RELIABILITY ANALYSIS ON REINFORCEDMASONRY BUILDING AGAINSTEARTHQUAKE HAZARD WITH SHAKINGTABLE TESTS

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ABSTRACT

In this paper, a new approach on assessment of the retrofitting methods for the masonry buildings is presented in order to provide an evaluation of the effects of the seismic performance improvement methods on thistype of building performances. For this aim, the results of experimental research used to present a reliability analysis for evaluating the effects of reinforcement methods onthe damage state in structure. With a focus on crack distribution method in samples, event tree of these tests are defined. With consideration of obtained event tree, the effect of reinforcement on damage state of samples was investigated. Result shows, whereas this method is very simple in comparison of other rigorous and more complex methods but, is very useful for fast and economic decision making in rural areas against disasters like earthquake.

INTRODUCTION

In thecommissioningandoperation ofanysystems, tworesultsmay occur; the first issystem succeeds and the second is system fails. If failure system method used for analysis of system, this study called fault treemethodand if succeed system method used for analysis of system, one of the studymethod is the event treemethod. Formore precisedefinitionofthe eventtreecan said: "If successfulperformance of a wrappedsystem or a facility was depended to the discrete time sequence, performance of this unite can be consider as an event tree". Generally, event trees model scenario which corresponds to the successive event, causes confront of event with hazards and eventually lead to inappropriate consequences. Therefore, it seems both approachhave a same result. Fault treemethod commonly used forprobabilistic risk assessment (PRA). Although, the results of fault tree analysis could be modified for use in success trees (e.g., event tree). In probabilistic risk assessment, a part of systemwhich is effective in the risks of that system determined. In other words, these parts of systems led to thecreation of uncertainty in results of systems. Uncertainty analysis is a part of any assessment in engineering calculation that mostly related to the model results in which system has failed. In drawing fault tree diagram for a system, it is expected to decisive event (top event) will not occur. So, all of events that lead to occur of this event must be considered in drawing fault tree diagram. For drawing of fault tree algorithm, it seems, it is more appropriate to start from decisive event (top event). In event tree method, as it mentioned before, succeed system method used for analysis of system. Figure 1 shows a sample of event tree for an analysis of system. In this method, subsystems must act to swerve an undesirable initialevent (e.g. failure a part of system) and achieve a desirable outcome (e.g. system succeeds; see Modarres (2006)).

There are many of industries and scientists whose display event trees for risk assessment such as nuclear power plant,aerospace facilitiesand emergency organisation (see, Peplow et al. (2004)).In this paper, event tree method, in accordancewith whatwasdescribedin the introductionis not used. But, theapproachto the designand deliver of the eventtreealgorithmisused.

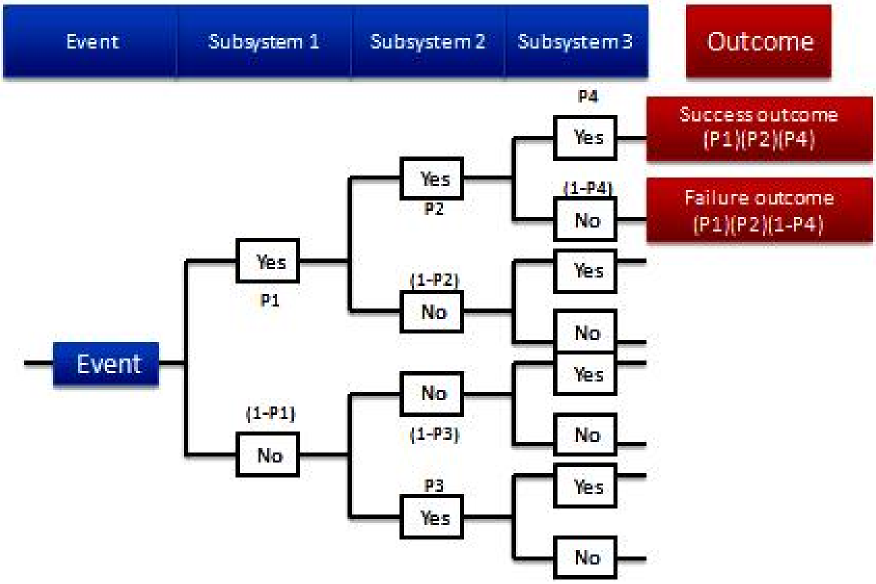


Figure 1. Schematic description of event tree for an analysis of system

DEFINATION OF CASE STUDY

It is clear unreinforced masonry construction is vulnerable to earthquake hazards. These types of buildings are constructed just for gravitational forces with no consideration of the lateral seismic loads. So, it seems these buildings needs reinforcement to remain in safe mode against lateral loads.

With presentation the eventtreealgorithm, evaluation of risk assessment of the retrofitting methods for the masonry buildings is presented. This approach provides an evaluation of the effects of the seismic performance improvement methods (Whichis describedin the following) on these building performances.The results of experimental research used to present a reliability analysis for evaluating the effects of reinforcement methods on the damage state in structure. Experimental tests were done on 9 masonry buildings samples with 1/10 scale Ersubasi and Korkmaz(2010); Samples were tested on the shaking table instrument (Figure 2).

Figure 2. shaking table test setup and controller (Ersubasi and Korkmaz, 2010)

Affected by dynamic loads on shaking table, fraction mode of samples categorized in to 6 type of damage that is presented in Table 1.Through this classification,eachofcracks can be attributed to the samples easily.

Table 1.Classification of Fraction mode

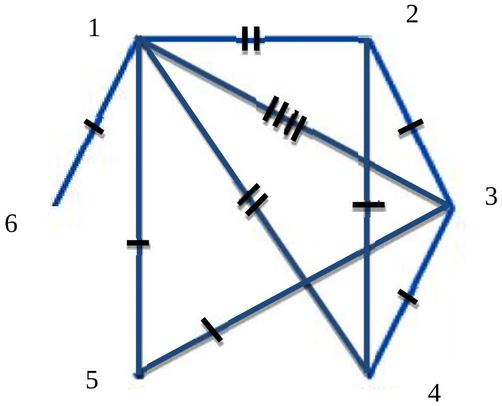
Type of Crack	Allotted code
Crack in openings	1
Diagonal cracks	2
X type cracks	3
V type cracks	4
Horizontal shear crack	5
Separation of roof from structure	6

Table 2 introduces the samples reinforced with different techniques has been presented where, in this table, the observed cracks also mentioned in each of samples.

Table 2.Observed cracks in each of reinforced Samples

Sample	Reinforcement detail	Observed cracks
Ref Sample	Without reinforcement	1-2-3-4
CF1	CFRP strips above the openings	1-4
CF2	CFRP horizontal strip above the ground level	1-3
CF3	Corner of the structure was covered with strengthening material	1-3-5
SWSP	Steel strip on the inner and outer surfaces of the walls	1-6
SM	Mesh reinforcement and plaster application over the masonry walls	1-3
P1	Horizontal post tensioning was applied and wooden logs were used on the corners of the structure	5
P2	Similar to P1 but wooden logs were replaced with shorter wooden pieces	1
P3	Horizontal wrapping was applied only at the roof level. The structure was wrapped by steel rods and a box type behavior was obtained	1-2

As it mentioned in Table 2, various kind of cracks observed in each of the samples. With a focus on crack distribution method in samples, event tree of these tests are defined in Figure 3. The event tree shows combining risk in each of states. Combining risk also shows the average means of damage for each of the samples in given acceleration a_1. In this figure, the numbers on the apex of sides shows allotted code related to the type of cracks. Each side shows feasibility of synchronism occurrence for two kinds of cracks. Each side demarcate for demonstration the number of synchronism occurrence. For example,the probability ofsimultaneous of cracks1and3 is equal to 4/9. Therefore,the probability ofnon simultaneous occurrence ofcracks1and 3 is equal to 5/9.



Type of Crack	Occurrence Probability (Damage Pi)		Proportion of Damage (Ci)		Component of risk (Ri)
Crack in openings		×	16.66%	=	14.8%
Diagonal cracks	$\frac{2}{9}$	×	16.66%	=	3.7%
X type cracks	$\frac{4}{9}$	×	16.66%	=	7.4%
V type cracks	$\frac{2}{9}$	×	16.66%	=	3.7%
Horizontal shear crack	$\frac{2}{9}$	×	16.66%	=	3.7%
Separation of roof from structure	$\frac{1}{9}$	×	16.66%	=	1.85%
Mean value of Damage	demonstrate ⟵		Combining risk $\sum R_i$		35.05%

Figure 3. The event tree of this test

Figure 4 showsthe probability ofnon simultaneous occurrence ofcracks (system succeeds) inthe samples. For example, the probability ofnon simultaneous occurrence ofcracks1and 2is equal to 0.77,which marked with arrow in this figure.

This number obtained from the information which provided in table 2. As it shows in this table, crack 1 and 2 occurred in "Reference Sample" and "P3 reinforced sample" simultaneously. So, from total of9 samples, these cracks observed in 2 cases and not observed in 7 cases. Therefore, with dividing of 7/9, the amount of 0.77 obtained for probability of non occurance. Details ofthe calculations for other states presented in Table 3.

With consideration of Table 4 and event tree (as shown in Figure3), the effect of reinforcement on damage state of samples was investigated. For example, in CF1 sample, cracks with code 2, 3, 5 and 6 not observed (from 6 total crack state); so then, probability of non-occurrence is equal to 0.76 with dividing 4/6.

As it shows in Table 4, P1 and P2 reinforced samples has priority to use because it has a maximum probability of non-occurrence due to lateral seismic loads. Results of this method indicated post tensioning of masonry walls (P1 and P2) increased the lateral load carrying and shear and bending capacities providing ductility, Experimental observation also substantiated these results. Figure 5 shows sample P2 before

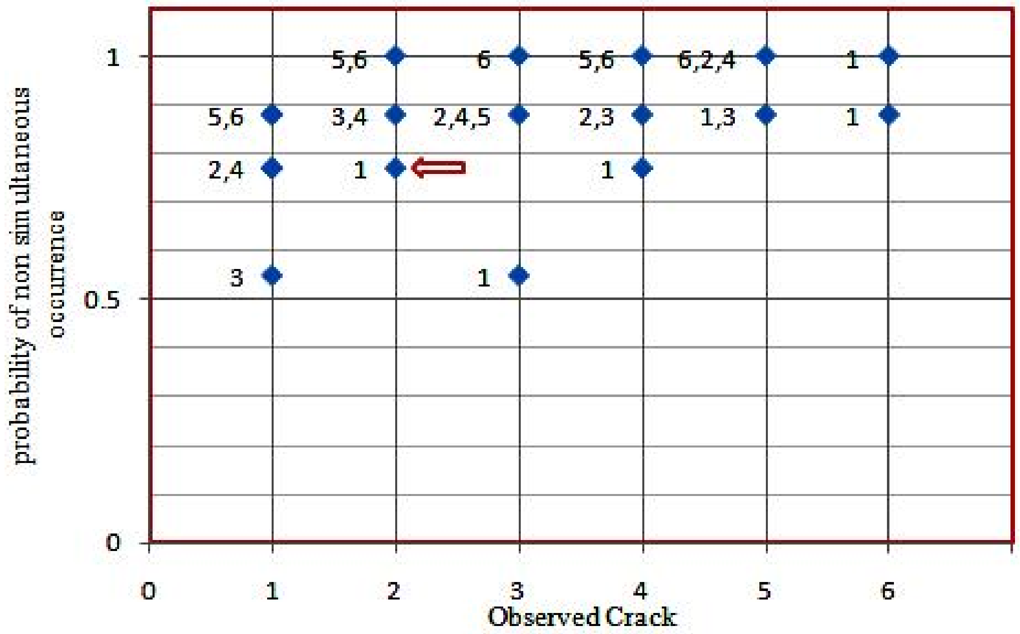


Figure 4. The probability of non-simultaneous occurrence of cracks

Table 3.Details of the calculations relating to the probability of non simultaneous occurrence of cracks

Probability of non simultaneous occurrence of cracks	Observed cracks	Probability of non simultaneous occurrence of cracks	Observed cracks
0.77	4 and 1	0.77	**1 and 2**
0.88	4 and 2	0.55	**1 and 3**
0.88	4 and 3	0.77	**1 and 5**
1.00	4 and 5	0.88	**1 and 5**
1.00	4 and 6	0.88	**1 and 6**
0.88	5 and 1	0.77	**2 and 1**
1.00	5 and 2	0.88	**2 and 3**
0.88	5 and 3	0.88	**2 and 4**
1.00	5 and 4	1.00	**2 and 5**
1.00	5 and 6	1.00	**2 and 6**
0.88	6 and 1	0.55	**3 and 1**
1.00	6 and 2	0.88	**3 and 2**
1.00	6 and 3	0.88	**3 and 4**
1.00	6 and 4	0.88	**3 and 5**
1.00	6 and 5	1.00	**3 and 6**

and after test. As it shows, wooden logs used on the corners of the structure and different states of destruction seen during shaking test.

It must be mentioned, as it shows in Figure 3, crack in opening has highest component of risk incomparable of other type of cracks. So, it needs more retrofitting to resist against lateral loads. It seems retrofitting method that used in sample P2, as it shows in Table 4 with priority 1, can resist against cracks in opening and this method has a priority to use for reinforcement.

Table 4.Effects of reinforcement on damage state

Sample	Observed cracks	Non-observed cracks	Probability of non-occurrence	Priority
Ref. Sample	1-2-3-4	5-6	0.33	**4**
CF1	1-4	2-3-5-6	0.67	**2**
CF2	1-3	2-4-5-6	0.67	**2**
CF3	1-3-5	2-4-6	0.50	**3**
SWSP	1-6	2-3-4-5	0.67	**2**
SM	1-3	2-4-5-6	0.67	**2**
P1	5	1-2-3-4-6	0.83	**1**
P2	1	2-3-4-5-6	0.83	**1**
P3	1-2	3-4-5-6	0.67	**2**

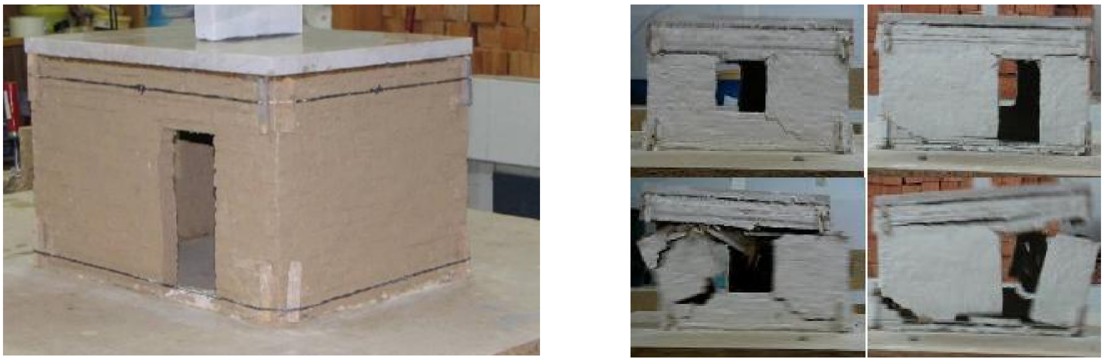


Figure 5. Sample P2 before and after test on shaking table test (Ersubasi and Korkmaz, 2010)

In following, obtained results (in Table 4) normalized to determinemore preciseresults. For normalization of data, equation 1 used:

$$\hat{C} = Cr / C_0 \quad (1)$$

In which, $\hat{C}$ is component of risk werenormalized, Cr is component of risk for each of samples and $C_0$is component of risk for reference sample. In reference sample, cracks code 1, 2, 3 and 4 observed; so then, summation of component of risk for reference sample is equal to 26.6,this valueis assumed to beequal to100%. So, other component of risk for each of samples normalized than this value. Details ofthe calculations presented in Table 5. For example, in CF1 sample, obtained result (18.5) divided to reference sample (26.6) to normalize component of risk.

Table 5. Details ofthe calculations for normalization of data

Sample	Observed cracks	Summation of component of risk	$\hat{C}$	Priority
Ref. Sample	1-2-3-4	26.6	100%	**7**
CF1	1-4	18.5	69.5%	**4**
CF2	1-3	22.2	83.4%	**5**
CF3	1-3-5	25.9	97.3%	**6**
SWSP	1-6	16.65	62.6%	**3**
SM	1-3	22.2	83.4%	**5**
P1	5	3.7	14%	**1**
P2	1	14.8	55.6%	**2**
P3	1-2	16.65	62.6%	**3**

CONCLUSIONS

In this paper a new approach of event tree used for evaluation of earthquake risk hazard in masonry reinforced structures. In this method, succeed system method used for analysis of system according to event treemethod. For this aim, new approach of event tree according to crack observation and calculation of probability of non-occurrence developed.Priority of reinforcement method was obtained from normalization of component of risk.

This study showsthatNormalized results shows the reinforced sample in whichhorizontal post tensioning was applied and wooden logs were used on the corners of the structure (P1) has priority to use because it has a maximum probability of non-occurrence.

Also, event tree calculation shows crack in opening has highest component of risk incomparable of other type of cracks and needs more retrofitting and the results between normalized and non-normalized calculation shows some of differences between them and normalized results has more reliable to determination of priority.

The method whichis used in the present study is very simple against other exist rigorous methods and is useful for fast and economic decision making in rural areas against disasters like earthquake and can guide designers to choose an effective method for reinforcement of masonry buildings.

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