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RETROFIT OF STONE MASONRY BUILDINGS IN GREECE
II. DETERMINATION OF COSTS

BY

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Abstract. This paper represents the continuation of a previous work concening the costs of seismic retrofit of stone masonry buildings in Greece. Studies dealing with the costs of retrofit are rare to date. Unlike the study of historic buildings, which is in most cases done for masonry buildings since reinforced concrete is not considered historical enough, for benefit–costs studies of seismic retrofit more studies were conducted for reinforced concrete buildings, as these are more common. First seismic retrofit measures for common masonry buildings are presented, using steel and reinforced concrete. Then the method to determine the costs is presented. The focus lays in division of seismic retrofit measures in singular steps and in the determination of the individual costs of the partial works. Compared to other costs determination works, which are based on space contents, floor surface, or utility surface, the proposed method has the advantage that it is relatively independent from similar works already performed. Some calculation examples are performed. Finally, examples of retrofit for whole buildings are given, considering monumental works; the similarity of the proposed method with professional practice is evident.

Key words: stone; masonry; costs; retrofit; historic buildings; Greece.

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1. Introduction

The majority of population lives and will continue to live in existing buildings. Therefore earthquakes pose a major threat to life and property of people living and working in such buildings, if situated in earthquake prone zones. Most existing buildings, especially the historic ones, were designed before seismic codes were introduced. In this case, in order to protect life and property from seismic risk the retrofit of existing buildings is an aim to be pursued. Resources for retrofit are limited; therefore the issue of economic efficiency is more and more important, near the structural, functional and aesthetic criteria involved in seismic retrofit.

Research in economic efficiency of seismic retrofit is scarce. In the US FEMA has published a database on seismic retrofit measures (1988). However, these are connected with data from the US, and therefore only limitative applicable for other geographic regions. Such databases for costs, not necessarily of building retrofit, but for rehabilitation, exist also for Germany, and were investigated for this work. Neddermann (2007) proposes a so-named *construction element method* as a subdivision method for the estimation of costs, and this was also taken in consideration in this work. This would be also suitable for Romania, where there are devices of costs for retrofit measures (INCERC, 2000), but with the results not in costs, but in formulas.

Also, as regards the economic efficiency studies, those from the US were the first ones. Such, FEMA 274 (1997) proposes a three dimensional interdependence on which on one axis there is represented the performance, on the other the earthquake severity and on the third axis, the relative cost. ATC-40 (1996) contains in its documentation costs studies. But these don't build a curves family, as it was the research aim of the first author.

A more recent study, based on probabilistic methods, comes from Turkey. Smyth *et al*. (2004) performed a costs benefit study for a common and vulnerable building type in Turkey and extended the results probabilistically.

Another recent studies were performed in Greece (Lekidis *et al*., 2005; Kappos & Dimitrakopoulos, 2008). The second study proposes the estimation of the reduction of structural vulnerability due to retrofit. An example is given for reinforced concrete buildings in Thessaloniki, Greece. It is a complex study tailoring decision making to benefit–costs and life–cycle analysis. The study relies on a previous one (Kappos *et al*., 1998) on how fragility curves for reinforced concrete buildings shall be computed in view to the measures, distinguishing between cheap and expensive measures for reinforced concrete buildings with frame or dual structure. Even more recently, using the databases after the 1999 Athens earthquake, studies were made for the Ana Liosia site (Kappos *et al.*, 2007; Lekidis *et al*., 2005). All these studies require the existence of databases on urban built stock in order to make the comparison between the computation and the real costs, as it is done for experimental and numerical simulations in civil engineering.

Certain attempts were made to go over from the statistical data in one region to those in another by employing probabilistic methods. Such were the ones (Zikas & Gehbauer, 2007; Zikas *et al*., 2006) within the Collaborative Research Centre "Strong Earthquakes" at the University of Karlsruhe, Germany. The last phase of the Collaborative Research Centre included a benefit–costs evaluation module, to be included in the GIS tool EQSIM, applied for Bucharest, Romania, and continued former research of the first paper on economic efficiency of retrofit on building scale. The results from this work were widely published during the research work in Karlsruhe (ex. Boştenaru, 2001, 2004; Boştenaru & Gehbauer, 2004), and finally summarized in a book (Boştenaru, 2006). Recently it was opened for Modernist heritage building studies (Boştenaru, 2009). The goal was to develop a method that doesn't require local specific values. The only basis is information available on each particular location, such as knowledge about the specific building practice in that country; the characteristics of the building stock and possible retrofit measures. Most of these publications had the focus on the economic efficiency of seismic retrofit of reinforced concrete buildings, for which a special methodology of costs curves in case of preventive retrofit *versus* repair after an earthquake was developed and verified using finite elements. Computations as in the studies of Kappos *et al*. (2005, 2008, 1998, 2007) are also possible taking into account that the output from the structural simulation programme permits counting the damaged elements and thus the length of damage is measurable, but, only for reinforced concrete skeleton/frame buildings. For masonry buildings no simulations were run.

The International Seminar on Seismic Risk and Rehabilitation of Stone Masonry Housing was an occasion to come back to an issue present at the begin of the research on economic efficiency of the first author, namely the economic efficiency of retrofit of old masonry buildings (Boştenaru & Bourlotos, 2008). In Romania, which was the country more extensively studied, stone masonry buildings are scarce, so, given that at the begin research was done supervising the individual study of a Greek researcher this work was done for the Greek stone built stock.

Each building is unique and a building retrofit measure only satisfies its scope when the identity of the construction work remains maintained.

The work is completed by analysing retrofit interventions on two monumental buildings in Athens: the National Library of Greece and the

National Theatre of Greece, described in the first part (Boştenaru *et al*., 2012) of this study.

2. Determination of Costs

In different stages of planning different costs determination methods can be used. They have different precision degrees and different requirements in what regards the precision wished. The kind of data available can be very different from one location to another and there is a strong relation between the collected data and the specific costs estimation methods for a country (Boştenaru, 2001). The last cited paper deals with the determination of costs for the interwar buildings in Romania, which are high rise buildings with reinforced concrete skeleton designed for gravity loads only.

The study building, the basis of this work, is an individual work regarding the determination of costs in the seismic retrofit of old buildings (Bourlotos, 2001). First the German costs estimation methods and tools were investigated, and also the examples given are using the German prices for the hour of work and for materials for 2001, even if earthquakes are rare in Germany. However, stone masonry housing is typical for Germany as well.

2.1. Overview of German Costs Determination Methods

As the case of codes for seismically resistant construction, also costs determination methods were first developed for new buildings. Later on, Neddermann (2007) developed a method for existing buildings renovation which developed into a bestseller as intervention on existing buildings is gaining more and more ground compared to the building of new constructions in Western Europe.

a) *Costs determination methods for new buildings*

In case of new buildings, there are two methods to determine costs in Germany (IWB, 1981): costs estimation and costs calculation.

The costs estimation is suitable for incipient stages of planning. In these stage the working scale is 1:200…1:100 and therefore the exact dimensions are not yet known. The only quantities operated with are the surfaces dedicated to different functions. In Germany the BKI (Baukosteninformation – Construction Costs Information) leads a database with costs of existing constructions, classified, among others, according to the function of the spaces. Therefore, with a simple table calculation tool, based on the costs of these documented built projects the costs for a new building can be estimated. Key area types such as gross floor area or main function area are compared (Boştenaru, 2001).

The costs calculation method is suitable for more advanced stages of planning. At this stage the scale worked with is 1:50…1:10. The quantities operated with are again surfaces, but surfaces of building elements. Building elements are classified according to their execution type. A first level is the so-called *vertical division* (IWB, 1981): real estate, furbishing up and making accessible, building – building engineering, building – technical assets, external arrangements, equipment and works of art, building extra expenses.

A second level of division is the *horizontal division*. An example on which costs can be calculated is that of building engineering, for which on this level of division we find (IWB, 1981): building cavity, foundation, external walls, internal walls, floors, roofs, building structural mountings, other measures for building engineering.

There are subdivisions for these, on which costs can be plotted. For example, for external walls (IWB, 1981): load bearing external walls, non-load bearing external walls, external columns, external walls and windows, exterior finishes of exterior walls, interior finishes of exterior walls, modulated external walls, anti-glare shield, external walls, others.

A recent update of BKI includes estimation according to these rules of the costs for upgrading and maintaining old buildings.

b) *Costs determination methods for existing buildings*

The method developed by Neddermann (2007) for the determination of costs for the renewal of buildings is based on that for new buildings. Neddermann goes beyond the last described level in the previous paragraph defining a new type of element, the so-called *old building element*. Such an old building element is a ready-made service pack for restoration. Each restoration pack has a description, a current number and descriptions and numbers for the individual building operations which have to be performed for that element. Previous approaches took in account building elements only as a collection of single execution steps. Neddermann (*op. cit.*) tries to define real constructional elements. According to this approach, a building can be divided in elements, which consist of their own constructionable parts (Boştenaru, 2001).

2.2. Approach to Costs Calculation of Retrofit Measures

Building retrofit is a particular case of building renewal. However, while aging affects a building uniformly in its whole substance, seismic damage is uneven and retrofit is only concerned with structural elements. Boştenaru (2001) has established a table showing these differences. Therefore the methods based on surface or space measurements are not suitable for retrofit measures.

The first author developed the concept of *retrofit elements* to support decision regarding the applicability and economic efficiency of retrofit measures (Boştenaru, 2003). “Retrofit elements” are spatial elements that are characteristic for the survey, present typical earthquake damages and are decisive for better seismic behavior in case of retrofitting. A retrofit element consists of all works that have to be done in order to retrofit, repair, rebuild or even build a structural member. To each retrofit element there were assigned

a) recognition characteristics for the building survey;

b) construction works with duration / needed resources;

c) finite elements simulation;

d) earthquake resilient features, seismic deficiencies and earthquake damage patterns.

For the building survey check lists were developed by the first author in frame of the Collaborative Research Centre 461 “Strong earthquakes” with focus on Vrancea. These aimed at the Rapid Visual Screening of the center of Bucharest, Romania. Since it was not possible at once to recognize the structural system, the check lists focused on the elements: walls, floors, etc. Then, a system to transpose this kind of information in a structural system, such as URM with timber floors, was developed. The system can be transferred to other countries easily. The construction works were taken into account as shown in the first part of this work for stone masonry housing.

The retrofit elements have to be able to be unitary simulated in finite elements simulation by taking in account the components before retrofit and after retrofit separately so the retrofit of pre-damaged buildings can also be simulated. Also, the employment of performance points can help assessing the damage with finite elements according to the stress and elongation in them. These retrofit elements build a database of the building (Boştenaru, 2001). With help of retrofit elements an interdisciplinary approach to building retrofit is possible, as it takes into account building survey, assessment, design of the measure, and economic factors. Since the aspects on which it builds is the building survey, detailed costs calculations can be made, as for an existing building exact dimensions are available.

2.3. Costs Determination in Case of Retrofit of Common Buildings

In the first part of this work reparation and retrofit measures are described, which will be considered for the costs calculation. The concept of economic efficiency of retrofit measures compares the costs of reparation of pre-damaged buildings with those of retrofit of a not damaged building. Therefore these two cases were considered for costs calculation.

a) *Retrofit measures in case of pre-damaged buildings*

Table 1 presents the costs calculation for infill stone masonry, while Table 2 presents the costs for load bearing stone masonry. Masonry walls can be buckled on one side or on both. For the calculations in Table 3 the example with both sides affected was taken.

Table 1
Small Rifts in Non-Bearing Masonry Walls (Boştenaru & Bourlotos, 2004)

No.	Operation	Working time/unit, [h]	Price/unit €	Number of units	Price/time €	Whole price €
1	Removal of the plaster on big surface, [m]	0.3		1	36	10.8
2	Enlarging the rift with hammer and chisel, [m]	0.2		1	36	7.2
3	Cleaning the rift, [m]	0.1		1	36	3.6
4	Filling the rift with mortar, [m]	0.1		1	36	3.6
	Reparation mortar, [m]		5	1		5
5	Transport of the removed plaster to container, [m]	0.07		1	36	2.52
6	Disposal of the removed plaster, [m^3]		13+18.40	0		0.05
7	New plaster, [m]	0.14			36	5.04
8	Plaster mortar, [m]		2.5	1		2.5
	Price, [m rift]					40.31

Table 2
Rifts in Load Bearing Masonry Walls (Boştenaru & Bourlotos, 2004)

No.	Operation	Work time/unit h	Price/unit €	Number units	Price/time €	Whole price €
1	Large removal of the plaster, [m]	0.3		1	36	10.8
2	Preparation of the base, [m]	0.2		1	36	7.2
3	Drilling, [m]	0.2		1	36	7.2
4	Cleaning of the drill holes, [m]	0.2		1	36	7.2
5	Battering the packer, [m]	0.2		1	36	7.2
6	Isolating, [m]	0.2		1	36	7.2
7	Verifying the patency, [m]	0.2		1	36	7.2
8	Turning in the nipples, [m]	0.2		1	36	7.2
9	Injection, [m]	0.2		1	36	7.2
	Injection means, [m]		5	1		5
10	Postinjection, [m]	0.2		1	36	7.2
11	Removing the isolation, [m]	0.2		1	36	7.2
12	Chipping out the packer, [m]	0.2		1	36	7.2
13	Closing the drill hole, [m]	0.2		1	36	7.2
14	Disposal of the removed plaster, [m^3]		13+18.4	0		0.05
15	New plaster, [m]	0.14		1	36	7.2
16	Plaster mortar, [m]		2.5	1		2.5
	Price, [m rift]					111.95

Table 3

Rehabilitation of Buckled Masonry Walls (Boştenaru & Bourlotos, 2004)

No.	Operation	Work time/ unit, [h]	Price/unit €	Number of units	Price/time €	Whole price €
1	Bolts to support the floor, [piece]	2		1	36	72
2	Demolition of masonry, [m³]	5.6		1	36	201.6
3	Disposal of demolished masonry, [m³]		13+6	1		19
4	Stonewalling of the demolished walls, [m³]	5.48		1	36	197.3
5	Stones, [piece]		0.25	275		68.75
6	Mortar, [L]		3.125/27	233		26.96
	Price, [m³ wall]					585.61

b) *Retrofit measures as preventive measures*

Frequent damages of stone masonry buildings in Greece affect corners. The first retrofit measure is envisaging the retrofit measures in case of lack of confinement of the corner. Intervention on corners can be also a reparation measure. The costs are the same for preventive retrofit or reparation (Table 4). The costs for the retrofit of door frames are given in Table 5.

Table 4

Confinement of Masonry Corners (Boştenaru & Bourlotos, 2008)

No.	Operation	Work time/unit h	Price/unit €	Number of units	Price/time €	Whole price, [€]
1	Bolten in two directions, [piece]	2		1	36	72
2	Demolition of masonry, [m^3]	5.6		4.38	36	883.01
3	Disposal of the demolished masonry, [m^3]		13+(46/2.5)	4.38		137.53
4	Reinforcement of the corner column, [piece]	0.5		1	36	18
	Steel, [100 kg/m³ concrete]		500	0.05		25
5	Forming the corner column, [piece]	1/3		1	36	13.5
	Formwork, [m^2]	–	8.5	10	–	85/4
	Formwork support, [m]	–	0.55	25	–	13.75/4
6	Concreting the corner column, [piece]	1		1	36	36
	Concrete, [m^3]		140	0.48		67.2
7	Striking the corner column, [piece]	1/3		1	36	13.5
8	Stonewalling the demolished walls (20% more height for the anchoring of the reinforcement), [m^2]	2		9.6	36	691.2
	Masonry stones		250/1,000 pieces	960		240
	Mortar, [L]		3.125/27 l	816		94.44
	Price, [corner]					2448.69

Table 5
Confinement of Door Frames (Boştenaru & Bourlotos, 2008)

No.	Operation	Work time/unit, [h]	Price/unit €	Number of units	Price/time €	Whole price €
1	Demolition of the door and the door frame including the transport to the building site rubble container, [door]	0.5		1	36	18
2	Disposal of the doorframe and the door, [t]		225	0.04		9
			46	0.25		11.5
3	Demolition of the masonry including the transport to the building site rubble container, [door]	0.5		1	36	18
4	Disposal of the demolished masonry, [m^3]		13+46/2.5	0.3		9.42
5	Cleaning of the demolished masonry rests with steel brush in order to remove rubble rests, [door]	0.5		1	36	18
6	Reinforcement steel of the door frame out of reinforced concrete anchored in the floor, [hole]	0.5/8 holes		8	36	18
7	Reinforcement, [door]	3/4		1	36	27
	Steel, [t]		500	0.02		7.5
8	Forming (the door frame has the function of framework for concreting), [door]	1/3		1	36	13.5
9	Concreting, [door]	1		1	36	36
	Concrete, [m^3]		140	0.3		42
10	Stripping the forms, [door]	1/3		1	36	13.5
11	Acquisition of the door and assembly, [piece]		368	1		368
	Price, [door frame]					609.42

2.4. Costs of the Seismic Retrofit of Monumental Buildings

In professional practice the costs are computed in similar way. The cost for the structural intervention by Penelis (see first part of this works for description) the National Library of Greece is shown in the Table 6, which is a direct extract from the official tender price BoQs, and is in June 2001 values. (According to Greek Ministry of Public Works the 2003 values should be multiplied by 0.22/0.158 = 1.46 to become present values).

The cost for the structural intervention by Penelis (see first part of this work for description) in the preserved part of the National Theatre of Greece is shown in the Table 7, which is a direct extract from the official tender price BoQs, and is in November 2003 values. (According to Greek Ministry of Public Works the 2003 values should be multiplied by 0.22/0.168=1.31 to become present values).

Table 6

Briced Bill of Quantities for the National Library of Greece (in 2001)

	Description	Quantity	Unit price €	Unit Price €	Cost €
1	Excavations, [m^3]	473.59	17.61	6,000.00	8,339.08
2	Refill with excavation material, [m^3]	228	7.34	2,500.00	1,670.51
3	Demolition of R/C, [m^3]	156	88.04	30,000.00	13,722.08
4	Demolition of floor finishing, [m^2]	2,142	3.52	1,200.00	7,544.42
5	Demolition of URM, [m^3]	25	26.41	9,000.00	660.31
6	Removal of windows with care, [m^2]	170	5.87	2,000.00	995.74
7	Concrete with 250 kg cement, [m^3]	202	58.69	20,000.00	11,841.53
8	Wire mesh S500, [kg]	905	0.88	300.00	796.77
9	Formwork for usual structures, [m^2]	785	8.80	3,000.00	6,907.26
10	1/2 of brick urm walls, [m^2]	167	14.67	5,000.00	2,450.48
11	Repositioning of wooden window frames, [m^2]	11	29.35	10,000.00	330.15
12	Repositioning of steel window frames, [m^2]	158	23.48	8,000.00	3,718.86
13	Steel sidewalk posts, [χλγρ]	3,008	3.82	1,300.00	11,475.86
14	New mosaics 3...4cm, [m^2]	86	23.48	8,000.00	2,012.03
15	New plastic tiles, [m^2]	153	17.61	6,000.00	2,701.10
16	New antislip concrete plates, [m^2]	215	16.14	5,500.00	3,465.44
17	Ioannina marble plates, [m^2]	170	58.69	20,000.00	9,977.99
18	Corner finishing with marbles, [m]	505	11.74	4,000.00	5,923.40
19	Renovation of wooden finishing's, [m^2]	30	11.45	3,900.00	347.60
20	Painting of steel structures, [m^2]	804	16.14	5,500.00	12,982.10
21	Painting of new surfaces with plastic colour, [m^2]	2,289	8.80	3,000.00	20,152.16
22	Painting of old surfaces with plastic colour, [m^2]	5,187	5.87	2,000.00	30,442.55
23	Glass windows 5 mm, [m^2]	207	23.48	8,000.00	4,851.42
24	Removal of demolition material from the roof, [m^3]	368	3.23	1,100.00	1,189.29
25	Demolition of the brick domes with care, [m^2]	895	6.31	2,150.00	5,644.26
26	Demolition of unreinforced concrete, [m^3]	200	49.89	17,000.00	9,990.96
27	Demolition of linings- finishings, [m^2]	1,367	2.93	1,000.00	4,012.94
28	Removal with care of prefabricated architectural fittings, [m^2]	1,704	9.39	3,200.00	16,006.10
29	Steel propping with cloth cover	5,195	3.52	1,200.00	18,293.53
30	Concrete C16/20, [m^3]	318	76.30	26,000.00	24,230.55
31	URM grouts, [item]	22,000	1.47	500.00	32,281.73
32	Wire mesh S 500s INOX # 50X50X2,5N, [kg]	3,234	8.22	2,800.00	26,574.32
33	INOX steel profiles, [kg]	5,454	11.53	3,930.00	62,903.07
34	Titanium stitches (blind) , [kg]	160	77.77	26,500.00	12,430.70
35	Titanium stitches prestressed from outside, [kg]	369	88.04	30,000.00	32,511.81
36	Rebuilding of URM domes, [m^2]	895	33.75	11,500.00	30,190.24
37	Structural steel profiles, [kg]	9,376	1.29	440.00	12,106.45
38	Steel blades and special items, [kg]	12,783	4.40	1,500.00	56,271.46
39	Treatment of steel anchors of steel beams and trusses, [τεμ]	214	55.17	18,800.00	11,806.90
40	New plastering, [m^2]	1,669	13.21	4,500.00	22,041.22
41	Rehabilitating of existing plastering, [m^2]	620	23.48	8,000.00	14,556.13

Table 6 (continuation)
Briced Bill of Quantities for the National Library of Greece (in 2001)

	Description	Quantity	Unit Price €	Unit Price €	Cost €
42	Repositioning with care of prefabricated architectural fittings, [m^2]	1,193	11.74	4,000.00	14,004.40
43	Roof finishing with special prefabricated plates (cement based) , [m^2]	511	44.02	15,000.00	22,508.58
44	Screed 3 cm, [m^2]	1,704	20.84	7,100.00	35,513.54
45	Corrosion protection of steel profiles, [m^2]	1,655	13.21	4,500.00	21,853.56
46	Treatment of steel profiles with brushing to remove rust, [m^2]	1,226	5.12	1,746.00	6,283.24
47	Cement based waterproofing, [m^2]	1,704	8.22	2,800.00	14,005.34
48	Crack repair with sealing, [mm]	1,236	2.64	900.00	3,264.43
49	Epoxy resign injections, [mm]	178	38.15	13,000.00	6,790.90
50	Opening of sockets in URM, [mm]	60	26.41	9,000.00	1,584.74
51	Placement of titanium dowels, [τεμ]	100	19.08	6,500.00	1,907.56
52	Rebars S500, [kg]	33,596	0.88	300.00	29,578.28
53	Heavy duty temporary propping, [m^2]	153	7.04	2,400.00	1,077.62
54	Polystyrene plates 5 cm, [m^2]	5	8.39	2,860.00	42.81
55	New steel F360 structure (temporary steel hangar), [kg]	126,500	1.53	520.00	193,044.75
56	Covering of hangar with aluminum sheets, [m^2]	2,178	24.65	8,400.00	53,690.98
57	Moving of hangar to new position (disassembly and re-assembly), [kg]	113,652	0.90	305.00	101,728.13
58	Disassembly and re-assembly of aluminum sheets, [m^2]	1,921.6	7.92	2,700.00	15,226.34
59	Steel profiles for the protective level above bookshelves, [kg]	3,937	1.28	437.00	5,049.07
60	Construction of support for steel protective level, [m^2]	13	527.37	179,700.00	6,813.57
61	Covering of steel protective level, [m^2]	418	27.13	9,245.00	11,340.90
62	Anchors HILTI H SLB 12/ 25, [τεμ]	200	7.01	2,390.00	1,402.79
63	Protective PVC sheets on bookshelves, [m^2]	4,089	6.88	2,345.00	28,139.72
64	Transfer of books that are movable, [m^2]	3,970	15.55	5,300.00	61,755.30
65	Steel structure Fe 510 (S335) for new mezzanine, [kg]	6,721	1.61	547.00	10,789.10
66	Steel sheet CONTI, 1 mm, [m^2]	77	20.47	6,975.00	1,570.01
67	Lightweight concrete C25/30, [m^3]	10	137.29	46,780.00	1,368.74
68	E&M installations of the mezzanine, [τεμ]	1	29,347.03	10,000,000.00	29,347.03
	Total Sum of Billed Cost				1,236,031.94
	Itemised cost				102,714.60
	Intermediate Sum				1,338,746.54
	General Expenses & Profit (18%)				240,974.38
	Contigency – 15%				200,811.98
	Total Cost of the Project				1,780,532.90
	VAT 18%				320,495.92
	GENERAL SUM				2,101,028.83

Table 7

Briced Bill of Quantities for Preserved Part of National Theatre (in 2003)

No.	Description	Quantity	Unit Price €	Cost €	Total cost €
1	Demolition of unreinforced concrete, [m^3]	30	60	1,800.00	
2	Demolition of reinforced concrete, [m^3]	70	64	4,480.00	
3	Demolition floor finishing's, [m^2]	470	3.5	1,645.00	
4	Demolition of URM, [m^3]	1400	28	39,200.00	
5	Wallet opening, [item]	120	25	3,000.00	
6	Drilling D5-15 cm, [item]	3690	23.5	86,715.00	
7	S000s for new R/C elements, [kg]	3600	0.9	3,240.00	
8	S000s for shotcrete jackets, [kg]	14350	1.2	17,220.00	
9	Steel plates and blades, [kg]	7430	3	22,290.00	
10	Shorctere C20/25 gunite 7 cm, [m^3]	205	925	189,625.00	
11	Concrete C20/25, [m^3]	45	100	4,500.00	
12	Dowels S500s D12-Φ18, depth of 100 cm, [item]	3,690	7.5	27,675.00	
13	Inox anchors for corners, [item]	120	30	3,600.00	
14	URM grouting, [L]	20,000	2	40,000.00	
15	Resign injections, [m]	180	29.5	5,310.00	
16	Non shrickable concrete (emaco), [L]	300	4.7	1,410.00	
17	Crack repairs, [m]	1,000	3	3,000.00	
18	Repairing of existing steel work support on URM walls, [item]	220	56	12,320	
19	Fiber reinforced strips CFK, [m]	500	76.3	38,150.00	
20	Demolition of brick domes, [m^2]	100	8	800.00	
21	Reconsitution of brick domes, [m^2]	100	34	3,400.00	
22	Fiber reinforced sheets C-640, [m^2]	20	440	8,800.00	
23	Corrosion repair and proetectioon for steel profiles, [m^2]	1,000	2	2,000.00	
24	New steel profiles, [kg]	1,000	2.5	2,500.00	
25	Treatment of oxidized R/S elements-corrosion inhibitors, [item]	100	29.5	2,950.00	525,630.00
	Total Sum of Billed Cost				525,630.00
	General Expenses & Profit (18%)				94,613.40
	Intermediate Sum				620,243.40
	Contingency (9%)				55,821.91
	Total Cost of the Project				676,065.31
	VAT 18%				121,691.76
	GENERAL SUM				797,757.06

3. Discussion

Costs were computer for retrofit elements. A comparison can be seen in Table 6. All of them are local measures, the employment of which does not affect the behavior of the whole building. Nevertheless, they are popular in Greece, therefore the costs calculation is useful for estimating future interventions. In Greece there is such frequency of earthquakes that stone masonry buildings experience more earthquakes during their lifetime. Such targeted measures can also help.

The concept developed by Boştenaru (2006) makes seismic retrofit dependent on the moment when this is applied, with regard to the earthquakes that affected and will affect the building. Thus, the concept of costs curves was developed. The costs of reparation and the costs of retrofit are additive, but the final curve depends on the moment when the measure is done related to the occurrence of earthquakes. For reinforced concrete the concept was followed to the end as the structural benefit of retrofit could be modeled in the simulation of earthquake damage with finite elements software. Such steps are also necessary in case of masonry buildings, namely to be able to Finite Element Method (FEM) retrofit elements where the retrofit component is only activated after the structure was subjected to an earthquake to evaluate performance points of the structural elements and thus their damage level afterwards.

A next step is the benefit–costs analysis and the decision making based on that. Although Boştenaru (2006) has proposed, a decision tree including the engineer, the architect, the inhabitant and the investor, the advice goes for considering decision systems which take into account non-measurable criteria such as architectural and societal issues are. For these a balancing system can be used comparing pairwise the retrofit systems and corresponding implementation strategies and the costs which occur if implementing them.

A factor not presented in this paper is the project management related one of the duration of the work. It was not presented because the works described at an element are linear, one work after the other. But if considering more of these measures at the same building, the simultaneity issues lead to a more complex project management argument.

4. Conclusions

Research concerning the structural side of seismic retrofit measures is much more spread than that regarding the economic efficiency. The present work is one of the few approaches and needs further development.

The few research approaches on economic efficiency studies of seismic retrofit concern that of reinforced concrete common structures, and not masonry, which is the material for also many heritage buildings. Such are the works by Kappos *et al.* (2008, 1998, 2007, 2005) or of Boştenaru (2001, 2004, 2007, 2009). A next step for the later would be the development of computation formulas as for the first.

For masonry, more research needs to be done in creating a link between the costs calculation and the finite elements simulation, additionally to the link done to the building survey and the earthquake damage patterns. Only then the transition from costs determination to economic efficiency can be done.

Also, only when the structural solution for the whole building is known, the complete issue of project management of non-linear processes on the building site can be approached.

Benefit–costs analyses are a key issue for decision making in choosing among retrofit systems or between the retrofit strategies to implement a retrofit system. Therefore the decision system shall be tailored to take into account the various factors which lead to a costs increase and their benefits, such as the reversibility of the measure, for example. As the method was not applied until now, statements about the certainty degree cannot be made.

Table 8

Overview of the Computed Costs (Boştenaru & Bourlotos, 2008)

	Measure	Costs
1	Small rifts in non-bearing masonry walls	40.31 € / m rift
2	Rifts in load bearing masonry walls	111.95 €/ m rift
3	Rehabilitation of buckled masonry walls	585.61 € / m³
4	Confinement of masonry corners	2448.69 € /corner
5	Confinement of door frames	609.42 € /door frame

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REFERENCES

Boştenaru-Dan M, *Integrated System for Building Survey and Evaluation of Seismic Retrofit Possibilities*. In Brebbia C.A. (Ed.) *Structural Studies, Repairs and Maintenance of Heritage Architecture*. **VIII**, WIT Press, Southampton, 2003, 555-564.

Boştenaru-Dan M., *A Cost-Effectiveness Study of Retrofitting and Strengthening Techniques for Damaged Buildings*. In Lungu D., Wenzel F., Mouroux P., Tojo I. (Eds.) *Earthquake Loss Estimation and Risk Reduction*. Vol. **2**, Independent Film, Bucharest, 2004, 161-170.

Boştenaru-Dan M., Bourlotos G., *Calculation of Costs for Seismic Retrofit of Stone Masonry Buildings in Greece*. In Oliveira C.S., Costa A., Nunes J.C. (Eds.) Proc. of Azores 1998 – Internat. Seminar on Seismic Risk a. Rehab. of Stone Masonry Housing, 2008.

Boştenaru-Dan M., *Calculation of Costs for Seismic Rehabilitation of Historical Buildings*. In Brebbia C.A., Corz A. (Eds.) *Earthquake Resistant Engineering Structures*. **III**, WIT Press, Southampton, 2001, 515-524.

Boştenaru-Dan M., Gehbauer F., *Applicability and Economic Efficiency of Seismic Retrofit Measures on Historic Buildings of Mid-XXth Century*. Proc. of the 13th World Conf. on Earthquake Engng., Vancouver, B.C., Canada, #*3347*, 2004.

Boştenaru-Dan M., *Wirtschaftlichkeit und Umsetzbarkeit von Gebäudeverstärkungs-maßnahmen zur Erdbebenertüchtigung*, 1st Ed., Shaker Verlag, Aachen, 2006.

Boştenaru-Dan M. *Economic Impact of Preventive Retrofit in Comparison with Post-Earthquake Repair*. In Canziani A. (Ed.), *Conservare l'Architettura: Conservazione programmata per il patrimonio architettonico del XX secolo* (*Conserving Architecture: Planned Conservation of XXth Century Architectural Heritage*), Electa, Milano, 2009, 194-203.

Boştenaru-Dan M., Penelis G.G., Bourlotos G., *Retrofit of Stone Buildings in Greece* (I). Bul. Inst. Politehnic, Iaşi, **LIX (LXIII)**, *2*, s. Constr., Archit. (2013).

Bourlotos G., *Kostenermittlung in der Erdbebenertüchtigung alter Gebäude*. Individual Study, Inst. für Maschinenwesen im Baubetrieb, Universität Karlsruhe (TH), Germany, 2001.

Kappos A.J., Dimitrakopoulos E.G., *Feasibility of Pre-Earthquake Strengthening of Buildings Based on Cost-Benefit and Life-Cycle Cost Analysis, with the Aid of Fragility Curves*. Natural Hazards, **45**, *1*, 33-54 (2008).

Kappos A.J., Stylianidis K.C., Pitilakis K., *Development of Seismic Risk Scenarios Based on a Hybrid Method of Vulnerability Assessment.* Natural Hazards **17**, 177-192 (1998).

Kappos A., Lekidis V., Panagopoulos G., Sous I., Theodulidis N., Karakostas Ch., Anastasiadis T., Salonikios T., Margaris B., *Analytical Estimation of Economic Loss for Buildings in the Area Struck by the 1999 Athens Earthquake and Comparison with Statistical Repair Costs.* Earthquake Spectra, **23**, *2*, 333-355 (2007)

Lekidis V. A., Karakostas Ch. Z., Sous I. I., Anastasiadis A., Kappos A., Panagopoulos G., *Evaluation of Economic Loss for Structures in the Area Struck by the 7/9/1999 Athens Earthquake and Comparison with Actual Repair Costs*. In Brebbia C.A., Beskos D.E., Manolis G.D., Spyrakos C.C. (Eds.), *Earthquake Resistant Engineering Structures*, **V**, 2005, 301-312.

Lekidis V. A., Karakostas Ch. Z., Sous I. I., Anastasiadis A., Kappos A., Panagopoulos G., *Evaluation of Economic Loss for Structures in the Area Struck by the 7/9/1999 Athens Earthquake and Comparison with Actual Repair Costs.* Earthquake Resist. Engng. Struct., **V**, WIT Trans. on the Built Environm., **81**, 301-310 (2005)

Neddermann R., *Kostenermittlung im Altbau: Aktuelle Baupreise – rechtliche Grund-lagen – technische Beurteilung – Kostenermittlungsmethoden*. 4th Ed., Werner, Neuwied, 2007.

Smyth A.W., Altay G., Deodatis G., Erdik M., Franco G., Gülkan P., Kunreuther H., Lus H., Mete E., Seeber N., Yüzügüllü O., *Probabilistic Benefit–Cost Analysis* *for Earthquake Damage Mitigation: Evaluating Measures for Apartment Houses in Turkey*. Earthquake Spectra, **20**, *1*, 171-203 (2004).

Zikas T., Engelmann H., Fiedrich F., *A Concept for an Open-Source Software Project for Earthquake Risk Management*. Proc. of the "100th Anniversary Earthquake Conference – Managing Risk in Earthquake Country", San Francisco, Mira Digital Publ., 2006.

Zikas T., Gehbauer F., *Decision Process and Optimization Rules for Seismic Retrofit Programs*. Proc. of the Internat. Symp. on Strong Vrancea Earthquakes a. Risk Mitig., MATRIX ROM, Bucharest, 2007, 472-484.

* * * *Probleme de economia construcţiilor*, INCERC, Bucureşti, 2000.

* * * *Seismic Evaluation and Retrofit of Concrete Buildings*. California Seismic Safety Commission, ATC-40, 1996.

* * * *Richtlinien für die Baukostenplanung. After Richtlinien der Baukostenplanung (RBK) der staatlichen Hochbauverwaltung des Landes Baden-Württemberg.* Informationsstelle Wirtschaftliches Bauen (IWB) (Ed.), **1**st Part, IWB RBK, Germany, 1988.

* * * *NERPH Guidelines for the Seismic Rehabilitation of Buildings.* FEMA 274, BSCC, Washington DC, 1997.

* * * *Typical Costs for Seismic Rehabilitation of Existing Buildings* (Summary and Supporting Documentation), FEMA 156-157, Washington DC, 1988.

CONSOLIDAREA CLĂDIRILOR DIN ZIDĂRIE DE PIATRĂ ÎN GRECIA
II. Determinarea costurilor

(Rezumat)

Se studiază costurile consolidării seismice a clădirilor din zidărie de piatră din Grecia. Studii care tratează costurile consolidării sunt rare. Spre deosebire de studiul clădirilor istorice, care se referă în cele mai multe cazuri la clădiri de zidărie, betonul armat nefiind considerat suficient de istoric, pentru studii de beneficiu–cost ale consolidării seismice au fost făcute studii mai numeroase privind clădirile din beton armat, care sunt mai răspândite. Întâi sunt prezentate măsuri de consolidare pentru clădiri din zidărie de piatră fără valoare deosebită, utilizând oțel şi beton armat. După aceea este prezentată metoda de determinare a costurilor. Accentul cade pe divizarea măsurilor de consolidare seismică în paşi singulari şi în determinarea costurilor individuale ale lucrărilor parțiale. Comparate cu alte lucrări de determinare a costurilor, care sunt bazate pe volumul spațial, suprafața planşeului sau cea utilă, această metodă are avantajul că este relativ independentă de lucrări similare care au fost deja realizate. Sunt date unele exemple de calcul. În final, sunt date exemple de consolidare pentru clădiri întregi, considerând lucrările monumentale; asemănarea metodei cu practica profesională este evidentă.