Chapter 19

A systematic approach concerning the assessment and strengthening of reinforced concrete buildings of Catania city

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Abstract

The Catania I Project has yielded some preliminary results regarding the losses consequent to different seismic scenarios in the area of Catania. The aim of the Catania II Project is to gain a deeper insight into the problem starting from the results of the previous project, through the development of a “Detailed seismic scenario finalized to losses reduction in the urban area of Catania city”. Concerning the losses mitigation, the authors have been involved in the development and implementation of two products: a Code of Practice concerning the Assessment and Strengthening of Reinforced Concrete Buildings, an intelligent Data Bank supporting and integrating the Guidelines and aiming at assisting the operators in the task of acquiring the data and assessing the vulnerability.

Keywords: assessment, strengthening, reinforced concrete, buildings, Code of Practice, intelligent Data Bank.

1 Introduction

The Catania I Project has yielded some preliminary results regarding the losses consequent to seismic scenarios in the area of Catania. In Pessina [2] a scenario earthquake is presented: an $M=7$ earthquake has been assumed in order to simulate the 11 January 1693 earthquake ($MCS = X-XI$). The scenario (Fig. 1) is characterized by PGA values ranging between 0.15 g and 0.35 g. Based on the $M=7$ scenario earthquake, in Faccioli *et al.* [3] a damage scenario for residential

buildings has been proposed. Two different approaches have been adopted, based on the vulnerability score and a simplified mechanical procedure. The vulnerability score assessment is based on the evaluation of a numerical index for a surveyed building and consequently on the attribution of a damage function. The mechanical approach is based on a displacement limit states assessment: four limit states have been considered going from a no damage condition to a condition corresponding to a high level of damage so that even if the building does not collapse the structure has to be demolished.

Figure 1: Catania earthquake scenario.

In Cosenza [4] further studies are presented with regard to seismic assessment of two reinforced concrete buildings representative of the most common RC typologies of Catania city. The studies carried out outlined a high vulnerability for the studied buildings: the collapse will occur for PGA values ranging between 0.1 and 0.15 g.

The aim of the Catania II Project is to gain a deeper insight into the problem starting from the results of the previous project, through the development of a "Detailed seismic scenario finalized to losses reduction in the urban area of Catania city". Concerning the losses mitigation, the authors have been involved in the development and implementation of two products: a Code of Practice concerning the Assessment and Strengthening of Reinforced Concrete Buildings, an intelligent Data Bank supporting and integrating the Guidelines and aiming at assisting the operators in the task of acquiring the data and assessing the vulnerability.

The Code of Practice concerns inspection, assessment and strengthening provisions. The inspection provisions concern all the activities needed to define building geometry and mechanical properties of concrete and reinforcement.

The proposed Data Bank is an integrated software expert system for the seismic vulnerability evaluation. The system provides an expert interface and a vulnerability analyzer. The expert interface assists the surveyor in the geometric and mechanical description of reinforced concrete buildings; the vulnerability analyzers will assist the engineers in the planning and estimation of the interventions for seismic risk management.

2 The Code of Practice

Among the recently proposed seismic assessment guidelines the ATC 40 proposal, Applied Technology Council [1], seems to be better tailored for the Italian scenario, save that some adjustment is needed. Since this document has been chosen as a model for the Code, a brief description of the principal topics of the most relevant chapters follows.

The ATC 40 “Seismic evaluation and retrofit of concrete buildings” is organized in two volumes: the first one describes the proposed methodology, the second one is organized in six appendices that contain four case studies (Appendices A-D) a cost effectiveness study (Appendix E) and supplemental information on foundation effects (Appendix F). The methodology (Volume 1) is presented in 13 chapters, among which some will be analyzed.

Table 1: ATC 40: Table of Contents.

<i>ATC 40 – Volume 1: Table of Contents</i>			<i>I. Introduction</i>
2. Overview	3. Performance Objectives	4. Seismic Hazard	5. Determination of Deficiencies
6. Retrofit Strategies	7. Quality Assurance Procedures	8. Nonlinear Static Analysis Procedures	9. Modelling Rules
10. Foundation Effects	11. Response Limits	12. Nonstructural Components	13. Conclusion and Future Directions

In chapter 3 the Performance Levels (PL) for a building are introduced, combining six Structural PLs (SP) with five standard Nonstructural PLs (NP) into several Building Performance Levels. Given an earthquake ground motion, the Performance Objectives (POs) are consequent to the PL, so that the PO is equal to “The Desired Building Performance Level for a given earthquake ground motion”. Three Structural Performance Levels corresponding to discrete damage states are defined: SP-1 = Immediate Occupancy: very limited structural damage has occurred; SP-3 = Life Safety: significant damage to the structure may have occurred (but structural collapse is prevented); SP-5 = Structural Stability: partial or total collapse has occurred. Other two PLs (SP-2 = Damage Control, SP-4 = Limited Safety) represent transition states (Performance Range) between SP-1 and SP-3, SP-3 and SP-5. Further on the SP-6 “provides a placeholder for situations where only nonstructural seismic evaluation or retrofit is performed”. As for Structural Performance Levels, Nonstructural PLs and transition states are introduced. Four NPs are defined: NP-A = Operational: nonstructural elements and systems are generally in place and functional; NP-B = Immediate Occupancy: the ability to function of equipment and machinery is not considered and some limitations on use or functionality may exist; NP-C = Life Safety: considerable state of damage to nonstructural components and systems is considered, but should not include collapse or falling of items heavy enough to cause severe injuries either within or outside the building; NP-D = Reduced Hazard: extensive damage to nonstructural components and systems is considered, as well as very low risk of failures that could put large numbers of

people at risk within or outside the building. In Table 2 the combination of Structural and Nonstructural Performance Levels is reported to form Building Performance Levels, four of which (the principal ones) are: PL 1-A = Operational, PL 1-B = Immediate Occupancy, PL 3-C = Life Safety, PL 5-E = Structural Stability. The combination of the PLs with three levels of earthquake ground motion gives the definition of the Performance Objectives. The levels of earthquake motion (described in chapter 4) are: SE = Serviceability Earthquake: ground motion with a 50% chance of being exceeded in a 50-year period; DE = Design Earthquake: ground motion with a 10% chance of being exceeded in a 50-year period; ME = Maximum Level: maximum level of expected ground motion. A dual or multiple level performance objective is selectable, combining ground motion and PLs. An example of Performance Objective for normal buildings is reported in Table 3.

Table 2: ATC 40: Building Performance Levels.

<i>Building Performance Levels</i>						
<i>Nonstructural Performance Levels</i>	<i>Structural Performance Levels</i>					
	<i>SP-1</i>	<i>SP-2</i>	<i>SP-3</i>	<i>SP-4</i>	<i>SP-5</i>	<i>SP-6</i>
NP-A	1-A	2-A	NR	NR	NR	NR
NP-B	1-B	2-B	3-B	NR	NR	NR
NP-C	1-C	2-C	3-C	4-C	5-C	6-C
NP-D	NR	2-D	3-D	4-D	5-D	6-D
NP-E	NR	NR	3-E	4-E	5-E	Not applicable

Table 3: ATC 40: sample performance objectives for normal buildings.

<i>Seismic Hazard</i>	<i>Source of Sample</i>			
	<i>New buildings</i>	<i>Current Common Retrofit</i>	<i>High Occupancy</i>	<i>Minimum Downtime</i>
<i>Combined Performance Level</i>				
SE				
DE	2C	3D	3C	1C
ME	5E		3D	

Chapters 5 and 6 provide an overview of “The process of developing retrofit strategies” on the base of the selected performance objectives. These chapters are tailored to be a good step by step guideline for those who deal with preliminary and general decisions, then involving both technical and non-technical matters: simple, clear and user friendly procedures and forms help both designer and owner to achieve good information and a complete overview of the project as well. A preliminary, even if simple, design of each strategy is required and consequently the comparison can be obtained by assigning a score to each strategy. Different parameters are defined and for each of them a score and a

weight are to be assigned so as to obtain a strategy evaluation matrix (see Table 4).

Table 4: ATC 40: sample strategy evaluation matrix.

Strategy	Cost	Schedule	Architectural impact	Occupancy disruption	Seismic performance	Score
Importance	10	3	7	3	10	
Exterior shear Walls	9	10	7	10	6	259
Ext. Braced frames	10	9	3	10	5	228
Interior Shear Walls	7	8	10	0	6	224
Int. Braced frames	8	7	10	0	5	221
Ext. Buttresses	9	10	3	10	6	231
Base isolation	3	5	10	0	10	215

In order to emphasize the importance of the non-technical aspects of a retrofit project, a brief example of “perception of effectiveness” is reported: the retrofit performed for the building hosting the Domiziano Viola elementary and Luigi La Vista nursery schools of Potenza (Braga coordinator, 1990) is a perfect example of how many different criteria can be involved and must be considered in projects of this kind. As shown in Fig. 2, the solution chosen (dissipative bracing) had a strong impact on the building’s aspect. Nevertheless, the same impact led the occupants (children and their parents as well as teachers) to acknowledge the added protection achieved.

Figure 2: Dissipative bracing example: Domiziano Viola and Luigi La Vista School Building (Braga coordinator).

Chapter 8 regards the non-linear static analysis procedures based on the pushover analysis method. The principal steps of the procedure (capacity curve evaluation, demand spectra definition and performance point identification) are presented. The step-by-step procedure to determine the capacity consists of 11 steps based on a pushover analysis, which includes the “adaptive pushover” as an

alternative. A procedure to model strength degradation is proposed. The demand is calculated using the Capacity Spectrum Methods (CSM) that involves the following steps: 1) conversion of traditional Response Spectra in ADRS format (Acceleration-Displacement Response Spectra); 2) conversion of capacity curve in capacity spectrum; 3) evaluation of the performance point by means of three equivalent procedures (direct, simplified and graphical) applied to the CSM. Steps 1) and 3) require the evaluation of the equivalent viscous damping to reduce the 5% damped spectra together with the definition of the substitute structure. The effective damping is evaluated according to the following expression

$$\beta_{eff} = k\beta_o + 5 \quad (1)$$

where

$$\beta_o = \frac{1}{4\pi} \frac{E_D}{E_{SO}} = \frac{1}{4\pi} \frac{\text{energy dissipated by damping}}{\text{maximum strain energy}} \quad (2)$$

The damping modification factor k is a measure of the quality of the seismic resisting system. Effective damping values are reported for three typologies as follows: A = Essentially new buildings ($k = 1$): “represents stable, reasonably full hysteresis loops”; B = Appropriate for the majority of existing retrofitted buildings: “represents a moderate reduction of the hysteresis loop area”; C = Appropriate for existing but not retrofitted buildings: “represents poor hysteretic behaviour with a substantial reduction of loop area”.

Table 5: ATC 40: structural behaviour types.

<i>Shaking Duration</i>	<i>Essentiality New Buildings</i>	<i>Average Existing Building</i>	<i>Poor Existing Building</i>
Short	Type A	Type B	Type C
Long	Type B	Type C	Type C

The ATC 40 also includes the Displacement Coefficient Method to evaluate the target displacement as

$$\delta_t = C_0 C_1 C_2 C_3 \times S_a \frac{T_e^2}{4\pi^2} \quad (3)$$

where T_e = effective fundamental period of the building; C_0 = modification factor to relate spectral displacement and likely building roof displacement (see Table 6); C_1 = modification factor to relate expected maximum inelastic displacement to displacement calculated for linear elastic response; C_2 = modification factor to represent the effect of hysteresis loops (see Table 7); C_3 = modification factor to represent increased displacement due to the second order effects.

Table 6: ATC 40: values for modification factor C_0 .

<i>Number of Stories</i>	1	2	3	4	10+
<i>Modification Factor</i>	1.0	1.2	1.3	1.4	1.5

Table 7: ATC 40: values for modification factor C_2 .

<i>Structural Performance Level</i>	<i>T = 0.1 second</i>		<i>T ≥ T_o second</i>	
	<i>Framing (T=0.1 sec.)</i>		<i>Framing (T ≥ T_o)</i>	
	<i>Type 1</i>	<i>Type 2</i>	<i>Type 1</i>	<i>Type 2</i>
Immediate Occupancy	1.0	1.0	1.0	1.0
Life Safety	1.3	1.0	1.1	1.0
Collapse Prevention	1.5	1.0	1.2	1.0

In Chapters 9 and 10 rules and formulas are suggested to model both structure and foundation components. While the latter mainly offers a good and well-detailed set of equations and models to deal with different geotechnical matters, the importance of the former is principally in order for the engineer to develop a correct and effective non-linear model. Chapter 11 includes both qualitative and numerical criteria (deformation limits) for structural checks.

The proposed Code of Practice (under development) is organized similarly as ATC 40. Two volumes are included: the first one describes the methodology, the second one concerns case studies tailored to the Catania reinforced concrete building typology. Though ATC-40 has been chosen for its unique completeness, at least as far as practice and the general procedures are concerned, it must be recognized that the methods therein implemented need some improvement and to be re-tailored for the Italian scenario. In order to do this, Performance Objectives will be revised (Chapter 3); due to the general direction of the Italian Code only one level of Earthquake Ground Motion will be considered; a set of indications on how to determine scores and weights (Chapter 6, see Table 4) of different strategies and solutions for each single project to compare the benefit of different strategies will be provided.

With regard to the Assessment Methodologies (Chapter 8) the parameters needed to apply the ADRS based methodology (k and β_o , see equation (1)) as well as the Displacement Coefficient Method (C_0 - C_3 , see equation (3)) will be re-evaluated. Further on it has to be recognized that the method therein implemented does not completely overcome the typical difficulties of the Static Equivalent Procedures, even if the one presented, the Capacity Spectrum Method (CSM), is able, more than others, to manage complex models (MDOF). In adopting such a method, the engineer must concentrate on the precision of the structural model, and pay attention to the load pattern and path. Evaluation of this aspect is still being performed. In particular, it must be emphasized, even more than is done in the ATC document, that the assumption of one single, constant load story and path does not offer any shelter against the uncertainties due to the existence of many different capacity curves, depending on load pattern

and path. Usually, the ADRS spectra are 2-D graphics: it is the mere projection of a spectral surface in the (S_Δ, S_a, ξ) space on a plan. In fact, the PP is defined as the intersection of the demand spectral surface and the capacity spectrum. It is represented on a plan by substituting the surface with its section characterized by the same ξ of the capacity spectrum at the PP. The capacity curve developed under the particular load path and pattern chosen shows that the response of the structure for the given family of demand spectra effectively occurs where indicated by the spot. If another load pattern and path are used, the capacity spectrum could change, and the PP may occur at a different maximum expected displacement.

Figure 3: Spectral surface in ADRS + ξ space.

Figure 4: Building inventory: localization of buildings selected as representative of RC buildings.

The second volume concerns assessment examples of the eight-story building representative of a widespread building typology (a preliminary inventory has been done acquiring data about the buildings located in the Fig. 4 map).

The assessment concerns the as built condition as well as the retrofitted condition. The last one will illustrate the case of base isolation as well as energy dissipation based strategy, and a more traditional strategy such as those based on internal shear walls. Examples of single beams and columns retrofitting will be illustrated. All the phases of the intervention will be described by means of detailed drawings (Fig. 5).

Figure 5: Interventions: description of stages.

3 The Data Bank

The proposed Data Bank (under implementation) is an integrated software expert system for the seismic risk calculation of “AEC organisms” (Architectural and Construction “objects”, like buildings) and for the production of the related seismic risk maps.

Figure 6: Database driven system.

Organism data are collected from on-site surveys, while the system provides an *expert interface* to assist the surveyor in the geometric and mechanical description of the AEC organism itself. Data are subsequently integrated in a CAD (Computer Aided Design) system interface and then analyzed on the basis

of “intelligent” risk estimation models, in order to compute the organism seismic risk. Finally, the “local” risk analysis is connected to the “global” analysis (city or province) through a GIS (Geographical Information System) interface (Fig. 6).

The objective of the project is to implement the proposed system by providing an expert system “shell” able to “intelligently” collect and store data and to perform both micro and macro seismic risk analysis. Along with this main goal, there is the objective of producing an adequate documentation of its algorithms and of its use.

The main beneficiaries of the *system* will be town and regional administrations, in planning and estimating the interventions for seismic risk management. Furthermore, building administrators will benefit as well from the “local” risk estimation and intervention proposal capabilities of the system. Two types of final users are foreseen: *surveyors* and *risk analyzers*. The *surveyors* will be trained technicians, while the *risk analyzers* will be principally engineers and architects.

The proposed “Data Base Driven System” will help the technician in applying the methodology proposed in the “Code of Practice” so that, on the basis of a Rule Based System, the Performance Objectives will be defined. Further on the system will drive, if needed, the engineer in the selection of the best retrofitting strategy by means of heuristic rules and comparative numerical simulation aimed at the calculation of the Strategy Evaluation Matrix scores (Table 4). Following this, the system allows large-scale vulnerability evaluation by means of a simplified mechanical model as well as vulnerability score-based assessment. The simplified mechanical-based module evaluates the expected damage by means of a simplified pushover analysis performed with an n-DOF stick model (Fig. 7). This model, versatile enough to represent different structural typologies, takes into account the presence of columns, shear walls and infills, each one of these elements being in turn described by a bilinear constitutive law.

Figure 7: MDOF lumped masses system.

The support operating system will be Microsoft Windows; backing the CAD and GIS settings will be respectively Autodesk AutoCAD and Autodesk MAP. Programming languages will be Microsoft Visual Studio and Visual Fortran. The

subdivision of the system into “software modules” has already been presented in Fig. 5, while in Fig. 8 are some “screen-shots” of the software modules already implemented (MD.01 and MD.02).

Figure 8: Database driven system: screen shots.

Table 8: Database: software modules.

Module ID		Phase description	Software modules to be implemented
MD	01	Database Middleware	Acts as interface between the user and the database, managing all the “low-level” operations on the database (add/modify/delete record, etc.)
MD	02	CAD Interface	Interfaces the system with the CAD environment (e.g. it draws/queries the system AEC intelligent objects)
MD	03	File Interface	Is responsible for read/write data from/to different formats (e.g. SAP2000, etc.)
MD	04	Seismic Risk Analyzer	Is the core calculus of the system, aiming to perform seismic risk analysis
MD	05	Query Creator	Is responsible to perform queries on the database and to display results in the GIS environment
MD	06	Expert System	Is able to assist the surveyors in data input and capable of proposing intervention strategies

The entire software development project has been divided into four main phases, each phase aimed at the implementation of specific software modules. The implementation strategy for each phase includes: Project feasibility analysis, Software requirement specifications analysis, Software implementation

specifications analysis, prototyping, implementation, alpha and beta testing. Implementation of phase 1 has been nearly completed and software modules Database Middleware (MD.01) and CAD Interface (MD.02) are currently under release. The overall master schedule of the implementation plan is reported in Table 8.

4 Conclusions

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