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OPTIMUM DESIGN OF INDUSTRIAL STRUCTURES VIA HARMONY SEARCH ALGORITHM INCLUDING CORROSION EFFECT

ABSTRACT

This paper presents optimum designs of industrial structures comprised of truss roof members and frame members including corrosion effect on steel cross-sections by using harmony search algorithm method. A profile list taken from AISC (American Institute of Steel Construction) is used in optimization. The stress and displacement constraints according to AISC-ASD (Allowable Stress Design) are applied in the optimum design process. A program was coded in MATLAB for incorporating with SAP2000-OAPI (Open Application Programming Interface). Harmony search algorithm method, one of the last stochastic techniques, is selected for optimum solution. In this study, optimum designs of the plane structures are studied for the cases with and without corrosion effects.

Keywords: Optimum Design, Harmony Search Algorithm, Corrosion Effect, Industrial Structure, AISC

ENDÜSTRİYEL YAPILARIN ARMONİ ARAMA ALGORİTMASIYLA KOROZYON ETKİSİNİ İÇEREN OPTİMUM TASARIMI

ÖZ

Bu çalışma kafes çatı ve çerçeve elemanlarından oluşan endüstriyel yapıların armoni arama algoritması kullanılarak çelik profillerde korozyon etkisini içeren optimum tasarımını sunmaktadır. Optimizasyonda AISC'den (American Institute of Steel Construction) alınan bir profil listesi kullanılmıştır. AISC-ASD' ye göre gerilme ve yer değiştirme sınırlayıcıları optimum tasarım işlemlerine uygulanmıştır. SAP2000-OAPI ile birlikte çalışan MATLAB'da bir program kodlanmıştır. Son stokastik tekniklerden biri olan armoni arama algoritması yöntemi optimum çözüm için tercih edilmiştir. Bu çalışmada düzlem yapıların optimum tasarımları korozyon etkisinin dahil edildiği ve edilmediği durumlar için çalışılmıştır.

Anahtar Kelimeler: Optimum Tasarım, Armoni Arama Algoritması, Korozyon Etkisi, Endüstriyel Yapı, AISC

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1. INTRODUCTION (GİRİŞ)

In this study, harmony search algorithm, a stochastic technique, is selected to conduct all optimization procedures. There are numerous studies available on optimum design of steel structures in literature using various stochastic techniques [1]. Researched a basic study of a new structural optimization based on harmony search algorithm [2]. Used harmony search algorithm for optimum design of steel sway frames according to BS5950 [3]. Use this algorithm for optimum design of geometrically non-linear steel frames with semi-rigid connections [4]. Studied minimum cost design of steel frames with semi-rigid connections and column bases [5]. Used harmony search algorithm for optimization of trusses under uncertainties [6]. Studied optimum design of steel space frames under earthquake effect using harmony search algorithm. In this paper, optimum designs of a 31-member industrial steel plane structure are researched for two different cases with and without corrosion effect. To carry out optimum designs, a program was coded in MATLAB to interact with SAP2000-OAPI. The optimum results obtained from these both cases are compared and the results show that corrosion effect on steel profiles increase the minimum weight of steel structure.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Optimum design of steel structures is very important for steel consumption in industrial structures. However, corrosion effect on optimum designs should be known for resistance of steel structures. So this study presents a research on optimum designs of industrial steel structures for two cases with/without corrosion effect.

3. EXPERIMENTAL METHOD-PROCESS (DENEYSEL ÇALIŞMALAR)

3.1. Harmony Search Algorithm (Armoni Arama Algoritması)

Harmony search algorithm is a stochastic algorithm technique and developed according to the procedures of a better musical harmony. All operations are carried out with harmony memory matrix (HM). Harmony memory consideration rate (HMCR) and pitch adjustment ratio (PAR) are also two important operators. Detailed information about harmony search algorithm method can be taken from the studies of [1, 2 and 3] in literature. The flowchart used in this study is presented in Figure 1.

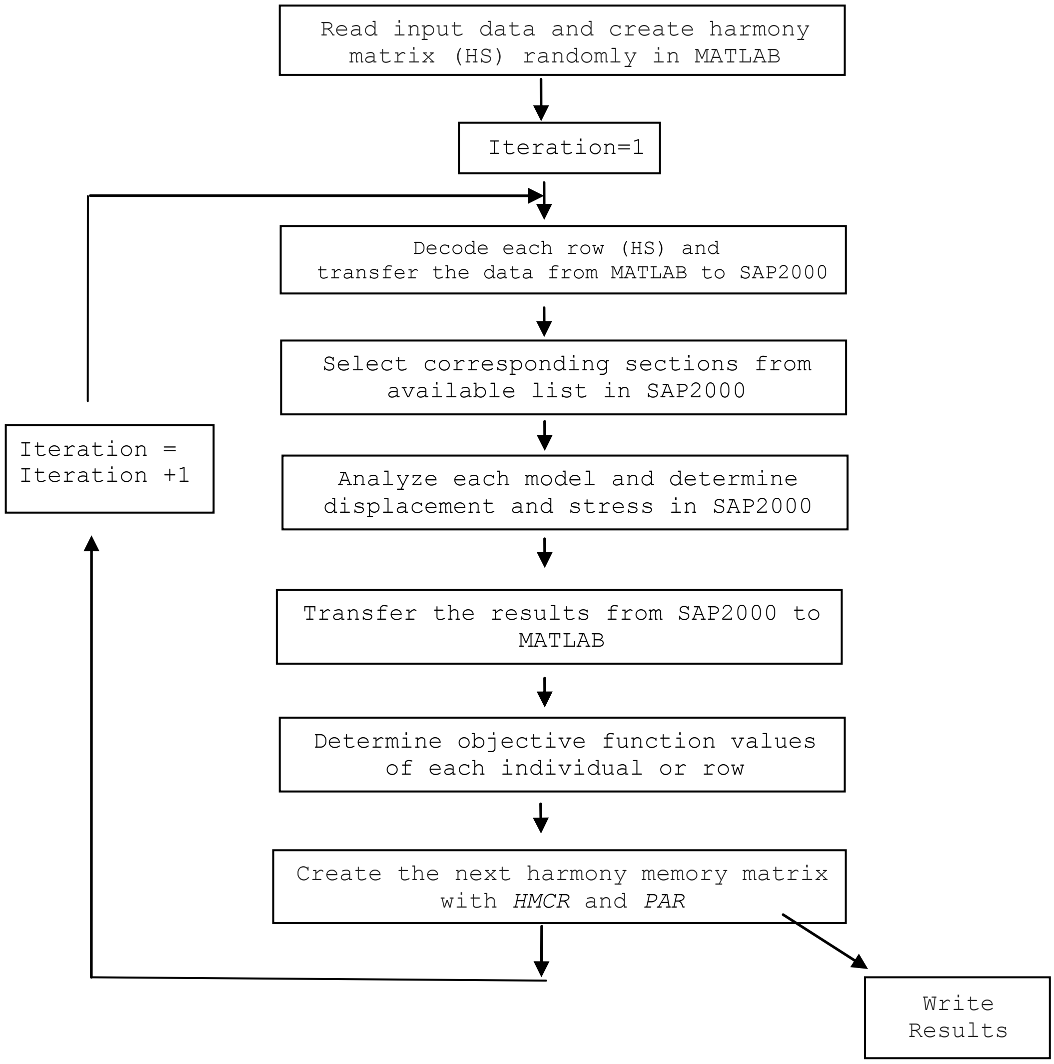


Figure 1. Flowchart for the optimum design procedures
(Şekil 1. Optimum tasarım işlemi için akış şeması)

3.2. Optimum Design Formulation and Constraints (Optimum Tasarım Formülasyonu ve Kısaltmaları)

In this study, optimum design for minimum weight of industrial structure including truss and frame members is defined as below,

$$\min W=\sum_{k=1}^{ng} A_k \sum_{i=1}^{nk} \rho_i L_i \tag{1}$$

where W is the weight of the frame, A_k is cross-sectional area of group k, ρ_i and L_i are density and length of member i, ng is total number of groups, nk is the total number of members in group k.
The stress constraints taken from [7] are presented as below;
For truss members (roof members):
For tension members,

$$\sigma_{t,all} = 0.6F_y \tag{2}$$

where $\sigma_{t,all}$ is allowable stress for tension members, F_y is yield stress.
For compression members, the allowable stresses are defined as below,

$$\lambda_m = \frac{K_m L_m}{r_m} \qquad m = 1, \ldots, ne \tag{3}$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}} \tag{4}$$

for inelastic buckling ($\lambda_m < C_c$) ;

$$\sigma_{c,all} = \frac{\left[1 - \frac{\lambda_m^2}{2C_c^2}\right] F_y}{\frac{5}{3} + \frac{3\lambda_m}{8C_c} - \frac{(\lambda_m^3)}{8C_c^3}} \tag{5}$$

for elastic buckling ($\lambda_m \geq C_c$) ;

$$\sigma_{c,all} = \frac{12\pi^2 E}{23\lambda_m^2} \tag{6}$$

Where λ_m is the slenderness ratio, K_m is the effective length factor (K=1.00 for truss member), r_m is minimum gyration radii, C_c is the critical slenderness ratio parameter.
For frame members (columns):

$$g_i(x) = \left[\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_{bx}}\right]_i - 1.0 \leq 0 \qquad i = 1, \ldots, nc \tag{7}$$

$$g_i(x) = \left[\frac{f_a}{0.60 F_y} + \frac{f_{bx}}{F_{bx}}\right]_i - 1.0 \leq 0 \qquad i = 1, \ldots, nc \tag{8}$$

if $\frac{f_a}{F_a} \leq 0.15$, Eq.(9) is calculated instead of Eq.(7) and Eq.(8),

$$g_i(x) = \left[\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}}\right]_i - 1.0 \leq 0 \qquad i = 1, \ldots, nc \tag{9}$$

where nc is total number of members subjected to both axial compression and bending stresses, f_a is computed axial stress, F_a is allowable axial stress under axial compression force alone, f_{bx} is computed bending stresses due to bending of the member about its major (x), F_{bx} is allowable compressive bending stresses about major, F'_{ex} is Euler stresses, C_{mx} is a factor.
-Displacement constraints are calculated as below,

$$g_{jl}(x) = \frac{\delta_{jl}}{\delta_{ju}} - 1 \leq 0 \qquad \begin{array}{l} j = 1, \ldots, m \\ l = 1, \ldots, nl \end{array} \tag{10}$$

where δ_{jl} is the displacement of j^{th} degree of freedom under load case l, δ_{ju} is the upper bound, m is the number of restricted displacements, nl is the total number of loading cases.

3.3. Atmospheric Corrosion Effect (Atmosferik Korozyon Etkisi)

Mild steel is used as the most important structural steel for buildings, bridges, etc. However its corrosion resistance is weak in industrial and marine environments due to presence of harmful pollutants and other industrial waste in addition to normal humid atmosphere. Atmospheric corrosion rates are influenced by local conditions and by the atmospheres classified by exposure conditions. The main categories based on potential corrosion rates are rural, urban, industrial, marine and interior. Marine environments which consist of a large amount of chloride ions are the most aggressive environment for atmospheric corrosion [8] has carried out significant experiments on the subject. In their study, they investigated the effects of chloride ions in the atmosphere on the mild steel corrosion rate. The metal exposed to a marine atmospheric environment (95m and 375m from the sea line) as well as to industrial atmospheric environment shown in Table 1 in order to analyze and quantify the effect of Cl- ion deposition on the corrosion process in the various exposure duration ranging from 3 to 24 months.

Table 1. Enviromental conditons of natural exposure sites [8]
(Tablo 1. Doğal maruz kalma alanlarının çevresel koşulları)

Environment	Avarage Temperature (°C)	Avarage Relative Humidity (%)	Cl^- (mg $100cm^{-2}$/day)	SO_2 (mg $100cm^{-2}$/day)
Marine	24.7	87	0.387	0.06
Industrial	9.2	66	0.0248	0.7651

Figure 2 reproduces results in Figure 3 by plotting the thickness loss against the exposure time in log-log coordinates. Figure 2 and Figure 3 shows that the highest corrosion rate is at the distance of 95m from the sea line. Therefore, in this paper corrosion rate at 95m from the sea line of is used.

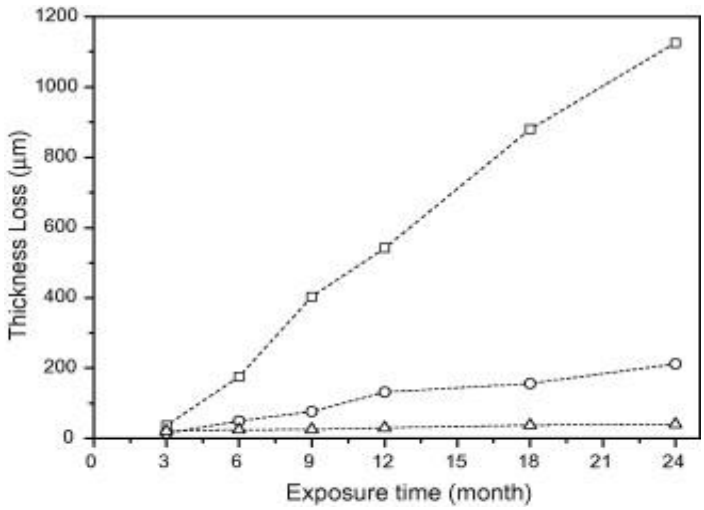


Figure 2. Thickness loss of carbon steel in the different environment as a function of exposure time, □: samples exposed at 95m station far from the sea line, Δ: samples exposed at 375m station far from the sea line, ○: samples exposed at industrial environment [8]
(Şekil 2. Farklı ortamdaki maruz kalma süresinin bir fonksiyonu olarak karbon çeliğinin kalınlık kaybı, □: deniz hattından uzakta 95m istasyonda maruz kalan numuneler, Δ: deniz hattından uzakta 375m istasyonunda maruz kalan numuneler, ○: Endüstriyel ortama maruz kalan numuneler)

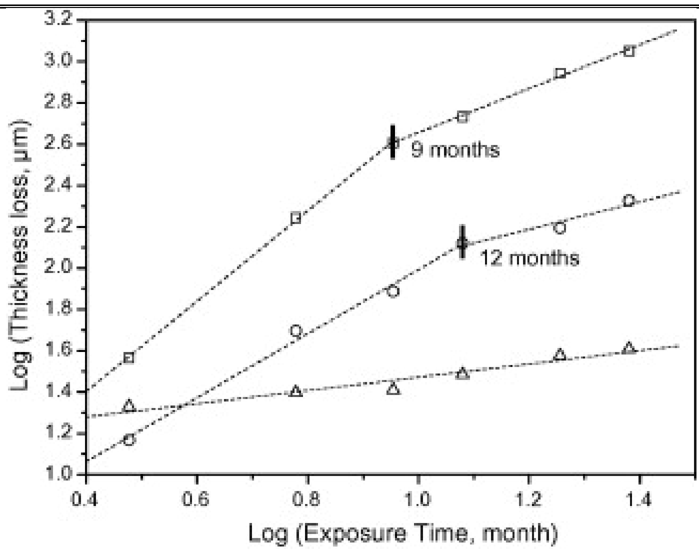


Figure 3. Bilogarithmic plots of data points from Figure 2. □: samples exposed at 95m station far from the sea line; Δ: samples exposed at 375m station far from the sea line; ○: samples exposed at industrial environment [8]
(Şekil 3. Şekil 2'de gösterilen bilgilerin bilogaritmik gösterimi □: deniz hattından uzakta 95m istasyonda maruz kalan numuneler; Δ: deniz hattından uzakta 375m istasyonunda maruz kalan numuneler; ○: Endüstriyel ortama maruz kalan numuneler)

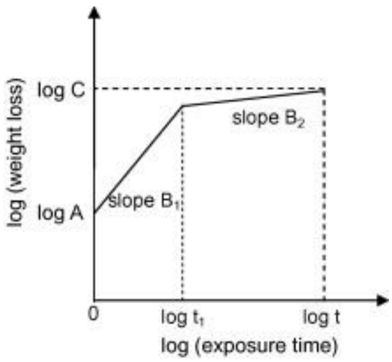


Figure 4. Schematic diagram of the variation of the thickness loss of mild steel in the marine atmosphere with time in log-log coordinate [8]
(Şekil 4. Deniz atmosferinde yumuşak çelik kalınlığı kaybının zamanla log-log grafiğindeki değişiminin şematik gösterimi)

In marine site atmosphere corrosion rate are described as;

$$C = A t_1^{B_1 - B_2} t^{B_2} \qquad t \geq t_1 \tag{11}$$

where C is the thickness loss, A is that at the first month, t_1 is the length in months of the first period of slope B_1, and B_2 is the slope in the second period. As a result of their experimental studies regression constants were determined as given in Table 2.

Table 2. Regression coefficients of the natural exposure corrosion data [8]
(Tablo 2. Doğal maruz kalma korozyonunun regresyon katsayıları)

Exposure Site	Distances from Sea Line (m)	A	B_1	B_2	Corresponding Equation
Marine Site	95	0.527	2.19	1.06	$C = A t_1^{B_1-B_2} t^{B_2}$

3.4. Design Problem: 31-Member Industrial Structure (Tasarım Problemi: 31- Elemanlı Endüstriyel Yapı)

Figure 5 shows a 31-member industrial structure composed of truss members and frame members. All members are collected into 5 groups as seen in Table 3. The loading used in the study (dead+wind loading) is presented in Figure 6. The maximum lateral displacement is restricted to 1.625cm (h/400). Optimum profiles are selected from a specified list including 128W taken from AISC. The required properties are E=200GPa, fy=250MPa and ρ=7.85ton/m^3. The optimum profiles are presented in Table 1 and the design histories of the both cases are presented in Figure 7. Figure 8 is also shows the industrial structure with optimum cross sections for the case without corrosion effect.

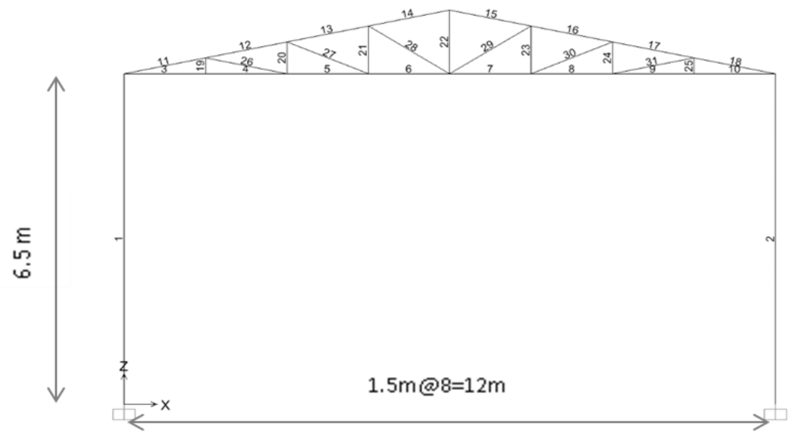
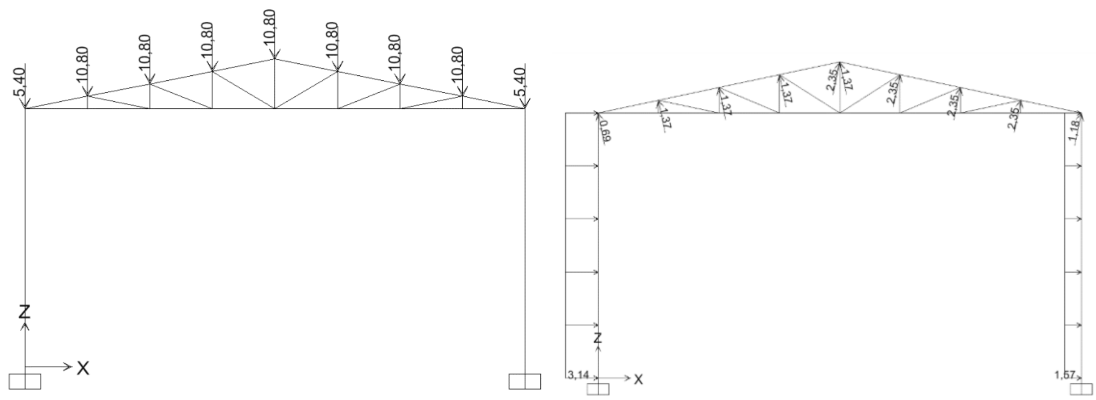


Figure 5. 31-member industrial structure
(Şekil 5. 31-Elemanlı endüstriyel yapı)



a) Dead Loading (Ölü yükler)

b) Wind loading (wind in X direction) (Rüzgar yükleri (X yönündeki rüzgar))

Figure 6. The loading in consideration (kN-m)
(Şekil 6. Dikkate alınan yükler (kN-m))

Table 3. Optimum results for both solutions
(Tablo 3. Her iki problem için optimum sonuçlar)

Group No	Member No	Case 1 Without Corrosion Effect	Case 2 With Corrosion Effect
1	1-2	W18X35	W21X44
2	3-10	W10X15	W12X14
3	11-18	W12X14	W12X14
4	19-25	W6X15	W12X19
5	26-31	W12X14	W8X15
Weight, kN		14.95	16.97

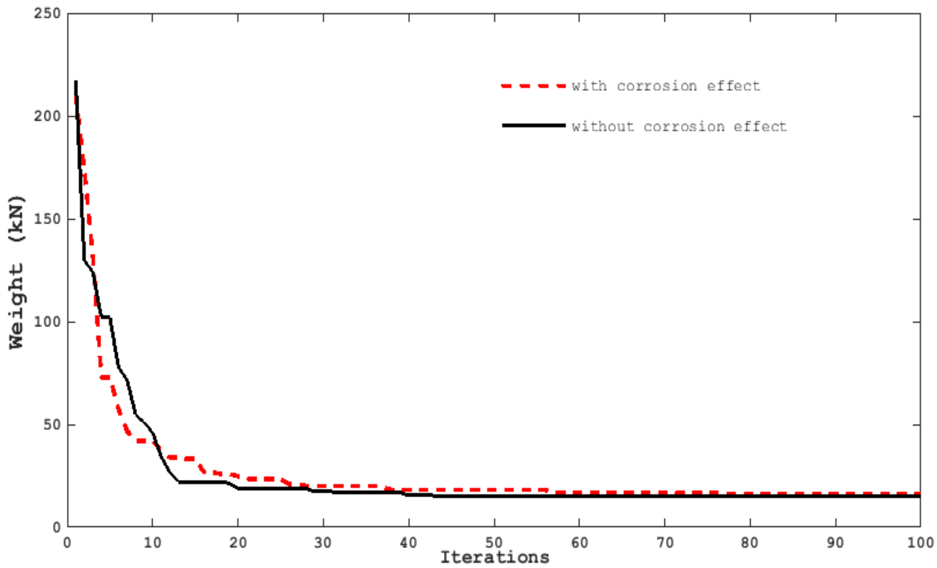


Figure 7. Design histories of both solution
(Şekil 7. Her iki çözümün tasarım adımları)

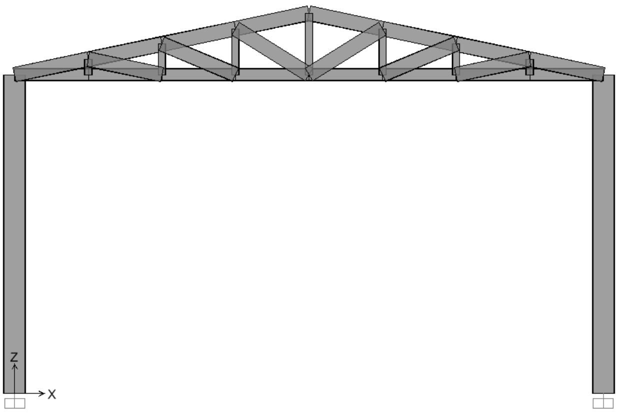


Figure 8. Industrial structure with optimum profiles without corrosion effect
(Şekil 8. Korozyon etkisi olmadan endüstriyel yapının optimum profilleri)

According to Table 3, the minimum steel weight of 31-member industrial structure for the case without corrosion effect is 14.95 kN. This minimum weight increases nearly 13% for the optimum solution of industrial structure including corrosion effect. It is experienced that the stress constraints play very active role in optimum solutions.

5. CONCLUSİONS (SONUÇLAR)

In this study, optimum designs of an industrial structure comprised of truss roof members and frame members are investigated for the cases with and without corrosion effect on steel cross-sections by using harmony search algorithm method. Atmospheric corrosion effect causes to decrease cross-section area and inertia moment of cross sections of structural members. The stress and displacement constraints according to AISC-ASD89 are used in the optimum designs. A program was developed in MATLAB to interact with SAP2000-OAPI. A 31-member industrial steel plane structure is designed for both cases with and without corrosion effects. The minimum weight of the industrial structure is obtained as 16.97kN for the case of which corrosion effect is included although the minimum steel weight is determined as 14.95kN when the corrosion effect excluded. In this study, the results obtained from the both solutions show that the optimum weight of the structure increases nearly 13% for the case of which atmospheric corrosion effect included.

NOT (NOTICE)

This work was presented at the 14th International Corrosion Symposium held in Bayburt on 5-7 October 2016.

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