CETRA2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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Faculty of Civil Engineering
Department of Transportation

CETRA[2014]
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
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EVALUATION AND MANAGEMENT OF SEISMIC ENDANGERMENT OF RING ROAD THESSALONIKI

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Abstract

The current paper presents the study that was implemented in the framework of a diploma thesis in the school of Civil Engineering of the Aristotle University of Thessaloniki aiming at evaluating and managing the seismic risk of the internal Ring Road of Thessaloniki in Greece, focusing on the bridges along it. To achieve this, the study includes the following steps: i) the assessment of the seismic hazard of the area, ii) the examination of the structural vulnerability of the bridges and iii) the redirection of traffic in the adjacent urban road network after the occurrence of seismic faults on some of the examined bridges. Towards this direction firstly, some general meanings are presented related to the seismic risk of everyday life activities' networks and the factors which influence them, namely the seismic hazard of the area, the structural vulnerability and the importance of the element under consideration, specializing in road networks. Secondly, the available methods for classification and creation of vulnerability curves of bridges at international and national level are described in detail. The geological and geotechnical aspects of the study area are given and in combination with the available soil simulants, the seismic response of the soil in the area around the bridges for a certain earthquake scenario is calculated. The earthquake scenario is calculated with an average period of reintroduction T_m=475 years and maximum acceleration on rocky background equal to 0.25g. Based on the method FEMA-NIBS (HAZUS), the corresponding vulnerability curves for all the bridges along the inner Ring Road are notified that are likely to experience higher levels of damage in the case of the examined earthquake scenario. With the results presented above, scenarios of traffic rearrangement are presented, in case of a possible blockade of roads due to repair works in two of these bridges. To this end, the best alternative route of the road network in the area is identified and the new distances and timing of such routes are evaluated. Finally, the conclusions drawn from the present thesis work are summarized.

Keywords: vulnerability curves, seismic risk, Ring Road of Thessaloniki, soil stimulants, traffic rearrangement

1 Introduction

Earthquakes are a very common natural phenomenon, particularly in Greece, and affect the operation of networks to a great extent. Despite this, however, these networks often comprise elements lacking seismic design, thus presenting a high probability of failure. In this light, earthquake engineering of utility networks – which aims at the assessment and management of the networks' seismic risk – is a most timely issue and a strategic field of activity under continuous development. The hazards deriving from Greece's high seismicity have not surprisingly raised many concerns. For this reason, it is imperative that seismic design be applied to all infrastructures and elements exposed to the natural phenomenon in order to reduce risk; this is primarily important for existing vulnerable structures. The necessary prerequisite

before taking action is to create and deploy an appropriate methodology for the assessment of seismic losses on the basis of which earthquake scenarios can be applied in order to rank priority policies in terms of preseismic and metaseismic design for the protection of areas. Given the exorbitant cost of applying overall reinforcement to all existing structures, attention has been focused on the logic of selective intervention based on the results of seismic risk assessment studies. Such studies are particularly important and imperative when they relate to utility networks and infrastructures.
The scope of this paper is to assess the seismic risk of bridges along the Thessaloniki Inner Ring Road and the redistribution of traffic to the adjacent urban road network in the event of a failure due to earthquake. This is undoubtedly an effort which due to the nature of the investigation, entails a great degree of uncertainty. Perhaps it would be more plausible to describe the objective as a prediction of the degree of losses on the elements under risk, i.e. whatever can potentially be exposed to the impact of a seismic excitation. As concerns the redistribution of traffic, the objective is to determine the optimum routes in terms of capacity within the congested urban road network of the area under investigation

2 Measurement instruments

In the context of investigating the seismic response of the area along the Thessaloniki Ring Road, two series of one-dimensional seismic ground response analyses were performed for the earthquake scenario with a mean recurrence interval of T_m = 475 years and maximum acceleration on the rocky subsoil equal to 0.25g. The first series of analyses was performed using EERA software, by means of nine (9) ground sections with a thickness range of 2 – 75 m and one (1) seismic excitation (Kozani ’95). Respectively, the second series of analyses was performed using STRATA software, by means of seventeen (17) ground sections with a thickness range of 2 – 143 m and five (5) seismic excitations, namely: a) KOZ95-T, b) THE78 D, c) UMB 98 855-Y, d) MONT 79, e) WWT-180, [1].

Table 1 Parameters of seismic excitations used in the one-dimensional ground response analyses

Fid	Name	Earthquake	Country	Date	Focal Depth (km)	Mw	Station Name	Building type	Geology	Epicentral Distance R (km)	PGA (g)
1	855-Y	Umbria-Marche	Italy	5/4/1998	10	4.8	Cubbio-Piene	Free-field	Rock	18	0.235
2	MONT_T	Montenegro	Yugoslavia	15/4/1979	12	6.9	Herceg Novi-O.S.D.Pav.Sch	Free-field	Rock	65	0.256
3	WWT180	N.Palm Springs	USA	8/7/1986	11	6.2	5072 Whitewater Trout Farm	Free-field	Rock	6	0.492
4	Koz95-T	Kozani	Greece	13/5/1995	14	6.5	Prefecture Kozani	Free-field	Rock	17	0.142
5	Thes78_Dec	Thessaloniki	Greece	20/6/1978	6	6.2	THE_6-City	Free-field	Rock	29	0.074

The series of ground sections along the Ring Road is illustrated in Figure 1. As concerns investigation of the bridges’ structural vulnerability, the vulnerability curves have been calculated on the basis of the following lognormal distribution function according to FEMA-NIBS 2003:

$$F(DP \geq DP_i|S) = \Phi\left[\frac{1}{\beta tot} \cdot \ln(\frac{S}{Smi})\right] \quad (1)$$

The Bridge Damage Index (BDI) and Link Damage Index (LDI) were then applied (Table 2) to quantify bridge damage – and the respective network served by the bridge–to the most adverse level which would require redirection of traffic along its network, [2].

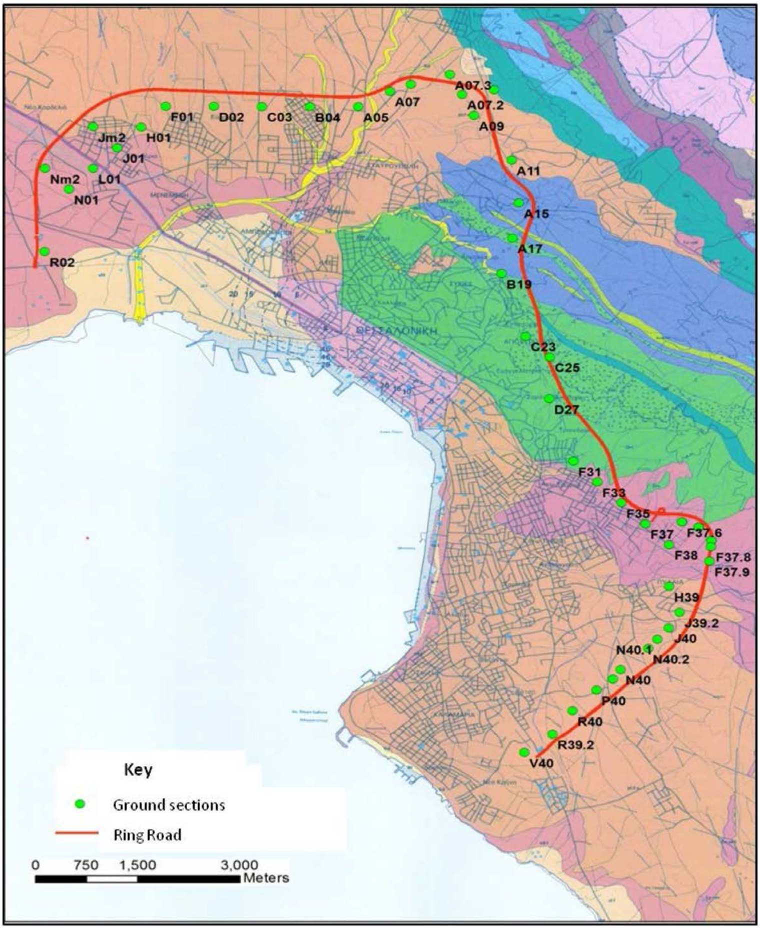

Figure 1 Spatial arrangement of ground sections

Table 2 BDI (Bridge Damage Index) – LDI (Link Damage Index) and traffic flow capacity

Bridge damage level	**BDI (Bridge Damage Index) U.S.A**	**BDI (Bridge Damage Index) Greece**
Low	0.1	0.1
Moderate	0.3	0.4
Extensive	0.75	0.85
Full	1.0	1.0

$$LDI = \sqrt{\sum_{j=1}^{n} (BDI)^2}$$

BDI=the indeks BDI of bridge J for the I network
JI= the numbers of the bridges for the I network

LDI (Link Damage Index)	Capacity traffic flow (U.S.A)	Capacity traffic flow (Greece)
LDI ‹ 0.5	100% (None network damage)	100% (None network damage)
0.5 ‹ LDI ‹ 1.0	75% (Low network damage)	75% (Low network damage)
1.0 ‹ LDI ‹ 1.5	50% (Moderate network damage)	0% (Moderate network damage)
LDI › 1.5	25% (Extensive network damage)	0% (Extensive network damage)

3 Methodology

The analysis results were used to estimate peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD), as well as spectral acceleration Sa for various frequencies, taking also into consideration the respective standard deviation of each measurement. The geophysical, geological and geotechnical characteristics of the area were used as a basis for correlation of the results to neighbouring locations so as to separate the Ring Road into zones of similar seismic ground response and calculate the seismic design parameters at surface level. The analysis results are provided in tables and diagrams which display the spatial rearrangement of traffic. Concerning the identification of the level of bridge damage on the Ring Road, two separate steps should be performed: classification of bridges into categories and estimation of the pertinent vulnerability curves. Following an extensive review of the available methods for classification and estimation of vulnerability curves– at both a national and international level – the most comprehensive method for the present study found to be: FEMA-NIBS using HAZUS software. Consequently, the related details were compiled for the entirety of bridges along the Inner Ring Road, with special reference to those most likely to present the highest levels of damage according to the earthquake scenario under investigation. Finally, the optimum alternative routes- in terms of capacity and environmental aspect–of the area's under investigation road network were defined and an indicative calculation was performed to derive the new travel distances and times respectively, [3].

4 Results

The above mentioned analyses using EERA and STRATA software led to the results presented in Aggregated Data Tables 3 and 4.

Table 3 Aggregated results using EERA software

Site	E	N	PGAo (g)	PGVo (m(s)	PGDo (m)	T=0.2s (g)	T=0.3s (g)	T=0.4s (g)	T=0.5s (g)	T=0.7s (g)	T=1.0s (g)	T=1.2s (g)	T=1.5s (g)	T=1.7s (g)	T=2.0s (g)	T=2.2s (g)	T=2.5s (g)	T=3.0s (g)
A07			-0.424	0.233	0.015	1.277	1.063	0.996	0.775	0.306	0.205	0.143	0.053	0.038	0.040	0.038	0.039	0.024
A07_16.5			-0.371	-0.186	0.008	1.294	1.271	0.840	0.485	0.180	0.128	0.115	0.040	0.035	0.035	0.032	0.035	0.023
A07_35			-0.359	0.238	0.013	1.092	0.816	0.925	0.687	0.213	0.167	0.128	0.047	0.037	0.038	0.035	0.036	0.023
A07_47			-0.410	0.248	0.014	1.477	0.953	0.998	0.679	0.206	0.162	0.128	0.047	0.039	0.039	0.036	0.035	0.023
A07_63			-0.416	0.243	0.014	1.258	0.992	0.968	0.766	0.287	0.197	0.139	0.050	0.038	0.040	0.037	0.038	0.024
F33			-0.284	-0.009	0.000	0.927	0.618	0.516	0.303	0.133	0.115	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F35			-0.273	-0.005	0.000	0.903	0.609	0.511	0.302	0.133	0.115	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F37			-0.266	-0.004	0.000	0.889	0.603	0.507	0.301	0.132	0.115	0.102	0.040	0.032	0.033	0.027	0.034	0.022
F37_0-2			-0.261	0.000	0.000	0.876	0.597	0.506	0.301	0.132	0.115	0.102	0.040	0.032	0.033	0.027	0.034	0.022
F37_0-5			-0.266	-0.002	0.000	0.889	0.603	0.508	0.301	0.132	0.115	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F37_0-10			-0.283	-0.010	0.000	0.921	0.617	0.515	0.304	0.133	0.116	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F37_0-20			-0.342	-0.046	0.001	1.062	0.670	0.543	0.314	0.137	0.116	0.105	0.040	0.032	0.033	0.028	0.034	0.022
F37_2-2			-0.265	-0.002	0.000	0.887	0.602	0.508	0.301	0.132	0.115	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F37_2-5			-0.269	-0.005	0.000	0.901	0.609	0.511	0.302	0.133	0.115	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F37_2-10			-0.293	-0.015	0.000	0.934	0.620	0.517	0.305	0.134	0.116	0.103	0.040	0.032	0.033	0.027	0.034	0.022
F37_2-20			-0.316	-0.046	0.001	1.065	0.670	0.543	0.315	0.137	0.116	0.105	0.040	0.032	0.033	0.028	0.034	0.022
F37_2-30			-0.298	-0.068	0.002	1.181	0.729	0.575	0.328	0.142	0.118	0.105	0.040	0.033	0.033	0.028	0.034	0.022
F37_2-40			-0.306	-0.108	0.004	1.145	0.786	0.615	0.355	0.150	0.121	0.107	0.040	0.033	0.034	0.029	0.034	0.022
J39			-0.397	-0.052	0.001	1.117	0.688	0.553	0.317	0.138	0.116	0.106	0.041	0.032	0.033	0.028	0.034	0.022
N01			-0.302	0.161	0.018	0.771	0.876	0.000	0.621	0.240	0.258	0.211	0.077	0.060	0.051	0.040	0.045	0.029
N40			-0.389	-0.187	0.009	1.203	1.002	0.799	0.469	0.173	0.129	0.116	0.041	0.034	0.035	0.032	0.034	0.023
N40_15			-0.446	-0.098	0.002	1.601	0.814	0.610	0.341	0.145	0.119	0.109	0.042	0.033	0.033	0.028	0.034	0.022
N40_30			-0.408	-0.164	0.006	1.657	1.061	0.729	0.407	0.166	0.126	0.109	0.040	0.034	0.034	0.031	0.034	0.022
P40			-0.390	0.245	0.013	1.621	0.937	0.901	0.607	0.212	0.159	0.127	0.046	0.037	0.038	0.035	0.036	0.023
P40_37			-0.438	-0.211	0.009	1.410	1.263	0.893	0.514	0.185	0.132	0.117	0.041	0.036	0.036	0.033	0.035	0.023
R39			-0.298	-0.174	0.013	1.213	0.861	0.729	0.445	0.235	0.210	0.153	0.056	0.042	0.040	0.033	0.039	0.024

Table 4 Aggregated results using STRATA software

Site	East	North	PGAo (g)		PGVo (cm/s)		PGDo (cm)	
			Mean value m	St. Deviation s	Mean value m	St. Deviation s	Mean value m	St. Deviation s
A05_855			0.329	0.067	24612.989	0.259	3300.104	0.306
A07			0.388	0.088	24325.618	0.267	3254.466	0.322
A07_16.5			0.398	0.054	20674.622	0.153	2755.649	0.331
A07_35			0.360	0.106	22118.123	0.233	3064.301	0.337
A07_47			0.349	0.153	3164.412	0.344	3164.412	0.344
A07_63			0.336	0.124	23823.828	0.278	3216.769	0.332
B04_855			0.376	0.135	23666.364	0.277	3197.397	0.346
C03_855			0.362	0.111	22854.721	0.247	3167.019	0.326
D02_855			0.347	0.104	23173.655	0.237	3206.980	0.321
F01_855			0.355	0.074	24590.776	0.219	3324.345	0.313
F33			0.296	0.161	13603.632	0.170	2568.896	0.300
F35			0.280	0.128	13492.327	0.174	2576.881	0.307
F37			0.273	0.103	13472.810	0.174	2582.420	0.310
F37_0-2			0.250	0.025	13436.348	0.176	2599.117	0.319
F37_0-5			0.266	0.069	13459.748	0.175	2587.262	0.312
F37_0-10			0.283	0.116	13542.723	0.172	2566.440	0.301
F37_0-20			0.311	0.079	14002.724	0.167	2572.493	0.296
F37_2-2			0.262	0.047	13464.719	0.174	2591.908	0.314
F37_2-5			0.277	0.120	13481.299	0.174	2577.364	0.307
F37_2-10			0.288	0.072	13635.394	0.171	2562.730	0.298
F37_2-20			0.320	0.098	14137.672	0.165	2578.705	0.297
F37_2-30			0.324	0.070	14657.435	0.166	2613.781	0.307
F37_2-40			0.316	0.050	15433.829	0.178	2634.071	0.315
H01_855			0.276	0.065	23011.567	0.273	3642.477	0.274
J01_855			0.340	0.099	4064.345	0.305	4064.345	0.305
J39			0.373	0.137	14706.858	0.135	2591.745	0.293
L01_855			0.284	0.081	24658.367	0.294	3926.527	0.286
N01			0.294	0.060	20930.409	0.231	3637.207	0.274
N40			0.383	0.026	19405.501	0.164	2798.368	0.327
N40_15			0.447	0.057	16157.415	0.155	2649.927	0.301
N40_30			0.435	0.095	18415.331	0.136	2718.868	0.321
P40			0.367	0.144	21745.482	0.265	3097.862	0.337
P40_37			0.403	0.053	21112.300	0.157	2867.836	0.319
R39			0.279	0.058	20351.713	0.280	3395.375	0.267

The procedure followed for the seismic risk assessment of bridges on the Thessaloniki Inner Ring Road produced the results summarized in Table 5.

Table 5 Aggregated results of seismic risk assessment

FID	BRIDGE/PLACE	YEAR	SPANS	TYPE	SUPPORT	CONTINUOUS	Sa (1.0 s)	Sa (0.3 s)	P [>=Low]	P [>=Moderate]	P [>=Extensive]	P [>=Collapse]	P [=None]	P [>=Low]	P [>=Moderate]	P [>=Extensive]	P [>=Collapse]	max P[=DS]	Expected D.L.[=]	Expected D.L.[>=]
0	Underpass to cementeries	1990	1	compact slab reinforced concrete	simple mounting	YES	0.27	1.20	0.04	0.02	0.01	0.00	0.96	0.01	0.01	0.01	0.00	0.96	1	1
1	GSC to junction K5 (Hospital Papageorgiou)	2003	1	compact slab reinforced concrete	monolithic	YES	0.28	1.36	0.04	0.02	0.01	0.00	0.96	0.02	0.01	0.01	0.00	0.96	1	1
2	Retziki Street GSC to junction K6	1988	1	beam prestressing concrete	simple mounting	YES	0.19	0.67	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
3	GSC to junction K7, E ptapirgiou Area	1987	1	concrete box intersection	simple mounting	YES	0.19	0.65	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
4	Viaduct (km position. 21+662.07)	1984	1	beam prestressing concrete	simple mounting	YES	0.19	0.65	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
5	Viaduct (km position. 22+576.66)	1984	1	beam prestressing concrete	simple mounting	YES	0.19	0.67	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
6	GSC to Saint Paul Area	1988	1	beam prestressing concrete	simple mounting	YES	0.19	0.65	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
7	GSC A-B section to junction K8 (km position 1+079.58)	2002	7	concrete box intersection	monolithic	YES	0.19	0.65	0.02	0.00	0.00	0.00	0.98	0.02	0.00	0.00	0.00	0.98	1	1
8	Toumpa Area GSC to junction K9	2002	7	concrete box intersection	monolithic	YES	0.19	0.67	0.03	0.00	0.00	0.00	0.97	0.02	0.00	0.00	0.00	0.97	1	1
9	Bridge stream Krioneri	1992	1	compact slab reinforced concrete	monolithic	YES	0.19	0.67	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
10	GSC to junction K10 East Ring Road	1994	1	beam prestressing concrete	simple mounting	YES	0.19	0.67	0.01	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.99	1	1
11	Underpass Ring Road (km position 26+282.00)	1990	1	compact slab reinforced concrete	simple mounting	YES	0.42	0.80	0.14	0.08	0.04	0.01	0.86	0.06	0.04	0.03	0.01	0.86	1	1
12	Pilaia-Panorama street GSC to junction K11	1990	2	slab with cydically interstices concrete	simple mounting	YES	0.21	1.15.	0.04	0.00	0.00	0.00	0.96	0.03	0.00	0.00	0.00	0.96	1	1
13	N.Diagonios Grade Separated Crossing (GSC) to junction K12	1992	3	concrete box intersection	simple mounting	YES	0.36	0.92	0.53	0.30	0.20	0.07	0.47	0.22	0.11	0.13	0.07	0.47	1	2
14	Carriageway A of N.Diagonios GSC to junction K12	1992	3	concrete box intersection	simple mounting	YES	0.36	0.92	0.53	0.30	0.20	0.07	0.047	0.22	0.11	0.13	0.07	0.47	1	2
15	Underpass Section A to junction K12	1992	1	beam prestressing concrete	simple mounting	YES	0.36	0.92	0.09	0.05	0.03	0.01	0.91	0.04	0.03	0.02	0.01	0.91	1	1
16	Monastiriou Street GSC to junction K17	1978	7	beam prestressing concrete	form type GERBER	NO	0.46	0.95	0.85	0.66	0.49	0.23	0.15	0.19	0.16	0.27	0.23	0.27	4	3
17	Lagkadas Road Interchange (I/C) to junction K18	1985	10	beam prestressing concrete	simple mounting	NO	0.33	1.03	0.68	0.49	0.33	0.12	0.32	0.19	0.16	0.21	0.12	0.32	1	2

By analysing the values of the table of results one can conclude that the expected performance of almost all the bridges under a possible seismic excitation is deemed as satisfactory. Nevertheless some of these call for special attention, due to their expected level of damage. Specifically, these bridges are:

1 N. Diagonios Grade Separated Crossing (GSC) to junction K12;
2 Carriageway A of N. Diagonios GSC to junction K12;
3 Monastiriou Street GSC to junction K17;
4 Lagkadas Road Interchange (I/C) to junction K18.

The purpose of the study was to identify the anticipated seismic damage to Thessaloniki bridges; to this end, only two bridges were examined, those being the ones presenting the highest levels of damage for the basic earthquake scenario with a mean recurrence interval of T_m=475 years, as shown in Figure 2. Specifically, the GSC of Monastiriou Street at junction K17 was assessed to sustain extensive damage (BDI equal to 0.85), while lower damage is expected at the I/C of Lagkadas Road at junction K18 (BDI equal to 0.1).

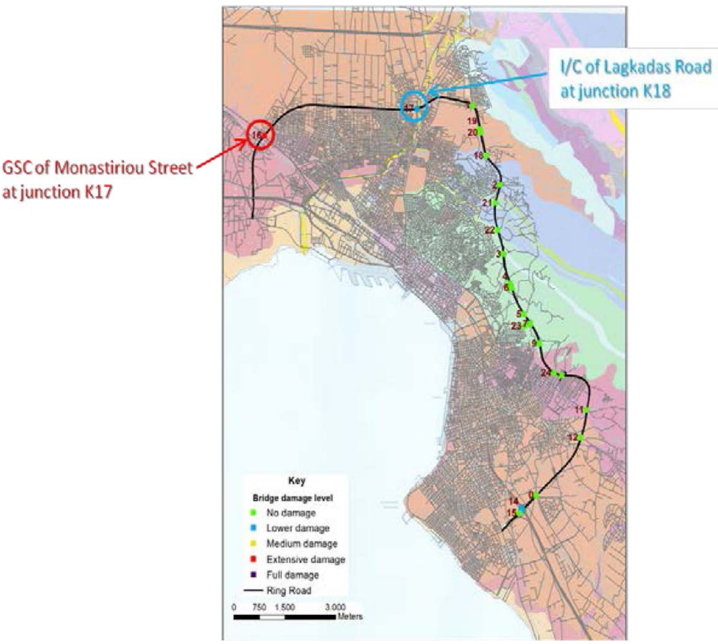

Figure 2 Visual representation of locations and bridge damage level on the Inner Ring Road

Using the BDI and LDI indices:

$$\mathrm{LDI} = \sqrt{0.85^2 + 0.1^2} = 0.86 \qquad (2)$$

Consequently, as concerns the local bridge network under investigation, the level of damage is expected to be low, since the LDI index was found equal to 0.86 and according to Table the traffic flow capacity will be reduced to 75% of its total. This data was the basis for proposing the respective traffic rearrangement scenarios in the event of roads being blocked due to repairs on the two bridges that were examined extensively. Thus at Lagkadas Road I/C there is zero increase in the new length of the alternative route, owing to the existence of a side road of satisfactory traffic capacity, whereas at Monastiriou Street GSC there is a moderate increase in the new travel distance in the eastward direction (1.90 km instead of 1.30 km) and a great increase in the westward direction (5.40 km instead of 1.30 km). Moreover, the new travel distances, in conjunction with reduced traveling speeds due to the poor geometric characteristics of the alternative road segments (45 km/h as opposed to 90 km/h) lead to two-fold (0.73 min instead of 0.37 min, Lagkadas Road I/C) or even 9-fold (7.2 min instead of 0.87 min, Monastiriou Street GSC in westward direction) travel times respectively.

5 Conclusions

In conclusion, the results of the present investigation contribute towards three interesting topics, i.e. the assessment of the seismic hazard of the area, the examination of the structural vulnerability of the bridges and the impact of the redirection of traffic on the adjacent urban road network in case of bridges failure. Concerning the assessment of the seismic hazard of the area it was found that the maximum PGA with an average value of 0.447 g at ground surface is expected on the eastern part of Thessaloniki, within the boundaries of the Municipality of Kalamaria. As concerns the study of structural vulnerability of bridges along the Inner Ring Road, these are as a whole in satisfactory condition and are not expected to sustain serious damage in a potential seismic excitation under the examined earthquake scenario, with minor exceptions. Finally, concerning the impact of the redirection of traffic on the adjacent urban road network the main finding is that the lack of a sufficient transportation infrastructure in the Urban Agglomeration of Thessaloniki does not provide with alternative routes of appropriate capacity in case of the closure of critical elements-as the case of bridges- leading thus to increase in travel time and cost and generally to users' inconvenience during the period of repair works.

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