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A Systems Approach to Earthquake Vulnerability Assessment

By

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Abstract

The ability to take decisions about the expected response of existing projects (i.e. buildings, lifelines, cities) to an earthquake is difficult and complex. The behaviour of a few selected parameters of the main structural system (e.g. inter-storey drift) are commonly used to make judgements. The behaviour of a project clearly depends upon the structure but it also depends upon many other factors which often are not considered. These include, safety culture, management, condition, use, construction, materials and so forth. The modelling and measurement of these factors vary in quality since they are very different in nature. A model which enables these factors to be put together to assess the proneness to failure of a particular project is proposed. The model follows a systems approach and concentrates on the modelling and management of information. The management of the uncertainty, which is classified into fuzziness, incompleteness and randomness, is an important part of the model. Hierarchically arranged holons describe the processes making up the project and capture inherent fuzziness of the problem. The model includes tests (such as audits) which a project must pass in order to be declared dependably safe. Dependability is a measure of the degree to which an engineering theory has been tested in practical problems. The proposed methodology combines existing numerical models as well as ways of processing vague information and expert judgement. It is also a very flexible tool which allows the handling of various types of projects and situations which are slightly different from past experience. Experts will use linguistic assessments to measure the evidence about the dependability of processes to sustain their function during an earthquake. Linguistic assessments are matched to interval probability numbers. An interval number is used to capture, in a practical manner, features of fuzziness and incompleteness. Interval probability theory is used to combine evidential support values throughout the hierarchy. A computer implementation of the model (i.e. EVAS) was developed to show its potential for practical use. The software developed was used to apply the methodology to the Hospital Regional de Buenaventura in Colombia. Further testing of the proposed model and EVAS in practical applications should be carried out to ensure their dependability.

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Declaration

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The research on which this thesis was based was carried out under the supervision of Doctor C.A. Taylor and Professor D.I. Blockley. It is entirely due to the author except where otherwise acknowledged in the text and has not formed the basis for the submission for any other degree. The views expressed in the dissertation are those of the author and not of the university.

The following papers are based on the work described in this thesis:

1. Sánchez-Silva M., Taylor C. A., Blockley D.I. (1994) "Evaluation of Proneness to Failure of a Project in an Earthquake". Fifth US National Conference on Earthquake Engineering, 427-436, Chicago, July.

2. Sánchez-Silva M., Taylor C. A., Blockley D.I. (1994) "Proneness to failure of Buildings in an earthquake: a systems approach". Proceedings of 11th European Conference on Earthquake Engineering. Vienna, September.

3. Sánchez-Silva M., Taylor C., Blockley D.I. (1995) "Evaluation of Earthquake Induced Failure of Buildings in Buenaventura, Colombia". Chapter 12, *Design and construction of buildings and structures to withstand earthquakes.* IDNDR/ODA. Thomas Telford, London.

4. Sánchez-Silva M., Taylor C. A., Blockley D.I. (1995) "Hazard management of projects in an earthquake". CERRA - ICASP 7, 7th. International Conference on Applications of Statistics and Probability in Civil Engineering. Paris, July.

5. Sánchez-Silva M., Taylor C. A., Blockley D.I. (1995) "Towards an integrated model for seismic zonation". Proceedings of the 5th. International Conference on Seismic Zonation. Nice, October.

6. Sánchez-Silva M., Blockley D.I., Taylor C. A. (1996) "Uncertainty Modelling of Earthquake hazards". Journal of Microcomputers in Civil Engineering. Vol. 11, No 1, January.

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Date:...

"Now what I want is, Facts. Teach these boys and girls nothing but Facts. Facts alone are wanted in life. Plant nothing else, and root everything else. You can only form the minds of reasoning animals upon Facts: nothing else will ever be of any service to them.... We hope to have, before long, a board of fact, composed by commissioners of fact, who will force people to be a people of fact, and nothing but fact.."

"Hard Times" Charles Dickens

"Many years later, as he faced the firing squad, Colonel Aureliano Buendia was to remember that distant afternoon when his father took him to discover ice... The world was so recent that many things lacked names, and in order to indicate them it was necessary to point...."

"A hundred years of solitude" Gabriel García Marquez

To my father, my mother and my sister

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Notation

a(τ)	- Ground acceleration during the earthquake (Arias (Husid 1973)).
A_{rms}	- Root mean square of the ground acceleration (Wen et al. 1988).
AND	- Logical operator for the intersection of sets.
$App_{B/R}$	- Applicability of B for the rule R.
B_i	- A component holon of B.
Conf	- Confidence.
c/cc	- Viscous damping ratio (Arias (Husid 1973)).
D	- Damage Index (Stephens and Yao 1987 and Park and Ang 1985).
Di,	- Damage Index
dE	- Dissipated hysteretic energy (Park and Ang 1985).
Dep_R	- Dependability value of the rule R.
$(Dep_R)_l$	- Necessary support value of the Dependability of the rule R.
$(Dep_R)_u$	- Possible support value of the Dependability of the rule R.
g	- Acceleration of gravity
I_{Bi}	- Importance value of B_i where $B_i \in B = \{B_1, B_2, ...B_n\}$.
I	- Importance
I	- Ground motion intensity measure (Housner 1952, Husid 1973, Fajfar 1990).
Ic	- Characteristic Intensity of the ground motion (Wen et al. 1988).
Indep	- Independence.
K	- Flexural damage ratio (Banon and Veneziano 1982).
m	- Constant (Powell et al. 1988).
Maxdep	- Maximum dependence.
Mindep	- Minimum dependence.
Ms	- Magnitude of an earthquake in the Richter scale.
Mutexc	- Mutual exclusive.
N	- Normalised cumulative rotation (Banon and Veneziano 1982).
OR	- Logical operator for the union of sets.
$P(A)$	- Probability of A.

$[S_n(A), S_p(A)]$	- Interval probability number, where $S_n(A)$ and $S_p(A)$ are defined as the lower and upper bounds of the probability $P(A)$ for any event or proposition A.
$P(A \cap B)$	- Intersection between events A and B.
$P(A \cup B)$	- Union between events A and B.
Qy	- Static yield strength (Park and Ang 1985).
s_i	- Demand (Bertero and Bresler 1971).
$S_n(A)$	- Necessary support for the proposition A.
$S_n(A_i)_w$	- Weighted necessary support for the proposition A.
$S_p(A)$	- Possible support for the proposition A.
$S_p(A_i)_w$	- Weighted possible support for the proposition A.
r_i	- Capacity (Bertero and Bresler 1971).
t_o	- Strong motion duration (Arias (Husid 1973) and Wen et al. 1988).
t_D	- Duration of the ground motion after Trifunac and Brady (1975).
$V\varsigma$	- Pseudo-velocity spectrum (Housner 1952).
v_g	- Ground velocity (Fajfar et al. 1990).
w_i	- Weights (Bertero and Bresler 1971).
w_{Bi}	- Weight value of B_i where $B_i \in B = \{B_1, B_2, ..., B_n\}$.
$(w_{Bi})_l$	- Necessary support value of the weight of B_i where $B_i \in B = \{B_1, B_2, ..., B_n\}$.
$(w_{Bi})_u$	- Possible support value of the weight of B_i where $B_i \in B = \{B_1, B_2, ..., B_n\}$.
α	- Constant (Stephens and Yao 1987).
β	- Constant (Park and Ang 1985).
$\Delta\delta_p$	- Positive change in plastic deformation (Stephens and Yao 1987).
$\Delta\delta_{pu}$	- Positive change in plastic deformation at failure (Stephens and Yao 1987).
ρ	- Degree of dependence.
$\rho_{B1B2...Bm-1,Bm}$	- Dependence relationship between $B_1, B_2, ..., B_{m-1}$ and B_m
ρ_l	- Necessary support value of the dependence.
ρ_u	- Possible support value of the dependence.
ρ_{AB}	- Dependence relationship between A and B.
δ	- Damage parameter $\delta = 1 - (\delta_d/\delta_o)$.
$\delta_{Bertero}$	- Damage Index (Bertero and Bresler 1971).

δc	-	Calculated value of the damage parameter (Powell et al. 1988).
δ_h	-	Cumulative damage (Powell et al. 1988).
δd	-	Value of structural property in damaged state (Powell et al. 1988).
δ_{max}	-	Maximum response deformation (Newmark and Rosenbluelh 1974 and Park and Ang 1985).
δo	-	Value in undamaged state (Powell et al. 1988).
δt	-	Threshold value of the damage parameter (Powell et al. 1988).
δu	-	Ultimate value of the damage parameter (Powell et al. 1988).
δ_u	-	Ultimate elastic deformation (Park and Ang 1985)
δ_y	-	Yielding deformation (Newmark and Rosenbluelh 1974).
μ	-	Ductility factor (Newmark and Rosenbluelh 1974).
η_i and γ_i	-	Service factors that model the cumulative nature of damage (Bertero and Bresler 1971).

Glossary

Some of the main concepts used in this thesis are defined in this section[1].

Accident	an unplanned *failure event* (Blockley 1994).
Construction	implementation of the design to create an artefact that is fit for its intended use (Dester 1992).
Culture	is a shared set of beliefs, norms, attitudes, roles and practices (Comerford and Blockley 1993).
Damage state	a particular level of loss of value or fitness for purpose of a project. A damage state may be personal harm or loss to property, plant, or a loss of business opportunity (Blockley 1993).
Danger	liability or exposure to an *accident* (Blockley 1993).
Dependability	is the extent to which an engineering theory has been tested in practical decisions (Blockley 1980)
Design	is the process that transforms the conceptual design into a form which can be directly developed into an artefact (Dester 1992).
Expert	is a person who has detailed knowledge and experience of a topic, situation or activity (Dester 1992).

[1] Italics denote a term that has also been defined in this section.

Event	is some occurrence that may cause the state of a system to change (Booch 1994).
Failure of an artefact	is the lack of correspondence between a required state of the world and the actual state of the world (Blockley 1992).
Failure event	is one in which an artefact or project is *damaged* (Blockley 1993)
Form	is the "essence" as initially defined by Plato. (i.e. What *it* is).
Function	fitness for purpose (Blockley 1992).
Fuzziness	imprecision of definition (Blockley 1993).
Hazard	is a set of incubating preconditions for failure (Blockley 1993).
Hierarchy	is a ranking or ordering of concepts logically connected at different levels of definition.
Holon	is both a whole and a part (Koestler 1967). Holons exhibit emergent properties. These are not properties of any of the parts but emerge from the co-operation of the parts.
Model	is a representation of a defined system for a purpose (Blockley 1993).
Operation	is a process which encompasses all activities, systems and procedures that are necessary for the use of an artefact. This includes maintenance, repairs and modifications (Dester 1992)
Parent holon	is the holon in the immediate upper level of the hierarchy

Process	a series of actions which produce a change or development. This is a transformation of a initial state into a final state. Processes are defined by needs and objectives.
Project	is a set of facilities and activities which may be defined in terms of processes at varying levels of definition. Facilities consist of elements such as buildings, the ground, the foundation, the lifelines and so on. The project may be defined at the level of a specific building (or indeed a specific element within the building) or at the level of a city, region or country. The activities with the processes are those which define the purpose of the project, for example a hospital.
Proneness to failure	is a measure of the available evidence concerning the *hazard* that an artefact might suffer a *failure event* (Blockley 1993).
Randomness	is the lack of a specific pattern in a set of data (Blockley 1993).
Risk	is the combined effect of the chances of occurrence of some *failure* and its consequences in a given context (Blockley 1993).
Reliability	is a measure of the chances that an artefact or project will not suffer an *accident* (Blockley 1993).
Safety	is freedom from unacceptable *risk* (Blockley 1993).
Society	the system of interrelationships which connects together the individuals who share a common *culture* (Giddens 1989).

Sufficient refinement is the extent to which the dependability of the result is appropriate. The appropriateness of the result may be defined by external restrictions such as the requirements of the client, law regulations, the quality of information or the grounding of the model.

System is defined as a structured set of objects and/or attributes together with the relationships between them (Wilson 1984). The concept *system* embodies the idea of a set of elements connected together which form a whole, showing emergent properties which are properties of the whole which result from the co-operation of the component parts.

Uncertainty is lack of knowing (Blockley 1993).

Vulnerability is defined as the susceptibility to failure of an artefact (structure, facility and so forth) under any arbitrary action (Wu et al. 1993).