Abstract

Planning of construction processes besides technical and technological issues involve economical analyses. In the case of buried flexible structures one would consider elements like total investment costs, timing and life cycle costs. One the elements of total investment costs of building bridges or culverts made from corrugated buried structures is the cost of their assembly. As this cost is vulnerable to uncertainty and risk of error of estimation due to number of factors influencing the assembly process it is important to apply appropriate methodology in predicting it [1,2,3,4]. There has been several models for predicting costs of assembly developed over years. A short summary of those is presented in this paper with comparison analysis of results. Special emphasis is placed on multi-factor approach in modeling the costs prediction presented in one of the discussed model called LITCAC.

Key words: buried flexible structures, assembly cost, prediction, model

1. INTRODUCTION

Assembly technique of corrugated steel plate structures (CSPS) or simply flexible structures differs significantly from techniques used to build concrete culverts or bridges [1]. Its’ unique character requires use of manpower and application of simple hand tools and machines (small cranes, often pay-loaders and excavators) [5]. Assembly process is influenced by many factors thus can be described as multi-factor process. Assembly techniques are commonly known around the world, however different models for estimation of labor consumption and costs of assembly are used throughout the world. To evaluate applicability of those, models a comparison of results of labor consumption predictions have been recently performed in Poland [6]. This comparison unveiled the fact that all of the models are fixed to certain factors (number of workers, machinery and tools used for assembly, etc.), which predominately determine the results based
on change of other identified factors, like weight of CSPS, number of plates, number of screws, others. Therefore those models can be described as “closed” as they will not simulate sensitivity of results based on change of one group of factors.

Recently in Central European countries a model for estimating the labor consumption and cost of assembly of flexible culverts has been developed. Based on 6 years in field chronometric study conducted by Janusz [1] from 1996 to 2002, a number of 162 various cases of installation of flexible structures have been investigated. This extensive research have been carried our mainly in Poland and concerned in most cases (148) CSPS with corrugation of 150*50 mm. Results from this research were compared with predictions obtained from identified 13 methods for estimation of labor consumption from 11 countries applied on test set. It showed substantial differences in output (labor consumption). Investigations result were an incentive to create a new multifactor model. Complete considerations of the new model and description of assembly process have been presented in [1]. This paper will provide a short description of the new model which is called LITCAC (Labor consumption, Time and Cost of Assembly of flexible Culverts). Practical application of the model with combination of multiple-criteria decision making support software called TOPSIS [1,3], showed its’ usefulness for optimal decision making which is a powerful tool for practitioners.

2. GENERAL COMMENTS RELATED TO ASSEMBLY PROCESS AND SHORT DESCRIPTION OF EXISTING MODELS USED FOR ESTIMATIONS OF LABOR CONSUMPTION OF ASSEMBLY

There are some general rules that may be applied for setting cost estimations of assembly of buried flexible structures. Based on American experience [7] there are 7 main areas which are relevant for assembly cost estimations:

1. Structure features (weight, number of plates, other).
2. Function of structure (culvert, bridge, tunnel, other).
3. Location (distance, travel time, inne).
4. Assembly conditions (difficulties, other).
5. Availability of equipment and its’ cost.
6. Local labor market (labor rate, working hours, other).
7. Availability of lodging and cost of accommodation for the assembly crew (hotel cost, food cost, other).

Based on experience from many job sites another element should be included—financial incentives for speed assembly. It is very often confirmed that pay-per-job-done approach motivates assemblers to assembly faster rather than normal
pay-per-hour approach. As mentioned earlier the identified existing models are presented mostly as very simple mathematical equations consisting of one or two variables. They would determine the labor consumption based on mass of a structure, or number of plates in cross section and length of a structure, at last number of bolts included in a structure or number of plates in a structure. Most of them would fix the resources used for assembly as constant without options for changing them from case to case. Therefore their nature is rather closed, not addressing the dynamic change of an assembly process and their shortcomings are inability to find optimal crew composition for a specific assembly task and lack of cost estimation.

Three out of 13 identified existing models are presented below.

a/ British model by Asset International Ltd [1]

This model is applied for structures having corrugation 200*50 mm. A graphical nomogram model is applied to estimate labor consumption. Labor consumption is estimated as function of number of plates cross section and the length of a structure. Model assumes us of a crane and at leats two air-wrenches.

Another assumption is the number of people in assembly crew:
- for small structures (marked as „small” at nomogram) – three assemblers, one foreman, crane operator,
- for large structures (marked as „large” at nomogram) - six assemblers, one foreman, crane operator.

![Figure 1. Nomogram for labor estimation in Asset model](image)

Following correction factors are used to estimate labor consumption (Table 1):

By using using his model applied on test data an average efficiency of assembly of 79.75 kg/ man-h was obtained.
Table 1. Correction factors for labor estimation

<table>
<thead>
<tr>
<th>Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>+5% for plates 5.5 mm, 6.25mm, 7 mm</td>
</tr>
<tr>
<td>+10% for Super-span structures</td>
</tr>
<tr>
<td>+30%, when mechanical wrenches are not used</td>
</tr>
<tr>
<td>+15% for 20 bolts/m</td>
</tr>
<tr>
<td>+15% with watertight washers at bolting connections</td>
</tr>
</tbody>
</table>

b/ Model used in South Africa (so called “Armco model”) [1]

\[ T = 1.25 \times N \times L \]  

(1)

where:

-\( T \) - labor consumption [man-hours]
-\( N \) – number of plates per ring of a structure [pcs],
-\( L \) – length of a structure [m],
- 1.25 – correction factor [man-hours /m].

An assumption of average assembly conditions with use of hand wrenches and a crane. Suggested number of crew is 12 laborers and one foreman. Following correction factors are applicable:

- +10% for plates 6 mm i 7 mm,
- +15% for unsymmetrical scattered bolting connection (15 bolts/m),
- +20% for fully symmetrical two-rows bolting connection (20 bolts/m),
- +20% for pipe-arches („pa”),
- -20% when mechanical wrenches are used,
- +20% when plater are coated with bitumous paint,

Figure 2. Graphical Armco model for estimation of labor consumption
Predicting costs of assembly of buried flexible structures

By using his model applied on test data following average efficiency of assembly was obtained: 87.70 kg/man-h.

c/ Model used in New Zealand (so called “CSP model”) [1]

\[ T = L \times P \times F, \]  

(2)

where:

- \( T \) - labor consumption [man-hours],
- \( L \) – bottom length of a structure [m],
- \( P \) - number of plates per ring of a structure [pcs],
- \( F \) – correction factor:
  - \( F = 1.0 \) for round shapes,
  - \( F = 1.2 \) for pipe-arches and so called underpass,
  - \( F = 1.35 \) for arches.

By using using his model applied on test data an average efficiency of 81.94 kg/man-h was obtained. Below, in Table 2, a setting of efficiency of assembly obtained by applying mentioned 12 models and results from research is presented.

Efficiency of assembly is a fundamental parameter to specify labor consumption. Costs of assembly are a direct consequence of the latter.

Table 2. Setting of efficiency of assembly obtained from various models [1]

<table>
<thead>
<tr>
<th>L.p.</th>
<th>Model used for estimation of labor consumption</th>
<th>Efficiency of assembly [kg/ man-h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Armco</td>
<td>87.70</td>
</tr>
<tr>
<td>2</td>
<td>CSP</td>
<td>81.94</td>
</tr>
<tr>
<td>3</td>
<td>Ingal</td>
<td>110.31-142.47</td>
</tr>
<tr>
<td>4</td>
<td>RSMeans</td>
<td>32.25</td>
</tr>
<tr>
<td>5</td>
<td>AIL</td>
<td>142.04</td>
</tr>
<tr>
<td>6</td>
<td>Asset</td>
<td>79.75</td>
</tr>
<tr>
<td>7</td>
<td>GV</td>
<td>91.89</td>
</tr>
<tr>
<td>8</td>
<td>GG</td>
<td>123.00- 150.42</td>
</tr>
<tr>
<td>9</td>
<td>VC</td>
<td>115.48-134.72</td>
</tr>
<tr>
<td>10</td>
<td>Oy ViaPipe</td>
<td>94.50</td>
</tr>
<tr>
<td>11</td>
<td>HAMCO</td>
<td>133.00</td>
</tr>
<tr>
<td>12</td>
<td>Sytec</td>
<td>111.11</td>
</tr>
<tr>
<td>13</td>
<td>KNR 2-33</td>
<td>7.64</td>
</tr>
<tr>
<td>14</td>
<td>Tests</td>
<td>60.49</td>
</tr>
</tbody>
</table>

A graph showing a comparison of the results of labor consumption from various models is presented in Figure 3.
An analysis of the graph shows that except of RS Means model (which overestimates the results), other models underestimate the labor consumption.

3. APPLICATION OF MULTI-FACTOR MODEL LITCAC

LITCAC model is entirely based on results of the research. The research conducted allowed describing the sub-processes that occur during assembly in a symbolic way. The recognized sub-processes are called primary processes and consist of:

1. internal transport of plates on the job site
2. mounting of plates to shape the steel barrel
3. bolting the plates together by means of bolts
4. torque the bolts to required torque moment.

Based on research model LITCAC incorporates factors affecting assembly:

1. group A: features of a structure: weight, number of plates, number of bolts, area of steel shell,
Predicting costs of assembly of buried flexible structures

2. group B: assembly crew (number of workers, experience, motivation systems),
3. group C: used resources (electric wrenches, hand wrenches, cranes, scaffolds, etc.),
4. group D: assembly techniques (plate by plate, sub-assembly, full pre-assembly),
5. group E: external factors (weather, site conditions, other).

LITCAC involves four modules in one integrated software. Details of the model are described in [1,2,3]. Following equations (4,5,6,7) present mathematical construction of the model:

\[ L = \left( \frac{W(n_1 + n_2)}{\delta_i(n_1 + n_2 \alpha_i)} + \frac{Wn_3 \xi_i}{\delta_i(n_1 + n_4 \beta_i)} \right) \xi_i \quad \text{labor consumption [man-hours]} \quad (4) \]

\[ T = \left( \frac{W}{\delta_i(n_1 + n_2 \alpha_i)} + \frac{W \xi_3}{\delta_i(n_1 + n_4 \beta_i)} \right) \xi_i \quad \text{time of assembly [hours]} \quad (5) \]

\[ C_{direct} = WC_1 \xi_i \left( \frac{n_1 + n_2 (1 + \sigma)}{\delta_i(n_1 + n_3 \alpha_i)} + \xi_3 \frac{n_3 + n_4 \kappa}{\delta_i(n_1 + n_4 \beta_i)} \right) \quad \text{direct assembly costs [money]} \quad (6) \]

\[ C_{total} = WC_1 \xi_i \left( \frac{n_1 + n_2 (1 + \sigma)}{\delta_i(n_1 + n_3 \alpha_i)} + \xi_3 \frac{n_3 + n_4 \kappa}{\delta_i(n_1 + n_4 \beta_i)} \right) + \]

\[ + \frac{c_0}{r} \left( \frac{W}{\delta_i(n_1 + n_2 \alpha_i)} + \frac{W \xi_3}{\delta_i(n_1 + n_4 \beta_i)} \right) \xi_i \quad \text{total costs of assembly [money]} \quad (7) \]

Notations:

- \( W \) – weight of structure,
- \( c_1 \) – cost of labor,
- \( n_1 \) – number of hand keys for torque the bolts,
- \( n_2 \) – number of mechanical keys for torque the bolts,
- \( n_3 \) – number of workers in an assembly crew,
- \( n_4 \) – number of cranes or other lifting and transporting mechanical equipment,
- \( \alpha_i \) – an increase index due to mechanization of bolting and torque,
- \( \beta_i \) – an increase index mechanization of mounting steel plates,
- \( \delta_i \) – efficiency of hand torque and bolting,
- \( \delta_{r} \) – efficiency of on site transportation and mounting of plates,
- \( \kappa \) – an index of relative cost of use of heavy equipment versus use of manpower in mounting of plates (\( \kappa = k_3/c_1 \)), where \( k_3 \) – cost of using mechanized equipment for lifting and transporting steel plates,
\( \sigma \) – an index of relative cost of use of mechanical wrenches versus use of hand-tools in torque of bolts \( (\sigma = k_2/c_1) \), where \( k_2 \) – cost of using mechanized wrenches, 
\( \xi \) – corrective indices accounting for parallel processes occurrence, 
\( c_o \) – daily overhead costs for job side, [USD/shift], 
\( r \) – duration of a shift [8 hours].

An example of output generated by the model is presented on Figure 4 to 6 (structure assembled by crew of 6 laborers and a crane).

![Labor consumption of assembly](image)

Figure 4. Labor consumption graph generated by LITCAC

![Direct cost of assembly](image)

Figure 5. Direct cost of assembly generated by LITCAC
Analysis of results from LITCAC model show that it is very flexible model and sensitive to change of input data: both related to construction and economy. Based on the results of the example a substantial decrease of total costs related to assembly is observed when mechanization of works increases. With 50% decrease of labor consumption we can obtain 40% decrease of direct costs of assembly and even 700% decrease in total assembly costs. This is directly linked with daily overhead costs that occur at the jobsite and that are attributed to processes or constrains related to assembly of buried structures i.e. costs of using land, diverted traffic, etc.

4. CONCLUSIONS

Applications of various models in predicting the costs of assembly needs additional effort in relating resulted labor consumption to rate costs. Only LITCAC model which is open and interactive tool incorporates various factors and automatically generates costs of assembly together with time, labor consumption. It provides also a total costs of assembly including non-direct cost related to overheads and other costs influenced by time of assembly. Prediction of costs of assembly is necessary to plan for construction processes in a flexible way that enables consideration of various assembly scenarios.

REFERENCES


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**PROGNOZOWANIE KOSZTÓW MONTAŻU KONSTRUKCJI PODATNYCH Z BLACH FALISTYCH**

Streszczenie

Planowanie procesów budowlanych poza aspektami technicznymi i technologicznymi obejmuje również analizy ekonomiczne. W przypadku podziemnych konstrukcji z blach falistych rozpatruje się w tym aspekcie elementy takie jak całkowite koszty inwestycji, czas realizacji oraz koszty obejmujące okres użytkowania tych konstrukcji. Jednym z elementów kosztów budowy obiektów z konstrukcji lub rur z blach falistych jest koszt montażu. Z uwagi na to, że proces montażu konstrukcji z blach falistych wkracza w obszar niepewności i ryzyka popełnienia błędu przy oszacowaniu kosztów montażu co jest skutkiem wieloczynnikowego charakteru procesu montażu, w celu właściwego prognozowania kosztów montażu należy zastosować odpowiednią metodę działania [1,2,3,4]. Na przestrzeni lat stworzono wiele modeli służących do prognozowania kosztów montażu konstrukcji z blach falistych. W referacie zaprezentowano krótkie ich podsumowanie wraz z analizą porównawczą. Szczególnie ujęto podejście wieloczynnikowe modelowania kosztów montażu zaprezentowane w jednym z opisanych modeli o nazwie LITCAC.