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Application of Computational Programming Softwares In Teaching of Structural Analysis In Industry 4.0 Period

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Abstract— *In Vietnam, nowadays, due to the requirement of changing the training program, it leads to a change in the teaching time of subjects in general and structural analysis in particular. In addition, with the development of information technology, the courses require the use of computational programming softwares to help students understand the nature of the subject matter and in a shorter time solving more complex problems without mathematical difficulties. Based on these requirements, the article introduces how to apply some computational softwares to teaching structural analysis and the analysis of advantages and disadvantages as well as the applicability of each software. Besides, the article introduces some subroutines established by the author to teach students in the parts of structural analysis.*

Keywards— *Structural analysis, computational programming softwares, MathCad, Matlab, Ansys, internal forces, displacement, stability analysis, dynamic analysis*.

I INTRODUCTION

The subjects "structural analysis" may be divided into three large principal groups. They are static analysis, stability, and vibration analysis which are the basis subjects for training engineers in civil and industry construction. The requirements of these modulus of the subjects are the students must be knowledgeable about calculation methods, know how to use them to determine internal forces and displacements in the static analysis, determine the critical loads in stability analysis, and determine the specific oscillation frequency, dynamic internal forces diagrams. In addition, students will be equipped with the knowledge of optimization calculations in the subject of optimization theory. From the knowledge gained from these subjects, students can easily enter specialized subjects, as well as knowledge of different structural systems to work after graduation and can implement the practice structures.

The training program in Vietnamese universities gradually changed. Previously, teachers can guide students to do a larger volume of exercises. But now, it is required students to spend more time studying their self at home. The time of interaction between students and teachers in classroom is shorter. Therefore, within a prescribed time according to the class program, teachers using traditional teaching methods to solve problems manually like before will not be able to do complicated exercises. Moreover, today with the development of information technology, especially its application in the field of construction in general and structural analysis in particular, requires students to well understand and to implement the problems with application of computational calculation softwares to be able

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to work easily when becoming a construction engineer. Prior to that problem, the requirement for the lecturers is how to probably apply computational software in teaching the subject “structural analysis”. Depending on the each part of the subject, the lecturers have to choice appropriate software as the students still understand the nature of the structural problem in each part and solve complicated problems without mathematical difficulties.

II INTRODUCTION OF SEVERAL APPLIED SOFTWARES IN STRUCTURAL ANALYSIS

II.I. MathCad calculation programming software

The purpose of using computational programming software in the learning and teaching of structural analysis subjects is to allow teachers and learners to save time on complicated problems. It is necessary to select suitable software for students' qualifications for each academic year. Mathcad programming software is not being too difficult to use as professional programming languages, allowing users without deep knowledge of programming to quickly access and gain the skills to use at certain level. Therefore, MathCad programming software is suitable for teaching and learning for first-year students. This is one of the most popular mathematical programs. The software has powerful math tools to solve problems without extra procedures: Tools for vector and matrix calculations; solving equations and systems of algebraic equations (linear and nonlinear); solving differential equations and systems (Cauchy problem and boundary conditions); integral and derivative calculations; solve partial differential differential equations; solving optimization problems.

Visualization is a remarkable advantage of MathCad software compared to other calculation software. MathCad is the only mathematical program whose interface is built on the principle of "What you see is what you get". This means that each change is directly visible and printed as text format. Working with computers is exactly the same as on paper but it is more efficient. MathCad software allows simultaneous implementation of model setting and editing. Math expressions written in MathCad use familiar symbols and in the same positions as shown in regular mathematical expressions that distinguish with other programs that use characters under a special rule. Therefore, the content of the structural analysis problems by MathCad software is intuitive and easy to understand.

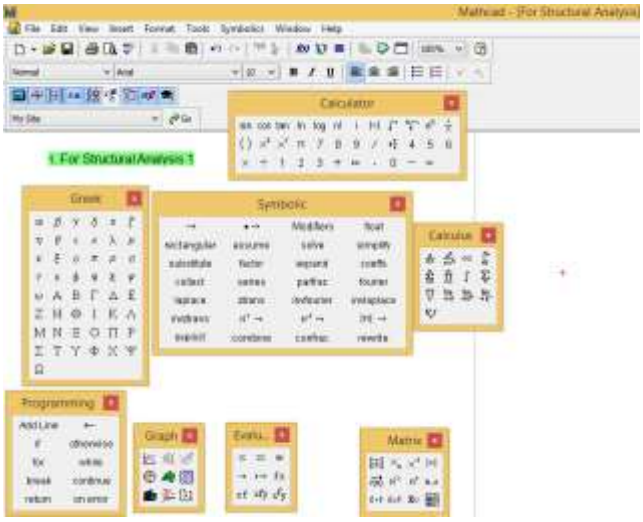

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Figure 1. Illustrations of software images and mathematical toolbars in MathCAD

II.II. Matlab programming software

Matlab handles numerical calculation and high-quality graphics, provides a convenient interface to build subroutine libraries and incorporates a high-level programming language.

MATLAB is a computer program that provides the user with a convenient environment for performing many types of calculations. This can cause a sort of complication toward writing the MATLAB program which is dedicated to predict the behavior of the engineering case studied.

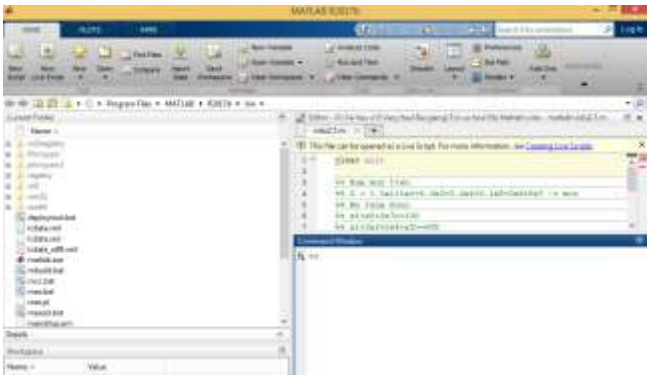

Figure 2. Illustration of software images and mathematical toolbars in Matlab

Matlab software helps solve complex problems due to its powerful features, but the usage is not intuitive and requires users to have certain knowledge of programming. Therefore, it is suitable for subjects for final year students of undergraduate programs such as numerical methods or specialized subjects such as the theory of optimization in construction.

II.III. ANSYS mechanical simulation software

Unlike the two above mentioned mathematical programming softwares MathCad and Matlab, Ansys software is a simulation software that also can be applied in teaching structural analysis subjects.

ANSYS was established in the 1970s, by the research team of Dr. John Swanson. Swanson Computing System in the US is a software package based on finite element method to analyze physical problems, to convert differential equations, derivative equations from the form numerical analysis with the use of discrete and approximate methods to solve and simulate the behavior of a physical system subjected to different types of loads.

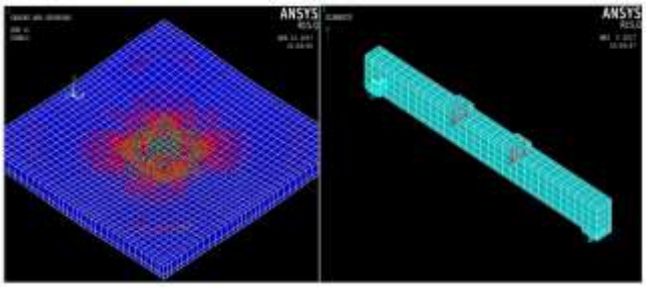

Figure 3. Example of illustration of building structure simulation by ANSYS

The software is widely used all over the world, has long-term development prospects and has full support

documents. Students can use it to study specialized subjects and to apply in the design process. Software allows direct simulation by code. The use of code is necessary if students want to improve speed and efficiency while solving problems with changing parameters, structures to be optimized, and automation of calculation processes. There are three usage modes in ANSYS APDL: graphical interface (GUI), scripting mode (COMMAND) and mode of running text files containing compiled instructions. Program parameter (Batch Mode)

ANSYS has the following main features:

- Powerful graphic capabilities that help simulate structure very fast and accurate as well as transmission of CAD models;
- Large element library and it can be easily add or remove elements, change element stiffness in the calculation model;
- Advanced results processing section allows drawing graphs, optimal calculations;
- Ability to study physical responses such as stress field, temperature field, electromagnetic influence;
- Create test samples for environments with difficult working conditions;
- The intuitive MENU system helps users easily implement all steps for solving problem.

III STRUCTURAL ANALYSIS PROBLEMS AND THE CHOICE OF APPROPRIATE PROGRAMMING SOFTWARE

In Vietnam nowadays, the modules of structural analysis vary depending different ways of regulations of each university. However, it is often divided into the following modules: structural mechanics part 1, structural mechanics part 2, stability analysis, dynamics analysis, numerical methods and optimization theory in construction. In some universities, the optimization theory in construction is studied at a higher level such as the graduate program.

III.I. Structural mechanics part 1 and part 2

In these two modules, the main purpose of the course is that students must have knowledge about each type of structures, and must know how to determine internal forces and displacements in the structure. In the first part of structural mechanics student must study how to determine internal forces and displacements in different types of static determinate systems, while in part 2 of structural mechanics to determine internal forces and displacements in different types of indeterminate structures. To determine internal forces and displacements in the determinate structures, analytic method is used, specifically the cross-section method, determining each value in special sections and equations illustrated the function of internal force and displacement in the corresponding element segments. From there draw the diagram for the system and the displacement value at the searched points. Similarly, to determine internal forces and displacements in the indeterminate structures, a number of different analytical methods are applied: force method, displacement method, mixed method. The ideas of these methods are all about calculating on primary systems and establishing canonical equations to determine the primary unknowns of the problem. Then draw the internal force diagrams as well as determine the displacement value at searched point.

In order to apply the computational programming software for these two modules, it is convenient to use the matrix establishment. After investigation of several math programming softwares, the author recommended that MathCad software suitable for applying the problems of these 2 modules. The reason is that MathCad software is a highly intuitive software, suitable for students who do not have well programming knowledge. Calculation procedure is

displayed on the screen. From there, help students master the calculation procedure according to the choosen method and control any arising errors during the calculation process.

In [1] the author has written computational procedures and a number of subroutines that help determine internal forces and displacements in different types of systems. Figure 4 shows the block diagram of determination of internal forces using force method by MathCad software.

III.II. Stability analysis

Stability analysis in deformational elastic system is the determination of the critical load acting on the system according to the stability criteria. It can be used many different methods for solving problems of stability analysis. The principles of these methods are based on the manifestations of stable equilibrium in various forms such as: expressing stable equilibrium in the static form, in the form of energy and in the form of dynamic form. However, in the above criteria of expression of stability equilibrium, the criterion of stability equilibrium in the form of statics or static method allows users to approach more easily. The content of the method is: Create the system considering a balanced form that deviates from the original equilibrium form; determine the critical force from the stability equation.

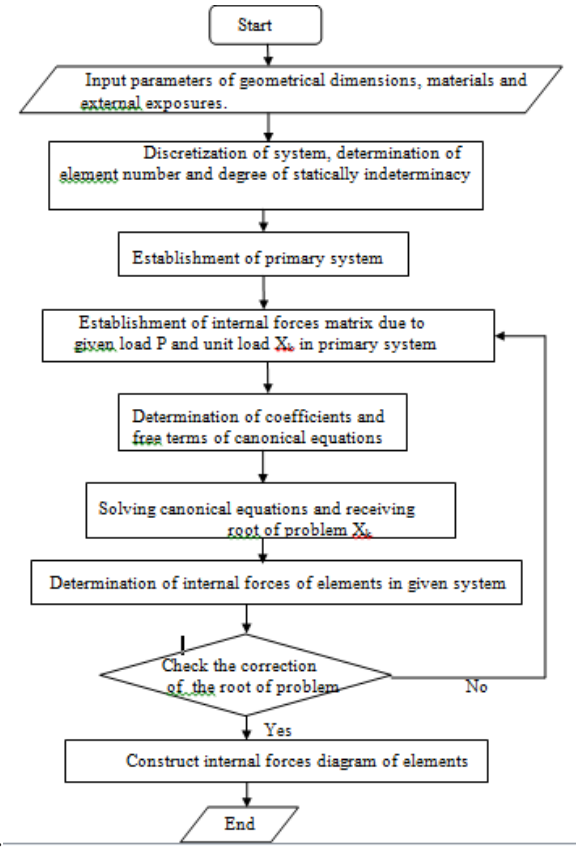

Figure 4. Block-scheme of determination of internal force using force method by MathCad software

In order to conveniently apply matrix algorithms with the use of MathCad software the article presents how to implement the problem by displacement method. In [1] the author has established a number of different sample elements for bending moment with compressive forces (fixed-fixed support element, fixed-hinged support element, fixed-clamped support element) subjected to different types of external exposures (load, settlement of support,

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temperature change)

The procedure of stability analysis problem by applying matrix algorithm in MathCad software can be carried out as follows:

Step 1: Given input parameters of the problem (moment of inertia of cross-sections of element; modulus of elasticity of materials; geometric sizes of elements; compressive load applied to each element in system).

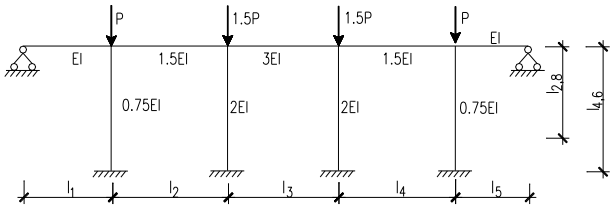


Figure 5. Illustration of example for stability analysis by MathCad software

Step 2: Discretization of system, determination of the number of elements and the degree of kinematical indeterminacy by displacement method;

Step 3: Establishment of the primary system by displacement method

Step 4: Establish internal forces matrices due to displacement and compressive load P in primary system

- Establishment internal forces matrix due to displacement Z_k=1 and compressive load P in primary system (internal force due to each displacement Z_k is written in one column, for each element is written in one row of the matrix, the rank of the matrix is "mxn", wher n is the degree of kinematical indeterminacy, m is the number of the elements in the system). For elements subjected only displacement, apply the sample element as specified in [1], for elements subjected both displacement and compressive load, it is necessary to take into account the effect of compressive load as follows:

$$\varphi_2(\upsilon) := \frac{\upsilon\cdot(\tan(\upsilon)-\upsilon)}{8\cdot\tan(\upsilon)\cdot\left(\tan\left(\frac{\upsilon}{2}\right)-\frac{\upsilon}{2}\right)} \qquad \varphi_3(\upsilon) := \frac{\upsilon\cdot(\upsilon-\sin(\upsilon))}{8\cdot\sin(\upsilon)\cdot\left(\tan\left(\frac{\upsilon}{2}\right)-\frac{\upsilon}{2}\right)}$$

$$\varphi_1(\upsilon) := \frac{\upsilon^2\cdot\tan(\upsilon)}{3\cdot(\tan(\upsilon)-\upsilon)} \qquad \eta_3(\upsilon) := \varphi_1\left(\frac{\upsilon}{2}\right) \qquad (1)$$

$$\eta_1(\upsilon) := \frac{\upsilon^3}{3\cdot(\tan(\upsilon)-\upsilon)} \qquad \eta_2(\upsilon) := \eta_1\left(\frac{\upsilon}{2}\right) \qquad \varphi_4(\upsilon) := \eta_3(\upsilon)$$

(9)

The sample elements for element subjected to displacement and compressive load are established in [1] by MathCad software.

Step 5: Establishment matrix of coefficient adjustment of structure.

This matrix is established for each type of element with different supports and figures that is written in [1]

Step 6: Determination of coefficients of canonical equations.

The coefficients of canonical equations are determined by following formula:

$$R(\upsilon) := M_1(\upsilon)^T\cdot B\cdot M_2(\upsilon) \qquad (2)$$

In which $M_1(\upsilon)$ - matrix of internal forces due to displacement and compressive loads;

$M_2(\upsilon)$ - matrix of internal forces due to only displaecment.

Step 7. Establishment of equation of stability state. Solving the equation, obtained the root of problem

$$y(\upsilon) := |R(\upsilon)| \qquad (3)$$

The critical load is determined by the following:

$$P_{th} := \frac{\upsilon^2 \cdot E \cdot I}{l^2} \qquad (4)$$

The procedure and calculation block scheme of stability analysis are written in [1].

III.III. Dynamic analysis

In the module "dynamics analysis", student must be equipped the knowledge about dynamic characteristics of the structure system as well as calculation of the effect of dynamic load. Specifically, students must understand how to calculate specific vibration frequencies for different types of structural systems, as well as draw dynamic internal forces diagrams and determine displacements in the searching positions.

In own researches, the author also realized that application of MathCad programming software is the most convenient, helping students to control the calculation process as well as control all errors arising in calculation process. In [1], the author presents the specific calculation procedure and block scheme of dynamic analysis using MathCad programming software. The procedure of dynamic analysis is written as follows.

Here, consider example of scheme of problem of dynamic analysis.

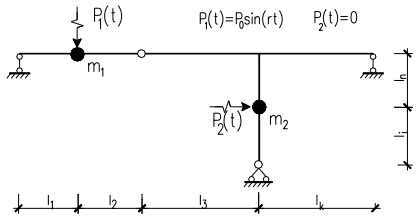


Fig. 6. Example of scheme of problem of dynamic analysis

Step 1: Given input parameters of the problem (Elastic modulus of element, inertia of cross-section of elements, geometrical dimension, masses m_k distributed in the system);

Step 2: Discretization of calculation system, determination of number of elements.

Step 3: Establishment of internal forces matrices due to unit load.

The internal forces matrices due to load F_k=1 applied in the position of masses m_k. The matrix is written for each element, and is written in a row of matrix, the internal force matrix due to one load F_k=1 in the position of mass m_k written in a column of matrix. The rank of matrix is "mxn", in which n is number of masses in the system.

Step 4: Determination of coefficients and free term of canonical equations.

The coefficients and free terms of canonical equations are determined by following formulas:

$$\delta_{i,j} := \sum_{k=1}^{m} \left(\int_0^{L_k} \frac{M1(x)_{k,i} \cdot M1(x)_{k,j}}{E \cdot I} dx \right) \qquad (5)$$

Step 5: Establishment of matrix of masses in system

$$M := \begin{pmatrix} m_1 & 0 & .... \\ 0 & m_2 & .... \\ ... & ..... & ..... \\ 0 & ..... & m_k \end{pmatrix} \quad (6)$$

Step 6: Solving equations, receiving the root of problem which are the natural frequencies.

$$D := \frac{\delta \cdot M}{\delta_{1,1}} \qquad u := \text{eigenvals}\ (D) \quad (7)$$

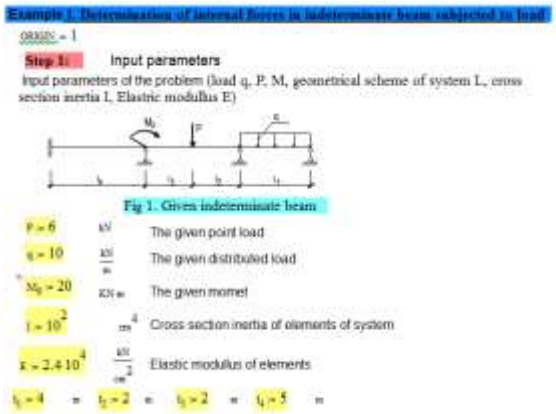
III.IV. Numerical methods

In this module, students are equipped with a certain amount of knowledge about the different types of structures, the suitable calculation methods for each type of structure. The requirement is to know how to apply new methods to be able to solve complex problems by applying programming software. The current most popular numerical method is finite element method; another method mentioned in this subject is finite difference method. In computer programming software, Matlab software is preferable, allowing easy programming for each different computing module. Appropriate for students in the period who have a relative understanding of some analytical methods as well as programming knowledge equipped in some subjects of applied informatics.

III.V. Optimization theory in construction

This is a research module, depending on the universities that this module is studied to the undergraduate program for final year students or for graduate students in the master's program in construction engineering universities. The purpose of the module is to introduce optimal calculation methods for building structures and apply those methods to different types of optimal problems for different structural systems. It is possible to apply Matlab's toolbox to optimize calculation or set up the procedure according to the methods available with MathCad programming software. However, with complex problems such as non-linear optimization with objective functions and complex systems, design variables are a function, it is common used Matlab programming software to solve them as this software has a powerful toolbox to solve problems.

IV EXAMPLE OF APPLICATION OF PROGRAMMING SOFTWARES IN STRUCTURAL ANALYSIS



Example 1. Determination of internal forces in indeterminate beam subjected to load

ORIGIN = 1

Step 1: Input parameters

Input parameters of the problem (load q, P, M, geometrical scheme of system L, cross section inertia I, Elastic modulus E)

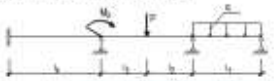


Fig 1. Given indeterminate beam

$P = 6$ kN The given point load

$q = 10$ kN/m The given distributed load

$M_0 = 20$ kN·m The given momet

$I = 10^{-2}$ m^4 Cross section inertia of elements of system

$E = 2.4 \cdot 10^4$ kN/cm^2 Elastic modulus of elements

$l_1 = 4$ m $l_2 = 2$ m $l_3 = 2$ m $l_4 = 5$ m

Step 4: Establishment of internal forces matrix due to load and unit load in primary system

+ Establish matrix of internal forces (bending moment) Mp due to load in primary system (for each element written in a row of matrix, matrix rank "m x1", in which m - number of elements)

+ Establish matrix of bending moment M1 due to unit load Xk=1 in the primary system (the effect of one unit load Xk=1 written in a row of matrix , matrix rank "m x n", in which n - degree of statical indeterminacy)

$$Mp(x) = \begin{bmatrix} \frac{q\,x^2}{2} \\ q\,l_1\left(x + \frac{l_1}{2}\right) \\ P\,x + q\,l_1\left(\frac{l_1}{2} + l_2 + x\right) \\ M_0 + P\,(l_3 + x) + q\,l_1\left(\frac{l_1}{2} + l_2 + l_3 + x\right) \end{bmatrix}$$

Matrix of bending moment due to load P in primary system

$$M1(x) = \begin{bmatrix} -1 \cdot x & 0 & 0 \\ -(l_1 + x) & -1 \cdot x & 0 \\ -(l_1 + l_2 + x) & -(l_2 + x) & 0 \\ -(l_1 + l_2 + l_3 + x) & -(l_2 + l_3 + x) & -1 \cdot x \end{bmatrix}$$

Matrix of bending moment due to unit load Xk=1 in primary system corbam

Step 5: Determination of coefficients and free terms of canonical equations

$$\Delta_{i,j} = \sum_{k=1}^{m} \left(\int_0^{l_k} \frac{M1(x)_{k,i} \cdot M1(x)_{k,j}}{E \cdot I} dx \right) \quad i = 1..n \quad j = 1..n \quad k = 1..m$$

The coefficients of canonical equations

$$\Delta p_i = \sum_{k=1}^{m} \left(\int_0^{l_k} \frac{Mp(x)_k \cdot M1(x)_{k,i}}{E \cdot I} dx \right)$$

The free terms of canonical equations

$\Delta = \Delta_{CVCB} + (\Delta p)$

Step 6: Solving equations

$X = -\Delta^{-1} \cdot (\Delta)$

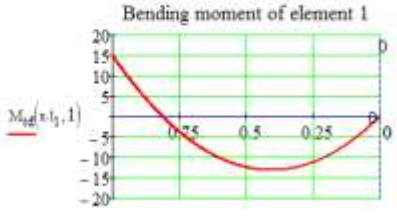
	1
1	16.23
2	33.34
3	-0.95

Step 7: Determination of internal forces for each elements in given system

$$M_{id}(x,k) = Mp(x)_k + \sum_{i=1}^{4} (X_i \cdot M1(x)_{k,i})$$

Step 9: Construct bending moment diagram in elements

$x = 0, 0.1 .. 1$



V CONCLUSIONS

Therefore, it can be seen that with the current development of information technology, the application of computational software as well as simulation software in teaching subjects in construction engineering in general and structural analysis in particular is indispensable and necessary.

The paper analyzed the characteristics of several applied computational softwares in construction engineering as its advantages and disadvantages as well as their suitability for each module of structural analysis. In the own research field, the author has written a number of subroutines to implement various problems of modules of the subject. From that it can be seen that the application of calculation programming softwares and structural analysis simulation softwares helps undergraduate students majoring in construction can be applied easily and helps them to understand the nature of problems and can implement complicated problems without having to deal with mathematical calculation difficulties.

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