Energy Loss Rate Failure Mechanism of Elastoplastic Components; The Case of Reinforced Concrete

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ABSTRACT

At this document it is shown how a Quatric Function of Structural Model named Theodore, named by the middle name of the author and the data which are given from two published articles are compared for the accuracy of Ultimate strength of two beam specimens. It is a combination of classic reinforced concrete design with a displacement of nonlinear Dynamic solution. Firstly it is computed the axial strength N due to the longitudinal reinforcement based to Eurocode and then it is non-linear Dynamically optimized the initial value of external displacement, which will predict the specimens energy loss rate curve by changing the initial value to another since the axial N value which were computed later is placed in the field where the curve shows maximum Axial N the same as the computed one. Finally there are estimated damage & failure curves mechanisms for both articles and there are compared with the experimental values to the model values. The damage & failure curves mechanisms have very good quality compared with the real failure of the specimens of both articles. It is important to emphasize that the predicted displacements are almost equal to the experimental's

Index Terms
Combination of Eurocodes design with elastoplastic finite element analysis, Damage & failure curve mechanism, Quartic force fields function optimization, Reinforced concrete beams.

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Introduction

According to the reinforced concrete background there is a tedency of using safety factors to all structures like beams and columns because with all algorithms it is not predicted the maximum load of bending resistance with accuracy and not only to factor of unknown and unpredictable factors. This document refers to a new way of calculation of reinforced concrete strength and uses the data of the calculations, which are taken from two published articles that were titled "Hybrid NSE/EB technique for shear strengthening of reinforced concrete beams using FRCM: Experimental study" and for the second "Flexural behavior of basalt fiber reinforced concrete beams with recycled concrete coarse aggregates". [1], [2]

Motivation

A. Beams strength accuracy due to design demands

The increasing of the known accurate value of break loss of energy or the loss rate curve mechanism, of a structure, is very important to correct and accurate design analysis giving the safety factors more or all of their value to the unknown or unpredictable factors.

B. Classic reinforced concrete beams design according to Eurocode

Elastoplastic materials like reinforced concrete, which it is made of steel and concrete materials and as for the maximum loads design it is needed to know when a beam or column will break at a certain value, like Eurocode design demands to have designed stronger columns than beams and that fact gives an important role to the accuracy predicted value and the energy loss rate of the structure that is loaded will be very important to know the accurate strength of the structure and the remaining energy for breaking or standing with a damage & failure curve mechanism. [3]

C. Elastoplastic analysis of finite elements

On the other hand it is very strongly recommended to use an elastoplastic analysis of finite elements to predict the loading factors of a structure. This is also a demand due to time and money consuming. In addition elastoplastic analysis of finite elements is mathematically accepted and very accurate if a model of plasticity is offered in every case. However the elastoplastic model would predict an accurate loading value for every specimen, this model is not so correct or in most cases it is used a theoretical model of older studies.

Objective

The negative for classic design is that concrete is not elastic to compute with plastic analysis. As some scientists prefer to use classic design for reinforced concrete and others prefer to use plastic analysis of finite elements in many cases there is an underestimate or overestimate of reinforced concrete specimens strength, which means that for the first case of safety factors they are not enough in reality of a structure and at the second case of overestimated safety factors, it is money consuming and not accurate or correct designed, which means that overestimations could be as well as for beams rather than for columns. A new model that is created by the author, a model of physics structural model that is so accurate as well as the model finds the energy loss rate of new physic and structural model, named Theodore by the middle name of author, is using non-linear displacement plastic analysis with combination of classic design gives the accuracy that is needed and giving also the safety factors a real meaning, while it is hope to be under acceptance in both calculation ways of studies, as a new alternate application.

Statement of Method

A. ethodology for finding the strength of reinforced concrete specimens

The methodology for solving Theodore model is relatively simple to understand. The model is a quadratic physics-mathematical equation, which is derived from four physics equations. These equations of Physics are Hooke's Law, the principle of conservation of momentum, the principle of conservation of kinetic energy, and the principle of conservation of kinetic energy due to rotational motion. The equations are graded, as the first equation derived from Hooke's law is linear, the second equation derived from the principle of conservation of momentum is exponent of the power of two, the third equation derived from the principle of conservation of momentum energy, is an exponent of the force of three and the fourth equation derived from the principle of conservation of kinetic energy due to rotational motion is an exponent of the force of four. These four derived equations consist of four unknown variables. Therefore there are four equations with four variables. [5] The system of equations therefore has four roots from solving the quadratic equation with respect to a variable. This variable chosen to be solved for the fourth degree equation is the variable “A“ which is the sum of the internal displacements, the perpendicular displacement “y“ and the vertical displacement “z“, such as the reference axes y and z respectively. Once the quadratic equation is solved, the form of which is given below, the finding of the other variables follows. Note that in order to solve the quadratic equation with an unknown variable “A“, it is necessary to first determine the displacement “G“ due to gravity, as the displacement due to the same weight of the beam or element. The other variable displacement “F“ is the unknown external displacement due to external loading, which is also the cause of damage or destruction of the beam or structural element. This external displacement “F“ is calculated by tests, until the axial force of the variable “N“ is found after different values of the variable “F“, in the same step, in which the axial force “N“ shows the corresponding transverse force “Qy“ at the maximum value of the transverse force-displacement charge curve. The determination of these steps is performed on any spreadsheet by solving the elasticity matrix, as well as the yield of a linear value for the deformation from values of 0.01% to 0.05%. The other internal variables of axial “x“, vertical “y“, vertical “z“, of the steering axes, x, y and z, have been calculated from the previous ones by the substitution method based on the four physics equations mentioned above. The latter method is the finite element method with known or calculated from the previous equations of physics, the corresponding movements to find the intensity values of resistance.. The following equation is Theodore's quadratic equation for the computation of the displacement variable “A“:

“ $A^4 + (F + G) \times A^3 + 12 \times F \times G \times A^2 + (15 \times F^2 \times G + 15 \times F \times G^2 - 2 \times F^3 - 2 \times G^3) \times A + (- 15 \times F^2 \times G^2 + 2 \times F^3 \times G + 2 \times F \times G^3) = 0$ “

with the variables as previously explained, solved as a mathematically. [5]

The following is the basic figure of the Theodore model, in which a beam is shown on the left which is subjected to an external load with a movement vector “F“ such as the movement due to external force in a downward direction, with a second vector in a downward direction, but this applies to the “G“ vector such as moving downwards due to the same weight. In the same figure is presented another vector on the underside of the illustrated beam. This vector, however, has an upward direction and, unlike previous vectors, shows a downward direction, compressing the beam in reverse. This “E“ vector such as Erosion or damage indicates the breakage or loss of the specimen or component. To the right of the image of the fundamental shape of the Theodore model is the cross section of the beam, where the corresponding vectors that govern the balance of the vectors of external, internal and Erosion movements are presented. The following is the basic Theodore scheme.

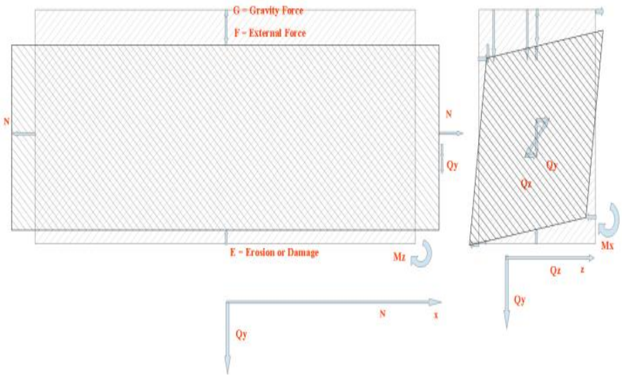

Figure 1: Basic fundamental shape of Theodore model

The following are the four displacement equations as previously explained. Specifically, the four derived equations from the four physics equations mentioned above are presented. From these equations came Theodore's quadratic equation, as presented earlier.

1. $F + G = A + E$

2. $F^2 + G^2 = A \times x + E^2$
3. $F^3 + G^3 = A \times x^2 + E^3$
4. $F^4 + G^4 = A^2 \times x^2 + E^4$

Four Equations of external coefficients F for external Force and G for structures Gravity displacement, A as $A = y + z$, with y and z the internal displacements of y and z axe and x as the internal longitudinal displacement in x axe, E for erosion or damage.

The following is the modified finite element method, based on the Theodore displacement model.

$$\begin{bmatrix} N \\ Qy \\ Mz \\ -N \\ -Qy \\ -Mz \end{bmatrix} = [\varepsilon] \begin{bmatrix} \frac{AE}{L} & 0 & 0 & \frac{-AE}{L} & 0 & 0 \\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & \frac{-12EI}{L^3} & \frac{6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & \frac{-6EI}{L^2} & \frac{2EI}{L} \\ \frac{-AE}{L} & 0 & 0 & \frac{AE}{L} & 0 & 0 \\ 0 & \frac{-12EI}{L^3} & \frac{-6EI}{L^2} & 0 & \frac{12EI}{L^3} & \frac{-6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & \frac{-6EI}{L^2} & \frac{4EI}{L} \end{bmatrix} \begin{bmatrix} x \\ y \\ z*y \\ -x \\ -y \\ -z*y \end{bmatrix}$$

Figure 2: Finite element matrixes based on displacements for every step [4]

with N as axial Force, Q as vertical Force and Mz as Bending Moment, with constant elastic stiffness matrix, with linear strain ε and always nonlinear displacements x, y and z. where, S = Section of an element, E = Factor of Elasticity, L = Length or height or opening of an element and I = Moment of Inertia.

So far, the calculation process has involved the Theodore quadratic equation and the finite element method. However, as previously mentioned, the present study concerns the combination of the design method of reinforced concrete based on Eurocode and finite elements, in this case with the method of displacement tests of the movement model Theodore. The question therefore arises as to how these two methods of calculating the intensive strengths of structural elements are related. The following simple explanation follows the procedure for calculating the reinforced concrete beam to find the strength value of the longitudinal reinforcement. This value of the longitudinal reinforcement is the aforementioned axial force "N", which is identical to the repetitive tests also mentioned above. [3]

B. Methodology for finding the energy loss rate mechanism

As mentioned in the title of this paper, the main innovation is to find the energy loss rate failure mechanism. This way of failure mechanism of the respective structural element, in this case the two reinforced concrete beams, is to find a curve that expresses displacement, as the energy loss is expressed through the displacements. Therefore this energy loss curve is the form of crack failure of the structural elements measured from the height of the beams and longitudinally from the smallest application side of the external force. This application of the shortest distance from the external force concerns in this case a beam uniformly reinforced with uniform stirrups and in the second case a beam with two eccentric loads but with a uniform distribution of reinforcements as well. Find this curve computed by dividing the external movement "F" by the internal movement "A". The cumulative value of these dimensionless motion divisions reaches a maximum percentage value greater than or equal to 100%. By multiplying the height of the beam by the cumulative energy loss values and by multiplying the span of the length of application of the external load, it is computed respectively in the form of a corresponding cross-section the form of cracking or the energy loss rate failure mechanism, for a given beam height and one side of failure due to external load application.

Results

A. Two reference beam specimens of two published articles

For the reason of greater conviction about the applicability of the Theodore model and the combination of Eurocode-based structural design and elastoplastic finite element design, two published journals using transverse load-strength tests were selected. The results of the strengths as well as the displacements from which the data failures resulted were compared to validate the suitability of the new Theodore quadratic equation displacement model.

The data needed for the calculations were obtained from the published journals entitled "Hybrid NSE / EB technique for shear strengthening of reinforced concrete beams using FRCM: Experimental study" and "Flexural behavior of basalt fiber reinforced concrete beams with recycled concrete coarse aggregates". [1], [2]

B. First article's data for reference beam

The published article entitled "Hybrid NSE / EB technique for shear strengthening of reinforced concrete beams using FRCM: Experimental study" refers to a reinforcement experiment of thirteen beams. This study concerns the beam reference structural element. The charge value at which the beam reference component reached its failure was 104 KN and concerned the right side of the beam component as the charge was eccentric. The displacement value at which the beam component showed the damage was 3.25 mm. Finally, the deformation value of the structural element was 1425 με. Taking into account all the data of this article for the construction materials of the reference beam, the value of axial strength "N" of the longitudinal reinforcement was initially calculated according to Eurocode, which axial strength "N", as mentioned before, is the target value in its method. elastoplastic analysis of finite elements. The displacement due to gravity "G" of the structural element is then calculated and this value is constant in the calculation method.

The accuracy of the Theodore model is almost perfect. With the computational method for finding the Forces of Axial N and Vertical Qy, as for the Bending Moment Mz, there is estimated an accuracy of difference for the predicted moments with the published results at about 13,7 % or having an accuracy of similarity for the predicted loading with the published results at about 86,3 %. Eurocode design Moment Mz value is 34,23 KNm and the Theodore's computed value is 28,85 KNm. The computed axial N force corresponds to a model computed Qy value of 104,884 KN with the experimental value to be 104 KN as mentioned before.

The deformation value at which the component presents the final damage is 1550με. Therefore the similarity between the experimental and the calculated according to Theodore model is of the order of 91.93%. The following is the load of vertical strength "Qy" - deformation diagram in which the damage occurred where the maximum charge value of the previously mentioned structural element presents an initial target value of the axial force "N" set as the target value. It is important to mention that the computed axial "N" according to Eurocode is equal to -412.67 KN. This value is a guide for every step until its vertical strength "Qy" reaches a maximum value in the following curve.

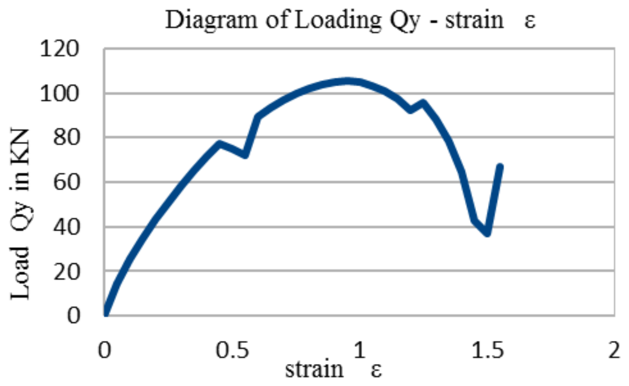

Figure 3: Diagram of Loading Qy with strain ε

Whereas the experimental displacement was 3.25 mm, the displacement value at which the component presents the final damage is 3,258 mm. Therefore the similarity of the experimental with the calculated according to Theodore model is of the order of 98.93%. The following is the load-displacement diagram in which the damage occurred where the maximum charge value of the previously mentioned component presents an initial target value of the axial force "N" set as the target value. The maximum displacement value shown in the following curve is 7.76 mm..

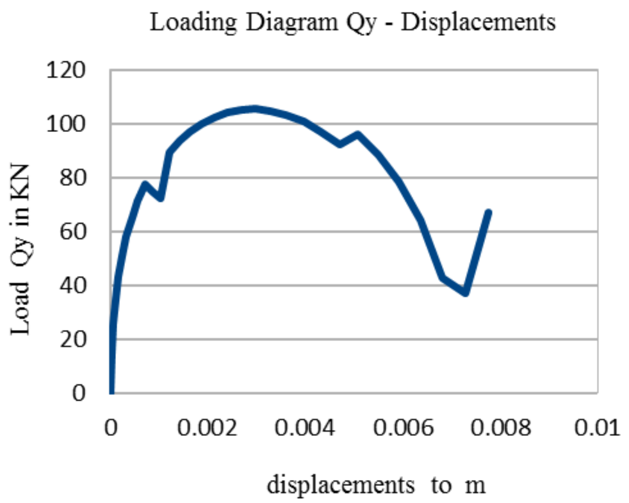

Figure 4: Diagram of Loading Qy with displacements

Finally, the main innovation of this document is the rate of energy loss mechanism elastoplastic structural elements. This curve is contained between the right end of the beam and the eccentric to the right side from the application of external loading. In this way the dimensions of the sides are proportional to the height of the beam with the middle span of the beam. Below is the diagram in question, the curve of which shows the shape of the beam damage dams. Obviously it is a form of surrounding damage and not the faults themselves. Therefore with the above condition the form of the energy loss rate curve is presented below.

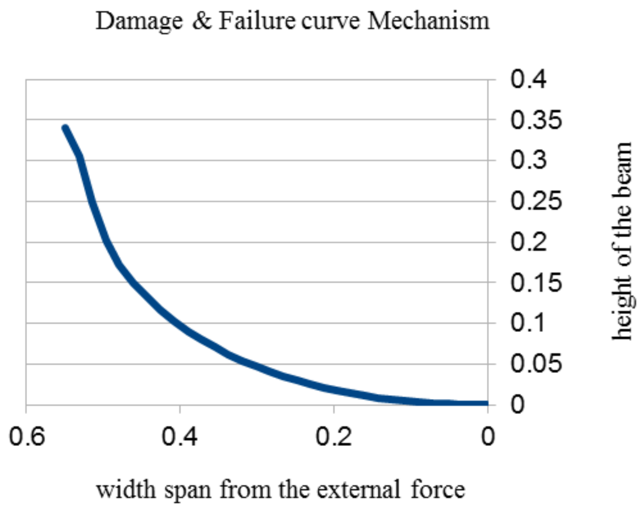

Figure 5: Diagram of energy loss rate failure mechanism [1], [3], [4]

C. Second article's data for reference beam

The published article entitled "Flexural behavior of basalt fiber reinforced concrete beams with recycled concrete coarse aggregates" refers to a reinforcement experiment of sixteen beams. This study concerns the beam reference structural element. The charge value at which the beam reference component reached its failure was 113.1 KN and concerned the middle span of the beam component as the charge was eccentric. The displacement value at which the beam component showed the damage was 2.57 mm. Finally, the deformation value of the structural element was about 1300 με. By the same way as previous, taking into account all the data of this article for the construction materials of the reference beam, the next articles value of axial strength "N" of the longitudinal reinforcement was initially calculated according to Eurocode, which axial strength "N", as mentioned before, is the target value in its method. elastoplastic analysis of finite elements. The corresponding displacement due to gravity "G" of the structural element is then calculated and this value is constant in the calculation method.

The accuracy of the Theodore model is almost perfect and with great quality. With the computational method for finding the Forces of Axial N and Vertical Qy, as for the Bending Moment Mz, there is estimated an accuracy of difference for the predicted moments with the published results at about 8.86 % or having an accuracy of similarity for the predicted loading with the published results at about 108.86 %. Eurocode design Moment Mz value is 15.96 KNm and the Theodore's computed value is 17.38 KNm. The computed axial N force corresponds to a model computed Qy value of 115.84 KN with the experimental value to be 113.1 KN as mentioned before. This vertical force Qy is estimated an accuracy of difference 2.24% or an accuracy of similarity of 102.24%.

The deformation value at which the component presents the final damage is 1140με. Therefore the other similarity between the experimental and the calculated according to Theodore model is of the order of 87.69%. As previous the following is the load of vertical strength "Qy" - deformation diagram in which the damage occurred where the maximum charge value of the previously mentioned structural element presents an initial target value of the axial force “N“ set as the target value. It is important to mention that the computed axial “N“ according to Eurocode is equal to -262.58 KN. This value is a guide for every step until its vertical strength “Qy“ reaches a maximum value in the following curve.

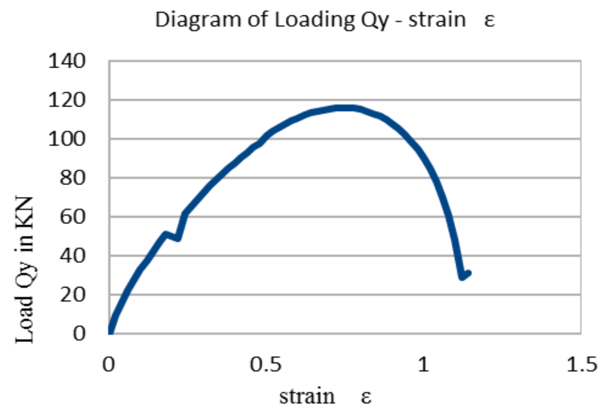

Figure 6: Diagram of Loading Qy with strain ε

Whereas the experimental displacement was 2.57 mm, the displacement value at which the component presents the final damage is 2.264 mm. Therefore the similarity of the experimental with the calculated according to Theodore model is of the order of 88.09%. The following is the load-displacement diagram in which the damage occurred where the maximum charge value of the previously mentioned component presents an initial target value of the axial force “N“ set as the target value. The maximum displacement value shown in the following curve is 5.05 mm..

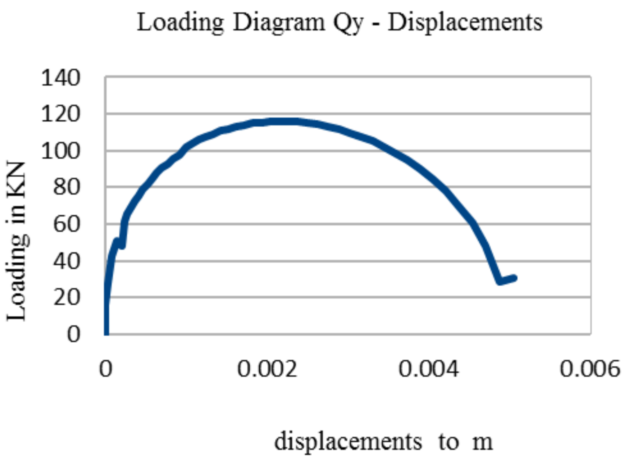

Figure 7: Diagram of Loading Qy with displacements

Finally, as mentioned before the main innovation of this document is the rate of energy loss mechanism elastoplastic structural elements. This curve is contained between the right end of the beam and the eccentric to the middle span from the application of external loading. In this way the dimensions of the sides are proportional to the height of the beam with the middle span of the beam. Below is the diagram in question, the curve of which shows the shape of the beam damage dams. Obviously it is a form of surrounding damage and not the faults themselves. Therefore with the above condition the form of the energy loss rate curve is presented below.

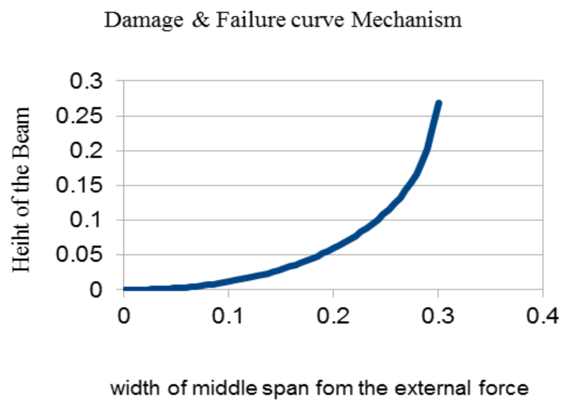

Figure 8: Diagram of energy loss rate failure mechanism [2], [3], [4]

Discussions

From the study so far of the physical-mathematical model Theodore quadratic equation, it appeared that in relation to experimental results, the methodology is verified only by applying the data of the materials and the dimensions of the structural elements.

It is worth noting that in the two cases examined, with reference to the first case, there was a uniform reinforcement distribution both longitudinally and transversely, where the load of the beam was eccentric and therefore the smaller side from the point of application of the load was chosen as the failure side. , on the other hand as for the second case, there was a double eccentric loading, but this time with a smaller side on the inner side from the application of the two forces, as well as there was uniform reinforcement for the ends of the beams while for the middle of the beam there was different but uniform transverse reinforcement. These two conditions did not make the calculations difficult, but it is being investigated how much the results of the calculations, beams or columns or any reinforced concrete structural elements, with a more complex distribution of longitudinal and transverse reinforcement, could be affected. It is also under discussion whether the successful choice of axial force “N“ as a target value for the calculations differs from other regulations. The selection or application of other reinforced concrete design regulations in relation to the Eurocode should not present different results in finding the axial reference force. Also, this solution of the two cases was solved with the help of spreadsheets, in which the equations were made, after entering the data from the selected published journals, the results were calculated with the help of a non-linear solver.

It is also being investigated whether this methodology could be solved with the help of a programming language with the application of automatic non-linear solution, or even at a much later stage, when there is an additional picture of the influence of possible additional charging elements, such as prestressing, or other building blocks, whether and to what extent it was possible to implement software to solve problems of interest corresponding to reinforced concrete components or whether it could be an application to other existing reinforced concrete troubleshooting software concrete.

Finally, it is worth noting that with the knowledge of the energy loss rate of elastoplastic elements such as reinforced concrete, for beams or columns or any other element, it is possible the appropriate dimensioning so that the imposition of safety factors has a clear meaning, as knowing the exact value the design of the element can be redefined both in the design based on Eurocode or any similar regulation, as well as in the design using the elastoplastic analysis of finite elements.

Conclusion

The new structural model "Theodore" uses successfully both classic reinforced design like Eurocode and elastoplastic analysis of finite elements with a great accuracy and quality as for the strength as for the failure mechanism.

Specifically, it deals with the value of transverse strength Qy with great accuracy, which is usually what is required in the problems of strength of materials such as reinforced concrete, in applications of beams, columns and any other corresponding material.

In addition, with regard to the values of the bending moments, it is worth noting that the Eurocode values and the Theodore model values do not show exact differences in their percentages, but this is due to the fact that both values are very small and while they do not differ as values, however differ as percentages of difference or similarity.

With regard to the values of the displacements, it can be argued that the Theodore displacement model itself treats with great success the accuracy and quality of the displacements as well as the quantitative differences or similarities.

Finally, as a reference for the failure curve of the energy loss rate of the two beams, it is worth noting that the calculated curves satisfactorily approach the form of cracking of the experimental data, but being a form of surrounding failure and not the representation of all structural faults.

The experimental values of the two articles used were satisfactorily verified by Theodore model.

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This publication is the first publication of the author and is very encouraging to find acceptance in a demanding scientific research environment where everyone is invited to give their best for a state of the art scientific achievement based on the scientific background of every scientist.

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Mr Achilleas Theodore Theodoroulis was born in Larisa of Greece at 7th of July in 1987. He graduated the Second High School of Larisa, of Secondary Education, for Technological Direction, with Grade: 19.4/20, 19001 units with 19.1 access degree, since 2005. He is a Civil Engineer, Graduate of the Aristotle University of Thessaloniki (AUTH) since 2012. His undergraduate Diploma specializes in Hydraulics and Environmental Engineering. Additional he specialized in the field of water resources as a Graduate of the Interdisciplinary-Interdepartmental Postgraduate Study Program “Water Resources Science and Technology”, coordinated by the School of Civil Engineering of the National Technical University of Athens (NTUA) since 2015. He also specialized in the field of Construction as a graduate of the Interdisciplinary-Interdepartmental Postgraduate Study Program “Analysis and Design of Structures”, coordinated by the School of Civil Engineering of the NTUA since 2018. By February 2019 he is an Undergraduate Student at the School of Rural and Surveying engineering of the NTUA. By February 2013 he is a Member of Technical Chamber of Greece (T.C.G.) and by May 2013 he started working at his Office as Civil Engineer, making his own databases for several projects of groundwater and surface water needs according to European Aspects. In 2013 to 2014 he was the Alternate Member, Representative for Environment at Department of Central. & West. Thessaly Technical Chamber of Greece. By March 2016 to present he works for a European project (ESPA 2014-2020) for new Scientists providing Technical Consultancy Services in General, at his office in Athens Greece. He also attended an 18 hour intensive seminar of Daylighting in 2013, at University of Thessaly.