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Unified All-Metal Structures Built According to Flexible Methods

Structures métalliques standardisées construites selon une méthode industrielle souple

Standardisierte Stahlbrückentragwerke in flexibler Fertigung

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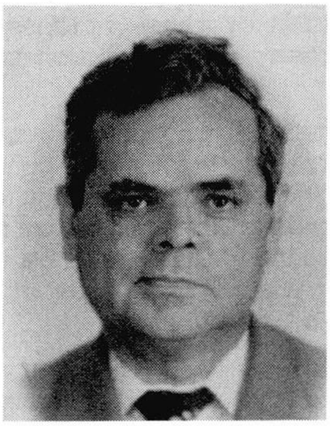


Igor Tsarikovsky, born 1931, received engineering degree at the Institute of Railway Engineering in Tbilisi. For 21 years he was involved in bridge construction. For the past 14 years, he has been responsible for technical guidelines governing the construction and manufacture of bridge structures in the Soviet Union.

SUMMARY

The purpose of this paper is to describe the development in the USSR of flexible industrial methods in fabrication of steel bridge components. These methods have been developed and implemented in production plants for the fabrication of technologically unified elements and modular blocks of steel bridge superstructures. Technologically unified methods of bridge construction are described along with the necessary equipment.

RESUME

L'article décrit le développement de la méthode industrielle souple, utilisée à grande échelle en URSS pour la fabrication d'éléments de ponts métalliques. Cette méthode a été mise au point et appliquée dans les usines destinées à la fabrication d'éléments standardisés et de blocs modulaires pour les superstructures des ponts métalliques. Cet article décrit en détail la méthode de standardisation technique applicable à la construction de ponts, en y incluant les équipements indispensables.

ZUSAMMENFASSUNG

Der Aufsatz beschreibt die sowjetische Entwicklung flexibler Fertigungsmethoden bei der Herstellung von Stahlbrückenkomponenten. Die Entwicklung und Umsetzung dieser Methoden erfolgte in Werkstätten zur Fertigung technologisch standardisierter Elemente und modularer Baugruppen für Stahlbrückenüberbauten. Die zu den Baumethoden erforderliche Ausrüstung wird beschrieben.

The topic of this presentation can be regarded as one of the most progressive in modern bridge construction. Steel superstructures of different systems prevail in the construction practice of large bridges. Moreover, a number of them are considered to be one-of-a-kind, according to their technical parameters. At present, the use of suspension and cable stayed bridges has become particularly widespread.

The most remarkable structures have been built in the USA, Japan, France, Germany, Argentina, India, Yugoslavia, Italy, Portugal, Czechoslovakia, Turkey and other countries. A number of large bridges have been constructed in the Soviet Union in different climatic zones: from the Far North to the sub tropics. The construction of these bridges has made a certain contribution to the development of bridge construction.

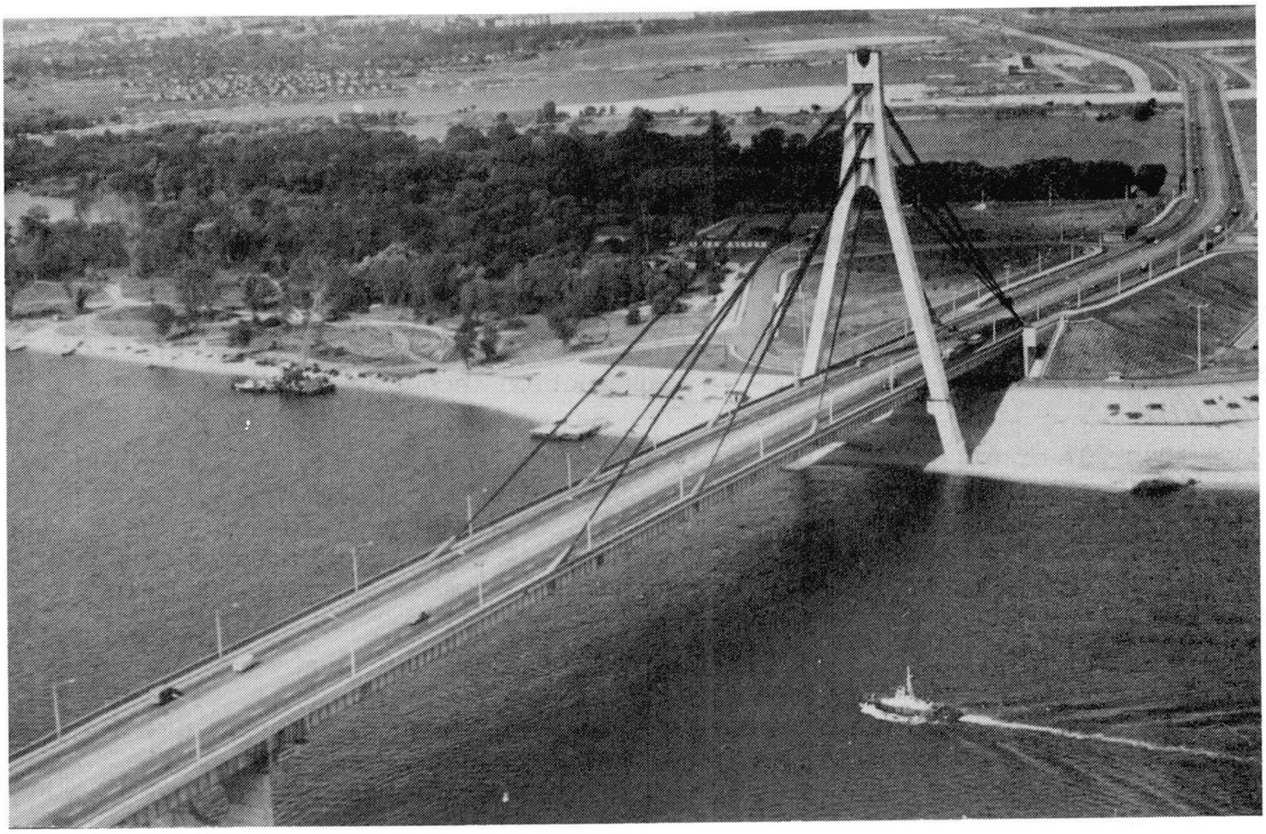
The expenditure method of determining construction costs is used as a basis for calculation of the efficiency of bridge construction projects as well as other kinds of construction. In this regard the expenditures related to the design process and the methods of construction must be considered as an inseparable part of these costs. It should be emphasized that the technology of manufacturing and construction of bridges determines a considerable part of the cost of a structure.

In addition, reasons of prestige often play a considerable role when final selection of a bridge alternative, especially a unique one, is made. In addition, it should be pointed out the architectural qualities of the system as related to local conditions, navigational requirements and the choice of the main material also comes into play

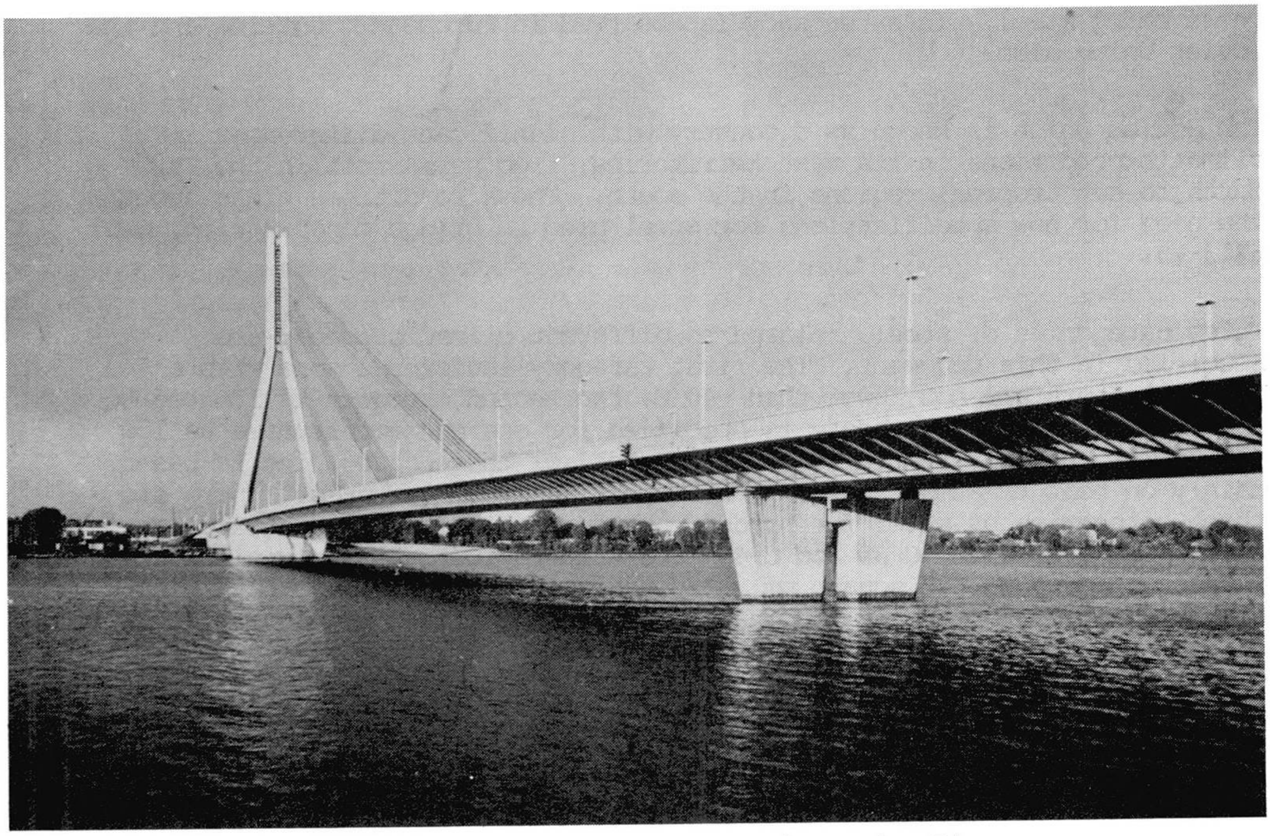
Under these conditions, the aspiration to award the tender creates the necessity to search for new designs and technological methods as well as improve existing ones. It is obvious that the required technical base should be developed with high efficiency and only companies with high scientific and technological standing are able to compete in a tough tendering process.

A thorough statistical analysis of data related to bridge construction and maintenance helps direct technology towards perfection in the methods of construction. For example, research conducted in France in 1975-76 showed that up to one thousand bridges and culverts are put into operation every year. Most of them (92%) are small bridge structures and overpasses. At the same time the remaining 8%, representing large and unique bridges comprises 47% of the investment on all structures and 41% of the roadway area put into operation.

A similar analysis in the Soviet Union has been carried out, starting in 1970, both for the railway and highway bridges. During the 1970 to 1990 period the increase in the volume of construction, in linear meters, amounted to 167.5%. The share of large structures was 10 - 15% during these years. About 80,000 linear meters of bridges with a total area of 342,000 square meters have been put into operation in 1990. This includes 29,600 linear meters of railway bridges, with a total roadway area of 16,000 square meters, and 49,000 linear meters of highway bridges, with a total area of



Photograph 1: Moskovsky Bridge across the Dniepr river in Kiev, with the main span of 310 m



Photograph 2: Bridge across the Daugava river in Riga, with the main span of 312 m

326,000 square meters. The share of the large bridges was 15% by units, 50.6% by area and 60% by cost. This can be explained by the fact that construction of structures, especially of large bridges, involves significant costs not only at the design stage, but also during the construction and manufacturing of components. This cost often comprises up to 50% of the total cost of large structures. Therefore, the search for new ways to reduce these costs goes alongside improvements in the construction and manufacturing process which in turn affects the design process.

Rapid growth in the construction industry, including transportation of structures, has resulted in extensive development of construction machinery, based on significant achievements in construction technology.

More than 70% of all bridges presently in operation in the Soviet Union have been built since the Second World War. Two-thirds of all bridges in Germany, for example, have been built during the last three decades. The following facts are of interest: about 60% of all Japanese bridges are made of steel; steel bridges dominate in the USA and a number of other countries; at the same time, the wide spread use of concrete bridges (up to 80% of the total number) is typical for European countries.

These facts, as well as our experience, show that the choice of material for bridge construction is as a rule, determined by the general level of the manufacturing industry, the availability of required technology and most important, by climatic conditions.

As a result of the necessity to cross large bodies of water, suspended and cable-stayed bridges prevail in the USA and Japan, the main material for these being steel. This tendency is observed in European countries and the Soviet Union also.

The Soviet Union is known as a country with significant differences in climatic conditions in its vast territories: from permafrost in the Far North to sub tropical regions in the south. These conditions bring about the need for new specifications for steel used in bridge construction, GOST 6713-75.

Three categories of steel, related to different climatic zones, are specified in this document. The first category is for the zone with a design temperature not lower than $-40^{o}C$; the second category is limited to $-50^{o}C$, and the third category is specified for design temperatures as low as $-70^{o}C$. The differentiation between steel of these categories is based mainly on heat treatment methods and impact test temperatures. There are three categories of steel for bridge construction, classified according to their strength: C-23, C-35 and C-40 (the numbers indicate the minimum yield stress in kg-force per square mm). In addition, a special two-ply steel, with a stainless upper ply, is manufactured for bridge construction.

Extensive scientific, technical and organizational work, based on statistical information was carried out by bridge engineers in the Soviet Union, and concluded by development at the end of the 1980's of a long term technological forecast.

As a result, general directions towards a comprehensive solution of bridge construction problems, including the use of steel for mass construction have been established. These include:
- Development of flexible technology for the design and construction of large highway and urban bridges with superstructures made of technologically unified elements and blocks.
- Development of the manufacturing industry producing structural steel for bridge construction and introduction of production lines for mass manufacturing of technologically unified elements and blocks of superstructures.
- Establishment in the industry for the manufacture of specialized technological equipment and machinery required in the production and erection of unified elements and blocks of superstructures.
- Development of new atmospheric-resistant types of steel, which permit to eliminate painting from manufacturing, erection and maintenance processes
- Development of new technological methods of manufacturing and erection of bridge structures: high productivity welding with metal alloys; in-plant preparation of contact surfaces for friction joints assembled with high strength bolts; mechanized tightening of high strength bolts up to the specified design force, using hydraulic wrenches, etc.
- Introduction of a program of bringing the Soviet bridge construction industry up to the level of the best world achievements.

In order to carry out these programs which were largely relying on the existing design bureaus, the Institute for the Development of Technological Designs (GIPROSTROIMOST) was established. A number of specialized bridge design institutes also took part in this undertaking.

The mutual work of the above organizations, combined with an active participation of construction companies, brought about the achievements in the area of new designs and technologies. This work was carried out in several directions, with the purpose of unification of superstructure elements, by their dimensions, and by the manufacturing and construction technology.

RAILWAY BRIDGES

Standardization has been achieved 100% in the area of railway bridge design and construction for a wide range of spans from 18.2 m to 154 m. This means practically all railway bridges have been standardized.

The peculiar uniformity of initial design data of railway bridges made the task of technological unification of superstructure elements easier. Both plate girders and truss superstructures were used for unification of railway bridges.

Plate girders, irrespective whether they are all steel or composite steel concrete type, through girder or deck girder systems, are manufactured in the same standard lengths: 18.8 m, 23.6 m, 27.6 m, 34.2 m 45.8 m and 55.8 m.

Superstructures both for a deck truss type (the most widely used) and the through truss type are manufactured with standard design lengths of 33.0 m, 44.0 m, 55.0 m, 77.0 m, 88.0 m, 110.0 m, 132.0 m and 154.0 m.

The difference in the principles of unification is caused by the fact that plate girders can be manufactured in any length on the same production line, but the truss superstructures can only be made on the same line when both the truss height and the panel length are matched. In order to develop a unified system and decrease the number of different production lines producing railway trusses, the following dimensions were adopted; truss heights of 8.5 m, 11.25 m, 15.0 m and 24.0 m and panel lengths of 5.5 m, 8.25 m and 11.0 m. As a result, only three modifications of production lines were necessary to set up in order to produce all sizes of truss superstructures.

Superstructures are manufactured both for new construction and replacement structures. Adaptations to the lengths of old superstructures are made by introduction of non-standard panels: either lengthened or shortened in relation to standard length panels.

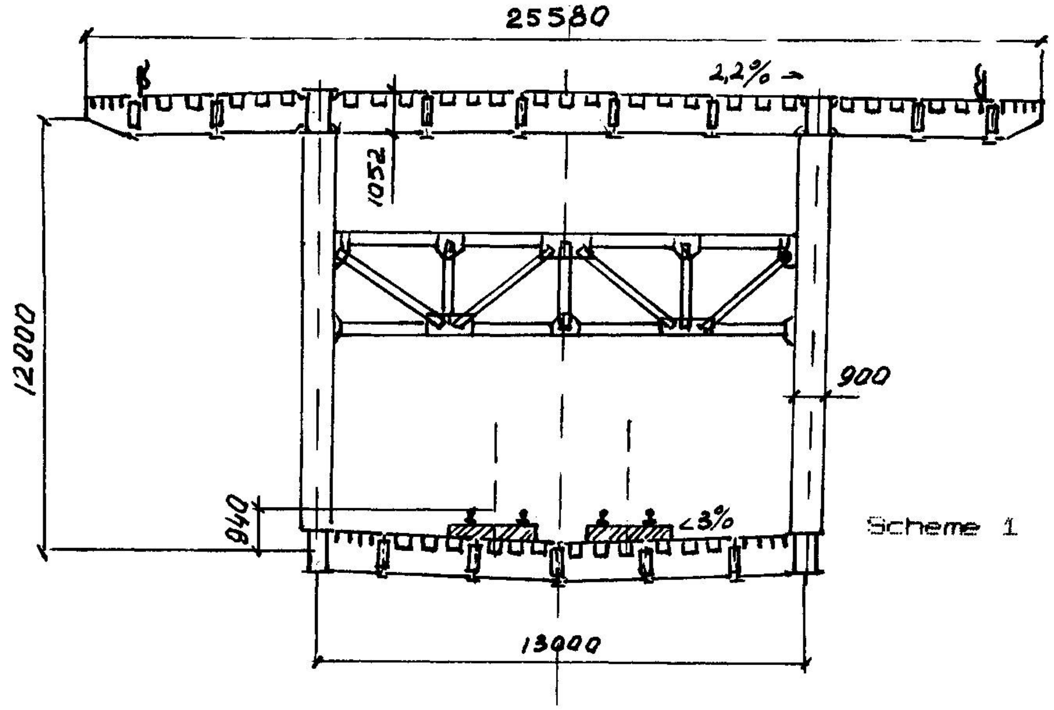
Unification and standardization of blocks, elements and details opened a wide opportunity for unification of the manufacturing technology, e.g. technological processes, highly mechanized technological lines in the plants, equipment and tools.

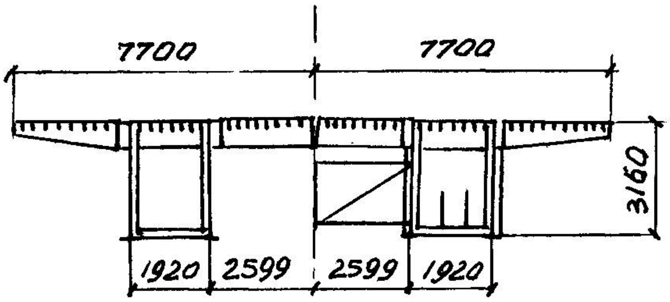
Unification of erection technology took place at the same time. Thus erection of plate girders included the following:
-For spans up to 34 m, the erection of these fully assembled prefabricated superstructures is carried out by cantilever cranes and occasionally by railway cranes; e.g. steel box superstructures with a bimetallic ballast deck are erected in this way. For spans of 45 - 55 m, the erection is carried out using large blocks, with cantilever cranes, and if necessary, temporary piers.

The main type of erection joints, both for plate girders and, in particular, for trusses, are the friction-type high strength bolted joints, assembled with preceding sandblasting of faying surfaces. As a result of a research program, glued slip resistant high strength bolted joints were developed. This means that sand blasting of the joint on site is not necessary thus decreasing labour input and accelerating erection. At present, newly developed hydraulic wrenches have been widely used for this application, which has significantly reduced physical demands, increased labour productivity three-fold and has kept the fluctuation of torque within 4% of design values.

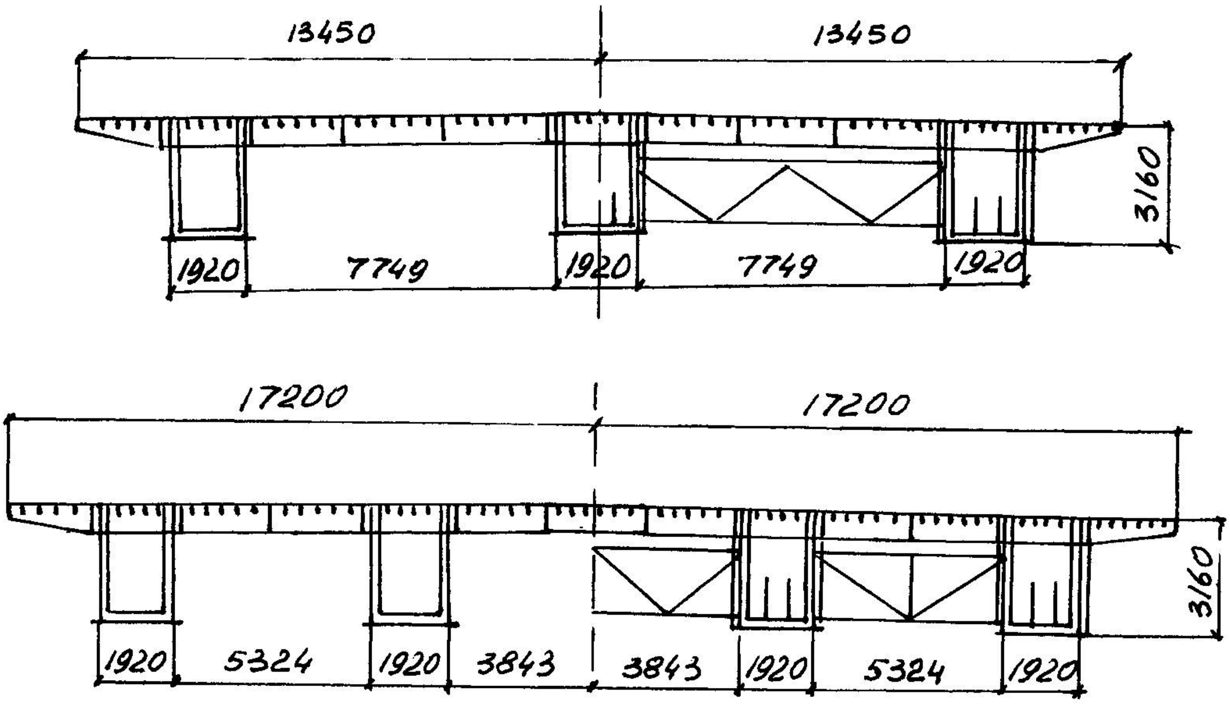
The developed and consequently implemented system of technological measures has allowed to reduce requirements of material and labour to accelerate the construction process. One span of a 110 m length is thus assembled in 10-12 days with two work shifts, and is put into operation 20 days after the beginning of erection.

Air-tight box elements of superstructures have shown to be of great importance in meeting modern requirements, particularly for new truss superstructures. Their advantage lies in elimination of painting of internal surfaces of the box elements for the whole life span of the structure.





Scheme 1



Scheme 2

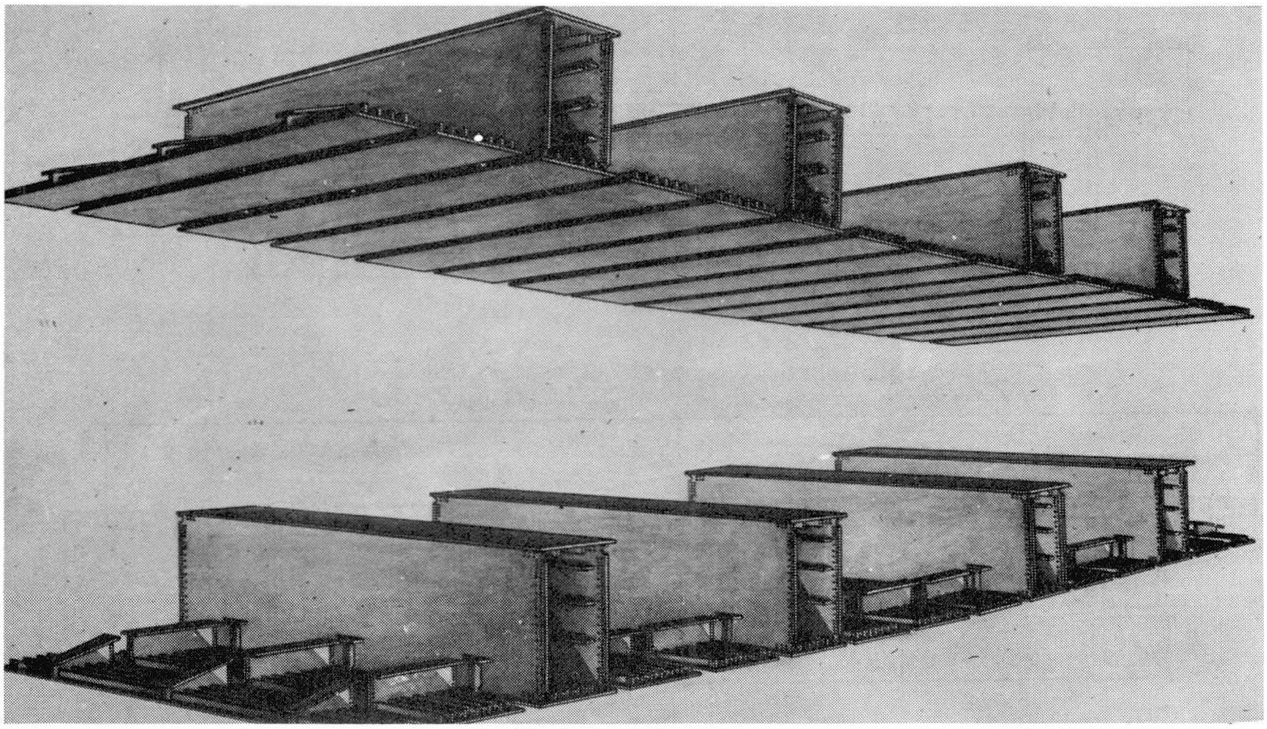
Lately, a continuous truss superstructure, 2 x 220 m, with an orthotropic deck and two levels of traffic has been developed. The bottom level accommodates a double railway track and the upper level, a four lane highway (see Scheme 1).

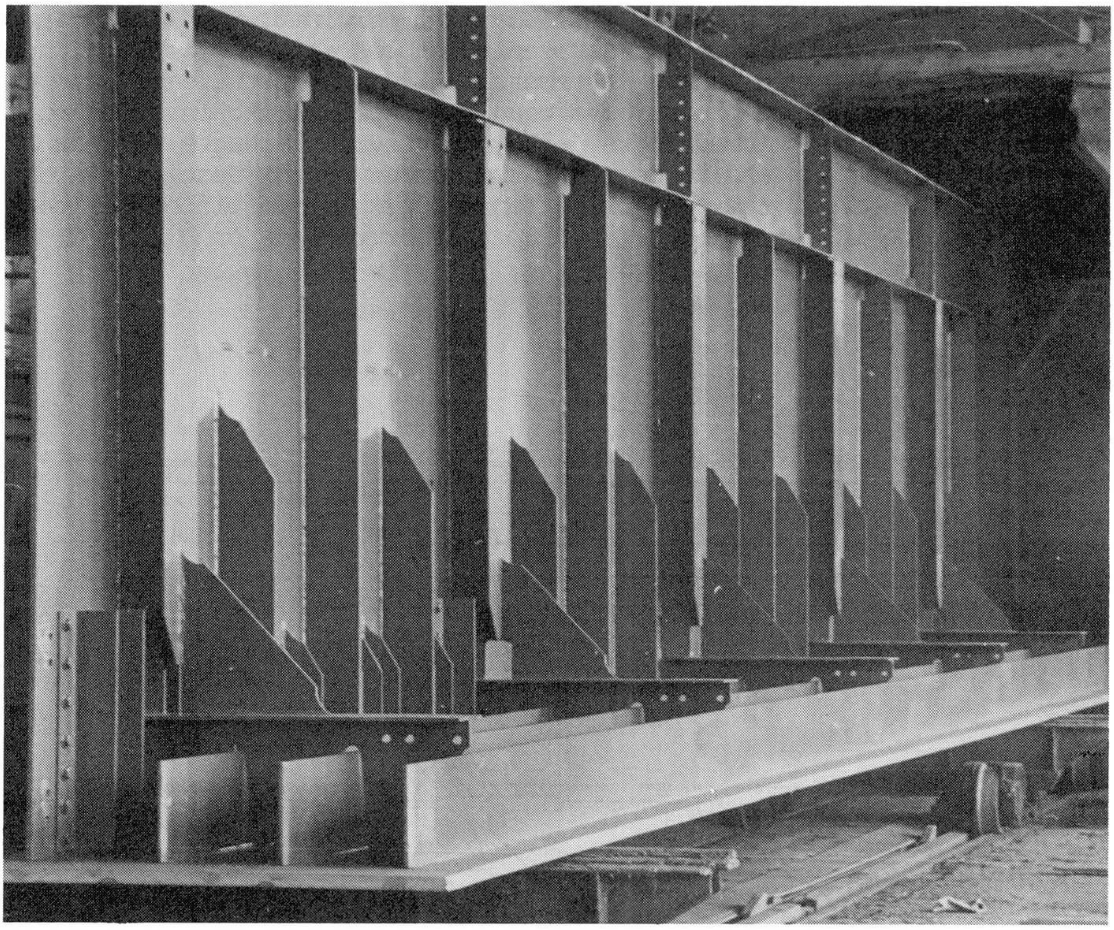
This superstructure, like the others is assembled from unified truss elements and unified blocks of orthotropic decks. The efficient truss design has allowed for reduction of the steel requirement to 17 tons per linear meter of structure. A similar truss design is planned as a stiffening girder in a cable-stayed bridge with 2 x 407 m spans to be built across the Volga River. Assembly of the continuous superstructure is planned to be carried out using preassembled blocks delivered to the site by tug boats. Erection will be done using the cantilever method.

In order to satisfy the particular requirements of highway bridges, a number of designs were load tested on the test railway ring near Moscow, where heavy trains are used to simulate traffic intensity to a higher degree than that on operating lines. Axial loads are also substantially increased. At present, a number of test programs have been concluded, including butt welds of girders with full penetration of web, box superstructures with ballasted track bed, high strength bearings, etc.

URBAN AND HIGHWAY BRIDGES

The so-called flexible (universal) technology of construction, based on the unification of elements and modular blocks of superstructures has been developed in our country for the first time in world practice for mass construction of urban and highway bridges. It can be attributed, first of all, to the development of fully prefabricated modular box blocks and the unified blocks of orthotropic decks, from which the all-steel superstructure is assembled.





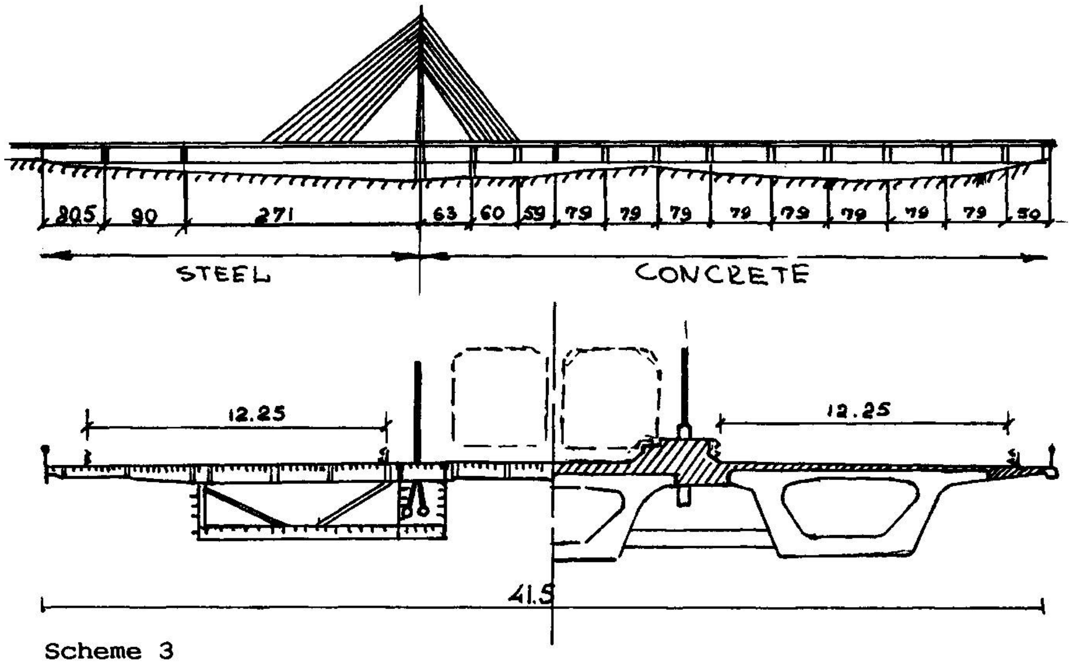
A research based system of structural design, directed towards the development of a universal and, at the same time, technologically efficient superstructure, composed of a minimal number of unified elements and blocks, has allowed to achieve high levels of productivity during the manufacturing and erection processes. Such an approach stimulated the search for fundamentally new solutions of technical problems.

As a result technologically new methods of manufacture and erection of superstructures are now available. In particular, an automatic machine for inverted welding, a production bed for the assembly of I-beams, fillet welding with full penetration as well as other kinds of technological equipment are being tested at present. These new methods along with related equipment have found wide application in the construction of unique and also, combined bridges.

For example, the following bridges have been built using the newly developed structural and technological design methods: Daugava River Bridge in Riga, North Bridge across the Dnieper River in Kiev, bridge across Northern Dvina in the City of Archangelsk and others.

A highly effective solution has been found by using both steel and concrete modular blocks in the cable-stayed superstructure of the South Bridge on Dnieper River in Kiev: a concrete girder, made of modular blocks originally designed for continuous girder bridges, serves in this case as a counter-weight in a cable-stayed superstructure.

These solutions are used for spans of 42 to 147 m (divisible by 21 m) for any clearance. The introduction of suspending cables and special structures allows to increase the span length in excess of 147 m. At the same time the structures made of L-shaped blocks have been developed which, in combination with the orthotropic and ribbed decks, allow to provide packages for box sections of any dimension and to decrease the number of box sections in the structure. In this case, the prefabrication process is simplified but the labour input during the erection of the superstructure made of L-shaped sections is increased substantially.



Scheme 3

Erection joints of modular blocks of main girders are made of welded, bolt-and-weld and friction connections. To ensure a longer life span of the roadway, the plate joints of orthotropic decks are always welded. For this operation the automatic welding with metallic and chemical additives is extensively used. Besides the saving of electricity and welding materials, it reduces four times the amount of labour required for welding and subsequent ultrasonic testing.

The erection operation of a superstructure consists of the rear-conveyor assembly and the subsequent longitudinal launching, using an inventory system of struts and temporary floating piers. In order to reduce the translational deflection of a temporary pier (acting as a cantilever) special devices have been used.

Launching is carried out on launching bearings, whose main element is friction reducing material, a textile with a high compression strength (140 kg force/sq.mm) and a very low coefficient of friction (0.02 - 0.04). One of the most important properties of such bearings is the consistency of the coefficient of friction (including the start off) for a wide temperature range (from +60 to -80 ^{o}C).

The erection of the steel portion of the bridge was carried out by using the rear conveyor assembly operation with the subsequent longitudinal launching of the assembled portion from the left bank. The balanced cantilever erection of the continuous concrete superstructure, made of modular box sections, was carried out from the right bank. The joint between the concrete and steel portions of the superstructure was made in the alignment of two columns of the bridge tower.

Utilization of the previously developed modular structural and technological design allowed to substantially reduce the requirements for materials and labour needed for the design and construction of large, individual, temporary technological systems, as happened in the past, when constructing non-standard bridges. Cables in the South Bridge are made of enclosed, factory made strands, 62 mm in diameter, provided with original wedged anchors. The construction of the South Bridge crossing on the Dnieper River in Kiev was completed in 1990, thus becoming an example of the flexible technological design system both for concrete and steel bridge construction.

MANUFACTURING OF STEEL BRIDGE STRUCTURES

According to the program of complex development in the industry, the Main Administration for Bridge Construction of the Ministry of Transport Construction of USSR has the production capacity of 140 thousand tons of steel bridge structures per year. Production plants are located in the European regions of the USSR, in the Ural region and eastern regions of the country. This allows for savings in transportation costs. Even though each plant is capable of manufacturing a variety of different bridge structures, each is specialized. This allows for increase in both production output and labour productivity.

Along with the main structural steel plants, there are specialized plants for production of technological rigging, equipment, and machinery for bridge construction. Demands for higher efficiency technological rigging, equipment and machinery creates the need to further increase the output of these plants.

CONCLUSION

The design of bridges which is carried out in the USSR with close coordination between the manufacturing and erection technology is a practical example of the main principle of systematic approach, the principle of the so-called "structural-and-technological design".

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