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Research Article

Seismic early warning systems for the transport cascade under the “SHIPKA” pass

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Abstract

The report presents an early warning system against earthquakes of the conceptual design of the tunnels under the “Shipka” Pass. Bulgaria gives many victims on the roads - those killed in traffic crashes and accidents. In the case of tunnel facilities in seismic areas, chain accidents in tunnel pipes are particularly dangerous. Early warning systems for tunnels make it possible to immediately stop traffic by the traffic police or automatically, to include additional ventilation equipment and turn on the additional reserve lighting installations.

Introduction

The idea of digging a tunnel under the „Shipka“Pass dates back 125 years. The tunnel will connect the road networks of Northern and Southern Bulgaria and is the most important transport facility in the country (7 million inhabitants) at the beginning of the 21st century. The Early Warning Systems against earthquakes are most particularly effective in tunnel structures [1-12]. Tunnel “Shipka” Pass (transport cascade – four tunnels, retaining walls, bridges) will connect the road networks of Northern and Southern Bulgaria and is the most important transport facility in the country (7 million inhabitants) at the beginning of the 21st century [9-11]. Crisis Management. Early Warning Seismic Systems are the most particularly effective in the tunnel structures [9,10].

“The Ghost Larissa” [11]

The article [11] describes the state of early warning systems in the World, Europe and the Balkans Figure 1. The map in Figure 2 shows that in the modern era is an observed tendency of increased seismic activity. For now, it is very predictable.

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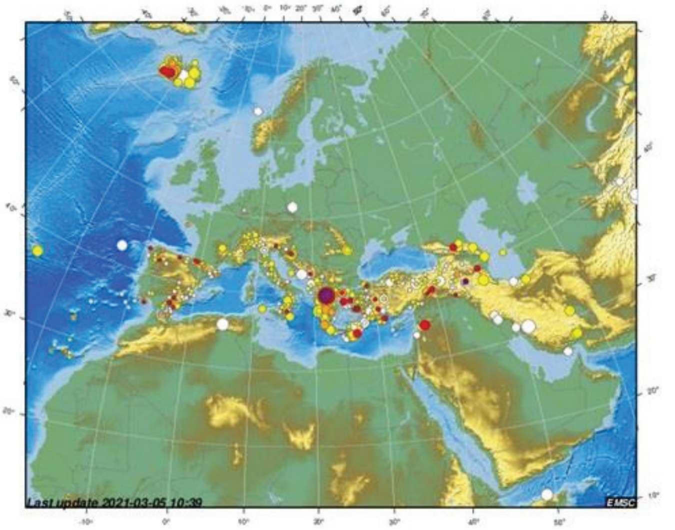

Figure 1: 1200 earthquakes in two weeks in the Larissa region. Early warning systems have been set up all around us - Sofia is lagging.

A virtual kinematic early warning system in case of a strong earthquake - Figures 3-5

On March 4, 1977, at 21 hours and 4 minutes happens an earthquake with a magnitude of M=7.2 and with the epicentre of Mountain Vrancea (Romania) [1]. The victims on the territory of Romania and Bulgaria are thousands. Half a century later, two trends were formed for the protection of engineering structures from seismic impacts. The first trend is related to the idea of the creation of systems for assessment of the future seismic activity in a given area [8,9]. The second trend involves the construction of an early warning system for earthquakes [12]. This report examines the construction of an early warning system for the “Shipka Pass”. An example of earthquakes in the area of Larissa [11] convinces us that it is useful to build Bulgaria a system for early warning of earthquakes in the area of the transport cascade of the “Shipka Pass”.An important element of modern transport is traffic accident analysis and

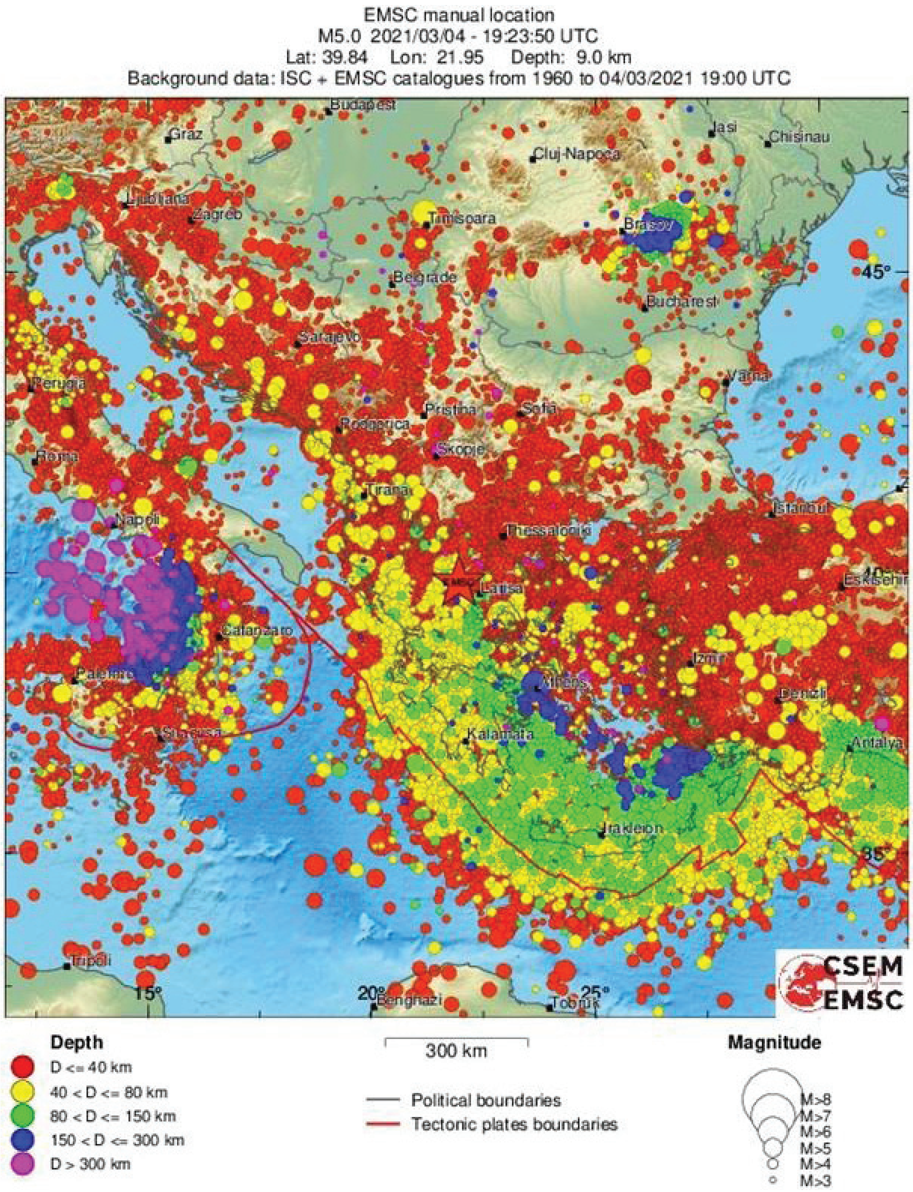

Figure 2: Earthquakes map in the Balkans over the last 60 years.

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accident prevention and investigations in these areas. Some common signaling systems can also be used for early warning of earthquakes [2,9,10,12] Figure 3.

All known Seismic Early Warning Systems (SEWS) is based on the fundamental physical property of the seismic wave's propagation: the P-waves (with lower amplitudes and smaller destructive potential) travel approximately 1.41 times faster than the S waves. The P-waves have compression/extension movements of the particles of the solid strata and move to the ray propagation path. These waves are the fastest and have the highest velocity – between 6 and 8 km/s. The amplitudes of the P-waves are frequently the lowest in the whole phase package of any seismic wave emitted by the seismic source. The S-waves - with several times larger amplitudes and much more destructive potential due to the medium particle movement perpendicular to the wave ray propagation have lower velocity, the lowest in the whole phase package of any seismic wave emitted by the seismic source. The S-waves - with several times larger amplitudes and much more destructive potential due to the medium particle's movement perpendicular to the wave ray propagation have lower velocity. The S-waves also do not propagate through liquids. The range of the Vs and Vp according to the theory is $2^{-1/2}$ The equation:

$$Vp/Vs = 2^{-1/2} \quad (1)$$

Is the fundamental relationship on which functioning of the kinematic SEWS. This relationship always exists in the solid ideal body and is an immanent property of any ideal elastic medium. Frequently in the earth's crust, this relationship shows a smaller value due to the not ideal elasticity of the Earth's strata. The travel time function F (d, $t_{p,s}$) presents the relationship between the travel times of the different wave phases (S, P, Sg, Pg, Sb, Pb, etc.) and the distance to the seismic source. The function in the coordinate system (d, t) is usually a straight line, depending on the velocity of the seismic waves in the respective layer. The travel time function is the main relationship, which is used to calculate the kinematic models of the time deficit EWS. The main principle of the SEWS requires longer time propagation from the seismic source to the threatened territory, which means a longer distance. This time (t_p-t_s) is called "warning time" and presents the difference between the P and S wave's arrivals to the threatening object. In the real environments, the relation (1) can be written in a more general form:

$$\lim_{V_p,V_s,\to V_{p0},V_{s0},} \frac{V_p\left(\omega,E,t\right)}{V_s\left(\omega,E,t\right)} = k\left(r,\omega,E,t\right), \quad (2)$$

where t - is the time parameter, V_p, V_s, k – are the real functions, r – is the distance, ω - are the frequency properties of the medium, E – are the rheological properties of the medium, V_{po}, V_{so} are boundary values. Of course, in the case of real early warning systems, the formula (1) is used and the k is a constant k = $2^{-1/2}$ The formulas (1) and (2) (reflection and refraction processes) are investigated in detail in [2,9,10] theoretically and experimentally – see Figure 3 in the time and the frequency domain.

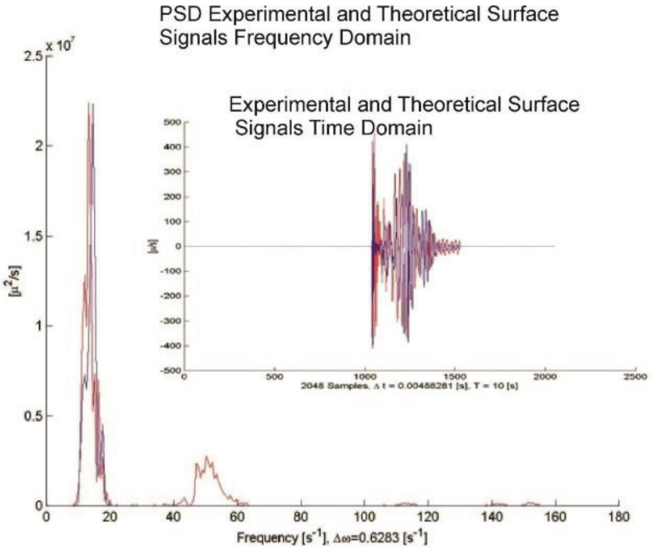

Figure 3: Theoretical and experimental signals – the difference is less than 1 % [2,9,10].

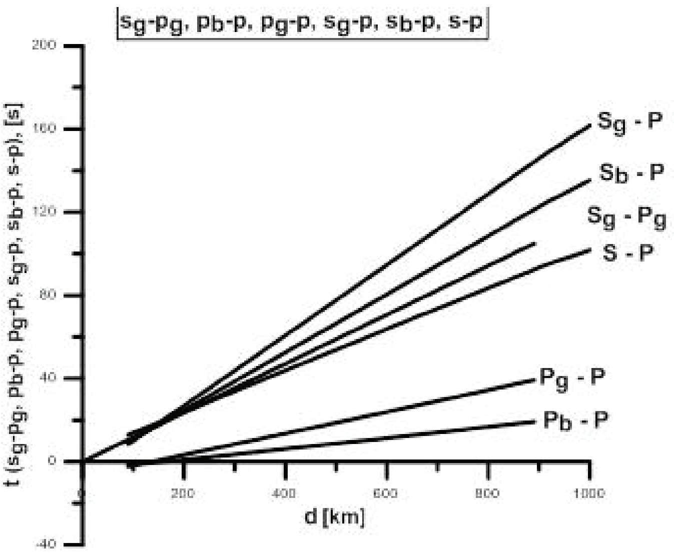

Figure 4: The example of the different S, and P travel times differences and their phases according to the distance.

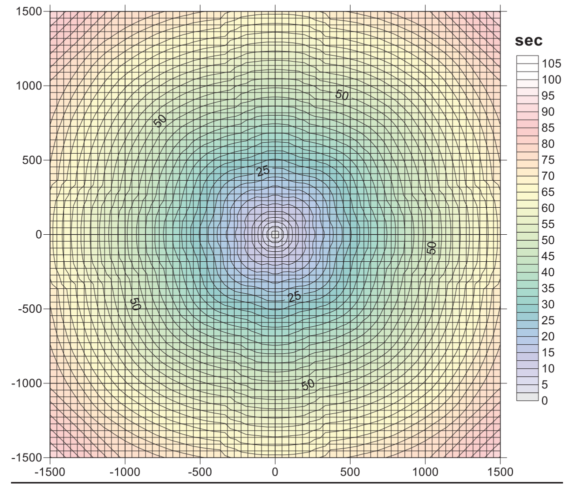

Figure 5: The example of the different S, and P travel times differences and their phases according to the distance.

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A virtual kinematic model for the Bulgaria seismic sources

Sofia, Kresna, Plovdiv, Gorna Oriahovitca, Shabla.

The Bulgarian virtual kinematic model for SEWS is developed in [12]. To build up such a kinematic model several seismic sources are outlined (these are coinciding with the approximate locations of the real earthquake sources on Bulgarian territory) and presented in the following Table 1.

Table 1: Approximate locations of the real earthquake sources on Bulgarian territory.

N	Seismic Source	Coordinate φ [N]	Coordinate λ [N]	Depth [km]
1	Sofia	23°20'00"	42°40'00"	10
2	Kresna	23°10'00"	41°50'00"	10
3	Plovdiv	25°00'00"	42°10'00"	10
4	Gorna Oriahovica	25°50'00"	43°10'00"	10
5	Shabla	28°30'00"	43°30'00"	10

The functional intended algorithm

The algorithm is developed on the basics described in the beginning paragraph and considers the different velocities of the P and S waves.

The installation of the hardware needs to follow some general considerations

The installation of the hardware needs to follow some general considerations: 1. Selection of the locations according to the seismic sources geography. 2. Travel times curves for the transformation of the distances to the time domain. 3. Use of the P-waves times for the signalization of the event and triggering the whole system. 4. Seismic station optimization according to the seismic sources' locations and common use (in some cases) of the same equipment (if possible): 4.1. The trigger stations are located to the nearest point of any epicentre. 4.2. Use of some station's locations of the equidistant travel times to the seismic sources. 4.3. Peripheral stations for detection of the strong seismic motions with sources outside the network geometry. The general steps of the algorithm follow the philosophy that it is essential to have a signal for the hazardous event (earthquake) as soon as possible after its generation. As the seismic P, S - waves velocities are in the range of km/sec it is essential to have a seismic sensor as possible to the nearest point of the epicentre. When the threshold is considered for the dangerous event, if the registered level is higher, then the whole algorithm is triggered. Then the following steps are necessary: 5. P-wave's signal detection that the event is generated and the waves are propagated. (Usually such signal triggers the entire network). 6. Modelling of the wave's propagation direction, following the consecutive triggered seismic devices. 7. Modelling of the time of incoming S-waves (for the SEWS) and the time delay of the S-waves, following the P waves. Zonation to near distance, middle distance and long-distance and introduction of the "red", "orange", "yellow", and "green" signalled zones-Figures 6, 8. The decision for the warning issue – the decision matrix development. 9. Warning issue to the clients – population, civil defence authorities, decision-makers, administrations, etc.-Figure 7, 10. The transmitting possibility of the warning is in various ways – SMS, i-phone ads, e-mail message, pager signal, TV, radio emissions, sound or light signals, etc. 11. Cancellation of the warning after the event passed.

To perform these algorithms a lot of specific actions must be performed. The most important one is the hardware (devices) installation as possible closer to the seismic source. This could be a specialized seismic strong motion device or the nearest seismic station of the national seismological network.

Study the area of the "Shipka pass" through the offered kinematic model

The main result of the study is the calculated differences Ts-Tp [s], shown in Table 2 for the „Shipka" pass region.

Conclusion

The Crisis Management scientific area shows that the early seismic warning systems are particularly effective in transport construction and building of tunnel structures. When the appearance of a "P" wave, the tunnel structures can be immediately put in emergency mode. Traffic police immediately stopped the movement of vehicles in both directions and directed them to spare parking lots at the two ends of the tunnel. The probability of chain accidents in tunnel pipes is reduced. Reserve additional ventilation equipment is included. Reserve electric battery systems are included. If it is necessary, emergency restoration work begins immediately. At both ends of the tunnel are organized sites for emergency landing and helicopter takeoff. The situation is controlled by the traffic police, and drones can be placed in the tunnel pipes. The operation of tunnel structures can be insured with various new types of insurance.

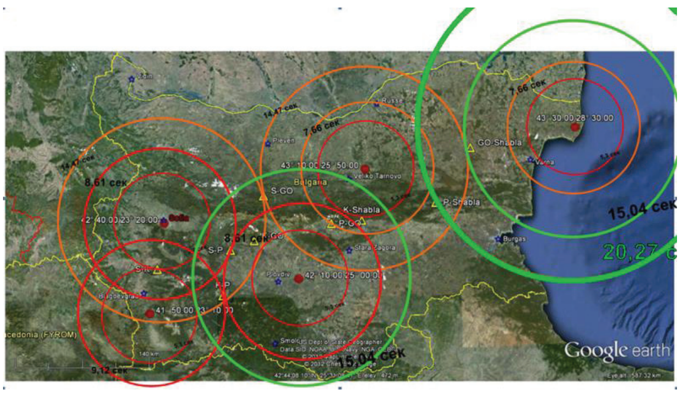

Figure 6: Modelled isochrones versus distances - coverage of the knots. In the model, they represent the seismic sensors The t_s-t_p isochrones of each seismic source at the levels of 5.3 (dark red), 7.6 (light orange), 8.6 (red), 14,5 (orange) 15 (light green) and 20,2 (green) seconds, covered almost the entire territory of Bulgaria.

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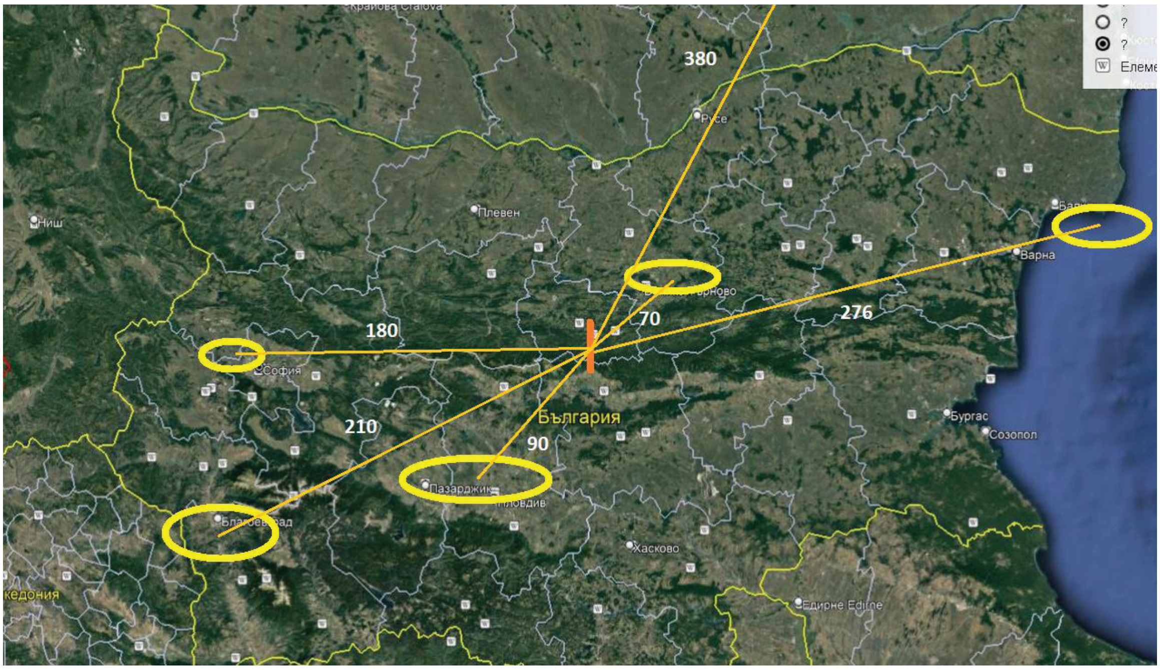

Figure 7: Distances between main seismogenic sources in Bulgaria and Vrancea (Romania) to "Shipka" pass.

Table 2: Distance Ts-Tp [s] travel times from seismic sources to "Shipka" pass.

Source	Distance [km]	Tp [s}	Ts [s]	Ts-Tp [s]
G.Oriahovica	70	13.6	20.8	7.2
Plovdiv	90	18.4	31.3	12.9
Sofia	180	30.0	51.8	21.8
Kresna	210	33.8	68.7	24.9
Shabla	276	42.0	73.0	31.0
Vrancea	380	55.5	99.8	44.3

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