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With this publication, the CD with all papers from the International Conference on Information Technology and Development of Education, ITRO 2017 is also published.

INTRODUCTION

The Technical Faculty “Mihajlo Pupin”, Zrenjanin, of the University of Novi Sad, the Republic of Serbia organizes VIIIth International Scientific Professional Conference “Information Technologies and Development of Education 2017” (ITRO 2017). The Conference will be held on 22nd June 2017 at the Technical Faculty “Mihajlo Pupin” in Zrenjanin, Serbia.

The Conference “Information Technologies and Development of Education 2017” (ITRO 2017) is organized due to the needs to connect science, profession and education through topics and content concept, first of all concerning the teaching process as base of information society. The tendencies of developed countries are in accordance with the efforts of UNESCO to improve this area related to the needs of life and work in the XXIst century. It is necessary to assess the state, detect the problems and perspectives of the development of education by competent professionals and teachers as well as the influence of the development of education on the development of the society as a whole.

The central topic of the meeting is the model of dual education as base for creating good base for the development of industry. Thus, our aim is to gather the representative entities who are able constructively contribute to establishing link between the educational system and industry as follows: Chamber of Commerce of Serbia – Centre for Dual Education, Ministry of Education, Science and Technological Development, Union of Employers of Serbia, ZREPOK – Business Organization of Zrenjanin and Companies that run their business in the region, directors of grammar schools and secondary vocational school, members of the academic communities and other participants who are interested in the topics.

The main topics of the scientific professional conference are:

- Model of dual education
- Teaching based on the concept of entrepreneurship

Other thematic areas of the Conference:

- Theoretical and methodological questions of contemporary Pedagogy
- Digital didactics media
- Contemporary communication in teaching
- Curriculum of contemporary teaching
- Developing teaching
- E-learning
- Management in Education
- Teaching methods of natural and technical subjects
- Information-communication technologies

The Chairman of the Organizing Committee of the ITRO 2017 Prof. Dragana Glušac opened the Conference. The participants were addressed by the vice dean of the Technical Faculty »Mihajlo Pupin«, Prof. Dijana Karuović; provincial secretary for science, higher education and scientific Research prof. Zoran Milošević, and the vice-major of Zrenjanin Mr. Dusko Radisic.

There were total of 143 authors that took part at the Conference from 12 countries, 2 continents: 82 from the Republic of Serbia and 61 from foreign countries such as: Macedonia, Bulgaria, Slovakia, Austria, Cyprus, Albania, Hungary, Spain, Bosnia and Herzegovina, USA, Portugal.

The Proceedings of papers contains 60 papers and it has been published in the English language.

President of the Organizing Committee
Prof. dr Dragana Glusac

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CONTENTS

Wave equation with Dirichlet boundary conditions

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Abstract - Partial differential equations derived from relationship between different physical and geometric problems where the function depends on two or more independent variables. Hyperbolic equations are a type of partial differential equations. In this paper, we consider the wave equation as a special form of hyperbolic equations. In addition, we are using computer simulation of the wave propagation on a specific numerical model occurring due to Dirichlet boundary conditions. We used formulation of the wave equation via the velocities, strains, and stresses. For simulation, we are using FORTRAN programming language.

I. INTRODUCTION

Most of the physical problems (heat transfer, electromagnetic theory, quantum mechanics, etc.) are resolved by application of partial differential equations. Partial differential equations derived from relationship between different physical and geometric problems where the function depends on two or more independent variables, most of the time t and of one or more spatial variables.

These equations can be divided into three groups:

- Elliptical (Laplace equation)
- Parabolic (heat equation)
- Hyperbolic (wave equation)

The solutions for each type of equation vary and therefore additional conditions are considered for solving each type of equation. Additional conditions are initial conditions (at time t=0) or boundary conditions (prescribed values of the solution u or some of its derivatives on the boundary surface S, or boundary curve C, of the region) or both. For one and two dimensional wave equation there are two initial conditions (initial displacement and initial velocity).

In this paper, we will focus on numerically solving of problems by applying one-dimensional wave equation as a special form of hyperbolic equation.

II. WAVE EQUATION

As a first important hyperbolic partial differential equation, we will consider the equation which is used for small transverse vibrations of an elastic string, such as a violin string. We place the string, parallel on the x – axis strained along length L, and fastened at the ends x = 0 and x = L. Next, we are distorting the string and at some moment of time (for example when t = 0), we releasing it and it starts to vibrate. Our purpose will be to determine the vibrations of the string and finding its deflection u(x,t) at any point x and at any time t > 0 (Fig.1).

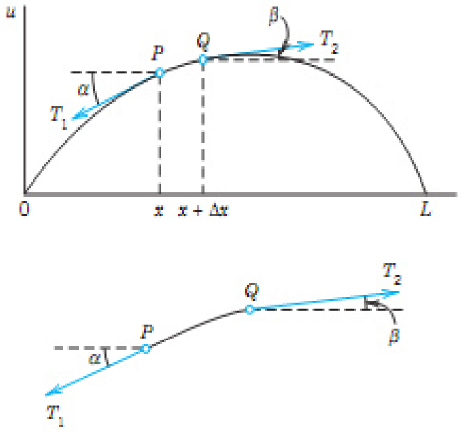


Figure 1. Deflected string at fixed time t (redrawn from Kreyszig, 1999)

In fact, u(x,t) will be a solution of the partial differential equation. For this equation to be solved the following assumptions are made:

- The mass of the string per unit length is constant. The wire is perfectly elastic and it makes no resistance during modifications.
- The tension caused by stretching of the string before its fastened at the ends is so large that

the action of the gravitational force on the string can be neglected.

- The string makes small transversal movements in a vertical plane. Each particle of the string is moving only vertically, causing a deflection and the slope at every point of the string is always small.

To derive a differential equation, we take into consideration the forces which act on a small portion of the string (Fig. 1). Because the string doesn't offering resistance to bending, the force of tightening is the tangent to the curve of the string at each point. Let T_1 and T_2 be the forces of tightening at the ends points P and Q. Because, the points of the string are move vertically, there aren't movements in the horizontal direction. Therefore, the horizontal components of the forces of tightening must be constant. By using the notation from Fig. 1, we obtain:

$$T_1 \cos\alpha = T_2 \cos\beta = T = const \quad (1)$$

In vertical direction there are two forces, called vertical components $-T_1 \sin\alpha$ and $T_2 \sin\beta$ for T_1 and T_2. The minus sign appear because the component at P is directed downward. By Newton's second law, the result of these two forces is equal to the mass $\rho\Delta x$ of the portion multiplied by acceleration $\frac{\partial^2 u}{\partial t^2}$, evaluated at some point between x and $x + \Delta x$, where ρ is the mass of the string which is not deviated per unit length and Δx is the length of the string which is not deviated . Hence:

$$T_2 \sin\beta - T_1 \sin\alpha = \rho\Delta x \frac{\partial^2 u}{\partial t^2}$$

By using (1), we can divide this with $T_2 \cos\beta = T_1 \cos\alpha = T$ and then obtain:

$$\frac{T_2 \sin\beta}{T_2 \cos\beta} - \frac{T_1 \sin\alpha}{T_1 \cos\alpha} = \tan\beta - \tan\alpha = \frac{\rho\Delta x}{T} \frac{\partial^2 u}{\partial t^2} \quad (2)$$

Tan α и tan β are slopes of the string at x and at $x + \Delta x$

$$\tan\alpha = \left(\frac{\partial u}{\partial x}\right)\Big|_x \quad \text{and} \quad \tan\beta = \left(\frac{\partial u}{\partial x}\right)\Big|_{x+\Delta x}.$$

By using the partial derivations of the u(x,t) and by dividing of (2) with Δx, we thus have:

$$\frac{1}{\Delta x}\left[\left(\frac{\partial u}{\partial x}\right)\Big|_{x+\Delta x} - \left(\frac{\partial u}{\partial x}\right)\Big|_x\right] = \frac{\rho}{T}\frac{\partial^2 u}{\partial t^2}$$

For Δx→0, we obtain a linear partial differential equation

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}, c^2 = \frac{T}{\rho} \quad (3)$$

This equation is one dimensional wave equation (1D) which is solution of our problem. 1D equation means that equation includes only one spatial variable x.

III. THE MODEL

A 1D Wave equation is represented with equation (4)

$$\rho \frac{\partial^2 u}{\partial t^2} = \frac{\partial \sigma}{\partial x} \quad (4)$$

For establishing this equation we need to define the velocity of propagation of the wave $\beta = \sqrt{\frac{\mu}{\rho}}$

where μ is shear modulus of the material, and ρ is density of the material from which the rod is made. The parameters ρ and μ are different and specific for each material from which the rod is made. $\sigma=\mu\varepsilon$ is shear stress and ε is shear strain of the wave.

For establishing the iterative procedure, the equation (4) is presented as the first order system of partial differential equations through the velocity of movement v and through strain ε.

By replacing $v = \frac{\partial u}{\partial t}$ for the velocity in equation (4), we get:

$$\frac{\partial v}{\partial t} = \frac{1}{\rho}\frac{\partial}{\partial x}(\mu\varepsilon) = \frac{\mu}{\rho}\frac{\partial \varepsilon}{\partial x} \quad (5\ a)$$

Then, if the both sides of identity $\frac{\partial u}{\partial t} = \frac{\partial u}{\partial t}$ are differentiated with respect to x, we obtain $\frac{\partial^2 u}{\partial t \partial x} = \frac{\partial^2 u}{\partial t \partial x}$. By replacing ε with $\varepsilon = \frac{\partial u}{\partial x}$ in the last equation, we then get the equation 5b:

$$\frac{\partial \varepsilon}{\partial t} = \frac{\partial v}{\partial x} \quad (5\ b)$$

The equations 5a and 5b can be presented as vectors as follow:

$\{U\}_{,t} = \{F\}_{,x}$ or $\frac{\partial U}{\partial t} = \frac{\partial F}{\partial x}$ where $U = \begin{Bmatrix} V \\ \varepsilon \end{Bmatrix}$ and

$$F = \begin{Bmatrix} \frac{\mu\varepsilon}{\rho} \\ V \end{Bmatrix} = \begin{Bmatrix} \frac{\sigma}{\rho} \\ V \end{Bmatrix}$$

The vector U at point i and time (j+1)Δt is

$$U_{i,j+1} = U_{i,j} + \Delta t\left(\frac{\partial U}{\partial t}\right)_{i,j} + \frac{\Delta t^2}{2}\left(\frac{\partial^2 U}{\partial t^2}\right)_{i,j} + \cdots$$

By replacing $\frac{\partial U}{\partial t}$ with $\frac{\partial F}{\partial x}$, we obtain

$$U_{i,j+1} = U_{i,j} + \Delta t\left(\frac{\partial F}{\partial x}\right)_{i,j} + \frac{\Delta t^2}{2}\frac{\partial}{\partial t}\left(\frac{\partial F}{\partial x}\right)_{i,j} + \cdots$$

We can write the part $\frac{\partial}{\partial t}\left(\frac{\partial F}{\partial x}\right)$, as $\frac{\partial}{\partial x}\left(\frac{\partial F}{\partial t}\right)$ where $\frac{\partial F}{\partial t} = \frac{\partial F}{\partial u}\frac{\partial U}{\partial t} = A(U) * \frac{\partial U}{\partial t}$ or

$$A(U) = \frac{\partial F}{\partial U} = \begin{bmatrix} \frac{\partial \sigma}{\rho \partial v} & \frac{\partial \sigma}{\rho \partial \varepsilon} \\ \frac{\partial v}{\partial v} & \frac{\partial v}{\partial \varepsilon} \end{bmatrix} = \begin{bmatrix} 0 & \frac{\partial \sigma}{\rho \partial \varepsilon} \\ 1 & 0 \end{bmatrix}$$

In A(U), $\frac{\partial \sigma}{\rho \partial v} = 0$ and $\frac{\partial v}{\partial \varepsilon} = 0$ because σ does not is depended of v.

Hence, for $U_{i,j+1}$, we obtain

$$U_{i,j+1} = U_{i,j} + \Delta t\left(\frac{\partial F}{\partial x}\right)_{i,j} + \frac{\Delta t^2}{2}\frac{\partial}{\partial x}\left(A(U) * \frac{\partial F}{\partial x}\right)_{i,j} + \cdots$$

For incident excitation in our example, we take a semi - sine pulse (Fig.2). U_{0max} presents the amplitude, and t_d is duration of the pulse.

$$U_0 = \begin{cases} A * sin\frac{\pi t}{t_d}, t \le t_d \ (6a) \\ 0, \qquad t > t_d \ (6б) \end{cases}.$$

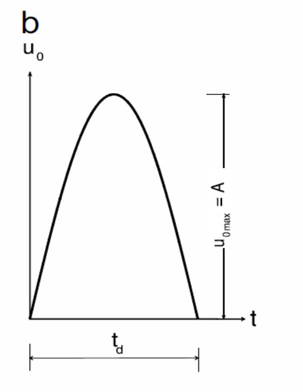


Figure 2. Incident excitation

Our problem is with wave equation to calculate the displacement at each point x during the each time t in 1D medium-rod. The rod is divided into 200 equal spatial intervals. By every displacement, the rod is vibrating. At every point, we calculate the final central difference with the formulas (7) and (8).

$$\frac{\partial^2 u}{\partial x^2}(x_i, t_l) \approx \frac{u_{i-1}^l - 2u_i^l + u_{i+1}^l}{\Delta x^2} \qquad (7)$$

and $$\frac{\partial^2 u}{\partial t^2}(x_i, t_l) \approx \frac{u_i^{l-1} - 2u_i^l + u_i^{l+1}}{\Delta t^2} \qquad (8)$$

where $x_i = (i-1)\Delta x, i = 1, \dots, n$ and $x_l = l\Delta t. l = 0.1 \dots$

IV. THE RESULTS

The velocity of propagation of the wave is $\beta = 300$ m/s, the amplitude is A=0.1m and the duration of the pulse is t_d=0.1s.

The displacement as a function of x is obtained from (6a) as

$$u = Asin\frac{\pi t\beta}{t_d\beta} = Asin\frac{\pi x}{t_d\beta} \qquad (9)$$

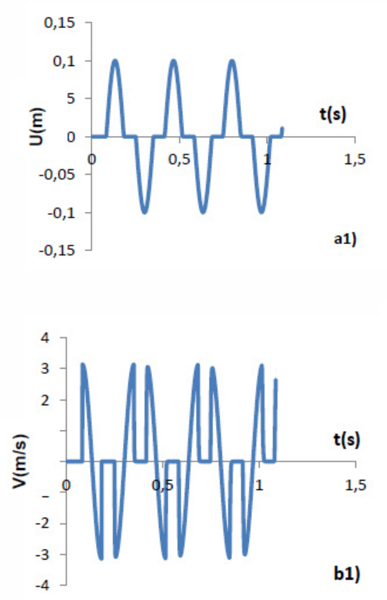
By differentiating equation (9) with respect to x, we obtain

$$\frac{\partial u}{\partial x} = \frac{\pi A}{\beta t_d}cos\frac{\pi x}{t_d\beta} \qquad (9a)$$

So, for the maximum value of the strain ε, we have

$$\varepsilon = \frac{\pi \cdot 0.1}{300 \cdot 0.1} \sim 0.01.$$

We solved this problem by using FORTRAN as programming language. In Fig. 3 are presented the results of the numerical simulation of spreading of the wave in the form of semi - sine pulse at the middle point $x = \frac{H}{2}$ opposite the time for $\beta = 300\ m/s$.



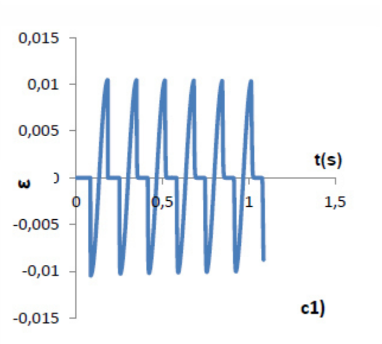


Figure 3. Graphical representation of the solution (displacement, velocity and strain) at the point on the middle of the beam, x = H/2 versus time

In Fig.3 a graphic representation of the solution at the middle point of the rod when we have point 100 and x = H / 2 or 25m is given. The displacement u, the velocity v and the strain ε in depend of time t are shown. The graphic representation is given for fixed ends when U=0 at the bottom, x=0 and at the top x = H = 50 m (Dirichlet boundary conditions). In this case when we have the fixed boundaries after the reflection, the pulse changes the sign and in the middle of the rod (in the point 100) comes with opposite (negative) displacement compared to the first pass through this point (the second peak in Fig. 3a1 is with negative sign). The situation is identical also for the velocity (Fig. 3b1). In contrast to the velocity and the displacement, the strain after reflection does not change the sign i.e all the semi-cosine waves (Fig. 3C1) begin with negative sign and finish with positive sign.

So when we have fixed ends (Dirichlet boundary conditions), after the reflection the sign of displacement u and the velocity v changes, but the sign of strain ε does not change. After several reflections, the amplitudes of the pulse remain unchanged.

V. CONCLUSION

For values 0≤r∗≤1 for the parameter r, this model will be stable, so from the equation (6) we can expect an acceptable result for the discontinuities initial data. In addition, we can conclude that for fixed ends such as Dirichlet boundary conditions like in our example after reflection sign of displacement, u and velocity, v changes, while the sign of strain, ε does not change.

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