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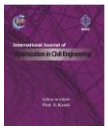

THE COST OPTIMIZATION OF A COMPOSITE METAL FLOOR DECK BY HARMONY SEARCH METAHEURISTIC ALGORITHM

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ABSTRACT

The purpose of this research to present for the first time a practical plan to cost optimize the composite metal floor deck, so that the designer, by having the dimensions of the main beam framing, will be able to come to the most design including: the section of composite steel beam, the beam span, the thickness of metal deck sheets and the thickness of the concrete slab. The main method of optimization by using metaheuristic algorithm is harmony search which its objective function is equal with these costs: steel beam, metal deck and concrete slab in one square meter of the floor. The standards of this design is according to SDI code and the Iranian National Building Code, Part 10: Design and Construction of steel buildings -allowable stress method. In this design all the metal beam profiles are the common and practical sections in building industry. Also the chosen metal deck, by the brand name Sundeck 75, is the most economical metal deck produced in the country Iran which is invented by the writer 1 and has been confirmed by Road, housing and Development Research center. In the end to ensure all the results of the harmony search optimization, several questions has been optimized, so the comparison of its results with the harmony algorithm results indicates that the high convergence in this algorithm.

Keywords: cost optimization; composite metal floor deck; steel beam; harmony algorithm.

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1. INTRODUCTION

The Composite metal floor deck is one of the latest structural floors which in the last years have attracted many researchers' attentions and have been replaced by the common composite floor in the building. Metal decks as a panel of profile sheeting, are divided into composite and non-composite types which the composite type besides performing as

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permanent form, it performs as tensile reinforcement floor. Designing and calculating these floors are done in a accordance with SDI code [1] in composite deck-slab and the Iranian National Building Code, Part 10 [2]: Design and Construction of steel buildings in composite steel beams. The designer now faces two main subjects. first: by the use of the two codes at the same time and increasing design parameters, the complete floor design is related to the mastery and skill of the designer. More importantly structural designers are always trying to find the most economical design consist of: size and distance between composite steel beams, the type of metal deck, the thickness of metal deck sheets, reinforcements and the thickness of concrete slab. In practice the full design composite metal floor deck is complicated and time consuming. By considering the wide range of variables and high volume of calculation, the optimized design of composite metal floor deck by trial and error. Today using evolutionary and metaheurisitc algorithms are a profitable method to optimize these engineering problems. So the mentioned floor can be cost optimized by the help of these algorithms. Though in the last four decades researches have been published on the cost optimization of composite floor system, no extensive research into cost optimization of composite deck by the use of the metaheuristic algorithm has been done.

Bhatti [3] presented a formula to optimize the composite floor which its objective function comprises only the costs of steel beam and shear stud. But Kim and Adeli [4] in another research in their own objective function besides the costs of steel beam and shear stud, they also comprised the concrete, too. The most completed objective function in the composite floor optimization was in Kavanja and Silih's research [5], which comprised all the floor properties: steel beam, shear stud, concrete, reinforcement, fire proof coating, welding and formatting floor. In another research Al Ansari and Senouci [6] presented cost optimization of composite beam by the genetic algorithm which its objective function would comprise costs of metal beams, shear stud and the concrete. Their design was based on the AISC-LRFD. Kaveh and Shakouri [7] studied the optimization of composite floor according to AISC-LRFD design with the algorithm of harmony search and an improved harmony search which its objective function was the minimum cost of concrete of floor and steel beam. But Kaveh and Ahangaran [8] in more completed research the composite floor based on AISC load and resistance factor design specification and plastic design concept was optimized by social harmony search model which its objective function is the minimum costs of concrete, steel beam and shear stud. In the next research Kaveh and Massoudi [9] studied the optimization of composite floor according AISC-LRFD with ant colony optimization which objective function is the minimum costs of concrete of floor, steel beam and shear stud. Finally, Kaveh and Behnam [10] optimized the composite floor and one-way waffle slab according to AISC-LRFD by the use of revolutionary algorithm and the charged system search algorithm.

2. SEARCH METHODOLOGY

The rest of this paper is organized as follows: Section 2 we introduce composite metal floor deck and Specifications of sundeck75 as the deck which is used in this research in section 3 the optimization of these floors is explained by the global search method to ensure the accuracy of the results of the harmony search algorithm. In section 4 harmony search algorithm is introduced as an effective evolutionary algorithm to engineering cost optimization. In section 5, model formulation and objective function are introduced. In section 6 design constraints which is the constraints of the problem is defined. In section 7 the cost optimization of some practical problems about composite metal floor deck according to the harmony search algorithm and global search is mentioned. Finally, section the article's conclusion is discussed.

3. THE INTRODUCTION OF COMPOSITE METAL FLOOR DECK

Composite metal floor deck is one of the new structural technologies in the country's building industry. The properties of this floor- Fig. 1- are: beam, steel profile sheeting (Metal deck), shear connector (shear stud) and reinforcement mesh.

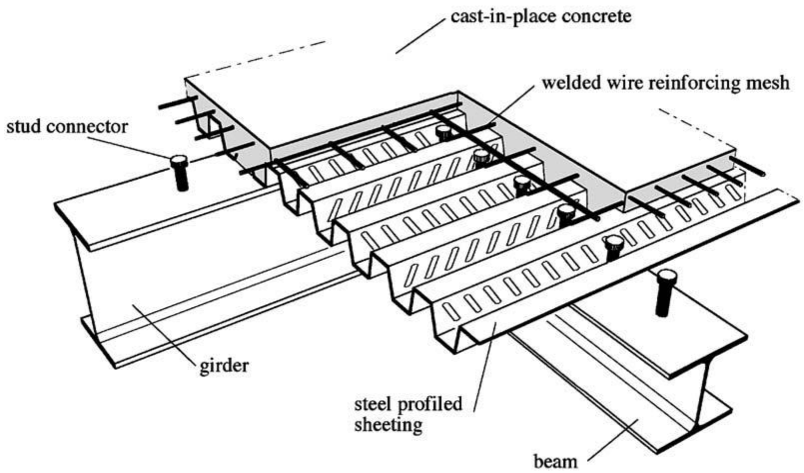


Figure 1. Properties of the floor

The advantages of this floor system are: the use of metal deck as permanent form, speedy erection, Increase the distance between secondary beams and saving in steel structure. Metal decks in terms of performance are categorized by composite and non-composite. The non-composite decks have no embossment or inappropriate embossments. The definition of embossment is the indent on the ribbed surface of the profile of metal deck which performs as shear connector to transfer shear stress continuity from concrete slab to the metal deck. In this case metal deck and the concrete slab perform as composite which metal deck can be operated as tensile reinforcement of concrete slab positive transverse.

So the non-composite decks can be used only as form deck but composite decks due to embossment can perform as the tensile reinforcement of slab positive transverse. As this result by the use of composite decks the most economical design is available. In this research the composite floor deck optimization, which has the best performance, has been developed to have a more practical design. One of the composite decks (produced in Iran under the brand name Sundeck 75) has been used in this research to optimize composite metal floor deck.

3.1 Introduction and specifications of sundeck 75.

Sundeck 75 is the first metal deck achieving technical certification of Road, Housing and Development research center, which this center has confirmed the composite behavior. This product is the only metal deck which is protected by patent applied by the writer 1 and confirmed by the Iranian research organization for science and technology. In the year 2016 it was one of the best patents in patents festival of national elite foundation. Specifications of sundeck75 is: high ratio of section modulus to area section, the use of continuous and spot embossments drawn in Fig. 2, the minimum weight of the deck and use it as tensile reinforcement making this product one of the most economical and widely consumed metal deck in the country's construction industry.

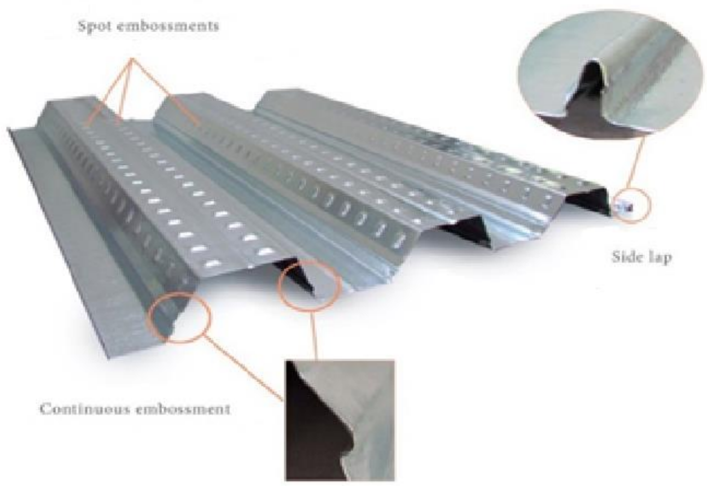


Figure 2. Continuous and spot embossments

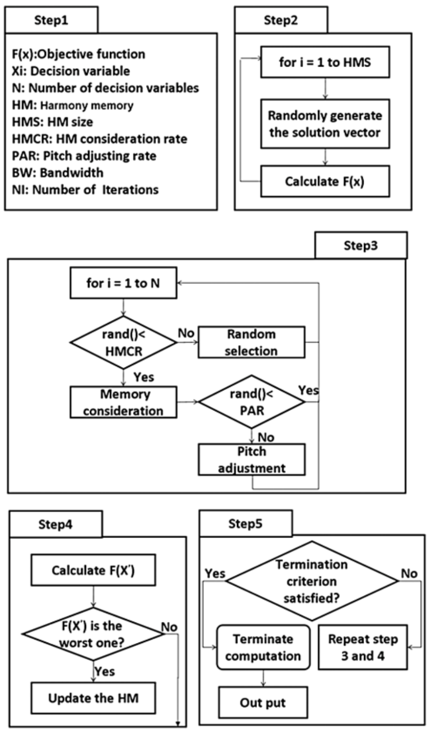
4. GLOBAL SEARCH

The global search method is an obvious and comprehensive method to solve the problems. This method not only includes all the possible solutions to solve a problems, but also it checks and rechecks whether any of the possible solutions can solve the problem or not. The main disadvantage of the global search in many scientific issues is that the possible answers are a lot. For example the number of possible answers to find the divisors of n will be n. Thus to find the divisors of a 16 digit number, there is a need of 1015 searches which it takes several days by a typical computer. But in this research the total possible answers will be 13000 that the problem will be answered in a shorter period of time. The advantage of the global search is that to conclude an answer will be definite because all the possible answers are checked.

5. METAHEURISTIC HARMONY SEARCH ALGORITHM

The metaheurisitc optimization algorithm imitates natural phenomenon. Harmony Search (HS) was first developed by Zong Woo Geem et al in 2001 [11], Harmony search metaheurisitc algorithm has been inspired by natural process of playing music. As the composer is trying to write the most beautiful piece of music in the optimization process, we are trying to find the best answer for the problems. The correct answer in the optimization process is gotten by checking the objective function. In writing a piece of music the composer plays each instrument in its range of possible steps, so playing all instruments forms a harmonic vector. It repeats to play different melodies. In each melody if all instruments have god steps, this melody will be memorized by the composer; thus the composer plays an instrument with a specific step. The next step three things would happen to the instrument. The instrument is played by the step memorized in the composer's memory. The instrument is played by the next step. The instrument is accidentally played by another step. Similarly, in metal floor deck optimization first for each variable an amount from all the variable amounts is defined. Variable amounts of the question forms all the vector call. To get a new amount for a variable, one of the three below decisions is made:

One: variable amounts of one of the existing variables in memory consideration is considered for that variable. Two: variable amount of an approximate amount of one of the variable amounts in memory consideration is considered. Three: variable amount of a random amount of the possible amounts is considered for that variable. These three rules in the harmony search metaheuristic algorithm are controlled by two parameters memory consideration rate (HMCR) and pitch adjustment rate (PAR). The harmony search metaheurisic algorithm steps are shown in Fig. 3.



6. MODEL FORMULATION

To make the search results more practical the optimizer software program which is programmed by structural designers in all the composite metal floor deck projects. The Model formulation is done when the designer has a panel dimensions of the main particle beam floor plan and wants to get the most economical plan for the floor properties: size, span, thickness of the metal deck sheet and finally the concrete slab thickness by the optimizer software program. In reality the above variable is the most important factor in the composite metal floor deck optimization. Size and the distance between shear studs are the composite steel beam According to the metal deck in this research, which is unchangeable, the shaer studs are not comprised as the effective variable in the optimization. temperature reinforcement due to its minimum range has no effect in cost optimization. Variation range of the main four variables has been practically used (equation 1 and 4) to optimize according to global search and harmony search metaheuristic algorithm:

1. 1900 (mm) $\leq l \leq$ 4000 (mm)
2. $t_d = 0.7 . 0.8 . 0.9 . 1$ (mm)
3. $h_c = 60 . 65 . 70 . 75 . 80\ (mm)$
4. Profile: IPE140 to PG 500

   l: Distance between steel beams
   t_d: metal deck sheet thickness
   h_c: concrete slab thickness above the metal deck
   Profile: composite steel beams size as a total of 140 profiles

6.1 Objective function

The objective function is: Ct

$C_t = c_{deck} + c_{concrete} + c_{st}$

C_t: total costs of floor in square meter
c_{deck}: cost of metal deck in square meter
$c_{concrete}$: cost of concrete in square meter
$c_{concrete}$: cost of steel beams in square meter

The aim of this problem is to find an answer which minimizes C_t function in all the optimization problems. Objective function is affected by constraints. problem constraints are criterion according to the design to the codes.

7. DESIGN CONSTRAINTS OF THE COMPOSITE METAL FLOOR DECK.

Composite metal floor deck constraint is explained in two chapters:

7.1 Composite metal deck design constraints

In this section by choosing composite metal deck under the brand name Sundeck 75. Design constraints of this metal deck which is according to SDI code [1] will be explained in two parts: construction stage and composite stage.

7.1.1 Deck design in construction stage (non-composite)

7.1.1.1 Flexural stress control f_{bd}

$f_{bd} \leq 0.6\, f_{yd}\ .f_{bd} = Md/s$

f_{yd}: yield stress of metal deck sheeting

Md: metal deck bending moments which is calculated according to SDI [1] loading and anchorage condition

S: sundeck 75 composite metal deck section modulus

7.1.1.2 Deflection control

$\delta_d \leq min\{\frac{l}{180}, 19(mm)\}$

δ_d: metal deck deflection due to the wet concrete weight and temporary load which is calculated according to SDI code [1] loading and anchorage condition

l: Distance between steel beams

7.1.1.3 Metal deck shear resistance control

$V_{ud} \leq V_{nd}$

V_{ud}: metal deck shear when due to the wet concrete weight and temporary load which is calculated according to AISI S100 [3]loading and anchorage condition

V_{nd}: sundeck 75 metal deck shear capacity

7.1.2 Deck design in composite stage

7.1.2.1 Shear bond control

This parameter is related to the shear bond control between concrete slab and metal deck which is composite metal deck behavioral parameter. It is related to the embossment quality.

$V_{ub} \leq V_{nb}$

$$V_{nb} = (h_{dc} - c)(1000)\left[\frac{4K_5}{l} + K_6\right]$$

V_{ub}: shear force in composite metal deck slab

V_{nb}: shear bond resistance of metal deck according to SDI [1]

h_{dc}: composite metal deck slab depth.

$h_{dc} = h_d + h_c$

DL: floor dead load

SDL: floor super dead load

LL: floor live load

K_5 , K_6: shear bond factors of sundeck75 according to SDI T-CD

7.1.2.2 Composite slab flexural moment capacity control

$Muc \leq Mnc$

$M_{nc} = 0.85 f_{yd} I_{cr}/(h_{dc}\text{-}y_{cc})$

Muc: flexural moment *in slab*

Mnc: Yield moment for the composite deck-slab, considering a cracked cross section
I_{cr}: cracked section moment of inertia
y_{cc}: distance from top of slab to neutral axis of cracked section

7.1.2.3 One-way shear resistance control

$V_{uc} \leq V_{nc}$

$V_{nc} = 2700 t_d{}^2 \sqrt{f_{yd}} + V_{cc} \leq (0.2 h_{dc}{}^2 + 45.7 h_{dc}) \sqrt{\boldsymbol{f_c}}$
V_{uc}: one-way shear of slab
V_{uc}: shear resistance of sundeck 75
t_d: thickness of metal deck sheet
V_{cc}: shear resistance of concrete slab
$\boldsymbol{f_c}$: concrete comprehensive strength

7.1.2.4 Deflection of composite deck-slab

$\delta_{lc} \leq \frac{l}{360}$, $\delta_{tc} \leq \frac{l}{240}$
δ_{tc}: total deflection of composite deck slab
δ_{lc}: deflection of composite deck slab under live load

7.2 composite steel beam design

7.2.1 composite beam design in construction stage (non-composite)

In reality composite steel beams are regularly designed without unshoring which its design constraint are according to the Iranian National Building Code, Part 10 [2]: Design and Construction of steel buildings

7.2.1.1 Flexural stress control $\boldsymbol{f_{bb}}$ according to clause 1-5-1-10 of the Iranian National Building Code, Part 10 [2].

$f_{bb} \leq 0.66\, f_{yb}$
f_{bb}: steel beam moment stress in construction stage (non-composite)
f_{yb}: steel beam yield stress

7.2.1.2 Steel beam deflection control $\boldsymbol{\delta_{tb}}$(3-12-1-10 the Iranian National Building Code, Part 10 [2]

$\delta_{tb} \leq \frac{l_b}{240}$
δ_{tb}: steel beam deflection in construction stage (non-composite)
l_b: beam span

7.2.2 Composite metal beam design in composite stage

7.2.2.1 Flexural moment stress $\boldsymbol{f_{bc}}$*according to chapter 9-1-10 of the Iranian National Building Code, Part 10 [2]*

In this chapter geometric characteristics of transformed section by considering incomplete performance of composite is calculated because in composite metal deck floors in vertical beams on metal deck the number and space between shear studs is definite. In another word inside the stud deck congress one stud will be welded to the beam.

$f_{bc} \leq 0.66\ f_{yb}$

f_{bc} tensile stress of composite steel beam

f_{yb}:yield stress of steel beam

7.2.2.2 shear resistance control $\boldsymbol{f_v}$ *(according to the clause 4-5-1-10 of the Iranian National Building Code, Part 10 [2])*

$f_v \leq 0.40\ f_{yb}$

7.2.2.3 deflection control according to the clause 3-12-1-10 of the Iranian National Building Code, Part 10 [2]

$f_v \leq 0.40\ f_{yb}$

δ_{tbc}: total steel beam deflection

δ_{lb}: composite steel beam deflection under live load

7.2.2.4 frequency control $\boldsymbol{f_z}$*(according to the clause 3-12-1-10 of the Iranian National Building Code, Part 10 [2]*

$$f_z = 70\sqrt{\left(\frac{I_{tr}}{4l(Dl)l_b}\right)}$$

I_{tr}: inertia moments of transformed composite beam

8. NUMERICAL EXAMPLES

In this research the suggested method performance in finding the most optimized design of composite metal floor deck was checked by several examples which in this experiment the result of objective function optimization in harmony search was checked by the result of global search. In chart 1, 15 different sample questions in composite metal floor deck have been cost optimized by harmony search and global search. Variable inputs in this question are:

l_b: beam span

l_t: beam panel width

LL: live load

f_{yd}: yield stress of metal deck sheeting

The fixed variable inputs are:

$$c_c = 90000، c_d = 3000، f_c = 21، f_{yb} = 2400، w_{con} = 2400، SDL = 270، E_b = 2060000، f_{yr} = 3000$$

By the comparison of the results in harmony search from 15 examples solved in 13 examples with less than 200 iteration, the answer was optimized which it was the same as global search result but In global search due to the search space was completely checked the time to get the results was longer than the harmony search.

Table 1: Result of cost optimization of composite metal floor deck

					Harmony Search with iteration:200				Global Search			
	l_b	l_t	LL	f_{yd}	l	t_d	h_c	$Profile$	l	t_d	h_c	$Profile$
1	600	6000	200	240	3000	0.8	60	38	3000	0.8	60	38
2	600	6000	200	300	3000	0.7	60	38	3000	0.7	60	38
3	600	6000	500	240	3000	0.9	70	38	3000	0.9	70	38
4	600	6000	500	300	3000	0.7	70	38	3000	0.7	70	38
5	600	7500	200	240	2500	0.7	65	38	2500	0.7	60	38
6	600	7500	200	300	3750	60	60	38	3750	60	60	38
7	600	7500	500	240	2500	0.7	60	38	2500	0.7	60	38
8	600	7500	500	300	2500	0.7	60	38	2500	0.7	60	38
9	750	6000	200	240	3000	0.8	60	64	3000	0.8	60	64
10	750	6000	200	300	3000	0.7	60	64	3000	0.7	60	64
11	750	6000	500	240	3000	0.9	70	67	3000	0.9	70	67
12	750	6000	500	300	3000	0.7	70	67	3000	0.7	70	67
13	750	7500	200	240	2500	0.7	60	64	2500	0.7	60	64
14	750	7500	200	300	2500	0.7	60	64	3750	1	60	66
15	750	7500	500	240	2500	0.7	60	62	2500	0.7	60	62

9. CONCLUSION

This research, having a new topic, for the first time has been carried out to help find a practical plan to cost optimize composite metal floor deck. So no such research has been done so far. The distinction aspects of this research are considering metal deck calculations constraints according to SDI code [10]. The cost optimization is done in two ways: global search algorithm and harmony search metaheurisitc algorithm, the use of a typical & economical composite metal deck profile, the use of all typical steel beams. Optimization method has been done by minimizing objective function which comprises the costs of steel beam, Metal deck sheet and concrete slab. The software program has an interface which the designer can get the lowest cost by having a panel's dimensions of the floor main beam plan, importing inputs, choosing the search method and its iteration, floor properties. By optimizing several examples of metal floor deck and comparing the results of global search and harmony search, it can be concluded that harmony search method in cost optimization composite metal floor deck has high convergence. In this method the number of iteration to achieve the optimized results was less than 200. Overall results of this research can be used by structural designers in the country's building industry projects as a complete and practical plan to cost optimize composite metal floor decks.

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