THE 6TH JORDANIAN INTERNATIONAL CIVIL ENGINEERING CONFERENCE:

THE NEW ASCE 41-13 EVALUATION AND RETROFITTING OF EXISTING STRUCTURES & THE USE OF CFRP IN THE ACI 562 REPAIR CODE

I. A. DAMASHQIEH

Department of Structural Engineering, Demco.Structural &Earthquake Engineering Consultants, 82 Issam Ajluni street, Shmisani,Amman, P.O.Box 830654,Zahran11183, Jordan

INTRODUCTION

Jordan's high seismic Zones as defined by the Jordanian Seismic Code demands the use of new methods in order to retrofit and strengthen existing concrete buildings. The strengthening of R/C structural members (beams, slabs, columns, walls) using glued Carbon Fiber-Reinforced Plastic Sheets is a relatively new method of intervention. Upgrading existing reinforced concrete buildings especially in seismic regions is one of the most important and challenging tasks in civil engineering practice. Of great importance is selection of the most appropriate upgrading techniques among several alternatives depending on the type of the existing structure, type of damage or deficiency and desired strengthening level. An efficient upgrading technique is the one, which enhances deficient structural characteristics of existing structures without leading to any unfavorable failure mechanism. Based on recent research and common upgrading practice, this paper describes the new upgrading techniques using CFRP. The techniques presented in this paper can be implemented for upgrading structures subjected to static and dynamic forces due to wind or earthquake excitations. Rational engineering judgment is advisable for analysis and design of such upgrading techniques.

KEYWORDS: EVALUATION AND UPGRADING; RETROFITTING; REINFORCED CONCRETE; CARBON FIBER –REINFORCED PLASTIC; EARTHQUAKE; ACI 562 PERFORMANCE REPAIR CODE

ASCE/SEI STANDARDS

For the past 3 years the ASCE/SEI Standards Committee on Seismic Rehabilitation has been working to combine ASCE 31-03 into ASCE 41-06 while also updating both standards. The result of that humongous effort is the released ASCE 41-13: Seismic Evaluation and Retrofit of Existing Buildings. The new combined standard has eliminated any inconsistencies that previously existed between the two standards. Now the user decides if they want to go forward with lower performance objectives traditionally used for existing buildings, as was the case within ASCE 31 or an equivalent hazard to a new building, similar to the Basic Safety Objective in ASCE 41. In addition, the Tier 1 checklists have been significantly modified and reorganized. The use deficiency-only procedures (Tier 2) have been greatly expanded to regular buildings of greater heights. Plus, there have been a number of significant technical changes including updated analysis provisions with more emphasis on nonlinear response history analysis, provisions for bucking restrained braced frames, expanded liquefaction provisions, a new foundation rocking analysis procedure, substantially updated provisions, and a full updated Chapter on Seismic isolation and Energy dissipation.

The Tier 3 procedure is intended to be a systematic analysis of the building, which can be used either for evaluation or retrofit. The Tier 3 procedure encompasses all four analysis (Linear Static, Linear Dynamic, Nonlinear Static, and Nonlinear Dynamic) procedures from ASCE 41-06. The user can chose to apply any procedure, subject to specific limitations for each procedure. However, the permission to use a new building design standard for Tier 3, which was permitted in ASCE 31-03, has been eliminated because the new building standard cannot be properly applied to an existing building unless a completely new structural system is provided.

The outline of the new standard is as follows:

Chapter 1 General Requirements
Chapter 2 Seismic Performance Objectives and Ground Motions
Chapter 3 Evaluation and Retrofit Requirements
Chapter 4 Tier 1 Screening .
Chapter 5 Tier 2 Deficiency-Based Evaluation and Retrofit
Chapter 6 Tier 3 Systematic Evaluation and Retrofit
Chapter 7 Analysis Procedures and Acceptance Criteria
Chapter 8 Foundations and Geologic Site Hazards
Chapter 9 Steel Chapter 10 Concrete
Chapter 11 Masonry
Chapter 12 Wood and Cold-Formed Steel
Chapter 13 Architectural, Mechanical, and Electrical Components
Chapter 14 Seismic Isolation and Energy Dissipation Chapter 15 System-Specific Performance Procedures Chapter 16 Tier 1 Checklists
Appendix A Guidelines for Deficiency-Based Procedures
Appendix B Use of ASCE 41-13 within Mitigation Programs

The new standard is based on the philosophy that procedurally there is no difference between evaluation and retrofit design. Retrofit design is simply evaluating a building in an altered state and adjusting the alterations until the building's evaluation meets the desire performance objective. Therefore there is no difference between a Tier 2 or Tier 3 evaluation or retrofit. The analysis procedures and acceptance criteria are the same. If the user wishes to carry out an evaluation or retrofit with the intention of accepting higher risk of collapse or lesser performance, as was the case with ASCE 31-03, then the user must now explicitly choose a lesser seismic hazard or a lesser performance level.

Earthquake Hazard Parameters

It has been a commonly accepted within the profession to evaluate existing buildings to a lower force level than new buildings. The most common way this was carried out was to use 75% of new building design forces. That concept was contained with ATC-14 and carried through to ASCE 31-03. In the Tier 2 procedures in ASCE 31-03 the

75% factor was actually buried within the m-factors. Those m-factor were approximately 1.33 (1/0.75) times their ASCE

41-06 counterparts, with some additional simplifications. Then in the Tier 3 procedure of ASCE 31-03, the user was explicitly directed to use a standard such as ASCE 41-06 or ASCE 7-05 and multiply the demand forces by 0.75.

The new philosophy of permitting existing buildings to be evaluated, and even upgraded, to a lower hazard should be retained. There are a number of reasons for this, which are discussed in detail in the ASCE 41-13 Chapter 2 commentary. They are:

- Permitting buildings recently built to not be immediately rendered deficient when there are minor changes to the new design standards.

- The increased risk due to the lower hazard is acceptable because of the presumption that an existing building has a shorter remaining life than a new building.

- The cost of retrofitting to achieve commensurate performance can be disproportional to the increased benefit as opposed to doing something to make the building better by mitigating the most egregious deficiencies.

With the decisions to retain the philosophy of allowing existing buildings to be evaluated and possibly upgraded to a lower hazard than new buildings, the question then became what that hazard should be. While the 0.75-factor has been engrained within the profession for many years, it is somewhat arbitrary.

ASCE 41-13 Performance Objectives

The concept of marrying seismic hazard levels with structural and nonstructural performance levels to create a performance objective was retained in ASCE 41-13. Both ASCE 31-03 and ASCE 41-06 had various performance objectives set forth explicitly. ASCE 41-13 has two sets of explicitly defined performance objectives, the Basic Performance Objective for Existing Buildings (BPOE) and the Basic Performance Objective Equivalent to New Building Standards (BPON). In addition to those two sets of explicit performance objectives, ASCE 41-13 retains the Enhanced Performance Objective and Limited Performance Objective categories.

The Basic Performance Objective for Existing Buildings (BPOE) uses the BSE-1E and BSE-2E hazard levels. Unlike ASCE 41-06, the BPOE is not a single performance objective, but rather a table of different performance objectives based on the Risk Category that would be assigned to a building. The decision to map the performance objectives to Risk Categories was made because the widespread use of ASCE 31-03 and ASCE 41-06 had led to numerous building codes, various federal state and local jurisdictions, and engineers to do their own mapping of the Risk Categories to performance objectives, without consistency. The committee felt that it was important for there to be some standardization of this practice and therefore it was brought into the BPOE. Table 3 summarizes the BPOE.

This set of performance objectives are intended to be the one that approximates the performance objectives within ASCE

31-03 WHICH ACCEPTED A HIGHER LEVEL OF RISK. THE BPOE IS USED FOR ALL THREE TIERS OF EVALUATIONS. WITH TIER 1 AND TIER 2 ONLY REQUIRING EVALUATION AT THE BSE-1E LEVEL AND TIER 3 REQUIRING EVALUATION AT BOTH THE BSE-1E AND BSE-2E LEVELS.

ACI 562, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings [ACI 562] and Commentary," published by ACI and will truly become "official" with the 2015 International Existing Building Code (IEBC), which will make the use of the ACI 562 Code a requirement when working on existing concrete buildings.

ACI 318, CHAPTER 20 – IBC, CHAPTER 34

• 5% RULE TRIGGER FOR UPGRADE TO CURRENT CODE • REPAIR REQUIREMENTS VARY WITH EDITION – INTERNATIONAL EXISTING BUILDING CODE • FIRST PUBLISHED IN 2003 •

ACI 562 Philosophy emphasize Performance Based rather than prescriptive requirements.

The strengthening of R/C structural members (beams, slabs, columns, walls) using glued Carbon Fiber-Reinforced Plastic Sheets is a relatively new method of intervention. The CFRP sheets exhibit the following advantages compared to the steel sheets:

- They are light in weight
- They do not corrode
- They are available in large dimensions
- They have low modulus of elasticity accompanied by large elastic deformations up to failure, which are particularly useful properties for prestressing.

Thanks to the above advantages, CFRP sheets have been used in the development of new techniques for repair and strengthening of R/C structural elements, in which they replace steel sheets. It should be stressed that while these materials can be successfully used to increase strength in bending, shear and compression, they can not affect the stiffness positively. At the same time, in most cases they influence local ductility negatively.

The problem of upgrading existing weak buildings arises strongly and urgently in Jordan and the Middle Eastern Arab Countries, which are vulnerable to severe earthquakes. An example for this threatening problem is the latest earthquake in Izmit-Turkey, which caused thousands of human lives besides billions of dollars as loss in national property. Earthquakes of similar magnitudes and intensities are very likely to occur more often as statically the 1927 earthquake caused the failure of the King Hussain musk miner at at down town Amman, the 100 year occurrence of such major event is becoming closer. Consequently, the need for upgrading and retrofitting major important buildings to survive future earthquakes is a strategic decision to be taken.

Japan have the oldest experience of upgrading and repair where engineers have implemented several techniques after the 1968 Tokachi-Oki earthquake. Also, following the 1985 damaging earthquake in Mexico City, upgrading and repair efforts for damaged reinforced concrete structures were introduced. Also, in U.S.A., engineers employed similar upgrading efforts. The most common techniques used were the addition of concrete or masonry walls, and strengthening by external structural steel elements.

Several structural materials can be used for upgrading and repair of reinforced concrete buildings, most commonly reinforced concrete and structural steel. Reinforced concrete was the first material to be considered for such engineering work where it can be used mainly in two ways: either for jacketing of existing frame columns and beams, or by addition of infilled shear walls in designated openings. The main draw backs in using reinforced concrete for upgrading an old RC building is the amount of construction work required and the disruption caused by the evacuation of occupants. Besides, the additional weight of concrete causes increase in the inertia mass, which affects the dynamic response of the building and requires strengthening for existing foundations. On the other hand the use of CFRP can result in less weight of add material with the availability of prestressing

Upgrading of existing buildings by CFRP becomes more attractive and feasible considering the following advantages: fast construction time, less disruption to occupants, Almost no increase in inertia masses and forces on existing foundations, no interference with building function. Description of the most efficient upgrading conventional and new techniques for existing reinforced concrete buildings, which are the focus of recent research and practice, are presented by showing the application of CFRP and using the epoxy adhesive to bond externally to existing structural elements.

OBJECTIVES OF UPGRADING

Although some upgrading techniques can be used for both static and dynamic forces, there is a fundamental difference between the structural response for each case. This leads to different objectives for upgrading of structures under consideration. Upgrading of old buildings for static loads, which are externally applied quantities, require basically an increase in strength (axial, shear and bending) of the existing columns, beams, and slabs. This is usually done by making the structural elements larger. This was the result of conventional upgrading techniques, on the other hand the use of CFRP will result in no increase in the structural element size which is a required in many of the retrofitting cases.

The seismic loads are function of the interaction between the input ground motion and the structural characteristics. The main objective of any upgrading technique for an old structure against seismic loads is to improve some or all of the earthquake structural response characteristics, such as lateral strength, stiffness, ductility, and energy dissipation. Besides, the upgrading technique should be easy to construct with minimal disturbances. Simultaneously, the failure mode of the upgraded structure should be greatly anticipated avoiding any undesirable abrupt failure mode such as a soft-story mechanism. The use of CRFP in combination with the addition of shear wall either concrete or steel stiffening panels can result in an overall upgrading of the existing structure which satisfies FEMA requirements in high seismic regions.A seismically weak old building may lack one or more of the above resistance characteristics. The lateral strength can be improved separately as in the case of static loads by jacketing the main frame elements by either reinforced concrete or by structural steel members. However, improving stiffness of an old building leads automatically to additional strength. Thus, the displacement response (drift) of the upgraded structure is reduced by shortening its natural period than that of the core structure. This strategy works best if the modified period takes the structure into lower response spectrum regions, such as, when ground conditions have selective dominant periods. The two efficient upgrading techniques, which improve both strength and stiffness, are: RC shear walls and steel bracing.

Alternatively, the objective of upgrading can be improving ductility and energy dissipation especially when higher displacement response is expected during strong ground motions. In this case, some type of energy dissipation devices may be added to the columns of the main lateral resistant existing frame(s). These devices dissipate the input energy and eliminate most of the damage that could have occurred during severe earthquake. These devices can be replaced with little effort, and minimal damage occurs in the main frame(s).

In some particular cases, where several deficient structural characteristics need upgrading, the upgrading technique might be a combination of several schemes, such as CFRP with steel bracing in addition to energy dissipation devices.

CONCLUDING REMARKS

Interest in upgrading of older buildings has become increasingly important in recent years. Intensive engineering design has been expended on improving the structural performance of existing buildings most of it for better resistance to earthquakes. A brief review of state-of-practice and research on the subject of upgrading older RC structures is presented. The subject is too broad where the design and behavior of upgraded systems and their components is very complex. Although recent research have provided some understanding of the behavior of specific upgraded structures, anyone approaching design for upgrading of older buildings is advised to find out how various upgrading techniques performed in recent events. AISC 41-13 and ACI 562 further reinforced officially support the use of CFRP application specially with 5% criteria of global retrofitting the whole structural system if repair resulted for member demand increased.

REFERENCES

1. UNDP(1977)Repair of Buildings Damaged By Earthquakes, New York.
2. KARBHARI V.M., " Materials Considerations in FRP Rehabilitation of Concrete Infrastructure " Fibre Composites Workshop, Brisbane, September 2000.
3. AL-MAHAIDI R., TAPLIN G., " Analysis of Load Testing Results - Geelong Road Bridge over Little River " Department of Civil Engineering, Monash University, November 2001.
4. Yamamoto, Y., and Aoyama, H., "Seismic Behavior of Existing RC Frame Strengthened with retrofitting Steel Elements", Proceedings, U.S.-Japan Seminar on Repair and Retrofit of Existing Structures, Tsukuba, Japan. May 8-9, 1987.
5. Seki, M., Katsumata, H., and Takeda, T., "Study of Retrofit Method of Existing Structures by Steel Braces with Dampers", Proceedings, U.S.-Japan Seminar on Repair and Retrofit of Existing Structures, Tsukuba, Japan. May 8-9, 1987.