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TWO INNOVATIONS FOR CRITICAL INFRASTRUCTURE PROTECTION FROM NATURAL DISASTERS

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Abstract

The article elaborates on two innovations developed for the purpose of protecting critical infrastructure facilities from two specific natural disasters – kinematic system for early warning of earthquakes applicable for the Bulgarian nuclear power plant (NPP), and a system for early warning of floods along the river beds near artificial lakes barrages. Both developments are part of the execution of p.1.1.6 from National Scientific Programme (NSP) "Security and Defence" – "Analysis of risk and threats, design and development of conceptual generating models and software for improvement of efficiency of control of forces and means for critical infrastructure influence during natural disasters, accidents and crises, on the territory of Republic of Bulgaria".

Key words: critical infrastructure facilities, early warning system, earthquake, floods

Introduction. The critical infrastructure is a system of elements found in a country's territory. These elements are of major importance for supporting vital

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social functions, public health, safety and security, economic and social wellbeing of the population. The destruction or impairment of the critical infrastructure in a given state would have significant consequences as a result of the inability to support these vital functions [1]. Hence, the protection of the critical infrastructure elements from malfunction and damage are a priority of the national security. Often, various natural and anthropogenic threats are capable of inflicting severe damage on it. The development of models for design and implementation of systems for early warning is a modern scientific area that utilized the latest scientific advances for quick and efficient warning of the population and government structures with the major purpose – protection of the population and infrastructure from the negative influence of natural and anthropogenic hazards. Recently, the so-called kinematic models of systems for early warning are under rapid development.

Here we present two innovations used for protection of the critical infrastructure from two natural disasters typical for the territory of Bulgaria:

1. Kinematic system for early warning of earthquakes used for protection of the nuclear power plant (NPP)

2. Early warning system for floods along the rivers under dam lake barrage

Both topics are related to the fulfilment of p.1.1.6 from the National Scientific Programme (NSP) "Security and Defence" – "Risk and threats analysis, design and development of conceptual models and software for efficiency enhancement of force and means of control for influence of the critical infrastructure during natural disasters, accidents and crises in the territory of Republic of Bulgaria" according to Agreement No. D01-74/19.05.2022 between the Ministry of Education and Science and the Defence Institute "Prof. Ts. Lazarov" in the course of execution of NSP "Security and Defence", adopted with government decree No. 731 from 21.10.2021 [2]. Both innovations are subject to patent protection [3,4].

Concept and realization of kinematic system for early warning of earthquakes for critical infrastructure facilities (particularly the nuclear power plant). The familiar seismic early warning systems (SEWS) signalize the population and/or governmental institutions after the earthquake has taken place – those are simply information systems that inform of the seismic event and of stronger vibrations that are to be expected from secondary seismic waves. Further, some very urgent and stress measures might be undertaken such as stopping of the reactors at the nuclear power plant, pulling over of very fast trains, switching off of chemical production lines, natural gas and oil pipelines, etc. In lucky circumstances some people may react (especially in regions with low buildings) and evacuate themselves effectively in a few seconds thus saving their lives.

Known early warning systems use dynamic parameters of the seismic waves from the earthquake – time of occurrence, direction towards the epicentre, amplitudes, frequencies and periods of the seismic waves, etc. [2]. There exist also automated systems, for example NPP, which upon seismic wave arrival switch the reactors off [3]. A shortcoming of these early warning systems is that they activate when the seismic wave has arrived at the facilities and the elements of the critical infrastructure (for example the NPP reactor) while all other elements of the critical infrastructure remain isolated from the warning. Another drawback is the long time needed to process the data which may lead to better estimation of earthquake's parameters – magnitude, expected intensity in the site of critical infrastructure, etc. This leads to deficit of the time for operation, the latter being a substantial prerequisite for successful action against the disaster consequences.

Earlier experience with the developed SEWS (for examples in Baku and Venice) enables improvements in methodology of modelling by expanding itself under a formalized algorithm and precise evaluation especially for critical infrastructures (for example NPP).

Here we present a novel concept and principal realization of a kinematic system for early warning for earthquakes of critical infrastructure facilities. It is called kinematic because it uses only kinematic parameters of the seismic waves – times of arrival of the waves and their velocities.

Figure 1 presents a general schematic of the early warning kinematic system. In the scheme the used designations are: (1) – critical infrastructure, (2) – command centre, (3^{I},3^{II},…,3^{n}) – smart seismic receiver stations, (4^{I},4^{II},…,4^{n}) – seismic receivers (accelerometers), (5^{I},5^{II},…,5^{n}) – comparator-discriminators and (6^{I},6^{II},…,6^{n}) – telemetry modules. In the schematic, the epicentre is denoted by E. Between the smart seismic receiver stations (3^{I},3^{II},…,3^{n}) and the command centre (2) there is a redundant (double) telemetric connection (for example using cell phone and satellite phone).

Advantages of this system are that by positioning of the smart seismic receiver stations near all previously known expected strong earthquake sources, a short latency activation is achieved. The stations work autonomously and send warning signals without human intervention.

The implementation of fast acting communication systems (satellite, ratio, cell phones, Internet) for conveying of the warning signals in the design of the early warning kinematic system saves time. Reliability of the system may be improved by increasing the number of seismic receiver stations. The whole system works autonomously. Along with the warning signal it starts the whole multitude of sensors in mode of recording of the seismic waves. The recording of this data is utilised in consecutive analysis and corrections. The proposed early warning kinematic system is much cheaper than the existing early warning systems in operation.

The earthquake early warning kinematic system for critical infrastructure operates in the following manner. Once an earthquake has taken place, the seismic waves are spreading from the epicentre E in all directions. When the first longitudinal wave “P-wave” has reached the nearest smart seismic receiver station

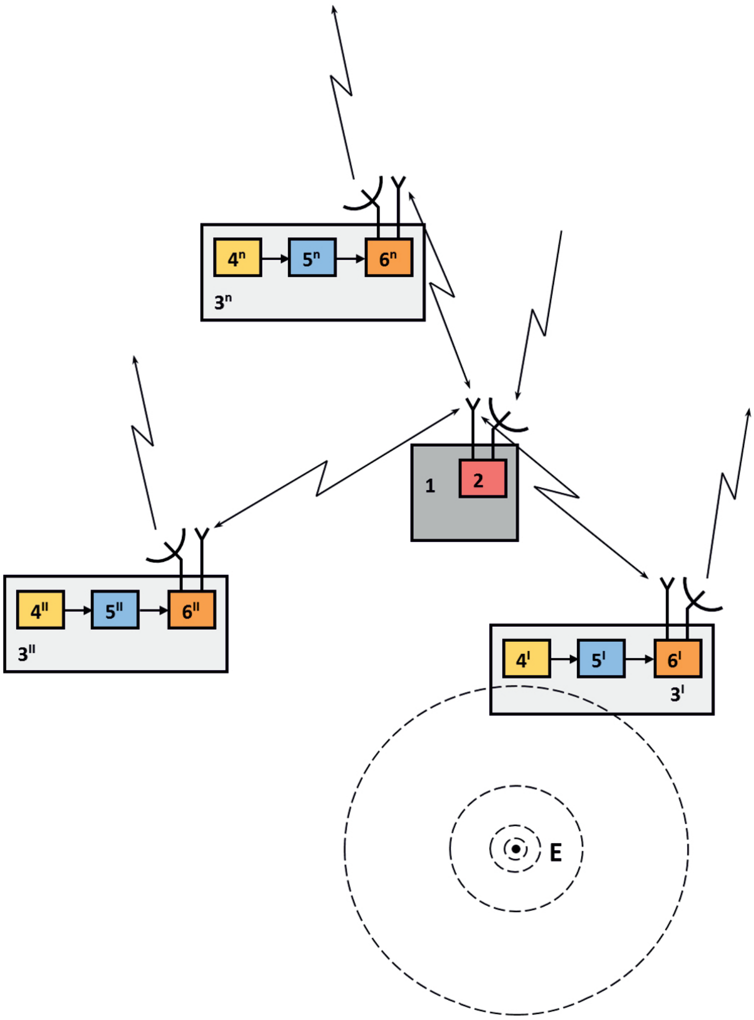

Fig. 1. Kinematic system for early warning of earthquakes used for protection of the nuclear power plant (NPP)

$(3^{\mathrm{I}},3^{\mathrm{II}},\ldots,3^{\mathrm{n}})$ the corresponding seismic receiver is activated $(4^{\mathrm{I}},4^{\mathrm{II}},\ldots,4^{\mathrm{n}})$. The latter generated electrical signal enters the corresponding comparator-discriminator $(5^{\mathrm{I}},5^{\mathrm{II}},\ldots,5^{\mathrm{n}})$. The comparator-discriminator is adjusted to engage at a certain amplitude level. If the amplitude of the seismic signal exceeds this level, a message is sent to the corresponding telemetry module $(6^{\mathrm{I}},6^{\mathrm{II}},\ldots,6^{\mathrm{n}})$. The telemetry module $(6^{\mathrm{I}},6^{\mathrm{II}},\ldots,6^{\mathrm{n}})$ conveys the message over two independent telemetry channels – a cell phone and satellite phone – to the automatic command centre (2). The latter operation takes, in practice, no time. The automatic command centre (2) activates and issues a corresponding command – in the case of the critical infrastructure (1) being NPP, this is an emergency shut down of the reactors. The command is triggered by outpacing signal coming from the smart seismic receiver station (3^{I},3^{II},...,3^{n}) being the closest to the epicentre, rather than from the incoming first vibrations as with the mode of operation of the current emergency systems. The redundancy telemetry connection aims at ensuring high reliability. In this way, before the arrival of the secondary "S-wave" carrying higher energy and being more destructive, automatic actions are taken to protect the critical infrastructure. Simultaneously, audible and light signals are being emitted or voice warning is being disseminated to facilitate evacuation or raised readiness of the personnel.

The warning signal generated by the primary wave outpaces the arrival of the stronger and more destructive secondary wave because it has been generated in the vicinity of the epicentre where a smart seismic receiver station has been installed (3^{I},3^{II},...,3^{n}). This warning signal alarms the critical infrastructure and activates the whole kinematic system. The latter starts recording of the seismic signals which may be used for later analysis. This is possible because the velocities of propagation of the seismic waves are extremely high (7–8 km/s for the primary waves and 1.41 times lower for the secondary seismic waves).

Conceptual model of an early warning system for protection from damage of critical infrastructure during flooding (for example Artificial Lake Iskar). Artificial Lake Iskar (also known as Iskar Reservoir) is a typical critical infrastructure [4] because it is the largest by volume (around 580 mln m^3 usable water and 673 mln m^3 total water volume) reservoir in Bulgaria having altitude of 820 m and being situated over a city with two million population with well-developed and important infrastructure.

Let us study a specific scenario related to possible damages inflicted by water escape from Iskar Reservoir. This water escape may be triggered by various reasons: overflow, controlled drainage through valves, breaking of parts or in whole of the dam as a result of terrorist attack or bombardment, etc. The most serious threat is the formation of a tsunami-like water wave having destructive shock wave as its first threat and flooding of vast areas as its following threat. The clogging of riverbeds invoked by the flooding and the rocks and trees carried along the water flow is inevitable. The consecutive breaking of these clogs will lead to secondary shock waves. Due to the turbulent water flow during the high speed phase of water dissemination, there are significant difficulties in creating models for simulation of the flooding processes. The characteristics of the water mass are hard to predict especially along smaller and sharper branches of the riverbed and inflows. All damages described so far are of primary character. There are also so-called secondary damages present with serious flooding [5]. Slight or severe consequences of the environment are possible. All said so far explains the difficulties with the creation of conceptual models of a system for early warning of such disasters and catastrophes.

The early warning system for floods along rivers under dam lake barrage consists of the following elements [6] (the general view of the system is shown in

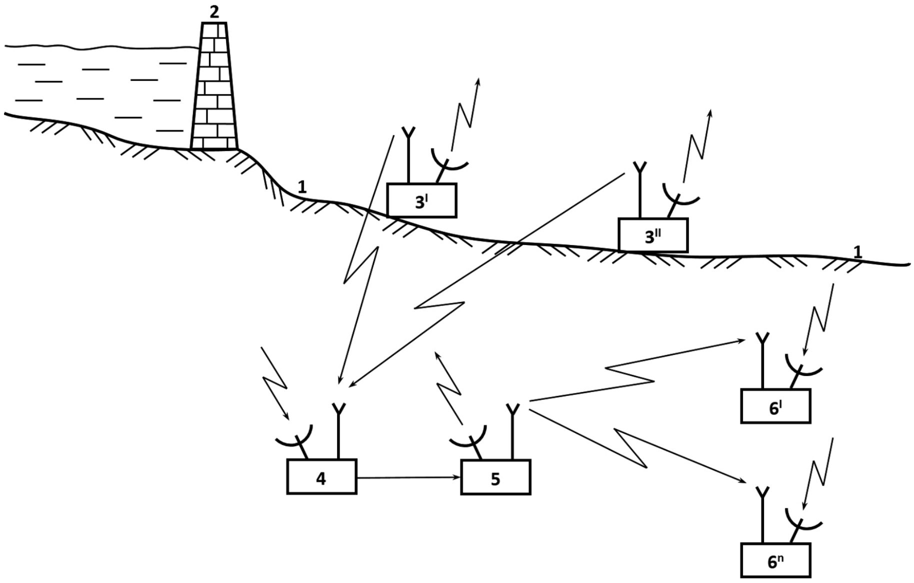

Fig. 2. Early warning system for floods along the rivers under dam lake barrage

Fig. 2): the river stream under the reservoir barrage (1), the barrage dam (2), control and measurement stations (CMS) (3^{I} and 3^{II}) located at suitable places along the riverbed, computational and logic module (4), automatic message centre (5), users of the system (6^{I},6^{II},...,6^{n}). All telemetry connections are redundant. Those include cell phone, satellite radio link and Internet connections.

The system operates in the following way. Upon the water wave arrival in the first control and measurement station (3^{I}), the latter sends information to the computational and logic unit (4). This information is sent along the redundant communication connection based on more than one communication channel, for example cell phone, satellite phone, Internet, etc. This information contains data about the water volume. When the water wave reaches the second control and measurement module (3^{II}), in the same way information is sent to the computational and logic module (4). The latter, utilizing this newly received information on the one hand, and employing prerequisite information about the topology of the terrain, on the other, calculates the velocity of the water flow and then, in accordance with the distance to the guarded infrastructure facilities (i.e. users), estimates the times of arrival of the water wave. These times are communicated to the automatic message centre (5) which, by means of cell phones, satellite communication or Internet connection sends corresponding messages to the users (6^{I},6^{II},..., 6^{n}) of the system. With the help of warnings, including audible, light signals or voice messages, the users are informed of forthcoming evacuation or other measures. In order to track the behaviour of the flood wave and the threat along the river bed, more control and measurement stations may be installed.

As a result of analysis, the locations for positioning the control and measurement stations are established. Also, the times for passing the distances from the barrage dam to the control and measurement stations and the users are precomputed, having assumed average velocities of water flow movement.

The system may be improved by installing additional control and measurement stations for tracking of the flood wave in the plain and valley areas away from the river bed.

Conclusion. Two innovative warning systems are under development. They are: kinematic seismic early warning system for critical infrastructure (the case of NPP) and anti-flooding system (the case of a large dam threatening by flood the capital city Sofia). Both systems are predominantly automated thus excluding the operators' actions and shortening the warning time [7,8]. Both systems are under patent protection.

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