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Research Article

OPTIMIZATION OF ASSEMBLY PLAN FOR LARGE OFFSHORE STRUCTURES

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ABSTRACT

The paper proposes a method of numerical encoding of large welded structures with the use of multisets. The method takes the types of details and connections that occur in structures into consideration. Mathematical optimization model for multistage structure assembly schedule was defined. Comparative analysis of selected decision variants for sample constructions and details sets is presented.

Keywords: structure, technology, prefabrication.

INTRODUCTION

Many ocean engineering objects used offshore in industry represent steel stiffened layer (SSL) constructions. These constructions include merchant vessels, large-size tanks and bridge elements. They are made of steel plates and rolled steel elements which are connected after processing to make details. The production process is conducted in stages. First, simple, then more complex prefabricates are made. In further stage the share of prefabricated elements to be connected is increasing.

The problem of construction optimisation with consideration for reducing production, exploitation and recycling costs, with regards to quantity and exploitation requirements, is very complex and difficult to describe with a mathematical model [4]. Presently, in order to design an SSL construction fragmentary optimisation models are used. Intensive development can be observed in such areas as welding deformation forecasting, cutting optimisation and production scheduling [5, 6]. However, the problem lies in such integration of the models that allows for early forecasting the technological maturity of the construction, as early as at the stage of selecting exploitation and strength parameters. With no integrated model the designers are made to use the so called spiral model [8, 10]. This elongates the design time and causes changes in the project, even at advanced stages of the construction works. The costs of such changes are enormous and often difficult to identify.

The division into prefabricates and the assembly instruction are the basic entry information for the tools stimulating the production of SSL constriction or for other CIM type tools [1, 11]. One may notice that the authors of publications offering computer aided design systems present a prefabricates' division in a form of block diagrams prepared by technologists. The data is treated as input parameters. There is no mathematical model that brings the problem of choosing prefabricate division to optimisation tasks.

The aim of the article is to propose a model allowing optimisation of multistage prefabricate division of the designed construction and consequent technological effects including: assembly scheme, material lists, material flow in time, detail, construction and workstation standardisation.

OPTIMISATION MODEL

Constructions as multisets of details and connections

There is a given finite ordered set of different types of details $\Delta=\{\delta_1,\ldots,\delta_m\}$. The set is m-dimensional space of details.

Construction K in the space Δ is a pair $K = (\upsilon(K), \mu(K)$, where $\upsilon(K)$ is m-element vector of repletion of set Δ, $\mu(K)$ is a symmetric matrix of the number of connections between the details. Both $\upsilon(K)$ and $\mu(K)$ are characterised by certain multisets, therefore the proposed construction coding is called DCM (ang.: Details & Connections Multisets).

Let us assume that each detail in the construction is connected to at least one other detail, and two details are connected to each other with at least one connection. As certain type of details can be multiple in K, there can be more than one type of connections between the details of two types.

Let us assume that K construction is included in L construction (or that K is the subconstruction of L) provided two conditions are fulfilled:

$$K \subset L \Leftrightarrow \forall i, j = 1,...,m : 0 \le \upsilon(K)_i \le \upsilon(L)_i \;\wedge\; 0 \le \mu(K)_{ij} \le \mu(L)_{ij} \tag{1}$$

We shall define the following function that allows comparing two constructions K, L encoded in the same space of details:

$$\phi(K,L) = \max\{k \in \mathbb{N}_0 : (k \cdot \upsilon(K), k \cdot \mu(K)) \subset (\upsilon(L), \mu(L))\}. \tag{2}$$

Set of acceptable solutions and optimisation criteria

A production task is a certain multiset of constructions $a_0 = (a_{0,1},...,a_{0,n})^T$, each of which is to be produced by connecting other constructions or details. The problem concerns the division of each construction into a multiset of sub-constructions (so called prefabricates), which will be suit the purpose best. Additional complication is the fact that prefabricates are also to be divided.

The selection of prefabricate division for a given repetition vector of a_0 construction on a construction set $\kappa = \{K_1,...,K_n\}$, encoded with DCM method, is the problem of defining the component values of the so called decomposition matrix. One acceptable solution is each matrix $P = (p_{i,j})_{nxn}$ that meets the following criteria (comp. function 2):

$$\forall i \neq j: \;\; p_{i,j} \in \mathbb{N}_0, \;\; p_{i,j} \le \phi(K_i, K_j), \tag{3}$$

$$\forall i = j: \;\; p_{i,j} = 0, \tag{4}$$

$$\forall j: \;\; \left(\sum_{i=1}^{n} (p_{i,j} \cdot \upsilon(K_i)), \sum_{i=1}^{n} (p_{i,j} \cdot \mu(K_i)) \right) \subset K_j. \tag{5}$$

Decomposition matrix constructed in such a way that its every column and line are ascribed to the construction with appropriate number in set κ. Every j-th column is a vector of prefabricate repetition, that j-th construction is devided into.

In order to select the best acceptable decomposition matrix, the criterion must be formulated. The following aim function must be accepted:

$$Q(P, a_0) = \tfrac{1}{q_1+q_2+q_3}\left(q_1 \cdot M(P) + q_2 \cdot S(P, a_0) + q_3 \cdot Z(P)\right) \to \max, \tag{6}$$

where q_1, q_2, q_3 are partial weighting factors. The criteria are defined in the following way:

- index of filling the construction with prefabricates:

$$M(P) = \frac{1}{n} \sum_{j=1}^{n} \left[\left(\sum_{r=1}^{m} \sum_{s=1}^{m} \left(\sum_{i=1}^{n} p_{i,j} \cdot \mu(K_i) \right)_{r,s} \right) \cdot \left(\sum_{r=1}^{m} \sum_{s=1}^{m} (\mu(K_j))_{r,s} \right)^{-1} \right], \tag{7}$$

- index of similarity to the initial set:

$$S(P, a_0) = \frac{1}{n} \sum_{i=1}^{n} s_i, \quad s_i = \begin{cases} 0 & \text{when } a_{0,i} = 0 \wedge P^{T\langle i \rangle} \neq \theta \\ 1 & \text{otherwise} \end{cases}, \tag{8}$$

where $P^{T\langle i \rangle}$ is the i-th line of the matrix, θ is a zero vector,

- dispersion index:

$$Z(P)=\frac{1}{n}\sum_{i=1}^{n} z_i, \quad z_i=\begin{cases}1, & \text{when } P^{T\langle i\rangle}=\theta \\ 0, & \text{when } P^{T\langle i\rangle}\neq\theta .\end{cases} \tag{9}$$

The index of filling the construction with prefabricated elements defines how many connections in the construction are included in prefabricates. The inde is defined for the whole matrix and does not depend on the multiset of input constructions.

The index of similarity to the initial set defines how many types of constructions must be made, even though they do not make our output. The dispersion index counts the number of zero lines in dispersion matrixes. Each zero line means that the corresponding construction will not have to be produced as a prefabricate.

EXAMPLE OF CALCULATIONS

Detail and construction spaces

Let us consider a nine-dimension space of details and ten constructions built upon its area (comp. Figure 1).

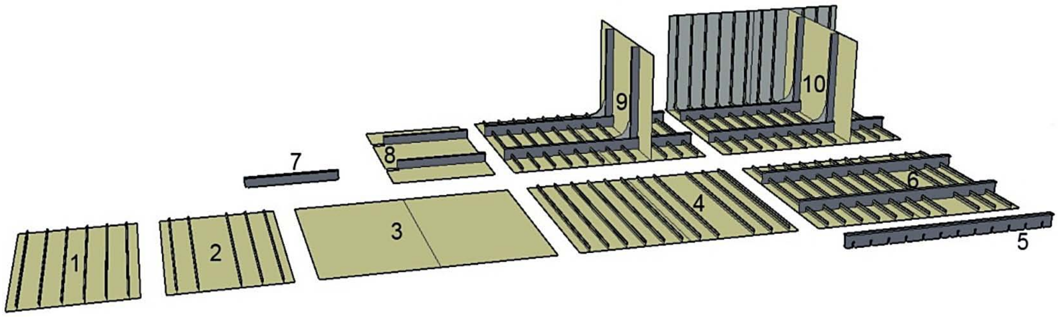

Fig. 1. Space of structures

DCM models of the constructions limited to a non-zero lines and columns (numbers of the lines and columns were marked on details' repetition vectors) are the following:

$$\upsilon(K_1)=\begin{array}{c}8\\9\end{array}\!\begin{pmatrix}1\\6\end{pmatrix},\ \mu(K_1)=\begin{pmatrix} & 6\\ 6 & \end{pmatrix},\ \upsilon(K_2)=\begin{array}{c}8\\9\end{array}\!\begin{pmatrix}1\\5\end{pmatrix},\ \mu(K_2)=\begin{pmatrix} & 5\\ 5 & \end{pmatrix},\ \upsilon(K_3)=8(2),\ \mu(K_3)=(1),$$

$$\upsilon(K_4)=\begin{array}{c}8\\9\end{array}\!\begin{pmatrix}2\\11\end{pmatrix},\ \mu(K_4)=\begin{pmatrix} & 11\\ 11 & 1\end{pmatrix},\ \upsilon(K_5)=\begin{array}{c}5\\6\end{array}\!\begin{pmatrix}1\\1\end{pmatrix},\ \mu(K_5)=\begin{pmatrix} & 1\\ 1 & \end{pmatrix},$$

$$\upsilon(K_6)=\begin{array}{c}5\\6\\8\\9\end{array}\!\begin{pmatrix}2\\2\\2\\11\end{pmatrix},\ \mu(K_6)=\begin{pmatrix} & 2 & & \\ 2 & & 4 & 22\\ & 4 & 1 & 11\\ & 22 & 11 & \end{pmatrix},\ \upsilon(K_7)=\begin{array}{c}3\\4\end{array}\!\begin{pmatrix}1\\1\end{pmatrix},\ \mu(K_7)=\begin{pmatrix} & 1\\ 1 & \end{pmatrix},$$

$$\upsilon(K_8)=\begin{array}{c}3\\4\\7\end{array}\!\begin{pmatrix}2\\2\\1\end{pmatrix},\ \mu(K_8)=\begin{pmatrix} & 2 & 2\\ 2 & & \\ 2 & & \end{pmatrix},\ \upsilon(K_9)=\begin{array}{c}1\\3\\4\\5\\6\\7\\8\\9\end{array}\!\begin{pmatrix}2\\2\\2\\2\\2\\1\\2\\11\end{pmatrix},\ \mu(K_9)=\begin{pmatrix} & & 2 & 2 & & & & \\ & & 2 & 2 & & 2 & & \\ 2 & 2 & & 2 & & & & \\ 2 & 2 & 2 & & 2 & & & \\ & & & 2 & & & 4 & 22\\ & 2 & & & & & 1 & \\ & & & & 4 & 1 & 1 & 11\\ & & & & 22 & & 11 & \end{pmatrix},$$

$$\upsilon\left(K_{10}\right)=\begin{array}{cc}\begin{array}{c}1\\2\\3\\4\\5\\6\\7\\8\\9\end{array} & \begin{pmatrix}2\\11\\2\\2\\2\\2\\1\\4\\22\end{pmatrix}\end{array},\ \mu\left(K_{10}\right)=\begin{pmatrix} & & & 2 & 2 & & & & \\ & & & & & & & & 22 \\ & & & 2 & 2 & & 2 & & \\ 2 & & 2 & & 2 & & & & \\ 2 & & 2 & 2 & & 2 & & & \\ & & & & 2 & & & 4 & 22 \\ & & 2 & & & & & 1 & \\ & & & & & 4 & 1 & 1 & 22 \\ & 22 & & & & 22 & & 22 & \end{pmatrix}.$$

The analysed decomposition matrixes

In order to present the methods of making calculations of function values, two variants of matrix decomposition were compared (zero lines and columns were hidden):

$$P^1=\begin{array}{cc} & \begin{array}{cccccc}1&4&6&8&9&10\end{array} \\ \begin{array}{c}2\\3\\4\\5\\6\\7\\8\end{array} & \begin{pmatrix}1&&&&&\\&1&&&&\\&&1&&&1\\&&2&&&\\&&&&1&1\\&&&2&&\\&&&&1&1\end{pmatrix}\end{array},\ P^2=\begin{array}{cc} & \begin{array}{cccccc}1&4&6&8&9&10\end{array} \\ \begin{array}{c}2\\5\\7\end{array} & \begin{pmatrix}1&2&2&&2&2\\&&2&&2&2\\&&&2&2&2\end{pmatrix}\end{array}. \tag{10}$$

It is seen that these solutions are acceptable. Obviously, it is possible to generate larger number of solutions in the formed task.

Variant comparison

Two, out of three, particle criteria can be determined with the knowledge about the shape of decomposition matrix:

$$M\left(P^1\right)=0{,}317,\ Z\left(P^1\right)=0{,}3,\ M\left(P^2\right)=0{,}293,\ Z\left(P^2\right)=0{,}7\ . \tag{11}$$

It can be noticed that the first of the compared variants has a lower index of filling the construction with prefabricates. The situation is reverse in case of dispersion index.

In order to define the index of similarity to the input set (equation 8) it is necessary to define the repetition vector a_0. The index determines only whether the components a_0 vector are smaller or larger than zero. Therefore, the problem covers 2^{10}=1024 of all possible binary 10-bit sequences. Such a number of calculations was made for both variants of decomposition matrixes (comp. Table 1).

Table 1. The values of similarity to the output sets

Value $S(P^i)$	Occurance frequency	
	P^1	P^2
0,3	8	0
0,4	56	0
0,5	168	0
0,6	280	0
0,7	280	128
0,8	168	384
0,9	56	384
1	8	128
Σ=	1024	1024

The value of similarity index to the input set repeat with certain frequency. On the basis the obtained results, one notices that variant P^2 gives most often the value of S higher than P^1.

It is clear that the final evaluation of decomposition is not unambiguous, requires forming a production task and weighting factors for particular criteria.

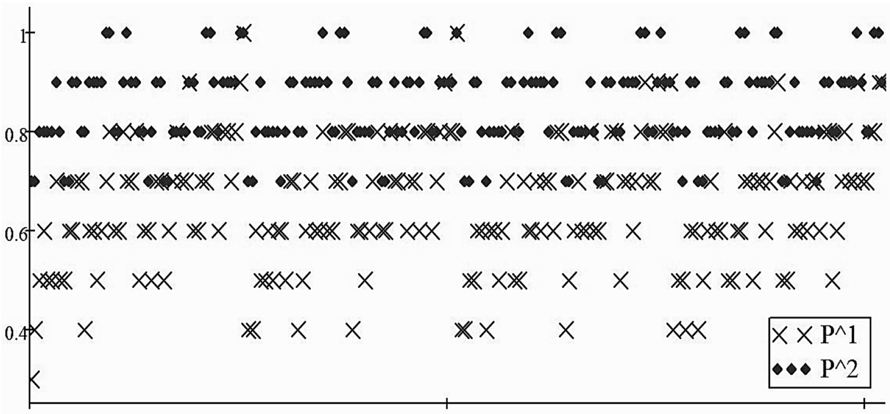

Fig. 2. The values of the objective function for weight coefficients: $q_1=q_2=q_3=1$

Figure 2 presents the juxtaposition of value of aim function for equivalent particular criteria. The results for random 204-element subset of production tasks are presented.

It is clear that for equivalent criteria the second variant is most often the best solution, although it is not a rule. For instance, for the input production: $a_0 = (0,1,1,1,1,1,1,1,1,0)$ both variants are equally good ($Q = 1$).

CONCLUSIONS

The article presents a model of describing SSL-type large-size construction that are commonly used in offshore industry. The model uses multisets of details and connections. The use of multisets allows using the term construction inclusion, what is significant from the perspective of large-size products produced in multistage prefabrication.

The problem of making prefabricate division is solved thanks to technologists' experience of omitting the quantitative analysis of decision-making. The model allows analysing from different perspectives. The three implemented particular criteria consider common strive to standardise production and implement group technologies [2, 7, 9, 12].

Weighting factors, which are the parameters of aim functions, allow flexible adaptation of the proposed tool to the priorities of a given company. It is possible to minimise the diversity of prefabricates or to limit the number of details connected to the construction at later production stages.

The problem the was not covered in the article is the selection of method for searching for an optimal solution for given weighting factors and a given schedule of output production. It is a combinatorial task, therefore, the necessity to use randomised algorithms should be anticipated. The problem is not going to be addressed in the present article.

The use of the proposed model is broader than optimisation of the prefabricate division only. It can be used as an efficient tool in the process of construction designing and to provide information on its future technology. The condition that needs to be fulfilled to implement the model in practice is to provide a technological database covering the completed and prototypical constructions. Such a database should function as a module of an integrated IT system of the company [3]. The process of designing connected with the proposed model and the database with a loop feedback. In such a way the idea of *design for production* has a chance to function in planning and design companies that make stiffened-layer constructions.

REFERENCES

1. Aoyama K., Nomoto T., Watanabe K., Development of a shipyard simulator based on Petri nets. Journal of Marine Science and Technology, 1999, 4, pp. 35-43.
2. Ballakur A., Steudel H.J., A within-cell utilization based heuristic for designing cellular manufacturing systems. International Journal of Production Research, 1987, 25, pp. 639-665.
3. Biernat P., Tendencje i kierunki informatycznego wspomagania funkcjonowania przedsiębiorstw produkcyjnych, część 1. Warianty rozwiązania. Postępy Nauki i Techniki, 2012, 13, pp. 7-13.
4. Caprace J.-D., Rigo P., Towards a short time "feature-based costing" for ship design. Journal of Marine Science and Technology, 2012, 17, pp. 216-230.

5. Cho K.-K., Sun J.-G., Oh J.-S., An automated welding operation planning system for block assembly in shipbuilding. International Journal of Production Economics, 1999, 60-61 (1), pp. 203-209.
6. Costa M. T., Gomes A. G., Oliveira J. F., Heuristic approaches to large-scale periodic packing of irregular shapes on rectangular sheet. European Journal of Operational Research, 2009, 192, pp. 29-40.
7. Groover M. P., Fundamentals of modern manufacturing: materials, processes and systems, 4th ed. John Wiley&Sons, 2010.
8. Jastrzębski T., Projektowanie konstrukcji okrętowych i oceanotechnicznych. Wstęp do projektowania konstrukcji kadłubów okrętów. Politechnika Szczecińska, 1991.
9. Li M.-L., Efficiency measurement for multi-dimensional group technology. International Journal of Advanced Manufacturing Technology, 2007, 35, pp. 621-632.
10. Liang Z. X., Yan L., Shang J. Z., Collaborative multidisciplinary decision making based on game theory in ship preliminary design. Journal of Marine Science and Technology, 2009, 14, pp. 334-344.
11. Sasaki Y., Sonda M., Ito K., Development of computer-aided process planning system based on knowledge base. Journal of Marine Science and Technology, 2003, 7, pp. 175-179.
12. Storch R. L., Hammon C., P., Bunch H. M., Moore R. C., Ship production, 2nd ed. Cornell Maritime Press, 1995.