1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.140

Assessment, repair, rehabilitation and strengthening of earthquake-damaged buildings

Alush Shala[1], **Jelena Bleiziffer**[2]

[1] *PhD Student*, Alb-Architect l.l.c., Kosovo, *alushshala@albarchitect.com*

[2] *Assistant Professor*, Faculty of Civil Engineering, University of Zagreb, Croatia, *jelena.bleiziffer@grad.unizg.hr*

Abstract

Buildings that have been subjected to seismic impacts must initially be assessed. The assessment is done in order to determine the degree of damage to buildings. Defining the method of intervention depends on the assessment. Generally, the assessment can be done using Eurocode norms, ACI, SIA, etc. The assesment of buildings determines the ability of buildings to be durable, even against a new possible earthquake of the same magnitutde or even stronger. The assessment should result in clear decision which buildings are close to collapse, and which are suitable for an intervention. Assessments should also take into account the importance of buildings such as historical, cultural, public, etc.

Key words: damage, earthquake, repair, rehabilitation, strengthening, assessment, materials

1 Assessment of earthquake-damaged buildings

Buildings that have been subjected to seismic impacts must initially be assessed. The assessment is done in order to determine the degree of damage to buildings. Defining the method of intervention depends on the assessment. Generally, the assessment can be done using Eurocode norms, ACI, SIA, etc. The assesment of buildings determines the ability of buildings to be durable, even against a new possible earthquake of the same magnitutde or even stronger. The assessment should result in clear decision which buildings are close to collapse, and which are suitable for an intervention. Assessments should also take into account the importance of buildings such as historical, cultural, public, etc. The type of assessment method chosen depends on the objective of the assessment but also on the availability of data and technology [1], as presented in Table 1.

Table 1. Methods for the assessment of the vulnerability of buildings [1]

expenditure	increasing computation effort →				
application	building stock		individual building		
methods	observed vulnerability	expert opinions	simple analytical models	score assignment	detailed analysis procedures

Repair is an intervention method that requires minor interventions in buildings due to seismic loads. Repair is the re-establishment of the initial strength of damaged structural members and the re-establishment of the function of damaged non-structural elements [2]. For the repair of buildings, different materials are used nowadays, starting from the ones with cement base to those on two-component base. Just after a damaging earthquake, temporary supports and emergency repairs are to be carried out, so that precariously standing buildings may not collapse during aftershocks and the less damaged ones could be quickly brought back into use [3].

In most of the buildings which have somewhat deeper but still superficial and small structural damage, the method of rehabilitation (restoration) is used. Even this method is a way of rehabilitation (restoration) of the building elements, but with a deeper intervention. The main purpose of restoration is to carry out structural repairs to load bearing elements. It may involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored [3].

A challenge in itself is the strengthening or retrofitting of buildings that have suffered serious and structural damage. In this paper we will address the methodology and reasonability of rehabilitation of individual elements separately, and for the building as a whole. Strengthening is an improvement over the original strength when the evaluation

of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future quakes [3]. This is especially important for buildings with great cultural and historical value.
After the action of an earthquake in the buildings which have been subjected to inertial forces produced by this earthquake, the need for an assessment arises. The assesment is based on several criteria taking into account international norms such as EC8, SIA, ACI, etc. First, the buildings will be assessed with technical criteri: what is the degree of their damage, the stability of the building and then the financial evaluation of its rehabilitation. Based on the damage observed, they are also divided into which area of rehabilitation they will fall: repair, rehabilitation (restoration) and strengthening (retrofitting). The fundamental requirements refer to the state of damage in the structure, herein defined through three Limit States (LS), namely Near Collapse (NC), Significant Damage (SD), and Damage Limitation (DL) [4]. The methods to assess buildings are: a.) visual inspection, b.) non-constructive testing of materials, c.) structural analysis and d.) nonlinear dynamic analysis and assessment.

2 Repair, rehabilitation and strengthening of earthquake-damaged buildings

The building which is analyzed is shown in Fig. 1. The most important dynamic characteristics of the analyzed models are presented in Table 2.

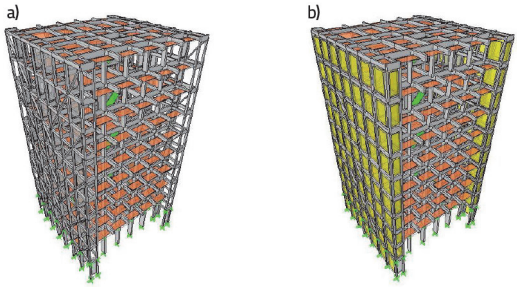

Figure 1. Geometrical model of a structure without and with tuff infillings [5]

Table 2. Modal properties for bare frame model and with tuff infill [5]

Model	mode	T [sec]	M_X	M_Y	M_{RZ}
Bare frame	1	1.35	0.65	0.00	0.25
	2	1.10	0.00	0.68	0.28
	3	0.93	0.00	0.00	0.14
Tuff infilled frame	1	1.33	0.65	0.00	0.27
	2	0.74	0.00	0.70	0.30
	3	0.64	0.00	0.00	0.14

Nonlinear analysis is used to determine the plastic points of the elements in the building. Hysterical curves for columns and beams need to be defined to analyze the condition of the building before the collapse, and to provide safety of users. Nonlinear models were analyzed using SAP2000 software. Generally, there is a focus on column-beam joints: nonlinear behaviour of RC columns is represented by a moment-rotation (M- θ) relationship, evaluated a priori. In particular, each M-θ is defined through four characteristic points (Fig. 3): cracking (cr), yielding (y), maximum (max) and ultimate (u) [5].

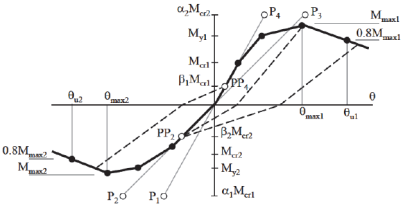

Figure 2. Columns' M-θ backbone and hysteretic behaviour[7]

Building repair: After a site assessment and analysis of the damage done by seismic loads, the degree of damage is determined. In cases when we have limited damage to buildings and they are rated on the scale LS-DL, they need surface interventions or repair. The main purpose of repairs is to bring back the architectural shape of the building so that all services start working and the functioning of building is resumed quickly. Repair does not improve the structural strength of the building and can be deceptive in appearing to meet the strength requirements of the next earthquake. The actions will include the following [3, 6]: (1) patching up defects such as cracks and fall of plaster, (2) repairing doors, windows, replacement of glass panels, (3) checking and repairing electric wiring ,(4) checking and repairing gas pipes, water pipes and plumbing services, (5) rebuilding non-structural walls, chimneys, boundary walls, etc., (6) re-plastering of walls as required, (7) rearranging dislocated roofing tiles, (8) relayering cracked flooring at ground level, and (9) redecoration – whitewashing, painting, etc.

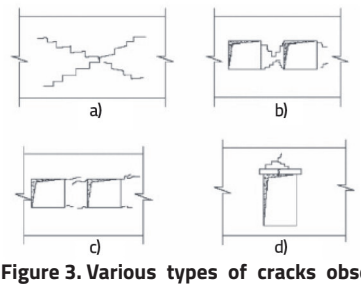

Figure 3. Various types of cracks observed in masonry walls [2]

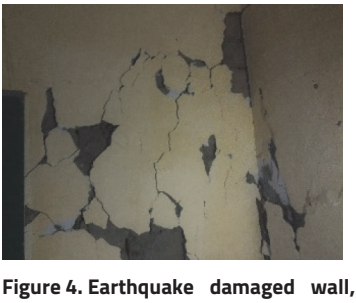

Figure 4. Earthquake damaged wall, Albania 2019

Rehabilitation or restoration of buildings is one of the most important processes because it has the task of addressing not only secondary elements, but also supporting or structural ones and bringing them to a previous state. It is especially important as a method used in the rehabilitation of cultural and historical buildings, taking into account its age of buildings, or even engineering structures that are of particular importance. With this method a structure must be able to withstand repeated impacts from earthquakes or other accidental forces. The main purpose of restoration is to carry out structural repairs to load bearing element [3]. It may involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored [3]-.The process may involve inserting temporary supports, underpinning, etc. Some of the approaches are stated below [3, 6]: (1) removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar; use of non-shrinking mortar is preferable, (2) injecting rich mortar, epoxy like material, which is strong in tension, into the cracks in walls, columns, beams, etc., (3) addition of reinforcing mesh on both faces of the cracked wall, attaching it to the wall through spikes or bolts and then covering it suitably; several alternatives have been used, (4) remove damaged column or beam, fix the reinforcing, add reinforcing if needed, and reconcreting, (5) injecting epoxy like material, which is strong in tension, into the cracks in walls, columns, beams, etc., and (6) use of materials with high strengthbased on carbon fibres, glass or aramid, etc.

Figure 5. Use of FRP materials in restoration

Strengthening or retrofitting of buildings: this intervention method aims to increase the bearing capacity of the structure and the intervention is mainly in the primary structural elements. With strengthening we manage to increase the durability of the building and structural elements.

The seismic behaviour of an old existing buildings is affected by its original structural inadequacies, material degradation due to time, and alterations carried out during its such as making new openings, addition of new parts inducing asymmetry in plan and elevation, etc. [3]. Commonly, strengthening procedures should aim at one or more of the following objectives [3, 6]: (1) demolish the weakness sources or sources that can make stress concentration in several parts – columns distribution is not symmetric, walls distribution is not symmetric, different stiffness from one floor to another, excessive openings, (2) improve building's integrity by tying together all of its components, (3) avoid brittle failure by re-arranging, adding reinforcing bars, and making the details in

accordance with ductility requirement, and (4) increasing the lateral strength by adding walls, columns, etc.
Comparison of different intervention methods is shoen in Fig. 6.

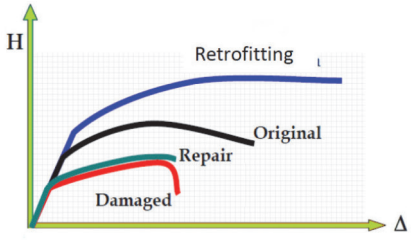

Figure 6. Diagram showing the difference between original, repaired and reinforced buildings [9]

References

[1] Lang, K. (2002): Seismic vulnerability of existing buildings, https://doi.org/10.3929/ethz-a-004333389

[2] Qaisar, A. (2009): Seismic Retrofitting and Repair Manual for Buildings, Earthquake Vulnerability Reduction Project (EVRP),UNDP Pakistan.

[3] Arya, A.S., Boen, T., Ishiyama, Y. (2012): GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION, International Association for Earthquake Engineering (IAEE), United Nations Educational, Scientific and Cultural Organization (UNESCO) and International Institute of Seismology and Earthquake Engineering (IISEE),

[4] The European Union, EN 1998-3 (2005): Eurocode 8: Design of structures for earthquake, Resistance-Part 3: Assessment and retrofitting of Buildings.

[5] De Luca, F., Verderame, G.M., Manfredi, G. (2014): Eurocode-based seismic assessment of modern heritage RC structures: the case of the Tower of the Nations in Naples (Italy): Naples, Italy.

[6] HOUSING RECONSTRUCTION PROGRAMME (2017): REPAIR AND RETROFITTING MANUAL For RCC STRUCTURE: Government of Nepal National Reconstruction Authority, Singhadurbar, Kathmandu