International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

The Economic Aspects of Application of the Evolutionary Theory of Identification of the Mathematical Models of Corrosion Destruction of Structures under Stress

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Abstract **- In paper is adduced a graphical representation of the drift of restrictions and the point of extremum of objective function under the using of evolutionary theory of identification of mathematical models of corrosion destruction of structures under stress (ETCD) and practical recommendations on how to avoid a significant financial losses at the optimal designing of structures interacting with aggressive media.**

I. Introduction

The evolutionary theory of identification of mathematical models of corrosive destruction, which is presented in [1-7] and in two monographs [8] and [9], researches the solution of such narrow problem that none of the experts in the design and manufacturing of designs that interact with aggressive media, still was not able to not only study this theory, but even to notice. The author not know of anybody in the world who is engaged in this issue. Meanwhile, the correct use of this theory could bring significant economic benefit without investing of any additional financial resources.

As follows from the above publications [1-7], the evolutionary theory of identification of mathematical models of corrosion damage (ETCD) can only be used at the optimal design of designs interacting with the aggressive environment. Typically, at the designing of such designs is applied the mathematical modeling of the process of corrosive destruction. Mathematical models, describing the process of corrosion damage, there are of two types: the models that do not take into account the effect of the stress-strain state (SSS) of designs and the models that take into account this state. The ETCD theory should be applied when using the models of the second type. It has long been observed that the rate of corrosion increases with the increasing of stresses and strains of designs. From here the term "stress corrosion".

Among the models that take into account the impact of SSS on the corrosion rate are, the models of V.M.Dolinsky (1), I.G.Ovchinnikov (2) (MMSS), V.G.Karpunin (3) (MMS), and others:

$$v = v_0 + m \cdot \sigma_i \,, \tag{1}$$

$$\frac{d\delta}{dt} = \beta\varepsilon_i(\sigma_i - \sigma_{\text{thr}}) + \alpha \tag{2}$$

$$\frac{d\delta}{dt} = \beta\sigma_i + \alpha \,, \tag{3}$$

Where: v_0 and α − the rate of corrosion of unstressed metal; m and β − coefficient taking into account the SSS impact on the rate of corrosion, σ_i − the intensity of the stresses; ε_i − the intensity of the strains; δ − the depth of corrosive damage; σ_{thr} − threshold stress.

II. About The Drift Of Points Of Extremal Values Of Objective Function

At the optimal designing of structures the coefficients, that take into account the SSS impact on the rate of the corrosive process are variables values. This is because in the process of optimization takes place the evolution of construction from non-optimum state to optimal state. During this evolution the stress-strained state (SSS) is changed. The coefficient of the influence of SSS on the rate of corrosive process, as a function of SSS changes from step to step during of the search process. This was proved theoretically in [1] and by numerical experiment in [1-3] for four optimization objects and for two mathematical models. In the Theorem 1 [1] was found that the magnitude of the influence of the SSS rate on the corrosion is directly proportional to the stiffness of the optimized design. It was also found that the lowest value of the coefficient of the influence of SSS on the rate of corrosion is received in the case when the project reaches the optimal state. The coefficient of such value is called "optimal". From here follows the corollary from the Theorem: If there is exist an "optimal" coefficient of the influence of SSS on the rate of corrosion, the optimum state of the design is reached from any point of the area of optimized parameters. In other words, before an optimization of structure, that interacts with aggressive environment, it is necessary to determine the minimum value of the coefficient of the influence of SSS on the rate of corrosion and then with this coefficient is necessary to optimize the design. The minimum value of the coefficient of the influence of SSS on the rate of corrosion can be received by "zero point" method, described in [3] or by the special analytical methods described in [5,6].

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

If you will not done it and will solve the task of optimization out of an arbitrary point with corresponding value of the coefficient of the SSS effect on the corrosion rate, you get the project on the (10-30)% worse, than the optimal project. Why so? Let us show this on a graphical example.

Let's consider the two-dimensional problem of nonlinear mathematical programming (Fig. 1). Vector of control variables $\mathbf{X}(x_1, x_2)$.

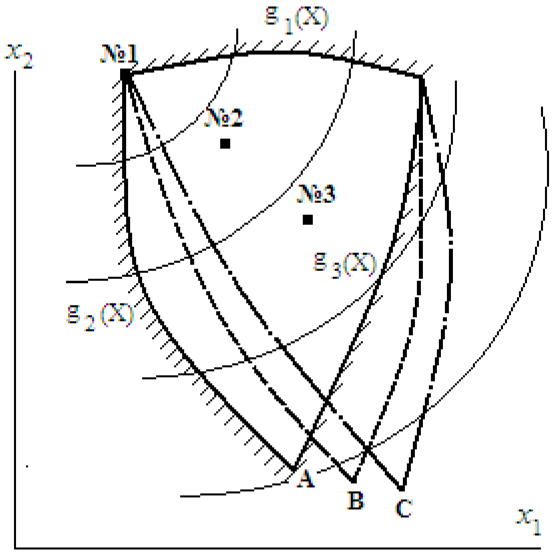

Fig.1. Deformation of the area of permissible solutions and drift of the point of extremum of objective function

The objective function: $F = f(\mathbf{X})$. Restrictions: $g_1(\mathbf{X}) \le a$: $g_2(\mathbf{X}) \le b$; $g_3(\mathbf{X}) \le c$. The starting point of the search is point №1. The area of permissible parameters is allocated by shaded curves of restrictions. For point №1 we carry out the identification by the experimental data, we determine the coefficient of the influence of SSS on the rate of corrosion β and with this coefficient we carry out the optimization. The mathematical minimum of the objective function is in the point A.

Let us choose as a starting point the next point №2 and will carry out the operations described above. At the point №2 is changing the stiffness of the optimized design, the coefficient of the influence of SSS on the rate of corrosion, the restrictions are changing the configuration, the area of permissible parameters is deformed and the mathematical extremum moves from point A to point B.

Then we choose as a starting the point №3 and we repeat the operations described above. The area of permissible parameters deformed again. Mathematical minimum of objective function moves in point C. Thus, there is a drift of the minimum value of the objective function. This drift will cease when the objective function will reach its optimum value. This value of objective function will correspond to lowest ("optimal") value of the coefficient of the influence of SSS on the rate of corrosion.

At this the area of permissible solutions can greatly deform or even move in space.Let us illustrate this hypothesis by the example of optimal designing of a compressed axially smooth cylindrical shell (Fig. 2).

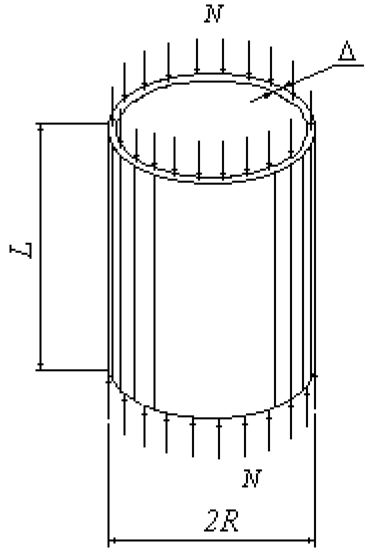

Fig.2. Estimated shell scheme

The cylindrical shell with the wall thickness Δ and the with the radius of the middle surface R is compressed by a longitudinal force N (Fig.7.2) and is subjected to corrosion on the inner wall surface.

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International Journal of Emerging Technology and Advanced Engineering
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According to model MMSS the corrosion damage depth is determined by the expression (2) [2].

Taking the corrosion rate of unstressed metal $\alpha = 0$, transform the expression (3) [2] to form:

$$\delta(t_j) = \beta \sum_{k=1}^{j} \left[\frac{1}{E} \left\{ \frac{N}{2\pi R(\Delta - \delta_{k-1})} \right\}^2 (t_k - t_{k-1}) \right], (k = 1,2,\ldots,j), \quad (4)$$

Where the expression $f(\sigma) = \frac{1}{E}\left\{\frac{N}{2\pi R(\Delta - \delta)}\right\}^2$ is a function of the stress-strain state (SSS) of the shell in accordance with the MMSS model.

We form the functional:

$$J = \left\{ \delta_j^e - \beta \sum_{k=1}^{j} \left[\frac{1}{E} \left\{ \frac{N}{2\pi R(\Delta - \delta_{k-1})} \right\}^2 (t_k - t_{k-1}) \right] \right\}^2, (j = 1,2,\ldots,n; k = 1,2,\ldots,j) \quad (5)$$

Where δ_j^e – experimental depth of corrosion damage.

Experimental data are presented in Table 1 in [2]. In this article also is listed the procedure for the identification of the mathematical model on experimental data. At the first stage of research we choose a point №1 (Fig.3) in a space of permissible parameters with coordinates: $\Delta_0 = 0{,}04$ m; $R_0 = 2$ m and we carry out an identification of model for this point using the procedure, described above. As a result we obtain the coefficient of SSS influence on the rate of corrosion process corresponding to this point $\beta = 0{,}448707$.

Further, from the point with coordinates: $\Delta_0 = 0{,}04$ m; $R_0 = 2$ m and with the coefficient $\beta = 0{,}448707$ we perform the optimization of shell. For the considered shell as the objective function is taken the cross-sectional area of the cylindrical part:

$$A = 2\pi R\Delta. \quad (6)$$

The restrictions are adduced:

$$\frac{2\pi E(\Delta - \delta)^2}{\sqrt{3(1-\mu^2)}} \geq N; \quad (7)$$

$$\frac{\pi^3 E(\Delta - \delta)R^3}{L^2} \geq N; \quad (8)$$

$$2\pi R(\Delta - \delta)\sigma_T \geq N; \quad (9)$$

$$\Delta^- \leq (\Delta - \delta) \leq \Delta^+; \; R^- \leq R \leq R^+. \quad (10)$$

The restriction (7) is a limitation to the critical buckling load for the ideal circular cylinder shell; the restriction (8) is a limitation of the critical buckling load of axis of the shell; restriction (9) is the restriction on strength and the restriction (10) limits the sizes and thickness of the shell wall.

Using the notations:

$$\left.\begin{aligned} A &= 2\pi; \quad B = \frac{\pi^3 E}{L^2}; \quad C = 2\pi\sigma_T; \\ D &= \frac{2\pi E}{\sqrt{3(1-\mu^2)}}; \quad x_1 = \Delta \quad x_2 = R \end{aligned}\right\} \quad (11)$$

and substituting them in equations (6)−(10), we obtain the following nonlinear programming problem: to find a non-negative values x_1 and x_2 minimizing the function:

$$F(\mathbf{X}) = Ax_1x_2 \quad (12)$$

at the performance of restrictions:

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$$\left.\begin{aligned} & g_1(\mathbf{X}) = D(x_1-\delta)^2 - N \geq 0; \quad g_2(\mathbf{X}) = B(x_1-\delta)x_2^3 - N \geq 0; \quad g_3(\mathbf{X}) = C(x_1-\delta)x_2 - N \geq 0; \\ & g_4(\mathbf{X}) = (x_1-\delta) - x_1^- \geq 0; \qquad g_5(\mathbf{X}) = x_1^+ - (x_1-\delta) \geq 0; \\ & g_6(\mathbf{X}) = x_2 - x_2^- \geq 0; \qquad g_7(\mathbf{X}) = x_2^+ - x_2 \geq 0 \end{aligned}\right\} \tag{13}$$

The results of multiple identification of the mathematical model (2) and optimization of the shell on each step of the search are shown in Table 2 in [2].

Out of Table 2 we'll choose the results listed in lines №1, №5 and №15 and the selected data we'll place in Table 1.

Table 1
The results of multiply identification and the optimal design of compressive cylindrical shell. model MMSS

№	Starting points			Extreme designs				
	A (cm^2)	Δ (cm)	R (cm)	β	A_{opt} (cm^2)	Δ (cm)	R (cm)	δ (cm)
1	5026,56	4,000	200,00	0,448707000	117,93	3,753	5,001	1,7877
2	2307,91	2,396	153,31	0,094581950	81,851	2,605	5,000	0,6399
3	269,54	0,703	61,057	0,001291586	62,149	1,838	5,383	0,0124

The aim of this study is a graphical representation of mathematical programming problem, of the deformation of permissible area, of the displacement of restrictions and drift of extreme solutions at changing the coefficients of the influence of SSS on the rate of corrosion. Fig.3 shows the area of permissible solutions, formed by restrictions $g_2(№1)$ и $g_3(№1)$. The extreme value of the objective function $A = 117{,}93$ cm^2 belongs to point A of permissible area. At the changing of the starting point №1 on starting point №2 by restrictions $g_2(№2)$ и $g_3(№2)$, a new permissible area with new coefficient β is formed, the value of objective function value gets equal $A = 81{,}851$ cm^2 and the extremum moves in point B.

At the next changing of starting point the extremum of the objective function is moved to the point C with even less of its value.

In fact, at every step when changing the starting points the new task is solving: at the beginning is performed the identification of mathematical model on experimental data, is determined the coefficient β and then is solved the problem of optimal designing with this coefficient. This process of local solutions will continue until such time as the "optimal" coefficient of the influence of SSS on the rate of corrosion not would be found. After this we can find the optimum solution of whole task.

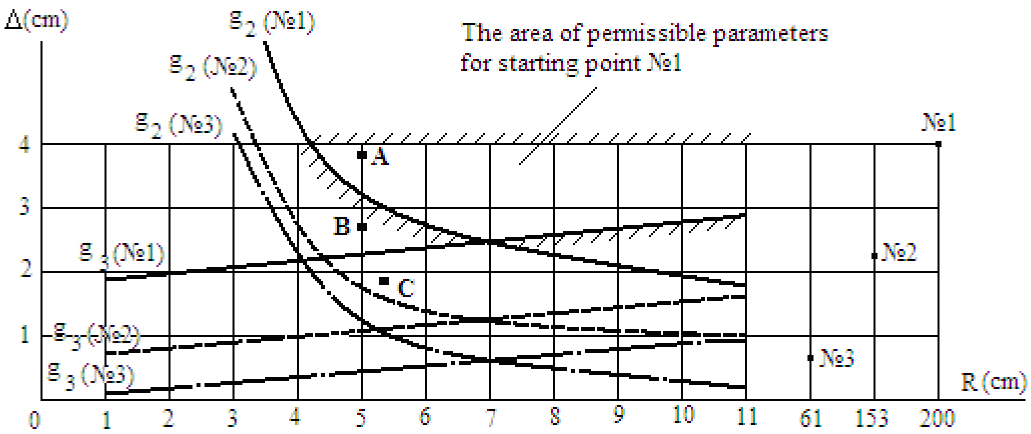

Fig.3. A graphical representation of the drift extreme solutions to the problem of optimal design of the compressed shell at multiple identification of mathematical model of corrosive damage.

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Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

The difference of the magnitude between of extreme local solution in the first state of the shell and in the optimum state may be several tens of percent. Arbitrary choice of starting point can lead to serious inaccuracies of the final solution of the problem and the considerable material losses.

It was noted in earlier [1] that the direct application of the method of multiple identification is very cumbersome. This method should be applied for research purposes or in cases when other methods do not work. To achieve the desired result we can solve the problem without the use of method of multiple identification. This can be done using, for example, the numerical empirical method "zero point", described in [3] or using analytical methods of the polynomial approximation [5,6].

These methods are enable without significant time determine the value of the "optimal" coefficient of the influence of SSS on the rate of corrosion, which we can use to determine the optimum value of the objective function optimized object from any point of the area of permissible parameters.

7.2. The economical effectiveness of ETCD theory

Let us estimate the cost-effectiveness of the application of evolutionary theory identification of mathematical models of corrosive destruction under stress. We'll do this on number of examples.

Example 1. Assume that You, dear reader, are the businessman and You are producing the containers for pressurized the storage of aggressive substances (Fig.4). Such containers you can make in your company, for example, $m = 500$ per year or more. The length of shell is equal $L = 3$ m.

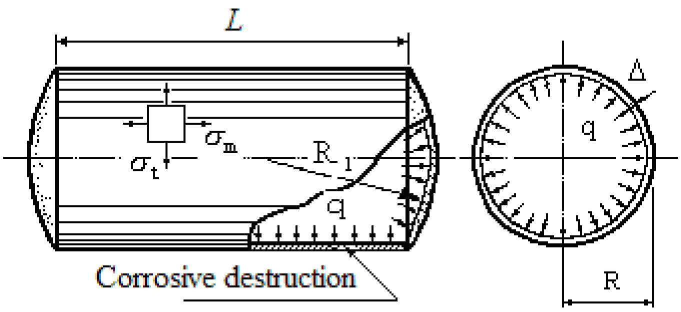

Fig.4 The thin-walled shell

Manufacturing such tanks requires the use of special steel. Let the cost of one ton of such steel is equal to $S = 1000\$$ US. To save money at the production of these containers, You are going to use the modern technology, including the optimal designing of structures. Before You get down to business, You have acquainted with the methodology of the designing and You know that at the optimal designing of structures interacting with aggressive media, use mathematical models of corrosive destruction. Such models before to optimize the containers must be identified from experimental data to make sure that your selected model has been adequate to corrosive process. In order to perform the identification of the model, you must have an object.

Is best to have the optimal object, but You don't have it yet. Therefore, You are choosing the object randomly from all possible. In applied mathematics such an object can be represented as a point in space of permissible parameters. By the permissible parameters of your object may be the thickness of the wall of the container Δ and the radius of the middle surface of the container wall R. So you have chosen a point (object) and You have performed the identification of mathematical model. Let us denote the chosen parameters of container as controlled coordinates of object of optimization. By identification you have found all coefficients of the model and the results you have recorded in Table 2. We use the already available results of such identification, set out in Table 2 of [1].

Table 2
The results of multiple identification at the optimal designing of the thin-wall shell by the using of MMSS model

№	Starting point			Extreme value				
	A (cm^2)	Δ (cm)	R (cm)	β	A_{opt} (cm^2)	R (cm)	Δ (cm)	δ (cm)
1	2310,60	3,645	100,89	0,2197	960,12	100	1,529	0,4464
2	720,760	1,147	100,01	0,0218062	720,75	100	1,147	0,0645

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Where: A − the cross-sectional area of the shell; β − coefficient of the influence of SSS on the rate of corrosion and δ − the depth of corrosive damage.

With coefficient β that had been found in the process of identification of the mathematical model you perform the optimization of container with the involvement of non-linear programming methods, such as random search method and the results of calculations You enter in the Table 2.

You are analyzing the results and You see that the cross-sectional area decreases to $A_{opt} = 960{,}12\ \text{cm}^2$, the wall thickness is reduced to $\Delta = 1{,}529\ \text{cm}$, practically has not decreased the radius of the container $R = 100\ \text{cm}$, but it is because you yourself have established the restriction on the size of radius of container − container radius must not be less than one meter. So everything like is OK and you are convinced that you have successfully completed the optimization and you may begin to manufacture the containers.

Let us calculate how much will cost the metal needed to manufacture the container:

$$V_1 = 2\pi R\Delta L + 2\cdot\pi R^2\Delta = 6{,}28\cdot 100\cdot 1{,}529\cdot 300 + 2\cdot 3{,}14\cdot 100^2\cdot 1{,}5297 = 384084{,}8\ \text{cm}^3.$$

At the beginning, we calculate the volume of the container: $V_1 = 384084{,}8\ \text{cm}^3$. Metal weight: $G_1 = V_1\cdot\gamma = 384084{,}8\cdot 7{,}85\cdot 10^{-6} = 3{,}015$ ton. Metal cost is: $C_1 = S\cdot G_1 = 1000\cdot 3{,}015 = 3015\$$ US. A bit costly, but in the end, You can save money on something else.

And then suddenly you remember that as an object in the identification of the mathematical model you have is not the best object, but the arbitrary object. But how to find the best entity? Guess is impossible, especially when there are a large number of control variables.

Besides, it is possible to select a point in an unacceptable range of parameters, and this causes distortion constraints, such as the condition of the tank strength. How to be?

Let's try to take advantage by the evolutionary theory of identification of mathematical models of corrosion damage (ETCD). This theory allows using the method of "zero point" in order to quickly determine the "optimum" coefficient of the influence of SSS on the rate of corrosion and use it to find the optimum design. Such a solution for our facility has already been found (Table 3 [1]). Add this solution in Table 2 and count the cost of the optimal design. The volume of the metal of container:

$$V_2 = 2\pi R\Delta L + 2\cdot\pi R^2\Delta = 6{,}28\cdot 100\cdot 1{,}147\cdot 300 + 2\cdot 3{,}14\cdot 100^2\cdot 1{,}147 = 288126{,}4\ \text{cm}^3.$$

Metal weight:

$G_2 = V_2\cdot\gamma = 288126{,}4\cdot 7{,}85\cdot 10^{-6} = 2{,}262$ ton.

Metal cost is: $C_2 = S\cdot G_2 = 1000\cdot 2{,}262 = 2262\$$ US.

Let us write down the data in Table 7.3 and determine the economic efficiency of ETCD theory in money and in percentages.

The metal price difference in both projects were as follows: $\Delta C = C_1 - C_2 = 3015 - 2262 = 753\$$.

As a percentage it is: $\bar{B} = \frac{\Delta C}{C_1}100\% = \frac{753}{3015}100\% \approx 25\%$. Annual efficiency of the use of the ETCD theory it would be $B = m\cdot\Delta C = 500\cdot 753 = 376500\$$. I think it's not bad.

Example 2. Consider the cost-effectiveness of ETCD theory at optimal designing of welded I-beam, that is subjected to influence of aggressive environment (Fig. 5).

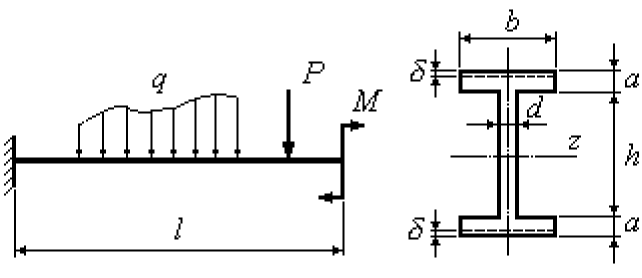

Fig. 5. The welded I-beam

The side surfaces of the beam are painted and not exposed to corrosion. The beam flanges are subjected action of corrosion from outside.

Initial data, setting the problem of identification of the mathematical model of corrosive destruction and the problem of optimal designing of the I-beam are given in [3].

Suppose that some businessman is going to produce these I-beams by length of $l = 6$ m each in the amount of $m = 500$ pieces during the year. Let the cost of the metal for steel beams is $S = 400\$$ US for one ton. Let us study the dynamics of the economic efficiency of ETCD theory.

To do this, we select the starting points in such a way in order each next point was be closer to the optimum point. Initial data about these points are given in Table 7.3. The corresponding extreme parameters of I-beams are given in Table 7.4. The numerical data for these Tables are taken from the Tables 2 and 3 in [3].

Table 3
The results of multiple identification and optimization of I-beam

№	Starting points, parameters of beam and the coefficients of SSS influence							
	A (cm^2)	J_z (cm^4)	W (cm^3)	d (cm)	h (cm)	a (cm)	b (cm)	β
1	410,00	567160,8	12465,37	2,000	85,000	3,000	40,000	0,1782815
5	376,04	474755,7	10875,70	1,981	80,565	2,811	38,504	0,0315626
10	291,13	285407,5	7281,81	1,831	72,700	2,470	31,996	0,0598440
15	216,63	164002,3	4693,06	1,635	65,617	2,137	25,576	0,0251562
20	162,18	181153,0	4401,99	0,910	77,227	2,539	18,097	0,0278127
25	148,69	197794,4	4491,61	0,731	83,099	2,384	18,440	0,0312500
30	141,90	196876,1	4343,37	0,681	84,988	2,829	14,843	0,0306252

Table 4
The optimal parameters of I-beam

№	Optimal parameters of I-beam, the coefficients of SSS influence and the depths of corrosive destruction						
	β	A_{min} (cm^2)	d (cm)	h (cm)	a (cm)	b (cm)	δ (cm)
1	0,1782815	141,89	0,6812	84,988	2,829	14,843	0,4787
5	0,0315626	138,58	0,6811	84,996	2,721	14,825	0,3679
10	0,0598440	133,39	0,6827	84,916	2,398	15,728	0,1789
15	0,0251562	129,95	0,6807	84,996	2,488	14,486	0,0788
20	0,0278127	130,18	0,6808	84,995	2,494	14,499	0,0865
25	0,0312500	130,47	0,6807	84,999	2,508	14,476	0,0968
30	0,0306252	130,42	0,6808	84,994	2,503	14,496	0,0950

Table 5
The results of additional identifications and the optimal parameters of I-beam after the improving of the coefficients of SSS influence

A (cm^2)	d (cm)	h (cm)	a (cm)	b (cm)	β
129,8	0,680	84,99	2,480	14,52	0,024312

In Table 5 are given the values of "optimal" coefficient of the influence of SSS on the rate of corrosion $\beta = 0{,}024312$, of the objective function and the of corresponding optimal parameters of the cross-section of the I-beam.

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Table 6
The data of economical effectiveness of the application the ETCD theory

№	The cost of one I-beam $US	Economical effectiveness in $ US	Economical effectiveness in %	Annual effectiveness $US
1	267,32	0	0	
5	261,08	6,24	2,33	6240
10	251,31	16,01	6	16010
15	244,83	22,49	8,41	22490
20	245,26	22,06	8,25	22060
25	245,81	21,51	8,05	21510
30	245,71	21,61	8,09	21610
Opt	244,54	22,78	8,52	22780

Fig. 6 shows a plot of the relative efficacy of the theory ETCD from the proximity degree of initial project to the optimum project in $ US and in%.

Formally, the degree of such proximity is determined by the coefficient of the influence of SSS on the rate of corrosion β. The smaller this coefficient, the initial project closer to the optimum.

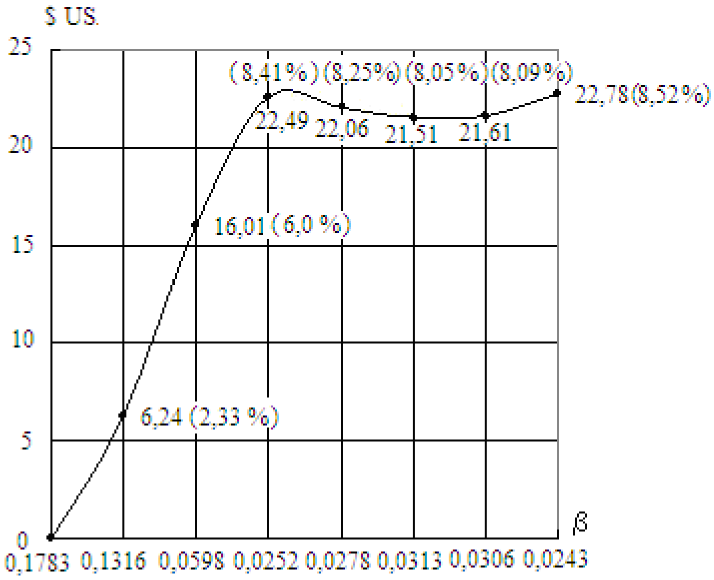

Fig.6. A plot of the relative effectiveness of the application of ETCD theory on the value of the coefficient of the influence of SSS on the rate of corrosion in $US and in % for one I-beam

How this graph can be interpret ? If You unsuccessful have selected the initial I-beam project that subjected to optimization (the point in the area of permissible parameters) with oversized values of flanges and wall (coordinates), and therefore with a high coefficient of the influence of SSS on the rate of corrosion, then you will be able to correct his mistake, using the theory ETCD and avoid unnecessary pecuniary losses. The figures on the graph indicate as far as the pecuniary loss for one I-beam in the $US and % for the selected by you project will be after optimization expensive than for the optimal I-beam.

As noted above, the optimal design can be found using the method of "zero point" in the process of additional identifications of mathematical models of corrosion damage. The graph in Fig. 6 shows, that the optimal project as a starting point is the most effective: reducing the cost of the I-beam will 22.78$US or 8.52%.

REFERENCES

[1] Filatov G.V. The Foundations of the Evolution Theory of Identification of Mathematical Models of Corrosion Destruction at the Optimal Planning of Constructions [Text] // G.V. Filatov / – International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 3, March 2016, p.p.166-180.

[2] Filatov G.V. The Numerical Experimental Verification of Evolutional Theory of Identification of Mathematical Models of Corrosive Destruction under Stress. Compressed Shell [Text] // G.V. Filatov / − International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 4, April 2016, p.p.1-9.

[3] Filatov G.V. Application of Evolutional Theory of Identification of Mathematical Models of Corrosive Destruction at Optimum Designing of Weld-fabricated I-beam [Text] // G.V. Filatov / − International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 5, May 2016, p.p.222-236.

[4] Filatov G.V. Optimal design of structures by the combined use of mathematical models of corrosion destruction [Text] // G.V. Filatov / − International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 6, June, 2016, p.p.6-15.

[5] The methods of Polynomial Approximation for the Determining the "Optimal" Coefficients of the influence of Stress-Strained State on the rate of Corrosion. Algorithm 1 [Text] // G.V. Filatov / − International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 7, July, 2016, p.p.13-23.

[6] Filatov G.V. Application of the Method of Polynomial Approximation for the Determining the "Optimal" Coefficient of the Mathematical Model of Corrosive Destruction. Algorithm 2. [Text] // G.V. Filatov / − International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 8, August, 2016, p.p.15-24.

[7] Filatov G.V. The Global Method of Random Search with Controlled Boundaries of the Interval Parameters to be Optimized. [Text] // G.V. Filatov / − International Journal of Emerging Technology & Advanced Engineering, Volume 6, Issue 8, September, 2016, p.p.231-247.

[8] Філатов Г.В. Основи еволюційної теорії ідентифікації математичних моделей корозійного руйнування. − Монографія. − Дніпропетровськ, УДХТУ, 2010, 192с.

[9] Филатов Г.В. Теоретические основы эволюции матмоделей коррозионного разрушения. – Монография. − Изд-во LAP LAMBERT Academic Pablishing. – Саарбрюккен. Германия. 2014. – 181с.