BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Tomul LII (LVI), Fasc. 3–4, 2006
CONSTRUCŢII. ARHITECTURĂ

EFFECT OF SUPERFICIAL ATMOSPHERIC CORROSION UPON THE INTERNAL STRESSES IN STRUCTURAL STEEL ELEMENTS

BY

MONEL LEIBA, *M. BUDESCU, **ELENA AXINTE and **ELENA–CARMEN TELEMAN

A research program is presented showing the stress status determined by the corrosion phenomenon inside a specimen of a structural steel element. Several stains are studied their diameters ranging from 1 mm to 6 mm and thickness of the corroded layer under 0.5 mm. The physical modeling is the result of testing in laboratory the phenomenon of superficial atmospheric corrosion and the numerical modeling was developed under a FEM program, ALGOR. A number of 3,200 finite elements of BRICK type were created and the evolution of normal and tangential stresses was scrutinized under the process of loosing elementary material transformed into scrap. Stresses in the damaged sphere were graphically put into evidence and determined with accuracy due to the performances of the program, showing the local perturbations and the pattern of stress concentrators. The studies showed the importance of reproducing with both physical and mathematical methods the intricate mechanism and sometimes unpredictable effects of corrosion phenomenon upon the structural steel elements.

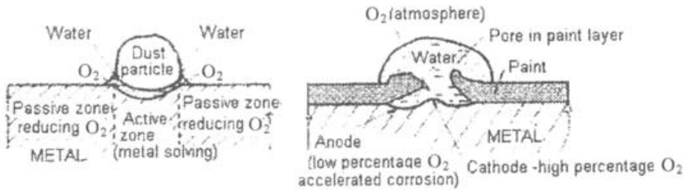
1. Introduction

In order to insure a sustainable development of the society, the environmental conditions must be extensively evaluated, for a realistic quantification of all the factors that may induce the decay processes, alternatively, may lead to a substantial improvement of its natural features. Both total and specific energy consumption, water supply and other unrecoverable resources are constantly increasing every day and that is a fact with a high level of impact on the environment. It is a most rational reason to study the causes and consequences of the corrosion decay because they will ultimately lead us to the means of finding the best solutions for a sustainable development of the whole human society.

Now-a-days corrosion is most evidently associated with sustainability, a multitude of protection measures being more and more imposed, varying according to the domain in which this phenomenon manifests itself. Usually, the totality of these measures is the result of a compromise between several considerations: technical, economical and ecological [1], [5], [6].

Atmospheric corrosion is one of the most over-spread forms of corrosion decay of metals because, mainly, the steel elements are parts of constructions living their service life in open air. Atmospheric corrosion takes place under an electro-chemical process pattern, or under thin or very humid layers (Fig. 1) [1], [2].

a



b

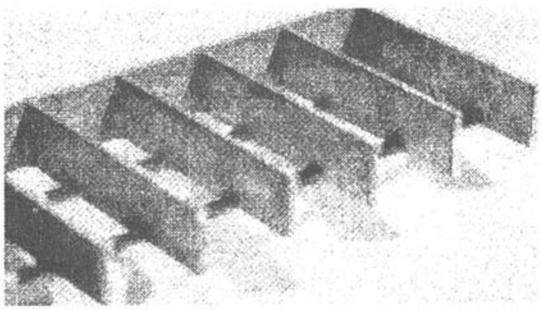


Fig. 1.– Atmospheric corrosion; *a* – the phenomenon from chemical point of view, *b* – rust on a steel structural element.

Several different components of the terrestrial atmosphere participate to this process and because of these random components, the behavior of the corroded elements vary considerably according to the type of atmosphere in which they are immersed: rural, urban, industrial, marine, etc.

Even considering that the steel is the best choice for a structural element, corrosion will represent the price to pay and this will be put in evidence in the technical, economical and social areas.

In the last decades the general apprehension of the finite dimensions and even of the extinction of the global energy and raw materials supply is more and more consistent. Studies developed all over the world [3] come to the conclusion that almost 10% (or 5×10^7 t) of the annual steel production represents the quantity of steel needed to replace the corroded elements. The pessimists' evaluation of the quantity of steel turned into scrap is about 30% from the world wide production. The corroded steel is thrown away and some alloying metals, like chrome and nickel, are irrecoverable [4].

A most severe consequence, which is almost impossible to quantify – the alteration of the steel strength capacities as an effect of corrosion – is the human lost or accidents that lead to mutilation and incapacities of work, all caused by the structural damages inside of a corroded construction and here we may specify commonly known situations like: explosions inside buildings, airplanes crashes, sinking of commercial ships.

Removing the causes of corrosion represents a most important aspect to which much attention must be paid, because even from the antiquity a known truth is that "*if we clear away the cause we remove the effect*".

The corrosion causes are difficult to be removed because they are the direct effect of technological processes. New technological solutions and corrosion resistant materials are studied to be put into practice, in the race of finding solutions to this problem.

Modern approaches of the corrosion resistant materials and structures imply all the complexity of the mechanical, physical or chemical characteristics of a great number of elements placed in various conditions (composition, proportions, temperature, pressure, etc.). Researches referring to this intimate mechanism and the measures of struggling against corrosion are consequently developed.

2. Modeling the Superficial Corrosion Effects Considering the Stresses Status

Modern researches regarding the corrosion decay of steel structures are involved in the study of the evolution of corrosion processes on metallic surfaces, the prognosis in the development of these processes and in defining the role played in strength alterations. The evolution of corrosion processes is put into evidence by quantifying the effects and the prognosis of the effects entangled by this evolution is based on experimental data, in order to adopt certain scientific hypotheses. Prognosis of the extension of this process is a very important aspect in determining the strength capacity during the service life of the steel structures.

Physical modeling is a modern laboratory research tool for specific cases in study assisted by mathematical modeling; it is universally extended and has unlimited possibilities. Mechanical modeling of the corrosion processes were designed to incorporate chemical and electro-chemical reactions series in the complex interaction with the diffusion and migration process. Some specific situations are fit to describe mechanic models useful for the explanation of the principal characteristics that govern the corrosion processes. These models are expressed either in the equation formulation or in other non-explicit forms.

Whenever the mechanism of the fundamental corrosion process is too intricate, encountering difficulties in the accuracy of a theoretical model, empirical models are used. The complexity degree of an empirical model is seldom evaluated in the initial stage of the model's evolution. A pragmatic approach of the development of modeling consists in settling, at the beginning, a limited number of variables followed by an increase of their complexity at the refining level of modeling, based on the evolution of the reliability. Some examples may be given: modeling of the corrosion inhibitors, model tests, systems for selection of the alloys subjected to high temperatures, models for corrosion under fatigue, etc.

Practically, all the models of examination are equipped with specific facilities that are able to represent the knowledge level. This implies structuring the information in order to put into evidence the limits and the relationships between different levels of knowledge, finally eliminating the ambiguities. Modern mathematic techniques, based on computer assistance, are able to surpass the uncertainties like the expert systems (ESs) that develop, based on existent information, models of stopping the corrosion processes (cathode protection, diagnosis, inhibitors, options of specific materials, risk analysis, etc.) or like artificial neuronal networks (ANN), used for the risk prognosis of developing cracking corrosion at the stainless steels under stress [3].

Corrosion effects must be quantified in terms of stress - strain status inside a system. Generally it is difficult to put into evidence the distortion of this status and a starting case of study consists in analysing with FEM methods a steel element subjected to a simple stress and under the corrosion process. The corrosion pattern was a superficial one, localized on a 1 to 6 mm diameter area and having a stain aspect, 0.5 mm thick [1].

In Fig. 1 the natural scale model is presented: a steel plate of 10 mm width, 20 mm length and 2 mm thickness. The element is subjected to tension stresses along the $x - x$ axis and at the end A. Parallel with the tension direction, $x - x$ axis, restraining connections were aligned on the opposite edge, B; on the direction of $y - y$ axis five transversal restraints were placed and finally only one restraint on $z - z$ direction (Fig. 2 a). The restraints pattern is chosen as to model an externally static determinate system, whose translations under exterior actions are free both on $y - y$ and $z - z$ directions.

The steel specimen was modeled with BRICK type finite elements having the regular sides of 0.5 mm thickness. A total number of 3.200 finite elements resulted. The analysis was run under ALGOR program [5]. A sequence of the program with the pattern of the chosen refinement is presented in Fig. 2 b.

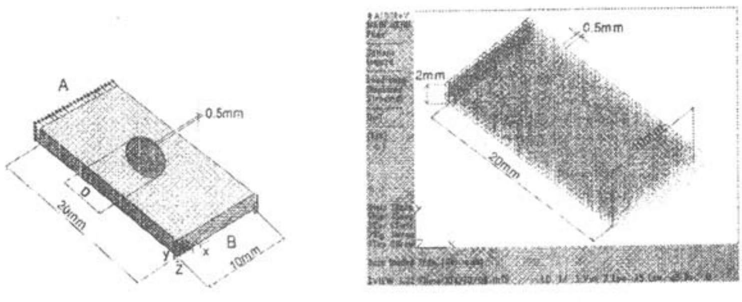
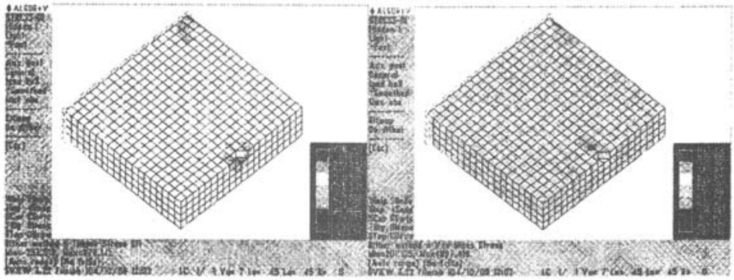


Fig. 2.- a - Studied system (physical model); b - computation model.

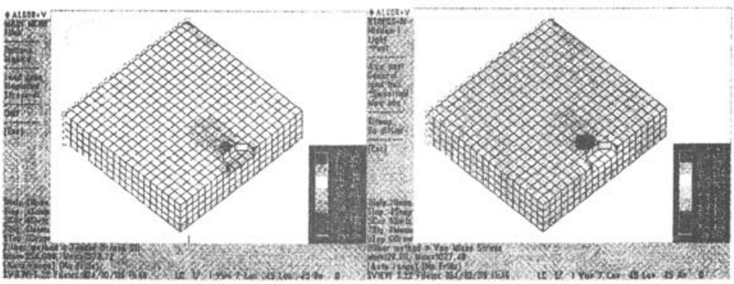
The stresses developed in the piece of steel due to progress of the corrosion process are shown in the Figs. 3,...,8.

For obtaining a thorough description of the behavior of the steel specimen, the normal, S11, and tangential stresses, S12, were analysed; further on, the principal maximum stresses and those obtained through von Mises relationships were put into evidence.



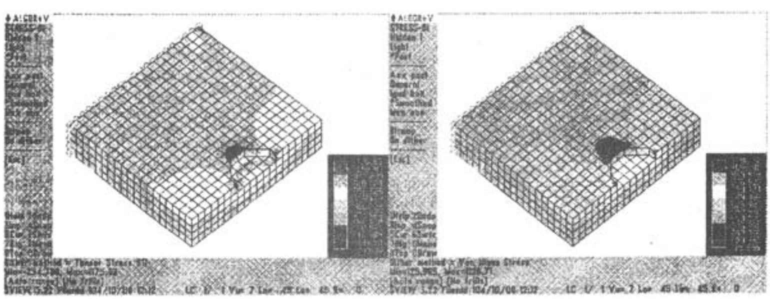
a *b*

Fig. 3.– Stress status in a 1 mm diameter stain of corrosion on the steel specimen: *a* – normal stresses; *b* – von Mises stresses.



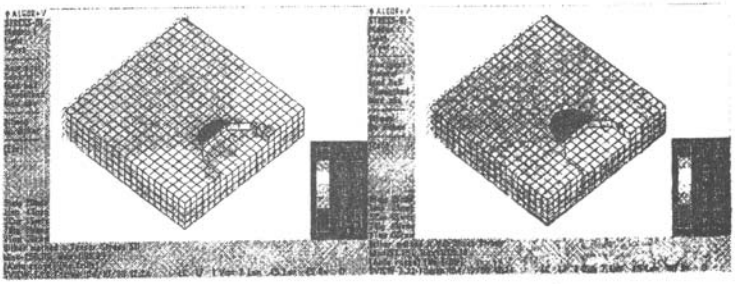
a *b*

Fig. 4.– Stress status in a 2 mm diameter stain of corrosion on the steel specimen: *a* – normal stresses; *b* – von Mises stresses.



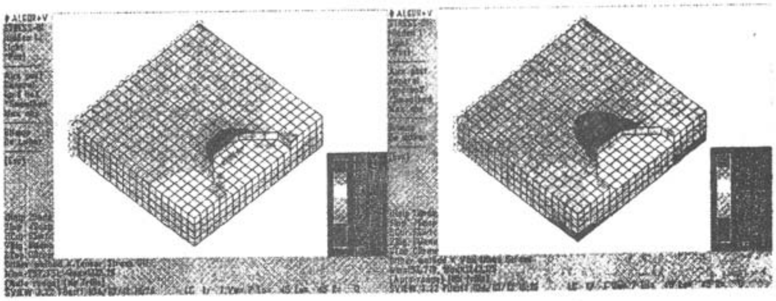
a *b*

Fig. 5.– Stress status in a 3 mm diameter stain of corrosion on the steel specimen: *a* – normal stresses; *b* – von Mises stresses.



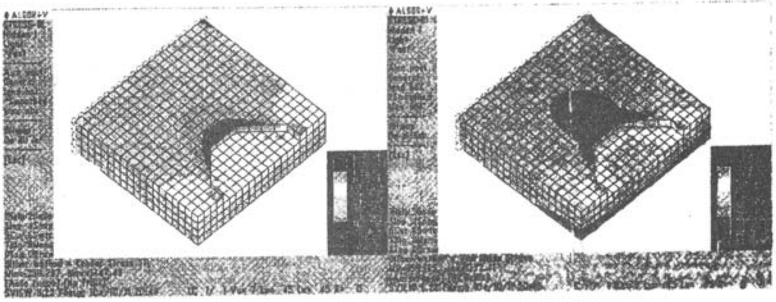
a *b*

Fig. 6.– Stresses status in a 4 mm diameter stain of corrosion on the steel specimen: *a* – normal stresses; *b* – von Mises stresses.



a *b*

Fig. 7.– Stress status in a 5 mm diameter stain of corrosion on the steel specimen: *a* – normal stresses; *b* – von Mises stresses.



a *b*

Fig. 8.– Stress status in a 6 mm diameter stain of corrosion on the steel specimen: *a* – normal stresses; *b* – von Mises stresses.

The evolution of the maximum stresses in the steel specimens around the corrosion stains with 1 to 6 mm diameter is shown in Fig. 9.

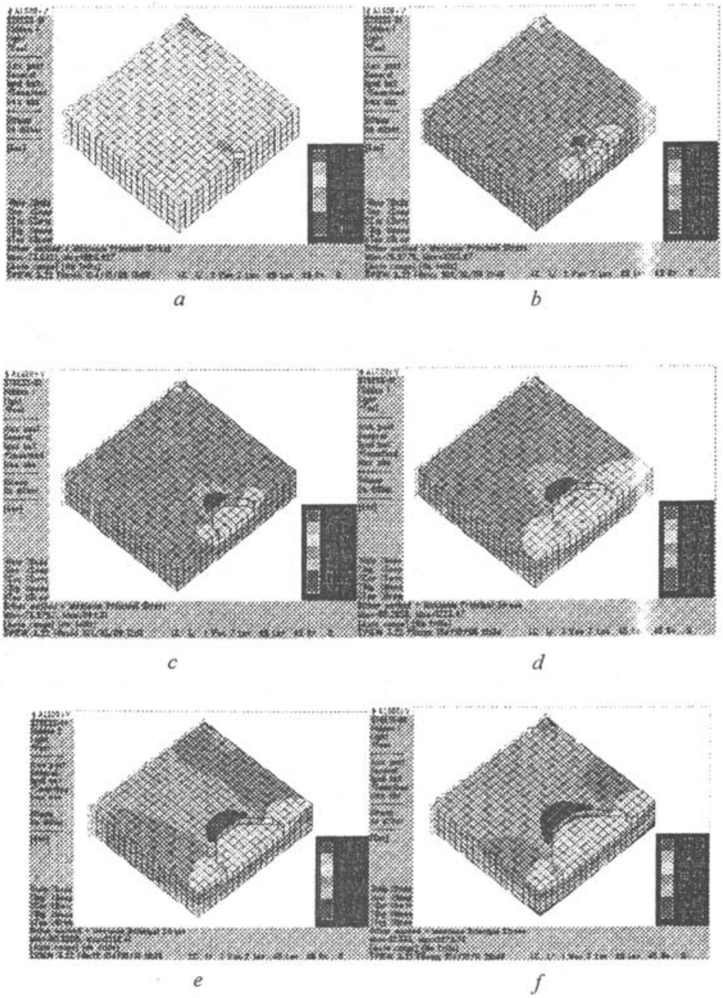


Fig. 9.– Variation of the principal maximum stresses with the corroded area having: *a* – 1 mm, *b* – 2 mm, *c* – 3 mm, *d* – 4 mm, *e* – 5 mm and *f* – 6 mm.

3. Results and Discussion

The synthesis of the research results is presented in Figs. 10 and 11, a relative linearity being observed in the variation of stresses with the variation of the stain [1]. All stresses increase their values with the dimension of the corroded area.

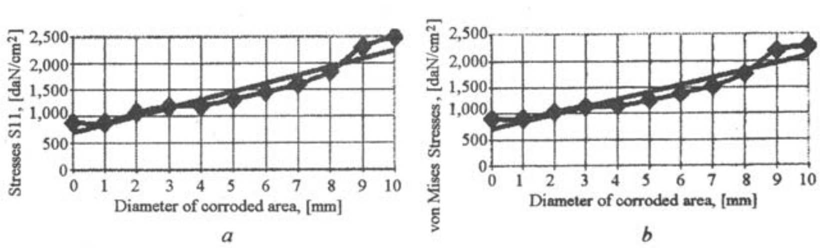


Fig. 10.– Variation of the normal stresses (S11) and of von Mises stresses with the diameter of the corroded area.

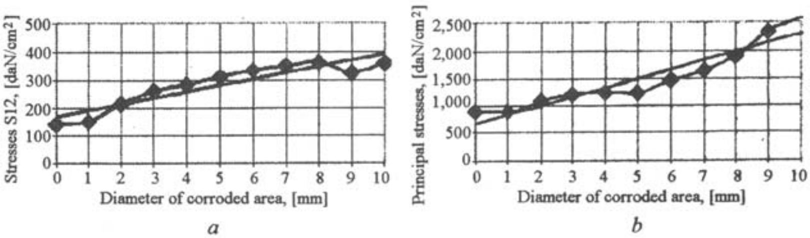


Fig. 11.– Variation of the tangential stresses (S12) and of von Mises stresses with the diameter of the corroded area.

The distortions of the plane shapes of the specimens are also put into evidence. In Fig. 12 the vertical translations of the free end of every specimen are presented, here clearly showing the parabola shape as the diameter of the stain grows.

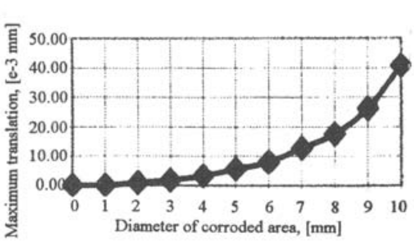


Fig. 12.– Variation of the maximum translations of the free end with the variation of the diameter of the corroded area.

As a result of the complex study described herein important stress concentrators were put into evidence. Although at the first sight these concentrators are not supposed to affect much of the whole behavior of the system, (*e.g.* the strain status) local effects may show suddenly their importance. An important observation is that the stress concentrators grow with more than 10% for each 1 mm increase of the corroded area.

It is obvious that these results represent a particular case, but the phenomenon must be studied at a larger scale.

4. Conclusions

Corrosion prognosis and preventing methods derived from similar research studies are of a capital importance for the world economy in the construction domain and for the security in the exploitation of structures during their service life. A sensible evaluation of the corrosion damages may diminish the enormous expenses for protection and maintenance of steel structures.

The corrosion phenomenon is better understood nowadays and the decay of the steel elements concerns every domain of activity, new procedures and new techniques being developed all the time in order to control the corrosion phenomenon.

The creation of new materials and technologies with superior properties and characteristics, having higher resistance to corrosion challenges with the continuous modifications and increasing complexity of the aggressiveness of the environment. The direct result of this evolution is an increase in the diversity of the anti-corrosion protection systems which implies specific solutions and technologies put into practice by superior qualified personnel.

Received, February 26, 2007

National Police
Headquarters, Ramlah, Israel,
"Gh.Asachi" Technical University, Jassy,
Department of Structural Mechanics
and
*** Department of Civil*
and Industrial Buildings

REFERENCES

1. Shreir L.L., Jarman R.A, Burstein G.I., *Corrosion*. Vol **1**, *Metal/Environment, Reactions*; Vol 2: *Corrosion Control*, 1994.
2. Roberge R.P., *Handbook of Corrosion Engineering*. McGraw-Hill, NY, 1999.
3. * * * www.corrosion-doctors.org.
4. * * * www.otua.asso.fr.
5. Leiba M., *Contribuţii la studiul efectului coroziunii asupra elementelor de construcţii metalice, mijloace de protecţie şi combaterea coroziunii*. Ph. D. Diss, Techn. Univ. of Constr., Bucharest, 2005.
6. Dabosi F., Béranger G., Baroux B., *Corrosion localisée*. Editions de Physique, France, 1994.
7. Axinte E., Teleman E.-C., *Increasing the Durability of the Constructions in Steel through a Correct Management of the Corrosion Phenomenon*. Internat. Symp. "Composite Materials, Elements and Structures in Constructions", Timişoara, 2005, 297-303.
8. Axinte E., Teleman E.-C., *Metallic Corrosion under Cyclic Loading*. The 12th Internat. Sci. Techn. Conf. "transMOTAUTO'05+", Proc., vol. **3**, *Mechanics, Dynamics, Strength and Reliability*, Veliko Tyrnovo, 2005, 174-178.

EFECTUL COROZIUNII ATMOSFERICE DE SUPRAFAŢĂ ASUPRA STĂRII DE TENSIUNI DIN ELEMENTELE METALICE

(Rezumat)

Coroziunea reprezintă un fenomen deosebit de complex, generat şi influenţat simultan de o multitudine de factori. Adesea, prima manifestare a coroziunii este vizuală; se constată fenomenul prin localizarea sa sau prin modificarea aspectului exterior al metalului pe care-l afectează.

Cercetările moderne privind distrugerea prin coroziune a elementelor metalice sunt axate atât pe aprecierea stării evolutive a proceselor de coroziune pe suprafeţele metalice, având in vedere rezultatele evaluării efectelor acesteia, cât şi pe prognozarea dezvoltării acestor procese, fundamentată pe date experimentale şi influenţa pe care o au asupra capacităţii portante a elementelor de construcţii.

Efectele coroziunii trebuie cuantificate şi în starea de tensiuni şi deformaţii care rezultă într-un sistem. Se prezintă rezultatele unui studiu al variaţiei stării de tensiuni şi deformaţii într-un element din oţel supus la o solicitare simplă, afectat de procesul de coroziune atmosferică sub formă de pete, utilizând metoda elementului finit. Ca urmare a studiului efectuat rezultă că pot apărea concentrări de tensiuni importante, care deşi nu afectează substanţial comportarea de ansamblu a sistemului, pot produce efecte locale importante.