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MEGASTRUCTURES: SHEIKH JABER AL-AHMAD AL-SUBAH CAUSEWAY PROJECT OF KUWAIT – 4TH LONGEST BRIDGE OF THE WORLD

BY

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Abstract. This paper presents a particular situation about technology optimization required for the project execution of the Sheikh Jaber Al-Ahmad Al-Subah Causeway bridge pillars in Kuwait. The initial approach to technological solution regarding the mounting process of the reinforcement cage of the pillars, was not efficient for the minimum time and maximum precision criteria. A new technological system design was proposed and adopted after several attempts, from January to March 2015 through the collaboration of the authors via Skype.

Keywords: circular steel reinforcement cage; technological system; time optimization.

1. Introduction

Sheikh Jaber Al-Ahmad Al-Sabah Causeway Project is a major infrastructure project with a very important role in the development of the Kuwait emirate. Subiyah, a new future city which will be constructed after this project will be connected to Kuwait City by this mega-structure which will

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bring a major dynamic in the development of the country (Kuwait Ministry of Public Works, 2010).

The bridge has a total length of 36.1 km, 27.5 km will be constructed on water and 8.6 km on land, thus gaining the title of the fourth longest bridge in the world. The bridge deck will be constructed of independent prefabricated post-tensioned reinforced concrete caissons. This aerodynamic and torsion resistant system has a width of 15.3 m and will provide eight traffic lanes. The bridge will have 1,186 spans and 1,215 pillars.

A truly spectacular part of this project is the asymmetric cable stayed bridge with a single tower and a span of 280 m. The project also includes two artificial islands, each having a surface of 300,000 m^2. These artificial islands will provide a monitoring platform for the bridge and boat facilities.

The beneficiary of the investment is the Ministry of Public Works of Kuwait, and the deadline for the construction is 5 years. The general structural designer is *Systra*, the general contractor is the *Hyundai Engineering & Construction* and *Combined Group Contracting Co* consort and the consultant is Dar Al-Handasah.

The project consists of 12 main parts, according to the zones where the bridge will be constructed as shown in fig.1. These parts are presented below:

1. Ghazali Transition – 0.4 km bridge constructed on land;
2. Shuwaikh Port Bridge – 1.2 km bridge on land;
3. Shuwaikh Port Interchange – entrance and exit ramps – 1.4 km bridge on land;
4. Shuwaikh Bridge – 4.1 km bridge on water;
5. Bay Island – South – 0.6 km bridge over the first artificial island;
6. Approach Bridge South – 4.4 km bridge on water;
7. Main Bridge – 0.3 km cable stayed bridge;
8. Approach Bridge North – 9 km bridge on water;
9. Bay Island – North – 0.6 km bridge over the second artificial island;
10. Subiyah Bridge – 7.9 km bridge on water;
11. Subiyah Embankment – 4 km bridge on land;
12. Subiyah Interchange – entrance and exit ramps – 2.2 km bridge on land.

1.1. Bridge Sections Built on Land

These sections present vertical and horizontal alignment modifications and also deck section modifications due to the entrance-exit ramps resulting in the following technical solution:

1° The infrastructure will be made of bored piles in metallic casings, spaced at 40 m apart, with a diameter of 2.5 m and a length of 33 m. After casting the concrete in the metallic casings will be extracted. The pillars will be cast on site on top of the piles, with the same diameter and varying lengths up to 12 m. The connection between the pile and pillar longitudinal reinforcement will be achieved with mechanical connectors.

Fig. 1 – General view of the bridge.

2º The superstructure will be made of post-tensioned reinforced concrete caissons, cast on site (Fig. 2), having the dimensions presented in Fig. 3.

Fig. 2 – Bridge deck construction.

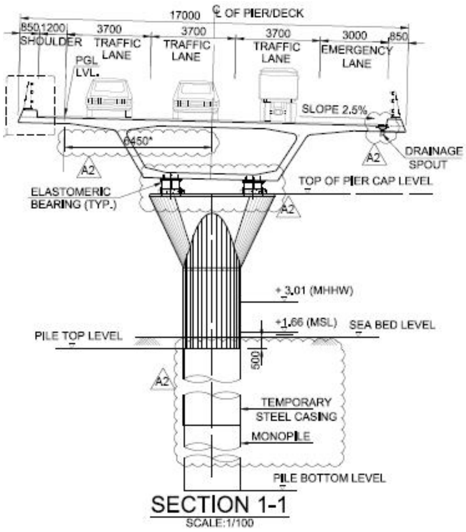


Fig. 3 – Transversal section of the bridge (RA140-10-BRG-CW-TR-00814-A5).

1.2. Bridge Sections Built on Water

These bridge sections will cross waters with variable depths, between 0.5 m and 12 m, thereby, two technical solutions were adopted:

1. The 4.1 km Shuwaikh Bridge section which connects the southern bank to the first artificial island, crossing waters 0.5 m,...,2.8 m deep, will be constructed by using a temporary metallic bridge (fig. 4) which will be removed at a later stage.

Fig. 4 – Temporary metallic bridge for the construction of the infrastructure and superstructure of the reinforced concrete bridge.

The infrastructure will be made of bored piles with metallic casings, spaced at 40 m apart, with a diameter of 2.5 m and a length of 33 m and the pillars will be made of reinforced concrete, cast on site, on top of the piles, with a 2.5 m diameter and variable length between 9 m and 10.3 m.

The superstructure will be made of prefabricated pre-stressed reinforced concrete, 40 m span sections, with the cross-section dimensions presented in Fig. 5. The sections will be lifted and placed with the cantilever crane (Fig. 6) (AASHTO, 2007).

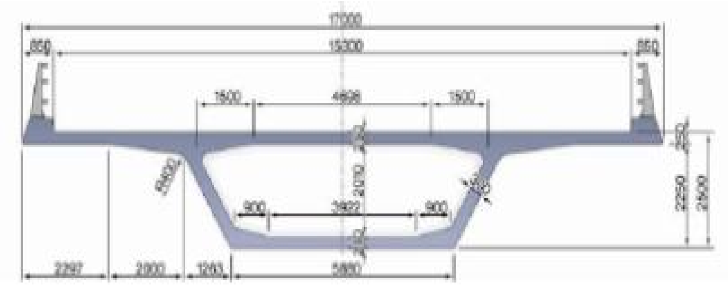


Fig. 5 – 40 m span bridge deck section.

Fig. 6 – 40 m span bridge deck section construction.

2. The rest of the bridge sections, where the water depth is between 5.2 m and 12 m, will be mounted with barges.

The infrastructure will be made of bored piles with metallic casings, spaced at 60 m apart, with a 3 m diameter and the length ranging between 51 m and 58 m. The pillars will be made of reinforced concrete, cast on site, with a diameter of 3 m and length ranging between 10.4 m and 17 m. The pillars will be constructed with the aid of circular caissons (Fig. 7), connected by welding.

Fig. 7 – Watertight circular caissons.

The superstructure will be made of prefabricated pre-stressed reinforced concrete 60 m span sections, with the cross-section presented in Fig. 8, and mounted with the floating crane (Fig. 9).

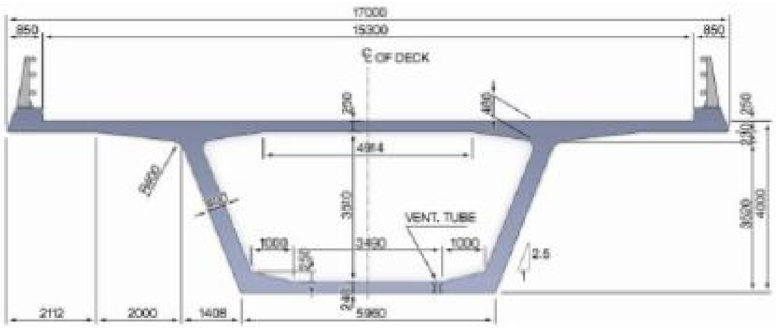


Fig. 8 – 60 m span bridge deck section.

Fig. 9 – 60 m span bridge deck section construction.

2. Construction Process and Specific Issues

The construction process duration is a very important economic aspect for all members involved in the project, especially for the contractor. In order to increase the efficiency of the project development, the engineers responsible for the construction process must always find innovative and unique technical solutions specific for every project. Starting with traditional methods which are very well known and established in practice, sometimes the search and design of new and improved methods is required. This also happened within this mega-project, involving the technological methods of creating and mounting the reinforcement cages.

Therefore, different optimization methods were designed for the construction of reinforcement cages, of formworks and prefabricated concrete elements on a large fabrication yard consisting of industrial halls and specially appointed spaces due to the large number of elements required to construct the 1,186 spans of the bridge.

The fabrication yard for the prefabricated concrete elements was established on the northern bank of the construction site, in Subyiah (Fig. 10). The production halls provided not only high quality elements and a shorter production time, but also good working conditions for the workers, especially during summer time.

Fig. 10 – Fabrication yard for the precast concrete members.

The precast members will be transported on the construction site with barges and trailers and will be mounted with road cranes, floating cranes and cantilever cranes.

The fabrication yard organization is made as follows:
a) reinforcement trimming and assembly;
b) prefabrication of superstructures members;
c) storage space for finished members;
d) formwork assembly space.

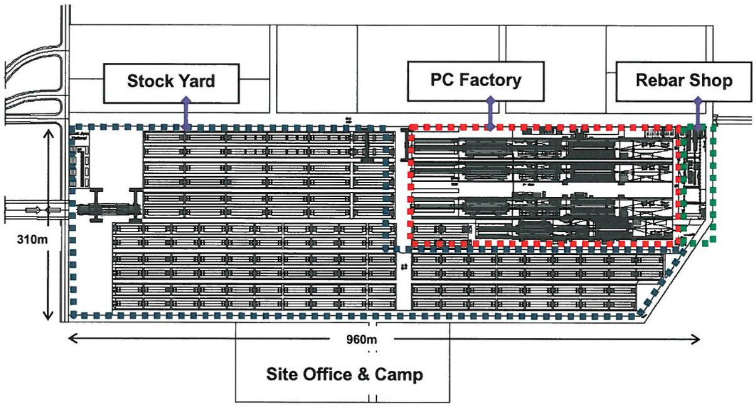


Fig. 11 – Fabrication yard organization layout (RA140-10-BRG-CW-TR-00814-A5).

Fig. 12 – Aerial view of the fabrication yard.

2.1. Construction Technology in the Initial Phase of the Project

2.1.1. *Pile Reinforcement Cages*

The pile reinforcement cages will be made for two pile diameters: 2.5 m and 3 m, with variable lengths up to 12 m. The longitudinal reinforcement is made of one or more rows of Ø 40 mm, Ø 36 mm and Ø 32 mm bars. The transversal reinforcement is made of Ø 25 mm and Ø 20 mm spirals and stiffening rings. The cages will be made with special machines which will create the cage and will automatically weld the longitudinal reinforcement to the spiral (Fig. 13). The cage sections will be joined together with mechanical connectors.

a *b*

Fig. 13 – Pile reinforcement: *a* – reinforcement cage machine ; *b* – reinforcement cage.

2.1.2. *Pillar Head Reinforcement Cages*

Pillar head reinforcement cages were made both on site after placing the formwork, a more expensive and longer duration method, and prefabricated which is a more advantageous solution. Therefore, these cages were constructed by using a template made of rectangular tubes which copies the formwork shape. During the construction of the reinforcement cage, steel tubes will be installed in the longitudinal bars position (Fig. 14). The tubes are removed after the cage is mounted.

a *b*

Fig. 14 – Pillar head reinforcement details: *a* – reinforcement cage; *b* – reinforcement cage mounting.

2.1.3. *Pillar Reinforcement Cages – the First Technological Issue*

Careful attention is given to the pillar reinforcement cage system. The pillars have diameters of 2.5 m and 3 m.

The classic system of pillar reinforcement consists of building work platforms, transporting the reinforcement cages and mounting them with the aid of cranes and the appropriate work force (Fig. 15).

a *b*

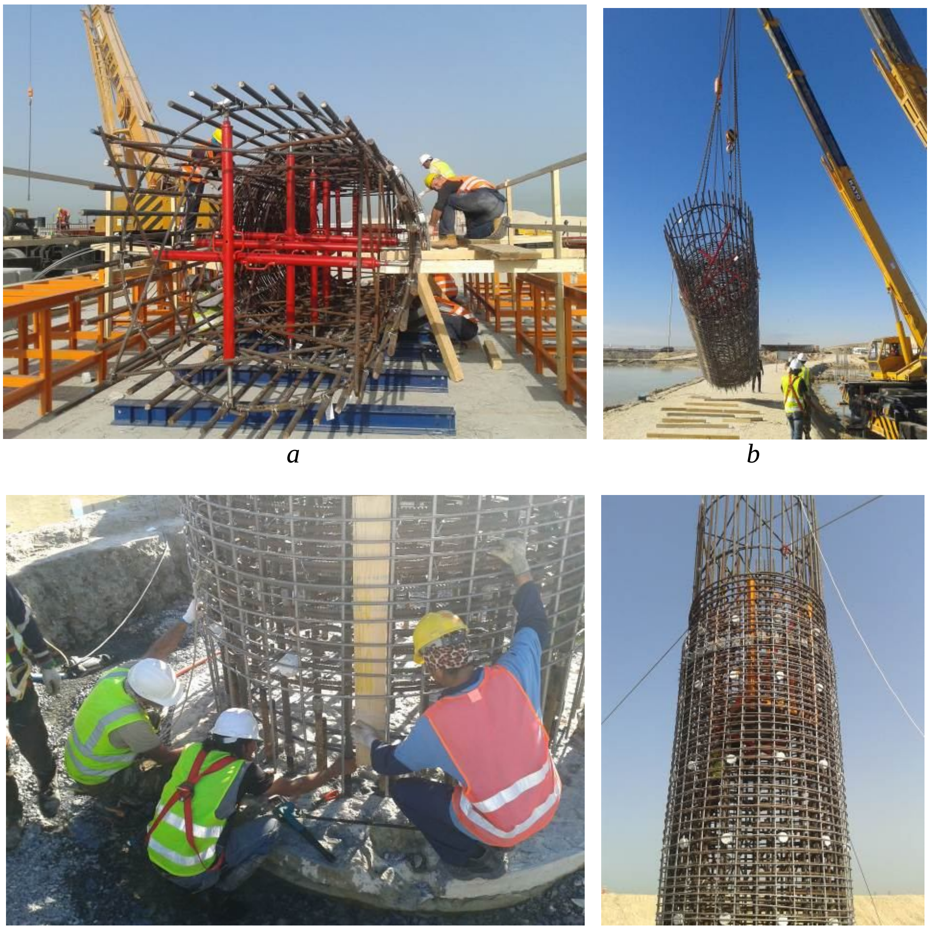
Fig. 15 – Pillar reinforcement details: *a* – work platforms; *b* – reinforcement cage mounting with cranes.

The first step in anchoring the reinforcement cage is to introduce metallic props placed on orthogonal directions at every meter along the entire length of the reinforcement cage as shown in Fig. 16 *a*.

This system proved to be functional but it presents a series of major disadvantages. During the lifting of one of the cages one of the props detached and put the workers in danger. Another disadvantage is that two cranes are necessary to lift and mount one cage and this proved to be expensive. Additionally, a very long time was necessary to detach the metallic props after the cage was mounted and the precision was poor, resulting in a deviation of the completed member of at least 50% above the allowable tolerance for this type of structural elements. This system required its redesign and optimization resulting in a new system.

2.1.4. *Pillar Reinforcement Cages Assembly and Mounting Redesign*

The innovative technological solution consists of a completely new concept of constructing the reinforcement cage. This system needed to be precise, universal – with variable length and diameter, rigid, easy to manipulate, demountable and able to be positioned in protected spaces.



a *b* *c* *d*

Fig. 16 – Pillar reinforcement cages assembly and mounting phases.

The transportation and mounting of the reinforcement cages is made by using only one crane.

The design criteria of the new system include the reinforcement particularities of the pillars, the assembly and coupling with the pile reinforcement:

i) diameters of 2.5 m and 3 m;

ii) impossibility of welding the reinforcement bars;

iii) the longitudinal reinforcement will be made of maximum two rows having Ø40 mm, Ø36 mm and Ø32 mm diameter bars;

iv) the transversal reinforcement is made of circular stirrups spaced at 15,...,25 cm;

v) the reinforcement cage will be provided at the exterior with a stainless steel reinforcement made of Ø 16 mm longitudinal bars and Ø 12 mm stirrups necessary for the protection against corrosive agents from the sea;

vi) the connection between the pile reinforcement and pillar reinforcement will be made with mechanical connectors manually installed by the workers, which implies the necessity of having an interior access space.

The advantages of these technological solutions are: short construction time, the crane is not necessary for the reinforcement cage assembly, the workforce will be significantly reduced.

2.1.5. *The Design of the Reinforcement Cage Anchoring Device*

Due to the fact that the reinforcement cage cannot be welded, the danger of its dismantling during manipulation arises.

The main design issues:

a) the device needs to be strong and stiff so that it will be able to carry weight of the cage during assembly and mounting;

b) the device needs to ensure the stability of the cage during transportation and mounting;

c) the device needs to adjust to the reinforcement cage variable length and diameter.

Starting from the above mentioned requirements, a metallic case made of adjustable rectangular tubes is proposed. On the transversal direction the elements are placed around a hexagonal central core which creates an access space for the workers. On the exterior 3 segments are provided – 120º circular arcs which can provide diameters from 2.30 m up to 3.00 m, thus having the possibility of retracting the circular elements in order to extract the device after the reinforcement cage is mounted on the spot. On the longitudinal direction the device is designed to be extended from 4.00 m up to 12.00 m lengths. This device will be subjected to its own weight and to the weight of the reinforcement cage in different hypotheses: during assembly and during manipulation (AISC, 2012), (AISC, 2006).

The design was made with a FE environment. The cross-sections which satisfy the strength and rigidity conditions under a load of 10,000 kg and having the extended length of 12.00 m are rectangular tubes. The design position of the device is horizontal with a simple support at one end and 3 cables at the other (cables attached to the crane hook). Details are presented in Fig. 18.

The connection between the rectangular tubes is made by welding. On the circumference an extensible circle is made of Ø50 mm × 5 mm circular tubes. This circle is retractable and extensible in order to provide the required pillar reinforcement diameter. On radial direction, from the hexagon's nodes, rectangular tubes are mounted in order to provide support for the extensible exterior bars. The reinforcement will be fixed via a stiffening ring made of Ø36 mm reinforcement bars.

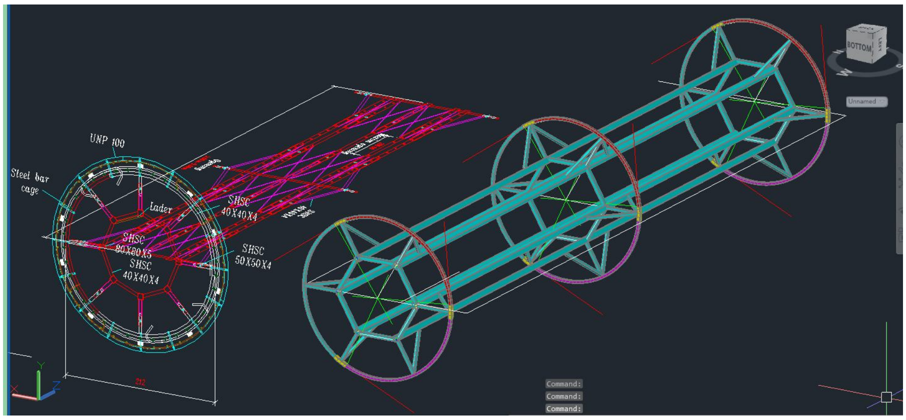


Fig. 17 – Reinforcement cage anchoring device.

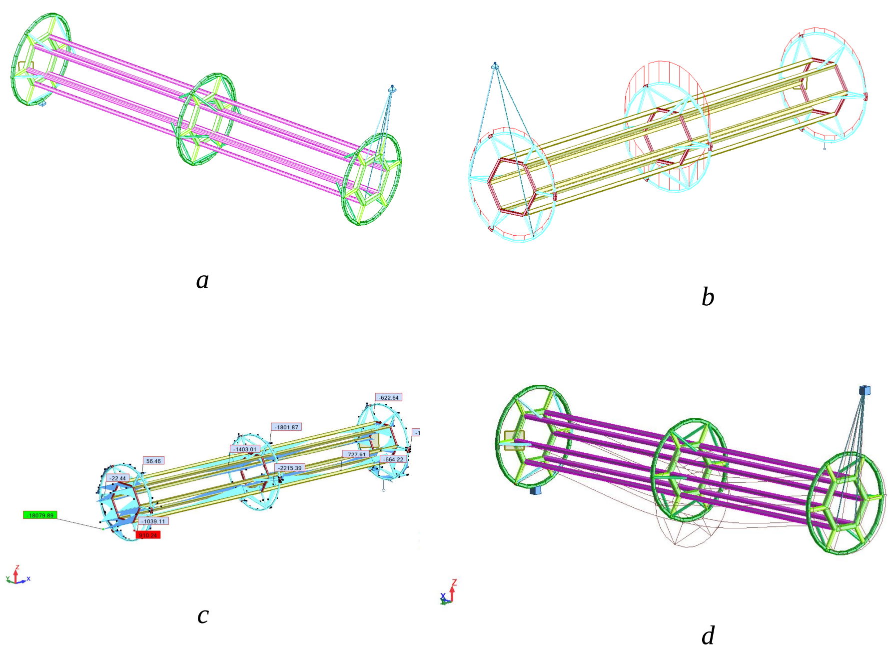


Fig. 18 – Reinforcement cage anchoring device design: *a* – geometry; *b* – load distribution; *c* – maximum principal normal stress; *d* – deflected shape.

In Figs. 19 and 20 details are presented regarding the constructed anchoring device being used during assembly and mounting of reinforcement cages. When the reinforcement cage is lifted in vertical position, the anchoring device is provided with a detachable guiding system which has the purpose of preventing the bending of the reinforcement during lifting (Fig. 19 *b* and 20).

a *b*

Fig. 19 – Reinforcement cage anchoring device: *a* – reinforcement cage assembly; *b* – detachable guiding system for anchoring device.

a *b*

Fig. 20 – Reinforcement cage mounting: *a* – reinforcement cage lifting; *b* – detachable guiding system removal.

In order to retract the transversal rings after mounting and connecting the reinforcement cage, the rings winches are manually removed and the anchoring device is extracted from the cage. Details are presented in Fig. 21.

a *b*

Fig. 21 – Reinforcement cage mounting and connecting to pile reinforcement:
a – einforcement cage connecting; *a* – removing the anchoring device.

3. Conclusions

Every construction project, either big or small, the search of innovative solutions is very important in order to increase the efficiency of the construction works, to reduce the construction time, to simplify the construction process and to increase the work quality and the precision of the structural elements.

An efficiency increase of 10% for a mega project like the one presented in this paper is very important. Specifically, for the first technological solution 3 to 4 hours were needed to assemble and dismantle the metallic props in comparison to the second solution where the time needed was reduced to 0.5 hours. In addition to this aspect which implies human resources, another improvement was the reduction of necessary cranes from 2 to 1, also with a shorter construction time. Overall, the system has increased productivity by 30% and costs have been reduced by up to 20%.

The Sheikh Jaber al-Ahmad al-Subah Causeway Project of Kuwait has as main objective the construction of a mixt bridge over land and water in the Kuwait Golf which will facilitate and shorten the link between two cities: Kuwait City and Subiyah, a city which currently doesn’t exist but will eventually be developed and which would be twice as far away traveling on land. The construction time is 5 years, from November 2013 until November 2018. Currently, in 2016 the construction is almost 50% finished, but the eventual delays could be recovered with ease due to the nature of the works and the experience gained so far in the project.

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MEGASTRUCTURI: SHEIKH JABER AL-AHMAD AL-SUBAH CAUSEWAY PROJECT DIN KUWAIT – AL 4-LEA CEL MAI LUNG POD DIN LUME

(Rezumat)

Este prezentată o situație particulară de optimizare a tehnologiei de execuție pe parcursul montării carcaselor de armătură a pilonilor podului Sheikh Jaber Al-Ahmad Al-Subah Causeway Project din Kuwait. Abordarea inițială a sistemului de realizare şi montare a carcaselor de armătură a pilonilor a condus prin spiritul inovator la identificarea şi conceperea unui sistem adițional cu rolul de a reduce timpul de execuție, resursa umană şi mecanizată, respectiv de creştere a calității şi preciziei lucrărilor. Proiectarea sistemului tehnologic s-a derulat in perioada Ianuarie – Martie 2015 prin colaborarea autorilor lucrării via Skype.