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# Prefabricated Reinforced Concrete Bridges for High Speed Construction

## Structures préfabriquées en béton armé pour la construction rapide de ponts-routes

## Vorfabrizierte Stahlbetonbrücken zur schnellen Erstellung von Autobahnbrücken

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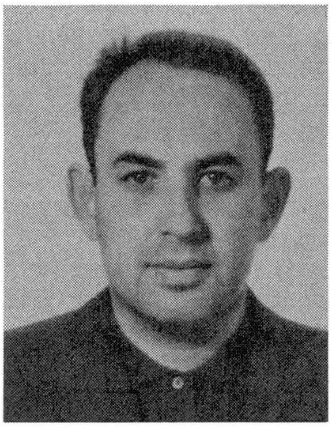


A.L. Tsejtlin, born in 1931, Moscow Highway Institute graduate, deals with problems of design and construction of reinforced concrete bridges including those of prestressed segmental type.

**SUMMARY**

The accelerated erection of precast concrete bridge structures in the USSR is based on the utilization of two main types of prefabricated superstructures. Discussed in this report are the main design and production principles behind their development as well as some aspects of the accelerated erection process.

**RESUME**

La mise en œuvre rapide d'éléments structuraux de ponts préfabriqués en URSS repose sur l'utilisation de deux types principaux de superstructures préfabriquées. Le présent article examine l'étude technique et les principes de fabrication ayant favorisé leur développement, ainsi que certains aspects du procédé de mise en œuvre accélérée.

**ZUSAMMENFASSUNG**

Die Erhöhung der Brückenproduktion in den UdSSR basiert auf der Verwendung von zwei Typen vorfabrizierter Betonbrücken. Dieser Beitrag beschreibt die Hauptentwicklung der Aspekte von Entwurf und Konstruktion sowie einige Eigenheiten der schnellen Montage.

The development of the accelerated erection methods in bridge construction was made possible by resolving the organizational, economic as well as technical problems associated with the methods and production capabilities of the industry.

This also involved the problems related to the establishment of necessary construction organizations, financing, availability of skilled labour as well as that of equipment and materials.

The problem of the accelerated construction of bridges has a very high priority in USSR. It is resolved through an extensive application of prefabricated, factory assembled units including the ones manufactured by press-technology. This approach has proven to be quite economical, since the USSR has the industrial base necessary for the manufacturing of prefabricated bridge components for spans up to 150 m, and over 50 years of experience in erection of these structures.

With regards to the railway bridges, the accelerated construction is designed to overcome the following challenges:
- short construction seasons in the northern climatic zone (Siberia, Arctic region, Far East) due to severe weather conditions;
- erection of adjacent (so-called "next-track") structures, i.e. those in close proximity to the operating railway tracks;
- reconstruction of the operating railway structures subjected to heavy traffic, which is difficult to carry out due to the strict time schedules.

In view of the above and due to the strict requirements of structural reliability imposed on railway bridges in USSR, reinforced concrete superstructures for these bridges, including their waterproofing, are fully prefabricated. The prefabricated components must be free of any field work except for simple erection operations required for the installation of bridge girders in their design positions and placement of the bridge deck.

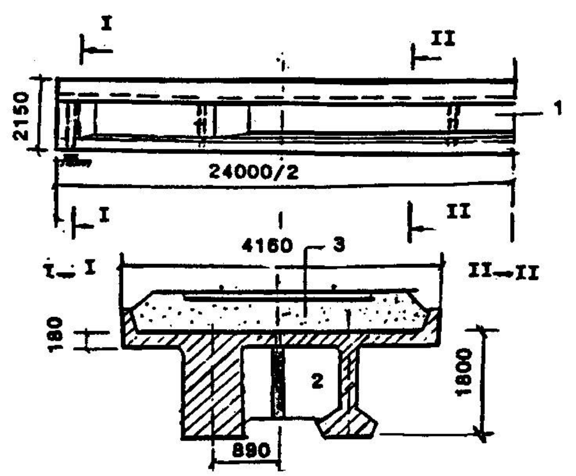
These are the types of concrete superstructures currently in production for railway bridges:
- for spans up to 16 m - simple slabs (Fig 1) or T-beams, with regular reinforcement.
- for spans up to 33 m - T-beams, prestressed, with the tendons being tensioned before the concrete is placed (Fig 2).

Until recently, the standard designs have called for two prefabricated members per one railway track (Fig 1 & 2). However, as a result of modernization of railway facilities, the width of bridge decks had to be increased to ensure their compatibility with the mechanized road base maintenance equipment. With this in mind, the four-beam per track prefabricated superstructures for the spans of over 24 m were developed (Fig 3).

The technological process which ensures the effectiveness of the accelerated construction system consists of the following:
- equipment and devices of the production plants having a production capability of tens of thousands of tons of prefabricated concrete structures for the spans of up to 33 m, one half of this volume being prestressed structures.

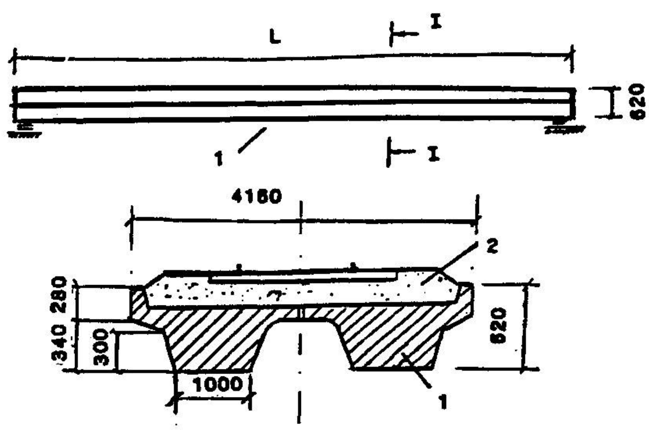
-railway transportation facilities capable of transporting bridge girders to distances in excess of 1000 km.
-cranes and other erection equipment with maximum capacity of over 120 tons.

Elevation




Cross Section
Figure 1 - Railway Superstructure
1-Girder 2-Diaphragm
3-Ballasted Floor

Elevation




Cross Section
Figure 2 - Railway Superstructure
1-Flat Slab
2-Ballasted Floor

Elevation

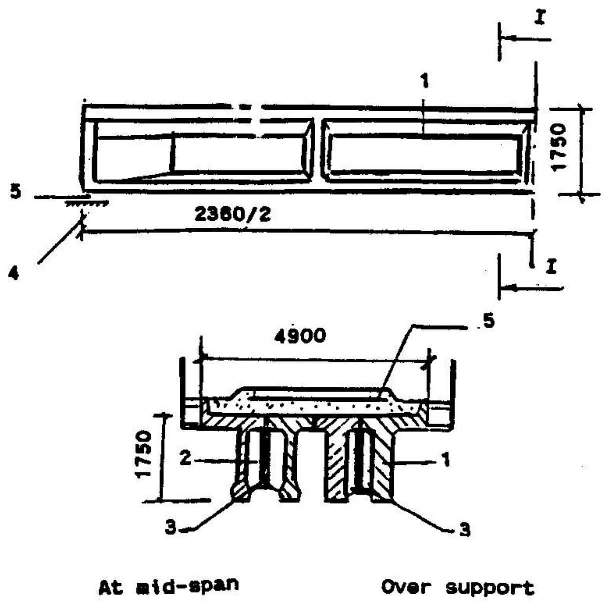



Figure 3 Railway Superstructure
1-Girder 2-Diaphragm
3-Joint Diaphragm 4-Pier 5-Bearing
6-Ballasted Floor

Elevation

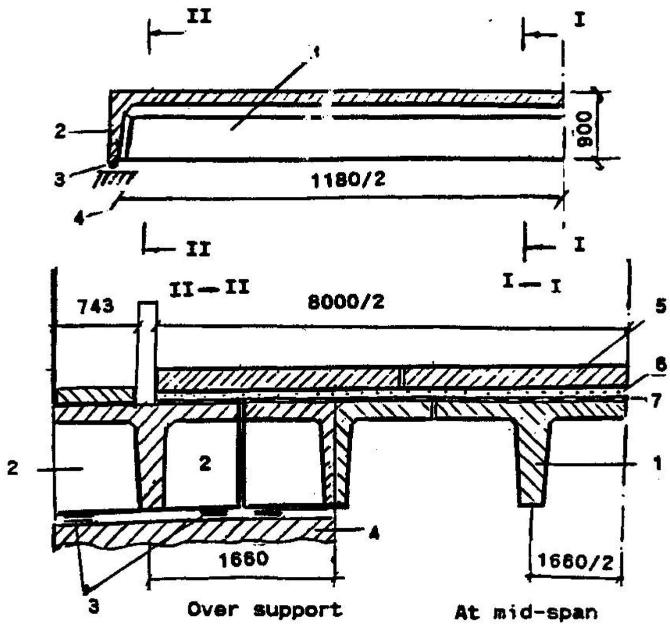



Figure 4 Highway Superstructure
1-Girder 2-Diaphragm 3-Bearing
4-Pier 5-Precast Road Slab
6-Road Bed (Special Sand)
7-Bitumenous or Polymer Pavement

The production of prefabricated structures is effectively the bottle-neck of this system. The average output of a plant form is two girders per month, the minimum time of the production process being 10 days and the maximum time 20 days. Such a low output can be attributed mainly to the complexity of prefabricated members and to the uncompromising requirements of high quality.

The construction of bridges of the Baikal-Amur railway line is a vivid example of the accelerated erection process. It was preceded by an extensive research work to ensure the development of technology necessary for the erection of prefabricated bridge components: superstructures, piers, abutments. This approach made it possible to carry out bridge construction work all year around.

The effectiveness of the system was such that it took only one work shift to have a bridge superstructure erected, since there was practically no need for any in-place concreting. Obviously, with the operations carried out in a simultaneous fashion the mounting rate becomes even higher.

The accelerated construction of highway bridges, viaducts and overpasses is a recent development which was intended to resolve two pressing problems: The first was associated with the construction of highways in Western Siberia and the non-chernozemic zone of Russia. In Western Siberia roads are designed for the industrial development and the servicing of oil and gas fields. The expected service life of these roads is limited to 20 years. Bridges on these roads must be capable of carrying special heavy-load vehicles (including the caterpillar-tread transporters) while withstanding the severe weather conditions. These bridges are erected, as a rule, in the areas of limited maintenance capability and, therefore, are limited to maximum spans of 12 m.

There are two principal designs selected for the construction of highway bridges in Western Siberia. In principle, both designs used the same approach (see Fig. 4 & 6).

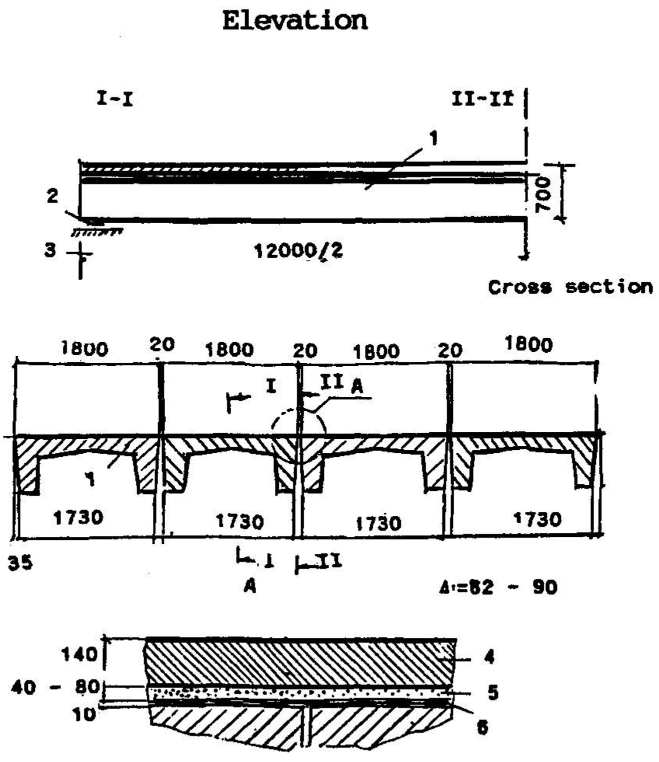



Figure 5 - Highway Superstructure
1-Girder 2-Bearing3-Pier
4-Precast Road Slab 5-Road Bed [Special Sand] 6-Bituminous or Polymer Pavement

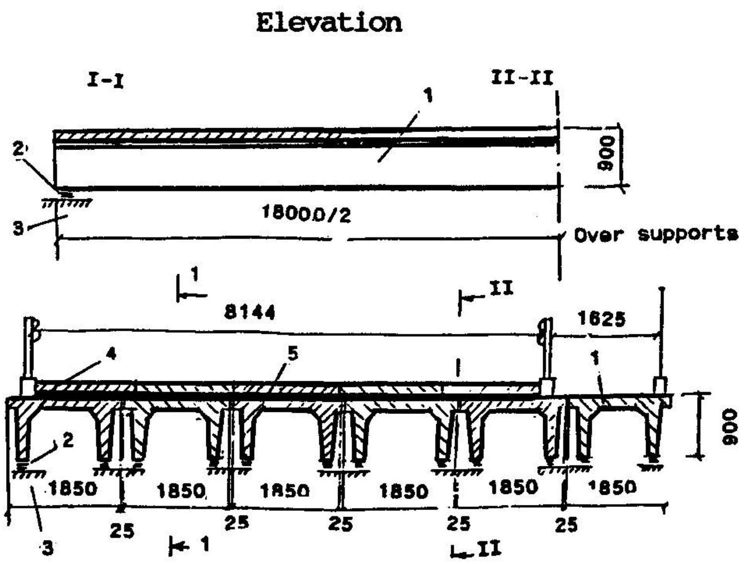



Figure 6 - Highway Structure
1-Girder 2-Bearing 3-Pier
4-Precast Road Slab 5-Road Bed
[Special Sand] 6-Bituminous or
Polymer Pavement

The superstructures, which are assembled from prefabricated members, are not joined by any transverse connectors which would create a continuous framework. As a consequence, each prefabricated component of the superstructure carries load independently. The top face of each precast girder is provided with a factory applied waterproofing. The reinforced concrete deck slab is placed on a layer of a select sand, spread over the top faces of the girders. As a result, these bridges can be built all year around very quickly and with a minimum number of workers and pieces of equipment. Besides that, the presence of the precast concrete deck slab prevents the waterproofing of girders from being damaged by the caterpillar tread transporters.

The principal designs differ in the configuration of the girders. In the first case (see Fig 4 & 5), it is a T-girder with supported diaphragms. These girders rest on bearings placed under the diaphragms (Fig 4) in such a manner as to ensure their work both in bending and torsion.

In the second case the precast girder is shaped as a channel (see Fig 6). The girder has no diaphragm and rests on bearings placed under each leg.

In both cases precast members are reinforced by regular unstressed bars of Class A-III. As a possible alternative, both the T-shaped and the channel shaped girders may be reinforced by bars preassembled into flat planes. The experience of bridge construction in Western Siberia has shown that the channel shaped girders are more efficient. They are easier to fabricate, transport and erect.

The experience in Western Siberia has made it also possible to find a better solution for the accelerated bridge construction in non-chernozemic areas of Russia. The highway bridges in these areas are of "permanent" design with a normal service life expectancy. They are usually comprised of spans of up to 18 m long. Besides the "common" designs intended for the application in such cases, the use was made of some special designs of bridges with prefabricated reinforced concrete superstructures. They applied the principles of accelerated construction of bridges in Western Siberia, based on utilization of prefabricated structures assembled from the factory made components.

This special design alternative is a further development of the channel shaped girders. The prefabricated member is shaped as a double tee girder. The cantilever can facilitate deck drainage, thus contributing to the durability of the structure. The variable width of these girders ensures the more rational use of bridge deck dimensions. The longer service life expectancy has necessitated a certain change in reinforcement. Three types of girders are in production: girders with non-prestressed reinforcement, girders with external plate reinforcement and girders with prestressed reinforcement (two steel strands K-7).

Even though the quantity of concrete in each special design superstructure has slightly increased, in comparison with the "common" design, they offer a better flexibility in manufacturing and transportation. One such bridge superstructure can be assembled by a team of 5 men in one work shift (8 hours).

Unfortunately the simplified deck designs made it impossible to recommend them for the use on the primary and secondary highways. But the newly proposed fully assembleable superstructures with a span of up to 30 m, fabricated for the accelerated construction, are free of this drawback. One such superstructure is shown in Fig. 7. The superstructure consists of the following three prefabricated components: girder(1), standard diaphragms (2), and standard deck slab (3).

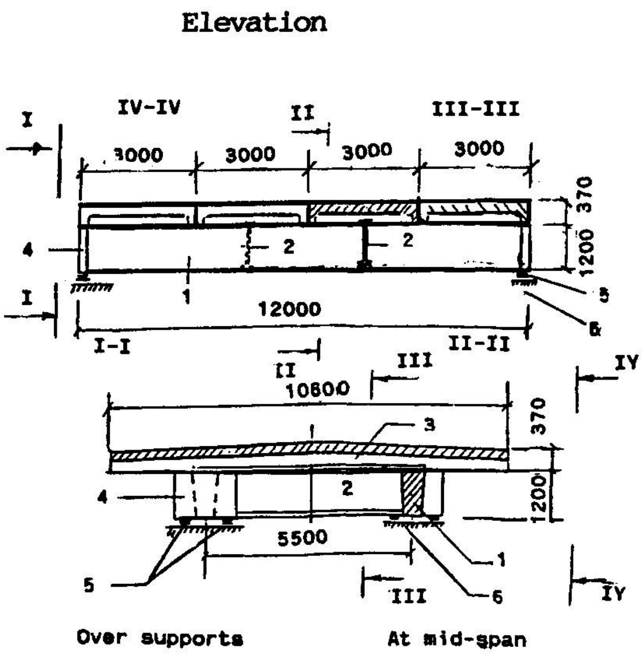


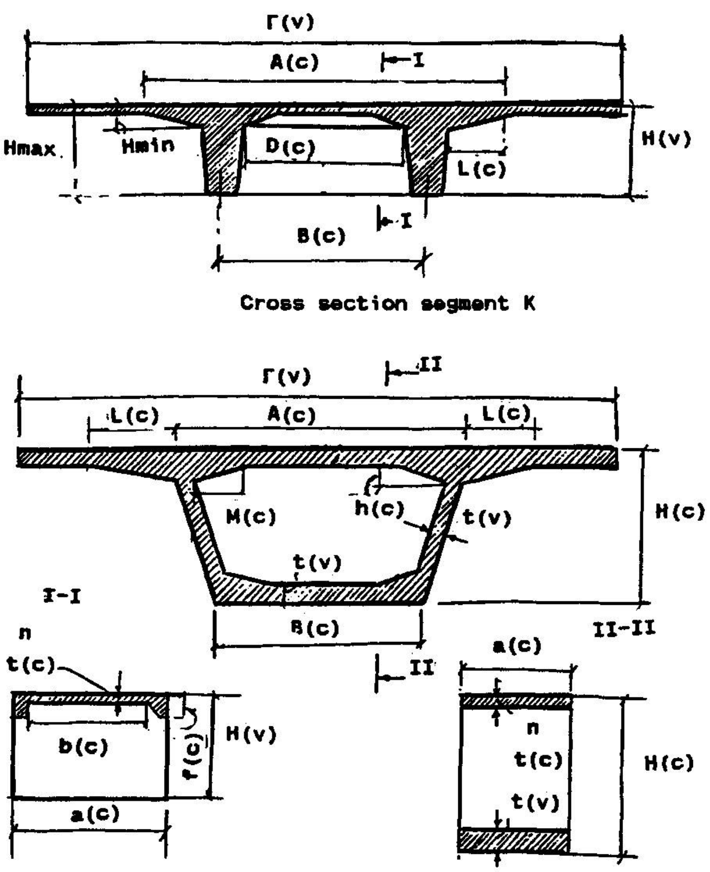

Figure 7 - Highway Superstructure
1-Girder 2-Precast Diaphragm in Span 3-Precast Slab 4-Diaphragm at the end girders 5-Bearing 6-Pier

The girder is of a trapezoidal cross-section which simplifies modifications of its height and length. As a result, the same form can be used for the manufacturing of girders ranging from 12 to 33 m in length. The deck slabs are 3 m wide with their length matching the width of the superstructure. Dimensions of deck slabs and diaphragms, as well as their reinforcement, are independent from those of the main load-bearing member (the girder). This facilitates the design of versatile precast, factory finished structures. This bridge superstructure can be easily adapted for skewed and curved crossings. The prefabricated members are furnished with unique inter-locking units, which makes it possible to have them erected in one work shift.

The solution of the second problem of the accelerated bridge construction is associated with the development of the "multi-purpose (versatile) technology of construction of long span highway and urban bridges"[2]. The main goal of this development was the creation of a process that would enable reduction of construction time by half, quantity of material by 25 per cent and improve the structure reliability and quality. This work resulted in the development of a technological process of construction of reinforced concrete superstructures with spans of 33 to 105 m, which can be erected by various methods of assembly and are suitable for different roadway widths on straight, curved and skewed crossings.

This technological process is based on the following three principles:
- modular construction, i.e. the development of bridge superstructures of a wide range of spans and cross-sectional dimensions, suitable for fabrication as modular, factory-assembled units and fit for transportation by rail and highways;
- flexibility of design and construction, i.e. the design, manufacturing and erection technology should provide the possibility for construction of straight, skewed and curved bridges, including sharp turns, with multi-span superstructures;
- variability of erection methods, i.e. the bridges assembled from standardized modular components should be suitable for different erection methods with the help of an appropriate erection and special equipment.

Cross Section Segment K




<u>Figure 8 Segment "PRK" and "K"</u>
V-Varying Size C-Constant Size

The above principles laid the basis for a new form of technological design, namely the computer aided design. The bridge superstructures thus developed were of the segmental type.

Two modular assemblies have been developed, the assembly of the slab-on-stem sections "PRK" for the spans of 33 - 63 m and the assembly of the box section "K" for the spans of 63 to 105 m (see Fig 8).

Despite their difference in shape both modular assemblies have similar outside dimensions and weight. Therefore, their transportation and storage are handled by the same lifting and transportation equipment. Both assemblies are factory-manufactured and their production is based on common principles: use of reinforcement assembled in planes, application of duct tubes, utilization of the same equipment and fixtures for concrete mixing, placement, consolidation and curing. The parameters of these assemblies are divided into constant or "fixed" (c) and flexible or "(variable)"(v). The first, (c) parameters, make it possible to have the basic dimensions standardized in order to improve the production adaptability and simplify the forms. The second, (v) parameters, make it possible to produce components for various purposes. The dimensions of the assemblies ensure their transportation by rail and highways with no specific limitations. The mass of each assembly is within 60 t. which ensures their lifting and transportation by standard facilities.

The prestressing steel can be placed both inside the cast-in ducts and on the outside of the assembly. To conform to the road geometrics, the top surface of the bridge deck is made either with a crown or flat. The flat bridge decks are intended both for the roadways with a uniform superelevation and for the roadway with a variable superelevation. The uniformly superelevated bridge decks are constructed by adjusting their supporting parts, while the variable superelevation is ensured by the method of casting [4]. The bridge decks on straight alignments are made rectangular in plan. On skewed or curved alignments the deck shape is trapezoidal in plan which is accommodated by the moulding fixtures [3].

A specific feature of the slab-on-beam assemblies [3] is the utilization of the pair of beams directly under the deck (see Fig. 8).

There are two alternatives of the slab-on-beam assembly. The first is intended for highway construction. In this case the structural depth of the assembly is normal and is equal to the 1/20 of the span. The second alternative is designed for the construction of urban viaducts and overpasses. These structures and their architectural outlook are subject to more stringent requirements. The assembly has a shallower construction depth equal to 1/25 of the span. In the case of the slab-on-beam assemblies, the ducts for post tensioning reinforcement are provided only in the beams. In the case of the first alternative the beams are 750 mm thick, and those of the second alternative are 1250 mm thick. Substantial dimensions of the beams ensure an adequate arrangement of tendons and regular reinforcement and facilitate the forming of the assembly.

A specific feature of the box-section assembly ("K") is that its outside dimensions H(c), B(c) and A(c) plus L(c) are constant. Depending on the longitudinal position of the assembly in the superstructure, the variable dimension t (v) is changed through modifications to the inside dimensions of the cross-section. As a result, these assemblies, like the slab-on-beam ones, are suited for alternative methods of erection: balanced cantilever method, span-by-span construction, incremental launching, progressive placement. Another feature of the box-section assemblies is that the ducts for post-tensioning are arranged at the ends "in a standard way" which makes it possible to standardize the butt-end forms. This being the case, the length of the assembly and the pitch of post-tensioning ducts are in direct relationship.

The systematic design approach made it possible to use the modular assemblies in forming of continuous and frame structures with joints treated by an adhesive. In order to strengthen these structures, post-tensioning is provided by steel strands of a capacity determined by the method of erection. In the case of the cantilever method of construction, the strength of steel strands is 200 tf, and for the span-by-span construction and incremental launching it is 200 and 300 tf respectively.

The production lines for manufacturing of the slab-on-beam and the box section assemblies (PRK and K assemblies) are based on the method of incremental casting and a step-by-step procedure, with the form retained in a stationary position. The forms of the matrix type are outfitted with vibrating plates for the mechanized placement and consolidation of concrete. These forms use the compensating heating system which, for the process of hardening of concrete, utilizes mainly the exothermic heat of cement. The deficiency in the exothermic heat energy is compensated by external sources of heat transferred through the internal and external panels of the form. In the process, the forms are positioned at two stations. The first station is used for concreting and the second for the subsequent curing of the cast block. The heat treatment of the cast block is provided at both stations. Provisions are made for the moisture retention of the hardening concrete. Since the matrix-type forms cannot be disassembled, the whole casting table is moved from the first station to the second. This is done by a "manipulator" which is also used for transportation purposes inside and outside the shop. The forms allow for three-dimensional changes of the shape[4], providing for the rotation of the butt-end forms in relation to the casting table in the vertical plane by an angle $\alpha$ . The position of the casting table relative to the direction of concreting can be changed in the horizontal plane by an angle $\beta$ . These operations, necessary in forming of skewed and curved shapes required on curved sections of highways are controlled automatically and need no interference by operators.

Geometric parameters of each block and its position in relation to other members of the erected structure are checked with the help of a special system of reference marks made on the blocks during their casting.

The production line uses an automatic temperature control system that provides the compensated heating of concrete. This system makes it possible to accurately predict the strength gain of concrete.

The highest rate of production of the assembly blocks is one block per day for a single outfit. The labour intensity required for slab-on-stem assembly blocks is about 2.5 times lower than that of the box sections.

The modular assemblies were developed bearing in mind their suitability for the erection methods discussed earlier. These methods are well known in the Soviet Union and were extensively used for the erection of the monolithicaly cast segments [3] except for the method of progressive placement.

Presently, the USSR has plants for manufacturing of the modular assemblies, with an output of 20000 $m^3$ of reinforced concrete elements a year.

To resolve some specific problems of construction and to ensure a gradual development of the so called "multi purpose production", two methods of erection are widely used in the USSR today: span-by-span erection from the PRK asemblies (Fig. 9 & 11) and balanced cantilever method of erection from the K assemblies (Fig.10)

The bridge superstructures made from the PRK assemblies both on the curved and straight road sections are erected by the span-by-span method [4] with the help of a mobile erection set. The maximum rate of erection is one 42 m long span per week.

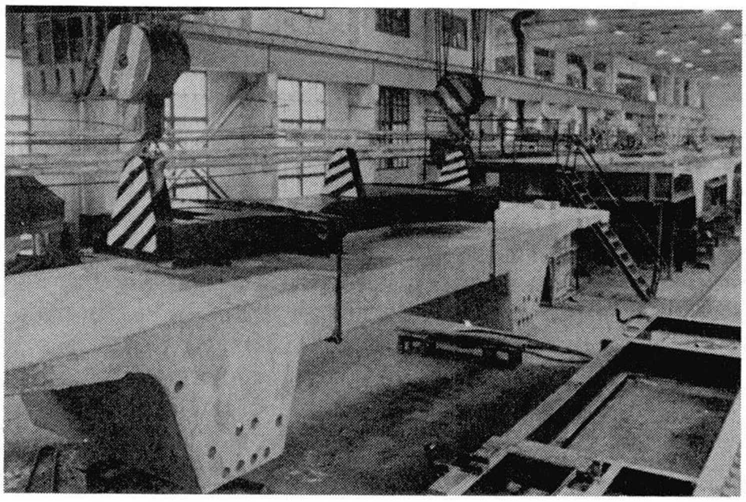


Figure 9 - South Bridge - Inside view of the precasting factory. Short-line precasting segment "PRK".

Figure 10 - South Bridge - Segmental in progress. One typical precast segment "K" placed in the superstructure.

The bridge superstructures made from K assemblies are erected by the cantilever method in sections, with the help of a new, efficient erection set, crane MA-65, weighing 50 tons. It is a walking machine that requires no special track. This set has mechanized all operations of the cantilever method, including the placement and tensioning of strands. The maximum rate of erection, with the help of the MA-65 crane, is one span of 80 m in 20 days, including site preparation and set up of the crane.

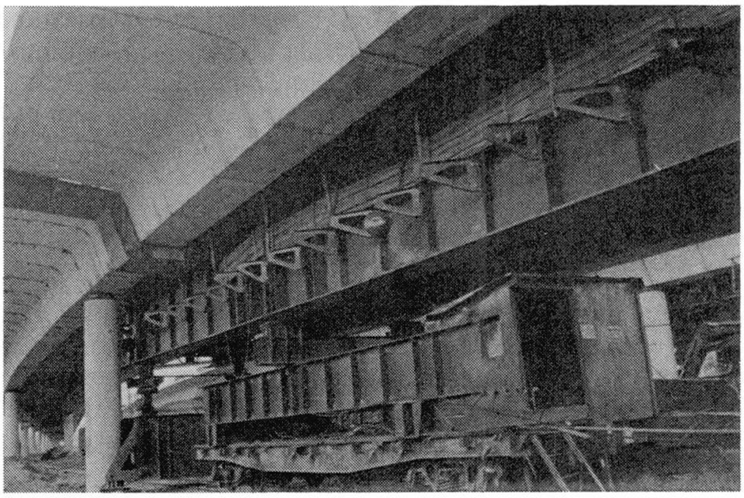


Figure 11 - Curved structure of the South Bridge
Span-by-span assembly of precast segment "PRK".

In increasing the rate of construction of segmental structures, an important role is played by the so-called "group cementing" method. It was originally developed for the erection of the PRK assemblies with the help of a mobile trestle [3]. The "group cementing" technique is based on a simultaneous application of the cementing adhesive to a group of prefabricated members arranged on the trestle and a subsequent post-tensioning operation. One PRK section, 42 m long, comprised of 16 blocks, is assembled during one work shift (8 hours).

This job is done by a team of about ten men. The total weight of the erected members is 400 tf, the area of one cemented joint being 8 $m^2$. This technology is applied to the cantilever erection process, in which case a section on the pier consisting of 5 to 7 K assembly blocks is cemented in one work shift. Besides considerable reduction in erection time, this technology ensures a high accuracy of erection of the base sections on the pier, and consequently the accuracy of the position and dimensions (both plan and elevation) of the entire structure. Provisions have been made for the application of the "group cementing" method when mounting the K assembly blocks on mobile trestle or when mounting either K or PRK assembly blocks "on the floor" for the subsequent erection by the incremental launching method.

Application of alternative erection methods is associated with the development of new equipment: sluice jib cranes for the progressive placement construction, outfits for the balanced cantilever method, mobile trestles, etc. On one hand these pieces of equipment require a considerable investment of materials and on the other hand they can only be used in certain specific situations. For this reason use is now made of specially developed multi-purpose erection devices (UMK) from which the necessary erection outfits can be assembled.

Principles of the accelerated erection of railway bridge superstructures through application of so-called "flexible (multi purpose) technology" have been put to work during the construction of the South Bridge trestle in Kiev. The experience of this construction has proven to be very useful. Long overpasses made from the PRK assemblies with spans of 42 m [4] and flood plane trestles from the K assemblies with spans of 80 m were subsequently constructed.

The rate of construction in this case has not been the fastest possible, yet. It is believed that further improvements in the above process depend on a stricter adherence to the assembly schedule, fine tuning of organizational aspects and the application of computer aided design. Computer aided design, in this case, utilizes software which has already been developed for personal computers. Development of the first computer aided composite system is based on non-interacting models of the construction sequence, representing the manufacturing, transportation and erection of segments.

Development of the first composite model was completed during construction of the South Bridge trestle in Kiev [1].

The second composite model (CBD) has now been developed for the computer aided design of segmental structures. It will ensure a prompt adaptation of the modular assemblies to the construction problems in real conditions.

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