforced concrete frames using external steel jackets and plates.
2. Seismic retrofit with energy dissipators.
3. Evaluation of the strength, stiffness, and ductility of older steel frame structures.
4. Experimental evaluation of slab-column frame buildings and the use of ductile steel.
5. Behavior of clay brick and concrete masonry infill walls.
6. Repair and rehabilitation research coordination mechanisms.

OTHER REPAIR AND REHABILITATION PROGRAMS

NCEER Program

In addition to the NSF seismic repair and rehabilitation program, on a national basis, the National Center of Earthquake Engineering Research (NCEER) of the State University of New York at Buffalo also has a separate program in this research topic area. The two NSF and NCEER programs are being coordinated respectively with one another in order to focus work and leverage research studies in the respective topic areas to their maximum capacities. While duplication of work is being avoided, some overlap in some specific topic areas with critical long-term objectives and high priority study, such as old unreinforced masonry structures for example, are being jointly pursued. Seismic repair and rehabilitation areas of study among others in the NCEER program include the following:

1. Retrofit of lightly-reinforced concrete frames.
2. Retrofit of non-ductile flat plate connections.
3. Retrofit of old unreinforced brick masonry walls.
4. Behavior of infill walls in frame structures.

Between the two organizations, plus other seismic repair and rehabilitation work by other individual principal investigators funded by NSF after the 1985 Mexico, 1987 Whittier-Narrows, 1987 Chile, 1989 Loma Prieta, and 1990 Philippines earthquakes, research study in this area is being carefully orchestrated on a national basis. By the end of the five-year cycle of funding, 1994, it is anticipated that a comprehensive set of design guidelines for the seismic repair and

rehabilitation of existing structures in the United States will be substantially finalized for distribution to professional design offices for immediate application and implementation in the field.

FEMA Program

The Federal Emergency Management Agency (FEMA) has among its responsibilities to develop design practices and manuals though translation of research and technology into seismic hazard reduction approaches. Policies, products, and programs over the years, through its affiliated Building Seismic Safety Council (BSSC) and subcommittees under BSSC, a number of design practices and manuals have been published. In connection with the seismic design of existing buildings, efforts were made to identify nationally applicable strengthening techniques and to prioritize seismic rehabilitation in light of complex public policy and societal implications. A series of FEMA publications (1989) indicating the results of these efforts have been issued and are available through FEMA's Earthquake Program and BSSC in Washington, D.C.

SUMMARY AND CONCLUDING REMARKS

A national research program on seismic repair and retrofit of existing structures by NSF and its companion support programs conducted by NCEER and FEMA are described. These programs represent a concentrated, strategical attack to the complex problems the country is facing in its seismically vulnerable regions. While many technical problems remain that could be approached and improved on a piecemeal basis, it is considered important to integrate the current knowledge and develop generic applicable techniques for broad engineering applications. It is expected that the program described in this paper will contribute to the nation's pressing problems in the seismic safety of existing structures.

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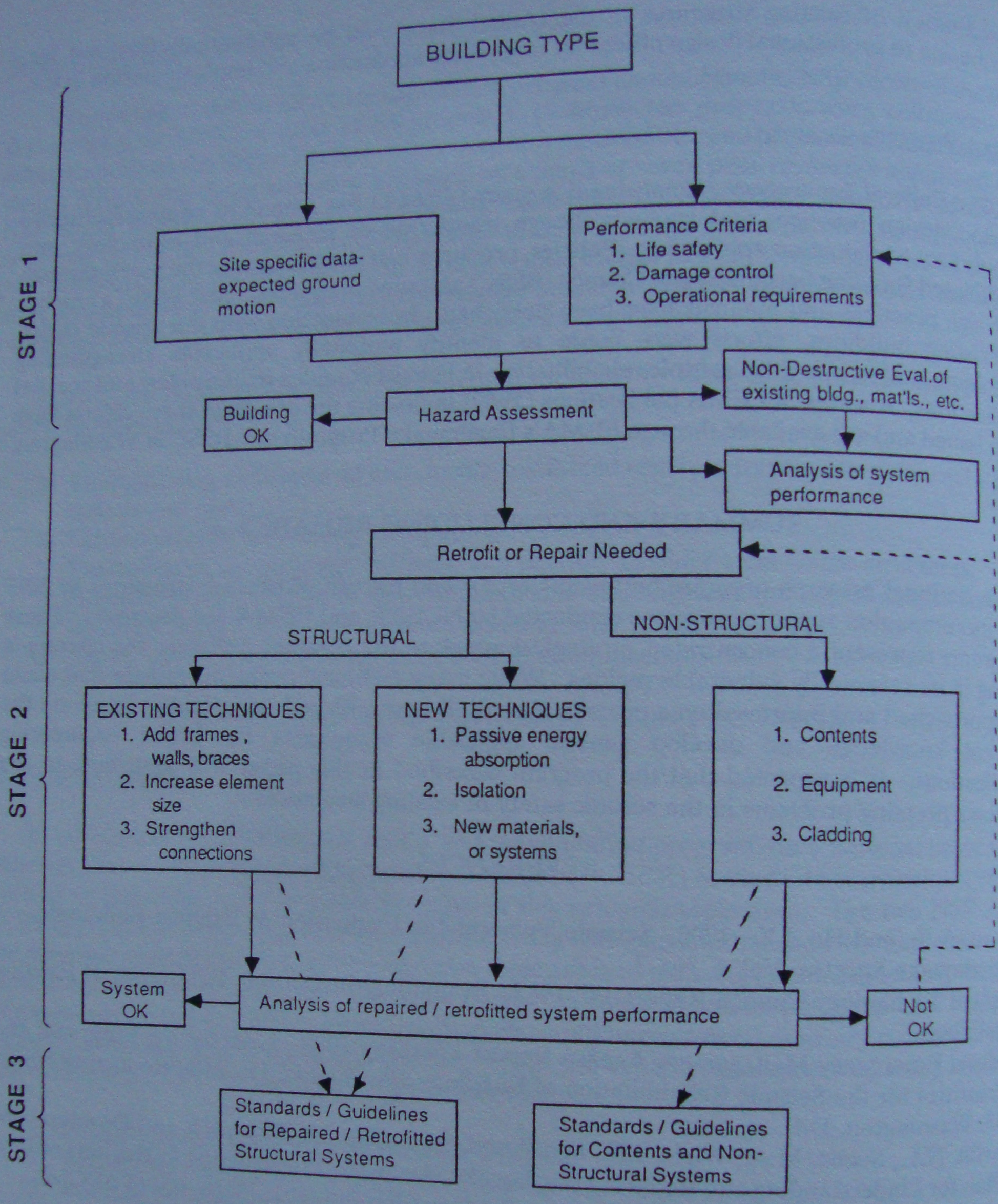

Figure 1. Stages in Hazard Reduction of Existing Buildings (from Los Angeles Workshop)