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# IMPORTANCE OF TRANSPORTATION SYSTEMS AND OTHER LIFELINES FOR EARTHQUAKE DISASTER PREPAREDNESS

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## ABSTRACT

The development of emergency response capability based on proper disaster preparedness strategy rather than pure engineering mitigation is preferable due to the low economic strength of the country and insufficiency of engineering mitigation measures, as manifested in recent major seismic events in the world. A comprehensive multisectoral pre-disaster planning considering the performance of lifelines will greatly improve coordination, mitigate sectoral conflicts and overlaps and rapidly advance the recovery period. Required elements for such a planning process, based on behavior of transportation and selected water supply systems, as vital components for assuring the decided level of emergency assistance and public health in immediate post-earthquake conditions, are defined through composite seismic hazard and risk assessment for the region of Western Macedonia.

## KEYWORDS

seismic risk; disaster preparedness; lifelines; transportation system; water supply system

## INTRODUCTION

Disaster preparedness is a component of emergency management concerned with the extrinsic factors of hazards i.e. the causes of the vulnerability of community. Considering the characteristics of earthquakes as natural hazards the disaster preparedness is emphasized as a most efficient mechanism in enhancing the level of readiness to respond to any emergency (managerially and technically). Historical evidence indicates that during a major seismic event significant human casualty, million of dollars in property loss and vital lifeline systems disruption may instantaneously occur. "During and following a major damaging event communities are immediately confronted with the complexities of changing conditions, competing priorities and unexpected demands" (Lagorio, 1994).

The seismic performance and restoration of lifelines (water supply, sewerage, gas supply, electric power, communications, transportation) and emergency public services (hospitals, fire and police forces) are two of the most critical components in a community's capacity to mount successful response actions and operations during the immediate post-earthquake recovery period. While the damage of buildings is often more spectacular, it is the damage and failure of utility and other lifelines that pose the greatest hazard to public health (water supply and sewerage) and public safety (gas supply); lead to chaos and an increase in the potential for occurrence of various secondary disasters, decrease the efficiency or even suspend disaster relief operations. The restoration process of lifelines is the most difficult, expensive and time consuming due to their physical and functional interaction. Consequently, comprehensive and multisectoral pre-disaster planning considering the performance of lifelines in a such process will greatly improve coordination, mitigate sectoral conflicts and overlaps and rapidly advance the recovery period.

## SEISMIC RISK ASSESSMENT

The results from the composite hazard and risk assessment for the region of Western Macedonia have recently become available and used for defining the Elements for Disaster Preparedness Planning and organization of the activities of the Macedonian Red Cross for the region of Western Macedonia (Petrovski and Milutinovic, 1994 and 1995). Analyzed and incorporated in such a planning process was the behavior of lifelines (transportation and selected water supply systems) as vital components for assuring the decided level of emergency assistance and public health in immediate post-earthquake aftermath.

### Seismic Hazard Analysis

The entire territory of Macedonia, as a part of Alpine-Himalayan belt in the East Mediterranean orogene zone is exposed to strong earthquakes originating from 10 dominant autochthonous seismic sources as well as seismic sources located in bordering regions of the country. Based on the data on seismicity of Macedonia, seismic hazard analyses are performed for three characteristic return periods that generally comply with the requirements of the Aseismic Design Code of the Republic of Macedonia, i.e.:

- Frequent Scale Earthquake (FSE) - the earthquake expected to occur within 5 years return period with 10% exceedance probability;
- Moderate Scale Earthquake (MSE) - the earthquake expected to occur within 10 years return period with 10% exceedance probability; and
- Large Scale Earthquake (LSE) - the earthquake expected to occur within 50 years return period with 10% exceedance probability.

### Vulnerability and Risk Analysis of Urban Water Supply Systems

Urban water supply systems in Macedonia have mostly been developed during the last 30 to 40 years parallel to the growth of the urban areas and the economy of the country. In general, they have been designed and constructed according to modern standards fulfilling the prescribed technical and sanitary conditions. Almost all town and large rural water supply systems use water from near-by spring catchments or underground wells. The diameters of the main and distribution water supply pipelines are in the range D=100-200 to 1600 mm. The most commonly used are asbestos-cement (AC), polyvinilchloride (PVC) and cast iron (CI) pipes as well as steel pipes (ST). The steel pipes are connected by welding, while connection of pipes constructed of other materials is performed via sockets or slaves. The diameters of the service water supply systems, supplying water to end users are considerably smaller, ranging from D=20-25 mm to 60-100 mm. The most commonly are used steel zinc-plated tubes, recently PVC and AC pipes. The burial depth of main and distribution water supply pipelines is generally 1.0-1.2 meters for pipes of smaller diameter, while for large diameter pipes it is 1.2-1.5 m. Characteristic to all urban water supply systems for which the data were available, are heavy losses of water, amounting to even 40%, due to leakage caused from loosening of connections and damages due to soil instabilities, traffic-induced vibrations, corrosion, etc.

The seismic vulnerability and risk assessment of the urban water supply systems have been made for selected urban areas (municipalities of Skopje and Ohrid) considering only the main and the distribution pipeline networks that make a certain functional entity, since their damage jeopardizes the function of the entire water supply system or its larger service components.

Although the data for consistent vulnerability and risk analyses of urban water supply systems were unavailable, in particular the configuration of the water supply networks in relation to local geotechnical conditions, an attempt is made to quantify the number of breaks due to the vibration effect only. Large ground deformations, liquefaction and the other effects that can affect the function of the water supply systems have not been considered.

For urban regions of municipalities of Skopje and Ohrid and the adopted MSE and LSE earthquake scenarios, the expected number of failures for asbestos-cement (AC), cast iron (CI) and steel (ST) pipes of the main and distribution pipeline networks are presented in Table 1. For analyzed total length of about 206 km, the expected number of failures related to effect of the ground vibrations only and the average soil conditions is estimated at 59 (0.286 failures/km) for MSE and 110 (0.534 failures/km) for LSE scenario. For terrains of unfavorable ground conditions (municipality of Ohrid) susceptible to various modes of ground failures the higher seismic risk than estimated shall be expected.

Table 1. Expected number of failures of Skopje and Ohrid main and distribution water supply networks (Petrovski and Milutinovic, 1994 and 1995)

| Municipality | Total length (km) | Scenario | Estimated intensity (MMI) | Pipe material | | | Total |
|---|---|---|---|---|---|---|---|
| | | | | AC | CI | ST | |
| Skopje | 156.7 | MSE | 7.8 | 2 | 19 | 23 | 44 |
| | | LSE | 8.7 | 3 | 32 | 50 | 85 |
| Ohrid | 49.2 | MSE | 7.9 | 1 | 6 | 8 | 15 |
| | | LSE | 8.6 | 2 | 9 | 14 | 25 |

Vulnerability and Seismic Risk of Transportation System

Considering the importance of the transportation system for communication and normal post-earthquake function of all activities in the country, or some of its regions, the existing network of highways, principal and regional roads of Republic of Macedonia has been analyzed as the principal element at risk. The transportation network of the Republic of Macedonia is generally developed for the last 50 years. Based on the data from the National Road Network Authority, the total length of the principal and regional road transportation network in Macedonia is 2,331 km, out of which 942 km (44.4%) are highways and principal roads and 1,389 km (59.6%) are regional roads. 255 km (27.1%) of the principal roads pass through solid rock formations, 111 km (11.8%) through degraded rocks and 576 km (61.1%) through sedimentary rock formations or recent soil deposits. 671 km (48.3%) of the regional transportation network pass through solid rock formations, 249 km (17.9%) through degraded rocks and 469 km (33.8%) through sedimentary rock formations or recent soil deposits.

Based on:

- Analysis and synthesis of post-earthquake field survey data as well as of data on dynamic soil instabilities (landsliding, rocksliding, rockfalling, slope instabilities, etc.) occurred in past earthquakes as reported in the literature or by authorized institutions;
- Analysis and synthesis of macroseismic data in terms of intensity and corresponding iso-accelerations, as well as strong motion data from past earthquakes causing dynamic soil instabilities of various kinds; and,
- Analysis and synthesis of wide volume of field and laboratory data on dynamic behavior of various kinds of soil materials under dynamic loading,

derived is the criteria for estimation of the dynamic soil instability potential (Table 2, Petrovski and Milutinovic, 1994 and 1995), and for considered earthquake scenarios estimated are: 1) the dynamic soil instability potential at regional scale for the transportation network of the Republic of Macedonia, and, 2) the critical sections of high and moderate dynamic soil instability potential.

Table 2. Criteria for Estimation of Dynamic Soil Instability Potential (Petrovski and Milutinovic, 1994 and 1995)

| Mark | ZONE | | | Geotechnical Media | max acc (g) |
|---|---|---|---|---|---|
| | Instability Potential | Description | Index | | |
| LP | Zone with LOW POTENTIAL for dynamic instability | Probability for occurrence of dynamic instability is very low | r | The geotechnical media of this zone is composed of highly consolidated sediments as well as magmatic and metamorphic rock complexes | < 0.15 |
| | | Probable instability in exceptionally rear cases at limited microlocalities | s | The geotechnical media of this zone is composed of unconsolidated recent sediments | |
| MP | Zone with MODERATE POTENTIAL for dynamic instability | Possibility for occurrence of rockfalls, rockslides and landsliding of surface weathered rock materials | r | The geotechnical media of this zones is composed of consolidated sediments, metamorphic schists and volcaneous, but with frequent presence of zones with surface withering and degradation | 0.15 - 0.30 |
| | | Possibility for occurrence of landslides, slope instability, densification and liquefaction | s | The geotechnical media of this zone is composed of unconsolidated young quaternary and recent sediments | |
| HP | Zone with HIGH POTENTIAL for dynamic instability | There is a great possibility for rock falls, rock slides and sliding of surface weathered rock materials | r | The geotechnical media of this zone is composed of older sediments, metamorphic and volcaneous rock complexes, but with presence of greater zones of weathered and degraded rock masses | > 0.30 |
| | | There is a great possibility for: landslides, slope instability, densification, liquefaction and etc. | s | The geotechnical media of this zone is composed of unconsolidated neogen-quaternary and recent sediments | |

The critical sections of principal and regional transportation network are determined based on two level estimates: 1) The upper bound (UB) that considers that certain modes of high dynamic instability potential can occur even in compact rock masses; and, 2) The lower bound (LB) that excludes the possibility for high dynamic instability potential in compact rock masses when exposed to high dynamic excitation level, i.e., the estimated HP figures are relocated to MP potential class.

For principal transportation network the UB estimates isolate about 28.3% for MSE and 89.1% for LSE of its 942 km total length as critical (Tab. 3, Fig. 1). The corresponding LB estimates (Tab. 3, Fig. 2) are 182 km (19.3%) and 622 km (66.0%). For regional transportation systems and MSE scenario, the UB estimates identifies 461 km (33.2%) as critical, whereas the LB 235 km (17.0%). The corresponding values for LSE scenario are 1,126 km (81.1%) and 598 km (43.1%).

Table 3. Upper and lower bound estimates of dynamic soil instability potential (Petrovski and Milutinovic, 1994 and 1995)

| Transportation route | Total length (km) | MSE | | LSE | |
|---|---|---|---|---|---|
| | | UB (%) | LB (%) | UB (%) | LB (%) |
| Principal | 942 | 28.3 | 19.3 | 89.1 | 66.0 |
| Regional | 1,389 | 33.2 | 17.0 | 81.1 | 43.1 |

Irrespective of the estimate type (UB or LB), there is high probability that in the case of MSE earthquake the regions of Debar, Struga and Ohrid in West and South-West Macedonia (Figs. 1 and 2), as well as the regions of Gradsko, Valandovo-Gevgelija-Dojran, Strumica, Berovo and Pehcevo in the South and South-East Macedonia will be inaccessible (blocked). For LSE scenario, the situation is even worse, the blocking potential is significantly increased implying the possible blockage of many municipal centers including the city of Skopje.

## ELEMENTS FOR EARTHQUAKE DISASTER PREPAREDNESS

### Water Supply Systems

Water supply systems are important for the functioning of emergency services such as fire suppression activities, police services, hospitals and entire health care system, and emergency operation services; livelihood of individuals and the economic well-being of business and industry. Level of sanitation and some of the actions taken in epidemics prevention are strongly dependent on their functioning.

Seismic risk analyses of water supply systems of two stated municipalities indicate the following:

- The water supply system in the municipality of Ohrid (43,000 inhabitants) is estimated as unreliable with high probability of loss-of-function in the case MSE and LSE scenario earthquakes. Due to the unfavorable soil conditions (soft lacustrine sediments) the probability that the estimated figures will be exceeded is very high.
- The level of seismic risk of water supply system in the municipality of Skopje (563,102 inhabitants) is also high due to high concentration of lifelines, lifeline interaction, concentration of population and other material properties.

The activities necessary to be taken in the immediate post-earthquake period are the following:

- Development and construction of utility's Emergency Operation Service;
- Comprehensive assessment of damage potential and loss-of-function of the water supply systems and interaction with other regional and urban lifelines;
- Identification of facility hazards and water-quality health related problems;
- Designation of alternative water sources and construction of backup systems for larger urban centers;
- Development and implementation of emergency media communication procedures (on-time public information on the functioning of the water supply system, quality of drinking water and other relevant information); and
- Training of public, development of public awareness and community skills for self-management capacity.

### Transportation Systems

The importance of roads and urban transportation network in post-disaster conditions becomes paramount since their accessibility controls the efficiency and the scale of the emergency assistance to be provided in the very immediate post-earthquake emergency and relief period.

The health priorities for emergency response such as:

- search and rescue, triage, medical evacuation and hospitalization, hospital emergency care;
- activation of surveillance system (rapid needs assessment);
- special services for homeless and displaced (food, sheltering); and
- care of dead

are strongly dependent of sustainability of urban transportation networks.

The possibility that disaster susceptible region might be blocked during the immediate post-earthquake period, due to the secondary (geologic) hazards, requires specific and self-dependent organization of disaster relief institutions. Consequently, the estimates of accessibility of the vital transportation routes in earthquake prone regions is of utmost importance not only for planning of effective and on-time disaster relief operations, but also for organization of Government Agencies and NGO's at municipal or regional level, as well as for the planning of necessary resources to be sufficient until the function of transportation system is restored. The sustainability of communications in such conditions is greatly emphasized.

The high potential of disturbed functioning of the transportation system in Western Macedonia might be expected in the vicinity of municipalities of Debar, Ohrid and Struga (Figs. 1 and 2). In this way, the stated municipalities should be considered isolated and self-dependent with significantly reduced accessibility to rural areas.

### Disaster Preparedness Strategy

The development of emergency response capability based on proper disaster preparedness strategy rather than mitigation is preferable due to low economic strength of the country and malfunction of engineering mitigation measures manifested in recent major seismic events. Consequently, the following main directions considering the importance of lifelines in developing proper disaster preparedness strategy of the Republic of Macedonia are:

- Provision of indispensable resources for self-dependency of regions susceptible to geologic hazards and strengthening the level of readiness and alert of emergency response units and services to cope effectively until extrinsic aid and assistance becomes available;
- Development of sustainable communication system;
- Stockpiling of critical materials in particular of the vulnerable components such as repair parts;
- Training and simulation exercises of available personnel for effective reconnaissance and repair work;
- Dissemination of updated technical information related to particular hazards;
- Establishment of early warning and information systems; and
- Establishment of secondary command headquarter, in the case the main command center is damaged or inaccessible.

## CONCLUSIONS

Disaster preparedness strategy has been developed considering the importance of transportation and water supply systems in emergency response operations during immediate post-earthquake recovery period. Required elements for such a planning process are obtained through composite seismic hazard and risk assessment for the region of Western Macedonia. Analyzed water supply systems have shown high level of seismic risk basically due to soil instabilities, high concentration of population, as well as shortage of high quality water supply, especially in summers. By maintaining proper stockpiling of critical materials, vulnerable parts and training of available personnel for reconnaissance and repair work the restoration process will greatly advance. The possibility that disaster susceptible region might be isolated during the immediate post-earthquake period, due to the secondary (geologic) hazards, requires specific self-dependent organization of disaster relief institutions, providing indispensable resources and strengthening the level of readiness and alert of emergency response units and services to cope effectively until extrinsic aid and assistance becomes available.

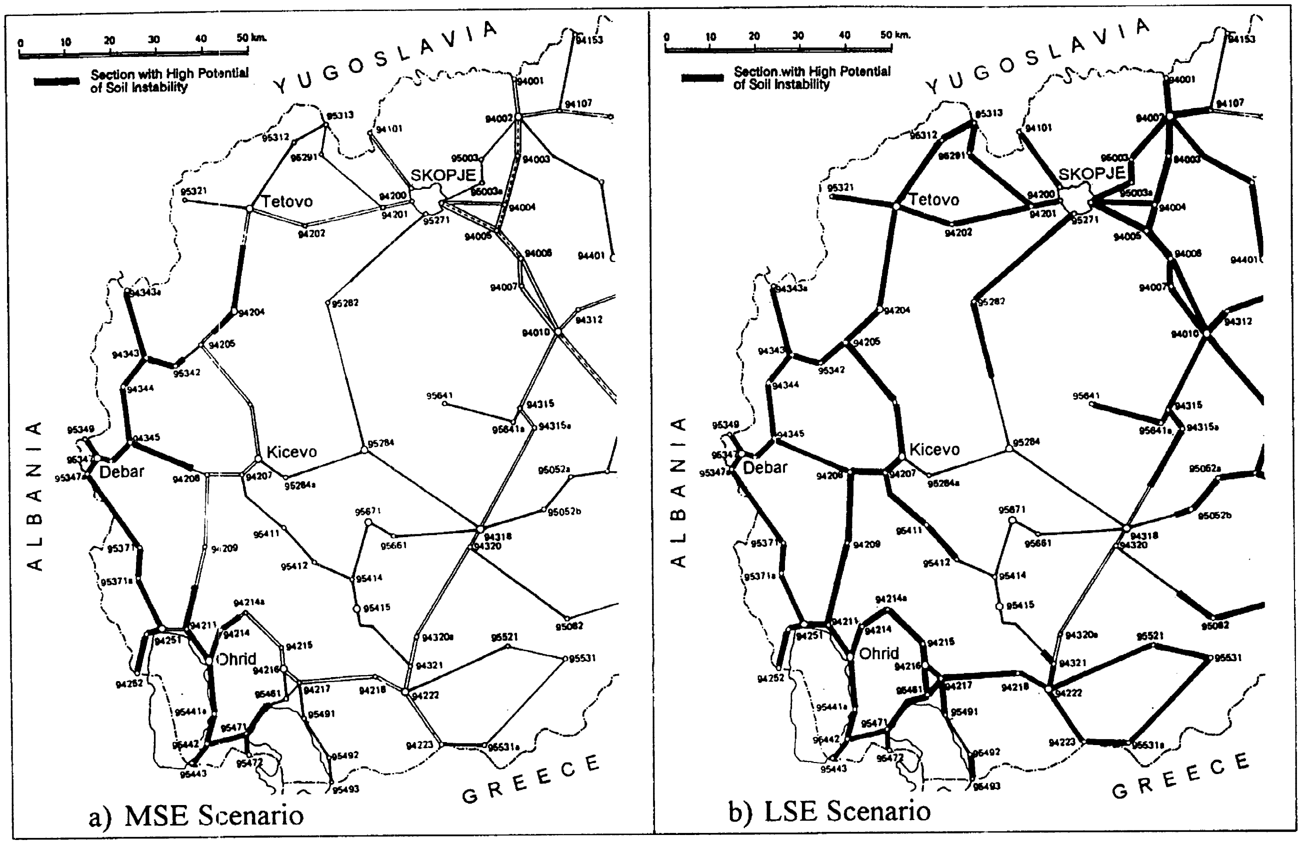


Fig. 1 Section of high dynamic soil instability potential of vital transportation routes - Upper bound estimate

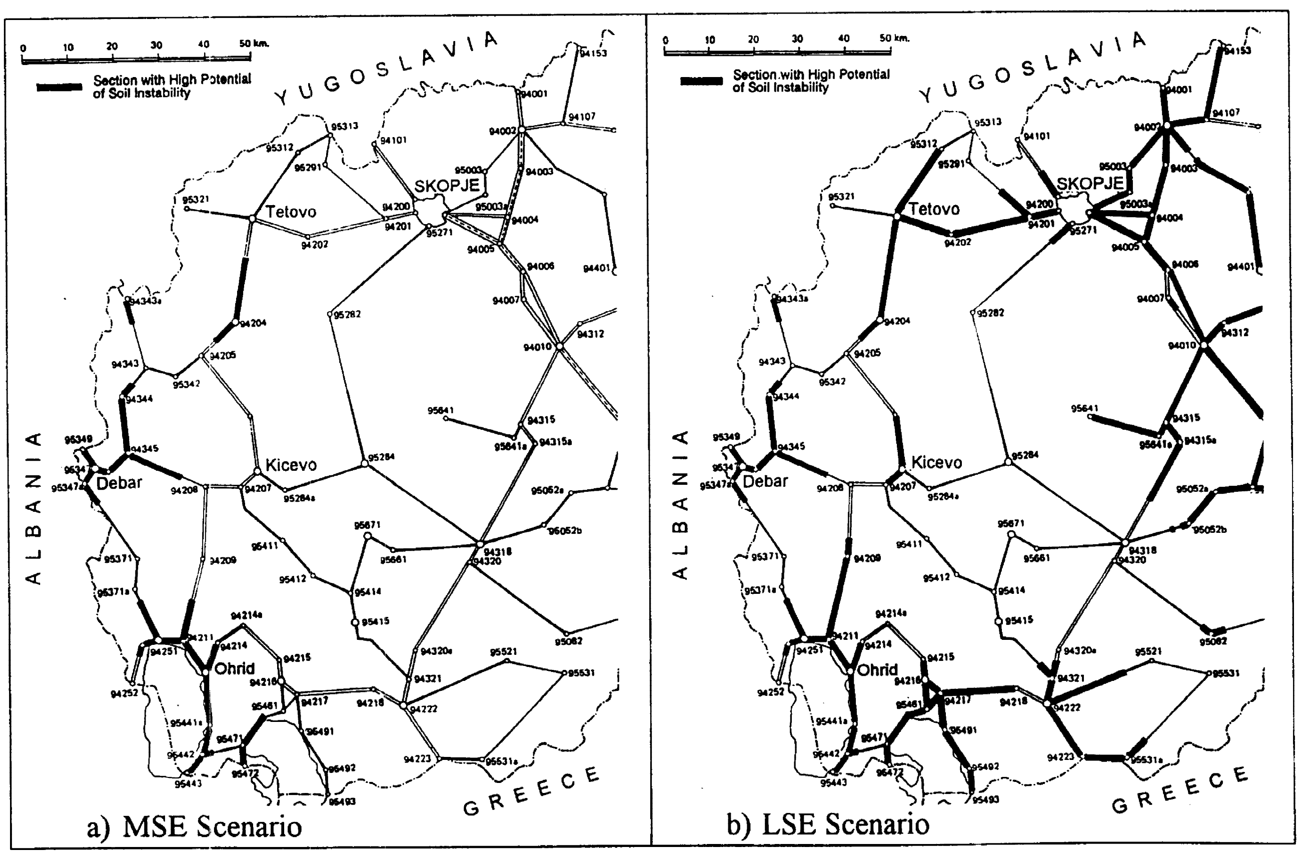


Fig. 2 Section of high dynamic soil instability potential of vital transportation routes - Lower bound estimate

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