CHAPTER 2

Theoretical Background

This chapter provides an overview of the theoretical background. Introducing the earthquake risk assessment. Five topics will be discussed in this chapter: (a) Rapid Visual Screening of buildings for potential seismic hazards, (b) Spatial analysis and GIS application, (c) Fuzzy logic, (d) Multi-criteria decision making and (e) Artificial Neural Network, respectively.

2.1 Rapid Visual Screening of buildings for Potential Seismic Hazards

The rapid visual screening procedure (named RVS herein after) has been developed for identify, inventory, and rank buildings that are potentially seismically hazardous. The RVS is a simple procedure for quick evaluation and inexpensive to develop a list of potentially seismically hazardous buildings without the high cost of performing a detailed seismic analysis of every individual building. If a building receives a high score, the building is considered to have adequate seismic resistance to prevent collapse during a rare earthquake. Otherwise, if a building receives a low score on the basis of this RVS (Tier 1 evaluation) procedure, it should be evaluated in detailed evaluation (Tier 2 and 3 evaluations, which are given in FEMA 310, respectively) by a professional engineer experiences in seismic design.

The RVS method is usually based on sidewalk inspection from the exterior, and as well as if possible, the interior for each building using data collection forms depending on the seismicity of the region being surveyed. The form is provided for each of three seismic regions i.e. low, moderate and high seismicity region. The data collection form includes the space for documenting building identification information, the occupancy and size, a photograph of the building, sketches, and documentation of pertinent data related to seismic performance, including the development of a numeric seismic hazard score. Therefore, the RVS procedure will be completed for each building screened through execution of the following steps: (FEMA 154, 2002)

(1) Verifying and updating the building identification information;

(2) Walking around the building to identify its size and shape, and sketching a plan and elevation view on the Data Collection Form;

(3) Determining and documenting occupancy;

(4) Determining soil type, if not identified during the pre-planning process;

(5) Identifying potential nonstructural falling hazards, if any and indicating their existence on the Data Collection Form;

(6) Identifying the seismic lateral-load resisting system (entering the building, if possible, to facilitate this process) and circling the related Basic Structural Hazard Score on the Data Collection Form;

(7) Identifying and circling the appropriate seismic performance attribute Score Modifiers (e.g., number of stories, design date, and soil type) on the Data Collection Form;

(8) Determining the Final Score, S (by adjusting the Basic Structure Hazard Score with the Score Modifiers identified in Step 7), and deciding if a detailed evaluation is required; and

(9) Photographing the building and attaching the photo to the form (if an instant camera is used), or indicating a photo reference number on the form (if a digital camera is used).

The completed data with identifying parameters are used to determine the numerical score of the buildings. The RVS parameters are;

(a) Basic Structural Hazard (BSH) Score
   - Seismic Hazard Intensity

- Building Type

(b) Score Modifiers

- Building High
- Vertical Irregularity
- Plan Irregularity
- Pre-code
- Post Benchmark
- Soil Type

(c) Other Information

- Building address
- Screener information
- Photograph
- Occupancy
- Number of persons
- Falling Hazards

The Basic Structural Hazard Score and Score Modifiers are based on (1) design and construction practices in the region, (2) attributes known to decrease or increase seismic resistance capacity, and (3) maximum considered ground motions for the seismicity region under consideration. The final score (S) is the sum numbers of Basic Score and the Score Modifiers that reflect to the building safety index, with higher S scores corresponding to better seismic performance.

2.1.1 Basic Structural Hazard (BSH) Score

BSH score is based on damage and loss estimates for different building types on each data collection form. It reflects the estimated likelihood that building collapse will occur if the building is subjected to the maximum considered earthquake ground motions in the region. More precisely, the BSH score is defined as the negative of the logarithm of probability with base 10 that the building will collapse at the level of the ground shaking corresponding to the maximum considered earthquake (FEMA 155, Equation 6-1)

$$BSH = -\log_{10}(P_{collapse}\, given the\, MCE) \qquad (2.1)$$

where

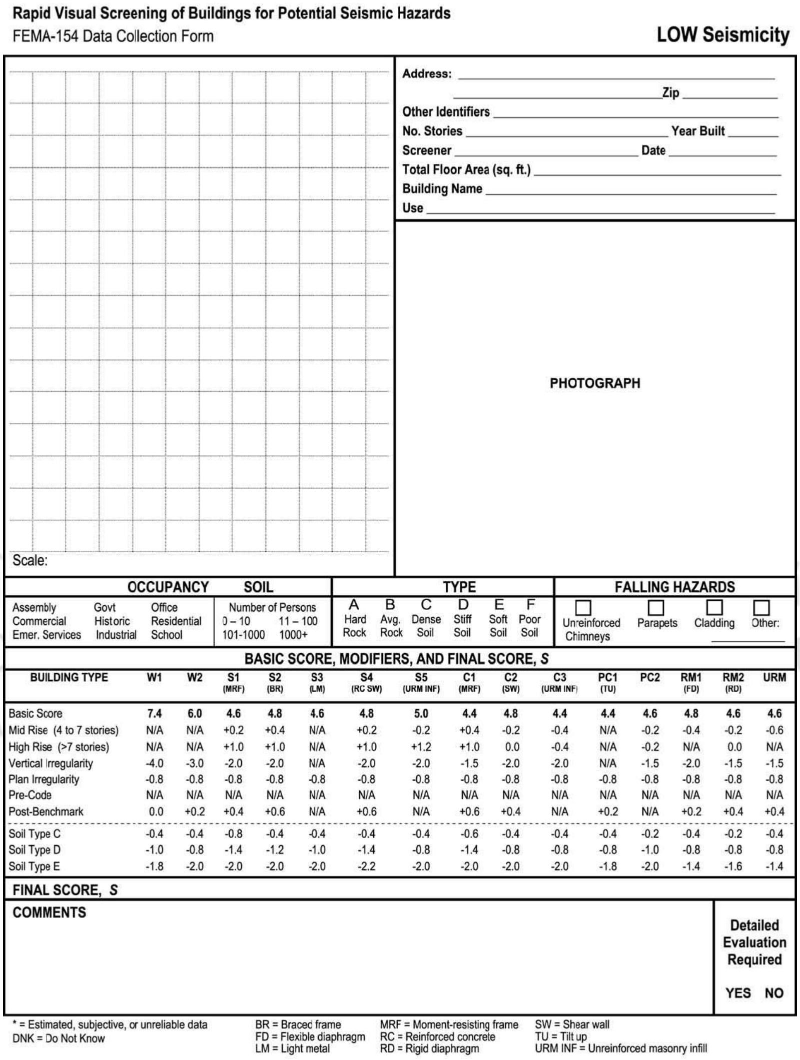
BSH	:	Basic structural hazard scores
$P_{collapse}$ *given the MCE*	:	The probability that the building will collapseat the level of ground shaking

corresponding to the maximum considered earthquake (MCE)

The definition of the MCE as two thirds of the 2% in 50 year ground motion conforms to the usage in the RVS calculations (FEMA, 2002b, Section 6.2)

- Seismic Hazard Intensity

It is related to the intensity of the earthquake hazard level for each country to correlate with one of the following three intensities as shown in Table 2.1 (1) High hazard intensity or (2) Moderate hazard intensity or (3) Low hazard intensity. Figures 2.1 – 2.3 have shown the data collection forms with different earthquake hazard levels.


Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA-154 Data Collection Form

LOW Seismicity

Address: ____________________
Zip ______
Other Identifiers ______
No. Stories ______ Year Built ______
Screener ______ Date ______
Total Floor Area (sq. ft.) ______
Building Name ______
Use ______

PHOTOGRAPH

Scale:

OCCUPANCY			SOIL							TYPE	FALLING HAZARDS
Assembly Commercial Emer. Services	Govt Historic Industrial	Office Residential School	Number of Persons 0 – 10 11 – 100 101-1000 1000+	A Hard Rock	B Avg. Rock	C Dense Soil	D Stiff Soil	E Soft Soil	F Poor Soil		Unreinforced Chimneys / Parapets / Cladding / Other:

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	7.4	6.0	4.6	4.8	4.6	4.8	5.0	4.4	4.8	4.4	4.4	4.6	4.8	4.6	4.6
Mid Rise (4 to 7 stories)	N/A	N/A	+0.2	+0.4	N/A	+0.2	-0.2	+0.4	-0.2	-0.4	N/A	-0.2	-0.4	-0.2	-0.6
High Rise (>7 stories)	N/A	N/A	+1.0	+1.0	N/A	+1.0	+1.2	+1.0	0.0	-0.4	N/A	-0.2	N/A	0.0	N/A
Vertical Irregularity	-4.0	-3.0	-2.0	-2.0	N/A	-2.0	-2.0	-1.5	-2.0	-2.0	N/A	-1.5	-2.0	-1.5	-1.5
Plan Irregularity	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Pre-Code	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Post-Benchmark	0.0	+0.2	+0.4	+0.6	N/A	+0.6	N/A	+0.6	+0.4	N/A	+0.2	N/A	+0.2	+0.4	+0.4
Soil Type C	-0.4	-0.4	-0.8	-0.4	-0.4	-0.4	-0.4	-0.6	-0.4	-0.4	-0.4	-0.2	-0.4	-0.2	-0.4
Soil Type D	-1.0	-0.8	-1.4	-1.2	-1.0	-1.4	-0.8	-1.4	-0.8	-0.8	-0.8	-1.0	-0.8	-0.8	-0.8
Soil Type E	-1.8	-2.0	-2.0	-2.0	-2.0	-2.2	-2.0	-2.0	-2.0	-2.0	-1.8	-2.0	-1.4	-1.6	-1.4

FINAL SCORE, *S*

COMMENTS

Detailed Evaluation Required
YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know
BR = Braced frame
FD = Flexible diaphragm
LM = Light metal
MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm
SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Figure 2.1 Data Collection Form for Low Seismicity (FEMA 154, 2002)

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA-154 Data Collection Form

MODERATE Seismicity

Scale:

Address: ____________________
____________________ **Zip** ________
Other Identifiers ____________________
No. Stories ____________ **Year Built** ________
Screener ____________ **Date** ________
Total Floor Area (sq. ft.) ____________________
Building Name ____________________
Use ____________________

PHOTOGRAPH

OCCUPANCY			SOIL		TYPE						FALLING HAZARDS			
Assembly	Govt	Office	Number of Persons		A Hard Rock	B Avg. Rock	C Dense Soil	D Stiff Soil	E Soft Soil	F Poor Soil	☐ Unreinforced Chimneys	☐ Parapets	☐ Cladding	☐ Other: ______
Commercial	Historic	Residential	0 – 10	11 – 100										
Emer. Services	Industrial	School	101-1000	1000+										

BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S*

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	**5.2**	**4.8**	**3.6**	**3.6**	**3.8**	**3.6**	**3.6**	**3.0**	**3.6**	**3.2**	**3.2**	**3.2**	**3.6**	**3.4**	**3.4**
Mid Rise (4 to 7 stories)	N/A	N/A	+0.4	+0.4	N/A	+0.4	+0.4	+0.2	+0.4	+0.2	N/A	+0.4	+0.4	+0.4	-0.4
High Rise (>7 stories)	N/A	N/A	+1.4	+1.4	N/A	+1.4	+0.8	+0.5	+0.8	+0.4	N/A	+0.6	N/A	+0.6	N/A
Vertical Irregularity	-3.5	-3.0	-2.0	-2.0	N/A	-2.0	-2.0	-2.0	-2.0	-2.0	N/A	-1.5	-2.0	-1.5	-1.5
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-0.2	-0.4	-0.4	-0.4	-0.4	-0.2	-1.0	-0.4	-1.0	-0.2	-0.4	-0.4	-0.4	-0.4
Post-Benchmark	+1.6	+1.6	+1.4	+1.4	N/A	+1.2	N/A	+1.2	+1.6	N/A	+1.8	N/A	2.0	+1.8	N/A
Soil Type C	-0.2	-0.8	-0.6	-0.8	-0.6	-0.8	-0.8	-0.6	-0.8	-0.6	-0.6	-0.6	-0.8	-0.6	-0.4
Soil Type D	-0.6	-1.2	-1.0	-1.2	-1.0	-1.2	-1.2	-1.0	-1.2	-1.0	-1.0	-1.2	-1.2	-1.2	-0.8
Soil Type E	-1.2	-1.8	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6

FINAL SCORE *S*

COMMENTS

Detailed Evaluation Required

YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know
BR = Braced frame
FD = Flexible diaphragm
LM = Light metal
MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm
SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Figure 2.2 Data Collection Form for Moderate Seismicity (FEMA 154, 2002)

Rapid Visual Screening of Buildings for Potential Seismic Hazards

FEMA-154 Data Collection Form **HIGH Seismicity**

Address: ______________________________

______________________ **Zip** __________

Other Identifiers ______________________

No. Stories ______________ **Year Built** ________

Screener ______________ **Date** ________

Total Floor Area (sq. ft.) ______________

Building Name ______________________

Use ______________________

Scale:

PHOTOGRAPH

OCCUPANCY			SOIL						TYPE	FALLING HAZARDS			
Assembly Commercial Emer. Services	Govt Historic Industrial	Office Residential School	Number of Persons 0 – 10 11 – 100 101-1000 1000+	A Hard Rock	B Avg. Rock	C Dense Soil	D Stiff Soil	E Soft Soil	F Poor Soil	☐ Unreinforced Chimneys	☐ Parapets	☐ Cladding	☐ Other: ______

BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S*

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	**4.4**	**3.8**	**2.8**	**3.0**	**3.2**	**2.8**	**2.0**	**2.5**	**2.8**	**1.6**	**2.6**	**2.4**	**2.8**	**2.8**	**1.8**
Mid Rise (4 to 7 stories)	N/A	N/A	+0.2	+0.4	N/A	+0.4	+0.4	+0.4	+0.4	+0.2	N/A	+0.2	+0.4	+0.4	0.0
High Rise (> 7 stories)	N/A	N/A	+0.6	+0.8	N/A	+0.8	+0.8	+0.6	+0.8	+0.3	N/A	+0.4	N/A	+0.6	N/A
Vertical Irregularity	-2.5	-2.0	-1.0	-1.5	N/A	-1.0	-1.0	-1.5	-1.0	-1.0	N/A	-1.0	-1.0	-1.0	-1.0
Plan irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-1.0	-1.0	-0.8	-0.6	-0.8	-0.2	-1.2	-1.0	-0.2	-0.8	-0.8	-1.0	-0.8	-0.2
Post-Benchmark	+2.4	+2.4	+1.4	+1.4	N/A	+1.6	N/A	+1.4	+2.4	N/A	+2.4	N/A	+2.8	+2.6	N/A
Soil Type C	0.0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0.0	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6	-0.6
Soil Type E	0.0	-0.8	-1.2	-1.2	-1.0	-1.2	-0.8	-1.2	-0.8	-0.8	-0.4	-1.2	-0.4	-0.6	-0.8
FINAL SCORE, *S*															

COMMENTS

Detailed Evaluation Required

YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know

BR = Braced frame
FD = Flexible diaphragm
LM = Light metal

MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm

SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Figure 2.3 Data Collection Form for High Seismicity (FEMA 154, 2002)

According to FEMA 154 (2002), the level of hazard intensity will be determined in hazard map of the country, find the design Spectral Accelerations (SA) for the time period of 0.2 second and 0.1 second, then multiply the value by a factor of 2/3 and check the calculated values as shown in Table 2.1

Table 2.1 Hazard Intensity based on Spectral Acceleration (FEMA 154, 2002)

Level of seismic Hazard Intensity	Spectral Acceleration Response (horizontal direction)	
	Calculated 2/3 SA for Period of 0.2 second	Calculated 2/3 SA for Period of 1.0 second
Low	Less than 0.167 g	Less than 0.067 g
Moderate	0.167 g - 0.500 g	0.067 g - 0.200g
High	Greater than or equal to 0.5 g	Greater than or equal to 0.2 g

2.1.2 Building Type

The seismic vulnerability of the different building types depends on the buildings materials and structural system. There are 11 types that are most commonly found in Chiang Rai Municipality as shown in Table 2.2.

Table 2.2 Building Types commonly found in Chiang Rai Municipality

No	Type	Description
1	C1	Concrete moment resisting frame buildings
2	C2	Concrete shear Wall buildings
3	C3	Concrete frame with unreinforced masonry infill buildings
4	S1	Steel moment – resisting frame buildings
5	S2	Steel braced frame buildings
6	S3	Light metal frame buildings
7	W1	Light wood frame building, area ≤ 464.5 sq.m.
8	W2	Wood frame building, area > 464.5 sq.m.
9	W1C3	Concrete frame with unreinforced masonry infill buildings and Light wood frame building, area ≤ 464.5 sq.m.
10	W2C3	Concrete frame with unreinforced masonry infill buildings and Light wood frame building, area > 464.5 sq.m.
11	URM	Unreinforced masonry bearing-wall buildings

The basic structural scores are provided on each data collection from in the first row of the structural scoring matrix in the lower portion of the data collection form (see Figures 2.4).

Basic Structural Scores

BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S*															
BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	5.2	4.8	3.6	3.6	3.8	3.6	3.6	3.0	3.6	3.2	3.2	3.2	3.6	3.4	3.4
Mid Rise (4 to 7 stories)	N/A	N/A	+0.4	+0.4	N/A	+0.4	+0.4	+0.2	+0.4	+0.2	N/A	+0.4	+0.4	+0.4	-0.4
High Rise (>7 stories)	N/A	N/A	+1.4	+1.4	N/A	+1.4	+0.8	+0.5	+0.8	+0.4	N/A	+0.6	N/A	+0.6	N/A
Vertical Irregularity	-3.5	-3.0	-2.0	-2.0	N/A	-2.0	-2.0	-2.0	-2.0	-2.0	N/A	-1.5	-2.0	-1.5	-1.5
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-0.2	-0.4	-0.4	-0.4	-0.4	-0.2	-1.0	-0.4	-1.0	-0.2	-0.4	-0.4	-0.4	-0.4
Post-Benchmark	+1.6	+1.6	+1.4	+1.4	N/A	+1.2	N/A	+1.2	+1.6	N/A	+1.8	N/A	2.0	+1.8	N/A
Soil Type C	-0.2	-0.8	-0.6	-0.8	-0.6	-0.8	-0.8	-0.6	-0.8	-0.6	-0.6	-0.6	-0.8	-0.6	-0.4
Soil Type D	-0.6	-1.2	-1.0	-1.2	-1.0	-1.2	-1.2	-1.0	-1.2	-1.0	-1.0	-1.2	-1.2	-1.2	-0.8
Soil Type E	-1.2	-1.8	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6
FINAL SCORE *S*															

Figure 2.4 Basic structural scores (FEMA 154, 2002)

2.1.3 Score Modifiers (SMs)

Score Modifiers have been developed to modify the BHS score, based on characteristics of the building as follows:

Building Height: The height of a structure is related to the vulnerability of the building. Low rise buildings are less vulnerable than high rise building as the tall building may behave strong and longer shake duration. The height of a storey is approximately in the range 3 – 4 m. Two ranges are considered e.g. mid-rise (4 – 7 storeys) and high rise (> 7 storeys).

Vertical Irregularity of the building: The building vertical irregularity includes setbacks, hillside buildings, and buildings with soft stories as displayed in Figure 2.5 (FEMA 154, 2002). The earthquake forces developed at different floor levels in a building along the height to the ground level any deviation or discontinuity in this load transfer path results in poor performance of the building.

For example, building vertical irregularity, building which on slope ground have unequal height columns along the slope, which causes ill effects like twisting and damage in shorter columns.

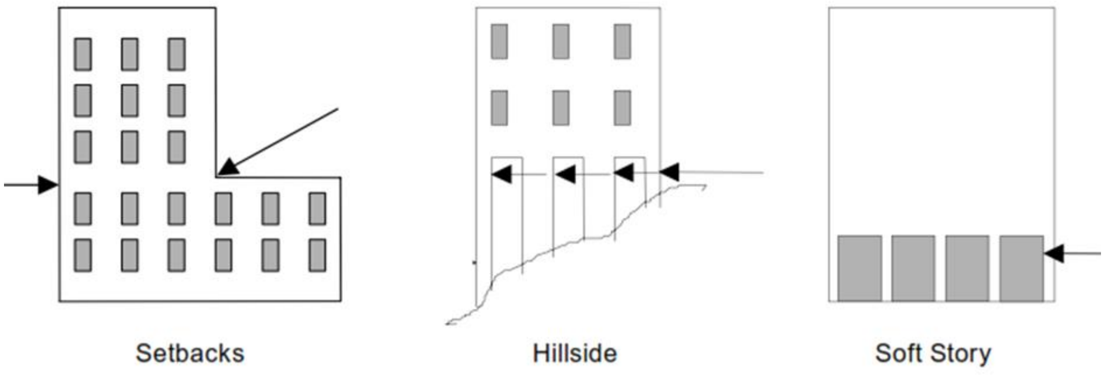


Figure 2.5 Elevation views showing vertical irregularities, with arrows indicating locations of particular concern (FEMA 154, 2002)

Plan Irregularity of the building: Buildings with simple geometry in plan have performed well during earthquakes. Plan Irregularity is a building with re-entrant corners including those with long wings that are E, L, T, U or + shaped as displayed in Figure 2.6. Buildings with major stiffness eccentricities in the lateral-force-resisting system may cause twisting (torsion) around a vertical axis lowering the performance of a building under earthquake. Thus, the score modifier has a negative value.

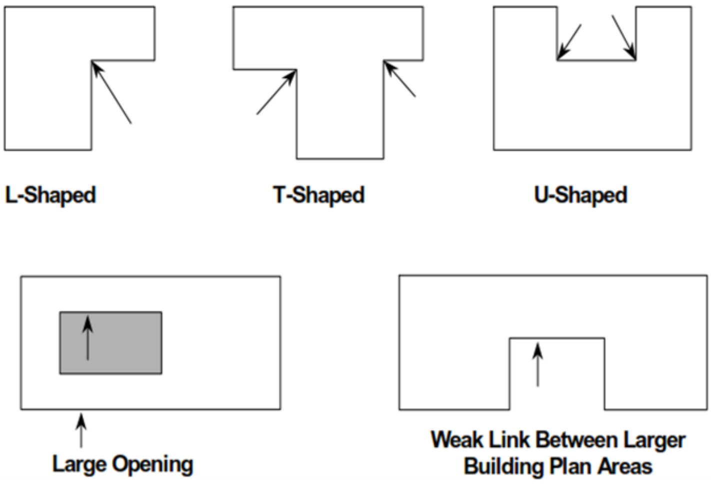


Figure 2.6 Plan views of various building configurations showing plan irregularities; arrows indicate possible areas of damage (FEMA 154, 2002)

Code Detailing: Two situations are considered (1) Pre Code and (2) Post Benchmark, respectively. Pre Code, the design and construction of the building was done before the seismic building code was adopted. In Thailand the earthquake code was published in 1997, then all buildings constructed before 1997 are considered without earthquake resistant design. This score modifier indicates the decrease of seismic safety and will have negative score modifier. Post Benchmark, the design and construction of the building was done after significantly improved seismic applicable for that building type were adopted and enforced by the local jurisdiction.

Soil Type: Soil type has a major influence on amplitude and duration of shaking, and thus structural damage. Six soil types are considered in the RVS procedure of FEMA 154 (2002) as follows:

(1) Type A (hard rock): measured shear wave velocity, Vs > 1524 m/sec.
(2) Type B (rock): Vs between 762 - 1524 m/sec.
(3) Type C (soft rock and very dense soil): Vs between 366 - 762 m/sec., or standard blow count N>50.
(4) Type D (stiff soil): Vs between 183 – 366 m/sec, or standard blow count N between 15 – 50.
(5) Type E (soft soil): More than 30 m. of soft soil with plasticity index PI > 20, water content w > 40%, or a soil with Vs ≤ 183 m/sec.
(6) Type F (poor soil): Soils requiring site-specific evaluation, very compassable in nature.

2.1.4 Other Information

They include building address, screener information, photograph, falling hazards (i.e. unreinforced chimneys, parapets, cladding and others), the number of persons (the occupancy load is defined in ranges such as 1-10, 11-100, 101-1000, and 1000+ occupants), and occupancy. The occupancy types are explained as below;

Assembly: Places of public assembly are those where 300 or more people might be gathered in one room at the same time. Examples are theaters, auditoriums, community centers, performance halls, and churches. (Occupancy load varies greatly and can be as much as 1 person per 0.93 sq.m of floor area, depending primarily on the condition of the seating fixed versus moveable).

Commercial: The commercial occupancy class refers to retail and wholesale businesses, financial institutions, restaurants, parking structures ad light warehouses. (Occupancy load varies; use 1 person per 4.65 - 18.58 sq.m).

Emergency Services: The emergency services class is defined as any facility that would likely be needed in a major catastrophe. These include police and fire stations, hospitals and communications centers. (occupancy load is typically 1 person per 9.29 sq. m.).

Government: This class includes local, municipality and district non-emergency related buildings (occupancy load varies; use 1 person per 9.29 - 18.58 sq. m.)

Historic: This class varies from community to community. It is included because historic building may be subjected to specific ordinances and codes.

Industrial: Industrial occupancy class included factories, assembly plants, large warehouse and heavy manufacturing facilities. (Typically, use 1 person per 18.58 sq. ft. except warehouses, which are perhaps 1 person per 46.45 sq.m.).

Office: Typical office buildings that house clerical and management functions (use 1 person per 9.29 - 18.58 sq.m.).

Residential: This occupancy class refers to residential buildings such as houses, townhouses, dormitories, motels, hotels, apartments and condominiums, and residences for the aged or disabled. (The number of person for residential occupancies varies from about 1 person per 27.87 sq.m. of floor area in dwellings, to perhaps 1 person per 18.58 sq.m. in hotels and apartments, to 1 per 9.29 sq.m. in dormitories).

School: This occupancy class includes all public and private educational facilities from nursery school to university level (occupancy load varies; use 1 person per 4.65 to 9.29 sq.m.).

2.1.5 Interpretation of RVS Score, Analysis and uses

The structural damage has been categorized in different grades depending on their impact on the seismic strength of the building. Table 2.3 shown building damage classifications based on the European Macroseismic Scale (EMS-98) defines building damage to be in Grade 1 till 5. With damage potential can be estimated base on the RVS score and is given in Table 2.4, respectively.

Table 2.3 Buildings damage classification (EMS – 98)

Classification of damage to the masonry buildings	**Classification of the damage to reinforced concrete buildings**
Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage) Hair line cracks in very few walls. Fall of small pieces of plaster only.	Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage) Fine cracks in plaster over frame members or in walls at the base Fine cracks in partitions and infills.
Grade 2: Moderate damage (Slight structural damage, moderate non-structural damage) Crack in many walls. Fall of fairly large pieces of plaster. Partial collapse of the chimneys and mumptys.	Grade 2: Moderate damage (Slight structural damage, moderate non-structural damage) Cracks in columns and beams of frames and in structural walls. Crack in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of the wall panels
Grade 3: Substantial to heavy damage (Moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual noon-structural elements (partition, gable walls etc.)	Grade 3: Substantial to heavy damage (Moderate structural damage, heavy non-structural damage) Cracks in columns and beam-column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, bucking of reinforced bars. Large cracks in partition and infill walls, failure of individual infill panels.

Table 2.3 Buildings damage classification (EMS – 98), (continued)

Classification of damage to the masonry buildings	**Classification of the damage to reinforced concrete buildings**
Grade 4: Very heavy damage (Heavy structural damage, very heavy non-structural damage) Serious failure of walls (gaps in walls); partial structural failure of roofs and floors.	Grade 4: Very heavy damage (Heavy structural damage, very heavy non-structural damage) Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforcing bars; tilting of columns. Collapse of a few columns or of a single upper floor.
Grade 5: Destruction (Very heavy structural damage) Total or near tota collapse of the building.	Grade 5: Destruction (very heavy structure damage) Collapse of ground floor parts (e.g. wings) of the building.

Table 2.4 Structural score with damage potential

RVS Final Score (S)	Damage Potential
S<0.3	High probability of Grade 5 damage; Very high probability of Grade 4 Damage
0.3<S<0.7	High probability of Grade 4 damage; Very high probability of Grade 3 Damage
0.7<S<2.0	High probability of Grade 3 damage; Very high probability of Grade 2 Damage
2.0<S<2.5	High probability of Grade 2 damage; Very high probability of Grade 1 Damage
S>2.5	Probability of Grade 1 damage

The final S score is an estimate of the probability (or chance) that the building will collapse if ground motions occur that equal or exceed the maximum considered earthquake (MCE) ground motions. The calculations are shown below (FEMA 155, equation 6-2):

$$S = BSH \pm SMs \tag{2.2}$$

Where

S : Final structural score

BSH : Basic structural hazard scores

SMs : Score modifiers

Similarly from equation (2.1),

$$S = -\log_{10}(P_{collapse}\ given\ the\ MCE) \quad (2.3)$$

Or, equivalently,

$$(P_{collapse}\ given\ the\ MCE) = 10^{-S} \quad (2.4)$$

For example, a final score of S = 2 means that the calculated probability of building collapse at maximum considered earthquake is (10^{-2}). It implies that there is a chance of 1 in 100 (a 1% chance of collapse), that the building will collapse if such ground motions occur. For example, calculated probabilities of collapse at the MCE corresponding to final scores between 4.0 and 0.0 are shown in Table 2.5 (Wang and Goettel, 2007).

Table 2.5 Calculated probability of collapse versus final score, *S* (Wang and Goettel, 2007)

Final Score, S	Probability of Collapse
4.0	0.01%
3.5	0.03%
3.0	0.10%
2.5	0.32%
2.0	1.00%
1.5	3.16%
1.0	10%
0.5	32%
0.0	100%

FEMA 154 (2002) suggests the final score of 2 as a cut-off giving slight to moderate damages which may be acceptance for building safety. The final score less than 2 gives heavy structural damage. In addition, the final score less than 0.7 indicates high vulnerability requiring detailed evaluation and refitting of the building.

2.2 Fuzzy Logic

Zadeh (1965, 1973) proposed the fuzzy logic theory. The fuzzy logic provides a language with sematics to translate qualitative knowledge into numerical reasons. The fuzzy mode is able to incorporate both descriptive knowledge and numerical data.

The fuzzy logic was developed base on the major demand for conceptual framework, to solve uncertainty and lexical imprecious. Fuzzy logic's key characteristic are relating to the following:

- Exact reasoning is treated as a limiting case of approximate reasoning.
- Everything is a matter of degree.
- Knowledge is interpreted as a collection of elastic or, equivalently fuzzy constraint on a collection of variables.
- Inference is treated as a process of propagation of elastic constraints.
- Any logical system is able to transfer fuzzy system (fuzzified).

For better performance on specific applications, two main characteristic of fuzzy systems could be apply.

- An uncertain or approximate reasoning, especially the system with difficult mathematical model could be suitably solved by using fuzzy system
- Fuzzy logic allows decision making with estimated values under incomplete or uncertain information.

Zadeh (1965) presented that fuzzy set is a class of objectives with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging between zero and one. By contrast, in Boolean logic, the numbers of variables may only be 0 and 1, often called "crisp" values. Thus a fuzzy set describes the relationship between an uncertain quantity x in set $\tilde{A}$ and membership function μ_x, which ranges between 0 and 1 as shown in equation (2.5).

$$\mu_{\tilde{A}}(x) = \begin{cases} 1, & x \in \tilde{A} \\ 0, & x \notin \tilde{A} \end{cases} \tag{2.5}$$

where $\in$ and $\notin$ denote contained in and not contained in, respectively.

The membership function is a critically important input for the fuzzy logic system. It requires translating the qualitative description into a quantitative measure. Several geometric mapping functions have been widely adopted, such as triangular, trapezoidal and S-shaped membership functions as shown in Figure 2.7 and 2.8, and Equations (2.6) and (2.7) as follow (Meesad, 2012):

(1) Triangular membership function

$$Triangular\,(x : a,b,c) = \begin{cases} 0 & x < a \\ (x-a)/(b-a) & a \le x < b \\ (c-x)/(c-b) & b \le x < c \\ 0 & x > c \end{cases} \tag{2.6}$$

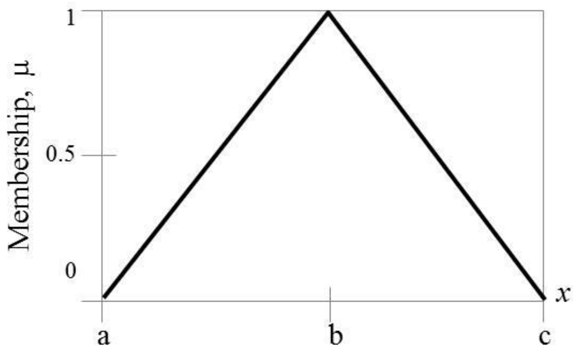


Figure 2.7 Example for triangular membership function

(2) Trapezoidal membership function

$$Trapezoidal\,(x:a,b,c,d)=\begin{cases}0 & x<a\\(x-a)/(b-a) & a\le x<b\\1 & b\le x<c\\(d-x)/(d-c) & c\le x<d\\0 & x\ge d\end{cases} \tag{2.7}$$

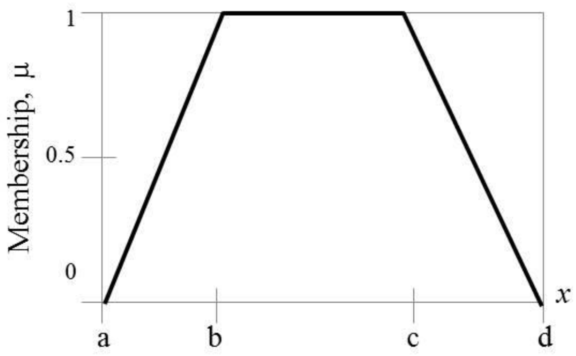


Figure 2.8 Example for trapezoidal membership function

The fuzzy inference system (FIS) contains three basic features (Tesfamariam and Saatcioglu, 2008). First, linguistic variables were transformed into numerical variables with assumed scale and then relationships between the variables using IF-THEN rules were made. Finally, inference mechanism using approximate reasoning algorithms were adopted to formulate relationships. The fuzzified measurements were then used by the inference engine to select the control rules stored in the fuzzy rule. The general scheme of fuzzy logic based decision making system is shown in Figure 2.9.

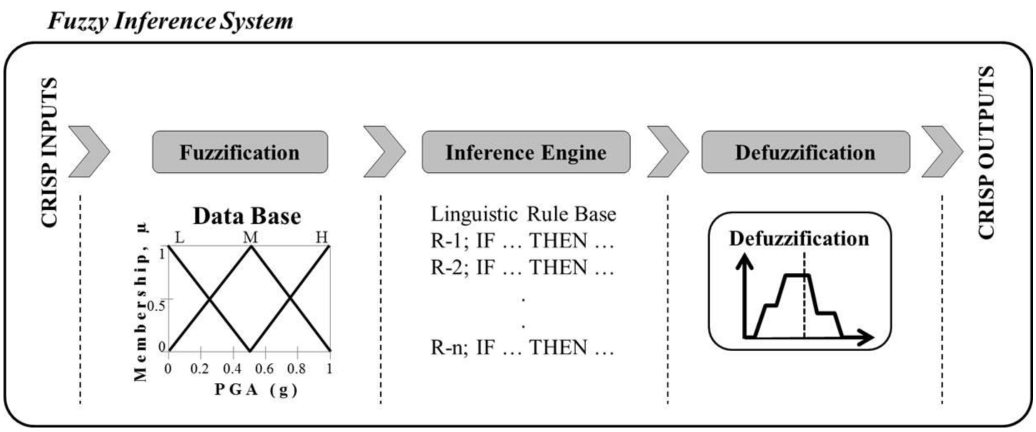


Figure 2.9 A general scheme of a fuzzy logic decision system

The fuzzified variables were then combined that consists of three connectives: the aggregation of antecedents in each rule “AND” connectives is interpreted as the fuzzy intersection, implication (i.e., IF-THEN connectives), and aggregation of the rules (ELSE connectives).

The final process is defuzzification. It is the process of producing a quantifiable result in fuzzy logic. Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value. Then the crisp results were defuzzified using weighted average method. It is given by the algebraic expression as equation 2.8. The weighted average method is formed by weighting each membership function in the output considering its respective maximum membership value (Ross, 2004).

$$Z^* = \frac{\sum_{i=1}^{N} \mu_{\tilde{C}}(Z_i) \cdot Z_i}{\sum_{i=1}^{N} \mu_{\tilde{C}}(Z_i)} \qquad (2.8)$$

where Σ denotes the algebraic sum and z_i is the centroid of each symmetric membership function, $\mu_{\tilde{C}}(Z_i)$ is the output fuzzy value in fuzzy set *i*, and Z^* is the defuzzified value.

2.3 Multi-Criteria Decision Making (MCDM)

Multi-Criteria Decision Analysis (MCDA) and Multi-Criteria Decision Making are discussed synonymously. MCDM considers a set of alternatives, which are evaluated on the basic of conflicting criteria, whereas criteria involve objectives and attributes. In general, multi-criteria decision making (MCDM) problems involve the following six components: (Malczewski, 1999)

(1) A goal or a set of goals the decision marker (interested group)

(2) The decision marker or group of decision makes involved in the decision-making process along with their preferences with respect to evaluation criteria

(3) A set of evaluation criteria (objectives and/or attributes) on the basis of which the decision markers evaluate alternative courses of action

(4) The set of decision alternatives, that is, the decision or action variables

(5) The set of uncontrollable variables or states of nature (decision environment)

(6) The set of outcomes or consequences associated which each alternative-attribute pair.

The relationships between the elements of MCDM are shown in Figure 2.10. The central element of this structure is a decision matrix consisting of a set of columns and rows. The matrix represents the decision outcomes for a set of alternatives and a set of evaluation criteria.

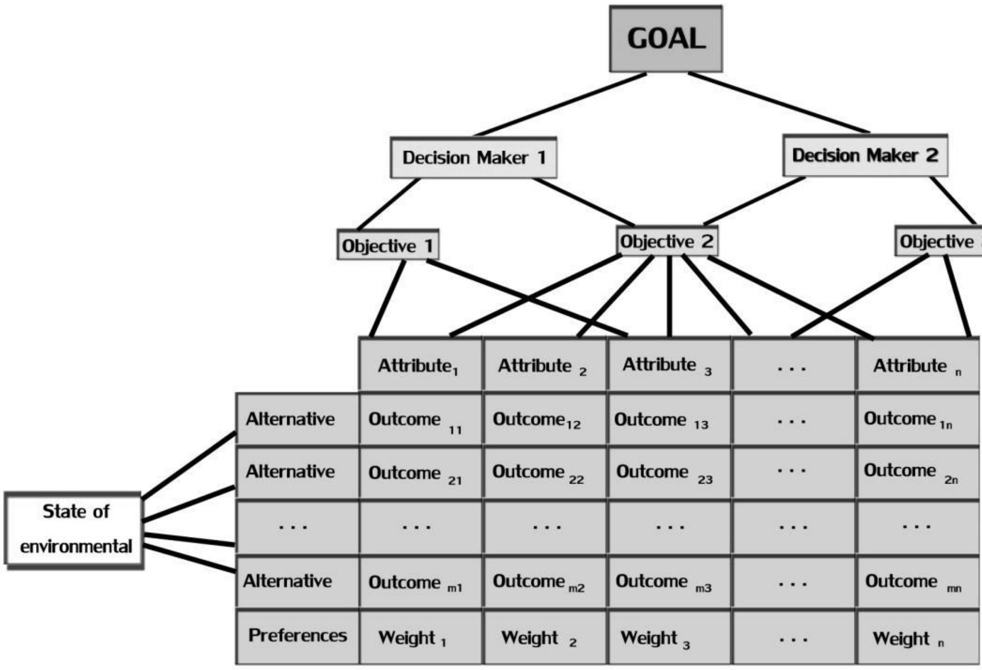


Figure 2.10 Framework for multi-criteria decision analysis (Malczewski, 1999)

Figure 2.10 represents the framework for Multi-Criteria Decision Analysis. First, the structure of the columns consists of levels representing the decision makers, their preferences, and evaluation criteria. These elements are organized in a hierarchical structure. The most general level is goal. At this level a desired end state resulting from decision-making activity is specified. Second, the row of the decision matrix represents decision alternatives. All decisions are made in some kind of environmental context and therefore involve many factors beyond the control if the decision maker. Third, the decision outcome, is depend on the set of attributes for evaluating alternative. Consequently, an entry in the intersection of each row and column of the decision outcome associated with a particular alternative and attribute. The matrix cells contain a single entry if a single state of nature is considered, and they contain a number of outcomes if the decision situation required consideration of more than one state of nature. Thus the decision outcomes in each row of the matrix are represented as the attribute levels, which measure the degree of achievement or performance of a decision alternative. The decision problem requires that the set of outcomes are ordered so that the best alternative can be identified.

2.3.1 Pairwise Comparison Method (AHP)

The pairwise comparison method was developed by Saaty (1980) in the context of the Analytic Hierarchy Process (AHP). This method involves pairwise comparisons to create a ratio matrix. It takes as an input the pairwise comparisons and produces the relative weights as output. These comparisons may be taken from actual measurements or a from a fundamental scale which reflects the relative strength of preferences and feelings. The AHP has a special concern with departure from consistency, its measurement and on dependence within and between the groups of elements of its structure. It has found its widest applications in multi-criteria decision making (MCDM), planning and resource allocation and in conflict resolution. In its general from the AHP is a nonlinear framework for carrying out both deductive and inductive thinking without use of the syllogism by taking several factors into consideration simultaneously and allowing for dependence and for feedback, and making numerical tradeoffs to arrive at a synthesis or conclusion (Saaty, 1987).

The analytic hierarchy process proposed by Saaty (2008) as following steps:

(1) Define the problem and determine the kind of knowledge sought.

(2) Structure of decision hierarchy from the top with the goal of the decision, then the objectives from a board perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

(3) Construction a set of pairwise matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

(4) Use the priorities obtained from the comparisons to weight the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighted values and obtain it overall or global priority. Continue this process of weighting and adding until the final priorities of the alternatives in the bottom most level are obtained.

To make comparisons, need a scale of numbers that indicates how many times more important or dominate one element is over another element with respect to the criterion or property with respect to which they are compared. Table 2.6 exhibits the scale.

Table 2.6 The fundamental scale of absolute numbers

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; it dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	It activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1-1.9	If the activity are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

The last steps, was estimation of the consistency ratio. In this step we determine if our comparisons are consistent. It involves the following operations: (a) determine the weighted sum vector by multiplying the weight for the first criterion and (b) determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously.

Now that have calculated the consistency vector, need to compute values for two more terms, lambda λ and the consistency index (*CI*). The value for lambda is simply the average value of the consistency vector. The calculation of *CI* is always greater than or equal to the number of criteria under consideration (*n*) for positive, reciprocal matrixes, and $\lambda=n$ if the pairwise comparison matrix is a consistent matrix. Accordingly, λ -*n* can be considered as a measure of the degree of inconsistency. This measure can be normalized as equation 2.9

$$CI = \frac{\lambda - n}{n-1} \tag{2.9}$$

The *CI* term, referred to as the consistency index, provides a measure of departure from consistency. Further, we can calculate the consistency ratio (*CR*), which is defined as equation 2.10.

$$CR = \frac{CI}{RI} \tag{2.10}$$

RI is the random index, the consistency index of a randomly generated pairwise comparison matrix. It can be shown that RI depends on the number of elements being compared (see Table 2.7). The consistency ratio (*CR*)

Table 2.7 Random Inconsistency Indices (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

From the previous Table 2.7 value approach proposed by Saaty (1980) is used to give overall consistency to the subjective choice. Starting from linguistic judgments expressed by the decision maker (DM), this approach allows the definition of the relative importance on the final decision of each criterion as well as obtaining the quantitative evaluations of criteria in respect of qualitative alternative. Furthermore, a consistency measure of the DM’s judgments ensures that no intolerable conflicts existing among them and that the final decision is logically sound and not a result of random prioritization. As it will be clear in the following, criteria weight may be determinant for the final selection as they amplify or de-amplify the evaluation of the solution in respect of each criterion by means of its relative importance. Therefore, a sensitivity analysis on the final result may give a quantitative measure of the actual sensitivity of the results of application of the MCDM method to the criteria weight.

2.4 Artificial Neural Networks (ANN)

Joghataie (1994) suggested that the artificial neural networks are manmade systems that can perform intelligent activities, similar to those of the human's brain (see Figure 2.11). They can learn and acquire the knowledge about a phenomenon and can also be trained to respond to that phenomenon appropriately. This characteristic of the artificial neural networks puts them in a place between the conventional computational devices and human brain. That is why recently the scientist in many fields has been utilized in solving problems in different fields of research and engineering problems.

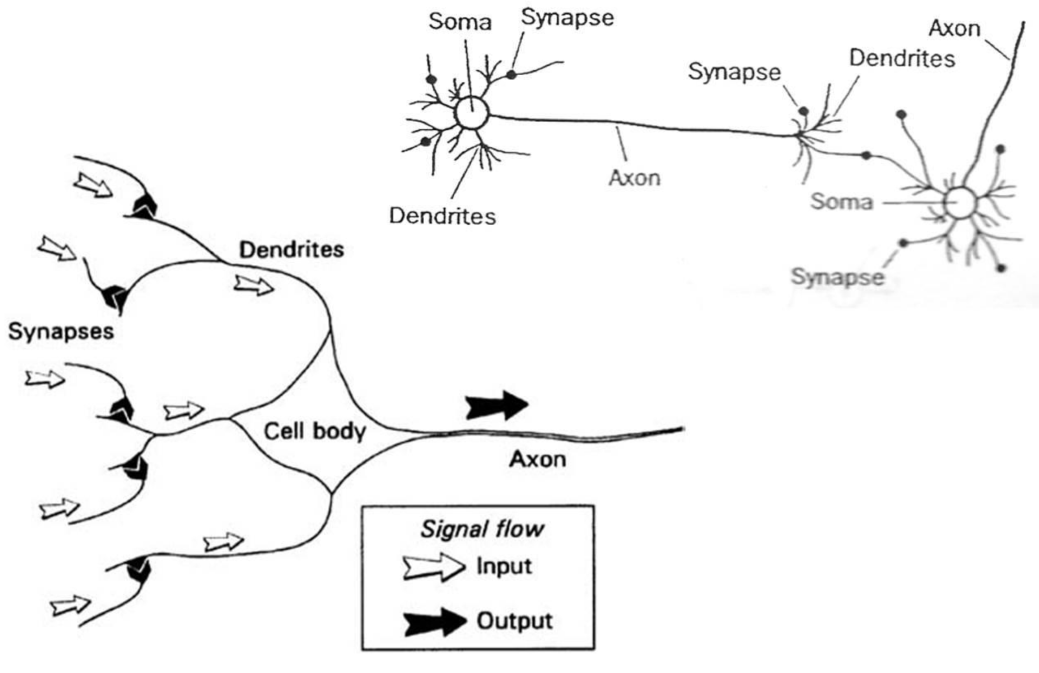


Figure 2.11 Essential components of neuron (Gurney, 1997)

An artificial neural network is highly adaptive nonlinear systems and powerfully able to predict and classify the information to be closely with actual intformation.

During the adaptive process, the neural network is able to determine a problem composed of several variables; also, it can be repeatly trained to learn the intrinsic relationships of different characteristics in each event. For the adaptively characteristics, an indentifing process can be unnecessary. Through training process of the neural network, the indentification will be accomplished implicitly and automatically. Forthermore, the use of neural networks is beneficial to prepare a model for simulating the system behavior. The model with adaptive process is possible to train the neural network, to learn the intrinsic relationships between the variables in the system. The prediction of the total risk scores considers form three mainly parameter composing of a seismic hazard intensity, a building importance factor and building venerability. These problems can be handled by good trained neural networks.

Joghataie (1994) suggested that the primary steps in the construction of a suitable neural network are as follows:

(1) Representation: Determination of enough and concise input variables. Output variables are dictated automatically by the requirements of the problem.

(2) Selection of a suitable type of neural network: First, decision should be made about the type of neural network, whether it is a multi-layer feed forward neural network, a recurrent neural network, etc. Then, the architecture, training strategy and the required parameters which define the behavior of the network such as type of activation function, learning rate, etc. should be selected. This includes choosing or constructing an algorithm for updating the parameters of the neural network, growing mechanism, etc.

(3) Selection of a suitable training set: Number of the training cases should be large enough to cover all the possible situations that may occur during the real process. Meanwhile, it should be as small as possible to avoid excessive unnecessary time of training.

There are three types of neural network, i.e. (a) simple neural network, (b) one layer feed forward neural network, and (c) multi-layer feed forward neural networks.

2.4.1 Simple Neural Network

The fundamental building block for neural networks is the single-input neuron with bias, such as Figure 2.12

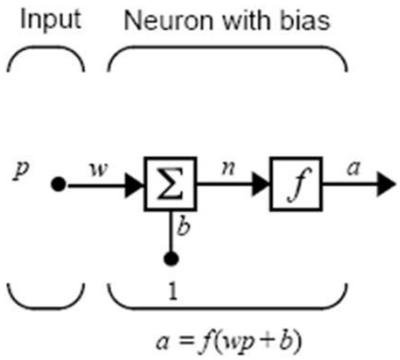


Figure 2.12 Simple neuron network (Meesad, 2012)

There are three district functional operations. First, the scalar input *p* is multiples by the scalar weight *w* to form the product *wp*, again a scalar. Second, the weighted input *wp* is added to the scalar bias *b* to form the net input *n*. (This case can view the bias as shifting the function *f* to the left by an amount *b*. The bias is much like a weight, except that it has a constant input of 1). Finally, the net input is the transfer function *f*, which produces the scalar output passed through *a*. The names given to these three processes are: the weight function, the net input function and the transfer function (Beale *et al*., 2013).

2.4.2 One Layer Feed Forward Neural Network

In this network, each element of the input vector *p* is connected to each neuron input through the weight matrix W. The i^{th} neuron has a summer that gathers its weighted inputs and bias to form its own scalar output *n(i)*. The various *n(i)* taken together form an *S*-element net input vector *n*. Finally, the neuron layer outputs from a column vector *a* as shown in Figure 2.13

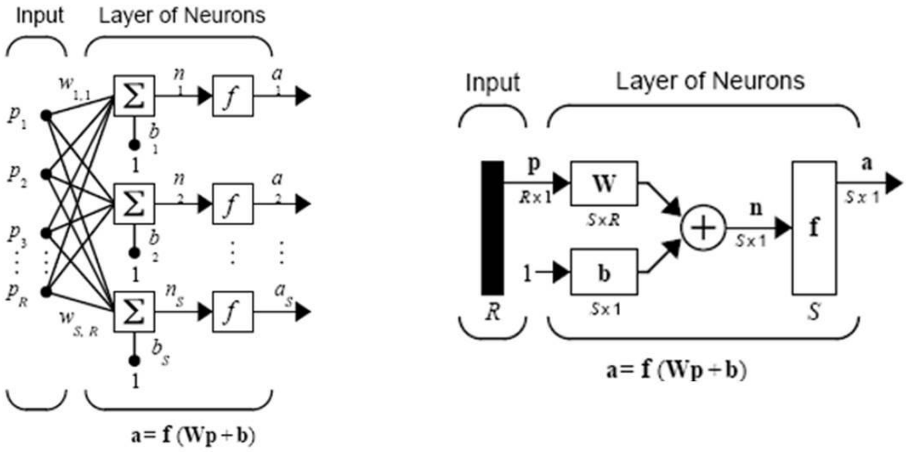


Figure 2.13 One layer neuron network with abbreviated notation (Meesad, 2012)

Where;

R = number of elements in input vector

S = number of neurons in layer 1

The *S* neuron *R*-input one layer network also can be drawn in abbreviated notation (Figure 2.13 right). Here *p* is an *R* length input vector, *W* is an *S x R* matrix, *a* and *b* are *S*-length vectors. As defined previously, the neuron layer includes the weight matrix, the multiplication operations, the bias vector *b*, the summer, and the transfer function blocks.

2.4.3 Multi-Layer Feed Forward Neural Networks (MFFNN)

Joghataie (1994) proposed the multilayer feed forward neural network is comprised of many processing units also called processing elements, nodes, neurons and neurodes. Each of these units has a simple behavior. The units receive signals from and send signals to the other processing units via wire-like connections. The complexity of a neural network comes from the cooperation of these very simple processing units. This is the fascinating point about the neural networks. The arrangement of these simple units is an important issue. The multilayer feed forward back propagation neural networks (MFFNN) are practically very useful because of their predefined architectural form, where the arrangement of their units follows a simple pattern.

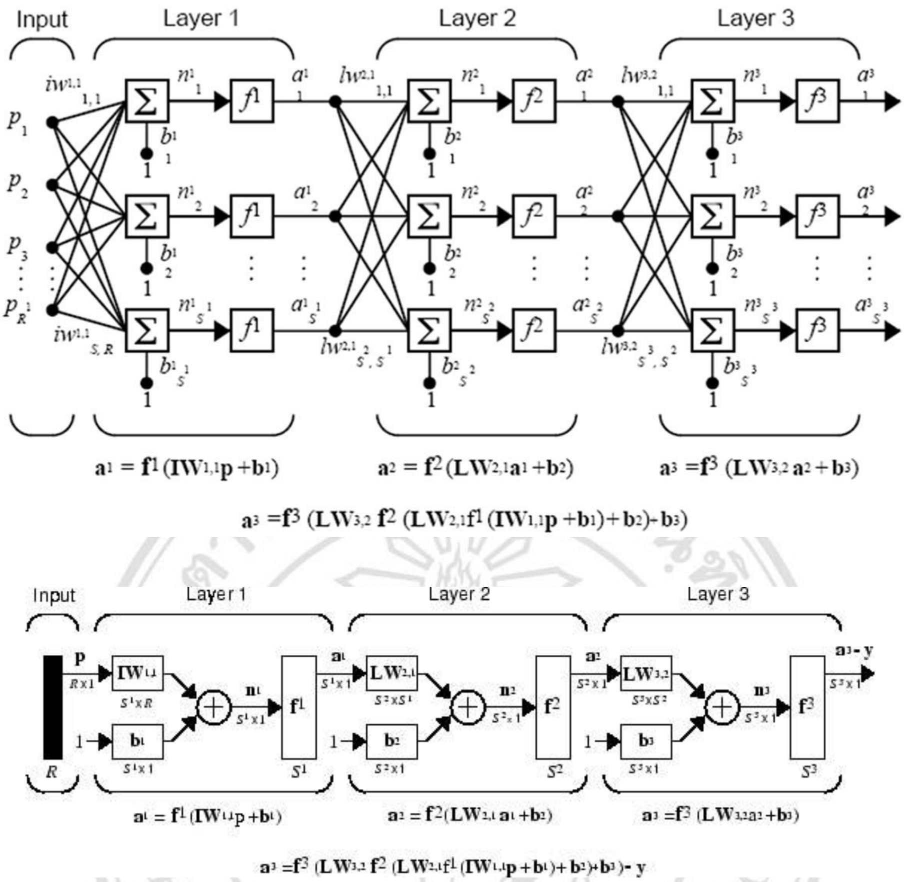


Figure 2.14 Multi-Layered Perceptron, MLP (Meesad, 2012)

Figure 2.14 shows the multi-layer feed forward neural networks (MFFNN) components. A MFFNN is comprised of layers of units. A unit receives only input from the units in the previous layer, and sends only signal to the units in the succeeding layer. Neither inter-layer connections nor cross layer connections are not permitted. Also, each unit in a layer is connected to all the units in the succeeding layer. The result is a neural network which is fully connected in the layers. The first layer receives input from surrounding. The last layer sends outputs to the surrounding. In other words, the first layer is the input layer, and the last layer is the output layer of the neural network. Also there should be at least one layer in between input and output layers. Theoretically, one hidden layer is enough for learning a mapping problem. In this study, multilayer feed forward neural networks will be used with updating the weight is the back propagation rule method.