INSTITUTE OF TECHNICAL SCIENCES OF THE SERBIAN ACADEMY OF SCIENCES AND ARTS

NIKOLA HAJDIN

THE MOST IMPORTANT SCIENTIFIC AND PROFESSIONAL ACCOMPLISHMENTS IN FOREIGN LITERATURE COMMENTARIES

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On the occasion of his eighty-fifth birthday

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Contents

THIS YEAR marks the eighty-fifth birthday and sixty years of scientific and constructive work of academician Nikola Hajdin. Widely appreciated, he is generally held to be an exceptional figure in the area of applied mechanics, particularly structural mechanics and equally in innovative construction practices. Well-known in international scientific circles, the President of the Serbian Academy of Sciences and Arts and member of four foreign academies, has given an enormous contribution to the renown of Serbian engineering in the world.

His associates and friends are marking his jubilee as a debt they owe him, the scientific public of our country and future generations of engineers who will draw upon his opus to find firm foundations for their own scientific and practical work.

Belgrade, 2008

Introduction

DURING HIS LONG scientific and professional activity spanning over half a century and going through different phases, professor Nikola Hajdin obtained results of greater or lesser significance depending on the state of development of science and technology. This overview singles out the results which, in our opinion and that of scientific criticism, rendered a specific contribution to the progress of science and its applications.

It is primarily his written work and his structures, predominantly bridges, which signified greater or lesser headway in these areas.

Here we have singled out, first and foremost, works which have been acknowledged and highly acclaimed in the country and abroad and which constitute a scientific or constructive contribution to progress.

Professor Hajdin's choices during studies seemed to indicate that he would devote his whole life to scientific work in the field of applied mechanics, especially structural mechanics. However, he soon realized that any significant and valuable effort in structural mechanics, in addition to a theoretical basis, required extensive knowledge of real structures, their development and tendencies substantially influencing scientific endeavor in this area. He realized at a very early stage that these were simultaneous and interactive processes.

Many outstanding structural achievements came into being under the influence and with knowledge of applied mechanics, such as the discoveries of French scientists such as Claude-Louis Navier, Barré de Saint-Venant and others, which extensively transformed practical know-how in the field of structures.

A feedback effect is visible everywhere. One of the most important is definitely the method of finite elements which sprang from practical needs and theoretical investigation of structures. There are very many examples of both.

Such a perception as well as the need for scientists to tackle practical problems and application in design prompted professor Hajdin to take up designing as a parallel activity, one he initially considered to be more of a hobby, and later a serious and responsible job in which he incorporated upon, as this survey will show, the results of his scientific work, with some of the applications serving to verify scientific results.

This will be discussed at length, for it is precisely this combination that is the chief characteristic of his work.

If one reads only his articles, monographs and books dealing with theory, one will not always be able to see where specific results applied to structures lead.

The creative opus of professor Hajdin can be broadly divided into six periods, i.e. six areas in which he gave a contribution to science and its applications, and one can say, indeed a contribution to general progress.

First period

Integral equations method

ALREADY AS A STUDENT he began, almost shyly, to go in for science. Thanks to professor Hlitchiev he published a work entitled *Triangular Pipe Torsion*[1] in the Almanac of scientific and specialized papers of professors of the Technical Faculty. This was a strong impetus for him to start dealing with science more seriously.

As an assistant he published the work *Contribution à la solution du problème plan*[2] in "Publications de l'Institut mathèmatique de l'Acadèmie serbe des sciences", which is cited in the then best-known book in Europe in the area of plates and shells, "Flächentragwerke" by Karl Girkmann, a great acknowledgement for a beginner and relatively young scientist.

The text reads:

> **Đurić und Hajdin haben rechteckige Scheiben berechnet, die an gegenüberliegenden Rändern antimetrisch oder symmetrisch verteilte Lasten tragen. Für die Spannungsfunktion wurden hierbei Ansätze mit Hilfe jener orthogonalen Funktionen gebildet, die im Lösungsergebnis für die freien Querschwingungen eines beiderseits eingespannten Balkens auftreten.**

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1. Хајдин, Н.: *Торзија троугласте цеви.* Годишњак Техничког факултета Универзитета у Београду, 1946-1947, 27-29
2. Hajdin, N.: *Contribution à la solution du problème plan.* Publications de l' Institut mathématique de l' Académie serbe des sciences. 5 (1953) 53-62.

/Đurić and Hajdin analyzed rectangular plates with symmetrically and anti-symmetrically distributed load at opposite edges. Formulas based on orthogonal functions were taken for the stress function which appear in the analysis of free lateral oscillations of a beam fixed at both ends./

[1] K. Girkmann: Flachentragwerke. – Springer Verlag, Wien, 1956.

This tribute did not elicit much interest in the milieu he lived in and only a rare few paid attention to that. But it meant a lot to him and strengthened his conviction that his efforts were worthwhile.

Sometime around 1954 professor Hajdin professionally focused more on arch dams which were of exceptional importance given the building of hydroelectric power plants. Regrettably, the theory for calculating such structures was not particularly developed. One may say that serious scientific analysis of this subject-matter at the global level was practically in its inception.

In response to pressing needs, designers made do by employing, from the standpoint of applied mechanics, relatively modest means and methods. The most widespread was the "trial load method"[3] which was based on the relatively primitive use of the logic of linear girders, by breaking down a monolith dam into a system of cantilevers and arches. Despite the lack of a scientifically grounded approach, the method yielded quite practicable results.

This, in addition to Marcus's method for plates[4], which was based on a similar philosophy, inspired professor Hajdin to, proceeding from a similar logic, arrive at an original, scientifically founded, numerical method, which he called the "Integral Equations Method".

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3. *Trial Load Method of analysing Arch Dams*, Bureau of Reclamation, Denver 1938.

4. Marcus H.: *Die Vereinfachte Berechnung biegsamer Platten*, Berlin 1929.

Fig. 1
Glažnja arch dam near Kumanovo (Macedonia)

The procedure, presented in a number of works (*)[5], (*)[6], (*)[7], (*)[8], could be used for calculating plates, arch dams and similar structures.

Given the fact that at the time (before the use of the method of finite elements) there did not exist, apart from the so-called method of finite differences, a serious numerical procedure for solving two-dimensional structural mechanics problems, professor Hajdin's procedure started being used in the country and to a certain extent also abroad.

At this point we should particularly draw attention to the use of the "method of integral equations" for some doctoral dissertations in England, for instance H. A. Hadid [2] and R. Stilwell [3], for the analysis of arch dams and similar problems. The work was later cited in works on acoustics by R. S. Srinivasan and S. Sankaran [4] and on transportation means by R. S. Srinivasan and C. Babu [5] and similar.

Before the use of computers, professor Hajdin's method had its place and certain advantages, for instance, over the method of finite differences, among

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5. Hajdin, N.: *A Contribution to the Analysis of Arch Dams with Remarks Concerning* «Trial Load» Method. – Résumé. – Paris: Commission internationale des grands barrages, 1958. – 21 p. ; 24 cm. – (Bulletin / Commission internationale des grands barrages ; n. 12)
6. Hajdin, N.: *A Method for Numerical Solution of Boundary Value Problems and its Aplication to Certain Problems of the Theory of Elasticity*. – Ein verfahren zur Numerischen Lösung der Randwertaufgaben und dessen Anwendung auf einige Probleme der Elastizitatstheorie). Зборник Грађевинског факултета. 4 (1958) 1-57.
7. Hajdin, N., Krajcinovic, D.: *Integral Equation Method for Solution of Boundary Value Problems of Structural Mechanics. Part I: Ordinary Differential Equations.* International Journal for Numerical Methods in Engineering. 4 (1972) 509-522.
8. Hajdin, N., Krajcinovic, D.: *Integral Equation Method for Solution of Boundary Value Problems of Structural Mechanics. Part II: Elliptical Partial Differential Equations*. International Journal for Numerical Methods in Engineering. 4 (1972) 523-539.

other because it required less numerical work and a reduced number of linear equations, which was a major advantage in computation. These advantages slowly decreased with the development of computer technology and the introduction of, primarily, the method of finite elements.

In a certain period the method also had its place in the analysis of dynamic problems, and the very philosophy of the procedure was a novelty in numerical methods.

Here are several quotations on Hajdin's method of integral equations:

I. **B679 Метод интегральных уравнений для решения краевых задач строительной механики. Ч. I Обыкновенные дифференциальные уравнения. Hajdin Nikola, Krajcinovic Dusan. Integral equation method for solution of boundary value problems of structural mechanics. Part I. Ordinary differential equations. Int. J. Numer. Meth. Eng., 1972, 4, No 4, 509-522 (англ.)**

Для задач строительной механики, описываемы обыкновенные дифференциальными уравнениями, предлагается следующий способ решения: высшая производная принимается за новую неизвестную функцию, поэтому искомая функция становится выраженной через интеграл от произведения функции Грина и новой неизвестной. Дифференциальное уравнение задачи в этом случае становится интегральным уравнением Фредгольма второго рода. Поэтому в дальнейшем вместо численного дифференцирования проводится численное интегрирование, а искомые функции определяются операцией дифференцирования. Для численного интегрирования авторы предлагают два метода:

Fig. 2
Railway bridge over the Sava River in Belgrade
Photograph by: Branislav Tomić

Для иллюстрации эффективности предлагаемых методов решения рассмотрены эйлерова задача устойчивости, продольно-поперечный изгиб балки с переменным сечением и свободные колебания шарнирно опертой балки. Отмечена высокая точность результатов при минимальном числе узлов интегрирования (не более четырех).

/B679 Hajdin Nikola, Krajčinović Dušan, Integral equation method for solution of boundary value problems of structural mechanics. Part I. Ordinary differential equations. Int. J. Numer. Meth. Eng., 1972, 4, No 4, 509-522.

For structural mechanics problems described by basic differential equations the following method of solving is proposed: the higher derivative is taken as a new, unknown function and accordingly, the requested function is expressed through an integral of the product of Green's function and a new unknown. In that case, the differential equation of the problem becomes an integral Fredholm equation of the second kind. Therefore, instead of numerical differentiation we proceed with numerical integration with the requested functions determined by the differentiation operation.

For numerical integration the authors propose two methods: To illustrate the efficiency of the proposed solution methods, Euler's resistance requirement, longitudinal-transversal buckling of the girder with variable cross section and free oscillations of the girder have been considered. Very precise results were observed with a minimum number of integration nodes, (four at maximum)./

[6] [International Aerospace Abstracts]

II. **The integral equation technique as developed by Hajdin for the analysis of arch dams and extended by Hadid for the analysis of plate and shell problems, is now attempted for the solution of orthotropic skew slab.**

[7] H. A. Hadid, B. M. Ahuja, M. A. Mohamed: Analysis of skew slabs using Integral Method. – The Bridge & Structural Engineer, Vol. 9, No 1, Journal of Indian Nat. Group of IABSE, New Delhi, March 1979.

III. The boundary value problem represented by the two linear differential Eqs. (5a – b) with the homogeneous boundary conditions (7a – b) has no analytical closed solution. **In order to solve the problem we employ a numerical technique developed by Hajdin for the solution of linear boundary value problems.**

[8] H. Hadid: Analysis of parabolic velaroidal shells with simply supported boundary conditions. – Journal of Structural Engineering, Vol. 8, No 4, 1982.

IV. **The third method employed at Southampton has its origins in the work of Hajdin (1958), (1964) and is further described by Tottenham (1964) and Bozovic (1964).** It is known as the "Integral equations Method" because in it the partial differential equations, together with the homogeneous boundary conditions, are transformed, with the help of Green's functions, into a set of linear integral equations. By numerical methods these are then reduced to a set of simultaneous linear algebraic equations. In all three the entire computation is carried out on a digital computer.

[9] J. R. Rydzewski: Recent Advances in the theory of Arch Dams-Applied Mechanics Reviews, Vol. 16, No 10, Oct. 1965.

Fig. 3
The "Sloboda" roadway bridge over the Danube in Novi Sad (after reconstruction)
Photograph by: Wolfgang Hunscher

V. Alternatively, the same differential equations have been solved by the integral equations technique, as presented by Hajdin, after suitable modifications. Here also various combinations have been tried for the refinement of the solution. In fact, combinations of variation and integral methods are found to give very encouraging results. **The integral equation method was found to be far more promising than any other approximate method, and gave good results when extended to hyperbolic and elliptic paraboloid shells. The special advantage of the method is the reduction of computer time and a more realistic distribution of influences on the whole region of the shell. This method therefore needs further investigation for more difficult cases, such as elastic beam supports, etc. to exploit its full possibilities.**

[2] H. A. Hadid: An analytical and experimental investigation into the bending theory of elastic conoidal shells (Ph.D.Thesis) – Univ. of Southampton, March, 1964.

VI. In this method, the equations of free vibration for a cylindrical shell based on Donnell's theory are considered. The expressions for displacements are taken in the form of series. Substituting these expressions into the governing partial differential equations reduces them to ordinary differential equations. **These are solved by using integral equation techniques (4) and (5). Numerical work has been done and the results are compared with others available.**

[4] R. S. Srinivasan, S. Sankaran: Vibration of Cantilever Cylindrical Shells. Journal of Sound and Vibration, Vol. 4, No 1, 1975.

VII. **A new method (Double Integration Technique) for solving partial differential equations numerically is developed by the authors on the basis of Integral equations technique of Hajdin.** By this method it becomes very convenient to take into account the effects of the geometry and complicated variable boundary conditions for any given loading. Moreover, the final expressions obtained are more stable and yields quicker results with better accuracy. Thus, comparatively a coarser net is required to obtain the results for the desired accuracy. This reduces the number of equations to be handled and thus saves the computer time to a large extent.

Hajdin's Approach

The numerical solution of partial differential equations given by Hajdin consists of the following main steps:

i. **converting the differential equations together with the boundary conditions into a set of linear integral equations of the Fredholm type, by using the Green's function techniques.**

ii. **reducing these integral equations to a set of linear simultaneous algebraic equations, by using a suitable, numerical method for integration such as Simpson rule, 3&8 points formulae or Weddle's formula.**

[10] S. K. Agarwal, D. Krishna: Double Integration technique, A new Numerical Procedure for Structural Analysis – "Cement & Concrete", New Delhi, Oct.-Dec., 1970.

Fig. 4
3D model of a bridge in Plock (Poland)

The method was used for the analysis of several arch dams, gravity dams and other structures in our country as well, among other for the "Grnčarevo", "Mratinje" and some other dams. As the designer of the "Glažnja" arch dam (Fig. 1), third in height (85 m) in the former Yugoslavia, professor Hajdin applied this procedure in all the design phases.

COMPOSITE STRUCTURES

THE TIME BEFORE THE SECOND WORLD WAR is characterized by the emergence of bridges in which the concrete carriageway slab is tied to the steel girder so that from the standpoint of bearing capacity they form a single system. This is efficiently achieved, in addition to the slab being supported by the girder, by mutually linking them with shear connectors which make for joint action regarding stress and deformation. The extent to which they will form a single whole depends on these elements which can differ in nature, such as steel shear connectors and similar.

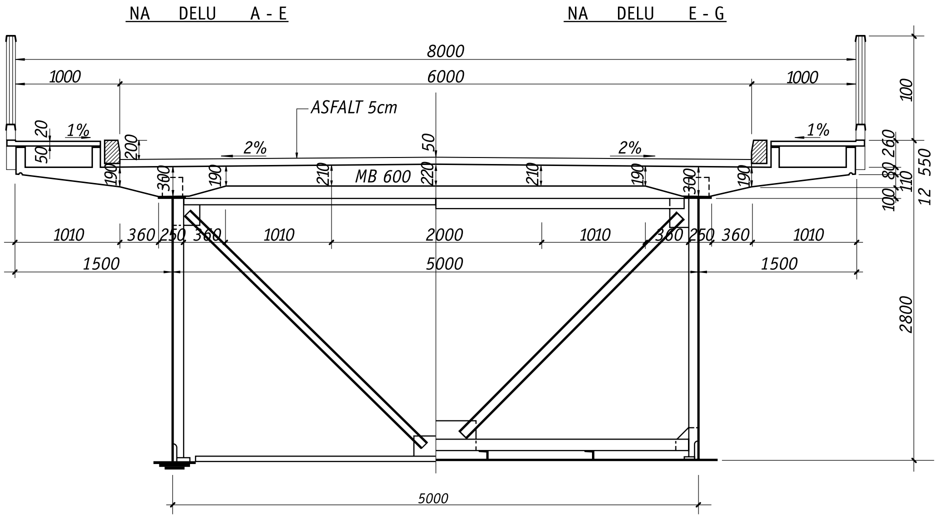
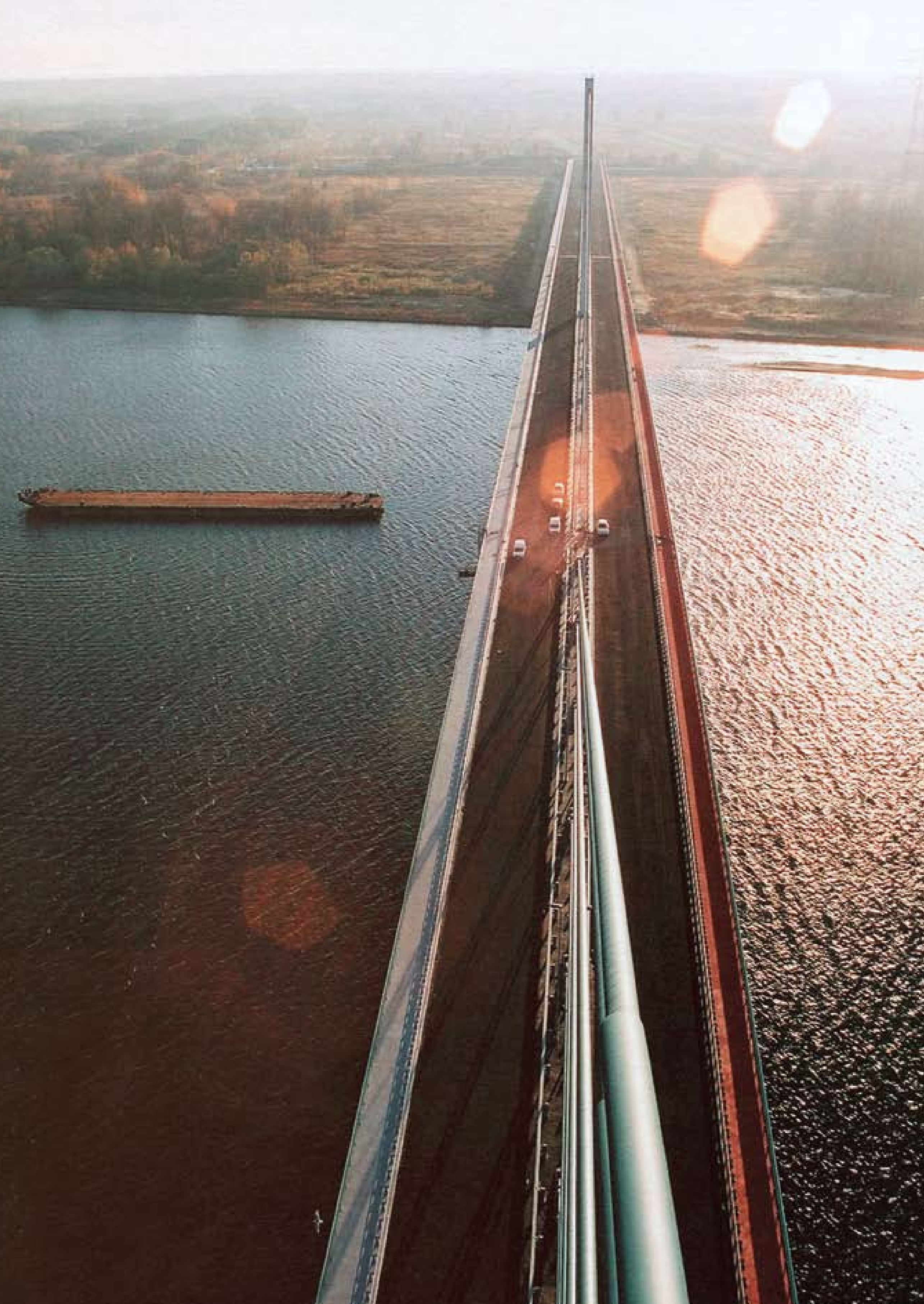


Fig. 5 – Cross section



Even with such a bond these two elements show different characteristics in terms of their behavior which, in the case of concrete, is manifested in a change of deformation in time, known as creep of concrete. In other words, the relation between the deformation and stress is not of an elastic nature and is given on the basis of observation through a more complex relation in which time features as an essential factor.

Accordingly, in a composite system there is a redistribution of stress which, to put it simply, means that over time the concrete slab is partially relieved and part of the load is transferred to the steel girder.

This phenomenon makes composite girders special and their analysis requires a new, more complex computation method which, accordingly, has its theoretical basis.

In our country, professor Milan Đurić[9] addressed this problem and contributed to the discipline a new procedure for the analysis of composite structures which was in both theoretical and practical terms a step forward.

A general characteristic of these methods is analysis of the system of girders with a concrete carriageway slab above and a steel girder below in the overall system.

Studying thin-walled girders, which will be dealt with later, professor Hajdin considered a composite girder in a more general way, with an arbitrary distribution of the concrete and steel elements in the overall cross section (Fig. 7).

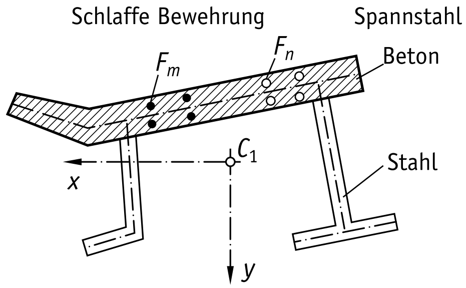


Abb. VII.2

Fig. 7 – Arbitrary section

9. M. Đ u r i ć : *Theory of Composite and Pre-stressed Structures,* SANU, monographs, volume CCCLXIV, 1963.

Fig. 6
Roadway bridge over the River Vistula in Plock (Poland)

Such an approach is presented in a number of works of which (*)[10] and (*)[11] merit attention.

This theoretical basis was used for analyzing the "Orašje" bridge over the River Sava (Bibliography [12], p. 89), (*)[13], (*)[14], where to a large extent thanks to this theoretical approach that the original girder with so-called double composite action was analyzed (Fig.8), i.e. with an upper carriageway and lower concrete slab in the zone of supports of the continuous girder which was the subject of the project. **This constituted an absolute novelty in the design of such bridges at global level. In addition, the "Orašje" bridge had the greatest span of all composite bridges in the world at the time.**

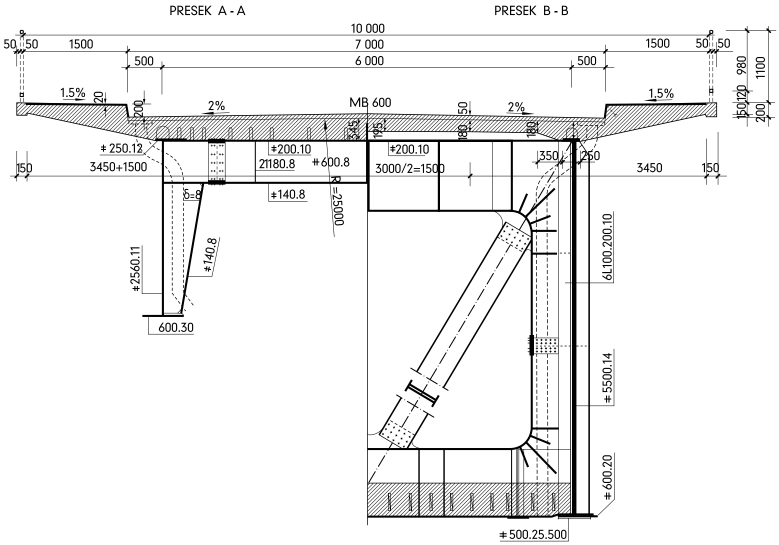


Fig. 8 – Roadway bridge over the River Sava in Orašje (Bosnia and Herzegovina and Croatia) – cross section

10. H a j d i n, N.: *Der Einfluss des Kriechens und Schwindens des Betons in dünnwandigen Trägern mit gekrümmter Achse.* – Influence of Creep and Shrinkage of Concrete in Thin-Walled Curved Beams.– Influence du fluage et du retrait du béton sur une barre courbe à parois minces. Symposium: L' Influence du fluage et du retrait, l' effet des changements de température sur les constructions en béton, Madrid 1970: Extrait du rapport final. Madrid: International Association for Bridge and Structural Engineering, 1970. p. 423-430.
11. K o l l b r u n e r, C. F., H a j d i n, N.: Dünnwandige Stäbe. Bd. 2: Stäbe mit derofmierbaren Querschnitten. Nicht-elastisches Verhalten dünnwandiger Stäbe. – Berlin: Springer-Verlag, 1975. – 284, XII p.; 26 cm

Only some twenty years later, the Germans, who had been the leaders in composite bridge technology, started designing composite bridges with double composite action.

Here are several quotations on this subject:

> It is a common practice since about 50 years to use the interaction between steel construction and the reinforced or prestressed concrete bridge floor in composite bridge superstructures. Both parts are doweled by shear connectors. The use of composite bottom flanges in the areas of negative bending moments is in fact obvious especially for economical reasons. In 1963 there was made a proposal for a bridge across the river Main [1], but this was never built. **From abroad there are known three bridges with double composite action: The bridge across the Save near Orasje in Yugoslavia [2,3], the Pont d'Illarsaz across the Rhone in Switzerland [4] and one bridge in the Netherlands.** A group of researchers of the Fritz Engineering Laboratory, Lehigh University studied the applicability of this building system and summarized in the final report, that the reduction or elimination of haunches and the omission of stiffeners allow a diminution of expenses.

[11] F. Nather: Steel Bridges with Double Composite action in Germany. Al II-lea Seminar de Poduri "Directii Actuale in calculul si proiectarea podurilor" Timisoara, martie 1996, 41-74.

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12. Г. Радојчић-Костић, Н. Марковић: *„Библиографија радова академика Николе Хајдина / Nikola Hajdin Bibliography*, САНУ Издања библиотеке 20, Београд, 2004.
13. Hajdin, N.: *Različite mogućnosti sprezanja betona i čelika u mostogradnji (Different Possibility of Composite Action Between Steel and Concrete in Bridges).* Spregnute konstrukcije. Beograd: Časopis Izgradnja, /1973/. Str. 30-37.
14. Hajdin, N.: *Einige Beispiele der Kombination von Stahl und Beton im Brückenbau. Schweizer Ingenieur und Architekt.* 103: 3 (1985) 37-39. Isto u: Festschrift Pierre Dubas zum 60. Geburtstag. – Zürich: Schweizer Ingenieur und Architekt, 1985. p.29-31.

It is not explicitly said here that the “Orašje” bridge is the first bridge of this type in the world. However, the other two mentioned bridges are of a later date. In addition, according to their caracteristics (span) they rank lower than the “Orašje” bridge. The following citation by the same author also indicates that the double composite action bridges in Germany were built later:

> In Deutschland wurden seit Mitte der achtziger Jahre eine Eisenbahnbrücke und vier Straβenbrücken fertig gestellt:
> – Die Brücke über den Inn bei Wasserburg [6-10]
> – die Elbebrucke Torgau [11-13]
> – die Moselbrücke Bernkastel-Kues [14]
> – die zweigleisige Eisenbahnbrücke über den Main bei Nantenbach [15-16]
> – und die Elbebrücke Magdeburg.
>
> /One railway and four road bridges have been built in Germany since the mid-80's:
> – the bridge across the Inn at Wasswerburg,
> – Torgau bridge across the Elbe,
> – the Bernkastel-Kues bridge across the Mosel,
> – the double-track railway bridge across the Main at Nantenbach, and
> – Magdenburg bridge across the Elbe/

[12] F. Nather: Stahlbrücken mit Doppelverbund in Deutschland Überblick und Ergebnisse von Forschungsaufträgen, Bauingenieur 72, Heft 3, 1997, 131-141.

The subject of Jorge Bernabey Larena’s doctoral thesis at the Madrid University were double action composite bridges. After a detailed analysis of the history of such bridges, the author says the following:

> **La primera aplicación que hemos localizado es el puente de Orasje, una realización de 1968, que salva un vano central de 134 m. La obra resulta muy atractiva y sus importantes dimensiones la sitúan como record de luz en su momento (cfr. 4.7.1),**

Fig. 9
Roadway bridge across the River Vistula in Plock (Poland)

a pesar de lo cual no es muy conocida (Hajdin, 1985; Gomez Navarro, 2000b). El tablero presenta una sección transversal de doble viga de canto variable con arrostramientos transversales que se cierra inferiormente en zonas de momentos negativos para constituir una sección cajón (Fig. 4.25; Fig. 4.26). Sobre el fondo del cajón se dispone una losa de hormigón de espesor variable hasta un máximo de 50 cm sobre pilas.

/The first application we found is the Orašje bridge, executed in 1968, which has a central span of 134 m. The bridge is very attractive and its impressive dimensions made it a record structure in terms of span at the time (see 4.7.1), despite the fact that it is not widely known (Hajdin, 1985; Gomez Navarro, 2000b). The cross section of the bridge consists of two steel girders of variable height with horizontal stiffening, which is closed off on the bottom side in the negative moments zone forming a box section (fig. 4. 25, fig. 4.26). A concrete slab of variable thickness up to a maximum of 50 cm above the supports is placed at the bottom of the box./

[13] Bernabeu Larena, J.: Evolucion tipologica y estetica de los puentes mixtos en Europa, Tesis doctoral, Universidad Politecnica de Madrid, 2004.

The statement "despite the fact that it is not widely known" has been used in reference to some other achievements of Serbian authors as well, but we shall not delve into that here.

Third period

Thin-walled girders

During his stay in Switzerland from 1958 to 1959, professor Hajdin got in touch with Curt F. Kollbrunner, a well-known scientist in the area of steel structures. During their cooperation on problems of bar stability and analyses of the behavior of segmental gates on hydro-electric power plants, Kollbrunner suggested that they focus on research into thin-walled girders over the long-term.

At the time this subject matter was very topical and insufficiently researched. Interest in this area grew, among other, due to the speedy development of new technologies: welding in metal structures and pre-stressing in concrete structures. Also, increasingly modern and courageous forms of designing were gaining momentum.

The research of the two scientists in this field started in the early 60's, with some assistance from the Swiss Association for Steel Structures.

Professors Hajdin and Kollbrunner cooperated for over twenty years producing over that period a series of 20 publications of over 2000 pages, mostly in German and to a lesser extent in English. The synthesis of this scientific work are two monographs issued by the "Springer-Verlag" publishing house (*)[15] and (*)[16].

15. Kollbruner, C. F., Hajdin, N.: *Dünnwandige Stäbe. Bd. 1: Stäbe mit underofmierbaren Querschnitten.* – Berlin: Springer-Verlag, 1972. – 296, XII p. ; 26 cm

16. Kollbruner, C. F., Hajdin, N.: *Dünnwandige Stäbe. Bd. 2: Stäbe mit derofmierbaren Querschnitten. Nicht-elastisches Verhalten dünnwandiger Stäbe.* – Berlin: Springer-Verlag, 1975. – 284, XII p. ; 26 cm

Fig. 10
Roadway bridge over the River Vistula in Plock (Poland)

These two fundamental books, together with preceding ones and later publications constitute an opus which is widely cited, used in scientific works, doctoral theses and in the practical designing of complex structures.

These publications which by their comprehensiveness and scientific approach represented an original contribution to science, include parts which reveal a unique theoretical view. In that context, we should, among other, emphasize the general theory of thin-walled girders itself, which brings together two areas, one of which is known as the folded-plate theory, created in the area of concrete structures, and the other exceptionally important in steel structures, known as the deformable cross section theory.

The following quotations describe this subject-matter and stress the originality of the scientific approach.

I. **Der besondere Wert der vorliegenden Arbeit liegt nun darin, dass es gelingt, die bisher klaffende Lücke zwischen diesen beiden Auffassungen zu schließen und die Theorie des dünnwandigen Stabes mit der Theorie des prismatischen Faltwerks auf ein einheitliches Ganzes zu bringen.**

Die Abfassung wird so allgemein vorgenommen, dass in ihr die Theorie des steifknotigen und des gelenkigen Faltwerks sowie die klassische Theorie der Wölbkrafttorsion enthalten sind. Außerdem ermöglichen sich dadurch die Erweiterung der klassischen Faltwerksberechnung auf die zusätzliche Berücksichtigung der Torsionsmomente in den Einzelwänden und die Erweiterung der klassischen Theorie der Wölbkrafttorsion auf Querschnitte, deren Wandstärke nicht klein im Vergleich zu den übrigen linearen Abmessungen ist.

Die übersichtlichen Ableitungen und Darstellungen der hier aufgedeckten Zusammenhänge werden für alle wissenschaftlich interessierten Fachleute, die sich mit den schwierigen Problemen der allgemeinen Belastung von dünnwandigen Stäben mit verschiedensten Querschnittausbildungen befasst haben oder befassen wollen, von besonderem Wert sein und

wesentlich dazu beitragen, die Vereinheitlichung in der Theorie solcher Tragwerke zu schaffen.

/The particular value of the presented work lies in the fact that the gap between these two concepts has been successfully filled and that the thin-walled bar theory and the prismatical shell theory have been represented as a single whole.

The presentation is so general that it contains the folded-plate theory with rigid and hinged nodes as well as the warping torsion theory. In addition, this enables the expansion of the classical calculation of folded-plate shells with the additional taking into account of torsion moments in individual walls and the expansion of the classical warping torsion theory to sections the wall thickness of which is not small in comparison with the other linear dimensions.

The clear presentation and representations of the relations presented here will for all experts interested in science who dealt or will deal with the difficult problems of the general analysis of thin-walled rods with different cross section shapes be of particular value and will significantly contribute to generalization in the theory of such girders./

[14] „Bauingenieur", H.3. 1969.

II. In der vorliegenden Publikation wird die Theorie der dünnwandigen Stäbe mit in ihren Ebenen deformierbaren Querschnitten, bzw. des langen prismatischen Faltwerks nach der Verschiebungsmethode gebracht, wobei einige vereinfachende Voraussetzungen getroffen werden.

Im Unterschied zu den üblichen Methoden in der Theorie der Faltwerke, bei welchen die Zerlegung des Tragwerks in die einzelnen Platten, aus welchen es zusammengesetzt ist, erfolgt, werden in der hier gebrachten Theorie die Deformationen und Spannungen für die als einheitliches Tragwerk aufgefasste

Stabschale abgeleitet. Die in diesem Helft dargelegte Theorie ist derart allgemein abgefasst, dass in ihr als Sonderfälle die Theorien des steifknotigen und des gelenkigen Faltwerks sowie auch die klassische Theorie der Wölbkrafttorsion enthalten sind.

Das Werk schließt sich an die Veröffentlichungen über Wölbkrafttorsion und St.-Venantsche Torsion in der Schriftenreihe „Mitteilungen der TKSSV“ an und ist mit der gleichen Exaktheit durchgearbeitet, die auch jene früheren Werke der gleichen Verfasser auszeichnet. Das Studium erfordert nebst ausgesprochenem mathematischem Geschick ein enormes Einfühlungs vermögen in den Verformungsmechanismus wie auch in die Zusammenhänge zwischen Verformungen und zugeordneten Beanspruchungen.

/The presented work presents the thin-walled bar theory with deformable cross section i.e. long prismatic folded-plate shells according to the deformation method, with some simplified assumptions being taken account of.

As opposed to the usual methods in the folded-plate theory, where girders are broken down into the individual plates comprising them, the theory presented here gives deformations and stress for the whole girder. The theory presented in this volume is so general that it contains, as separate, cases of the folded-plate theory with rigid and hinged nodes as the classical warping torsion theory.

The work continues on to the published works on warping torsion and Saint-Venant's torsion in the publications "Mitteilungen der TKSSV" and has been elaborated with the same precision as featuring in the earlier works of the same authors. In addition to an acutely keen mathematical sense this research also requires vast intuition in respect of the deformation mechanisms and the stress-strain relations./

[15] Schweizer Baublatt, No 6, Jan. 1969.

Fig. 11
Railway bridge over the Sava River in Belgrade
Photograph by: Branislav Tomić

III. The rod is analyzed with plate theory, where it is assumed that the deflections of the plates out of their planes are third-degree polynomials in cross sectional direction, their coefficients being the unknown functions of the coordinate in length direction. This leads to coupled ordinary differential equations which are solved by matrix methods. Different end conditions are properly taken into account. As is to be expected, torsion with different warping conditions is an important case. Where it was adequate, a simplifying condition for the membrane shear strain and a membrane normal strain in the plates was introduced.

The second half of the book deals with nonelastic behavior of rods. This means plastic behavior of metal structures and creep of (reinforced) concrete structures. The general theory is not for thin/walled rods, only most applications are.

The book gives a unitary treatment to various problems with many examples of modern interest in structural and civil engineering. It is rich in numerical data and graphics. As usual with this publisher, the layout is excellent.

[16] Applied Mechanics Reviews, USA, Vol.29, February 1976

IV. La trattazione é di elevato livello, i mezzi matematici usati piuttosto complessi. D'altra parte il fatto che sia con l'accialo, sia con il calcestruzzo, si costruisce con spessori sempre più sottili, rende necessario l'impiego e la conoscenza di questi procedimenti di calcolo. In compenso il loro impiego è reso possibile dalle sempre migliori prestazioni di calcolatori elettronici, che permettono di eseguire calcoli che dieci anni fa non erano pensabili, II V, il VII, I'VIII capitolo sono pertanto decisamente suscettibili di applicazioni pratiche di progetto avanzato, mentre il VII capitolo ha carattere più scientifico e monografico.

Si tratta in conclusione di un testo utile ad un ingegnere progettista di elevato livello ed a ricercatori o studenti di corsi di perfezionamento post-laurea, che vogliano specializzarsi nel calcolo di strutture, sia metalliche, sia in calcestruzzo armato, in particolare precompresso.

/The presentation is at a high level and the applied mathematical means are for the most part complex. On the other hand, the fact that this procedure refers to structures which are always of small thickness, whether of steel or concrete, renders necessary the use and knowledge of this method of calculation. As for the use of this method, that can be achieved thanks to the the ever-better performance of computers, which enable calculations unimaginable a decade ago. Chapters V, VI and VII for the most part contain examples of the above-mentioned project, while Chapter VIII is more of a scientific and monographic nature.

The conclusion may be drawn that this is a useful text for designers at a higher level as well as for researchers and post-graduate students wishing to specialize in calculations of structures, both metal and reinforced concrete and especially pre-stressed ones./

[17] Rivista de meccanica, Italien, Nr. 607, 1975.

V. **Diese Arbeit entstand in dem Bestreben, die Theorie des prismatischen Faltwerkes u. die Theorie des dünnwandigen Stabes zu einem einheitlichen Ganzen zu verbinden. Die Lösung des Problems der Berechnung des Faltwerkes erfolgt hier durch konsequente Anwendung der Verschiebungsmethode, wobei die Stab/Schale als einheitliches Tragwerk aufgefasst wird. Die dargelegte Theorie ist so allgemein abgefasst, dass die Theorien des steifknotigen u. des gelenkigen Faltwerks sowie die klassische Theorie der Wölbkrafttorsion in ihr als Sonderfälle enthalten sind.**

/This work is the result of the wish to link the prismatical folded-plate theory and the thin-walled bar theory into a single system. The solution to the problem of folded-plate shell calculation is presented here through the consequential application of the method of deformation where the bar/shell is treated as a single girder. The presented theory is so general that the theory of folded shell with rigid and hinged nodes, as well

as the classical warping torsion theory are contained in it as individual cases./

[18] Schrifttumkartei Bauwesen, 1969, Lfg. 3, Nr 546

These publications of professor Hajdin's explain the sense of some simpler but also less correct theories of girders with a closed cross section and present a completely proper approach to the problem.

Noel W. Murray drew attention to this circumstance in his book "Introduction to the Theory of Thin-walled Structures":

In the earlier parts of this book an approximate theory for closed profiles due to von Karman and Christensen (1944) has been described.

In certain cases where the longitudinal warping stresses σ_W are large and change rapidly, this theory is not accurate. A 'more accurate analysis' was developed by Benscoter *1954 (to overcome this problem. Both theories are detailed in the excellent volume published by Kollbrunner and Hajdin (1965)

[19] N. W. Murray: Introduction to the Theory of Thin-Walled Structures. The Oxford Engineering Science Series. Clarendon Press, 1984.

The afore-mentioned publications from this period also give a scientific contribution to the theory of composite structures which was discussed in the preceding chapter.

Finally, here are some further observations:

VI. Курт Колбруннер – известный специалист в области расчета тонкостенных стержневых систем, директор Научно-исследовательского строительного института в Цюрихе, опубликовал пять монографий по обсуждаемой проблеме. Николай Наждин – профессор Белградского университета – провел совместно с первым автором ряд исследований. Все эти результаты будут суммированы в двухтомной монографии, том 1 которой, посвященный упругим стержням недеформируемого контура поперечного сечения, рецензируется. Том 2 будет посвящен стержням с недеформируемым

Fig. 12
Roadway bridge over the River Vistula in Plock (Poland)

контуром поперечного сечения и неупругому поведению тонкостенных стержней.

Монография содержит обстоятельное и весьма квалифицированное изложение обсуждаемых вопросов и включает обширную библиографию. Ее можно рекомендовать и научным работникам и инженерам проектировщикам.

/Kurt Kollbrunner, a renowned expert in the area of thin-walled bar calculation, the director of the Scientific Research Civil Engineering Institute in Zurich, published five monographs on this subject. Nikola (Hajdin) is a professor at Belgrade University and together with the former undertook extensive research. All these results will be summed up in a two-volume monograph, the first volume of which, devoted to elastic rods with undeformable cross section contour, is currently being revised. Volume II will be devoted to rods with undeformable cross section contour and the non-elastic behavior of thin-walled rods.

The monograph exhaustively and very authoritatively presents the examined issues and contains an extensive bibliography. It can be recommended to scientific workers and engineers designers./

[20] Nowuje Knigi sa rubjeschom (UDSSR), 2, Serie A, 1974 Mathematik

VII. **Zusammenfassend sei gesagt, dass viele Kapitel eine Weiterentwicklung des bisherigen Stands der Wissenschaft bedeuten; die Darstellung ist übersichtlich und wird klar mit allgemein bekannten mathematischen Methoden durchgeführt. Deshalb verdient das Werk Lob und kann allen Interessierten sehr empfohlen werden.**

/To sum up, the numerous chapters mark further steps in this science; the presentation is easy to follow and is conducted by employing known mathematical methods. The work is therefore highly commendable and highly recommended to all interested./

[21] Konstruktion im Maschinen – Apparate – und Gerätebau, Heft 9, 1976

Fourth period

Cable-stayed bridges

a) Railway Bridge in Belgrade

Marking the early 1960's was the appearance of a new system, the system of cable-stayed bridges, which would in less than half a century become the dominant one for large span bridges. Superior in the economic and aesthetic sense, in the beginning for medium spans, today this system competes with suspended bridges even for spans over a thousand meters.

Appreciating the significance of this novelty, professor Hajdin devoted from the very beginning a considerable amount of his time to studying this system. He was greatly aided in this respect, inter alia, by his knowledge of and scientific work in the area of thin-walled girders, in particular of problems outside the classical structural mechanics theory, primarily the problem of torsion.

In the early 70's, when this system was in its incipient stage of development, and when no more than some ten large bridges had been executed, professor Hajdin got the opportunity to have a go at designing and building such a system. Namely, at that time, projects were invited for the construction of a new railway bridge in Belgrade, with a span of approximately 250 meters.

Together with professor Jevtović, he accepted to design this bridge as a cable-stayed bridge, and in fact, as the very first bridge of this system for railway traffic in the world.

Opinions concerning the application of this system for railway traffic, in the world and in the country, were negative at that time, and, generally speaking, justified, in view of the following reasons:

The system is relatively flexible and "soft" for railway traffic, and the deflections due to traffic load are in principle greater than with classical bridges.

Accordingly, vertical vibrations beyond acquired experiences were also to be expected, which could contribute to traffic discomfort and compromise safety.

Apart from that, material fatigue, especially of cables, bearing in mind the considerably greater loading of railway traffic compared to vehicular traffic, posed a problem in itself.

And, finally, the railway bridge as it was conceived had a record span for railway traffic.

All these unfavorable elements were eliminated in the designing stage by the very concept of the bridge and the use of a new type of cables (strands) unknown until then and more fatigue-resistant.

The project as a whole was based on a series of studies, including a small-scale model and several papers (*)[17], (*)[18], (*)[19] published in scientific and specialized literature.

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17. K o l l b r u n e r, C. F., H a j d i n, N., S t i p a n i ć, B.: *Contribution to the Analysis of Cable-Stayed Bridges*. – Zürich: Verlag Schulthess AG, 1980. – 45 p.; 23 cm. – (Institut für bauwissenshaftliche Forschung. Stiftung Kollbrunner/Rodio ; 48)
18. H a j d i n, N.: *Vergleich zwischen den Paralleldrahsteilen und Vershlossenen Seilen am Beispiel der Eisenbahnschrägseilbrücke über die Save in Belgrad. – Comparison between Parallel Wire Bundles and Closed Ropes Illustrated on the Cable Stayed Railway Bridge over the River Save in Belgrade. – Comparasion entre les câbles à fils parallèles et les câbles torsadés dans la cas du pont de chemin de fer haubanné sur la Save à Belgrade*. Dixième congrès de l'Association internationale des ponts et charpentes, Tokyo, September 6-11, 1976: rapport préliminaire. Zürich: Secrétariat de l' AIPC, 1976. p. 471-475.
19. K o l l b r u n n e r, C. F., H a j d i n, N., S t i p a n i ć, B.: *Contribution to the Analysis of Cable-Stayed Bridges*. Bridge Engineering Japan [in Japanese]. 19: 6,7 (1983) 16-23, 20-28.

Fig. 13
Railway bridge over the Sava River in Belgrade
Photograph by: Branislav Tomić

Following the design, the bridge itself was executed, which was an absolute novelty in world bridge-building and proof of our relatively developed technology.

The design having been completed in the early 70's, the bridge started to be built in 1974 and was completed in 1979.

Following are some of its basic technical characteristics:

The total length of the railway bridge over the Sava River and between the Novi Beograd and "Prokop" stations is 1928 m. It consists of main structure over the river and access lanes on the left and right banks. **This system for railway bridge with cable stays was practically the first one of its kind to be built in the world, as until then bridges of this system, similar to suspended ones, had been considered too flexible for railway traffic.**

The main bridge structure – the central part – is a continuous girder (a stiffening girder) with spans of 52.74 + 85.00 + 254.00 + 50.00 + 64.20 = 555.94 m, with cable stays in the central span. The stiffening girder consists of a twin box girder of a constant height of 4.45 m, mutually connected by orthotropic deck which bears the bridge floor and tracks. On both sides of the main span there are a couple of vertical pylons fixed in the stiffening girder. The cable stays are distributed in two vertical planes and they connect to the stiffening girder at about every fifth of the 254 m span; all cables are anchored above the supports of the 50 m lateral spans. By adopting steel cables with parallel wires of the BBR system with exceptionally fatigue-resistant Hi-Am anchor heads, and with measures to increase the bridge mass, excellent tension efficiency was obtained, excellent stress of the cables for constant load and a small influence of cable elongation on the deflection of the structure.

It should be mentioned that this was the first time cables of this type were used in Europe. From that time up to this day this type of cables is the dominant cable type for cable-stayed bridges in the world.

The bridge has been shown in a number of the author's publications of which we particularly single out (*)[20], (*)[21], (*)[22] and (*)[23].

It has been cited in a whole series of works, and the following quotation also gives some assessments:

> **A further proof of the cable stayed bridges' ability to carry heavy railway loading was delivered by the pure railway bridge across the Save River in Belgrade, Yugoslavia** (Figure 1.47) With a main span of 254 m, this bridge carried two tracks subjected to full railway loading including heavy freight trains with a wagon load of 72 kN/m on each track.

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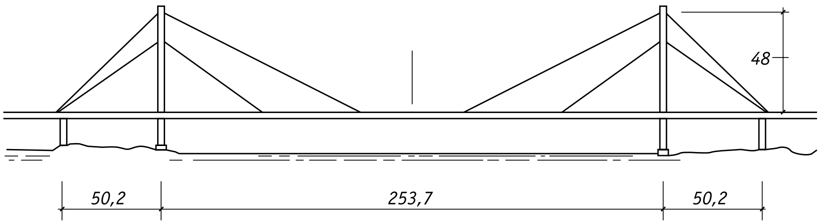
20. H a j d i n, N., J e v t o v i ć . Lj.: *Eisenbahnschräseilbrücke über die Save in Belgrad.* Der Stahlbau. 48: 4 (1978) 97-106.
21. Х а ј д и н , Н., Ј е в т о в и ћ , Љ., Ц в е т к о в и ћ , С., М а т и ћ , В.: *Нови железнички мост преко Саве у Београду. – (New Railway Bridge over Sava River in Belgrade).* VI конгрес Југословенског друштва грађевинских конструктора, Блед 26-29. 9. 1978. Београд: ЈДГК, 1978. Књ. Мостови-М, стр. 81-100. М 9
22. H a j d i n, N., J e v t o v i ć, Lj., C v e t k o v i ć, S., M a t i ć, V.: *The Railway Cable-stayed Bridge over River Sava in Belgrade.* IABSE Periodica 4 (1979): IABSE Structures C – 10 /79 – Bridges I. p. 30.
23. H a j d i n, N., C v e t k o v i ć, S.: *Some Yugoslav experiences in Design and Construction of Long-Span Bridges.* Steel Structures: Advances, Design and Construction / Ed. by R. Narayanan. London and New York: Elsevier Applied Science, 1987. p. 44-53.



Railway Bridge across the Save River in Belgrade, Yugoslavia

To obtain the required stiffness of the cable system, the length of the adjoining side span was chosen to be as little as 0.197 of the main span length. Furthermore, both stays of the main span (where the cable system could be described as a modified harp) were connected at the pylon to anchor cables attached to the stiffening girder at the ends of the side spans adjoining the main span.

A twin box stiffening girder was also used in the steel railway bridge across the Save River in Beograd. Here the box girders, placed outside the railway area, are of rectangular shape, as seen in Figure 4.70. In the main boxes the plate thicknesses vary between 12 and 50 mm. The two box girders are connected by an orthotropic steel deck with a 10 mm thick deck plate stiffened by longitudinal ribs at 400 mm distance and by floor beams spaced 2.5 m apart. To improve the transversal distribution of eccentric loads every sixth floor is 4.43 m corresponding to 1/57 of the main span length (254 m).

[22] N. J. Gimsing: Cable Supported Bridges. Concept and design. (Book). John Wiley & Sons, 1983.

Fig. 14
Railway bridge over the Sava River in Belgrade

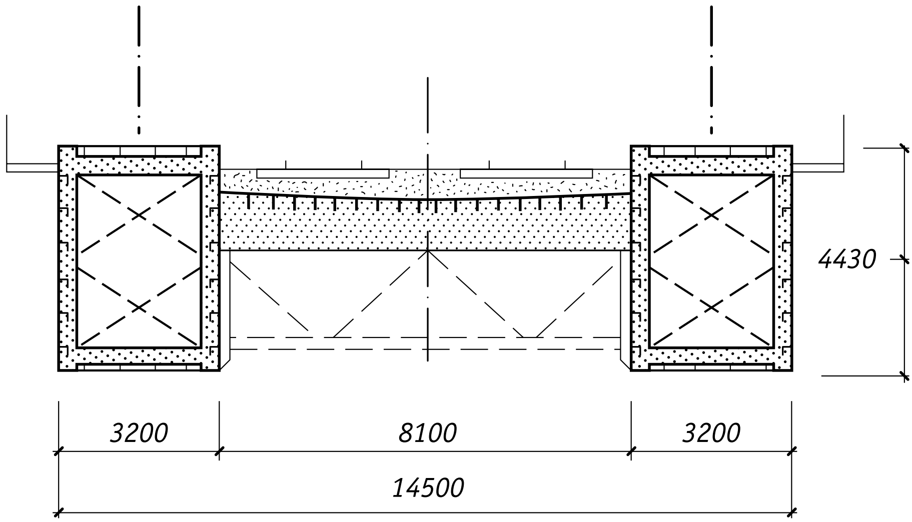


Fig. 15 – Cross-section of stiffening girder on the Railway Bridge across the Sava River in Belgrade

Numerous different publications refer to this bridge as the first railway traffic bridge employing this system:

First cable stayed bridge built solely for railway traffic.

[23] „Structure“ International data base and Gallery of Structures.

In respect of cable fatigue, the author’s work (*)[24] on cable fatigue applicable to the designing of a railway bridge which was undertaken as the theoretical basis for designing is cited.

A paper by a group of authors underlines the importance of this research:

> Long cables made–up of many parallel wires or strands are used in cable-stayed bridges or similar structures. **The specialized literature [3,32] presents the fatigue strength of the cables as a governing criterion for the design of such structures. Therefore, the knowledge of the statistical behavior under fatigue becomes essential.**
>
> [24] E. Castillo, A. F. Canteli, V. Esslinger, B. Thürlimann: Statistical Model for Fatique Analysis of Wires, Strands and Cables. IABSE Proceedings P-82, IABSE Periodica 1/1985, Periodica AIPC, IVHB Periodica, Februar 1985.

In a paper by W. Andra and R. Saul, they stress that the same article (*)[24] analyzes cable fatigue for the first time:

> Statistisch verwertbare Dauerfestigkeitsprüfungen für die hier interessierenden Drähte wuerden in grösserem Umfang erstamls für die Paralleldrahtbündel der Eisenbahnbrücke über die Save in Belgrad [8] gemacht.

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24. H a j d i n, N.: V*ergleich zwischen den Paralleldrahsteilen und Vershlossenen Seilen am Beispiel der Eisenbahnschrägseilbrücke über die Save in Belgrad. – Comparison between Parallel Wire Bundles and Closed Ropes Illustrated on the Cable Stayed Railway Bridge over the River Save in Belgrade. – Comparasion entre les câbles à fils parallèles et les câbles torsadés dans la cas du pont de chemin de fer haubanné sur la Save à Belgrade.* Dixième congrès de l'Association internationale des ponts et charpentes, Tokyo, September 6-11, 1976: rapport préliminaire. Zürich: Secrétariat de l' AIPC, 1976. p. 471-475.

/Statistically processed tests of cable fatigue for strands were undertaken on a larger scale for the first time for the parallel strand cables of the railway bridge over the River Sava in Belgrade./

[25] W. Andra, R. Saul: Festigkeit, insbesondere Dauerfestigkeit langer Paralleldraht – bündel. – Der Bautechnik, H. 4, 1979.

The bridge was also shown in the Engineering News –Record journal.

Yugoslav building cable-stayed railway span

Yugoslavia is building the world's first cable-stayed railway bridge, which will cross the Sava River at Belgrade.

The cable/stayed portion of the crossing has a 833-ft main span flanked by 164-ft side spans. Including three side spans not cable supported, the bridge is continuous over six spans.

The crossing was designed by Nikola Hajdin, a Belgrade University engineering professor and dean, and Ljubomir Jevtovic, consultant at Kirilo Savic Institute, for civil and processing engineering, Belgrade. They point out that the prime problems were fatigue strength and dynamic loading, which are greater on a rail bridge than on a vehicular bridge. Deflection under load, which they limited to 1/500 th, was another design consideration.

Each of two double-leg pylons support two pairs of cables. The cables, made up of 250 to 300 parallel steel strands in a polyethylane casing, are cut and anchored individually to each pylon leg. From each pylon, they connect to the main span and two side spans, each pair at different angels.

The superstructure consists of two steel box girders joined by an orthotropic plate. The girders are supported on concrete piers.

A test model was constructed and tested at Belgrade University to check out static behavior, free vibration and vibrations under load. Free vibration of the cable agreed closely with theoretical values.

The bridge is scheduled for completion by the end of next year.

[26] Engineering News-Record, July, 29, 1976

The Chinese Yingliang Wang encyclopedia of the most important bridges of Europe and America over the past 200 years, lists this bridge as well as three other bridges by Nikola Hajdin.

The text describes the basic characteristics of those bridges by Nikola Hajdin and contains a tabular survey.

尼古拉·哈丁(Nikola Hajdin)

尼古拉·哈丁是著名桥梁专家、前南斯拉夫科学院院士。

1923年4月23日生于塞尔维亚的Vrbovsko。

1951年毕业于贝尔格莱德大学土木系。

1956年获得贝尔格莱德大学博士学位。

主要研究结构力学、板壳强度理论。

桥名	建成时间	桥型	跨度	主要工作	附注
Orašje Bridge	1968	结合梁	134	设计	
Railroad Cable-Stayed Bridge Across the River Sava	1979	斜拉桥	254	设计	铁路桥
Sloboda Bridge	1981	斜拉桥	351	设计	
New Plock Bridge	2005	斜拉桥	375	设计	

In the Foreword, the author says, inter alia:

> (1)首先通过设计师介绍他们设计的主要桥梁、让读者品读这些欧美流派的世界名桥、这只是停留在知识的层面。
>
> (2)通过设计师设计的多座桥梁、我们可以看出他们在设计这些世界名桥的思维方式、当时这些设计方案是如何形成的、设计师设计的一系列桥梁后面又隐藏了怎样的思维转变过程。作者采用还原历史、比较、分析等方法、将不同桥型、方案进行比较、论证、有的地方可能没有结论(实际上也不可能得到结论)、但是通过多方面、多视角的比较和论证、就可以看到设计师的思维演变、最重要的是形成这些构思的过程。从这个层面来说是在探索大家智慧(智慧不同于知识、智慧是方法论、是正确的思维方式。随着时间流逝、知识可能过时了、但设计师的智慧是永存的)。
>
> 感谢著名桥梁专家Jean Muller生前对作者的帮助、感谢国际桥梁与结构工程协会 (IABSE) 副主席、美国科学和艺术外籍院士 Jörg Schlaich、国际预应力混凝土协会 (FIB) 名誉主席、国际桥梁与结构工程协会 (IABSE) 副主席Michel Virlogeux 先生、德国莱昂哈特 - 安德鲁公司技术懂事、IABSE 副主席Holger S. Svensson 先生、塞尔维亚科学院院长 Nikola Hajdin 院士、Christian Menn 教授、法国 JMI 国际公司前技术董事 Serge Montens 先生、西班牙 Leonardo Fernández Troyano 教授提供了部分资料、在百忙中校核了部分书稿、提出了很好的修建意见。
>
> 本书涉及的内容繁多、由于时间和笔者的水平有限、肯定存在不够完善和不当之处、恳请各位专家、同行和读者指正！
>
> 作者：王应良 2007 年 8 月

/(1) The author presents famous bridges in the world through their designers, and enables the readers to familiarize themselves with and understand the technology of famous bridges of Europe and America.

(2) These famous bridges enable us to grasp the thinking and wisdom of their designers and how the designs of well-known bridges are arrived at and how the ides of their designers evolve. The author compared different solutions of bridges by going back into history, comparing and analyzing. Although sometimes we are unable to fully understand (sometimes due to the impossibility of obtaining a result), we are able to follow the course and different aspects of transformation of the designer's train of thought. It is a treatise on wisdom. (Wisdom differs from knowledge. Wisdom is an exact way of thinking. As time goes by, the knowledge of the designer may become outdated, but the wisdom of the designer is eternal).

We owe great gratitude to the renowned expert on bridges Jean Muller who designed many bridges in France. Thanks is due to Jörg Schlaich, (Vice-president of IABSE, foreign member of the American Academy of Arts and Sciences), Michel Virlogeux, (Vice-president of IABSE, honorary president of the International Pre-Stress Association), Holger Svenson, (Vice-president of IABSE) technical director of "Leonhardt, Andrä and Partner", **to academician Nikola Hajdin (President of the Serbian Academy of Sciences and Arts)**, professor Christian Menn, Serge Montens (former technical director of "Jean Muller International") and professor Leonardo Fernández Troyano), who provided the documents, checked some books and gave some good advice./

[27] Design Thinking of Europe and America Bridges, 2007 [(5.1)242-248]

b) The "Sloboda" roadway bridge over the River Danube in Novi Sad

The roadway bridge in Novi Sad constitutes a further step forward in mastering the technology of cable-stayed structures applied to large bridges.

The principal structure of the roadway bridge across the River Danube in Novi Sad is a cable-stayed girder system. **With a span of 351 m, at the moment of building, this structure represented a world record for bridges of this type, with pylons and stays in the median plane of the bridge.**

The bridge consists of, starting from the Novi Sad side (left bank): a) pre-stressed concrete 301 m long bank structure, b) left bank composite access structure with spans 4 x 60 = 240 m, c) main steel cable-stayed girder system structure with spans of 2 x 60 + 351 + 2 x 60 = 591 m, and d) right bank composite access structure with spans 3 x 60 = 180 m. The total length of the bridge is 1312 m. The bridge was designed with six traffic lanes.

The main bridge structure is certainly the most prominent and the most complex section of the entire bridge. The stiffening girder or the main bridge has a trapezoid box cross section. The height of the box is 3.8 m, the width of the lower plate is 13.0 m and of the upper one 27.48 m, 16 m of the length of which is a component part of the closed profile. The bridge pylons are above the columns at the ends of the main span, located at the bridge axis and fixed into the stiffening girder. Three groups of steel ropes, with four cables of parallel strands each, starting from the pylon are attached to the main girder at intervals of 54 + 48 + 48 m, symmetrically on both sides in a harp-like configuration.

The bridge was partly demolished in 1999 during NATO's aggression, and underwent reconstruction from 2002 fully in accordance with the original design. The reconstruction was finished in October 2005.

In the analysis and calculation the know-how of the period was drawn upon, it being noted, however, that given its span, the bridge was to a certain extent an extrapolation in constructing a bridge with a record span for bridges with one vertical cables plane.

Fig. 16
The "Sloboda" roadway bridge over the River Danube in Novi Sad - after reconstruction
Photo: Zoran Jonić

Fig. 17
The “Sloboda” roadway bridge over the River Danube in Novi Sad - after destruction

Fig. 18
The “Sloboda” roadway bridge over the River Danube in Novi Sad - under reconstruction

Fig. 19
The “Sloboda” roadway bridge over the River Danube in Novi Sad – after reconstruction

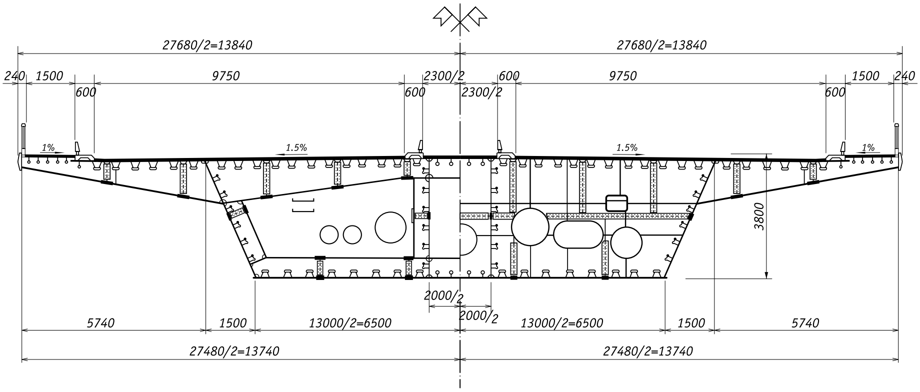

Fig. 20 – The “Sloboda” roadway bridge over the River Danube in Novi Sad – cross section

The bridge has been shown in a number of the author’s publications of which we particularly single out (*)[25], (*)[26], (*)[27], (*)[28], (*)[29], (*)[30], (*)[31], and (*)[32].

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25. Хајдин, Н.: *Мост* «23. октобар» *преко Дунава у Новом Саду (Bridge* “23 oktobar” *over river Danube in Novi Sad).* Изградња. 33: 7 (1979) 9-18. Исто: Изградња. 11-12 (1986) 70-79.
26. Hajdin, N., Dinić, S., Müller, H. R.: *Construction of the Cable-Stayed Bridge «Sloboda» (Bridge of Freedom) over the River Danube, Novi Sad, Yugoslavia.* The Ninth International Congress of the FIP, Stockholm, June 6-10 1982. Stockholm: FIP, 1982. p. 1-16.
27. *Хајдин*, Н., Гојковић. Љ.: *Изградња моста Слободе преко Дунава у Новом Саду (Construction of the Bridge “Sloboda” (“23 Oktobar”).* Наше грађевинарство. 37: 8 (1983) 1051-1058.
28. Hajdin, N.: *Strassenbrücke «SLOBODA» über die Donau in Novi Sad*. Der Stahlbau (Berlin). 52: 4 (April 1983) 97-103.
29. Hajdin, N., Cvetković, S.: *Some Yugoslav experiences in Design and Construction of Long-Span Bridges*. Steel Structures: Advances, Design and Construction / Ed. by R. Narayanan. London and New York: Elsevier Applied Science, 1987. p. 44-53.
30. Hajdin, N., Srećković, G., Lukić, D., Lazović, M., Mandić, R.: *Review of Damage and Reparation of Piers on Bombed and destroyed Bridge Sloboda over Danube in Novi Sad.* Proceedings 4th International Conference on Bridges Across the Danube 2001, Bratislava, Slovakia, September 13-15, 2001. p. 293-298.
31. Hajdin, N.: *Reconstruction of the Bridge Sloboda in Novi Sad*. Proceedings 4th International Conference on Bridges Accross the Danube 2001, Bratislava, September 13-15, 2001. Bratislava, 2001. p. 359-365.

The bridge has been cited several hundred times in specialized and scientific literature, including texts about the demolition of the bridge and its reconstruction. To that should be added the enormous number of citations in the domestic and foreign press about this bridge, its original version, its demolition, its construction and its new version, which is, as we have already stated, the same as the original design.

c) Cable-Stayed Roadway Bridge (375 m span) over the River Vistula (Poland) with B. Stipanić

The design of this bridge and its subsequent construction according to that design resulted from winning at an anonymous international competition in which 16 companies and individuals from Poland and elsewhere in Europe participated.

> The total length of the bridge is 1,200 m, 615 m of which is the length of the main bridge section over the Vistula riverbed, and 585 is the length of the access routes of the bridge over the inundation. The main bridge structure is a symmetrical steel structure, a cable-stayed bridge consisting of: a continuous girder (with spans 2 x 60 + 375 + 2 x 60 m), cable stays and two pylons.
>
> The bridge deck is of a torsionally stiff tricellular cross section of trapezoid shape (height 3.5 m, width of the bottom flange of the box 13.0 m, width of the top flange of the box 16.5 m), with cantilevers of 5.5 m each. The pylons, to which the cable stays transfer their tensile forces, are of steel and are fixed in the bridge deck. The cable-stays are placed in the median vertical plane of the bridge in a so-called modified harp distribution. Each cable stay consists of two individual cables (ropes) at a mutual axial distance of 750 mm.
>
> The bridge bearings of neoprene-teflon. The bridge columns are of reinforced concrete, of rounded form with clearly differentiated parts: the head, the shaft and the foot of the column.
>
> **The record 375 m span is among the largest spans in the world for cable-stayed bridges and cables in one, median plane.** The bridge was completed in 2005.

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32. H a j d i n, N.: *Destruction and Reconstruction of the Sloboda Bridge in Novi Sad.* First International Conference on Bridge Maintenance, Safety and Management (IABMAS 2002), Barcelona, July 14 – 17, 2002. Barcelona: International Center for Numerical Methods in Engineering (CIMNE), 2002. p. 1-8.

Fig. 21
Roadway Bridge over the River Vistula in Plock (Poland)

The bridge is a logical continuation of the idea previously applied to the *Sloboda* bridge and is yet another step forward in the development of cable-stayed bridges, in view of the fact that it was built over two decades after the erection of the *Sloboda* bridge.

This primarily refers to the system of cables which features greater density in the distribution of ropes, which can be ascribed to the prevalent tendency in constructing this type of bridges and which in the opinions of some, contributes to the aesthetic appearance. Apart from that, this bridge, with its span of 375 m, approximates the limit to which it is rationally possible to design bridges with one vertical cables plane.

The bridge has been shown in a number of the author's publications of which we particularly single out (*)[33], (*)[34], (*)[35], (*)[36], and (*)[37].

The bridge has been cited in a monograph by Jan Biliszczuk as the largest bridge of any system in Poland.

Biliszczuk, J.: Mosty podwieszone – projektowanie i realizacja. Arkady, Warszawa, 2005.

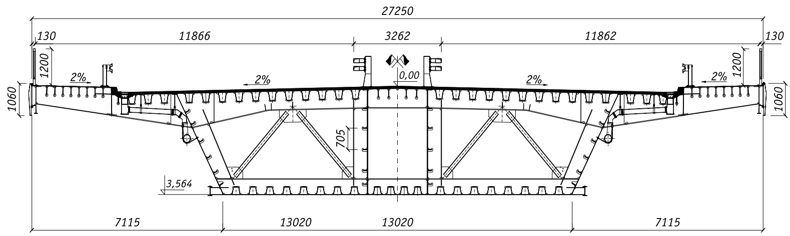

Fig. 22 – Roadway Bridge over the River Vistula in Plock (Poland) – cross section

33. Hajdin, N., Stipanić, B.: *Design of Bridge Over Vistula River in Plock – First Prize on the International Competition*. Proceedings IMS Institute (Belgrade). 25: 1 (1998) 5-13.
34. Hajdin, N., Stipanić, B.: *Cable-Stayed Bridge Across the Vistula River in Plock*. Proceedings of the Conference Eurosteel '99. Praha: ČVUT, 1999. p. 459-462.
35. Hajdin, N., Stipanić, B., Krawczyk, J., Wachalski, K.: *The Roadway Bridge over Vistula River in Plock (Poland), Design and Construction*. Bridges in Danube Basin: Proceedings of the 5th Int. conf. on Bridges across the Danube Novi Sad: Euro Gardi Group, 2004. Vol. I, p. 359-370.
36. Hajdin N., Stipanić B., Krawczyk J., Wachalski K.: *Cable-Stayed Bridge Structure over Vistula River as Main Part of the Roadway Bridge in Plock.* Proceedings of Seminarium "Mosty Podwieszone i Wiszace", Politechnika Wroclawska. Wroclaw: DWE, 2005. p. 154-162.
37. Hajdin N., Stipanić B., Krawczyk J., Wachalski K.: *The Cable-Stayed Bridge across Vistula River in Plock.* Proceedings of the International Conference on Bridges, Dubrovnik, May 2006. Zagreb: SECON, HDGK, 2006. p. 135-142.

Fifth period

Vehicle impact

From 1993, thanks to cooperation with Swiss organizations, in his work Professor Hajdin focused on studying the problem of vehicle impact on engineering structures, initially the problem of the impact of railway trains on civil engineering structures and somewhat later on the problem of the impact of vessels on primarily bridge piers in rivers.

Both types of studies were to a certain extent applicable to calculations of contemporary structures exposed to these types of impact.

At this juncture we shall only say something about the problem of the impact of vessels which has been analyzed and published in a number of professor Hajdin's works: (*)[38], (*)[39], (*)[40], and (*)[41].

The essence of this interesting and important problem of dynamics requires a parallel analysis of the vessel and its behavior at impact and of the civil engineering structure itself, most often bridge piers.

This typically interdisciplinary problem led professor Hajdin into the field of constructions in shipbuilding, in particular the problem of vessel deformations. The problem went beyond a dynamic analysis of vessels of

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38. Grob, J., Hajdin, N.: *Schiffsanprall.* Schweizer Ingenieur und Architekt. 30-31(1995) 1-8.
39. Hajdin, N., Mandić, R.: *Ship Collision with Bridges: a Contribution to the Standardization of Vessel Impact Forces for the Bridges on the Danube.* Proceedings / The Second International Conference "Bridges over the Danube", Cernavoda, 11-15 September 1995. p. 113-119.
40. Grob, J., Hajdin, N.: *Ship Impact on Inland Waterways.* Structural Engineering International. 4 (1996) 230-236.
41. Hajdin, R., Adey, B. T., Hajdin, N.: *Probable occurrence of ship impact forces on bridge piers in inland waterways.* IABMAS Conference "Bridge Maintenance, Safety and Management", Kyoto, Japan, October 19-22, 2004. p. 8.

the kind undertaken in the process of their construction. Small deformations up to the appearance and evolution of small plastic deformations are usually analyzed at that stage.

In impact analysis, large (crushing) deformations are in question, which, *inter alia*, also result in shortening the vessel by even several meters.

Thanks to some existing experimental data of Meier Doernberg (*)[42], professor Hajdin developed, together with R. Mandić, a practical model which proved successful in analyzing the problem of impact. (*)[43], (*)[44].

The model has a complex structure encompassing deformations of the vessel's deck and hull and the corresponding forces causing the deformations. At this point we shall not go into their calculation, which has several parts, account being taken of deck or hull deformation in their planes as well as of deformation which is characteristic of the so-called "folding" of elements on successive changes of the deformation force.

The results of that work, in addition to having been described in the mentioned papers, were also used in the proposed recommendations (*)[45] for calculations of structures on water in the Rhine sector, primarily on Swiss territory.

This problem, as well as the problem of the impact of railway trains, has, in view of the density of traffic and means of transportation, become very relevant to analyzing civil engineering structures, in addition to seismic analysis, and, in terms of importance falls into the category of extraordinary influences such as earthquakes, explosions or accidents caused by terrorist attacks.

It would greatly serve the interests of science if younger researchers devoted attention to these and similar problems.

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42. M e i e r D o e r n b e r g: *„Knautschkraefte und Verformngen der Bugpatien von Motorgueterschiffen bezueglich Anfahren an Pfeiler und Waende 2"*, Teilbericht TH Darmstadt, 1988.
43. H a j d i n, N., M a n d i ć, R.: *Ship Collision with Civil Engineering Structures*. Bulletin / Acadèmie serbe des sciences et des arts. Classe des sciences techniques. 120 : 28 (2000) 15-27
44. H a j d i n, N., M a n d i ć, R.: *Crushing of Ship's Bow Structure During Collision with Bridge Piers*. Proceedings of the 6th National Congress of Mechanics,Thessaloniki, July 19-21, 2001: dedicated to the memory of P.S. Theocaris. Thessaloniki: Hellenic Society of Theoretical and Applied Mechanics: Aristotle University, 2001. Vol. I, p. 178-183.
45. Kanton Basel Stadt Richtlinien Betreffend Entwurf und Bemessung von durch Schiffsanprall gefardeten Bauwerken Basel, Nov. 1993.

Sixth period

Patch loading

(Stability and bearing capacity of steel girders)

As already mentioned above, the first publications which came out as a result of professor Hajdin's cooperation with Kollbrunner concerned the problem of the stability of rods with a changeable section i.e. linear elements.

In the mid-seventies, professor Hajdin published a series of works addressing the problem of the stability and ultimate resistance of plate girders i.e. plate buckling problems. At that time, following a series of bridge failures, both theoretical and experimental research was intensified worldwide into the various aspects of the stability and carrying capacity of steel girders. In his works, professor Hajdin analyzes the latest state-of-the-art and its application within the framework of our regulations to the calculation of steel structures.

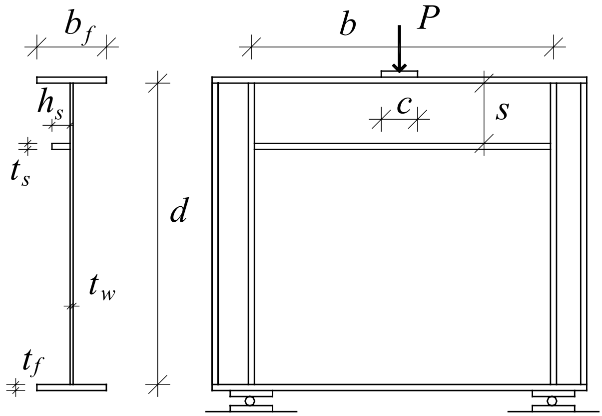

Fig. 23 – "Patch loading"

In the late 70s, particular attention started to be devoted in the world to the problem of what is referred to as "patch loading", the loading of plate girder flanges by a concentrated or load distributed over a small length by forces in the web plane, which may lead firstly to local buckling in the load application zone, and, depending on other conditions, also to the progressive collapse of the girder. This problem is particularly important for steel bridges assembled by being pulled over temporary or permanent supports. This is a complex theoretical problem to which fully satisfactory solutions have not as yet been found, so that this research is still on-going worldwide.

In the late 70's and early 80's, professor Hajdin led research in this field in Belgrade. His fellow researchers, B. Ćorić and N. Marković, of the Belgrade Faculty of Civil Engineering, were given the chance to participate in research that has been going on for a number of years in the world in this field at the University College of Cardiff in Great Britain, a very important research centre. They continued their own research back in the country. In the course of the 90's, D. Lučić from the Faculty of Civil Engineering in Podgorica joined them. In this period, the research was conducted as part of cooperation with the Institute of Mechanics of the Czechoslovak Academy of Sciences, i.e. with professor M. Škaloud.

This research resulted in a number of papers published in international journals and presented at international scientific conferences which were subsequently also cited by authors from various countries dealing with these problems.

Of these works, especially significant is the paper *A Contribution to the Analysis of the Behaviour of Plate Girders Subjected to Patch Loading* (*)[46], with N. Marković, published at invitation in 1992 in an issue of the "Journal of Constructional Steel Research" dedicated to state-of-the-art research into steel structures in central and east European countries. As part of preparations for further research in charge of which was professor Hajdin, within the framework of cooperation with the Institute of Mechanics of the Czechoslovak Academy of Sciences, i.e. direct cooperation with professor M. Škaloud, the research into the effects of patch loading up to that point was discussed. Among other things, in addressing this problem, an analysis was undertaken of the effects of longitudinal stiffeners in the zone of load introduction on plate girder buckling, and the paper proposes a formula which takes that effect into consideration. Until then there had been little research of this influence in the world, so that regulations for the calculation of structures either did not include it or only generally indicated its positive effect. There existed only several proposals in papers published in journals, compared to which this new proposal featured a simpler form as well as better agreement with existing experimental results.

In 2000, this proposal was accepted in its entirety in the new version of British regulations for bridges (BC 5400-3:2000 Steel, concrete and composite Bridges – Part 3: Code of practice for design of steel bridges. BSI, May 2001), which had earlier included only a calculation for girders without longitudinal stiffeners. Thus, that is the first regulation in the world which directly included the effect of longitudinal stiffeners on the bearing capacity of plate girders subjected to concentrated patch loading on the plate girders flange.

In the 90's, intensive research of this problem continued in the world with a view to improving upon the existing solutions. To date, quite a few doctoral and master's dissertations have been written, a considerable number of papers published, and many of them cite the above-mentioned work of Marković and Hajdin. In some of them, the proposed solution was used for comparison with new proposals based on later research.

Already in 1995, in his doctoral dissertation, O. Lagerqvist from Sweden, referred to this work (*)[46]:

> Markovic continued his research and published in 1992 [74], together with Hajdin, a paper concerning the influence of longitudinal stiffeners on the ultimate resistance. Results from a series of six tests, a continuing series from the one in [73], was presented. Four of the girders had longitudinal stiffeners applied to the web

46. M a r k o v i ć , N., H a j d i n, N.: A *Contribution to the Analysis of the Behaviour of Plate Girders Subjected to Patch Loading.* Journal of Constructional Steel Research. 21: 1-3(1992) 163-173.

> but the remaining two tests without stiffeners are given in the end od Table C: 2.23. In [74] a review of equations for the ultimate resistance suggested by other researchers was given as well as the result from a comparison of of the different equations with a total of 451 test results, 318 from tests performed on girders without longitudinal stiffeners. When all 451 test results was considered the best agreement was attained with equation (2.99), either in basic form or after corrections for the influence of longitudinal stiffeners and bending stresses.

[28] Lagerqvist, O.: Patch Loading – Resistance of Steel Girders Subjected to concen- trated Forces. Doctoral thesis, Lulea University of Technology, Div. of Steel Structures, 1994, 159D, Lulea, 1995.

This paper has also been cited many times by authors from Sweden, where after 2000 research of longitudinal stiffened girders continued, and the proposed solutions were also used for comparison with the new solutions of these authors.

The paper was also used in research undertaken by a group of authors from Sheffield, Great Britain, who studied steel element connections in conditions of fire and it was cited in several papers. In a work by S. Spyrou, J. B. Davison, I. W. Burgess, and R. J. Plank [29], the authors note:

> "…Existing empirical formulas for the capacity of column webs at ambient temperature were unsuitable, as these did not include the effect of the stiffness of the column flanges, **but studies by Markovic & Hajdin (1992) of plate girders subjected to patch loading proved useful. …"**

[29] Spyrou, S., Davison, J. B., Burgess, I. W. and Plank, R. J., Component Studies for Steelwork Connections in Fire, 5th International Conference on Stability and Ductility of Steel Structures, Budapest, Hungary, (2002) pp. 769-776.

The work has been cited a number of times in works presenting research carried out in Germany. A paper by U. Kuhlman and M. Seitz notes:

Aufbauend auf der Versuchsserie von /Januš et al., 1988/ und weiteren Versuchen **wird von /Marković & Hajdin, 1992/ ein neuer Erhöhungsfaktor**

$$f = 1{,}28 - 0{,}7 \cdot h_l / h_w \quad \text{für} \quad 0{,}1 < h_l / h_w < 0.4$$

vorgeschlagen, der auf die Stegbeulformel nach /Roberts, 1981/ abgestimmt ist und wiederum nur von der Lage der Steife abhängt. **Dieser Vorschlag ist inzwischen in die aktuelle britische Stahlbrückennorm /*BS 5400-3, 2000/* aufgenommen worden.**

/A new increment factor has been proposed /Marković and Hajdin, 1992/

$$f = 1{,}28 - 0{,}7 \; h1 / hw \quad \text{for} \quad 0{,}1 < h1 / hw < 0{,}4$$

It is based on a series of experiments (Januš et al., 1988) and other experiments, it is used along with the buckling formula according to Roberts, 1981, and depends solely on the position of the stiffener. **This proposal has been accepted in the current British regulations for steel bridges (BS 5400-3, 2000)./**

[30] Kuhlmann, U., Seitz, M.: Zum Tragverhalten längsversteifter Blechträger unter konzentrierter Lasteinleitung. In: Ofner, R. (Hrsg.) ; Unterweger, H. (Hrsg.): Festschrift Univ.-Prof. Richard Greiner. Institut für Stahlbau, Holzbau und Flächen tragwerke – Universität Graz, 2001, S. 19 – 28.

In her doctoral thesis, L. Davaine from France notes:

N. MARKOVIC qui a travaillé d'abord à l'université de Cardiff avec T. M. ROBERTS, a poursuivi ses investigations sur le "patch loading" en s'intéressant au raidissage longitudinal de l'âme à l'université de Belgrade avec N. HAJDIN. A Cardiff, MARKOVIC a réalisé 2 essais avec raidisseurs longitudinaux qui viennent s'ajouter à la base de données expérimentales. **Sa principale contribution s'est située dans la conduite, en 1992, d'une analyse statistique de cette base de données, soit 451 essais (dont 318 sans raidisseurs longitudinaux et 133 avec).**

Dans [62], il propose un nouveau facteur tr.s simple de correction de la charge de ruine F_{u}o pour tenir compte de la présence d'un raidisseur longitudinal:

$$f(h_l / h_w) = 1,28 - 0,7 \cdot h_l / h_w \quad \text{pour} \quad 0,1 < h_l / h_w < 0.4$$

/N. Marković, who previously worked with T. M. Roberts at Cardiff University, continued to research patch loading at Belgrade University with N. Hajdin, focusing on longitudinal web stiffeners. In Cardiff, Marković conducted two experiments with longitudinal stiffeners which were added to the experimental data base. **Their main contribution is the undertaking, in 1992, of a statistical analysis of a data base containing 451 experiments (318 of which without, and 133 with longitudinal stiffeners). In the work (62) a new coefficient was proposed, a very simple one, for correction of the ultimate load to take into account the presence of a longitudinal stiffener./**

$$f(h_l / h_w) = 1,28 - 0,7 \cdot h_l / h_w \quad \text{for} \quad 0,1 < h_l / h_w < 0.4$$

[31] Davaine, L.: Formulation de la résistance au lancement d'une âme métallique de pont raidie longitudinalement (Résistance dite de "Patch Loading"), These de docteur en Genie Civil, INSA (L'Institut National des Sciences Appliquees de Rennes, France, 2005, 270.

In this thesis, the mentioned work was used for comparison with the results of new research and the proposals of the author himself.

In lieu of an afterword

A DETAILED SURVEY of professor Hajdin's published scientific and professional works as well as of his most important structures can be found in the book " Nikola Hajdin - Bibliography"[47]. The accompanying compact disc contains all professor Hajdin's published works as well.

From the overall opus of professor Hajdin we singled out only what in our view was of greater importance, associating it with his contribution to the development of the corresponding branch of science and the structures which he designed.

Professor Hajdin's opus has been presented through six periods, which also represent the six fields in which he rendered a contribution to science and its applications.

We single out the following of his works as having particularly contributed to general progress:

A new and original *numerical method* for solving two-dimensional problems of Structural Mechanics and other branches of applied mechanics;

The original method for analyzing thin-walled composite structures with an arbitrary disposition of the component materials;

Designing of the Orašje bridge as the first double composite action bridge in the world. A novelty in bridge building, at the same time it had the largest span for bridges of that type;

A series of articles and monographs from the field of *Thin-Walled Bars* and structures ranks the author among the leading scientists in this field in

47. Г. Радојчић-Костић, Н. Марковић: *Библиографија радова академика Николе Хајдина / Nikola Hajdin Bibliography, САНУ,* Издања Библиотеке 20, Београд 2004.

the world. Scientists, doctoral candidates and engineers drew on his numerous publications in executing different structures;

Cable stayed bridges represented a major milestone in world bridge building. N. Hajdin is among the pioneers of that process. Every single bridge which he designed was a step forward in the development of this branch. Thus the railway bridge in Belgrade is the first bridge of this type for railway traffic, and at the same time a record one in respect of span. The bridges in Novi Sad and Plock (Poland) are exceptional structural and aesthetic achievements and have record spans for bridges of that kind.

Impact analysis posed a new challenge to the author. The solutions he gave were directly applied in practice in which of late this problem has featured as particularly significant in respect of the safety of structures in water and on land;

Patch Loading is a field which N. Hajdin with his associates studied for a number of decades. In addition to a series of articles in this field, the practical results are also certainly important. In that regard, the crown of this effort is the inclusion of one of the results in British standards, which is a great honor for our researchers and country.

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