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NEW ALGORITHM FOR ESTABLISHING THE BEHAVIOR OF REINFORCED CONCRETE ELEMENTS

BY

P. MIHAI, N. FLOREA and *DANIEL LEPĂDATU

Evaluation of residual mechanical characteristics for reinforced concrete structures is an actual problem in Romania where, a lot of buildings were designed and erected before year 1963 when the first seismic norms appear. For these buildings it is necessary to check the level of structural safety because the structures take-over more earthquakes without any intervention for rehabilitation between earthquakes. In the analysis process the most complicated problem is to insert the structural damages into the mathematical model. The authors propose a new approach of this problem with an original algorithm that permit to include in the structure damages specified for reinforced concrete elements.

1. Introduction

The simulating process is presented in the majority of engineering sciences, from aero-spatial industry to electronics. In civil engineering are used a lot of programs that can compute a structure and almost all are using Finite Element Method. The results consist in behaviour of the structures under a various types of loads.

Reinforced concrete is a particularly material in civil engineering because it is a double composite material. Firstly, concrete is a composite material formed by cement and the aggregate and with reinforcement is obtained a second-degree composite material. From this reason, the behaviour of reinforced concrete element is very complex and very difficult to describe with mathematical relations. In civil engineering exists mathematical relations who describe the behaviour of composite materials, but these relations cannot be used in case of reinforced concrete because the reinforcement is realized not in all concrete mass but in tensioned zones. This situation makes the simulating process of reinforced concrete elements very difficult, especially from bond point of view.

In the '70 are developed the first theories regarding mathematical models that can describe the behaviour of the reinforced concrete in Finite Element Method [1]. This researches are slow down because the computing process for Finite Element Method is possible only with a computer and in 1970...1980 the development of the computers was very limited. From this reasons, all the theoretical studies can't be checked with practical algorithms.

When the computer industry is developed more and the personal computers appear (series 8086), the problem was restarted [2]. First programs that can study the behaviour of reinforced concrete elements appear but the success was limited.

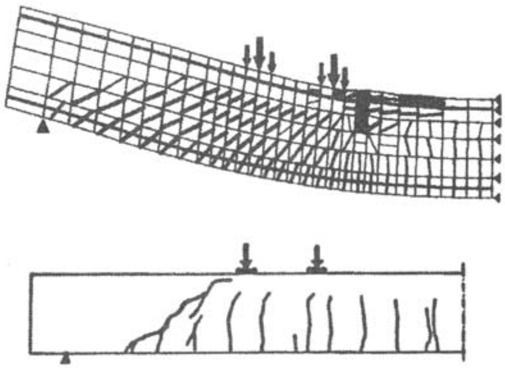

Fig. 1.– To many cracks into numerical models.

This think happens because the number of finite elements depends on computer memory and the computer memory was very small, so the programs can solve only simple problems. In 1990 Bill Gates said about the computers memory: "640 kB will be enough for everyone". Today, this words sound like a good joke and only one floppy disk have 1,440 kB capacity.

Personal computers are developed quickly in the next years and with them are developed a lot of programs, smaller or bigger, programs who can simulate the behaviour of reinforced concrete elements. Some programs are based on theories conceived in '90 years. A good example in this case is ATENA program, developed on basis of a theory developed by V. C z e r v e n k a [2]. Many other programs are developed with regard the theories elaborated after 2000 [3].

Political and social events have a big influence in the simulation of the reinforced concrete elements study. After the attempts from USA in September 11, 2001, were developed numerical simulations regarding crashing of different type of planes on a reinforced concrete structure [4].

At this time, in market exists a lot of programs who try to simulate the behaviour of reinforced concrete elements and structures. Some programs are very simple but others are more complex. The most complex program at this time is ATENA with the ultimate version 3.2.13. Details regarding this program can be accessed on http://www.czervenka.cz.

The authors made a lot of studies on these programs and see some differences between numerical and experimental results. The most important conclusions are the following:

a) in numerical results the cracking are presented in all tensioned nodes (Fig. 1); if the model have finite elements of 20 cm each, the results appear like real one; but if the mesh is refined to 1 cm for each finite element, the cracks appear at 1 cm and no one real bending element have cracks at 1 cm;

b) in numerical results the stresses into the concrete appear like in a simple concrete element, without reinforcement (Fig. 2); in the cracked zone, stresses into concrete is similar with the stresses into concrete in the zones between cracks; in real case (demonstrated by experiments) in the cracked zones stresses into concrete are very small compared with the stresses into concrete in zones between cracks;

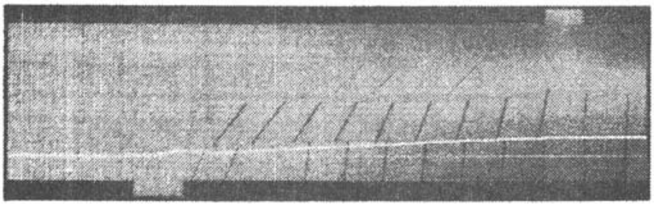

Fig. 2.- The stresses in numerical analysis.

c) numerical results show the stresses into reinforcement with a soft variation (Fig. 2), without local extremes; in real cases (demonstrated by experiments) when the crack appear, the stress into reinforcement increases right on crack zone and a few points with local extremes can be observed (Fig. 3), so the real variation of the stresses into reinforcement is not soft.

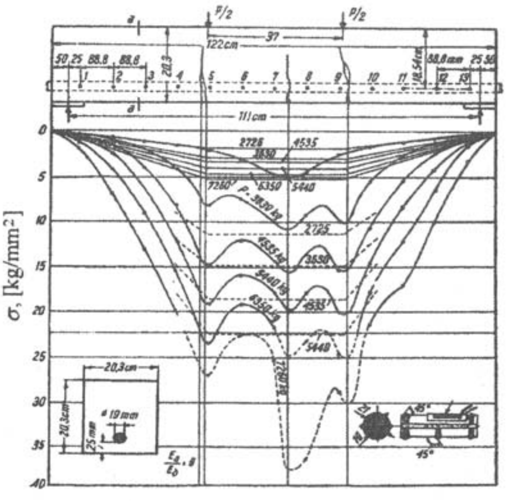

Fig. 3.- The stresses into reinforcement experimentally obtained.

So, the actual programs can compute elements from simple concrete without reinforcement but can't offer real results for reinforced concrete elements. From the personal studies, the authors find the main cause for these un-realistic results: the bond between concrete and reinforcement is not implemented correctly. The actual programs are based on general character of Finite Element Method and if are included in the model all the structural components, the result is usually correct.

This supposition work from steel structures but for reinforced concrete structures, because the bond between concrete and reinforcement is a very complex phenomenon, the simple meshing of concrete and reinforcement is not enough. At this time, the authors can't find a program who can compute reinforced concrete elements and who obtain real analytical results compared with experimental ones.

2. Proposed Model

To implement the new algorithm, all the studies are made on the reduced scale reinforced concrete girders. The structural model and the loads are presented in Fig. 4.

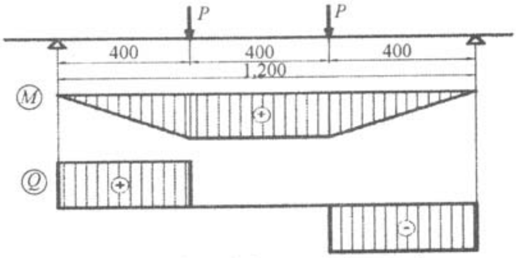

Fig. 4.– The girder used for study.

Like in the other programs, the numerical analysis follow some cyclic steps, presented in Fig. 5. The load is increased step by step and the behaviour of reinforced

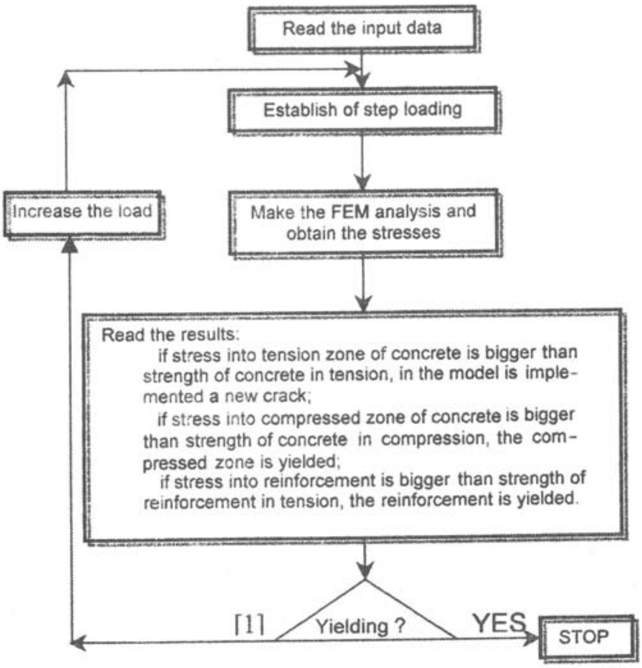

Fig. 5.– Steps followed for analysis.

concrete element is studied on every step. After the reading of input data, the program establishes the step loading and starts the cyclic analysis. In every step is checked if a new crack appears in tensioned zone or if appear yielding in compressed concrete zone and/or in the tensioned reinforcement.

If a new crack appear in the tensioned concrete, the program introduces a new discontinuity in the mathematical model on the horizontal direction but maintains the continuity of the material in the vertical direction.

The most difficult problem was to put into the mathematical model the bond between concrete and reinforcement. Usually, in the finite element program, when two or more elements are connected, the slipping of only one element in the node is not possible. The connections between finite elements do not accept slipping.

In the real case, when a crack appears in a reinforced concrete element, in the crack zone all the stresses are tacked by the reinforcement. Gradually, the bond between concrete and reinforcement transfers the stresses from reinforcement to the tensioned concrete between two consecutive cracks.

The bond between concrete and reinforcement is not a linear function and is not very simple to find it. To study this phenomenon and to implement it into the main algorithm, the authors made many experimental studies with different types of reinforcement. The result of bond study is included in the relation

(1)
$$l_b = \frac{d\sigma_r}{4\tau_b^{\max}},$$

where: l_b is the length where bond is affected by the crack, d – the diameter of the reinforcement, σ_r – the tension into the reinforcement and $\tau_b^{\max}$ – the maximum bond stress.

With the relation (1), included in the model, the final results are presented in the Fig. 6. Because the space is small, cannot be presented all the results obtained in all the steps. So, are presented only few results for the most important steps of loading.

Program permits to observe the evolution of the cracks when the loads are increasing. On first steps some cracks appear and, after the load is increasing, new cracks appear and the existent cracks increase. This can be observed on step 18, where appear tree cracks and on step 29 where a new crack appears but the first cracks have a bigger length.

To see if the algorithm is good, the authors compare the stresses obtained into the reinforcement with the experimental results. In Fig. 7 is presented the stress into the reinforcement at step 18 and can be observed the stresses into the reinforcement.

Where a crack appears, the stress into reinforcement is increasing and a locally maximum stress appears. This result is the same with those obtained with the experimental models and from the reinforcement point of view the model is correct.

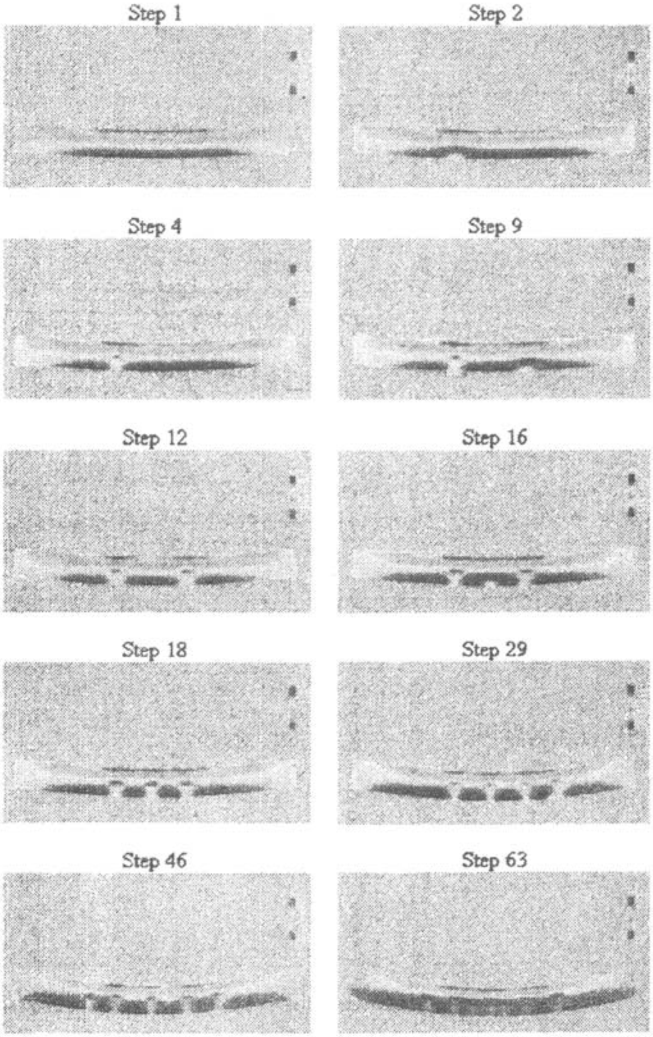

Fig. 6.- Numerical analysis results - tension into concrete.

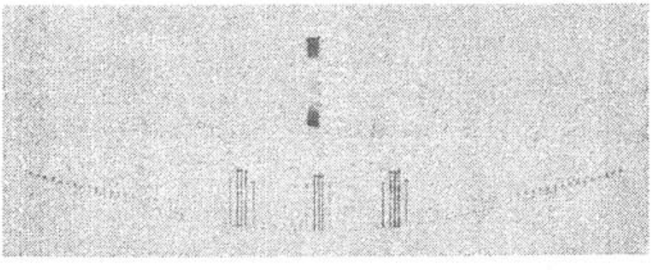

Fig. 7.- Tension into reinforcement - step 18.

In Fig. 6 can be observed the evolution of the cracks and the stresses into concrete, into the tensioned zone. When a new crack appears, the stress into the tensioned concrete is very small around the crack and all the stresses are tacked over by the reinforcement.

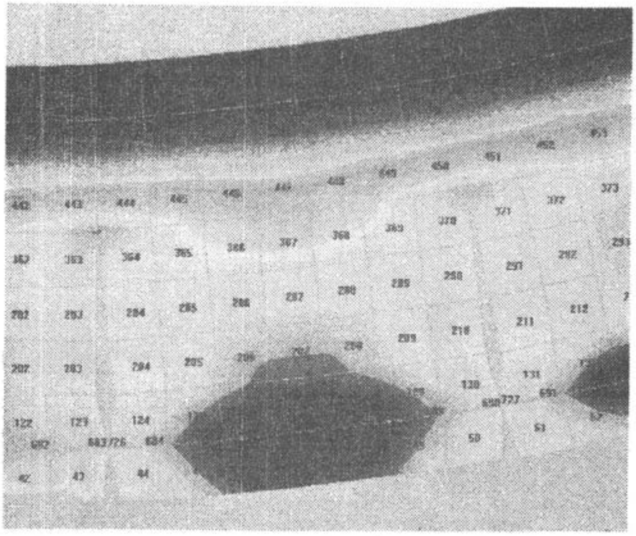

Fig. 8.– The stresses into concrete at step 52.

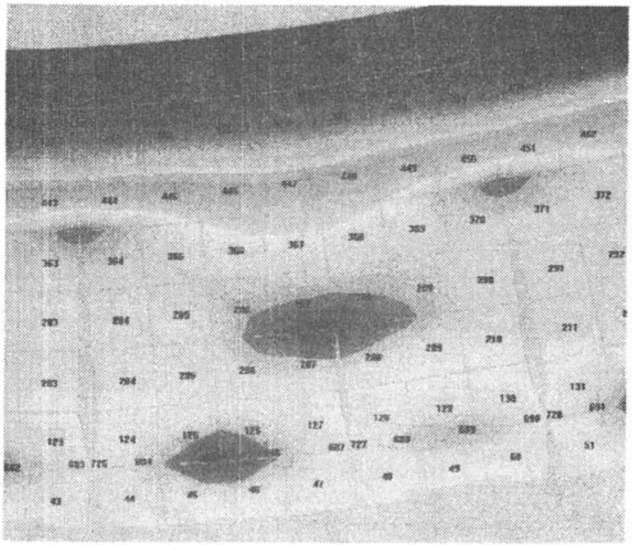

Fig. 9.– The stresses into concrete at step 53.

With the studied programs in the tensioned zone, the stresses into concrete are the same in the cracks and between the cracks. In the proposed model, the results are correctly showed and the stresses into the tensioned concrete in the crack are small compared with the stresses into concrete between cracks.

To study if the phenomenon is correctly obtained in the proposed model, in Figs. 8 and 9 is presented the same zone of the girder between and after a crack appears. The scale of cracks is increased and deformed very much to observe the phenomenon.

It is very easy to see how the program considers the bond between concrete and reinforcement and how between two consecutive cracks the stresses into concrete are bigger compared with stresses into the cracks.

3. Conclusions

The proposed algorithm can be applied for reinforced concrete elements to obtain the correct behaviour under different types of load.

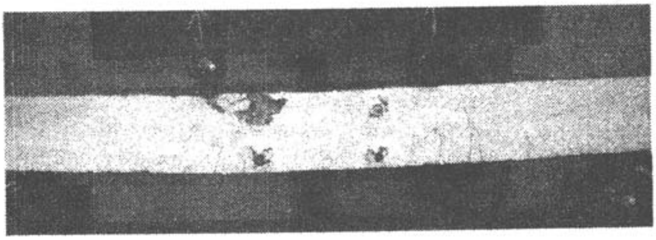

Fig. 10.- The cracks into the experimental girders.

The results obtained with numerical analysis (Fig. 7) are very close to the ones obtained on experimental girders (Fig. 10).

Unfortunately, the mesh must be very fine and the number of finite elements, very big. In this study are used square finite elements with dimension of 25 mm. From this reason the algorithm cannot be used for very big elements or for entire structures because the analysis time can be very big (days or weeks) and the memory of computers cannot be enough for very big problems.

Of course, can be used bigger finite elements to decrease the number of elements but in this case the results can be affected by a bigger error.

Another important parameter is the step loading. If it is used a very small step the accuracy of the results increases but the time to make the analysis it's growing up too.

If it's used a bigger step, cannot be obtained exactly the behaviour of the reinforced concrete element because at one loading step appear more cracks and cannot be specified which crack appears firstly. More, appearing of one crack have a big influence on the future stress into the tensioned concrete and reinforcement so, if the program don't know which crack appear first can make mistakes in computation of stresses.

The only parameter that is affected by the errors in proposed model is the cracks width because the algorithm who simulate the bond between concrete and reinforcement is not perfect. At this time the research team works to find a solution to reduce this errors.

The most important advantage of the proposed algorithm consists in the possibilities to introduce some initial cracks and to estimate the future behaviour of the elements. This possibility is very useful for existent reinforced concrete structures where the behaviour under different types of loads is imposed by the existent cracks. This type of analysis can be very important when the functionality of the structure is changed and the live loads have different distributions and values.

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"Gh.Asachi" Technical University, Jassy,
Department of Concrete
Structures, Buildings Materials,
Technology and Management
and
**Department of Civil and*
Industrial Engineering

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UN NOU ALGORITM PENTRU STUDIEREA COMPORTĂRII ELEMENTELOR DIN BETON ARMAT

(Rezumat)

Evaluarea caracteristicilor mecanice reziduale reprezintă o problemă actuală în România datorită numărului mare de construcţii afectate de seisme. În aceste condiţii singurele analize viabile pentru aceste structuri sunt cele analitice.

Se propune un nou algoritm pentru studiul comportării elementelor şi structurilor din beton armat. Algoritmul este bazat pe metoda elementului finit dar are implementate relaţii speciale pentru descrierea comportării structurilor din beton armat.