Cost Effectiveness of Precast Reinforced Concrete Roof Slabs

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Abstract. Engineers always seek to free interior space from intermediate supporting elements. Nowadays plants, being at the forefront of technology, produce a new generation of exclusive patented precast reinforced concrete elements with a high load-bearing capacity, excellent heat resistance characteristics combined with the aesthetics and beauty. It is a system of Seagull Gabbiano prestressed roof slabs for the spans of 12m - 40m. The article shows the advantages of the Seagull slabs over conventional precast reinforced concrete and metal roof trusses. It also gives the analysis of the technical and economic indices of design and construction of a building with the Seagull slabs depending on the size of spans to cover. The use of structural systems with increased spans allows for the modern buildings and structures of prefabricated reinforced concrete with enhanced functionality and aesthetics alongside with a wide range of planning solutions.

1. Introduction
When designing small industrial buildings or large-scale industrial facilities, engineers always strive to free the interior space from intermediate supporting elements [1]. This task can be solved by various structural methods. One of them is structures made of cast-in-situ reinforced concrete [2]. However, such technology significantly increases the duration of construction as the concrete should be kept in the formwork until it matures [3]. Besides, the technology of cast-in concrete involves additional expenditure for complex formwork systems and supporting structures, which leads to a significant increase in the cost of winter works [4-6]. Another way to cover large spans is to use metal structures consisting of roof trusses and secondary trusses or space frames working as a support for roof slabs. Roof slabs can be metal sandwich panels or 6 meters long common precast reinforced concrete slabs [7,8].

Prefabricated reinforced concrete slabs are perhaps the most common building material for roof structures. Reinforced concrete slabs are the most reliable and durable structural elements, and therefore are now widely used in civil and industrial construction. In addition, almost any building that can be built of cast-in-place concrete can also be made of prefab reinforced concrete structures [9,10].

The technology of prefabricated reinforced concrete appeared in Western Europe as far back as 1886. The main advantages of this technology are the high industrialization of the construction industry, the high quality of building structures and the considerable increase in the speed of construction works, as the main processes take place within factory premises with subsequent assembly at the construction site [11-14]. A significant limitation of this technology was the common dimensions of structures, depending on the size of the technological molds used to manufacture the elements [15].
However, being at the forefront of technology plants produce a new generation of exclusive patented prefabricated reinforced concrete elements with a wide range of sizes and subject to adjustment in just several hours. These elements possess a high load-bearing capacity, excellent heat resistance characteristics, aesthetics and beauty. All components of such system have a unified design and perfect compatibility with each other.

2. Seagull Gabbiano System

The structural profile Seagull Gabbiano has the characteristics inherent in a unique product. The system consists of a single design structural elements and is developed for roofs with a span size from 12 to 40 meters. All system elements are prefabricated and made of precast reinforced concrete. These elements are columns, beams with parallel chords and Seagull roof slabs. The roof slabs can be laid directly one to one with built-in seams in between or at certain spans necessary for installation of lighting systems (Figure 1). In the latter case, the number of slabs is reduced, which results in the cost reduction of structure fabrication.

![Figure 1. Seagull Gabbiano roof system, 1 – column, 2 – beam with parallel chords, 3 – Seagull roof slabs, 4 – wall panel.](image)

![Figure 2. Structural profile Seagull Gabbiano.](image)

The main structural element of the entire system is Seagull roof slab. It is a solid isolated waterproof painted T-slab made of pre-stressed reinforced concrete (Figure 2). The length of the slabs ranges from 12 to 40 meters. It should be specifically mentioned that it takes only a few hours to alter the length of the slab mold which allows the manufacturer to be sensitive to the changing requirements of the market, making tailor-made designs for each new customer. The width of the slabs is up to 2500 mm. The height of the slabs depends on the span and can vary from 1000 to 1500 mm.

It should be noted that prestressed concrete is a further development of reinforced concrete. Due to its significantly low tensile strength reinforced concrete fails to employ the properties of concrete and steel to their fullest unlike prestressed concrete [16]. Therefore, prestressed reinforced concrete has always been more preferable for large span structures [17,18]. The efficiency of prestressed concrete structures is based on their higher load-carrying capacity, economy of raw materials, increased cracking resistance resulting in better protection against corrosion and reduced sagging of structural elements during transportation and operation.

Seagull roof slab has two slopes and collects water in the center of the slab for external drainage. The slope is designed to accelerate the drain of rainwater directing it precisely along the slope lines of the roof. Thus, the roof remains washed, snow does not accumulate, which ultimately eliminates the costly seasonal repair.

The main surface of the slab can be either a single-layer or a three-layer. In case of a three-layer version, a layer of insulation is put between two layers of concrete during the manufacture of the slab. The top surface of the slab is made as waterproof as possible which makes roofing unnecessary and saves the cost.

The use of structural systems with increased spans allows for modern buildings and facilities of prefabricated reinforced concrete with enhanced functionality and aesthetics alongside with a wide range of planning solutions (Figure 3). The advantage of the above structural system is not only the flexibility in planning and redevelopment, but also extended life cycle of the building due to its...
increased adaptability. Thus, the building retains its commercial value for a much longer period of time [19].

Seagull system has a wide range of application. Its relatively small weight and increased length of the span make it practical for construction of production and storage facilities, malls, covered car parks, sports facilities, etc.

For example, a large-span version of covered parking lots allows for more cars due to the increase in the span length and the reduction of the column cross-sections [20].

In recent years, great importance has been given to large open spaces in the office buildings, where the desired layout of premises is achieved with the help of light-weight partitions.

In addition, it should be emphasized that the system under consideration can be classified as high-tech, i.e. meeting all the modern requirements for the function of objects, their structural implementation, the composition of materials and components used, and has significant differences from the characteristics of the previously produced similar systems.

The use of such system will significantly improve the technical, economic, competitive, consumer and other characteristics of the constructed facilities.

The economic effect of the implementation of this system is expected to result in the efficiency of cash management, high profitability of construction, as well as saving construction time and resources.

3. Advantages of large-span roof slabs

Currently, Seagull Gabbiano roof slabs are produced by the Open Joint Stock Company "Chelyabinsk reinforced concrete plant No. 1" (ZhBI-1), located in the city of Chelyabinsk. This dynamically developing enterprise is reconstructing its production workshops. One of the reconstruction stages is the construction of a multi-storey production building of the Autocomplex. The roof of this building is made of precast reinforced concrete slabs Seagull Gabbiano with a span of 21800 mm. (Figure 4).

![Figure 3. Interior view of Seagull Gabbiano premises.](image1)

![Figure 4. Computer model of the Autocomplex building.](image2)

Two standard types of roof structures commonly used in the construction of workshops, hangars, warehouses and other industrial facilities throughout the territory of the Russian Federation were taken for comparison [21].

The first type is standard prefab reinforced concrete double slope roof beams (DSRB) of 21.2.1-6K7 series with 22 meters span and ribbed reinforced concrete roof slabs of 1.865.1-15.1 series, 1.5m in width, 6 meters in length laid on roof beams (Figure 5). Secondary roof beams were used in accordance with GOST 20372-2015 in order to decrease the number of columns compared to the initial project of the building structural frame, since in the standard roof structure the span between columns comprises 6 meters and the number of columns is doubled.

The second type of the roof structure is standard metal roof trusses and secondary roof trusses of 1.460.3-14 "Steel roof structures of industrial buildings" series with spans of 18, 24 and 30 m, made of Molodechno closed rectangular hollow welded profiles (Figure 6) and ribbed reinforced concrete roof slabs of 1.865.1-15.1 series, 1.5m in width and 6 meters in length.
The calculations were made according to FER (Federal Unit Rates of the Russian Federation) and ENIR (Unified Norms and Prices of the Russian Federation) in the form of standard tables of cost estimates and labor input calculation for the production of the entire set of works for each type of roof structures. The installation of all structures, including lighting system, pre-assembly of metal trusses, and assembly of all structures by joint welding and grouting, as well as the installation of multilayer roll Bikrost roofing with a layer of insulant over a cement-sand screed were also included in the calculations. The total cost took account of the cost of the structures and raw materials themselves, and the cost of the structures assembly and roofing installation. The results of the calculations are presented in Table 1.

Table 1. Comparison of the roof structure options for the Autocomplex building.

| No | Type of element       | Labor intensity, (man-shift) | Assembly time, (days) | Cost of load-bearing structures, (RUR000’s) | Assembly and roofing cost, (RUR000’s) | Total cost (RUR000’s) |
|----|-----------------------|-------------------------------|-----------------------|--------------------------------------------|--------------------------------------|-----------------------|
| 1  | Reinforced concrete truss | 131.34                       | 26.3                  | 4888.5                                     | 3063.1                               | 7951.6                |
| 2  | Molodechno metal truss  | 129.34                       | 25.9                  | 5041.5                                     | 2773.8                               | 7815.4                |
| 3  | Seagull roof slab      | 48.23                        | 9.7                   | 7181.8                                     | 75.9                                 | 7257.7                |

As it is seen from the table, the cost of roof structure assembly and roofing installation is significantly reduced (by 40 times) when using Seagull roof slabs. It has been already noted above that there are practically no works on roofing, since the top surface of the prefab slab does not call for additional roofing layers. Though the prefabrication technology increases the total cost of the structure, the maximum difference in the overall cost of the roof structures given in the above table is as low as 8.7%. However, when employing Seagull roof slabs the labor and time of assembly were reduced by 63.3%, which makes this type of roof structure more preferable to use.

The calculations of the economic efficiency for the application of Seagull large-span roof slabs were carried out based on SN 509-78 [22] and Recommendations on the calculation of economic efficiency of technical solutions in the field of organization, technology and mechanization of work [23] using the following formula:

\[ E = E1 + E2 + E3 \]  

where \( E1 \) - the effect of reducing the cost of construction and assembly work; \( E2 \) - the effect of reduction of the construction time; \( E3 \) - the effect of early commissioning of the facility.

The calculations show that the overall economic effect was:

\[ E = 693931 + 239996 + 160220 = 1094147 \text{ RUR} \]

Thus, the economic effect of applying Seagull large-span roof slabs amounted to more than 1.09 million rubles (in 2017 prices) or 4.83% of the estimated cost of the small industrial building Autocomplex with an area of 1460 square meters.
4. Technical and economic comparison of different roof spans

The task of the following research was to determine whether the span of the building and the slabs affected the technical and economic parameters of the project and construction works. Since Seagull slabs, produced at the ZhBI-1 plant in Chelyabinsk, are available in the length range from 12 m to 30 m, three projects of an industrial building with different spans were designed. The subsequent calculations were made for the minimum span is 12 m, the maximum is 30 m and the average is 22 m, as is shown on the example of the "AutoComplex" building described above.

The same variants of roof structures for spans of 12, 22 and 30 meters were designed for prefabricated reinforced concrete trusses and Molodechno metal trusses. The results of calculations are presented in Table 2.

| No  | Type of element          | Labor intensity, (man-shift) | Assembly time, (days) | Cost of load-bearing structures, (RUR000’s) | Assembly and roofing cost, (RUR000’s) | Total cost (RUR000’s) |
|-----|--------------------------|------------------------------|-----------------------|---------------------------------------------|--------------------------------------|-----------------------|
| 1   | Seagull roof slab 12 m   | 44,14                        | 8,8                   | 4753432                                    | 63047                                | 4816479               |
| 2   | Seagull roof slab 22 m   | 48,23                        | 9,7                   | 7181800                                    | 75924                                | 7257724               |
| 3   | Seagull roof slab 30 m   | 50,21                        | 10,0                  | 7323928                                    | 85249                                | 7409177               |
| 4   | Reinforced concrete truss 12 m | 88,63                    | 17,7                  | 2999210                                    | 1892576                              | 4891786               |
| 5   | Reinforced concrete truss 22 m | 131,34                   | 26,3                  | 4888514                                    | 3063141                              | 7951655               |
| 6   | Reinforced concrete truss 30 m | 185,4                     | 37,1                  | 5933210                                    | 3905586                              | 9838796               |
| 7   | Molodechno metal truss 12 m | 77,49                      | 15,5                  | 3101280                                    | 1573868                              | 4675148               |
| 8   | Molodechno metal truss 22 m | 129,34                     | 25,9                  | 5041560                                    | 2773886                              | 7815446               |
| 9   | Molodechno metal truss 30 m | 186,65                     | 37,3                  | 6635280                                    | 3628857                              | 10264137              |

The results show that the application of Seagull Gabbiano has a number of economic and practical advantages over other roof structures. The main effect from the application of the Seagull roof structure is in the reduction of the labor and time required for the assembly of the roof structure and installation of roofing (Figure 7).

As it follows from the diagram, with the increase in the span of the building the difference in the labor intensity required for the construction of Seagull roof structure type in comparison with other types of roof structures also grows. Thus, with a span of 12 meters, the reduction in labor intensity is 50.0%, with a span of 22 meters it goes down by 63.3%, and with a span of 30 meters it is already 73.1%. It turns out that the increase in the span of a building by 1 meter leads to a reduction in labor intensity by 1.3%. Such effect can be explained by the increase in the number of slabs for bigger spans when using standard reinforced concrete and metal trusses. For Seagull type of structure the number of structural elements does not change. Of course, the proportion of the roof structure assembly in the total duration of the building construction is not very high and we should not expect a significant reduction in the construction time on the whole. However, with large areas of coverage, the economic effect can be very noticeable [24].

The total cost of all roof structure types is given in the form of a graph (Figure 8). As it can be seen from the graph, Seagull roof slabs cost slightly higher (by 0.03%) compared to common truss structures, but the slabs cost tends to reduce with the increase of the span. Thus, the reduction comprises 8.7% at a 22 meter span and totals for 27.8% at a 30 meter span.
5. Conclusion

Based on the above researches, we can confidently conclude that modern Seagull Gabbiano roof slab structures have a number of advantages in comparison with traditional types of roof structures. This is undoubtedly the increased length of the span at a relatively low weight of elements, the increased load-bearing capacity combined with raw material savings, excellent heat and frost resistance characteristics, increased crack resistance and, as a result, better corrosion protection of the reinforcement, functionality and aesthetics. All elements of this system have a uniform design and perfect compatibility with each other. In case of turnkey construction, such systems can provide not only the reliability and high functionality, but also the elegance of structural solutions. These advantages will undoubtedly bring recognition of potential clients at the market of construction services.

Among the technical and economic advantages of Seagull slabs it should be noted that the labor intensity and the assembly time of the structure are reduced by 50 ... 73.1% due to the constant number of structural elements and this percentage of reduction increases with the increase in the span of the buildings. And accordingly, the total cost of the roof structure also decreases significantly, starting from 22 meter spans and over. So, at a span of 30 meters the reduction in the total cost of the Seagull roof structure is 27.8%. We should expect a significantly greater effect from the use of such slabs on large areas of construction or when designing large spans, for example with a span of 40 meters.

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