Chapter 10

Conclusions and further work

10.1 Conclusions

1. The basis of an *Earthquake Disaster System* has been developed. Its purpose is to aid the overall management of the social, economic, technical and natural factors which can cause a loss of fitness for purpose to any group of society or their environment when an earthquake releases some of the energy (e.g. physical, organisational) pent-up within the system. It is argued, following Turner (1978), that earthquake disasters are not the result of a single cause, the ground motion. Rather, multiple causal factors accumulate over a considerable period of time, called *incubation period*, before the earthquake event. Thus, not only technical aspects but also social, economic and cultural characteristics of the affected population must be recognised as major preconditions for a disaster. Any model for assessing the proneness to failure of a system due to a natural hazard should ideally incorporate these aspects.

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2. Existing methodologies have been classified according to the type of project under consideration (i.e. single projects, cities, lifelines, etc.) or to the management and type of information (i.e. qualitative, analytic, expert opinions, etc.). The main weaknesses of existing methodologies were identified as: the incomplete characterisation of the ground motion; the lack of importance given to social and cultural aspects; the emphasis on identifying relevant factors but not on modelling their relationships; and the lack of a consistent method to combine different types of information. After a set of interviews with experts in earthquake engineering, aspects such as practicality,

transparency, management of uncertainty and organisation of information were identified as paramount for developing a new methodology. The review of existing methodologies and interviews of experts provided the grounding for the development of the methodology proposed in this thesis.

3. In any methodology for *earthquake vulnerability assessment* a great deal of effort has to be directed towards the management of the uncertainty associated with the evaluation of damage. The acceptable level of structural damage in a strong ground motion, provided by codes of practice for seismic design, cannot be determined only by a profit-safety relationship. Factors such as the function of the project, its social context, and its continuous changing nature have also to be considered. Damage has been defined as loss of value, or fitness for purpose (i.e. function), of any aspect of a system (e.g. physical, organisational etc.). Linguistic and economic values have shown to be incomplete and sometimes poor measures of damage. In addition, these measures of damage cannot be related to traditional numerical models of different aspects of the project. Uncertainty of damage assessments arises from a lack of knowledge and can be caused by imprecision of definition (i.e. fuzziness), lack of a specific pattern in data (i.e. randomness) and due to the inherent incompleteness of any system. The management of the uncertainty associated with different aspects of the system is difficult to model by using a single numerical measure.

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4. The proposed systems methodology can integrate 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 different projects and situations which are slightly different from past experience. The model provides a system model capable of synthesising multiple factors to reach an overall evaluation of proneness to failure. Risk analysis is a limited guarantee of a proper description of possible future scenarios and this is the basic reason for focusing on hazard. This is not to argue that risk analysis is not useful, rather that it is partial evidence. The model is a process of collecting evidence of the hazard content (i.e. incubating preconditions for the failure) of the project in an earthquake. Evidence can be obtained from different sources such as historical records, current assessments or projections of future scenarios. An

expert has to make a judgement on the extent to which this evidence is a measure of the ability of every holon to fulfil its *function*. This allows the combination of different types of data, knowledge and information within the same framework.

5. A methodology has been developed to (1) assess the *proneness to failure* of a project, not for prediction but for use as a management tool; and (2) provide a list of the most critical aspects of the project. *Proneness to failure* is an index which measures the hazard content of the system. In contrast, vulnerability is concerned with the identification of "weak links" in the *form* of the project (i.e. critical aspects) and the derivation of particular failure scenarios (i.e. maximum, minimum, etc.). The complexity of the problem is managed by the logical and consistent organisation of information in a hierarchical manner. Thus, the system is modelled as a hierarchy of processes at different levels of definition. Every process is a holon, which is a data structure with a set of attributes and behaviours. The assessment of every holon is carried out by an expert using linguistic variables. Linguistic variables are matched to single or interval numbers which represent a measure of belief of the evaluator on the assessment. The assignment of an interval number on (0,1) as a support value enables the modelling of the inevitable uncertainty in difficult judgements. Evidential support is combined throughout the hierarchy using Interval Probability Theory (ITP). Interval Probability Theory is intended for use in problems involving sparse data and incomplete and possibly inconsistent knowledge. It allows the different algebra of probability theory and fuzzy sets to be used within one framework. Interval probability theory, as compared to classical probability theory or to fuzzy logic, has the advantage of being able to manage different models of dependence between holons.

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6. A software system for managing the information of an *Earthquake Disaster System* has been developed. The *Earthquake Vulnerability Assessment System* (EVAS) is a computer based system designed following Object Oriented Programming (OOP) techniques. The internal structure of EVAS was designed based on a message passing system between software objects, which describe processes, arranged hierarchically at different levels of definition. EVAS provides a flexible system to develop a hierarchy

and to manage the conceptual and numerical aspects of the model. The organisation of the results can provide an appropriately complete picture of different aspects of the system depending on the amount of detail included. This includes basic information, statistical information of the hierarchical model, the overall evaluation of the proneness to failure of the system and a list of the most critical aspects. OOP is a good conceptual tool to develop software systems which are based on a systems approach. Version 2.2 of Kappa PC was selected as the software support environment for the development of EVAS. The computer implementation was developed as an illustration of the potential use of the model and further tests are required to improve its dependability.

7. It was concluded form the analysis of the Hospital Regional de Buenaventura that the proneness to failure of the *Hospital Project*, based on the expected *Ground Motion*, is *High*. The failure of the *Hospital Project* might be caused by the severe damage of the lifeline systems, by partial collapse the hospital physical system, or by the collapse of the management and administrative organisations. Failure was identified as the inability of the hospital to operate at its maximum capacity (Section 9.4.2) in case of a *High* intensity *Ground Motion*, as described by the evidence shown in Table 9.6. The numerical characteristics of the model showed that uncertainty values of the upper holons in the hierarchy were reduced when the system was assessed in the lower levels of the hierarchy. The methodology to select the most critical aspects showed to be appropriate in the identification of "weak links" of the project and therefore very valuable tool for earthquake vulnerability assessments. Also, it has been shown to be a flexible model for handling problems with differing qualities and availability of information.

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10.2 Recommendations for further work

1. Although the hierarchical representation of every project is unique, general hierarchical representations can be identified for certain classes of projects. For instance the hierarchical representation of standard residential buildings is likely to be

very similar, at least in the upper levels of the hierarchy. Generic hierarchies will facilitate the use of the model and provide more dependable hierarchical representations of different types of projects. Thus, the development of generic hierarchical models for different facility types (i.e. dwellings, residential buildings, vital facilities, motor-way systems, etc.) should be a primary task for further research. The development of generic hierarchies does not mean that they cannot be modified according to the particular characteristics of the project considered. They are dependable basic guides which can be obtained from previous experiences, expert opinions and so forth. These generic hierarchies should include technical as well as social, economic and cultural aspects.

2. One of the main features of the model is that it can incorporate technical as well as social and cultural aspects of earthquake disasters. Further research towards the identification and modelling of non technical aspects which have proved to be paramount for the occurrence of earthquake disasters is suggested (Chapter 2). This might require the interaction with experts in different areas, e.g. sociologists, psychologists and economists.

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3. Further work is required on the understanding and modelling of the concept of *dependence*. Although this concept was clearly defined in mathematical terms, the physical meaning is not very clear because there are many different reasons for dependence. The fact that heuristic judgements have to be adopted to provide a measure of dependence, restricts the application of the methodology especially for inexperienced engineers. Therefore, further research for a better understanding of its physical meaning and to find different modelling techniques is required.

4. The linguistic representation of the expert judgement of the evidence concerning the hazard content of every *process*, may be different. The fuzzy numbers which were used to represent the linguistic variables for the assessment might vary according to the *process* to be evaluated (Chapter 6). The model presented in this thesis uses the same linguistic representation for all *processes* in the hierarchy (Figure 6.6). Further

research towards the identification of more dependable representations of the linguistic variables for the assessment should be carried out.

5. Although the methodology was essentially developed for earthquake vulnerability assessments, its application can be extended to other type of assessments. These may include other natural phenomena as well as industrial processes, safety management, and other sorts of auditing processes. Although modifications maybe required, the conceptual basis can be used as a reference.

6. The software developed (EVAS) was created to illustrate the viability and practicality of a computer implementation of the model. It is, however, in a very early stage and further tests are required to enhance its dependability. Further developments will enable EVAS to assist designers by providing guidance in how to improve both the hierarchical system and the numerical aspects of the assessment. It will also be able to link different types of evidence and be used as an aid in the decision making process.

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Chapter 11

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Appendix A

Maps and Seismic information of the *Hospital Regional de Buenaventura*

A1 General aspects

In Chapter 9 the methodology proposed in this thesis was illustrated with a case study. The Hospital Regional de Buenaventura in Colombia was studied and the results and some of the main features of the model were presented. In Sections 9.2 to 9.4, the basic characteristics of the region and the *Hospital Project* were described. In this Appendix, some maps which are part of the evidence collected about the *Ground Motion* are presented. These are:

(1) Map of South America

(2) World map showing relation between the major tectonic plates and recent earthquakes and volcanoes (Bolt 1988).

(3) Distribution of earthquakes with Ms $\geq$ 4 in the Pacific Coast of Colombia (Costa 1990)

(4) Location of the main volcanoes in the south-west of Colombia (Sarria 1990)

(5) Seismic hazard map of Colombia (AIS 1984).

(6) Distribution of effective peak acceleration coefficient (Aa) for Colombia (AIS 1984)

(7) Distribution of effective peak velocity coefficient (Av) for Colombia (AIS 1984)

(8) Tsunami hazard map for the Pacific Coast of Colombia (Meyer et a. 1992)

(9) Map of Buenaventura - Cascajal Island

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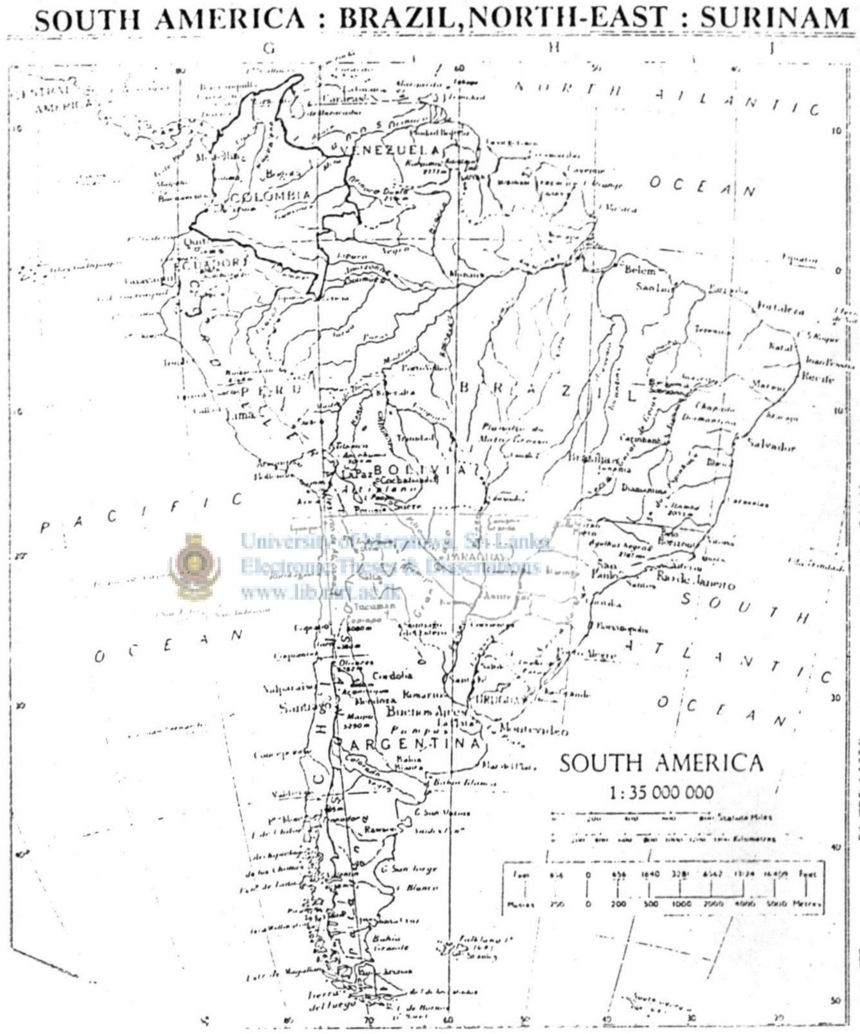
Map of South America



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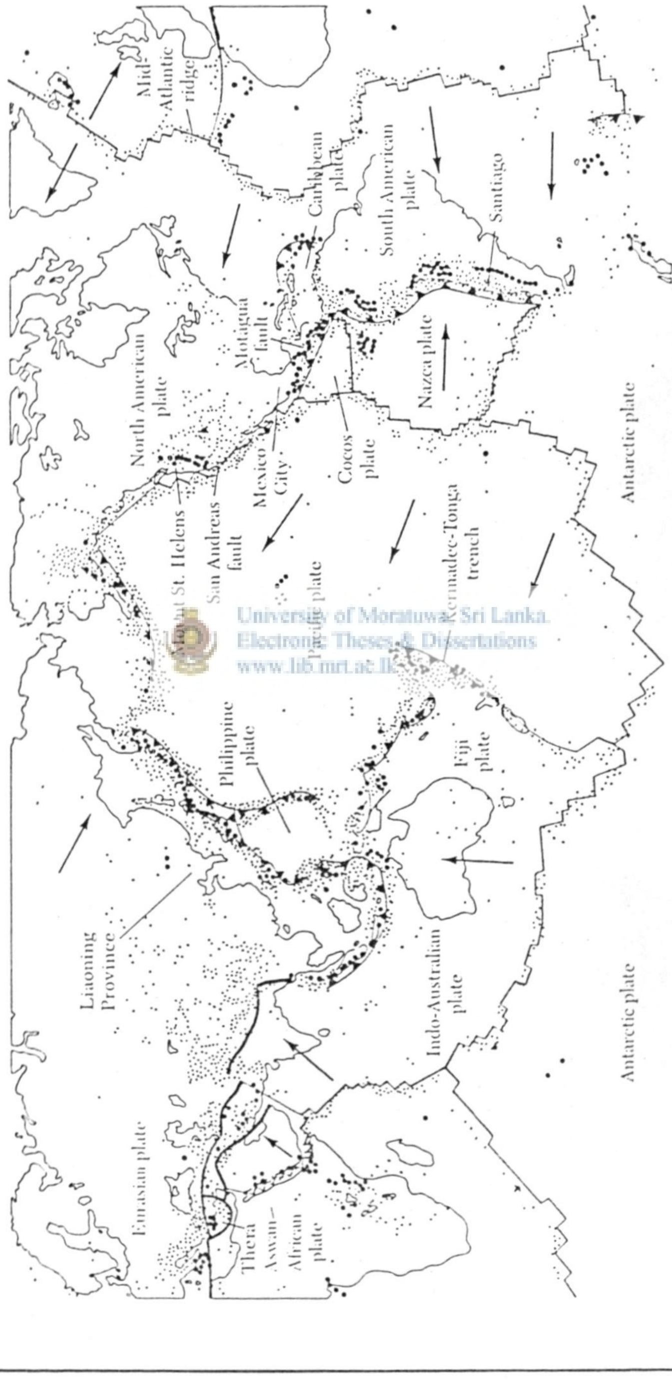
World map showing relation between the major tectonic plates and recent earthquakes and volcanoes (Bolt 1988)



Volcanoes — Subduction zone — Spreading ridge offset by transform faults

Earthquake zone — Motion of plate — Collision zone

Figure 4 World map showing relation between the major tectonic plates and recent earthquakes and volcanoes. Earthquake epicenters are denoted by the small dots, and the volcanoes by large dots.

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Distribution of earthquakes with Ms ≥ 4 in the Pacific Coast of Colombia (Costa 1990)

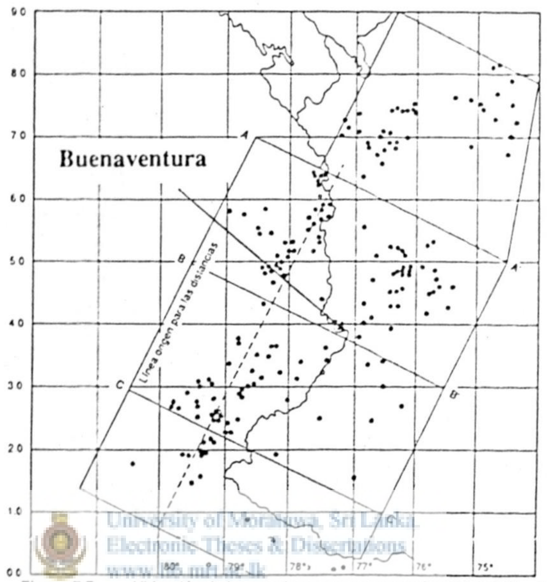

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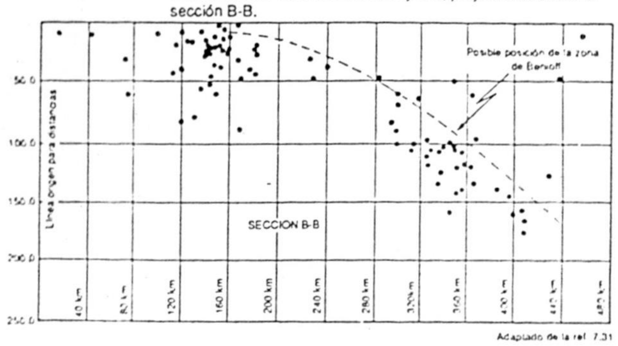
Figura 7.7 Ubicación de las secciones transversales. Sismos con M ≥ 4, ubicados entre las secciones A-A y B-B, proyectados sobre la sección B-B.



Location of the main volcanoes in the south-west of Colombia

(Sarria 1990)

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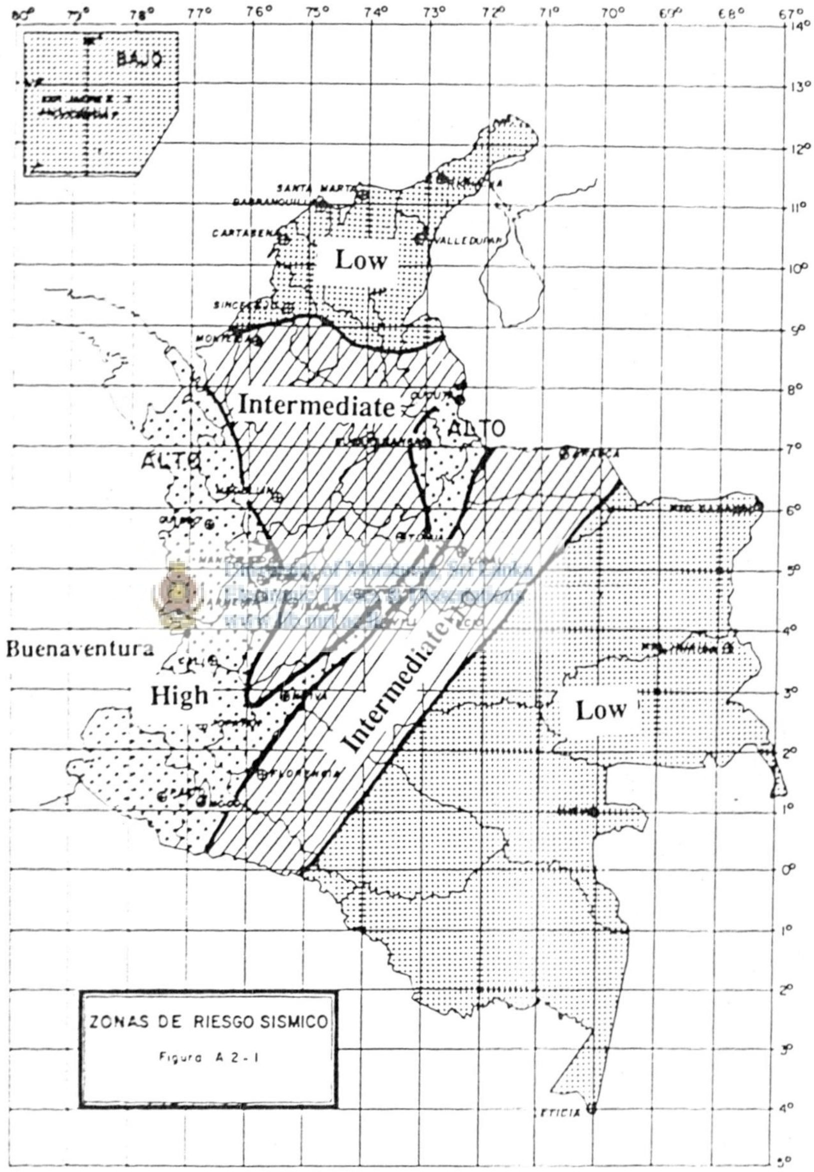
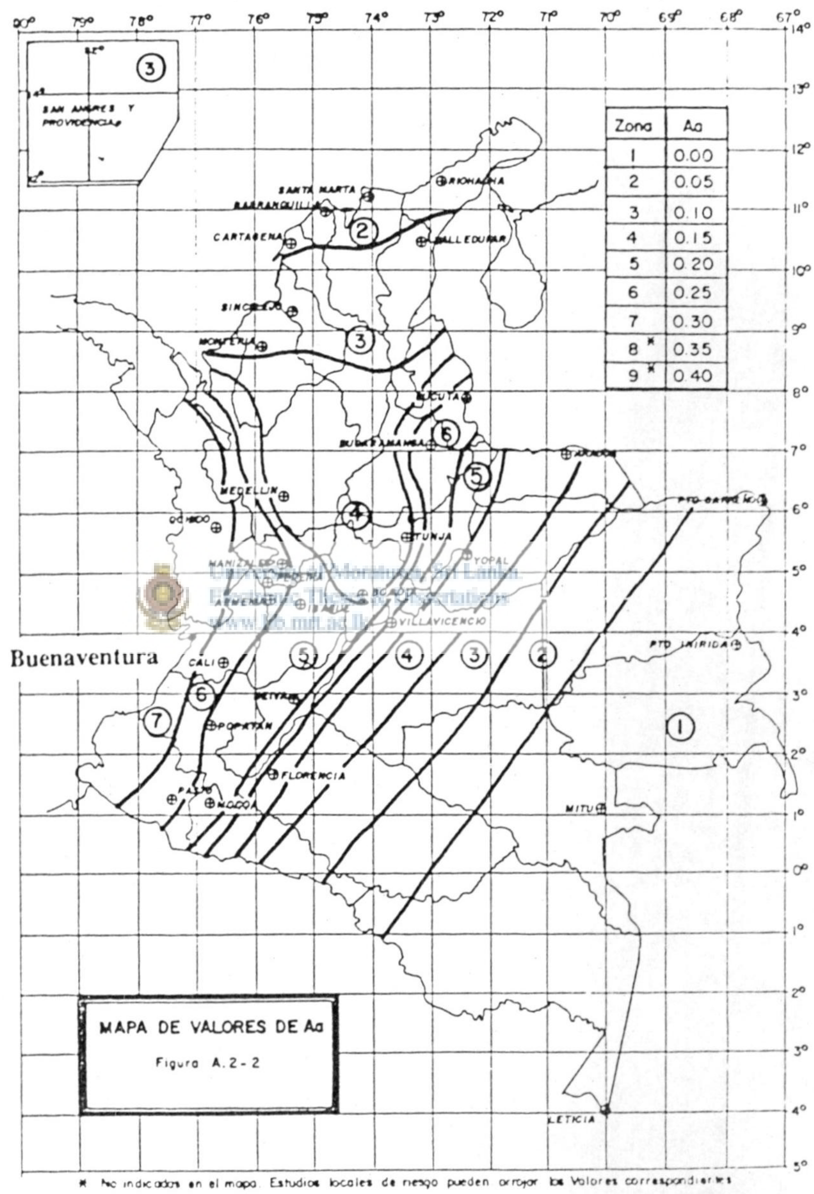
Seismic hazard map for Colombia (AIS 1984)



Distribution of effective peak acceleration coefficient (Aa) for Colombia (AIS 1984)



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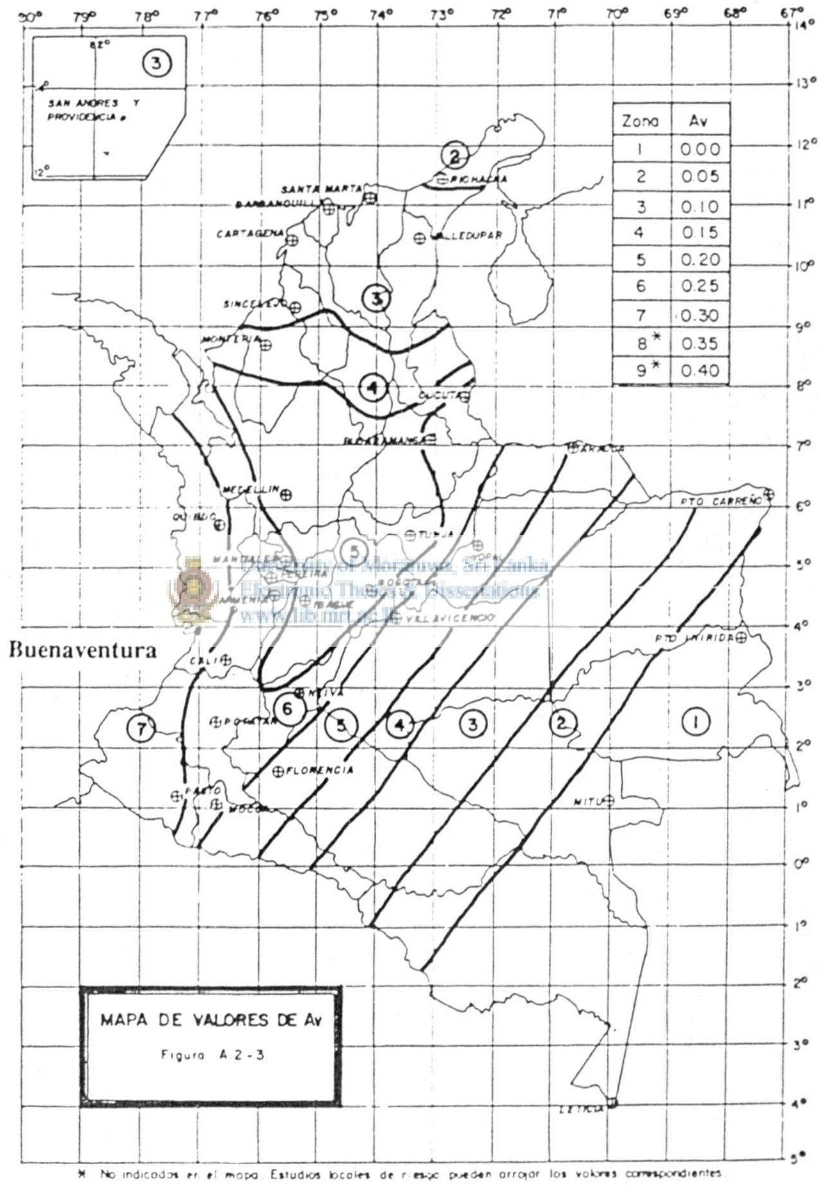
Distribution of effective peak velocity coefficient (Av) for Colombia (AIS 1984)



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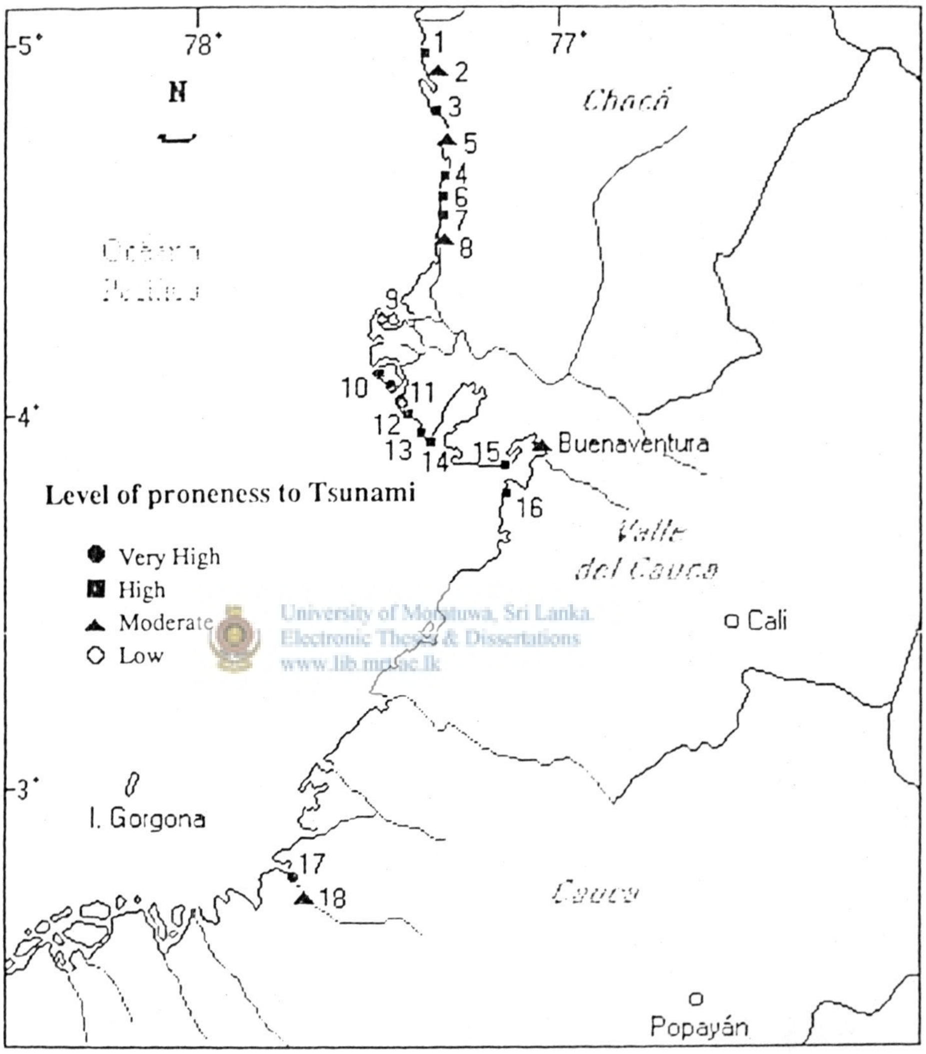
Tsunami hazard map for the Pacific Coast of Colombia

(Meyer et a. 1992)



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Cities and villages

1 Sivirú
2 Docampadó
3 Punta Ijuá
4 Boca Orpúa
5 Punta Abadía
6 El Venado
7 Pichimá
8 Togoromá
9 Charambirá
10 Boca Chavica- El Choncho
11 Pto. España
12 La Barra
13 Ladrilleros
14 Juanchaco
15 La Bocana
16 El Soldado
17 Nuevo Chacón
18 Timbiqui

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Appendix B

Calculation of proneness to failure of the *Hospital Regional de Buenaventura*

The main characteristics of the evaluation of the Hospital Regional de Buenaventura were described in Chapter 9. Although the developed software EVAS was used to carry out the assessment, the numerical calculations were also made using a spreadsheet. In this Appendix the spreadsheet used for the calculation is presented for the reader to understand the numerical model. The explanation of the spreadsheet values was presented in Chapter 8 (Table 8.2). The calculations presented in this Appendix are as follows:

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(1) Evaluation of the Ground Motion
(2) Evaluation of the Earthquake Disaster System at level 3
(3) Evaluation of the Earthquake Disaster System at level 4
(4) Evaluation of the Earthquake Disaster System at level 5
(5) Evaluation of the Earthquake Disaster System at level 6
(6) Evaluation of the Earthquake Disaster System at level 9

EVALUATION OF THE GROUND MOTION

Interval Probability Theory: Applications

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
Holons	*Linguistic Support*	*Confid.*	Suport Interval	Input Source	*Import.*	Import. Relative	Weighted Support	Type of Dependence	Dependence Support	Accumulated Value
Seismic Energy Dissipation										
Dissipation of energy during propag.	Very High	0.700	[0.830 1.000]	Assigned	1.000	0.556	[0.46 0.56]			
Modification of energy locally	High	0.700	[0.630 0.770]	Assigned	0.800	0.444	[0.28 0.34]	Indep	[0.46 0.56]	**[0.586 0.740]**
Ground Motion										
Transmission of seismic energy			[*0.586 0.740*]	Calculate	1.000	0.500	[0.29 0.37]			
Releasing of seismic energy	High	1.000	[0.675 0.725]	Assigned	1.000	0.500	[0.34 0.36]	Maxdep	[1.00 1.00]	**[0.586 0.725]**

Evidential support of the Ground Motion [0.586 0.725]

Note: Values of Confidence and Importance were assigned as single numbers

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EVALUATION OF THE HOSPITAL EARTHQAUKE DISASTER SYSTEM (*L3)

Interval Probability Theory: Applications

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
Holons	*Linguistic Support*	*Confid.*	Suport Interval	Input Source	*Import.*	Import. Relative	Weighted Support	Type of Dependence	Dependence Support	Accumulated Value
THIRD LEVEL IN THE HIERARCHY										
Hospital Project										
Design	Unknown		[0.000 1.000]	Assigned	1.000	0.333	[0.00 0.33]			
Construction	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	**[0.200 0.600]**
Operation	Moderate	0.300	[0.370 0.630]	Assigned	1.000	0.333	[0.12 0.21]	Mutexc	[0.00 0.00]	**[0.323 0.810]**

Evidential support for the hospital project [0.323 0.810]

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
TOP LEVEL IN THE HIERARCHY										
Hospital earthquake disaster system										
Hospital project			[*0.323 0.810*]	Calculated	1.000	0.500	[0.16 0.41]			
Ground motion			[*0.586 0.725*]	Calculated	1.000	0.500	[0.29 0.36]	Maxdep	[1.00 1.00]	**[0.323 0.725]**

Evidential support for the whole system [0.323 0.725]

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EVALUATION OF THE HOSPITAL EARTHQUAKE DISASTER SYSTEM (*L4)

Interval Probability Theory: Applications

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
Holons	*Linguistic Support*	*Confid.*	Suport Interval	Input Source	*Import.*	Import. Relative	Weighted Support	Type of Dependence	Dependence Support	Accumulated Value
FOURTH LEVEL IN THE HIERARCHY										
Design										
Design of Physical system	Poor	0.300	[0.570 0.830]	Assigned	1.000	0.400	[0.23 0.33]			
Design of Medical system	Unknown		[0.000 1.000]	Assigned	0.500	0.200	[0.00 0.20]	Mutexc	[0.00 0.00]	[**0.228 0.532**]
Design of Management system	Poor	0.300	[0.570 0.830]	Assigned	1.000	0.400	[0.23 0.33]	Mutexc	[0.00 0.00]	[**0.456 0.864**]
Construction										
Construction of Physical system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.400	[0.33 0.40]			
Construction of Medical system	Unknown		[0.000 1.000]	Assigned	0.500	0.200	[0.00 0.20]	Mutexc	[0.00 0.00]	[**0.332 0.600**]
Construction of Management system	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.400	[0.24 0.32]	Mutexc	[0.00 0.00]	[**0.572 0.920**]
Operation										
Operation of Physical system	Very Poor	0.500	[0.800 1.000]	Assigned	1.000	0.333	[0.27 0.33]			
Operation of Medical system	Moderate	0.500	[0.400 0.600]	Assigned	1.000	0.333	[0.13 0.20]	Mutexc	[0.00 0.00]	[**0.400 0.533**]
Operation of Management system	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.600 0.800**]

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THIRD LEVEL IN THE HIERARCHY

Hospital Project								
Design	[*0.456* *0.864*]	Calculate	1.000	0.333	[0.15 0.29]			
Construction	[*0.572* *0.920*]	Calculate	1.000	0.333	[0.19 0.31]	Mutexc	[0.00 0.00]	[**0.343** **0.595**]
Operation	[*0.600* *0.800*]	Calculate	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.543** **0.861**]

Evidential support for the hospital project [0.543 0.861]

TOP LEVEL IN THE HIERARCHY

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Hospital earthquake disaster system								
Hospital project	[*0.543* *0.861*]	Calculate	1.000	0.500	[0.27 0.43]			
Ground motion	[*0.586* *0.725*]	Calculate	1.000	0.500	[0.29 0.36]	Maxdep	[1.00 1.00]	[**0.543** **0.725**]

Evidential support for the whole system [0.543 0.725]

EVALUATION OF THE HOSPITAL EARTHQUAKE DISASTER SYSTEM (*L5)

Interval Probability Theory: Applications

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
Holons	*Linguistic Support*	*Confid.*	Suport Interval	Input Source	*Import.*	Import. Relative	Weighted Support	Type of Dependence	Dependence Support	Accumulated Value
FIFTH LEVEL IN THE HIERARCHY										
Design of physical system										
Design of lifelines	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.435	[0.26 0.35]			
Design of structure	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.435	[0.26 0.35]	Indep	[0.26 0.35]	[**0.431 0.605**]
Design of contents	Moderate	0.500	[0.400 0.600]	Assigned	0.300	0.130	[0.05 0.08]	Mutexc	[0.00 0.00]	[**0.483 0.683**]
FOURTH LEVEL IN THE HIERARCHY										
Design										
Design of Physical system			[*0.483 0.683*]	Calculate	1.000	0.400	[0.19 0.27]			
Design of Medical system	Unknown		[0.000 1.000]	Assigned	0.500	0.200	[0.00 0.20]	Mutexc	[0.00 0.00]	[**0.193 0.473**]
Design of Management system	Poor	0.300	[0.570 0.830]	Assigned	1.000	0.400	[0.23 0.33]	Mutexc	[0.00 0.00]	[**0.421 0.805**]
Construction										
Construction of Physical system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.400	[0.33 0.40]			
Construction of Medical system	Unknown		[0.000 1.000]	Assigned	0.500	0.200	[0.00 0.20]	Mutexc	[0.00 0.00]	[**0.332 0.600**]
Construction of Management system	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.400	[0.24 0.32]	Mutexc	[0.00 0.00]	[**0.572 0.920**]
Operation										
Operation of Physical system	Very Poor	0.500	[0.800 1.000]	Assigned	1.000	0.333	[0.27 0.33]			
Operation of Medical system	Moderate	0.500	[0.400 0.600]	Assigned	1.000	0.333	[0.13 0.20]	Mutexc	[0.00 0.00]	[**0.400 0.533**]
Operation of Management system	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.600 0.800**]

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THIRD LEVEL IN THE HIERARCHY

Hospital Project								
Design	[*0.421* *0.805*]	Calculate	1.000	0.333	[0.14 0.27]			
Construction	[*0.572* *0.920*]	Calculate	1.000	0.333	[0.19 0.31]	Mutexc	[0.00 0.00]	[**0.331** **0.575**]
Operation	[*0.600* *0.800*]	Calculate	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.531** **0.842**]

Evidential support for the hospital project [0.531 0.842]

TOP LEVEL IN THE HIERARCHY

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Hospital earthquake disaster system								
Hospital project	[*0.531* *0.842*]	Calculate	1.000	0.500	[0.27 0.42]			
Ground motion	[*0.586* *0.725*]	Calculate	1.000	0.500	[0.29 0.36]	Maxdep	[1.00 1.00]	[**0.531** **0.725**]

Evidential support for the whole system [0.531 0.725]

EVALUATION OF THE HOSPITAL EARTHQUAKE DISASTER SYSTEM (*L6)

Interval Probability Theory: Applications

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
Holons	*Linguistic Support*	*Confid.*	Suport Interval	Input Source	*Import.*	Import. Relative	Weighted Support	Type of Dependence	Dependence Support	Accumulated Value
SIXTH LEVEL IN THE HIERARCHY										
Design of Lifelines										
Design of Water supply system	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.167	[0.11 0.13]			
Design of Energy supply system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.167	[0.14 0.17]	Mutexc	[0.00 0.00]	[**0.243 0.295**]
Design of Gas supply system	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.167	[0.11 0.13]	Mutexc	[0.00 0.00]	[**0.348 0.423**]
Design of Sewage system	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.167	[0.11 0.13]	Mutexc	[0.00 0.00]	[**0.453 0.552**]
Design of Communication system	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.167	[0.07 0.10]	Mutexc	[0.00 0.00]	[**0.525 0.647**]
Design of Access system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.167	[0.14 0.17]	Mutexc	[0.00 0.00]	[**0.663 0.813**]
Design of contents										
Design of Non-strutural systems	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.588	[0.25 0.34]			
Design of Medical equipment	Very Poor	0.700	[0.830 1.000]	Assigned	0.700	0.412	[0.34 0.41]	Indep	[0.34 0.41]	[**0.491 0.632**]
Design of structure										
Design of superstructure	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.500	[0.32 0.39]			
Design of Foundation	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.500	[0.22 0.29]	Indep	[0.32 0.39]	[**0.447 0.580**]

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FIFTH LEVEL IN THE HIERARCHY

Physical system										
Design of lifelines			[*0.663* *0.813*]	Calculate	1.000	0.435	[0.29 0.35]			
Design of structure			[*0.447* *0.580*]	Calculate	1.000	0.435	[0.19 0.25]	Indep	[0.29 0.35]	[**0.414** **0.533**]
Design of contents			[*0.491* *0.632*]	Calculate	0.300	0.130	[0.06 0.08]	Mutexc	[0.00 0.00]	[**0.478** **0.616**]

FOURTH LEVEL IN THE HIERARCHY

Design										
Design of Physical system			[*0.478* *0.616*]	Calculate	1.000	0.400	[0.19 0.25]			
Design of Medical system	Unknown		[0.000 1.000]	Assigned	0.500	0.200	[0.00 0.20]	Mutexc	[0.00 0.00]	[**0.191** **0.446**]
Design of Management system	Poor	0.300	[0.570 0.830]	Assigned	1.000	0.400	[0.23 0.33]	Mutexc	[0.00 0.00]	[**0.419** **0.778**]
Construction										
Construction of Physical system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.400	[0.33 0.40]			
Construction of Medical system	Unknown		[0.000 1.000]	Assigned	0.500	0.200	[0.00 0.20]	Mutexc	[0.00 0.00]	[**0.332** **0.600**]
Construction of Management system	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.400	[0.24 0.32]	Mutexc	[0.00 0.00]	[**0.572** **0.920**]
Operation										
Operation of Physical system	Very Poor	0.500	[0.800 1.000]	Assigned	1.000	0.333	[0.27 0.33]			
Operation of Medical system	Moderate	0.500	[0.400 0.600]	Assigned	1.000	0.333	[0.13 0.20]	Mutexc	[0.00 0.00]	[**0.400** **0.533**]
Operation of Management system	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.600** **0.800**]

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THIRD LEVEL IN THE HIERARCHY

Hospital Project								
Design	[*0.419 0.778*]	Calculate	1.000	0.333	[0.14 0.26]			
Construction	[*0.572 0.920*]	Calculate	1.000	0.333	[0.19 0.31]	Mutexc	[0.00 0.00]	[**0.330 0.566**]
Operation	[*0.600 0.800*]	Calculate	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.530 0.833**]

Evidential support for the hospital project [0.530 0.833]

TOP LEVEL IN THE HIERARCHY

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Hospital earthquake disaster system								
Hospital project	[*0.530 0.833*]	Calculate	1.000	0.500	[0.27 0.42]			
Ground motion	[*0.586 0.725*]	Calculate	1.000	0.500	[0.29 0.36]	Maxdep	[1.00 1.00]	[**0.530 0.725**]

Evidential support for the whole system [0.530 0.725]

EVALUATION OF THE HOSPITAL EARTHQUAKE DISASTER SYSTEM (*L9)

Interval Probability Theory: Applications

HIERARCHICAL MODEL	ASSESSMENT					CALCULATION				
Holons	***Linguistic Support***	***Confid.***	**Suport Interval**	**Input Source**	***Import.***	**Import. Relative**	**Weighted Support**	**Type of Dependence**	**Dependence Support**	**Accumulated Value**
NINETH LEVEL IN THE HIERARCHY										
Deign of structural form										
Design of vertical configuration	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.500	[0.32 0.39]			
Design of horizontal configuration	Good	1.000	[0.275 0.325]	Assigned	1.000	0.500	[0.14 0.16]	Mutexc	[0.00 0.00]	[**0.453 0.548**]
EIGTH LEVEL IN THE HIERARCHY										
Selection of the structural system										
Design of structural form			[*0.453 0.548*]	Calculate	1.000	0.500	[0.23 0.27]			
Selection of materials	Good	1.000	[0.275 0.325]	Assigned	1.000	0.500	[0.14 0.16]	Mutexc	[0.00 0.00]	[**0.364 0.436**]
Modelling the structure										
Modelling loads	Moderate	0.300	[0.370 0.630]	Assigned	1.000	0.500	[0.19 0.32]			
Modelling structural system	Poor	0.300	[0.570 0.830]	Assigned	1.000	0.500	[0.29 0.42]	Mutexc	[0.00 0.00]	[**0.470 0.730**]
Detailed design of the structure										
Provide strength	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.333	[0.14 0.19]			
Provide stiffness	Poor	0.500	[0.600 0.800]	Assigned	1.000	0.333	[0.20 0.27]	Mutexc	[0.00 0.00]	[**0.343 0.457**]
Provide ductility	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.333	[0.21 0.26]	Mutexc	[0.00 0.00]	[**0.553 0.713**]

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SEVENTH LEVEL IN THE HIERARCHY

Design of the superstructure										
Selection of structural system			*[0.364 0.436]*	Calculate	1.000	0.333	[0.12 0.15]			
Modelling the structure			*[0.470 0.730]*	Calculate	1.000	0.333	[0.16 0.24]	Mutexc	[0.00 0.00]	**[0.278 0.389]**
Detailed design of the structure			*[0.553 0.713]*	Calculate	1.000	0.333	[0.18 0.24]	Mutexc	[0.00 0.00]	**[0.462 0.627]**

SIXTH LEVEL IN THE HIERARCHY

Design of Lifelines										
Design of Water supply system	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.167	[0.11 0.13]			
Design of Energy supply system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.167	[0.14 0.17]	Mutexc	[0.00 0.00]	**[0.243 0.295]**
Design of Gas supply system	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.167	[0.11 0.13]	Mutexc	[0.00 0.00]	**[0.348 0.423]**
Design of Sewage system	Poor	0.700	[0.630 0.770]	Assigned	1.000	0.167	[0.11 0.13]	Mutexc	[0.00 0.00]	**[0.453 0.552]**
Design of Communication system	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.167	[0.07 0.10]	Mutexc	[0.00 0.00]	**[0.525 0.647]**
Design of Access system	Very Poor	0.700	[0.830 1.000]	Assigned	1.000	0.167	[0.14 0.17]	Mutexc	[0.00 0.00]	**[0.663 0.813]**

Design of contents										
Design of Non-strutural systems	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.588	[0.25 0.34]			
Design of Medical equipment	Very Poor	0.700	[0.830 1.000]	Assigned	0.700	0.412	[0.34 0.41]	Indep	[0.34 0.41]	**[0.491 0.632]**

Design of structure										
Design of superstructure			*[0.462 0.627]*	Calculate	1.000	0.500	[0.23 0.31]			
Design of Foundation	Moderate	0.700	[0.430 0.570]	Assigned	1.000	0.500	[0.22 0.29]	Indep	[0.23 0.31]	**[0.379 0.532]**

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FIFTH LEVEL IN THE HIERARCHY

Physical system														
Design of lifelines			*0.663*	*0.813*	Calculate	1.000	0.435	0.29	0.35					
Design of structure			*0.379*	*0.532*	Calculate	1.000	0.435	0.16	0.23	Indep	0.29	0.35	**0.395**	**0.518**
Design of contents			*0.491*	*0.632*	Calculate	0.300	0.130	0.06	0.08	Mutexc	0.00	0.00	**0.459**	**0.601**

FOURTH LEVEL IN THE HIERARCHY

Design														
Design of Physical system			*0.459*	*0.601*	Calculate	1.000	0.400	0.18	0.24					
Design of Medical system	Unknown		0.000	1.000	Assigned	0.500	0.200	0.00	0.20	Mutexc	0.00	0.00	**0.184**	**0.440**
Design of Management system	Poor	0.300	0.570	0.830	Assigned	1.000	0.400	0.23	0.33	Mutexc	0.00	0.00	**0.412**	**0.772**
Construction														
Construction of Physical system	Very Poor	0.700	0.830	1.000	Assigned	1.000	0.400	0.33	0.40					
Construction of Medical system	Unknown		0.000	1.000	Assigned	0.500	0.200	0.00	0.20	Mutexc	0.00	0.00	**0.332**	**0.600**
Construction of Management system	Poor	0.500	0.600	0.800	Assigned	1.000	0.400	0.24	0.32	Mutexc	0.00	0.00	**0.572**	**0.920**
Operation														
Operation of Physical system	Very Poor	0.500	0.800	1.000	Assigned	1.000	0.333	0.27	0.33					
Operation of Medical system	Moderate	0.500	0.400	0.600	Assigned	1.000	0.333	0.13	0.20	Mutexc	0.00	0.00	**0.400**	**0.533**
Operation of Management system	Poor	0.500	0.600	0.800	Assigned	1.000	0.333	0.20	0.27	Mutexc	0.00	0.00	**0.600**	**0.800**

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FIRST LEVEL IN THE HIERARCHY

Hospital Project										
Design	*0.412*	*0.772*	Calculate	1.000	0.333	0.14	0.26			
Construction	*0.572*	*0.920*	Calculate	1.000	0.333	0.19	0.31	Mutexc	[0.00 0.00]	**[0.328 0.564]**
Operation	*0.600*	*0.800*	Calculate	1.000	0.333	0.20	0.27	Mutexc	[0.00 0.00]	**[0.528 0.831]**

Evidential support for the hospital project [0.528 0.831]

TOP LEVEL IN THE HIERARCHY

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Hospital earthquake disaster system										
Hospital project	*0.528*	*0.831*	Calculate	1.000	0.500	0.26	0.42			
Ground motion	*0.586*	*0.725*	Calculate	1.000	0.500	0.29	0.36	Maxdep	[1.00 1.00]	**[0.528 0.725]**

Evidential support for the whole system [0.528 0.725]

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