*Malaysian Journal of Civil Engineering 26(2):209-223 (2014)*

# VULNERABILITY ASSESSMENT OF BUILDING CONSTRUCTION PROJECTS

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**Abstract:** The present study deals with a vulnerability assessment carried on several Algerian buildings construction projects belonging to different seismic zones. The parameters governing the vulnerability of such buildings construction projects are identified. The priority order of these parameters is set using the Multiple Criteria Decision Making (MCDM) method, while a Partial Vulnerability Index (PVI) is proposed, to allow the identification of the intrinsic vulnerability. Finally, to enable a classification of the buildings according to their seismic vulnerability, a Global Vulnerability Index (GVI) is developed. The efficiency of the method was shown through several cases study which highlighted most vulnerable parameters. A classification between the different projects was also performed.

**Keywords:** *Vulnerability, building construction site, seismic risk, analytical hierarchy process*

## 1.0 Introduction

Risk management is essential to construction activities in minimizing losses and enhancing profitability. Construction risk is generally perceived as events that influence cost, time and quality objectives of projects (Baccarini, 2001; Williams, 1993; Williams, 1995). Risk analysis and management in construction depend mainly on intuition, judgment and experience. However, many researches' have been carried on to enhance management efforts in accidents prevention and safety performance of building projects (Teo and Feng, 2011; Feng, 2013; Love, 2002; Söderlund, 2004).

The inherent project hazard is a natural part of the initial construction site conditions owing to the scope and location of the project (Abdelhamid and Everett, 2000; Imriyas *et al*., 2007). Non-human related events like natural disasters and inclement weather are beyond control and prediction (Teo and Feng, 2010) were considered too. The concept of vulnerability is then introduced to deal with hazard and its impact (Chambers, 2006; Kelly and Adger, 2000; Turner *et al*., 2003; Watts and Bohle, 1993; Brooks, 2003). This is particularly true in the case of a seismic event affecting an industrial site where human and financial factors cannot be dissociated (Korkmaz *et al*., 2011; Salzano *et al*., 2009; Dikmen *et al*., 2008; Lee *et al*. 2009, Akintoye and MacLeod, 1997; Tsai and Chen, 2010). The purpose of vulnerability assessment is to make policies to improve adaptive capacities of a system to cope with hazard impacts (Watts and Bohle, 1993, Kelly and Adger, 2000) especially in the case of building construction site (Zeng *et al*., 2007; Zhang, 2007) subjected to earthquakes.

The present study deals with seismic risk management of building construction sites and aims to improve the impact of factors having an influence on the realization process of buildings. For this purpose, vulnerability indexes have been developed taking into account factors identified from past earthquakes. These factors were quantified using the techniques of the AHP (Analytical Hierarchy Process) (Zahaf and Bensaibi, 2011; Zahaf and Bensaibi, 2012). The obtained indexes allow the classification of buildings construction site according to its degree of vulnerability. This classification has been done according to a developed scale.

## 2.0 Basic Hypothesis

The north of Algeria is an area prone to seismicity (Figure 1). Based on seismic feedback experiences the most influencing factors that govern the vulnerability of building construction projects are identified. They are human component, equipments, supplies, organization and site.

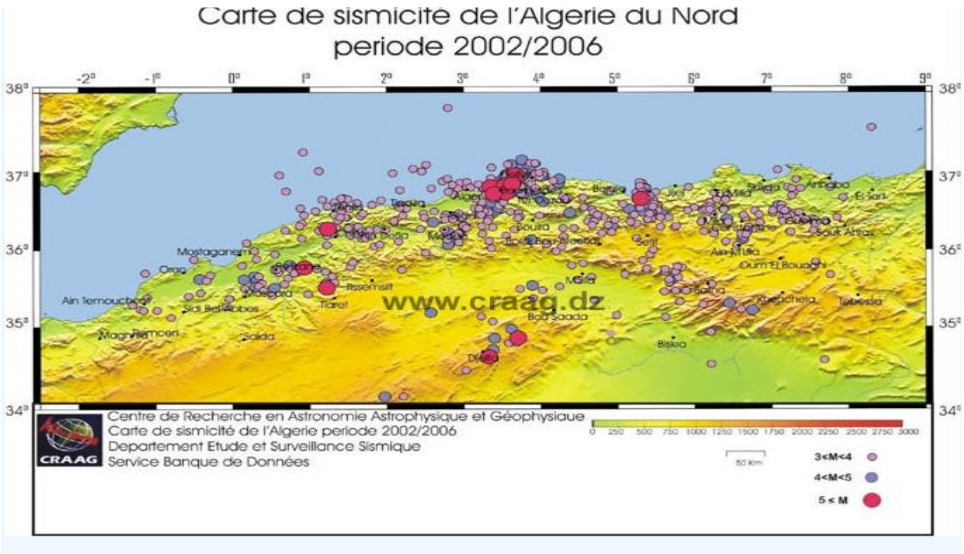


Figure 1: North Algeria seismic activity map

### *2.1 Human component*

The human component is the personal staff present on the project site. It can be subdivided in two categories, the leadership (director, engineers, etc.) and the laborers (masons, bricklayers, etc.). This factor will be denoted *CH*.

### *2.2 Equipment*

The equipment requirement in a project implementation is based on the importance of the project. It include all the engines needed (trucks, hoists, etc.). This factor will be denoted *Eq*.

### *2.3 Supplies*

The supplies are all the goods and means needed by the project. It means steel, cement, water, shovels and so on. This factor will be denoted *Ap*.

### *2.4 Organization*

The organization is all the schedules made for the project realization. For the successful execution of a project, effective planning is essential. Those involved with the design and execution of the infrastructure in question must consider the environmental impact of the job, the successful scheduling, budgeting, logistics, preparing tender documents and inconvenience to the public caused by construction delays. This factor will be denoted *Og*.

### *2.5 Site*

A site is the location where the construction project will be implemented. A site selection of a building or structure should be done based upon some surveys and considerations of various aspects of the site like the development of the site, on the cost and the stability of the proposed structure.

## 3.0 Used Tool

For a given site or a given seismic zone, the above parameters should be quantified. Judgment and experience play an important role in this process. Multiple Criteria Decision Making methods were often used for this purpose. In the present case, the Analytical Hierarchy Process (AHP) has been adopted (Triantaphyllou and Hman, 1995; Kamal and Al-Subhi, 2001, Lai *et al*., 2008).

### 3.1 AHP Background

The Analytical Hierarchy Process (AHP) is a decision-support tool developed by Saaty (Saaty, 1989; Saaty, 1990). It aims to help the decision-maker facing a complex problem with multiple conflicting and subjective criteria (e.g. location or investment selection, projects ranking, and so forth).
The advantages of this approach is that it organizes tangible and intangible factors in a systematic way, and provides a structured yet relatively simple solution to the decision-making problems (Saaty, 1990).

To perform the AHP several steps were defined (Kamal and Al-Subhi, 2001), they are, construction of the hierarchy, setting pairs of comparison, prioritization and checking the logic consistency of the analysis (Akintoye and MacLeod, 1997; Saaty, 1989; Saaty, 1990). A table was developed by Saaty (Table 1) in order to give a numerical value between two factors.

Table 1: Gradation scale for quantitative comparison of alternatives (Navneet and Kanwal, 2004)

| Options | Numerical value |
|---|---|
| equal | 1 |
| Marginally strong | 3 |
| strong | 5 |
| Very strong | 7 |
| Extremely strong | 9 |
| Intermediate value to reflect fuzzy inputs | 2 ,4,6,8 |
| Reflecting dominance of second alternative compared with first | reciprocals |

### 3.2 AHP Implementation

The hierarchy and the pair-wise comparisons being performed (Akintoye and MacLeod, 1997; Saaty, 1990), a priority vector $E_i$ must be determined. This one classifies the priority in an increasing or a decreasing relative order:

$$E_i = \sum_{j=1}^{n} W_{ij} / n \quad (1)$$

With:

$$W_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij} \quad (2)$$

Where n is the matrix size and $W_{ij}$ are the elements matrix and $a_{ij}$ are determined based on the seismic feedback experience using the relative scale measurement shown in Table 1. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

Having made all the pair-wise comparisons, the consistency is determined by using the eigenvalue, $\lambda_{max}$, to calculate the consistency index, CI as follows:

$$CI = (\lambda_{max} - n)/(n - 1) \quad (3)$$

With:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} E_i / E_i \quad (4)$$

Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table 2.

Table 2: Average random consistency (RI) (Saaty, 1990; Saaty, 1989)

| **Size of matrix** | **Random consistency** |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0.58 |
| 4 | 0.89 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |
| 10 | 1.49 |

## 4.0 Developed Methodology

Within this work, two vulnerability indexes were defined. The first one was called "Partial Vulnerability Index" (PVI) and the second one was called "Global Vulnerability Index" (GVI). The PVI was defined as the sum of the vulnerability of each parameter that has an influence on the activity of the building construction project. The GVI takes into account the seismic zone where the project is implemented.

So with:

$E_i$: Priority order of the parameter calculated by the AHP.
R: Potential risk related to the site or to the seismic zone.
$p_i$: Parameter value. The parameter value ($p_i$) is a score out of the referential parameter value (ten in the present study), obtained by the building company for each considered parameter, taking into account means at its disposal to carry out the project (This is a result of the tender process).
$n_i$ : Referential parameter value. In this study equal to 10.

The vulnerability of a parameter can be expressed by:

$$V_i = E_{i.} * p_{i\,/}\, n_i \tag{6}$$

The PVI of a building construction site is then:

$$PVI = \Sigma V_i \tag{7}$$

The partial vulnerability index above does not take into account the seismic zone. This is done through the GVI. It is defined as:

$$GVI = PVI/R \tag{8}$$

This one let the comparison between two building construction sites implemented in two different seismic zones.

According to the Algerian seismic code in use, five seismic zones are defined, from the less seismic zone to the most seismic one. They are zone 0, 1, 2a, 2b and 3. These ones let the determination of the potential risk R.A vulnerability classification of building construction site is proposed according the obtained vulnerability index (VI) (Table 3):

Table 3: Classification of building construction site

| **Class** | Red | Orange | Green |
|---|---|---|---|
| **VI** | 0÷0,25 | 0,25÷0,75 | 0,75÷1 |

The Green interval means that the building construction site is not vulnerable to seismic action and therefore there is no risk of major disruptions. The Red interval means that the building construction site is vulnerable to seismic action and therefore it might suffer from very important disturbances. The Orange interval is an intermediate situation.

The PVI is used as a value of the VI in order to classify building constructions sites located in the same seismic zone. In this case the seismic hazard is not taken into account. In order to deal with the seismic aspect, the GVI is then used.
To calculate the GVI, the potential risk R, must be determined. This one is deduced from the acceleration coefficient taken from the Algerian seismic code (RPA99) (MH, 2003) (Table 4).

Table 4: Acceleration coefficient according the seismic zone (MH, 2003)

| **Use group** | **Seismic zone** | | | |
|---|---|---|---|---|
| | **1** | **2a** | **2b** | **3** |
| **1A** | 0.15 | 0.25 | 0.30 | 0.40 |
| **1B** | 0.12 | 0.20 | 0.25 | 0.30 |
| **2** | 0.10 | 0.15 | 0.20 | 0.25 |
| **3** | 0.07 | 0.10 | 0.14 | 0.18 |

In the RPA99 the Use group is a classification of structures according to their importance. So four groups are distinguished (MH, 2003):

- Group 1A: For strategic structures and buildings of very high importance.
- Group 1B: For Important structures and buildings higher than 48 m. Water towers are included in this group.
- Group 2: For useful structures and buildings lower than 48 m.
- Group 3: For structures of low importance and temporary buildings

Based on the previous table, the values of *R* are taken according to the following table (Table 5):

Table 5: *R* values

| **Use group** | **Seismic zone** | | | | |
|---|---|---|---|---|---|
| | **0** | **1** | 2a | **2b** | **3** |
| **1A** | 1 | 1.15 | 1.25 | 1.30 | 1.40 |
| **1B** | 1 | 1.12 | 1.20 | 1.25 | 1.30 |
| **2** | 1 | 1.10 | 1.15 | 1.20 | 1.25 |
| **3** | 1 | 1.07 | 1.10 | 1.14 | 1.18 |

In the case of zone 0, the GVI and the PVI are the same, this is correct because there is no seismic risk in this area, so only intrinsic characteristics of the building construction project play a role on its vulnerability.

## 5.0 Studied cases

The proposed method has been applied on three projects in Algeria. The first one is located in the district of Blida, an area with a high potential of seismicity, Zone 3. The second is located in the district of Tissemssilt, Zone 2b, a district with an intermediate potential of seismicity and the third located in the district of Meftah, an area with a lower potential of seismicity, Zone 2a according to the Algerian Seismic Code (MH, 2003). The characteristics of each project are given in Table 6.

Table 6: Project' characteristics

| Project | Description | Location | Use group |
|---|---|---|---|
| **1** | 800 building units | Blida | 1B |
| **2** | School | Tissemssilt | 1B |
| **3** | Office building | Meftah | 2 |

### *5.1 Case Study One*

The estimated cost of this project (Figure 2) is around 45 million US$ and the completion period is 38 months.

Figure 2: Case study 1 in progress

### *5.1.1 Priority factors and consistency index*

Using the AHP the comparison pairs is established and $E_i$ (Table 7) is derived according to equation (2).

Table 7: Case study 1 decision matrix

| **CH** | **Eq** | **Ap** | **Og** | **$E_i$** |
|---|---|---|---|---|
| 1,00 | 3,00 | 4,00 | 5,00 | 0,520 |
| 0,33 | 1,00 | 3,00 | 4,00 | 0,268 |
| 0,25 | 0,33 | 1,00 | 3,00 | 0,141 |
| 0,20 | 0,25 | 0,33 | 1,00 | 0,071 |

According to equations 3, 4 and 5, CI= 0,061 and RI=0,89 so CR = 0,069. This value is less than 10% so the judgment matrix is consistent.

### *5.1.2 Parameters Evaluation*

After an in situ evaluation, the parameters value was derived for the different factors and the results are given in Table 8.

Table 8: Parameters value of the first case study

| | **Human component CH/10** | **Equipment Eq/10** | **Supply Ap/10** | **Organization Og/10** |
|---|---|---|---|---|
| **$p_i$** | 8 | 6 | 7 | 6 |

The PVI is computed and the results are given in Table 9.

Table 9: Vulnerability of the first case study

| **Factors** | **$E_i$** | **$p_i$** | **$n_i$** | **$V_i$** |
|---|---|---|---|---|
| **CH** | 0,520 | 8 | 10 | 0,4116 |
| **Eq** | 0,268 | 6 | 10 | 0,1608 |
| **Ap** | 0,141 | 7 | 10 | 0,0987 |
| **Og** | 0,071 | 6 | 10 | 0,0426 |
| **PVI** | | | | 0,7241 |

GVI = PVI/R = 0,7241/1,3
GVI = 0,557

This project has a medium vulnerability since its PVI and GVI belong to the orange range. The main parameters increasing its vulnerability are human component and equipments. So these two parameters should be taken into account in order to decrease the vulnerability of the project.

## 5.2 Case Study Two

The estimated cost of this project (Figure 3) is around 12 million US $ and the completion period is 25 months.

Figure 3: Case study 2 in progress

### 5.2.1 Priority factors and consistency index

Using the AHP the comparison pairs is established and $E_i$ (Table 10) is derived according to equation (2).

Table 10: Case study 2 decision matrix.

| **CH** | **Eq** | **Ap** | **Og** | $E_i$ |
|---|---|---|---|---|
| 1,00 | 4,00 | 3,00 | 4,00 | 0,521 |
| 0,25 | 1,00 | 2,00 | 2,00 | 0,205 |
| 0,33 | 0,50 | 1,00 | 3,00 | 0,181 |
| 0,25 | 0,50 | 0,33 | 1,00 | 0,093 |

According to equations 3, 4 and 5, CI= 0,071 and RI=0,89 so CR = 0,08. This value is less than 10% so the judgment matrix is consistent.

### 5.2.2 Parameters Evaluation

After an in situ evaluation, the parameters value was derived for the different factors and the results are given in Table 11.

Table 11: Parameters value of the second case study

| | **Human component CH/10** | **Equipment Eq/10** | **Supply Ap/10** | **Organization Og/10** |
|---|---|---|---|---|
| **$p_i$** | 7 | 8 | 7 | 7 |

The PVI is computed and the results are given in Table 12.

Table 12: Vulnerability of the second case study

| **Factors** | **$E_i$** | **$p_i$** | **$n_i$** | **$V_i$** |
|---|---|---|---|---|
| **CH** | 0,521 | 7 | 10 | 0,3664 |
| **Eq** | 0,205 | 8 | 10 | 0,1640 |
| **Ap** | 0,181 | 7 | 10 | 0,1267 |
| **Og** | 0,093 | 7 | 10 | 0,0651 |
| **PVI** | | | | 0,7222 |

GVI = PVI/R = 0,7222/1,15
GVI = 0,628

This project has a medium vulnerability since its PVI and GVI belong to the orange range. The main parameters increasing its vulnerability are human component, equipments and supplies, so these three parameters should be taken into account in order to decrease the vulnerability of the project.

### *5.3 Case study three*

The estimated cost of this project (Figure 4) is around 32,5 million US $ and the completion period is 34 months.

Figure 4: Case study 3 in progress

### *5.3.1 Priority factors and consistency index*

Using the AHP the comparison pairs is established and $E_i$ (Table 13) is derived according to equation (2).

Table 13: Case study 3 decision matrix

| CH | Eq | Ap | Og | $E_i$ |
|---|---|---|---|---|
| 1,00 | 3,00 | 4,00 | 3,00 | 0,497 |
| 0,33 | 1,00 | 2,00 | 3,00 | 0,243 |
| 0,33 | 0,50 | 1,00 | 2,00 | 0,156 |
| 0,33 | 0,33 | 0,50 | 1,00 | 0,103 |

According to eq. 3, 4 and 5, CI= 0,075 and RI=0,89 so CR = 0,084. This value is less than 10% so the judgment matrix is consistent.

### *5.3.2 Parameters Evaluation*

After an in situ evaluation, the parameters value was derived for the different factors and the results are given in Table 14.

Table 14: Parameters value of the third case study

| | Human component CH/10 | Equipment Eq/10 | Supply Ap/10 | Organization Og/10 |
|---|---|---|---|---|
| $p_i$ | 6 | 8 | 8 | 6 |

The PVI is computed and the results are given in Table 15.

Table 15: Vulnerability of the third case study

| Factors | $E_i$ | $p_i$ | $n_i$ | $V_i$ |
|---|---|---|---|---|
| CH | 0,497 | 6 | 10 | 0,2982 |
| Eq | 0,243 | 8 | 10 | 0,1944 |
| Ap | 0,156 | 8 | 10 | 0,1248 |
| Og | 0,103 | 6 | 10 | 0,0118 |
| PVI | | | | 0,6792 |

GVI = PVI/R = 0,6792/1,2
GVI = 0,566

This project has a medium vulnerability since its PVI and GVI belong to the orange range. The main parameters increasing its vulnerability are human component, equipments and supplies, so these three parameters should be taken into account in order to decrease the vulnerability of the project. A classification of the three projects is done on Table 16.

Table 16: Projects classification

| Projet n° | GVI | Rank |
|---|---|---|
| 1 | 0,557 | 3 |
| 2 | 0,628 | 1 |
| 3 | 0,566 | 2 |

The most vulnerable project is the project 2 and the less vulnerable project is the first one despite the fact that it is located in the most seismic area.

## 6.0 Conclusion

Vulnerability studies carried on buildings construction projects can highlight weak points and help project managers to reduce/or protect the site from hazard. Parameters such as human component, organization, supplies, equipment are main components defining the intrinsic vulnerability of a given construction site. Indeed, defining the priority order of such component is of great importance to approach its vulnerability. In this study, this order has been obtained using the AHP method. More ever, vulnerability classification was made on the base of the developed parameters PVI and GVI. The latest allows the classification of building construction project according its seismic vulnerability.

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