Seismic Vulnerability Index for Road Networks

S. ADAFER, M. BENSAIBI

Ecole Nationale Supérieure des Travaux Publics –ENSTP-, National School of Built and Ground Works Engineering, Algiers, Algeria

ABSTRACT: To prevent heavy damages in road network after a quake, vulnerability studies must be conducted. The framework of the present study aims to develop a vulnerability index (VI) method for roads. The most important parameters influencing the seismic behavior of roads are identified, based on the worldwide seismic feedback experience and data from past Algerian earthquakes (Ain Temouchent 1999 and Zemmouri 2003). A Multi Criterion Decision-Making (MCDM) method is used to derive the relative importance between parameters. The Analytical Hierarchy Process (AHP) allows the determination of weighting factors for each defined parameter. Using the developed model, several examples of roads are processed and the obtained results show a good adequacy with in situ observations.

KEYWORD: Earthquake; road; vulnerability assessment; vulnerability index; AHP (Analytical Hierarchy Process)

1 INTRODUCTION

Among the main lifelines is road network. It plays a fundamental role in transportation and economic exchanges. Therefore, during major disasters such as earthquakes, it allows emergency and recovery operations.

Past earthquakes showed the vulnerability of road networks under seismic event and highlighted the necessity to assess this vulnerability (Argyroudis et al., 2005), (Yin & Xu, 2010), (Arsik & Sibel Salman, 2013).

Several road network vulnerability assessment methods do exist (Berdica & Eliasson, 2004), (D'Andrea et al., 2006), (Jenelius et al., 2006), (Kiremidjian et al., 2007), (Yin & Xu, 2010), (Yang & Qian, 2012) and many methods for performing seismic scenarios were developed (ATC-25, 1991), (FEMA-NIBS, 2004), (RADIUS, 1996), (JICA, 2002), (RISK-UE, 2003), (Werner et al., 2006), (Syner-G D3.7, 2009).

In the present study, a seismic vulnerability assessment of roads is performed using the vulnerability index method. For this purpose, the parameters influencing the seismic vulnerability of roads are identified.

Furthermore, the AHP (Analytical Hierarchy Process) method is used to determine the weighting coefficients of the identified parameters. Finally, the expression of the vulnerability index 'VI' is used to

evaluate roads vulnerability and classify them according to their vulnerability.

2 DEVELOPPED METHOD

The developed method is based on the vulnerability index method. It allows assessing roads vulnerability on the base of an index resulting from an analytical expression that combines the main parameters influencing the seismic behavior of roads.

The description of the developed method is given here after.

2.1 Identification of the parameters influencing the vulnerability of roads

The main parameters are defined on the basis of seismic experience feedback over the world (EERI, 1991), (Erdik, 2000), (JICA, 2002), (FHWA, 2004), (D'Andrea et al., 2006), (Anbazhagan et al., 2011), (Zhang et al., 2012), (Wang & Zhang, 2013) and Algeria observations following Ain Temouchent and Zemmouri earthquakes (CTTP, 1999), (CTTP, 2003). This leads to distinguish two types of parameters, Structural and Seismic one. Moreover, these parameters are declined in items, factors and categories (Table 1). The aim is to prioritize and to determine a weighting coefficient for each parameter, item and factor.

Table 1. Hierarchy of parameters

Parameter	Item	Factor	Category
Structural	Pavement (1)	Number of lanes	> 2 lanes
			≤ 2 lanes
		Pavement Type	Paved
			Unpaved
	Embankment (2)	Height	H ≤ 2m
			2m < H ≤ 5m
			5m < H ≤ 8m
			H > 8m
		Compaction quality	Compliant with standards
			Compliant with technical provisions
			Other
		Slope	< 2/3
			= 2/3
			> 2/3
	Ground conditions (3)	Ground type	Rock
			Hard soil
			Soft soil
			Very soft soil
		Landslides potential	Low
			Medium
			High
	Maintenance conditions (4)	Pavement conditions	High
			Medium
			Low
		Slope protection measures	Compliant with standards
			Compliant with technical provisions
			Without any protections
Hazard	Seismic intensity (5)	-	C1*
			C2*
			C3*
			C4*
			C5*
	Liquefaction potential (6)	-	0 ≤ PL < 5
			5 ≤ PL < 15

* With: C1: MMI < VIII, C2: VIII ≤ MMI < IX, C3: IX ≤ MMI < X, C4: X ≤ MMI < XI and C5: XI ≤ MMI.

2.2 Quantification of the identified parameters

The AHP method (Saaty, 1980) is used to take into account the relative contribution of each parameter (Adafer & Bensaibi, 2014). For each level of the hierarchy, pairwise comparisons are carried out. These binary comparisons allow constructing matrices that are used to obtain criteria weighting coefficients. The obtained weights for each level (parameters, items and factors) are given in Table 2.

Table 2. Weighting factors

Parameter	W*	Item	W*	Factor	W*
Structural	0.250	(1)	0.108	Number of lanes	0.667
				Pavement Type	0.333
		(2)	0.283	Height	0.648
				Compaction quality	0.122
				Slope	0.230
		(3)	0.561	Ground type	0.200
				Landslides potential	0.800
		(4)	0.048	Pavement conditions	0.667
				Slope protection measures	0.333
Hazard	0.750	(5)	0.633	-	-
		(6)	0.106	-	-
		(7)	0.261	-	-

* Weight.

2.3 Determination of vulnerability index

Based on the feedback from past earthquakes, experts assigned a score to each category as given in Table 3. Then using the weighting coefficients (Table 2) and the assigned scores (Table 3), the vulnerability index VI is calculated using the following formula (Adafer & Bensaibi, 2014):

$$VI = \sum_{i=1}^2 W_i \sum_{j=1}^{3 \text{ or } 4} W_{ij} \sum_{k=1}^{2 \text{ or } 3} W_{ijk} C_{ijkl} \quad (1)$$

Where:

W_i the weighting coefficient of structural or hazard parameters,

W_{ij} the weighting coefficient of items,

W_{ijk} the weighting coefficient of factors, where $W_{ijk} = 1$ if $i = 2$

and

C_{ijkl} the score of category, where $l = 2$ or 3 or 4 or 5 .

Table 3. Assigned scores

Parameter	Factor	Category	Scores
Structural	Number of lanes	> 2 lanes	20
		≤ 2 lanes	40
	Pavement Type	Paved	20
		Unpaved	50
	Height	$H \leq 2\text{m}$	10
		$2\text{m} < H \leq 5\text{m}$	30
		$5\text{m} < H \leq 8\text{m}$	40
		$H > 8\text{m}$	50
	Compaction quality	Compliant with standards	10
		Compliant with technical provisions	30
		Other	40
	Slope	$< 2/3$	10
		$= 2/3$	30
		$> 2/3$	50
	Ground type	Rock	0
		Hard soil	10
		Soft soil	40
		Very soft soil	50
	Landslides potential	Low	10
		Medium	30
		High	50
	Pavement conditions	High	10
		Medium	20
		Low	40
	Slope protection measures	Compliant with standards	20
		Compliant with technical provisions	30
		Without any protections	50
Hazard	-	$\text{MMI} < \text{VIII}$	10
		$\text{VIII} \leq \text{MMI} < \text{IX}$	20
		$\text{IX} \leq \text{MMI} < \text{X}$	30
		$\text{X} \leq \text{MMI} < \text{XI}$	40
		$\text{XI} \leq \text{MMI}$	50
	-	$0 \leq \text{PL} < 5$	10
		$5 \leq \text{PL} < 15$	30
		$15 < \text{PL}$	50
	-	No intersection	10
		Intersection	40

3 STUDIED CASES

Three case studies have been treated. The studied roads are located in the town of Ain Temouchent (West Algiers). On 22 December 1999 an earthquake (MMI =VII) occurred and damaged these roads.

3.1 Case study 1:

This case study is related to a national road section (RN35) located at Ain Temouchent at the kilometer marker 5+500. This road links Ain Temouchent to Tlemcen a big City in the North-West of Algeria. This road section crosses a soft soil and contains a low embankment ($H=2\text{m}$).

The obtained vulnerability index (VI) using equation 1 is equal to 12.22.

3.2 Case study 2:

This case study is related to a national road section (RN35) located at Ain Temouchent at the kilometer marker 5+900. This road section crosses a soft soil and contains a high embankment ($H=10\text{m}$).

The obtained vulnerability index (VI) using equation 1 is equal to 14.45.

3.3 Case study 3:

This case study is related to a national road section (RN35) located in the suburb of Ain Temouchent at the kilometer marker 20+850. This road section crosses a soft soil and contains a high embankment ($H=7\text{m}$).

The obtained vulnerability index (VI) using equation 1 is equal to 13.59.

3.4 Discussion :

As it can be noticed the second value of the VI is greater than the other values, thus road section 2 is more vulnerable. This is due to the height of embankment, the quality of embankment compaction materials and the lack of slope protection measures. Furthermore, the pavement conditions are poorly than in the case study 1 and 3. The road section 1 is the least vulnerable.

The results of this study are in a good adequacy with in-situ observations. In fact, road section 2 suffered significant damages and great retrofitting activities were necessary after the quake (CTTP, 1999).

4 CONCLUSION

The developed method is used to calculate a vulnerability index for road networks. This index

allows classifying roads according their seismic vulnerability and prioritizing retrofiting activities. Therefore, this method can be used as a diagnosis tool. The developed method is well-adapted to emergency management and urban planning.

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