DEVELOPMENT OF EMPIRICAL AND THEORETICAL VULNERABILITY AND SEISMIC RISK MODELS

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SUMMARY

Based on classification of damage and usability of over 40,000 buildings damaged in the Montenegro 1979 earthquake detailed analysis has been performed in order to establish empirical and theoretical vulnerability functions. Selected vulnerability functions are presented in this paper as a basic evidence for the needs of damage estimate in evaluation of expected vulnerability and seismic risk. Implementation of developed functions in physical and urban planning, code calibration and reduction of earthquake consequences is discussed.

INTRODUCTION

Due to recent catastrophic earthquakes in Yugoslavia, Algeria and Italy within the Mediterranean region, a larger number of residential buildings, schools, hospitals and other public, administrative and industrial buildings, as well as other facilities of local and regional infrastructure have been severely damaged. The largest number of the damaged buildings are in the state that their use is not permissible before adequate repair and strengthening of the basic structural systems, nonstructural elements and installations. In order to assure appropriate safety and normal functioning of the damaged buildings, it will be important to recognize that these buildings will be exposed in the future to a large number of small and moderate earthquakes and with significant probability to the catastrophic earthquakes with large magnitudes similar to those in the past.

It would be of essential importance that in the stage of general, physical and urban planning, as well as during the process of repair and strengthening of damaged buildings, other facilities and new constructions, expected seismic hazard and its influence on seismic stability of the structures and installations should be taken into account in elaboration of safety criteria based on determined acceptable seismic risk levels, assuring that seismic protection in the future earthquakes is economically justified and that damageability levels will permit safe and undisturbed use.

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In order to have established acceptable seismic risk and damageability levels an attempt is made for development of empirical and theoretical vulnerability models and functions. Based on damage distribution analysis and available strong motion records in the recent earthquakes in Yugoslavia, empirical vulnerability models and functions have been developed for different categories of structures and their usage. Theoretical vulnerability functions have been developed based on seismic hazard studies and analysis of expected damageability levels for selected types of structural systems of residential and public buildings. Based on established developed empirical and theoretical vulnerability functions development of seismic risk models for planning of preventive measures, economical, physical and urban planning are briefly discussed.

EMPIRICAL AND THEORETICAL VULNERABILITY FUNCTIONS

Based on classification of damage and usability of buildings and structures performed in eight categories immediately after Montenegro April 15, 1979 earthquake about 40,000 buildings in seven communes and over 300 settlements with total gross area of about seven million square meters have been selected for development of empirical vulnerability functions or functions of observed vulnerability (7). Considering vulnerability as degree of loss to a given element of risk or set of risk elements, resulting from the occurrence of earthquakes of a given intensity, vulnerability functions are presented by two elements: vulnerability as a loss of total area of considered structural type or usage (set of risk elements) in respect to the observed seismic intensities presented in terms of equivalent ground acceleration (4) as most direct parameter connected with structural damage and soil conditions. For basically considered seven categories of structural types and eight categories of usage of the buildings classified in eight damage categories, detailed analysis has been performed for all 40,000 buildings considering equivalent ground acceleration for each of over 300 settlements based on recorded earthquake ground motions and local soil conditions for each settlement.

Several empirical vulnerability functions for different structural types and usage of buildings are presented in Figs. 1 through 10 and space distribution of observed vulnerability in the considered area (Figs. 13 and 14). In each vulnerability function percentage of the gross area of the considered types of buildings is given in respect to the total analyzed gross constructed area. Separately regression lines are defined for heavily damaged (repairable), severely damaged (non-repairable) and cummulatively of totally unusable buildings.

In order to estimate cost for repair and strengthening of heavily damaged buildings particular analysis has been performed of 105 buildings with normalization of the cost to the year of 1980, for different levels of equivalent ground acceleration. Four of developed relations of the cost for repair and strengthening of strengthened masonry and RC frame buildings are given in Figs. 11 and 12 and Figs. 15 and 16 cummulatively for all structural types for residential apartment buildings and hotels, respectively, considering separately structural and nonstructural cost.

Considering that empirical vulnerability functions are developed dominantly for nonseismic structures, of particular interest would be to estimate vulnerability of modern seismic structures like RC frame and wall structures. Based on damageability analysis of more than 50 selected buildings several theoretical functions are developed and two of them presented in Figs. 17 and 18. Vulnerability of structural and nonstructural elements is considered separately. Althrough calculated levels are rather high the advantage of RC wall structures is quite evident and cummulative vulnerability and seismic risk will depend on the level of expected seismic hazard.

IMPLEMENTATION

Developed empirical and theoretical vulnerability functions on observed and expected vulnerability could be directly implemented in development and analysis of the vulnerability and seismic risk models of specific urban area, region or entire country with similar types of the existing stock of buildings. By analysis of different alternatives in the future development different levels of seismic risk will be obtained and possibility for determination of acceptable and economically justified level of seismic risk could be created. Developed functions could be used for economical, physical and urban planning as well as seismic design code calibration, planning of organization of civil defense activity, preventive measures and measures for reduction of earthquake consequences after disastrous earthquakes. Further systematic studies of specific stocks of buildings and structures exposed to different earthquake magnitudes are needed in order to establish an appropriate data base for development of more general vulnerability and seismic risk models and functions.

REFERENCES

1. Algermissen, S.T., "Seismic Hazard and Risk Assessment: Some Case Studies", Working Group on Natural Disaster Insurance, Geneva, February 1983.
2. Aoyama, H., "Outline of Earthquake Provisions in the Recently Revised Japanese Building Codes", Bulletin of the New Zealand NSEE, Vol. 14, No. 2, June 1981.
3. Bertero, V. and R. Bresler, "Design of Engineering Decisions - Failure Criteria (Limit States)", Panel 3, 6 WCEE, New Delhi, January 10-14, 1977.
4. Kameda, H. and K. Sekiguchi, "Reliability-Consistent Structural Design for Seismic Loads", 27th National Symposium for Structural Engineering, Tokyo, February 1981, pp.47-58.
5. Petrovski, J., "Damage Distribution Analysis in El Asnam Region due to the Earthquake of October 10, 1980", Second Arab Seismological Seminar, Rabbat, Morocco, October 28-30, 1981.
6. "Assessment of Damageability for Existing Buildings in a Natural Hazard Environment", Volume I and II: Methodology, Technical Report No.80-1332--1, J.H. Wiggins Company, Redondo Beach, California, 1980.
7. "Study of Expected Vulnerability and Acceptable Seismic Risk of Six Coastal Communes and Cetinje for the Needs of Elaboration of Physical Plan of SR Montenegro", Volume I: Seismic Hazard, Empirical and Theoretical Vulnerability Functions of Buildings and Evaluation of Observed Vulnerability of Infrastructure", Special Synthesis Report, IZIIS 83-97--1, Skopje, July 1983.

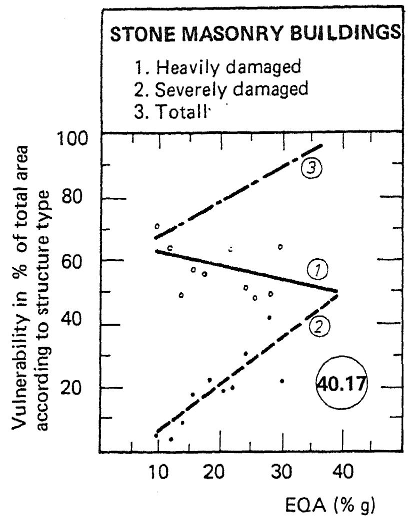


Fig. 1. Vulnerability empirical functions for stone masonry buildings

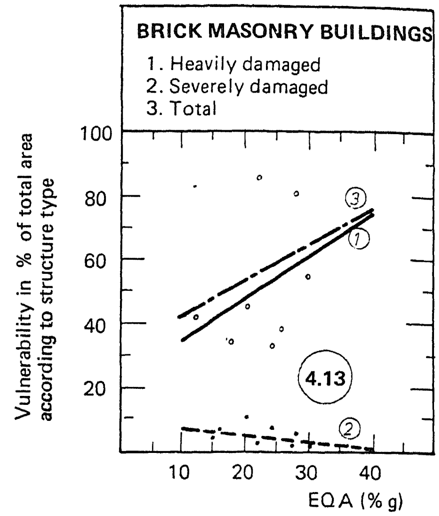


Fig. 2. Vulnerability empirical functions of brick masonry buildings

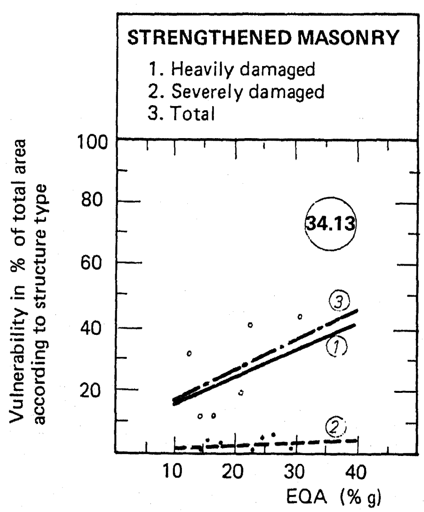


Fig. 3. Vulnerability empirical functions of strengthened masonry

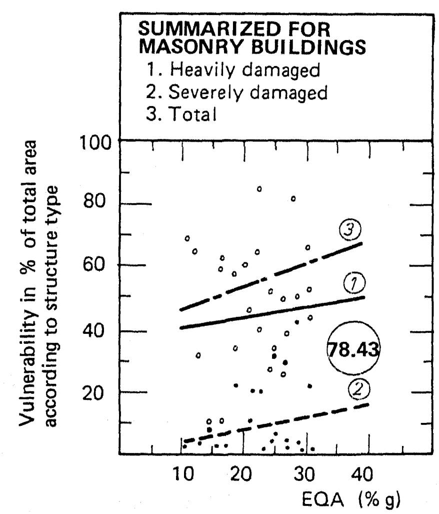


Fig. 4. Vulnerability empirical functions summarized for masonry buildings

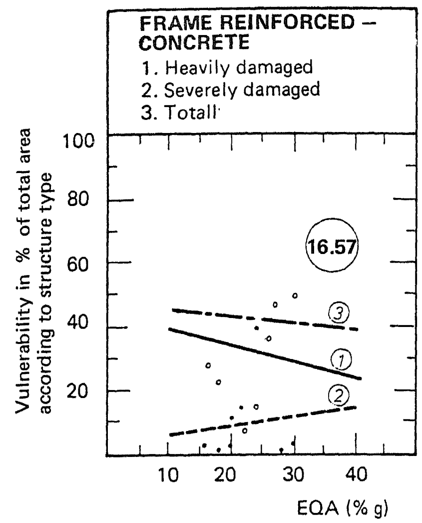


Fig. 5. Vulnerability empirical functions for reinforced-concrete frame buildings

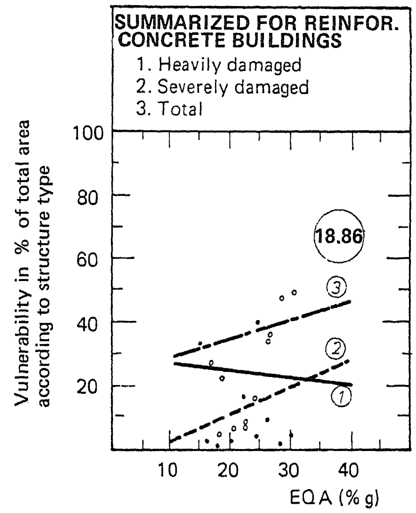


Fig. 6. Vulnerability empirical functions summarized for reinforced concrete buildings

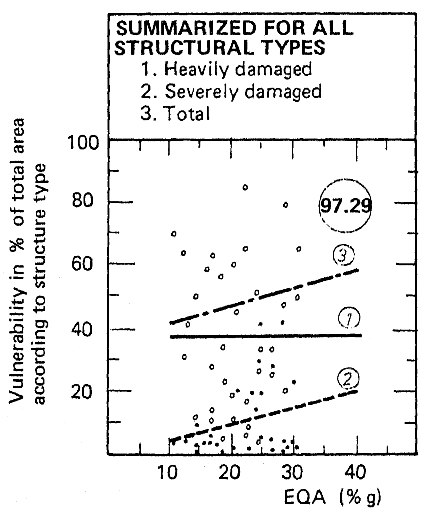


Fig. 7. Vulnerability empirical functions summarized for all structure types

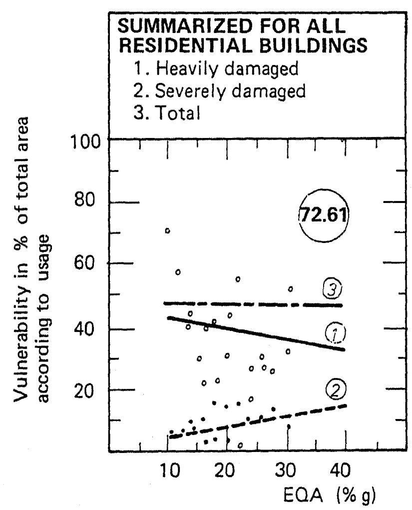


Fig. 8. Vulnerability empirical functions summarized for residential buildings

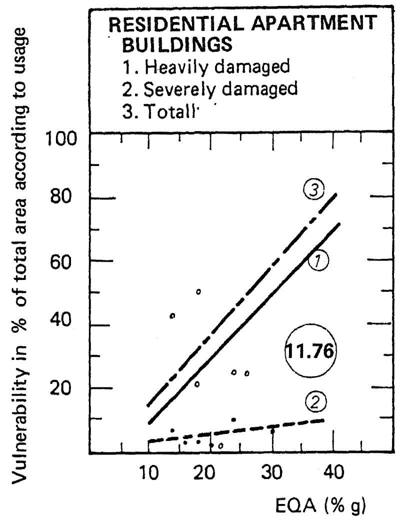


Fig. 9. Vulnerability empirical functions for residential apartment buildings

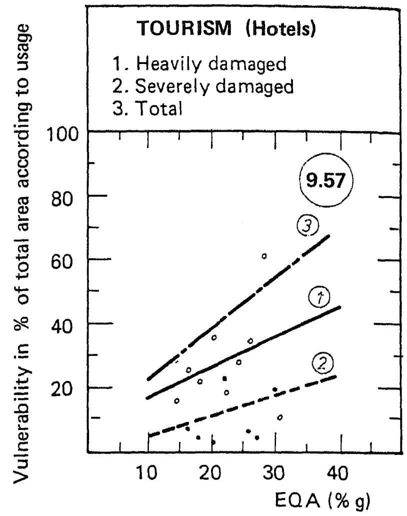
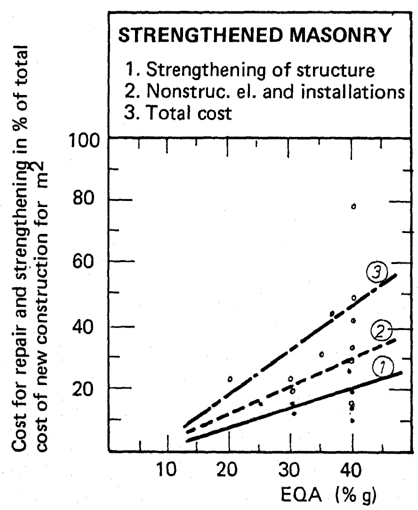


Fig. 10. Vulnerability empirical fuctions for tourism buildings



Fi. 11. Function of cost for repair and strengthening of apartment buildings of strengthened masonry

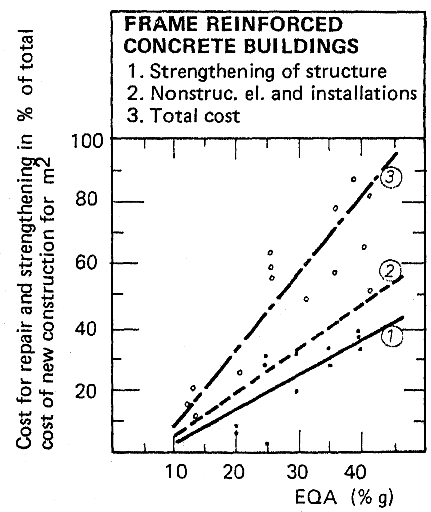


Fig. 12. Function of cost for repair and strengthening of frame reinforced concrete buildings

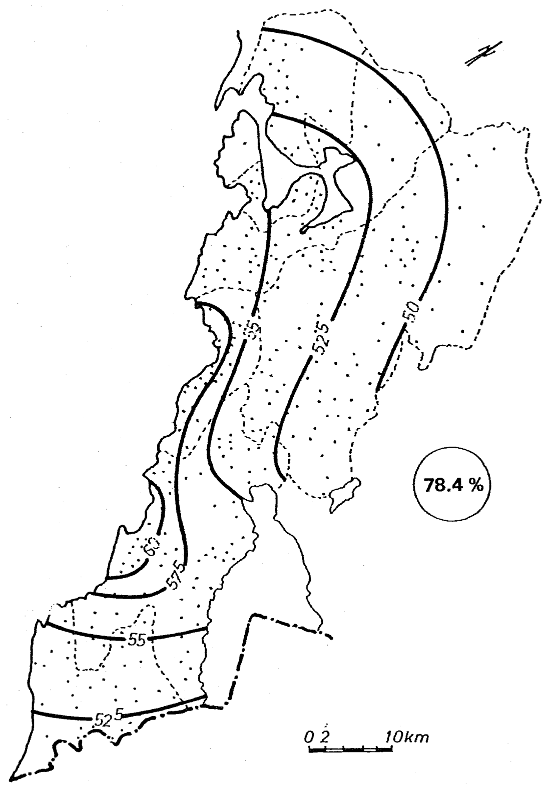


Fig. 13. Space distribution of observed vulnerability of heavily and severely damaged buildings summarized for masonry buildings

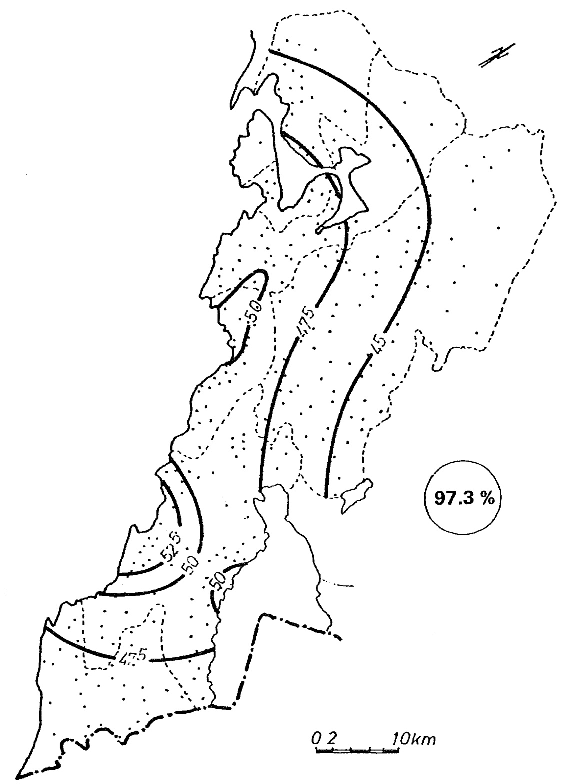


Fig. 14. Space distribution of observed vulnerability of heavily and severely damaged buildings, of all structural types

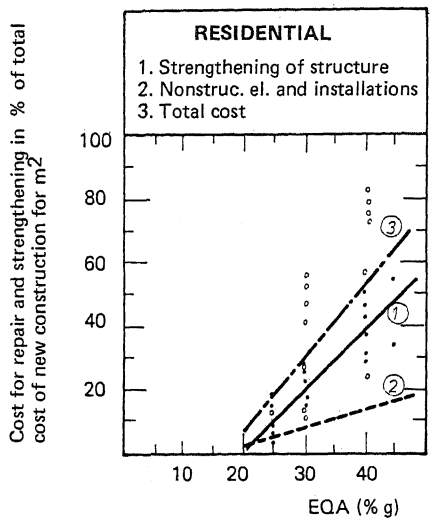


Fig. 15. Function of cost for repair and strengthening of residential apartment buildings

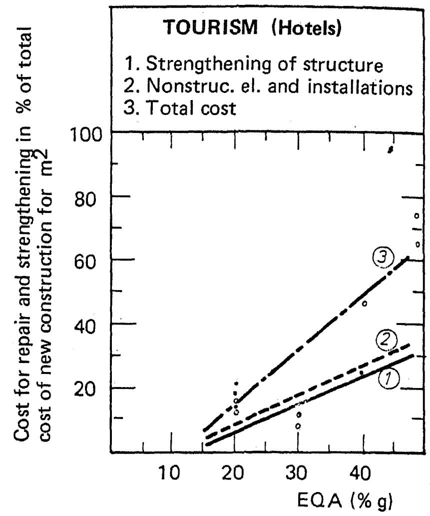


Fig. 16. Function of cost for repair and strengthening of tourism buildings (Hotels)

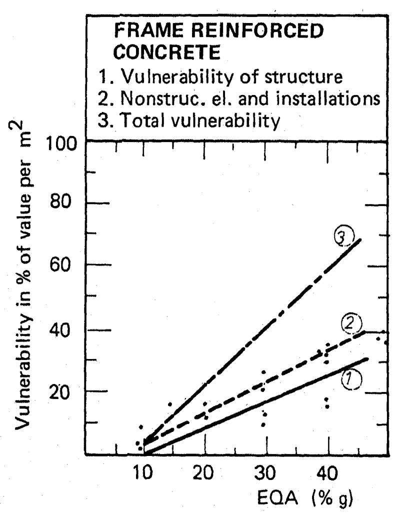


Fig. 17. Vulnerability function of repaired and new reinforced concrete frame buildings

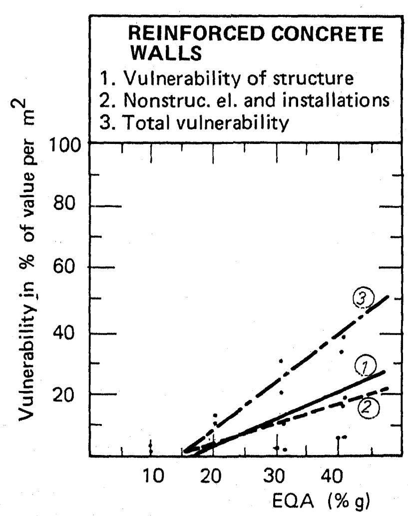


Fig. 18. Vulnerability function of repaired and new buildings with reinforced concrete walls