# ELECTRONIC BOARD CONTROL FOR STABILIZING BUILDING GYROSCOPIC SYSTEM

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*Abstract* – **This paper presents a technical approach for the seismic risk of buildings. After some descriptions of the seismic waves types, mathematical foundations are presented on the Euler angles subject. Under this frame one introduces the topic of gyroscopic system, at theoretically level. A gyroscopic system installed in the building's foundation increases the stability against seismic disturbances or wind effects, therefore one performed a study using a system with feed-back, achieved through a simulation in Matlab. The results revealed a good response of the building structure, in terms of seismic energy by downloading it. Afterward a micro-control equipment for the gyroscopic system is presented. This electronic system is built around an eight-bit microcontroller type PCB80C552 Philips. One provides a detailed description of the control structure, making reference to the sub-bus control, data display, data entry as well as RAM and ROM subsystems. A special attention is paid to a theoretical mathematical analysis, concerning the modality in which the seismic waves are propagating, based on a tensors model. Such an approach, with very few references in the specialty literature, has the capability to reveal the induced effects of soil characteristics on seismic wave propagation.**

***Keywords***: *building, control, gyroscope, seism, stabilization, waves.*

## 1. INTRODUCTION

The seismic waves have devastating influences on buildings, altering partially or totally the structure of resistance. The cause is the energetic discharging like a periodic perturbation at infrasound frequencies, ranging from 0.1Hz to 10Hz. Many solutions have been imagined into the time, with more or less efficiency. One of them consists into dynamic action of the massive rotating system, named gyroscopic system. The system works under the conservation momentum effect into the rotation movement.

## 2. CLASSES OF SEISMIC WAVES

The seismic waves can be classified into:
- volume waves
- surface waves.

The volume waves propagate within the Earth and carry on most of the seismic energy deep inside it. Their propagation velocity is related to the ground nature and is bigger at higher depths, increasing with the density of Earth's structures. The volume waves exhibit similar properties with the light during propagation. The waves are refracted and reflected, these phenomena depending on the propagation environment density and rigidity. Other factors that influence them are the temperature, composition and physical phase of the matter. The P and the S waves are examples for this category of waves [1].
The surface waves behave like waves on the smooth surface of a lake. They have a small propagation velocity but a large amplitude. From this class derives the Love waves and respectively the Raleigh waves [6].
This class of waves has interesting features, intensively studied in laboratories all over the world. At "Ştefan cel Mare" Suceava University some researches on this subject have been performing, using complex systems techniques and the fractal systems' theory.

### 2.1. P waves

The P waves are known as "primary waves". A P wave travels with the highest velocity (6÷8 km/s) and is therefore the first to be recorded. In isotropic and homogeneous solids, the type of a P-wave is always longitudinal. Thus, the particles in the solid have vibrations along or parallel to the travel direction of the wave energy.
The speed of P-waves is given by:

$$v_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

where $K$ is the bulk modulus (the modulus of incompressibility), $\mu$ is the shear modulus (modulus of rigidity, sometimes called the second Lamé parameter), $\rho$ is the density of the material through which the wave propagates, and $\lambda$ is the first Lamé parameter. Of these, density shows the least variation, so the velocity is mostly controlled by $K$ and $\mu$. These equations have an uncertainty quote because the models used are not very accurate. Consequently these relations can be provide only a qualitative description [6].

### 2.2. S waves

The S waves are called “secondary waves”. These are transversal waves with a typical velocity by 4÷5 km/s. Using delays measured between *P* and *S* waves, with three seismographs mounted into distinctly points, with known speeds, one can determine the seismic epicenter position.
The *S* waves can be polarized, so they can not propagate through liquid or gaseous environments.

### 2.3. Love waves

The Love waves are considered surface waves. They are named after A.E.H. Love, a British mathematician who created a mathematical model for these waves in 1911. They usually travel slightly faster than *Rayleigh* waves, about 90% of the *S* wave velocity. They are the slowest and have the largest magnitude.

### 2.4. Rayleigh waves

The Rayleigh waves, also called “ground roll”, are surface waves that travel as ripples with motions that are similar to those of waves on the surface of water. But, the associated particle motion at shallow depths is retrograde, and therefore the restoring force in Rayleigh and in other seismic waves is elastic, not gravitational as for water waves. The existence of these waves was predicted by John William Strutt, Lord Rayleigh, in 1885. They are slower than body waves, roughly 90% of the velocity of S waves for typical homogeneous elastic media.

## 3. MATH BASES

The mathematical fundaments consist into a stability analysis for the gyroscopic system and an analysis of the dynamic equations of the rigid body within rotation. In this sense one defines the Euler angles.

The main set parameters from Fig. 1 is:

- *ON – the line of nodes*
- *OP – the perpendicular to the line of nodes taken in the plane Oxy*
- *$\psi$ - the precession angle (angle between the fixed axis Ox’ and the line ON)*
- *$\varphi$ - the gyration angle (angle between the line ON and the mobile Ox axis line)*
- *$\theta$ - the mutation angle (angle between the fixed Oz’ axis and the mobile Oz axis)*

The instantaneous angular velocity vector is given by:

$$\vec{\omega} = \dot{\psi}\cdot \hat{Oz'} + \dot{\varphi}\cdot \hat{Oz} + \dot{\theta}\cdot \hat{ON} \qquad (1)$$

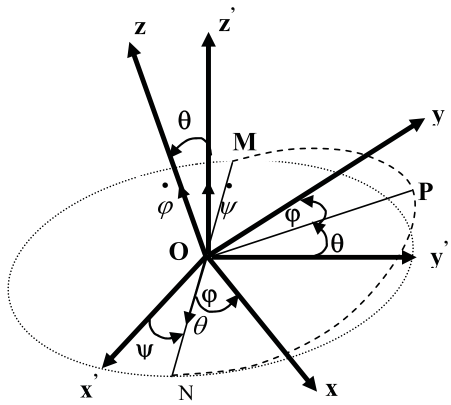


Figure 1: Euler’s angles definition.

In practice there are interesting relations between the $\omega_x$, $\omega_y$ and $\omega_z$ (projections of the $\vec{\omega}$ vector on the *Ox*, *Oy* and *Oz* mobile axes), and the $\psi$, $\varphi$, $\theta$ (used to denote the Euler’s angles).
Projection of the relationship (1) on the mobile axes leads to:

$$\begin{aligned} \omega_x &= \dot{\psi}\cdot sin\theta \cdot sin\phi + \dot{\theta}\cdot cos\phi \\ \omega_y &= \dot{\psi}\cdot sin\theta \cdot cos\phi - \dot{\theta}\cdot sin\phi \\ \omega_z &= \dot{\phi} + \dot{\psi}\cdot cos\theta \end{aligned} \qquad (2)$$

If one chooses the *Oxyz* coordinate axes for the mobile system, jointly with rigid in coincidence with the principal axes of inertia, one gets mixed moments of inertia of zero value. With these assumptions the following math system can be built:

$$\begin{aligned} J_x\gamma_x + (J_z - J_y)\omega_y\omega_z &= M_x \\ J_y\gamma_{yx} + (J_x - J_z)\omega_z\omega_x &= M_y \\ J_z\gamma_z + (J_y - J_x)\omega_x\omega_y &= M_z \end{aligned} \qquad (3)$$

with: $\gamma_k = \dot{\omega}_k$ , $k = x, y, z$.
These relations are known as Euler's equations. To solve the problem of motion, the equations 2 and 3 must be considered. So, one gets six scalar relationship with 5 unknown quantities: $\omega_x$, $\omega_y$, $\omega_z$, $\psi$, $\varphi$, $\theta$ .

## 4. THE GYROSCOPIC PRINCIPLE

The notion gyroscope is used to denote a rigid body which has a fixed point noted O, for which the inertial ellipsoid referred to this point is a rotation ellipsoid referred to the mobile rotation axis Oz that is joint with the rigid body. The axis *Oz* is called *gyroscopic axis*. One assumes that the only force acting on the gyroscopic system is the weight *G*, that the fixed point *O* coincides with the gravity center, noted *C*, and that the initial body has a very large angular speed $\omega_z = \omega_o$. In the absence of any disturbance, the movement will continue, because the *Oz* is a main central axis, behaving like a permanent axis of rotation. If a relatively small perturbation appears, acting over the rotation axis *Oz*, this acquires to gyroscopic motion a regular precession. The *Oz* axis has a very small displacement relative to the original position, with an angle $\theta_o$, smaller with the increasing of the angular velocity $\omega_o$. This property is called *gyroscopic stability*. One can prove that:

$$tg\theta_o = \frac{J_x}{2J_x - J_z} \cdot \frac{\varepsilon}{\omega_o} \qquad (4)$$

with: $\varepsilon = \sqrt{C_1^2 + C_2^2}$, where $\varepsilon$ is the $\omega_x$ angular velocity amplitude into generic direction, normal to the *Oz* rotation axis. The $C_1$ and respective $C_2$ constants were obtained into the integrating processes and depend on the initial system conditions [2].

Eq. (4) shows that $\theta_o$ is direct proportional to $\varepsilon$ and decreases when the angular velocity $\omega_o$ is increasing.

## 5. THE GYROSCOPIC SYSTEM

The gyroscopic system simulation has been performed using Matlab. Fig. 2 depicts the results yielded by program. On the ordinate axis one considered the angle between the stabilized plane and the instant plane after perturbation action. On the abscissa axis one considered the perturbation through the $\varepsilon$ amplitude.

It is useful to observe that an increased angular velocity results into an efficiency improvement.

An alternative application of the system is the reduction of wind action on the building structure. In this sense, Citicorp Center from New York has placed on the roofing area a big inertial mass (400 T) with amortization goal. The second example is the Hancock Building from Boston with two similar amortization systems [4].

A possible solution to improve stability is to place an energy absorbing blanket of composite matter between the Board Gyroscopic and the surrounding soil, inside the foundation. This layer is meant to dissipate some of the energy taken from the seismic wave. One practical solution would be an artificial construction of flexible structures based on steel bars combined with concrete substrate, but specialists in construction could provide better solutions, like stress structures over flexible base substrates or others such as.

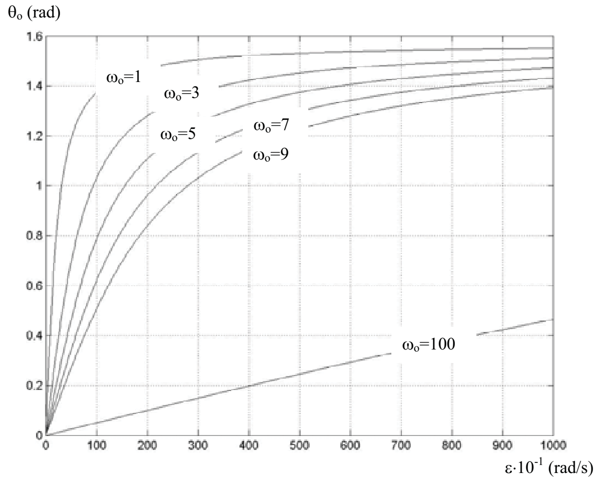


Figure 2: Results for system simulation.

A combination between a gyroscopic system mounted on the building foundation and another one mounted on the roof of the building can provide an interesting solution for stabilization, but care should be taken when designing the two systems taking into account the systemic interactions that can occur (phenomena of resonance or phasing as reactions to possible seismic waves' effects).

At present one performs studies over a gyroscopic system with stabilizer in vertical plane. In this sense one expects an increase of the stabilization effect over the buildings using a simply structure and construction of gyroscope.

## 6. PROGRAMMABLE MICRO-SYSTEM

In order to control the rotation of a gyroscopic system, one used an electronic subsystem.

The following requests were imposed:
- low cost
- safe operation
- low consumption
- uninterruptible function
- insignificant sensitivity to external factors
- programmable capabilities.

The radio signal is received from the epicenter's supervising area and has few seconds to react.

The reaction consists in speed-up commands and control for the gyroscopic system's rotation. Other function of this electronic system consists in the interruption of gas supply, connection of auxiliary power sources and alarming factors involved in rescuing people.

The micro-system designed and performed in the labs from "Ştefan cel Mare" Suceava University has been built around a Philips PCB80C552 microcontroller (Fig. 3). This chip has the following features:
- 64KB program memory
- 2KB read/write data memory

- 6 input/output ports on 8 bits
- 2 timer/counter on 16 bits
- 1 additional timer for trapping and comparing
- 2 priority levels
- 1 analogue/digital converter
- 1 PWM block
- 1 serial communication port
- 1 watchdog timer.

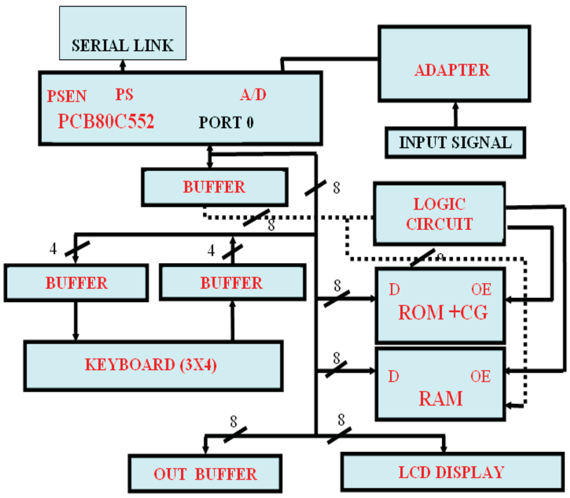


Figure 3: Micro-system logical structure.

This micro-system consists from one serial port adapter, one unit block control, one signal adapter block, two memory areas (RAM+ROM), one LCD display, one mini-keyboard and some buffers. The whole micro-system offers support for C programming and runs the applications loaded into the RAM memory from the PC connected computer. After the program loading, the micro-system becomes an autonomous system. The mini-keyboard and LCD display allow this regime.
The input data is achieved from the system's data bus and the output data is returned to system's data bus again.
All these mechanisms are performed under some routines implemented into the ROM memory area.
Figures 4 and 5 show the logical structures for the LCD display system and for the mini-keyboard system. With AB and DB one noted the address bus and the data bus for the main system.

## 7. MODELING OF THE SEISMIC WAVE PROPAGATION

For the time being there are not known any methods to prognoses time and location when a new seism movement is expected to arise, but it is possible to know with some seconds in advance the coming waves for a specific location [3].

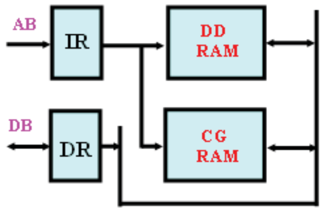


Figure 4: Logical display system.

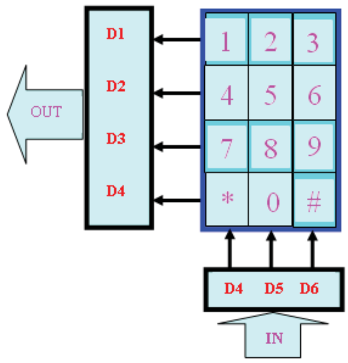


Figure 5: Logical mini-keyboard system.

This is possible because the front wave is propagating with a finite speed, and so one can apply a relation like as:

$$t = \chi \frac{d}{v} \tag{5}$$

where $t$ note the time propagation, $d$ is the distance between the seismic epicenter and the measurement location, and $v$ refers to the seismic wave propagation.
The $\chi$ parameter is a tensor which controls the movement of the phase wave's components into the propagation phenomenon. In consequence, the $\frac{d}{v}$ parameter must also be a tensor. Indeed, the direction and the velocity, treated individually, are simply scalars, but in conjunction a tensor can be obtained. Because the describing math space is two dimensional for the surface propagation and three dimensional for the volume propagation, these tensors must be of the orders two or three. The tensor's product must reduce the tensor order up to zero (to a scalar), because the left part of Eq. (5) is the time – a scalar expression. So, in the simplest case, the $\chi$ parameter is the unity scalar and the equation gets the classically form. But, in the general case the tensor's product involves two tensors. In the surface propagation case, the equation can be written as:

$$t = \chi_i^j \varphi_j^i$$
$$\varphi_j^i = \delta_{jk} \omega^{ik} \quad (6)$$
$$\omega^{ik} v_{ik} = 1$$

The meaning of the specified parameters is obvious. From (6) one obtains:

$$t = \chi_i^j \delta_{jk} \omega^{ik} \quad (7)$$

In all these relations, one considered the Einstein's rules of the summarization under the mutual indices.

The time in this relation has a complex form because during the propagation process more parameters are involved (the ground consistency, instantly wave's emergently direction, refraction, reflection and interfering waves components phenomenon etc.) All these wave propagation mechanisms conduct to an unpredictably featuring, with specificity for location measurement point. The involved tensors are difficult to obtain from above specified reasons.

## 8. CONCLUSIONS

A very interesting study can be performed for a specific point, providing that the seismic epicenter position is known. In this case one can measure the phases for the interfering wave components in the considered zone and so can detect the potential destructive areas. After that, one can perform the maps for some safe and unsafe areas for the buildings.

The study can start with a triangulation process and a decomposition of the seismic wave into $3 \times n$ sub-waves which are attached to the three circular evolution fronts that mark the seismic epicenter.

After that one must consider three ways of virtual wave propagation, in relation with the three consensual directions for the circular evolution fronts, in respect with Eq. (7). In the location where one performs the effect measurement, the wave's components are coming with different phases and interfere.

The result of those actions is an interfering pattern that stores into own structure all the information about seismic phenomenon.

Models used to describe the entire process of seismic wave propagation, interaction with the extra-ground object like buildings, and respectively energy dissipating mechanisms were made in the authors' laboratories

Based on the seismic data extracted from the previous earthquakes with seismic epicenter located in Vrancea region, one could realize the maps of action for the seismic wave at Suceava area. The final scope is to anticipate the risk zones from this area.

The seismic wave propagation trajectory is a fractal trajectory [5]. Between the fractal model and the classical mechanic trajectory model there are no fundamental theoretical relations. Future work is required in this direction.

Determining the fractal dimension is a first step into the new analysis of the theory of complexity models.

The fractal dimension has a major role for fractal models, providing the tools used to select the properties of the systems.

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