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# Calculation of seismic vulnerability index for steel structures

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**Abstract**

Seismic vulnerability analysis of steel structures requires some basic information on their mechanical and structural properties. The present study aims to quantify the seismic vulnerability of steel structures, through the use of the needed information. The first step to do so is the identification of the main parameters that play an important role in the seismic vulnerability of such structures. Then using seismic feedback experience, weighting coefficients of each parameter are determined. An expression of a vulnerability index is given and based on the obtained value a building under study is classified as safe or unsafe according a proposed classification.
A vulnerability index program (VIP) is developed in order to classify steel structures. This program is used to study several examples. The results are satisfactory comparing with in situ observations


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*Keywords:* Seismic vulnerability; Steel structures; Vulnerability index; Seismic parameters

## 1. Introduction

Steel structures offer an advantage against the seismic stress due their lightness and ductility. Despite these characteristics steel structures can suffer significant damage after an earthquake [1,2].

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The assessment of the seismic vulnerability of steel structures has been the subject of several studies HAZUS, RISK-UE, and RADIUS. Where vulnerability curves have been established using vulnerability index [3,4,5].This index is calculated based of some parameters having an influence on the seismic behaviour of steel constructions and allowing description of seismic quality of such constructions [6].

These studies do not consider all influencing parameters, so in order to improve the existing index and to quantify more accurately the seismic behavior of such structure a vulnerability index method is developed [7,8,9,10].

**Nomenclature**

| | |
|---|---|
| R | behaviour factor |
| Ki | weighting factor Ki |
| VI | vulnerability index |

## 2. Vulnerability index method

The parameters that have a significant influence on the seismic vulnerability of steel frame structures are given here after.

### *2.1. Selected parameters:*

These parameters are determined based on post-seismic observations and seismic experience feedback. The parameters taken into account are:

1- Ductility 5- Type of soils9- Modifications 13- Roof
2- Bearing capacity 6- Floor 10- Elevation regularity 14- Details
3- Assemblage 7- Buckling 11- Pounding effect
4- General maintenanceconditions8- Plan regularity12- Ground conditions

Among these parameters, Ductility, Bearing capacity and Buckling need calculation, the others parameters are related to the in situ observation. In this paper, only Ductility is presented because it is an important and complex parameter.

- Ductility : under a strong earthquake, steel frame structures undergo plastic deformations, due to their faculty of dissipation of energy. Indeed, they have the ability to resist greater strain than the design one.

  To take into account these plastic deformations, the seismic codes consider a reducing factor called “Behavior Factor” defined by the coefficient ‘R’ according to the Algerian seismic code (RPA 99 version 2003). The R values are given in table 1.

Table 1.Ductility according the behavior factor ‘R’ for steel frame structures.

| Ductility level | Value of "R" |
|---|---|
| High Ductility: Class A | [6 – 4 [ |
| Average Ductility: Class B | [4 - 2 [ |
| Low Ductility: Class C | $\leq$ 2 |

### *2.2. Parameters quantification:*

Weighting factors for each parameter are proposed on table 2. These factors are determined on a basis of a statistical data containing more than 300 constructions damaged by different earthquakes (Ain Temouchent (1999) and Boumerdes (2003)). The considered parameter can take only one factor. For each parameter and each considered class, a coefficient (ki) is identified expressing its seismic quality.

The "Details" parameter was specified as follows: studwork, dividing walls, balconies, railing, cornices, chimneys, ventilation space, electrical network, gas network, water network and sewage network.

Table 2.Weighting factor "Ki".

| N | Parameters | Classes/Ki | | |
|---|---|---|---|---|
| | | Class A | Class B | Class C |
| 1 | Ductility | 0.00 | 0.08 | 0.15 |
| 2 | Bearing capacity | 0.02 | 0.07 | 0.09 |
| 3 | Assemblage | 0.02 | 0.06 | 0.15 |
| 4 | General maintenance conditions | 0.08 | 0.06 | 0.08 |
| 5 | Type of soil | 0.03 | 0.04 | 0.05 |
| 6 | Floor | 0.03 | 0.04 | 0.05 |
| 7 | Buckling | 0.03 | 0.06 | 0.08 |
| 8 | Plan regularity | 0.03 | 0.04 | 0.05 |
| 9 | Modifications | 0.03 | 0.04 | 0.05 |
| 10 | Elevation regularity | 0.03 | 0.04 | 0.05 |
| 11 | Pounding effect | 0.03 | 0.04 | 0.05 |
| 12 | Ground conditions | 0.03 | 0.04 | 0.05 |
| 13 | Roof | 0.03 | 0.04 | 0.05 |
| 14 | Details | 0.03 | 0.04 | 0.05 |

Three classes are defined for each parameter. Each considered parameter can belong to one of the three defined classes A, B, and C. These classes are declined as follows:

- Class A expresses a parameter inducing a good behaviour of the structure during an earthquake,
- Class C expresses a parameter inducing a bad behaviour of the structure during an earthquake,
- Class B expresses an intermediate behaviour of the structure during an earthquake.

The vulnerability index, VI, of a construction is expressed according to formula (1):

$$VI = \sum_{i=1}^{14} k_i \quad (1)$$

According to the obtained value for the vulnerability index, three vulnerability classes Green, Orange and Red are proposed, table3:

Table 3.Vulnerability index classes.

| Class | Green | Orange | Red |
|---|---|---|---|
| VI | [0.36 – 0.54[ | [0.54 – 0.85[ | [0.85 – 1] |

- The first class associated to the green colour classifies the construction as resistant with no requirement to any repairs
- The second class associated to the orange colour classifies the construction as moderately resistant requiring reinforcement
- The third class associated to the red colour classifies the construction to be a construction with low resistance requiring demolition

## 3. Elaborated chart

In situ observations on structures are important information required to assess the vulnerability of steel frame structures. An investigation chart for a survey was elaborated. The chart contains:

1. General data
4. Information on the ground

2. Geometric characteristics
3. Information on the structural system
5. Details on the non structural elements
6. General maintenance conditions

Based on this chart, a program called Vulnerability Index Program "VIP using Delphi was elaborated providing the vulnerability index values for steel frame structures. It uses the elaborated chart in order to estimate the coefficient of the different parameters and classify the structures.

## 4. Application

Several examples have been treated. Here in, are two case studies presented as an example

### *4.1. Case study one:*

It is Zinc production manufacture built in 1949 and located in the west part of Algeria. The following figures show the damage undergone by this structure.

a

b


Fig. 1.(a) Damage in bracing system; (b) Corrosion of columns.

a

b


Fig. 2.(a) Damage in assembly system; (b) Damage in beams and collapse of a floors.

The results given by the program are given in table 4.

A vulnerability index of 0.87 was found, this indicates that the structure belong to the red class. The conclusions provided by the Structural Engineering Control (CTC: official organization in charge of control in Algeria) suggest the demolition and the rebuilt of the manufacture according the latest standards.

So, the two conclusions are in adequacy.

Table 4.Manufacture parameters vulnerability.

| N° | Parameters | Class | Ki |
|---|---|---|---|
| 1 | Ductility | B | 0.08 |
| 2 | Bearing capacity | C | 0.09 |
| 3 | Assemblage | C | 0.15 |
| 4 | General maintenance conditions | C | 0.08 |
| 5 | Type of soil | B | 0.04 |
| 6 | Floor | C | 0.05 |
| 7 | Buckling | C | 0.08 |
| 8 | Plan regularity | C | 0.05 |
| 9 | Modifications | A | 0.03 |
| 10 | Elevation regularity | C | 0.05 |
| 11 | Pounding effect | B | 0.04 |
| 12 | Ground conditions | A | 0.03 |
| 13 | Roof | C | 0.05 |
| 14 | Details | C | 0.05 |

*4.2. Case study two:*

It is about a manufacture inaugurated in 1975, and composed of four parts: manufacture, storage, maintenance and administration. It should be noted that the process of manufacturing zinc liberates H2SO4 which is very harmful to the metal, as it accelerates the corrosion process. This manufacture built near the sea on sandy soils and limited to the south by a high cliff. Photos below were taken on site during our visit.

a

b

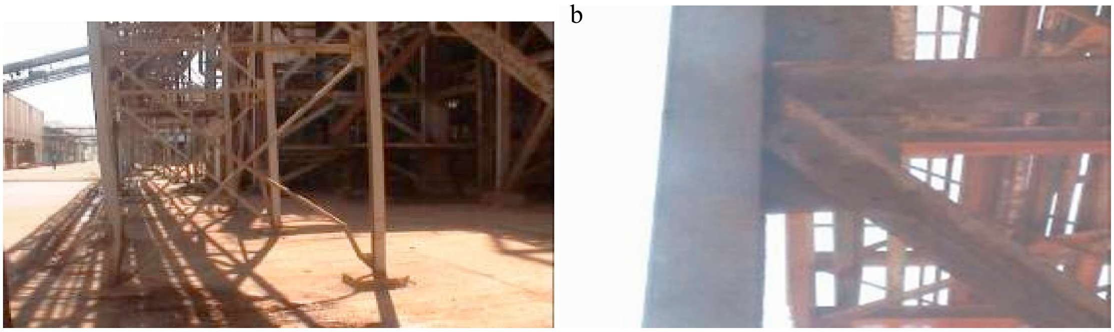

Fig. 3.(a) Deformation of bracing system and buckling column; (b) Lack of bolts in the assembly system.

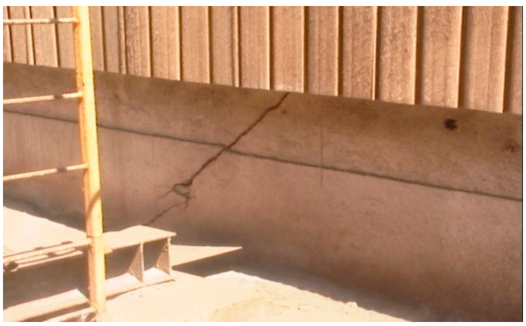

Fig. 4.Craking 45 degree to both directions and both side of joint.

The results given by the program are given in table 4.

Table 5.Result of the application of the Zinc manufacture.

| N° | Parameters | Class | Ki |
|---|---|---|---|
| 1 | Ductility | B | 0.08 |
| 2 | Bearing capacity | B | 0.07 |
| 3 | Assemblage | B | 0.06 |
| 4 | General maintenance conditions | B | 0.06 |
| 5 | Type of soil | C | 0.05 |
| 6 | Floor | B | 0.04 |
| 7 | Buckling | B | 0.06 |
| 8 | Plan regularity | C | 0.05 |
| 9 | Modifications | A | 0.03 |
| 10 | Elevation regularity | C | 0.05 |
| 11 | Pounding effect | C | 0.05 |
| 12 | Ground conditions | C | 0.05 |
| 13 | Roof | B | 0.04 |
| 14 | Details | C | 0.05 |

The program gives VI= 0.76, so the structure is classified Orange. This appears in concordance with in situ observations.

## 5. Conclusions

A vulnerability index method for steel structure has been developed and presented in this study. Elaborated specially for steel structures, it gives reasonable results regarding the influence of the different parameters such as Ductility, Bearing capacity and Buckling, on the seismic behaviour of steel structure.

A classification has been established; the results from this classification are in accordance with the one done in situ. As a result, this classification can be used by engineers to reduce seismic risk and casualties in case of an earthquake.

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