INTEGRATING ENGINEERING AND TECHNOLOGY IN EARTH SCIENCE EDUCATION PRACTICES

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ABSTRACT

Seismology is a complex science, multidisciplinary and close related to the fast evolution of technology that often may seem rigid and hard to understand by young pupils and students. To overcome this issue in the learning process, a seismic simulator (shake table) was developed in our attempt to bring seismology forward to young students, guiding them for future career possibilities. A software was also developed to control the mechanics of the shake table by converting a seismic wave signal into movement impulses induced to the shake table. Using this instrument, and understanding its functional principles can help in developing educational activities that ease the learning process of the basic concepts of seismology and earthquake engineering. Moreover, this educational tool can be used to illustrate practical methods of reducing the lateral forces induced in a building subjected to earthquake, by the use of base isolation systems and damping devices. The results of these educational activities can contribute to a better understanding of soil-structure behavior during an earthquake.

Keywords: Seismic simulator, Educational activities, Seismic risk awareness

INTRODUCTION

The Seismic Simulator, developed at the Timisoara Seismological Observatory, is a project with educational, scientific and social goals meant to offer a whole new learning experience to visitors, teachers and students. By organizing educational visits, creative activities and experiments, using the Seismic Simulator, we aim to promote an alternative way to the classical educational process. Introducing the Seismic Simulator as a didactic tool, we can focus on increasing the level of knowledge of teachers and pupils on earthquake phenomena, earthquake effects and measures of protection and preparedness. By doing so, Earth Science topics can be taught based on the concept “hands on activities” in a much more creative and interactive manner.

It is essential to make children, students and teachers understand the importance of seismic education knowing that among all natural disasters, earthquakes represent one of the most dangerous threats, due to their unpredictable occurrence and by the strong impact they have on the build environment. Having a solid grasp on seismology notions, students will understand better the importance of safety measures in disaster risk reduction.

Nowadays, preventing and raising awareness on the major risks we are all exposed represents one of the main challenges for every community that aims to be sustainable. Given their devastating effects, seismic events continue to cause major disasters since it is basically impossible to predict or prevent them from occurring (Boughazi et al., 2014). Romania is one of the most seismic prone countries in Europe and considering the fast urbanization process, that society is experiencing now, seismic risk becomes extremely complex related to the given context (geographic and geologic aspects but also economic and political issues due to the lack of proper safety measures applied and underdeveloped educational infrastructure regarding earthquake risk). We consider that one of the key measures for seismic risk mitigation is through education. Thus, by helping students understand why and how earthquakes occur, will guide them to discover earth sciences from another perspective. Seismic education is important in preparing students to understand the social implications of an earthquake. The seismic simulator provides an opportunity to present physics and technology concepts and skills to learners of all ages in a creative manner. Its purpose is to bring together activities such as research, science education and crafts, in order to find innovative approaches for creating experiments and simulations with a real impact on multiple target audiences, addressing the need of linking formal and informal learning environments (Tataru et al., 2016).

Countries with high seismic exposure of the population and high vulnerability of the infrastructure, such as Romania, need to understand that a lot of effort and resources would be necessary to mitigate the seismic risk (Dolce, 2012). Even tough, in case of a major earthquake, important losses are expected, seismic prevention remains the only way to prepare the population to withstand and recover after an earthquake. It is a complex and long-term task that must be sustained with responsibility. One of the basic steps in implementing a seismic safety program starts by early education in schools, so in this way, providing essential notions of seismology, attractive and up to date information, involving children and students in seismic simulations and motivating to build their own structures, will contribute raising the seismic education level of the future generations (Vanciu-Rău et al., 2019).

By introducing the Seismic Simulator as a didactic tool we are approaching a very problematic topic in regard to the present and future of Romania: the key role of education, in the perspective of a future major earthquake.

THE SEISMIC SIMULATOR USED AS A DIDACTIC INSTRUMENT

As researchers we are constantly seeking ways to communicate science to our peers, funding agencies, policymakers, and the general public in ways that they can appreciate its importance (Zaharia et al., 2016). We are currently developing at the Timisoara Seismological Observatory an educational Seismological Laboratory, having as center pieces two portable seismic simulators and one seismic platform designed to withstand weights up to 300 kg that includes also a base isolation system. The concept of a Seismo Laboratory was well received by teachers and students, and their increased interest to participate in the project made us design “hands on activities” such as experiments to understand how seismic waves propagate through Earth, illustrating the plate tectonics, creating layouts to demonstrate landslides and the liquefaction effect using the seismic simulator, constructing different building structures to be tested and to understand their behavior during an earthquake (Zaharia et al., 2016). All of these activities come along with a set of information guidelines freely available to teachers and students.

The idea of creating a local Seismo Laboratory, for the West region of Romania, came after creating the first set of portable seismometers destined to be part of the Seismological Laboratory of the National Institute for Earth Physics (NIEP) in the framework of the Romanian educational seismic network. We strongly believe that leading tests, making earthquake simulations using real earthquakes waveforms and building structures to be tested will facilitate the interaction between scientists, teachers and students. By allowing students and teachers to be more involved in research activities, and to scientists to share their knowledge and to participate in didactic activities, will lead to better communication between researchers and teachers (Tătaru et al., 2016). In order to identify the educational needs of students and teachers, regarding seismology, in 2012 NIEP researchers conducted a survey targeting schools to identify the knowledge level of seismology among pupils and their interest for this domain (Tătaru e. al., 2016). Results revealed that more than 60% of the pupils participating in the survey know very little or nothing on how to behave in case an earthquake occurs, while 79% declared that they have never participated in any activity on the earthquake theme. The interest of the children in activities related to seismology is very high: 70% of the children declared that they are willing to take part in activities related to earthquakes if they are to be organized in schools and 81% are interested in accessing an online platform offering information on the earthquakes (Tătaru et al., 2016).

Students and teachers consider that interactive lessons accompanied by experiments are a lot more useful and easier to understand. Starting from these statistics and considering the stated needs (expressed both by teachers and pupils) of practical examples when describing and teaching the seismic phenomena, during 2015 up to 2018, at the Timisoara Seismological Observatory were developed a series of four portable seismic simulators and a large platform (2m length and 1m wide) with an integrated base isolation system. These seismic simulators, were created to be used as comprehensive instruments for pupils when explaining the seismic phenomena and how seismic waves can affect buildings and manmade structures (Vanciu-Rău et al., 2019). For flexibility and educational purpose the seismic simulator was designed to replicate Secondary waves preparing students to observe and understand notions such as peak ground acceleration, amplitude and resonance frequency (Vanciu-Rău et al., 2019).

The Seismic Simulator’s purpose is to bring together activities such as research, crafts and science education, in order to find innovative approaches for creating experiments and simulations with a real impact on multiple target audiences, addressing the need for linking formal and informal learning environments. The portable seismic simulators can be easily transported to schools being used to enhance the teacher`s lecture on Earth science. But for a more complete experience, the Timisoara Seismological Observatory can host educational tours where students can test their scale models directly on the Seismic Platform. Therefore, both teachers and students can observe and note the resonance frequency point for each layout as the digital seismogram, from a real earthquake event, is being loaded into a dedicated software and transformed into a signal transmitted by a frequency inverter directly to the simulator.

These kind of constructive activities will contribute to children’s education related to seismic risk from an early age and, mostly by playing, they will understand how buildings and other structures respond during an earthquake. Such activities connect the research field with the social activities for seismic risk mitigation needed in an active seismic region (Tataru et al., 2016). Using the seismic simulator, teachers can outline the influence of input signal characteristics (e.g. Amplitude) on buildings and aspects related to the building's resonance frequency on its main axes. In addition, they can point out, by a simple geotechnical experiment, how important are the properties of the foundation soil and how the liquefaction effect can occur, under dynamic loading (Vanciu-Rău et al., 2019).

OPERATING PRINCIPLES

The seismic simulation platform (Figure 1) consists of two parts: one of them is fixed on the ground (a) while the second one has a degree of freedom on the horizontal direction (b). On the upper part of the rigid underframe there are 4 runways on which the mobile part will glide (c). Amplitude values can be followed by observing the marked grid the pointer indicates (d). There is an amplitude pointer attached directly on the platform and one attached to the base isolation system, in that way we can outline simultaneously how the two structures are exposed to different amplitudes, during an earthquake, with the help of the base isolation system (Vanciu-Rău et al., 2019). We managed to simulate the horizontal component of an earthquake by controlling the movement frequency of the platform using a frequency inverter and a crank mechanism. It is known that, in case of an earthquake, a building can withstand better to the vertical component of the motion (specific to the primary waves P) rather than to the lateral loading (specific to the secondary waves S) that usually leads to damaging buildings. Based on this fact, the Seismic Simulators were conceived and executed to perform a horizontal motion that can be adjusted in terms of frequency.

Figure 1 - The seismic simulation platform

We can set the movement frequency by adjusting the pulse frequency of the **Siemens SINAMICS V20 Inverter** following the instructions below:

Inverter control through serial RS-485 MODBUS: To control the inverter from the computer we use the commissioning preset Cn011: MODBUS RTU control. This means that the inverter will take commands on a serial RS-485 line using the MODBUS protocol [Link 1].

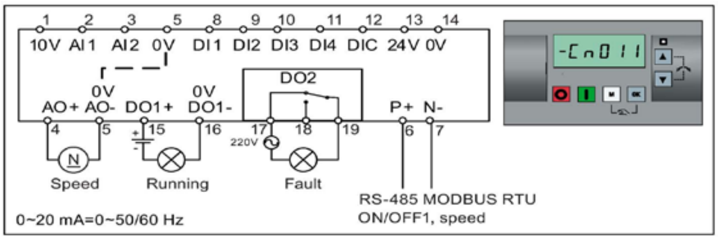


Figure 2 - The control panel for the Siemens SINAMICS V20 Inverter

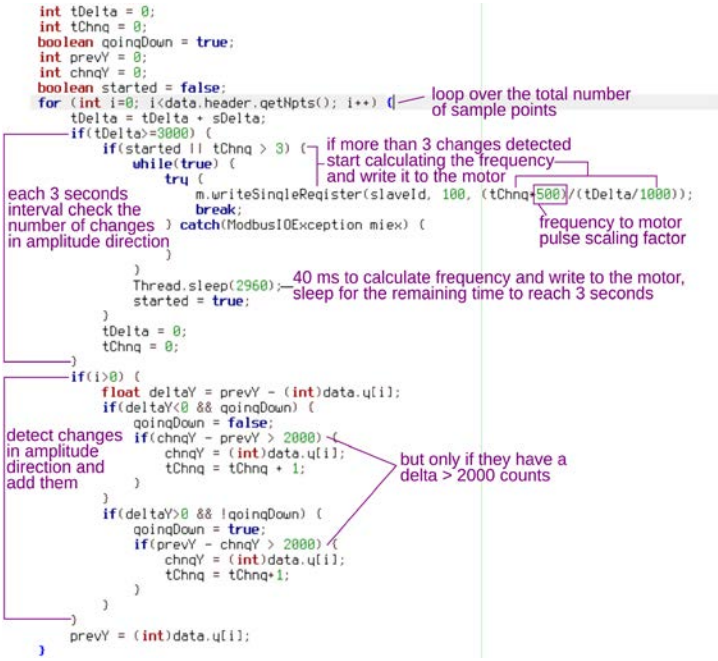
We found that another important step for controlling the inverter from the computer using this mode, Cn011, is to set the parameter P2014 of the inverter to 0. This makes it so that the time between receipts of two consecutive process data telegrams can be of any length [Link 2].

Serial connection and pulse motor control: using a USB to RS-485 adapter: The serial connection requires two electrical lines from the computer to the inverter, a couple of terminating resistors and a USB to RS-485 adapter. On the adapter that we used the connections are marked A/D+ and B/D-. On the inverter the connections are marked 6.P+ and 7.N- The connection should be A/D+ to 6.P+, B/D- to 7.N- For the terminating resistors, since we do not have a complex setup with multiple devices connected, we found that two 120 Ohm resistors across each end of the lines were sufficient.

MODBUS communication software: To test the communication between the inverter and the computer we wrote a couple of simple programs in Java: one to choose the serial port for the communication, one to read the holding registers from the inverter and one to set a register to a specific value. We used the JlibModbus [Link 3] open source library for the MODBUS protocol implementation and the jSSC (java Simple Serial Connector) [Link 4] open source library for serial communication

Pulse control commands: To initialize the pulse control of the motor on the inverter [Link 5] we have to set the STW register 40100 (index 99 in the MODBUS table). This register contains 16 bit flags that setup the pulse motor control. We have the enable (set to 1) the OFF2, OFF3, PULSE ENABLE, RFG ENABLE, RFG START, SETPOINT ENABLE, CONTROL BY PLC. The rest of the flags are set to 0, including the OFF1 (motor start flag). When assembled in the correct order this 16 bit field gives us the value 0x047E in hexadecimal and 1150 in decimal. So, the first step is to write 1150 to the register with index 99. The second step is to set the initial motor pulse. This is done by writing a value representing the pulse frequency to the HSW register 40101 (MODBUS index 100). The value is a number between 0 and 0x4000 hexadecimal, representing 0% to 100% of the maximum motor pulse frequency set in the motor setup parameters of the inverter. A value of 500 (decimal) is what we found that starts the motor very slowly and doesn’t cause an under-power whining sound. The next step is to start the motor by flipping the start motor OFF1 flag on the STW register. This means the value 0x047F in hexadecimal or 1151 in decimal to the register with MODBUS index 99. After this, we can write any value we want to register 100 to change the speed of the motor, and 1150 to register 100 to stop or 1151 to start the motor.

Figure 3 - The frequency extraction algorithm



EARTHQUAKE SIMULATION

Reading the SAC file: The code we are using to read the horizontal motion (Y) is taken from the SeisFile open source library written as part of the “Lithospheric Seismology program” at the University of South Carolina [Link 6]. This gives us an array of samples of the Y horizontal “counts”, the sample period, total number of samples and, depending on the file, a couple of metadata information from the header of the SAC file: time of the start of the recording, station information, scale of the recording etc.

Frequency extraction algorithm: Based on the data extracted from the SAC file we have implemented a very simple algorithm that takes periods of time (by default 3 seconds) and determines the number of change of direction in that interval and divides them by the interval length to get the frequency. In the algorithm the threshold can be set to ignore changes that have an amplitude difference lower than a set value (by default 2000 counts) of direction in that interval and divides them by the interval length to get the frequency.

PERFORMING A TEST USING THE SEISMIC SIMULATOR

A very simple application that can be performed by setting a structure on the shaking table and reproducing the frequency signal of a waveform we can observe the point the structure will fail by reaching resonance. The structure’s behavior can be tracked using sensors installed at the top of the structure. The basic principle is to decouple the structure from the soil, by introducing a flexible interface. By doing so, during an earthquake, the forces induced in buildings are reduced and the energy dissipated, in order to protect the structure`s integrity (Vanciu-Rău et al., 2019). This concept of the/on earthquake-protection system can be proved on the seismic simulator, as will be presented in the following experiment, using two identical scale models of structures.

This experiment was carried out for the two different configurations and the top responses of the two structures are presented in Figure 4. When subjected to ground motion, the responses of the two scale models with and without base-isolation were measured using accelerometers.

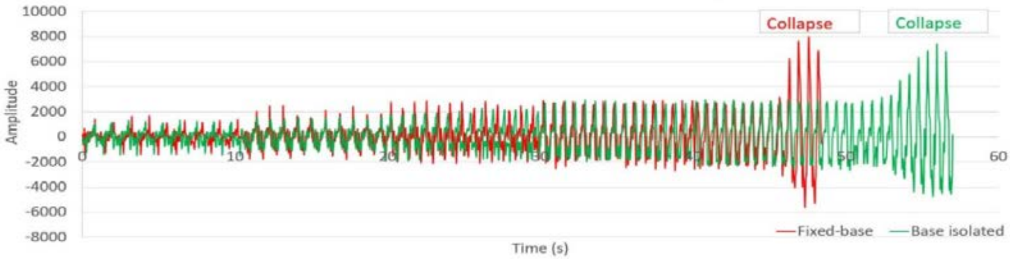


Figure 4 - Acceleration recorded on top of the structure for the two configurations

The frequency of the input motion was increased up to the collapse of the structures. The base-isolated structure experienced lower amplitudes than the fixed-base structure, for all frequency ranges and withstand a longer time until it collapsed.

Other types of demonstrations may consist of testing scale models on different soil structures. For example, soil-structure interactions, in case of an earthquake, may have reasonable effects for a light structure on relatively stiff soil but may have serious effects for a heavy structure resting on soft soil (Haiyang et al., 2019).

CONCLUSIONS

For seismic prone countries, such as Romania, seismic education and prevention represent key elements in building a sustainable society. Seismic prevention activities may be implemented in many ways, one of them is through education. When we started to build and perfect the Seismic Simulators and integrating them in a Seismic Laboratory our goal was to show how Earth Science topics can be learned in schools in other ways than the traditional ones, as they were more focused on activities and experiments related to seismology. Using the Seismic Simulator as a didactic tool, and enhancing it to simulate a waveform based on the frequency output, will help students in understanding physics and geophysics notions and to observe an earthquake`s impact on the built environment. Also, encouraging pupils and students to work in teams, to design and build up structures, meant to be tested on the seismic simulator, will motivate them to come up with more ideas and constructive solutions for better structures. Not only that it will be a creative and pleasant activity, but children will depict more easily concepts such as the influence of input motion amplitude on buildings and aspects related to the building's resonance frequency, on its main axes. Children can perform different experiments, within their reach, and see how important are the physical properties of the foundation soil and how the phenomenon of liquefaction can occur, under dynamic loading. The seismic simulator can also be used in performing experiments using base isolation systems, by using two structures, one placed directly on the platform and the other one placed on a flexible interface. Activities such as enhancing the capabilities of the Seismic Platform into controlling it's movement using a software program and performing earthquake simulations to demonstrate earthquake's impact over buildings and manmade structures were made possible through the collaboration of seismology researchers and a passionate programmer.

The Seismic Simulators as well as the development of educational tools and hands-on activities, simple enough to prove and demonstrate basic concepts of seismology can contribute to raising public awareness about seismic risk, and will enhance the preparedness level and provide a better response of the population in case of a strong seismic event.

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