Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 13 (1988)

Rubrik: VII. Advanced technologies for fabrication and erection

SEMINAR

VII

Advanced Technologies for Fabrication and Erection

Technologies d'avant-garde pour la fabrication et le montage

Neue Verfahren für die Produktion und Montage von Bauwerken

Chairman: D. W. Quinion, UK

Technical Adviser: H. Knöpfel, Switzerland

Organic Space Structure Based on Advanced Technologies

Structure spatiale organique basée sur des technologies avancées

Organische Raumstruktur beruhend auf fortgeschrittenen Technologien

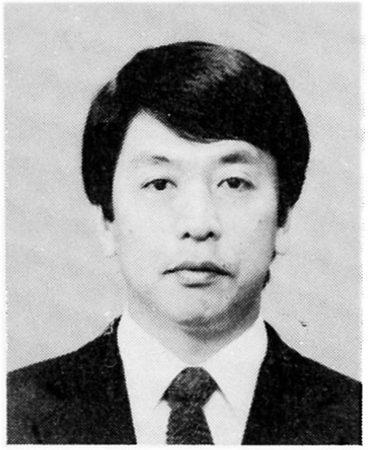
Hiroki KAWAI
Senior Struct. Eng.
Nikken Sekkei Ltd.
Tokyo, Japan

Hiroki Kawai, born 1938, obtained his Master of engineering degree at the University of Waseda. Since 1965 he has been working at Nikken Sekkei as a structural engineer. In 1974 he was involved in Trans-Alaska Pipe Line System project.

Akira WADA
Assoc. Prof.
Tokyo Inst. of Technol.
Tokyo, Japan

Akira Wada, born 1946, obtained his Doctor of engineering degree at the Tokyo Institute of Technology. His research interests are architectural building structures. He is a member of IABSE, AIJ, JCI, and JSCE.

Mamoru IWATA
Senior Manager
Nippon Steel Corp.
Tokyo, Japan



Mamoru Iwata, born 1947, obtained his Doctor of engineering degree at the Tokyo Institute of Technology. Since 1976 he has been responsible for the design, research and development of buildings and special structures.

SUMMARY
The refined systematized space truss system referred to as the "Organic Space Structure" is an integrated construction system composed of simplified elements which are systematically assembled for the purpose of defining space intended to be used for a specific purpose. This space structure system has an advanced, computer-aided manufacturing and assembly concept.

RÉSUMÉ
Le système spatial tridimensionnel, systématisé de façon affinée et désigné sous le nom de "Structure Spatiale Organique", est un système de construction intégrale se composnant d'éléments simplifiés lesquels sont assemblés systématiquement, délimitant un espace destiné à être utilisé pour un but spécifique. Ce système de structure spatiale est un concept avancé de fabrication et d'assemblage assistés pas ordinateur.

ZUSAMMENFASSUNG
Das verfeinerte systematisierte Raum-Fachwerk-System (Space Truss System), genannt "organische Raumstruktur" ist ein integriertes Bausystem bestehend aus vereinfachten Bauelementen, welche systematisch zusammengesetzt sind, um einen Raum, der einem spezifischen Zweck dienen soll, genau abzugrenzen. Dieses Raum-Struktur-System ist eine fortgeschrittene Konzeption der computergesteuerten Herstellungs- und Zusammenbautechnologie.

PREFACE

The term "organic space structure" is used to mean an integrated structural construction comprising simplified elements that are systematically put together to define a space intended to be used for a certain specific purpose. Accordingly, it may be simply called a space construction system. According to Webster's dictionary, the term "system" as used here is defined as "a complex of elements, often of various kinds, formed to work according to a common plan or serve a common purpose, or a group of bodies, such as the solar system, working in an interrelated manner or under the influence of related gravitational or other forces." Imagining the relationship between the providence and movement of the heavenly bodies in the universe, R. Buckminster Fuller defined their structural construction as "a group of patterns, such as a combination of mechanical phenomena, that is capable of inceptive regeneration." Furthermore, Descartes said, "Any structure, however complex it may look, can be constructed as one likes by putting together carefully designed simple basic elements or members." As may be easily perceived, any intricate structure is made up of members, plates and shells. The space truss is one of the systematized skeleton frameworks supporting large-space architectures. This paper deals with the characteristic features of designing, manufacturing, and assembling significant technologies of the space truss. Particular attention is focused on the technology to make high-precision, high-quality parts and the software technology to enable effective manufacture of multi-item, small-sized production.

1. DEFINING OF SPACE BY THE SPACE TRUSS

We consider that the space truss is one of the most effective systems to support large-space architectures. Among other similar structural systems are the shell, suspension and membrane structures. The space truss is a skeleton framework in which joints are used at all hinges. Assuming that all external forces work on the joints, the stresses which occur in its members are of only tensile or compressive force. As such, the space truss is a very effective structural system. A space truss structure is constructed by assembling prefabricated element members at the construction site or constructing such members at the construction site, as with a concrete building, or by combining both. Many attempts have been made to take advantage of the excellent structural feature and simple structural design capability of the space truss, but the need to prepare a large number of so many complicated kinds of component parts and the difficulties encountered in their joints have thwarted such attempts. They have long failed to provide the commercially required cost and quality levels. But it is now possible to build optimum structures using space truss members prepared on a commercially paying basis. The reason for it is one of our themes. This success is undoubtedly due to the recent remarkable progress in information processing and steel making and production technologies. The advancement in special steel quenching and heat treatment technologies has made it possible to make such bolts as can individually transmit such a huge amount of force of 10,000 kN or more. Such innovation has now extremely expanded the feasibility of applying the space truss system to the construction of large space architectures (Fig. 1).

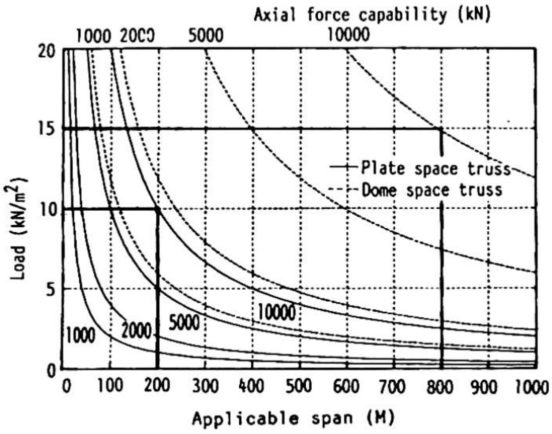


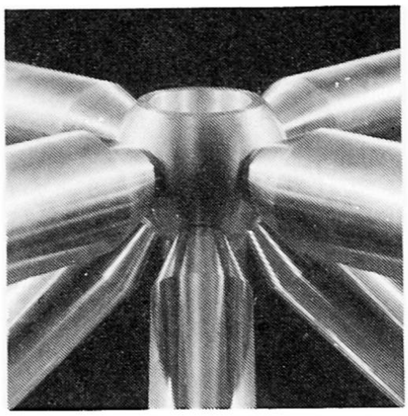
Fig. 1

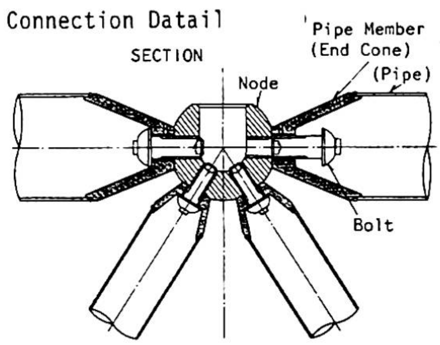
2. REQUIRED PERFORMANCE AND ACTUAL EXAMPLE OF SYSTEMATIZED SPACE TRUSS

For the space truss to realize systematized commercial production and obtain wide applicability, it is essential that its component parts have (1) the precise tolerances, (2) the ability to join many members at arbitrary directions, (3) an ability to resist a wide range axial force (of up to 10,000 kN), and (4) are supplied in various lengths. An ideal system unit to meet such requirements consists of a steel pipe, a spherical node, and a bolt joint. The reasons are: (1) Being resistant to buckling and as an axisymmetrical member having no directionality and high torsional strength, pipe is ideal as a member of the three-dimensional space truss. (2) Because the spherical node is point-symmetrical, all pipe members connected to a node never become eccentric to the center so long as they are accurately directed to the center of the spherical node. (3) The single-bolt joint is appropriate because the bolt is an axisymmetrical member like the pipe and the structural mechanical design of the system assumes the mechanism of a hinge. Although several different systems to meet such requirements have been developed and put to practical use in Europe, U.S., and Japan, our actual example based on an advanced technology (hereinafter called the Truss System) will be discussed in this paper (Fig. 2).

The maximum bolt (200 mm in diameter) of this Truss System is capable of transmitting an axial force of 10,000 kN (Fig. 3).
To ensure that the 200 mm diameter bolt meets the desired performance requirement, close quality control should be exercised in the choice of material, heat treatment and machining. To attain a high degree of reliability, all of the produced bolts are subjected to nondestructive inspection. The CZ-COAT applied to the bolt is stable and causes few hydrogen embrittlement problems. This coating consists of the Z and C coats. The Z coat is a layer of zinc applied on the bolt by projecting zinc iron. The C coat is a coating of metal chromate formed by chromate treatment. The combination of the Z and C coats provides a superb corrosion-resistant coating.

Material	SNCM630
Tensile strength	900 - 1,100 N/mm^2
Yield point	750 N/mm^2
Elongation	15%
Reduction in area	43%
Hardness	HRc 23 - 32





Component parts	Description
Pipe members	Chords and diagonals of the Truss System are made by welding end cones to both ends of pipe.
Nodes	Steel joints: thick spherical shells open at the top for bolt insertion.
Bolts	Special-high strength bolts for joining nodes and pipe members.

Fig. 2

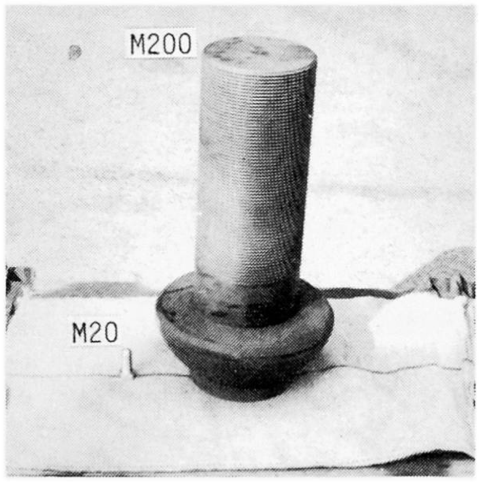


Fig. 3

3. DESIGN REQUIREMENTS FOR THE TRUSS SYSTEM

To assemble a satisfactory structure with the prefabricated members of the Truss System, it is considered necessary that (1) the members are capable of permitting angular adjustment at the joints, and (2) the members are capable of length adjustment or made with zero tolerance. But we have recently confirmed that the desired structure can be constructed with such members as are made with only the angular adjusting capability and to such a close length tolerance as plus or minus 1.0 mm, without the length adjusting capability as described below:

The assembling procedure of the Truss System is as follows (Fig. 4):

1) Connect lower chord members
2) Connect diagonal members
3) Connect upper chord members

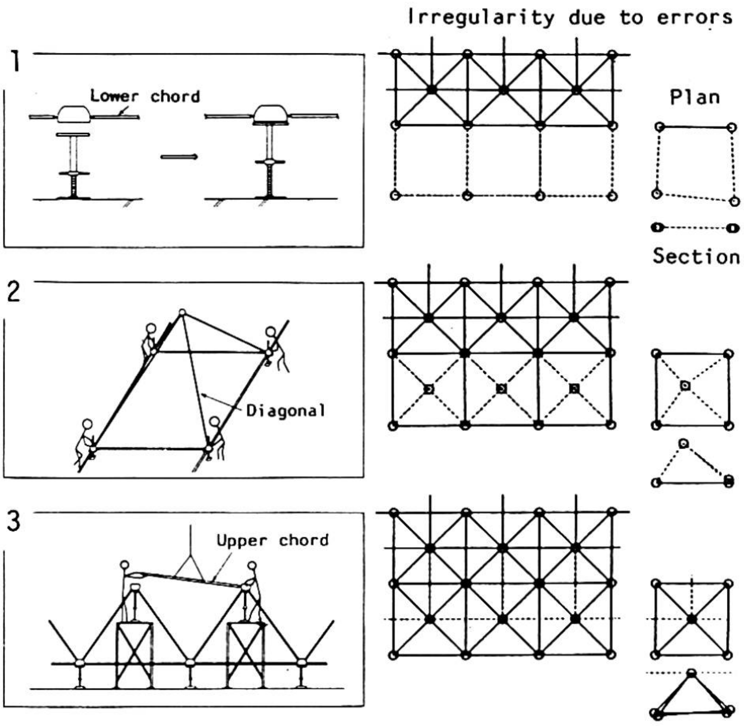


Fig. 4

It is necessary to study if irregularities in the assembled structure due to errors in the dimension of the nodes and the direction of members and the length of the upper- and lower-cord and diagonal members exercise any detrimental influence on the function and safety of the structure. This kind of influence, if any, must be clarified, too. Then, the obtained findings must be used in the establishment of an accuracy control standard. Simulation tests according to the Monte Carlo method were conducted to check how the Truss System will be assembled based on the assumptions that (1) the nodes could be made practically with zero tolerance, (2) the nodes were capable of adjusting the angle of the members fitted thereto (20/1000 radian), and (3) the upper- and lower-chord and diagonal members could be made to a tolerance of plus or minus 1.0 mm.

- Simulation Method

1) The length of all members making up the Truss System was varied within the standard deviation of 0.3 mm which was equivalent to the tolerance of plus or minus 1.0 mm according to the normal distribution.
2) The position of all node joints of the Truss System was calculated using the probabilistic combination of the members involving length errors in the order in which they were assembled.
3) The same calculation was repeated 10,000 times.

The simulation conducted on a plate space truss of 60 meters by 60 meters with 3 meter grid module showed that the accumulated perpendicular downward error at the center node amounted to about 1/220 maximum of the span with respect to the horizontal line.
To permit the construction of the Truss System, as such, it seems necessary and sufficient to keep the accuracy of the its members within the limit of plus or minus 1.0 mm.

4. PRODUCTION OF SYSTEMATIZED SPACE TRUSS

4.1 Information System for Manufacturing

As mentioned previously, the Truss System consists of nodes, pipe members, and bolts. All of the component parts of the Truss System have different characteristics. They have obviously different shapes and sizes. At the symmetrically opposite points of an axisymmetrical space truss structure, for example, nodes of the same shape and size should be considered to have different characteristics as pipe members are installed in different directions. It may be said that the components of each part have not only their own size and shape but also their own information of the character.
The parts information from a 50 grid by 50 grid double-layer plate space truss, for example, is that it requires 20,000 pipe members, 5,000 nodes and 40,000 bolts. In this case, approximately 200,000 pieces of information are needed for the design, quality control, transportation, and field assembling of the space truss. Smooth construction of the Truss System calls for the accurate processing of a vast amount of information. To carry out a plurality of construction projects simultaneously, it is necessary to work out an information processing system that can integrate not only technical information but also the flow of management and office work. To be more specific, computer-integrated manufacturing (CIM) supported by computer-aided manufacturing (CAM) and computer-aided planning (CAP) will provide an ideal information processing environment for the achievement of a satisfactory operation system (Fig. 5).

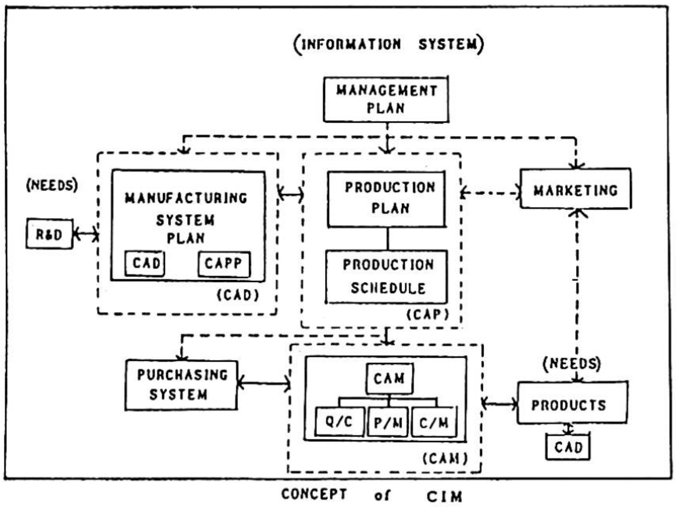


Fig. 5

4.2 Manufacturing of the Truss System Component Parts

The following is a brief description of the manufacturing method for the pipe members and nodes. It is based on a computer-aided automatic production system to permit speedy, high-precision and low-cost production of various kinds of parts, each in small quantities.

1) Manufacturing of Nodes
Manufacturing of nodes consists of forging and machining.

a) Forging (Fig. 6): A round bar is cut to a given length (with a tolerance of plus or minus 0.5 mm) having a large enough volume to be made to the ultimate design shape. The work is shaped into a breakdown by upsetting and striking, and then shot-blasted to get ready for subsequent machining.
b) Machining (Fig. 7): First, the external surface is machined by a numerical-controlled milling machine. Then bolt hole tapping and other machining operations are performed in accordance with the preliminarily loaded design information at the machining shop. The bolt hole tapping is controlled by increments of 1/1000 radian.

2) Manufacturing of Pipe Members

Manufacturing of pipe members consists of pipe cutting and the welding of end cones.

a) Pipe Cutting

Pipe is cut to the desired length based on the design information covering pipe diameter, wall thickness, and length.

b) Welding of End Cones

Welding of end cones is preceded by precision cutting (with the tolerance of plus or minus 0.5 mm) and beveling depending on the pipe diameter and wall thickness. To assure even welding and maintain accurate length, automatic welding is performed under the conditions chosen based on a shrinkage allowance estimated on the basis of room temperature, pipe profile, and welding material. The pipe length should be controlled within the limiit of plus or minus 1.0 mm.

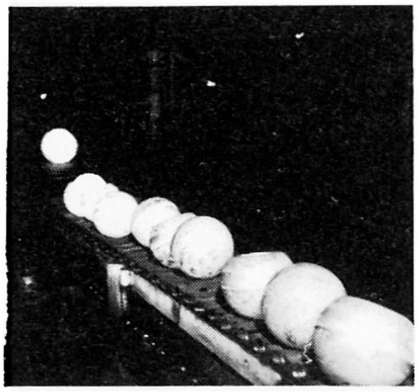


Fig. 6

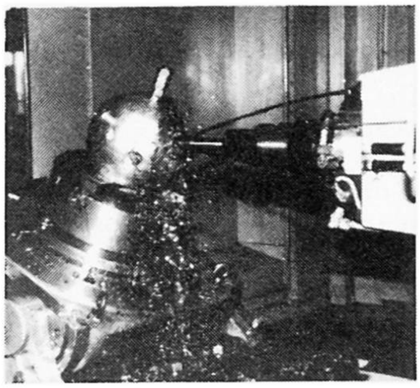


Fig. 7

5. CONCLUSION

It was discovered that the systematized space truss is applicable to the construction of ultra-large span structures and other structures of various shapes. It was also found out that such applications need advanced technologies for materials manufacturing, heat treatment, and design- and production-assisting information processing. The design of a structure composed of a group of component parts made with high reliability and precision needs new concepts and techniques absolutely different from those applied to conventional steel structures. We would like to show a 200 M high television tower with 3-layered observatory in China and a 100 M span x 3 units hangar for housing three jumbo jet planes in Indonesia made by use of the Truss System, which may serve as examples suggesting the expanding applicability of the space truss technology (Figs. 8 and 9).

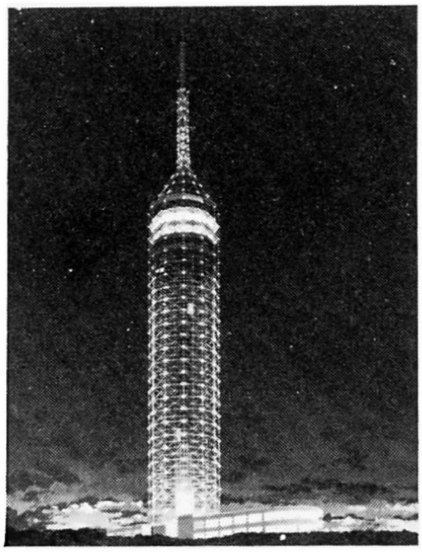


Fig. 8

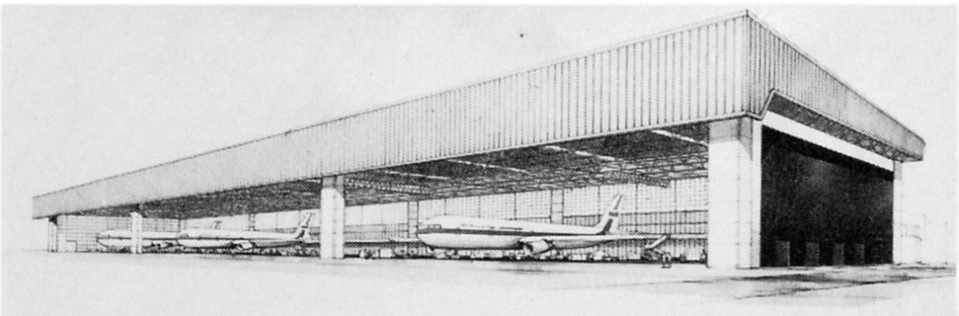


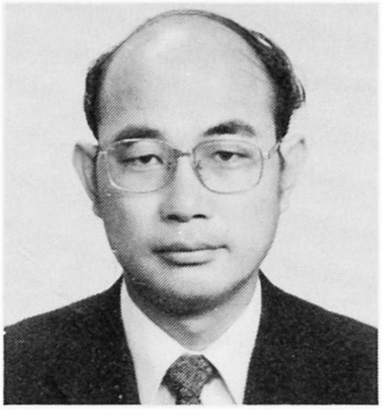
Fig. 9

Non-welded Structural System

Structures métalliques non soudées

Schweißfreie Stahlkonstruktion

Kunio UKAI
Structural Engineer
Nikken Sekkei Ltd
Osaka, Japan



Kunio Ukai, born 1940, obtained his civil engineering degree at the Nagoya Institute of Technology, Nagoya, Japan. Kunio Ukai is now Manager of Structural Engineering Department of a consulting firm in Japan.

Katsumi HARA
Structural Department,
Nikken Sekkei Ltd
Osaka, Japan

Tsukasa AOYAGI
Structural Department,
Nikken Sekkei Ltd
Osaka, Japan

Akio OTAKE
Central Research Laboratories,
Sumitomo Metal Industries, Ltd.
Ibaraki-ken, Japan

Hikaru SENDA
Structural Engineering, Sumitomo Metal Industries, Ltd.
Tokyo, Japan

Masahiro KATO
Structural Engineering, Sumitomo Metal Industries, Ltd.
Tokyo, Japan

Norihiko MURAKAMI
Structural Engineering,
Sumitomo Metal Ind. Ltd.
Tokyo, Japan

SUMMARY
In Japan, seismic forces and wind pressures are major loads which must be considered in structural design. To cope with these loads, connections of structural members are generally required to be made as rigid connections, which are made only by welding these days. This causes restrictions and problems concerning realization of more fully automatic welding, assurance of weld qualities, reduction of construction time, etc. This paper deals with a non-welded steel structural system which eliminates the above mentioned limitations and problems and thus enables to pursuing total rationality in all such aspects of design, fabrication and construction by fully utilizing CAD and CAM.

RÉSUMÉ
Au Japon, les charges dues au vent et aux tremblements de terre sont les deux charges principales qui doivent être prises en compte dans l'étude d'une construction. Ces charges impliquent des assemblages rigides entre les éléments de la structure, qui ne peuvent étre réalisées que par soudure. Il en résulte des problèmes de soudage automatique, d'assurance de la qualité des soudures, de réduction de la durée de construction. Ce rapport aborde certains aspects des structures non soudées qui permettent de se libérer de ces contraintes et de concevoir les éléments aussi rationnellement que possible en faisant appel à tous les moyens offerts par la conception et la fabrication assistées par ordinateur.

ZUSAMMENFASSUNG
In Japan müssen bei der Berechnung die Erdbeben- und Windlasten berücksichtigt werden. Dies bedingt feste Schweißverbindungen zwischen den einzelnen Elementen, wodurch jedoch Restriktionen hinsichtlich vollautomatischer Schweißung, der Schweißqualität, der Bauzeit usw. hingenommen werden müssen. Diese Schrift befaßt sich mit nicht geschweißten Stahlkonstruktionen, so daß die erwähnten Restriktionen entfallen und volle Rationalisierung der Konstruktion, der Fertigung und der Errichtung unter Verwendung von CAD und CAM Systemen realisiert werden kann.

1. INTRODUCTION

In Japan, buildings (not including detached or semi-detached houses) constructed of structural steel amounted to 34.50-million m^2 in floor area in 1986. About 95 % of them was accounted for by comparatively small buildings not more than five-storeyed.
Welding which began to be used for steel buildings more than 20 years ago has come to be used for construction of almost all buildings including the aforesaid relatively small buildings.
Despite a great deal of research effects made until now, welding still has its restrictions and problems concerning realization of more fully automatic welding, assurance of weld qualities and dimensional accuracy of products, development of effective measures against residual stresses and strains caused by welding, reduction of construction time, etc. many of which cannot be rationally solved even by today's highly developed electronic and mechatronic technology.
This paper deals with non-welded steel structural system (as shown in Fig. 1) which eliminates limitations and problems accompanying welding and thus enables to pursue the total rationality in all such aspects as design, market distribution, fabrication and construction by utilizing CAD and CAM. This system has been developed as a subsystem to a total building system which includes exterior cladding, electrical and mechanical systems, etc.

2. OUTLINE OF CONSTRUCTION METHOD

2.1 Framing System

As shown in Fig. 1, H-shapes are used as columns and beams. Rigid frames are used in the transverse direction, and braced frames or aseismic column frames in the ridge direction.

2.2 Detail of Column-Beam Connection

Reinforcing pieces are attached to inside of column flanges in order to reinforce the column flanges by sharing tensile forces from split tees and carrying them smoothly to the panel zone.

3. CONNECTION EXPERIMENTS

The following experiments were performed to determine strength, deformation capacity, reinforcing effect and other factors relating to beam-column connection.

3.1 Split Tee Unit Test for Investigating Split Tee Form and Deformation Capacity

Strength: Table 1 gives a comparison of measured values and calculated strength (Kato formula) for yielding strength F_y and maximum strength F_u. The calculated ones generally gave good agreement with the measured ones.
Deformation capacity: No. 5 in mode a, which takes no bolt separation, shows outstanding deformation capacity up to the final strength. It appears that there is deformation capacity of about d_{FU} = 10 mm even in modes b and c, which finally takes bolt separation. (See Fig. 2.)

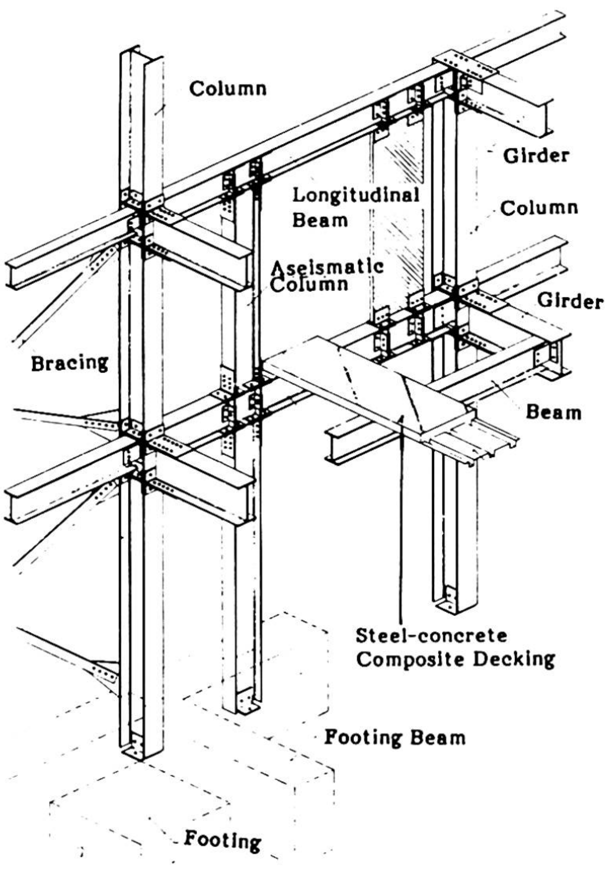


Fig. 1 Structural System

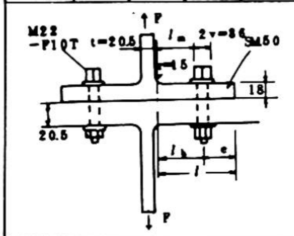
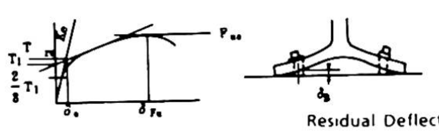
Test Specimen	Dimension (mm)				Computed Strength (Kato's Formula)			Test Results						
	l_m	l_b	e	l	Mode	T_{yt} (t)	T_{ut} (t)	T_{Ye} (t)	T_{ue} (t)	K_e (t/mm)	δ_e (mm)	δ_{Fu} (mm)	δ_B (mm)	Give-away Mode
No 1	20	38	80	118	c	88.2	97.9	92.5 (1.05)	113.4 (1.16)	116.9	0.554	6.6	3.5	Bolting torn-off by tensile force
No 2	30	48	40	88	c	68.2	75.8	74.5 (1.09)	93.0 (1.22)	147.4	0.505	11.53	4.8	"
No 3	30	48	70	118	(b→) c	81.2	90.3	83.5 (1.03)	106.2 (1.17)	197.8	0.422	9.13	4.6	"
No 4	60	78	40	118	b	44.1	61.4	54.5 (1.23)	78.2 (1.27)	54.2	1.006	23.18	4.35	"
No 5	60	78	70	148	a	44.1	66.2	57.5 (1.30)	94.8 (1.43)	50.2	1.145	39.10	5.6	"
No 6	90	108	40	148	b	29.4	51.6	36.0 (1.22)	71.9 (1.39)	22.9	1.57	41.42	4.9	"
					Bolt B = 27.27 t/bolt B_B = 30.3 t/bolt Flange (Actual Strength) σ = 4.08 t/cm² $σ_B$ = 6.13 t/cm²			T_{Ye} (F_{Ye}/F_R) T_{ue} (T_{ue}/F_{ut}) δ_e= F_{Ye}/K_e 						

Table 1 List of Test Specimens and Test Results

3.2 Tensile Test for Reviewing Column Flange Reinforcement

Experiments were performed regarding strength when the column flange was reinforced by a plate with stiffener (Types A and B), and results were further reviewed via yielding line analysis. Thus a reinforcement design formula was obtained. (See Tables 2 to 4 and Fig. 4.)

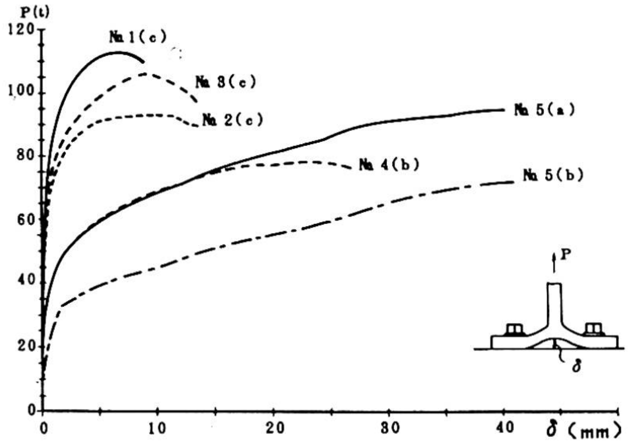


Fig. 2 Load-Displacement Relationship

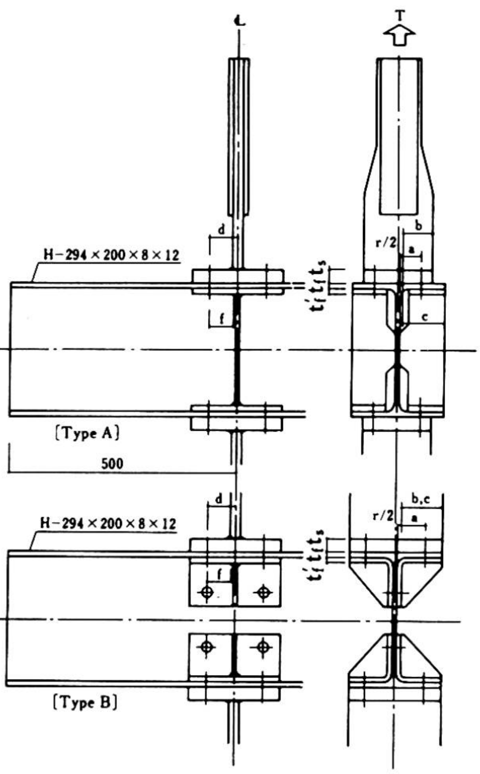


Fig. 3 Shape of Test Specimen

No	Reinforcing Type	Dimension (mm)					Bolt Size	t_f (mm)	t_f' (mm)	t_s (mm)
		a	b	c	d	f				
1	–	52	87	87	62.5	–	M22	12	–	30
2	A	52	87	87	62.5	56.5	M22	12	6	30
3	"	"	"	"	"	50.5	"	"	12	"
4	"	"	"	"	"	"	M16	"	"	"
5	"	36	62	"	"	56.5	M22	"	6	"
6	"	52	87	"	"	"	"	"	"	22
7	B	52	87	87	62.5	56.5	M22	12	6	30
8	"	"	"	"	"	50.5	"	"	12	"

t_f : Thickness of flange of column t_s : Thickness of split tee plate
t_f' : Thickness of reinforcing plate

Table 2 Dimensions of Test Specimens

No.	Measured				Analyzed (Mode)				Ratio (Measured/Analyzed)			
	$T_{Y\varepsilon}$ (ton)	$\Delta T_{Y\varepsilon}$ (ton)	Tmax (ton)	Torn-off Portion	T_Y (ton)	ΔT_Y (ton)	T_Y' (ton)	T_u (ton)	$T_{Y\varepsilon}/T_Y$	$\Delta T_{Y\varepsilon}/\Delta T_Y$	$T_{Y\varepsilon}/T_Y'$	T_{max}/T_u
1	32.0	—	81.0	B	43.2(2)	—	30.2(2)	63.9(2)	0.74	—	1.06	1.27
2	42.5	10.5	96.0	B,S	50.5(2)	7.3	39.1(2)	74.3(2)	0.84	1.44	1.09	1.29
3	70.6	38.6	100.0	B,S	68.1(2)	24.9	60.2(2)	99.9(1)	1.04	1.55	1.17	1.00
4	42.7	—	67.5	B	54.5(1)	—	45.3(1)	70.2(1)	0.78	—	0.94	0.96
5	54.4	—	102.3	B	77.3(2)	—	58.3(1)	94.3(1)	0.70	—	0.93	1.08
6	43.1	11.1	85.2	B,S	50.5(2)	7.3	39.1(2)	74.3(2)	0.85	1.52	1.10	1.15
7	46.7	14.7	91.0	B	54.1(2)	10.9	43.3(2)	79.3(2)	0.86	1.35	1.08	1.15
8	69.4	37.4	110.8	B	78.8(2)	35.6	73.0(2)	105.6(1)	0.88	1.05	0.97	1.05

B : Bolt S : Stiftener

Table 3 Comparison between Measured Values

3.3 Beam-Column Connection Mock-up Test

This confirmed that beam-column connections formed through non-weld techniques had strength and deformation capacity as good or better than those formed through welding techniques. (See Table 5 and Fig. 5.)

Test Specimen		Material	σ_Y (t/cm²)	σ_B (t/cm²)
H-294 x 200 x 8 x 12 (Fℓ)		SS41	3.07	4.55
PLATE	PL - 6	SS41	3.30	4.62
	PL - 12	"	2.62	4.22
BOLT	M16	F10T	10.4	11.2
	M22	"	10.8	11.5

Table 4 Mechanical Characteristics of Materials

No.	Column-Beam Connection	Cut Tee	Horizontal Stiffener	Reinforcing Plate
W	Welding	None	Welding	None
NW1	Bolting	CT-303 x 201 x 12 x 20	None	None
NW2	Bolting	CT-303 x 201 x 12 x 20	Provided	None
NW3	Bolting	CT-303 x 201 x 12 x 20	Provided	Reinforced at one side by panel
NW4	Bolting	CT-303 x 201 x 12 x 20	Clip Angle	None
NW5	Bolting	CT-303 x 201 x 12 x 20	Clip Angle	Reinforced at one side by stiffener
NW6	Bolting	CT-303 x 201 x 12 x 20	Clip Angle	Reinforced by stiffener and panel

Table 5 List of Test Specimens

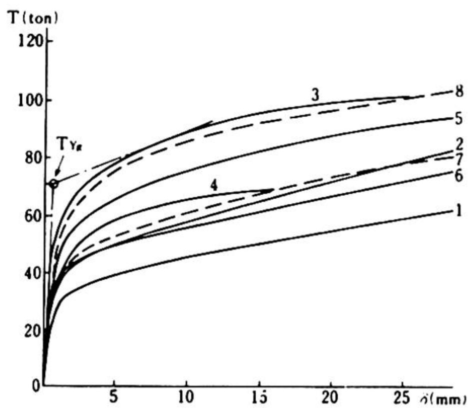


Fig. 4 Load-Deformation Curve

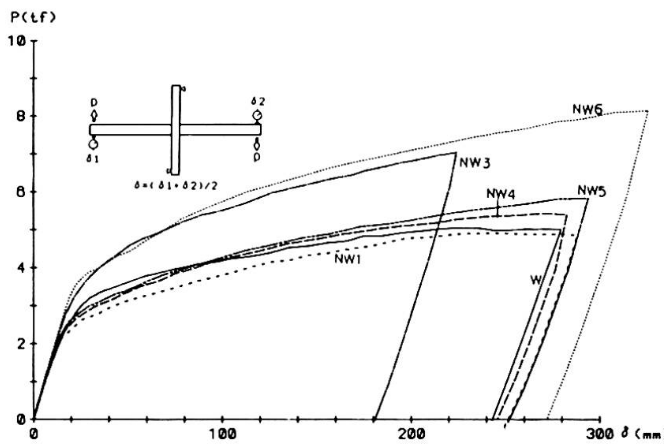


Fig. 5 Load-Displacement Relationship

4. DESIGN, FABRICATION AND CONSTRUCTION

4.1 Design

Once structural members have been determined from structural design and stress analysis, connection parts are determined automatically from combinations of beam-column members in connection design by virtue of the manualized system.
Strength of these connections are designed (retained strength design) to exceed that of beam members, and so connection strength checking is unnecessary.

These connections are also standardized, and this enables labor-saving in fabrication.

4.2 Fabrication

Shop drawings: These techniques assume the use of numerical control (NC), so shop drawings can be greatly simplified.
Fabrication at Workshop: Fabrication is performed using NC machine tools. The fabrication process is compared with conventional techniques in Fig. 7, and the new process achieves extreme reductions in processing and the number of process steps. Cut and drilled materials and parts are assembled according to fabrication drawings and fastened together with high strength bolts.

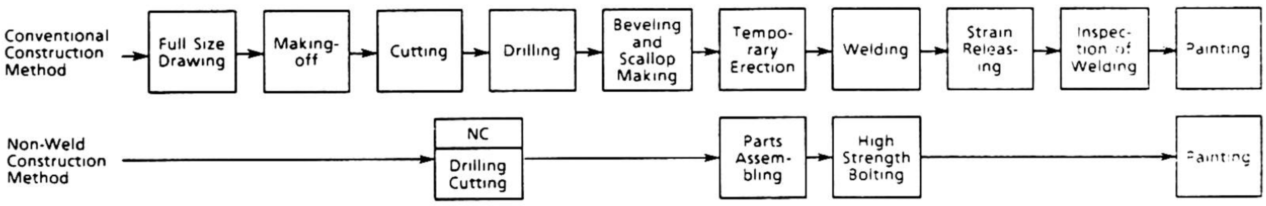


Fig. 6 Comparison of Construction Procedures

4.3 On-site Construction

In erection using these techniques, the split tee on the underside of the beam is mounted beforehand on a column, so the beam is placed on that split tee.
Because of this simple construction method for the beam-column connection, on-site construction workers can perform safe and rapid construction from a temporarily provided work space set up near the beam-column connection.
The number of high strength bolts used in these techniques is about 50 % more than that used in welding techniques, but a large number of bolts are installed beforehand at a workshop so the number of bolts installed on-site is not much different that in other techniques. In on-site erection, dimensional accuracy of materials and parts is good, so reconstruction is unnecessary and high precision construction is facilitated.

5. COMPARISON OF CONSTRUCTION COSTS

For the purpose of comparison between construction costs of buildings constructed by the conventional welding techniques and those of buildings constructed by the non-weld techniques, many types of model buildings (as shown in Table 6) were designed. Then steel costs, fabrication costs and construction costs (incl. erection and high strength bolt fastening) are estimated for all of these model buildings and compared in Table 6.

Comparison of non-weld vs. welding techniques
Steel costs: Non-weld technique steel costs may be somewhat higher. Using low cost materials such as rolled H-shapes almost eliminates the difference.
Fabrication costs: Since automatic machine tools using numerical control are employed in the former, cost become about 60 % of that of the latter.
Construction costs: With non-weld techniques, the number of high strength bolt connections increases, but many connections can be made at the workshop, so costs are almost the same as those for welding techniques. There is almost no difference in the cost comparison in the Table, but since transport costs are low and on-site construction techniques are improved, the cost of these techniques can be further reduced.

Model	Type	Construction Method	Structural System		Construction Cost				Remarks
			Span Direction	Transverse Direction	Cost of Steel	Manufacturing Cost	Erection Cost	Total	
(1) 3-story bldg Total floor area: 233 m²	B1	Weld	Rigid Frame	Bracing	39	32	29	100	Construction cost of Type B1 is taken at 100
	B1N	Non-weld	Rigid Frame	Bracing	40	22	30	92	
	R1	Weld	Rigid Frame	Rigid Frame	57	55	40	142	
	R1N	Non-weld	Rigid Frame	Rigid Frame	52	32	40	114	
(2) 4-story bldg Total floor area: 904 m²	B2	Weld	Rigid Frame	Bracing	42	31	27	100	Construction cost of Type B2 is taken at 100
	B2N	Non-weld	Rigid Frame	Bracing	45	20	28	93	
	R2	Weld	Rigid Frame	Rigid Frame	56	45	29	130	
	R2N	Non-weld	Rigid Frame	Rigid Frame	52	26	31	79	
(3) 2-story bldg Total floor area: 1,825 m²	B3	Weld	Rigid Frame	Bracing	49	25	26	100	Construction cost of Type B3 is taken at 100
	B3N	Non-weld	Rigid Frame	Bracing	50	15	27	92	
	R3	Weld	Rigid Frame	Rigid Frame	57	34	28	119	
	R3N	Non-weld	Rigid Frame	Rigid Frame	55	20	30	75	

Table 6 Comparison of Construction Costs

6. CONCLUSION

The strength, deformation capacity and reinforcing effect of connections with these techniques have been experimentally confirmed, and design formulas have been established from the obtained findings and findings obtained in current experiment and research. A complete structural system has been perfected for design, fabrication and construction. As already explained, the merits of these techniques include high economy, quality assurance and construction period reduction, and further improvements can be expected to fully enjoy these merits in the future through complete systemization, from structural design to construction.

These techniques employ high strength bolt tension connections, so there are limits on their applicability to large-scale structures, but in Japan, where there are large out-of-design forces such as earthquakes and winds, the authors have already applied the techniques to 8-storey structures, and they appear to be applicable to the majority of steel-frame structures.

At present, these techniques have been implemented in 20 cases (overall steel-frame tonnage 5,000 ton), so the advantages of these techniques have been proven in practice.

7. ACKNOWLEDGEMENTS

By taking this opportunity, the authors wish to express their cordial thanks to Dr. Toshiro Suzuki of Tokyo Institute of Technology, and Dr. Hiroshi Akiyama of The University of Tokyo, for their cooperation and advice afforded in the implementation of this study.

REFERENCES

1. HIKARU SENDA et all, An Experimental Study on Strengthening for Column Flange at High Strength Bolted Tensile Connections. The Conference held by Architectural Institute of Japan, 1985.

2. HIKARU SENDA et all, An Experimental Study on Strength of Split Tee for Weak Axis Which Simultaneously Strengthens Column Flange. The Conference held by Architectural Institute of Japan, 1986.

Advanced Industrialized Building Technology for the 1990's

Technologie industrielle de construction des années 90

Fortschrittliche industrielle Bautechnologie für die 90er Jahre

Asko SARJA
Prof. Dr.Tech.
Techn. Res. Centre of Finland
Espoo, Finland

Asko Sarja, born 1941, obtained his MScTech. degree at Oulu University in 1967 and Dr.Tech degree at Helsinki University of Technology in 1979. The first three years he worked at the Bridge Design Office and at the Water Resources and Waterways Administration. Since 1970 he has been involved in research at the Technical Research Centre of Finland. Since 1978 he has been working as Director of the Concrete and Silicate Laboratory.

SUMMARY
The development of the new-generation of industrialized system building has been going on from the year 1986 and will continue until 1991. The results, which up till now have been documented as preliminary proposals, include new structural systematics described as the modulated hierarchical system. The system is intented for mechanized and automated production of structural members in prefabrication plants and for rapid assembly and finishing on site. The structural system allows the standardization of the types of structures and connection. A new connection technique has enabled rapid assembly on site.

RÉSUMÉ
Le développement de la nouvelle génération de construction systématique industrialisée commença en 1986 et continuera jusqu'en 1991. Les résultats, qui jusqu'alors ont été présentés comme propositions préliminaires, comprennent une nouvelle systématique structurale appelée système modulé et hiérarchique. Ce système fut élaboré en vue de la production mécanisée et automatisée d'éléments de construction préfabriqués et en vue de l'assemblage rapide et la finition sur place. Le système structural permet la standardisation des types de construction et d'assemblage. Une nouvelle technique permet un montage rapide sur place.

ZUSAMMENFASSUNG
Die Entwicklung der neuen Generation des industrialisierten Systembaus begann im Jahre 1986 und wird sich bis 1991 fortsetzen. Die Resultate, die bisher als vorläufige Vorschläge festgehalten worden sind, beinhalten eine neue Struktursystematik, die als ein moduliertes hierarchisches System bezeichnet wird. Dieses System soll einer mechanisierten und automatisierten Produktion von Baugliedern in Fertigteilfabriken sowie einer schnellen Montage und einem schnellen Ausbau vor Ort dienlich sein. Es ermöglicht die Standardisierung der verschiedenen Konstruktions- und Verbindungstypen. Eine neue Verbindungstechnik hat die schnelle Montage vor Ort ermöglicht.

1. BACKGROUND

The development of the industrialised building technology in Finland started in the 1950's, which saw the first generation of element building technology. No element building system was available then.

The second generation started with the development of the open element building system "BES" at the end of the 1960's. The second generation aimed at mechanised element production and economical construction for the mass production of new satellite towns. This type of production became dominant in Finland the market share of multistorey apartment and office buildings being about 70 - 80 %.

Currently, the requirements have changed. The keywords now are good architectural and technical quality and flexibility of design and operation. The BES-system has been applied to these requirements but the need for new industrialised building systematic has been recognized. A development project was started in 1986 aimed at the third generation of industrialised building system and technology for the 1990's. The project will last until the year 1991. The generations and the phases of the development project are presented in Figure 1.

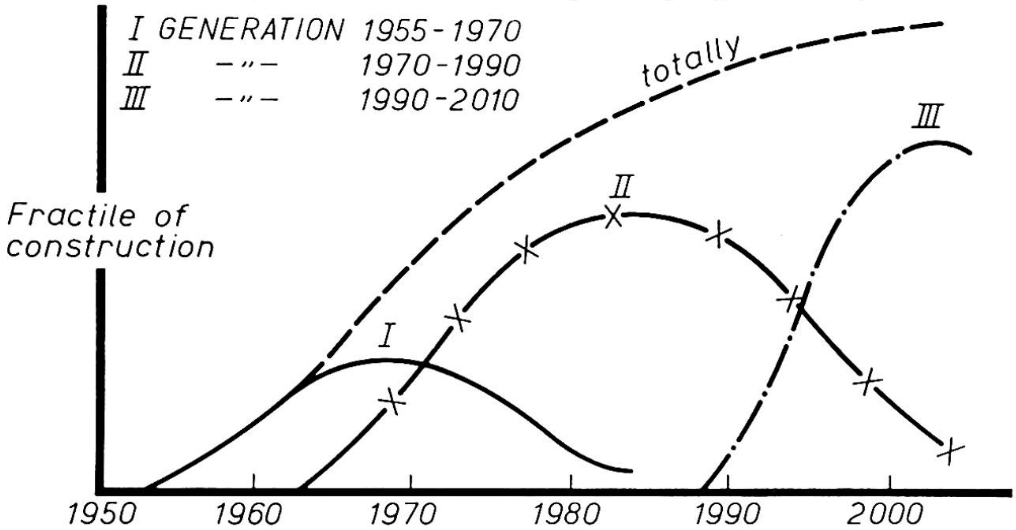


Fig. 1 The generations of the industrialised building technology in Finland and the phases of the development of the third generation.

The new generation of industrialised building technology has been named as the "TAT-system", which could be described in English as "Totally Adaptable Technology". The project is founded and realised by the two biggest prefabrication companies: Lohja Co and Partek Co and the four biggest contractor companies: Haka Co, Polar Co, Puolimatka Co and YIT-consern. The project is financed by the companies and the Technology Development Centre of Finland. The research and development work has been distributed among the Technical Research Centre of Finland, consulting companies and prefabrication and contractor companies. The structural system employed will mainly consist of concrete structures completed with composite structures.

2. BASIC IDEAS AND SOLUTIONS

The basic problem was to solve the complicated interactive contradiction between the requirements: quality, serviceability , flexibility and economy. Traditionally the view has been that industrialised production can lead to economical result, but with the loss in quality and flexibility. The model of the solution is presented in Figure 2.

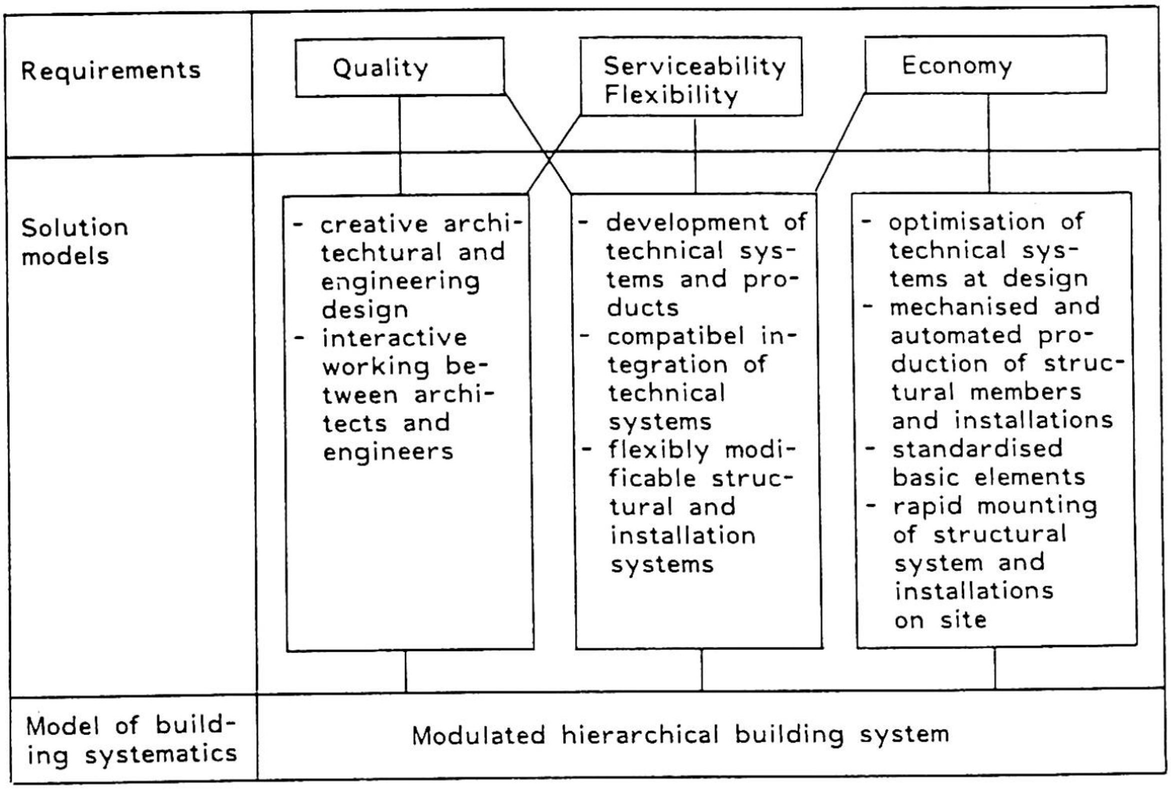


Fig. 2 Solution model for the fulfilment of requirements of the new generation of building technology

The key to the solution is the new line of thought in system building, which is concretized as the modulated hierarchical building systematics. It affords the possibility of flexible design of building using a limited number of installation and structural basic element types. The design methodology is based on a combination technique at the following levels of hierarchy: building level, sub-building level, module level and basic element level.

Typically, the architectural design at the phase of ideas and preliminary sketch mainly works on the sub-building and module levels. At the phase of drafting and final design the functional and optimization-based architectural and technical solutions will be concretized as technical systems, sub- systems, modules and basic elements resulting the designs for the basic elements of production at factories and the assembly plans for the site. The principal model for the adaption of the modulated hierarchical systematics is presented in Figure 3.

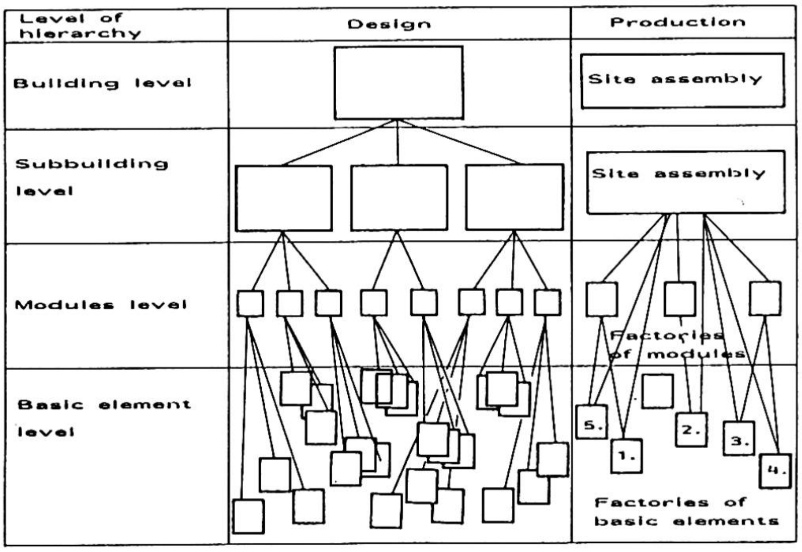


Fig. 3 Principal model for the hierarchical modulated building system in the design and production process.

As regards the work of structural engineers the structural combination and optimization technique plays an increasing role. A typical change will also be the increased importance of the design of structures to other factors in addition to traditional statical or generally mechanical requirements such as the design of operations and maintenance and the interactive compatible integration of structural and installation systems.

3. TECHNOLOGY FOR FABRICATION AND ERECTION

3.1 Principles

The principles of the structural production in TAT-technique are

- Mechanical and automated production of standardised types of basic elements in factories utilising flexible manufacturing methods
- Rapid assembly of structural members and compatible installations on site
- Assembly of prefabricated modules which are either structural modules or integrated structural and installation modules
- Possibility of applying increased automation and robotisation to on-site assembly
- Rational finishings and installation on site.

3.2 Fabrication

Mechanized, automated and computerized manufacturing is aimed at in the fabrication of structural members in element factories. The manufacturing methods will be selected taking into account the suitability for small portion flexible production. This aim raises the need for the structural type selected to suit the manufacturing methods.

Typical manufacturing methods in precast concrete plants are long line extrusion, long line continuous casting, slipform casting, battery forming, spraying and centrifugal casting. The extrusion and slipform casting without moulds can be used for slabs, beams, columns and walls. The battery forms are suited for columns, beams and walls. The spraying is best suited for architectural panels of external walls.

The application of flexible manufacturing methods and the "just on time" production principle in element plants is an important part of the new production process. The computer-aided production planning is a central part of the system. The computerised system of production planning and control also includes the automated manufacturing control, such as control of concrete mixing, control of concrete transport, control of casting and compaction machines, cutting of elements on long line production, transport of ready elements into store and the storage and delivery control. The most automated hollow core slab plants in Finland already apply the described level of automation and computerisation. This kind of production will also spread into the production of other structural members utilising the prescribed manufacturing methods.

Some structural parts and their installations are suited for assembly of integrated modules including the installation. Such modules are for example the bathroom, sauna and wc units.

3.3 Erection

The site production includes the assembly of structural members, modules, installation and furniture and the finishing work. The organization is based on the coordination by the main contractor company and on the realization distributed among several subcontractors. The subcontractors are at the same partly producers of products, partly specialised assemblers only.

Important factors pertaining to the development of rapid erection technique are connections, stabilising structural systems and the compatibility between structural and installation systems. All these factors are included into the TAT-system. As new connection technology the moment stiff connections made with prestressed bolts are applied. Therefore, it is possible to assemble stiff frames for the stabilization of the building. The connections work immediately after the assembly. The role of mortar is to quarantee additional statical, fire and corrosion resistance of the connection.

In the future, automation and robotisation can be applied to erection and finishing. In regard to erection the possibilities of automation increase especially regarding the assembly of connections and crane lifting automation with address system using suited sensors. In regard finishing the spraying robots and coating laying robots are possible.

REFERENCES

1. Sarja, A. TAT-building system. Manuscript 21.4.1987 (in Finnish). Technical Research Centre of Finland, Concrete and Silicate Laboratory.

2. Sarja, A. Computer aid in the development of construction planning and manufacturing process in factories and on site. Fourth International Symposium on Robotics & Artificial Intelligence in Building Construction. Building Research Station - Technion I.I.T-, Haifa, Israel 1987, Vol. 1. pp. 168 - 189.

3. Sarja, A., Towards the advanced construction technique of the future. Betonwerk + Fertigteiltechnik 1987, Heft 4, S. 236-239.

4. Leppänen, Pekka & Sarja, Asko. Preliminary models for the computer-aided building design and construction management process. Espoo 1987. Valtion teknillinen tutkimuskeskus, Tiedotteita - Technical Research Centre of Finland, Research Notes 606. 47 p.

5. Alasalmi, Matti & Ratvio, Juha, Development of production automation of the concrete industry. Preliminary Study (in Finnish). Espoo 1984. Technical Research Centre of Finland, Research Reports 271. 104 p. + app. 41 p.

6. Ratvio, Juha, Development of computer aided design system for prefabricated concrete construction. 1st Int. Conf. on Computer Applications in Concrete. Singapore, 26 - 27 March 1986. 8 p.

7. Serén, Karl-Johan, The concrete industry and expert systems. Espoo 1986, Technical Research Centre of Finland, Research Notes 571. 24 p. + app. 32 p.

New Composite Slab System by Large Scale PC Panel Cast in Site

Fabrication locale de plaques composites utilisant
un panneau en béton préfabriqué de grande dimension

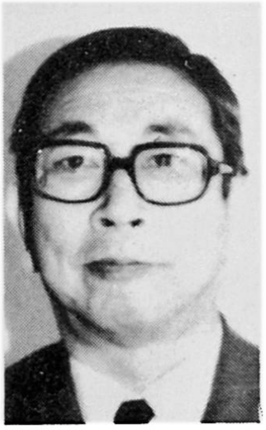
Neues Verbundplattensystem aus grossen Betonfertigteilplatten und Ortbeton

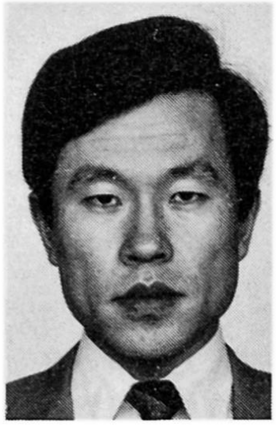
Hiroo TAKADA
Research Engineer
Shimizu-Corp.
Tokyo, Japan

Seiji KOKUSHO
Professor
Tokyo Inst., of Technol.
Yokohama, Japan

Yasuhiro MATSUZAKI
Assoc. Professor
Science Univ. of Tokyo
Tokyo, Japan

Katsumi KOBAYASHI
Assoc. Professor
Fukui Univ.
Fukui, Japan



SUMMARY
A new slab system whereby a concrete composite slab is constructed by placing concrete on a large scale PC panel cast on site allows the reduction of the construction period, saves manpower, and reduces the amount of temporary materials used thereby resulting in a great improvement in the economy of the work. This report describes the structural experiments required in order to design the composite slab, the creep of the concrete composite slab, software for making an optimum construction plan for the system and examples and effects of applications on site.

RÉSUMÉ
Un nouveau système de fabrication locale de plaques composites en béton consiste à couler le béton sur un panneau en béton préfabriqué de grande dimension. Ce système permet de diminuer le délai des travaux, d'économiser la main d'oeuvre et de réduire la quantité des matériaux provisoires. Il en résulte d'importantes améliorations en terme d'économie de travail. Ce compte-rendu décrit les expériences nécessaires à la mise au point de la plaque de béton, les caractéristiques de fluage, le logiciel permettant de réaliser une construction optimale du système ainsi que des exemples et des possibilités d'application concrètes.

ZUSAMMENFASSUNG
Ein neues System, bei dem eine Betonverbundplatte vor Ort hergestellt wird, indem Beton auf eine Grossplatte aus Betonfertigteilen gegossen wird, ermöglicht eine Verkürzung der Bauzeit, hilft Arbeitskräfte sparen und verringert den Aufwand an eingesetztem Baugerät und führt so zu einer wesentlich verbesserten Wirtschaftlichkeit bei der Arbeit. Dieser Bericht beschreibt die bautechnischen Versuche, die für den Entwurf der Betonplatten erforderlich sind, die Dehnung der Betonverbundplatten, die Software zur Erstellung eines optimalen Systembauplans sowie Anwendungsbeispiele und Erfahrungen auf der Baustelle.

1. INTRODUCTION

Large scale constructions are increasing in Japan but skilled laborers are in short supply and construction periods are shortened. Therefore, the development of advanced and reasonable technologies for construction work is an urgent theme. The authors have developed a new slab system (a precast and in-situ placed concrete composite slab system, PICOS System) and applied it to buildings on the premise that the system of formed slabs and computer aided engineering (CAE) is the key technology for increasing the economy of construction work.

2. OUTLINE OF THE PICOS SYSTEM

The main features of the PICOS System are as follows:
1) The large scale precast concrete panels are approximately the size of a grid surrounded by girders on four sides and are more than 70mm thick.
2) The precast concrete is cast on a horizontal concrete bed in-situ and is manufactured at the rate of one panel per day by multi-layer casting.
3) The precast concrete panel is combined with in-situ placed concrete by shear keys on each side in several lines. PICOS resists load as a composite structure and is designed as two-way slabs. The shear keys are 80mm square and have a depth of 8mm.
4) The PICOS System has a CAE sub-system as a useful tool for calculation, graphics and drafting to design the optimum conditions for construction planning. This results in economy.

3. EXPERIMENTAL RESEARCH

The following research and development work was performed in order to establish the standard specifications for the design and construction of the PICOS System.

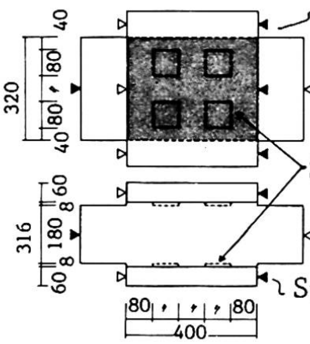


Fig.1 Shear key specimen for bearing and shearing test.

3.1 STRUCTURAL EXPERIMENT

The following experiments were carried out in order to investigate the transfer mechanism of horizontal shearing force at an interface between precast concrete and in-situ placed concrete.

3.1.1 Bearing and Shearing Strength

Shallow and concave shear keys are made on the surface of the PC panel in place of protruding reinforced trusses in order to form a concrete composite slab.
Experiments are carried out to study the effect of the shallow and concave shear keys in transferring the shearing force occurring at the interface between the PC panel and the in-situ placed concrete. A release agent is applied over the total surface of the PC panel in order to release it from the bond strength and

Shape of the shear key (mm)	Depth	30	4	8	30
	Width	80×80	80×80	80×80	80×80
Pieces of keys		2	8	8	2
PC panel surface finish		Finish by steel trowel Release agent applied			Finish by wood trowel
Condition at failure		Shear failure	Bearing failure		Shear failure
Maximum load (N)		76.5	72.5	141	642
Effective area (cm^2)		128	25.6	51.2	2560
Stress (MPa)		5.65	28.4	27.6	2.50

Table 1 Details of the experimental results.

to clear the shear key effect. The loading method applied is alternative loading. The structural specimen is shown in Figure 1 and the details of the experiments and the experimental results are shown in Table 1.
The experimental results allow us to design the size and number of shear keys. The bond strength is regarded as reserve strength.

3.1.2 Flexural and Shearing Strength
Short-term loading experiments are carried out in order to study the strength, deformation capacity and failure conditions of the composite slab. The results are studied by comparing them with those of a monolithic slab. A release agent is applied to the surface in order to clear the effect of the shear keys and also assume the case where there is no bond strength between the joint surface after a long period of time.
The effective span is shortened by assuming a case where large shearing force is applied. The loading method applied is 2-point line loading.
The structural specimens are shown in Figure 2 and the details of the experiments and the experimental results are shown in Table 2 and Figure 3. The experimental results prove that the shear keys to be made on the surface of the PC panel allow the construction of a composite slab with strength nearly equal to that of a monolithic slab.

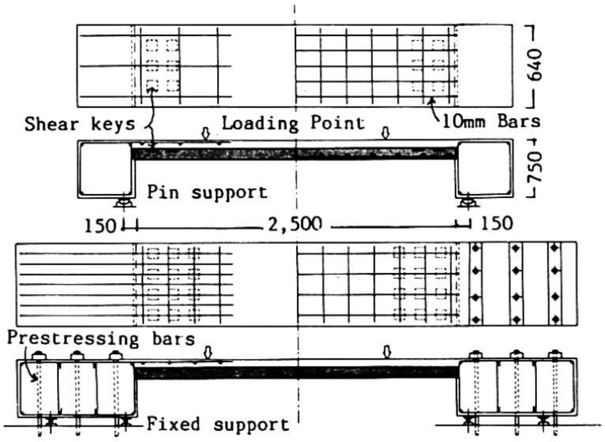


Fig.2 Slab specimen for flexural and shearing test.

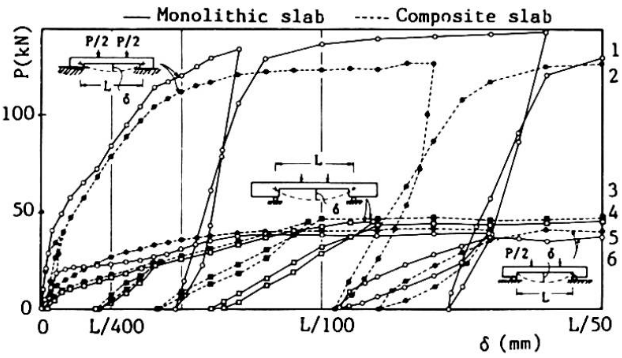


Fig.3 Load-deflection curves

Slab specimen	Effective span (L:mm)	Maximum load (N)	Fig.3
Monolithic slab	2,500	39.3	6
Composite slab(A)	(pin supports)	42.6	5
Monolithic slab	2,500	145	1
Composite slab(Ā)	(Fix supports)	127	2
Monolithic slab	4,500	38.3	4
Composite slab	(Pin supports)	40.5	3

(A): The surface of PC panel was finished by steel trovel and applied release agent.

Table 2 Details of the experimental results.

3.1.3 Creep Behavior
Long-term loading experiments are carried out in order to study the creep behavior of the composite slab and the long-term reliability of the shear keys.
The results are studied by comparing them with those of a monolithic slab. The loading method applied is uniformly distributed loading.
The specimens and loading method are shown in Figure 4 and the details of

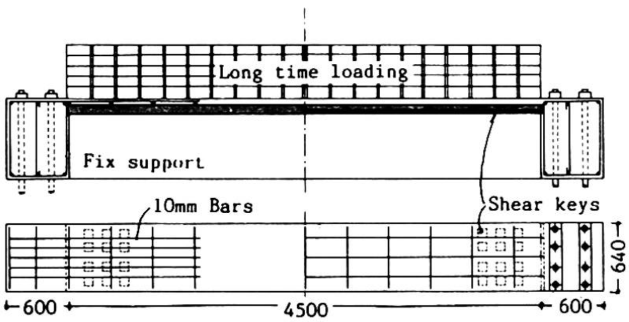


Fig.4 Slab specimen for long-term loading test.

the experiments and the experimental results are shown in Table 3 and Figure 5.
The experimental results show that the composite slab behaves similarly to a monolithic slab until the joint surfaces are completely separated and that no large deflection appears even if the separation proceeds.

Slab specimen	Effective span (mm)	Deflection (mm)		
		Loading	1Year	Ratio
Monolithic slab	4,500 (Fix supports)	1.70	14.4	8.47
Composite slab(B)		2.70	24.0	8.89
Composite slab		1.82	11.5	6.31

(B) : The surface of PC panel was finished by steel trowel and applied release agent

Table 3 Details of the experimental results.

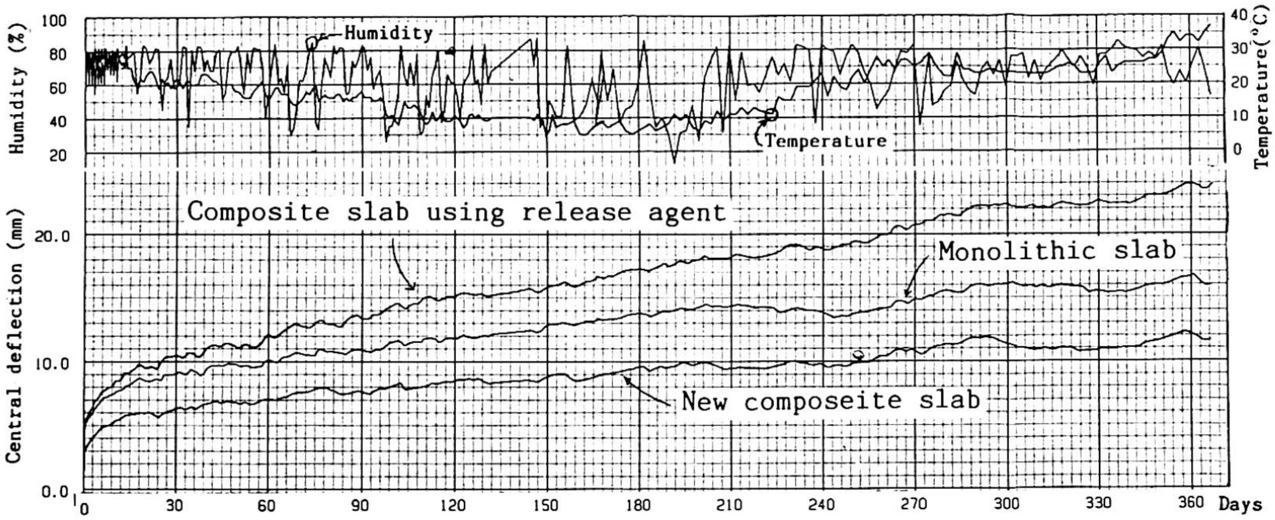


Fig.5 Changes in the central deffection of slabs by long-term loading test.

3.1.4 Drying Shrinkage

It is expected that the in-situ concrete may crack after a long term when concrete is cast in-situ on a PC panel because of the differences in dry shrinkage between the two. Experiments are carried out by changing such conditions as the thickness of the PC panel and the in-situ placed concrete, the composing period and the number of reinforcing bars.
The test results nearly agree with the corresponding values calculated by CEB/FIP. It is understood that no cracking occurs if the PC panel or the in-situ placed concrete is 50mm or more thick.

3.2 CAE SUB-SYSTEM

The logistics of minimizing manpower, temporary materials and other resources for prefabrication and erection in-situ were studied for the CAE sub-system of the PICOS System.
The logistics were based on the following ideas:

1) A crew composed of a fixed number of people repeats the same work every day.
2) Temporary materials and machines are reduced to as small a number as possible. Concrete for constructing the composite slab is cast directly from a truck mixer. Therefore, the total height of the composite slab cast by multi-layer casting is limited. The number of beds used for manufacturing PC panels is reduced to as few as possible.
3) The schedule for manufacturing PC panels is decided based on such conditions as the sequence of lifting the PC panels, the concrete strength appearance, the number of PC panel and the number of blocking construct areas.
4) The PC panel drawing is made by CAD. Some examples of the output from the CAE sub-system are shown in Figures 6, 7, and 8.

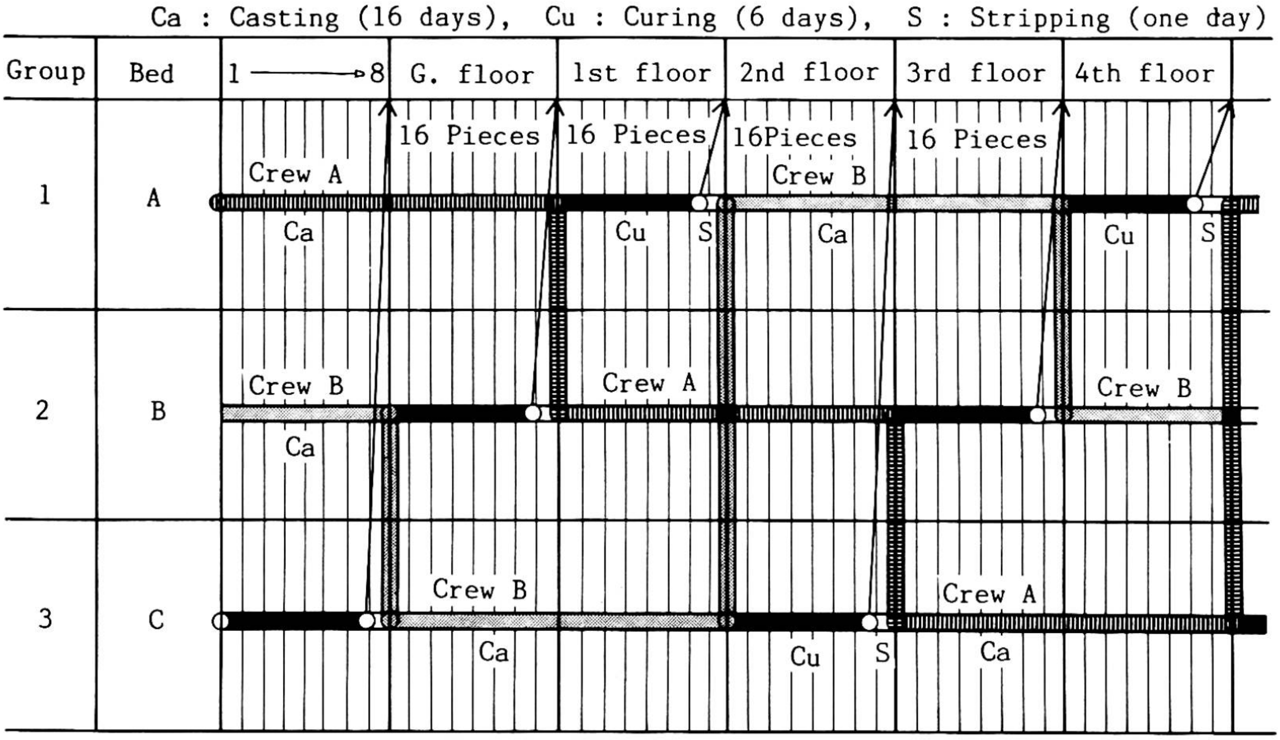


Fig.6 The crew balance chart for multi-layer casting in site.

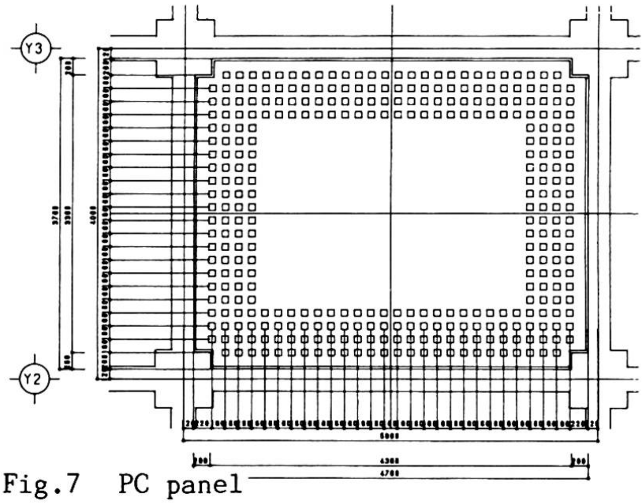


Fig.7 PC panel

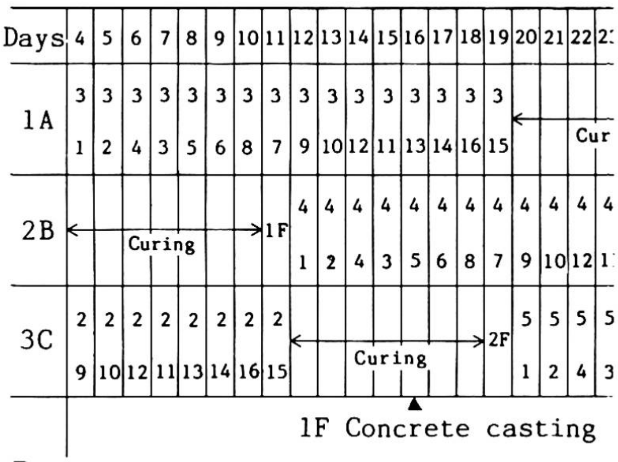


Fig.8 The manufacturing schedule

4. APPLICATIONS

4.1 APPLICATION EXAMPLE

The site plan of the D Building site is shown in Figure 9. The D Building Site is intended for the construction of a multiple dwelling house eight storeys tall. There are 16 slabs per floor and the construction period is eight days per floor. One blocking construct area is taken. The CAE subsystem calculates that the number of

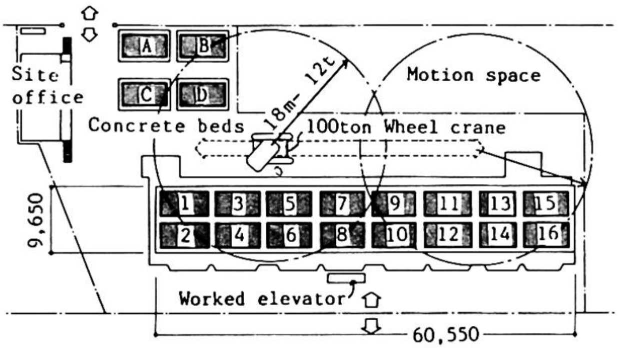


Fig.9 The site planning

beds required is three, the number of days for constructing the PC panels is 64, and the total number of workers is 256. In the actual work, the number of beds used is four , the number of days for constructing the PC panels is 56, and the total number of workers is 292.

4.2 MEASUREMENT OF WORKING HOURS

The results of the measured working hours for manufacturing PC panels at the D Building site are shown in Figure 10. The results of the average measured working hours for the A, B, C, and D Building sites are shown in Figure 11. The system is improved every time it is applied to construction and the skill of the workers is also improved. As a result, the quantity of work is now about eight worker-hours per PC panel and thus the economy is greatly improved.

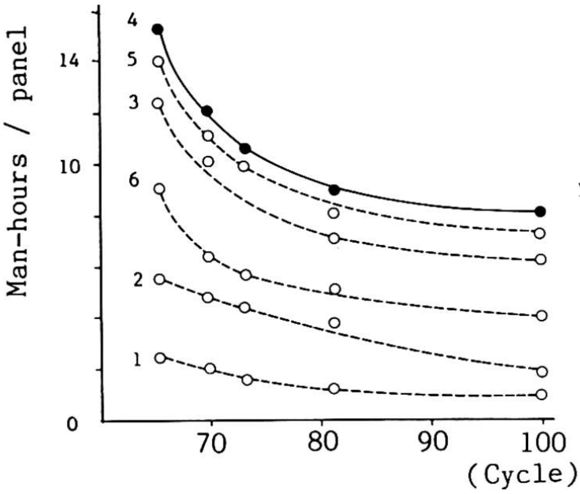


Fig.10 Man-hours (D Building Site)

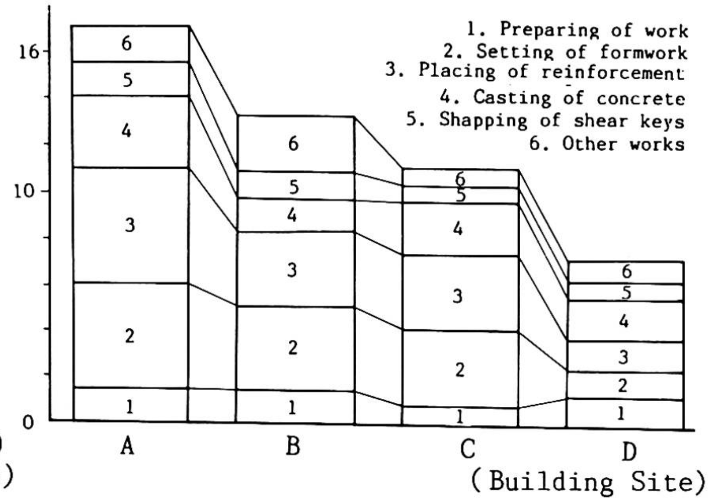


Fig.11 Total man-hours per panel

5. CONCLUSION

The PICOS System is now popular in Japan and has been applied to many construction buildings in a relatively short time. The PICOS System makes it possible to complete construction work satisfactorily and successsfully in a shorter period and thereby to save manpower and conserve materials.

The effects of the PICOS System on the economy of the construction work were examined in-situ as follows:

1) The labor productivity ratio of PICOS to the traditional method was 2 to 1. PICOS required repetitive and unskilled labor and had a more effective learning curve than did the traditional method.

2) The site management productivity ratio of PICOS to the traditional method was approximately 3 to 2.

3) The construction period required for PICOS was approximately half as long as that for the traditional method.

4) The weight of the temporary materials required by PICOS was one-eighth that of the weight required by the traditional method.

5) PICOS excelled the traditional method in terms of accurecy of concrete strength , thickness of slab, placement of the reinforcing bars and smooth-faced ceilings.

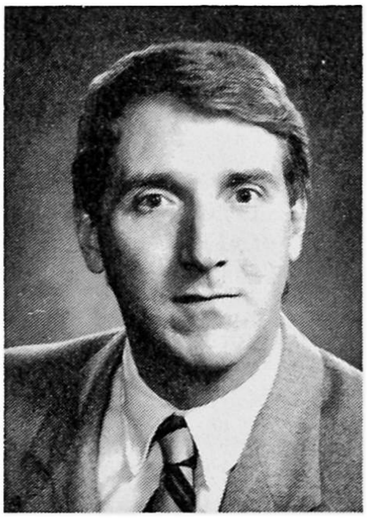
6) The PICOS System can be of great use for the systematization of construction methods, that is for the separated horizontal-and-vertical construction system, for the blocking construct area method, etc.

Automated Construction Schedule Analysis and Evaluation

Analyse et évaluation de programmes de construction automatisés

Berechnung und Ueberwachung von computergestütztén Bauprogrammen

C. William IBBS
Assoc. Prof.
Univ. of California
Berkeley, CA, USA



Professor Ibbs leads an active research group dedicated to applying advanced computer technologies to construction project control.

MM. De La Garza and Echeverry are graduate research assistants to Professor Ibbs at the University of Illinois, where he was previously affiliated.

J. M. De La GARZA
Res. Assist.
Univ. of Illinois
Urbana, IL, USA

Diego ECHEVERRY
Res. Assist.
Univ. of Illinois
Urbana, IL, USA

SUMMARY
This paper explains in some detail a knowledge-based computer system for the analysis and updating of construction schedules. Special attention is devoted to discussing the various representation forms and the relationships used to link the system's knowledge concepts. The project will be used in managing large-scale civil works construction.

RÉSUMÉ
Cet article présente en détail un système expert pour l'analyse et la mise à jour de programmes de construction. Il porte un intérêt particulier aux diverses formes de représentation ainsi qu'aux relations entre les différents concepts du système expert. Le projet sera utilisé pour la gestion de grands travaux de construction.

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt ein System zur Berechnung und Nachführung von Bauprogrammen. Spezielles Gewicht wird auf die verschiedenen Darstellungsformen und die Verbindungen zur Information des Computerprogrammes gelegt. Das Projekt wird für das Management grosser Bauaufgaben angewandt.

Introduction

Construction scheduling, along with estimating, cost control and quality assurance, is a vital ingredient to effective project control, particularly on renovation and rehabilitation work. Knowledge-based expert system (KBES) technology offers the promise of significant advance to all elements of project control, and in this article we outline the progress we have made in developing an intelligent scheduling system. Our approach has been to view scheduling from the owner's perspective and to examine both original submittals and updates.

The system being developed, CONSAES (CONstruction Scheduling Analysis Expert System), relies upon existing project control system software as its fundamental source of project data. The hardware, software, and communication linkage schemes we chose have also been documented in previous articles and interested readers are accordingly directed there (1, 2, 3).

KNOWLEDGE ORGANIZATION

As the "paper" knowledge base became larger, it began to exhibit some regularity in the sense that expressions of similar form frequently reappeared. Once these regularities were identified, they were captured by building an English-like knowledge acquisition grammar. This grammar allows us to express the facts, rules, and concepts of the construction schedule analysis domain. For example, the syntax for the rule and condition categories is:

```
(rule)          :: = IF (conditions) THEN (conclusions)
(condition)     :: = (frame) HAS (parameter) OF (value)
(condition)     :: = (frame) IS IN CLASS (frame)
```

As a specific example, RULE-111 within the Look-Ahead rule group can be represented by the following English and English-like grammars:

"Paper" knowledge base format:

Make projections based on what has happened versus what was planned.

Knowledge Acquisition format:

```
IF   ((?some-activity IS IN CLASS activities) AND
      (?some-activity IS IN CLASS concrete) AND
      (?some-activity HAS status OF finished   in-progress) AND
      (?some-activity HAS assessment OF slow-progress) AND
      (concrete HAS lagged OF ( > 5 )))

THEN ((?activities IS IN CLASS activities) AND
      (?activities IS IN CLASS concrete) AND
      (?activities HAS status OF unfinished) AND
      (set (?activities HAS new-duration OF (* old delay))))
```

Here, previous job experience with a particular class of work activities is scrutinized for a deterministic delay factor. If found, that modifier is then applied to all subsequent unfinished activities in that class to develop a new projected schedule duration. This update is advisory only in nature allowing the system user to see clearly and in real time the changes recommended.

Use of this English-like knowledge acquisition grammar reduces the effort expended on acquiring additional rules. In addition, the knowledge represented in this generic syntax can be easily adapted to a variety of inference engine designs.

KNOWLEDGE REPRESENTATION

The Automated Reasoning Tool (ART)™ programming environment has been selected and acquired as the inference engine to process the knowledge base. ART is a set of specialized tools that facilitates the rapid prototype of expert systems. ART's knowledge representation language supports the expression of a wide variety of different types of problem-solving knowledge. These include: if-then rules, facts expressed in a logical-relational notation, frames that describe general classes of objects in the application domain, and procedural strategies used to represent algorithmic knowledge not easily expressed in the classic AI if-then rule framework. A large part of construction schedule analysis involves considering and evaluating different possible actions or evaluating a situation that is changing over time. Towards the end, ART provides "hypothetical worlds" as its most fundamental technique for generating, representing, and evaluating either static or dynamic alternatives.

The power of CONSAES is derived largely from the knowledge captured within it. Object-oriented programming provides the facilities, e.g. objects, to structure information which describes a physical item, a concept, or an activity. Each object is represented as a frame, containing declarative, procedural, and structural information associated with the object. That is, a frame is a collection of facts that represent an object or class of objects that share certain properties. Object-oriented programming is an extremely advantageous feature of ART, which allows information of common nature to be stored declaratively in the frames, where it is easily accessible and modifiable.

Since CONSAES deals with a highly complex domain, it is necessary to impose a structure on the domain. For example, some of the data elements can be organized into related groups. This makes them easier to analyze, describe and manipulate than hundreds or thousands of unstructured facts.

The ART schema system is a language for classifying data logically as well as for reasoning about data that has been structured. In addition to providing a way to structure all or part of a complex database, the schema system offers a convenient language for indicating that some data items share properties. Schema definitions can be organized into hierarchies in which knowledge about an object can be automatically deduced or inherited based on the class or classes to which it belongs.

KNOWLEDGE IMPLEMENTATION

The specific manner in which CONSAES works is as follows. During the construction planning phase, a work breakdown structure is routinely defined based on project phases, goals and organization. Milestone descriptions are derived from the work breakdown structure as tasks suitable for scheduling and monitoring. Traditionally, milestone descriptions are defined in such a way that they convey both a building and a construction process, e.g. "cast in place 2nd floor slab." The hierarchical relationship as well as the inheritance path of such a milestone are shown in Figure 1. A relation connects a schema to one or more other schemata. The inclusion of one or more relations in a schema serves to establish it as a node in a hierarchy. In other words, relations are the links that establish a schema hierarchy and permit inheritance of attributes. Note that the arrows shown in the diagram have significance in that they originate with the object being defined. They point to each schema that is listed as the value of the relation.

UTILITY AND RELEVANCE OF THE RESEARCH

This research is leading to fundamental advances in the knowledge base of project control thought in four distinct ways.

First, the development of the prototype is demonstrating that this new approach is satisfactory for accelerating and, indeed, improving upon many of the brute-force analyses and calculations typical of routine scheduling.

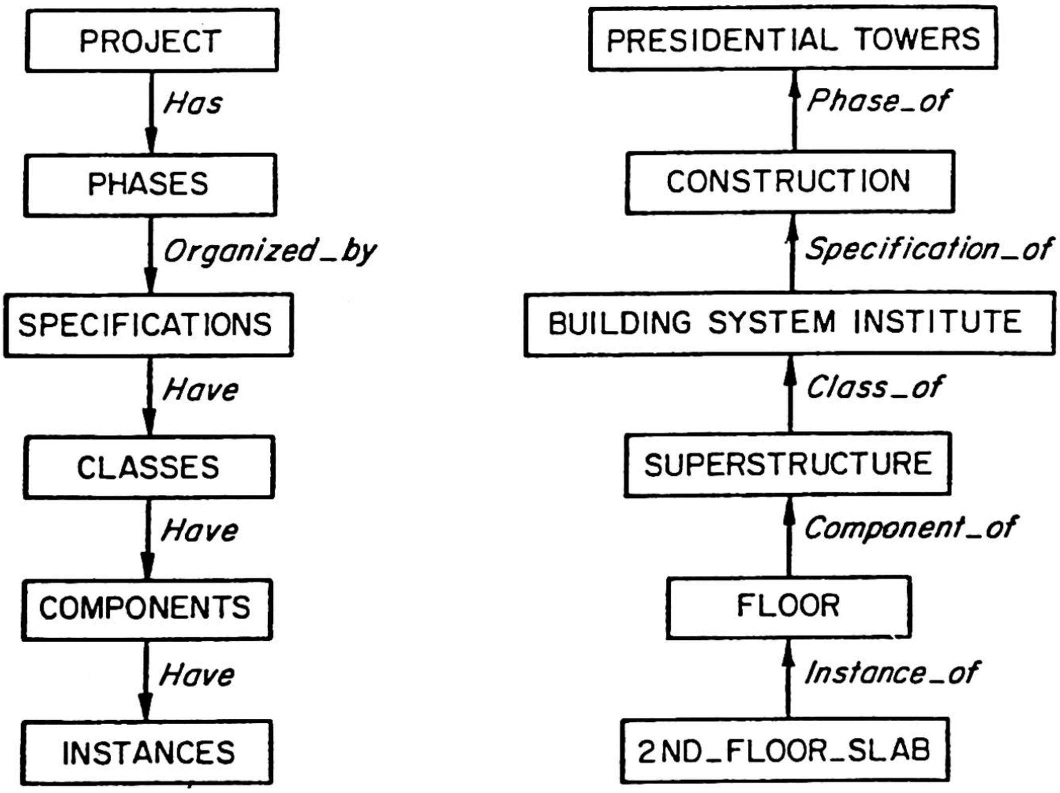


FIGURE 1 Knowledge Base Taxonomy

Second, this investigation identifies and organizes the knowledge (analytic and heuristic) that successful construction engineers use to schedule and time management projects. This work can be though of as a natural extension of important research conducted by a previous generation of investigators like Fondahl, Crandall and Halpin. They carried scheduling theory and practices to the refined science that it is today. Now that the analytical methods and mathematical theory are so mature, it seems quite proper, even critical, that researchers turn their attention to the project and practice-oriented features; e.g., developing or at least formalizing methods of re-estimating activity durations.

The third important advance represented by this research is of an applications nature. For a field as practice-driven as construction, expert systems concepts seem ideal. Especially so for a body of knowledge like scheduling which is part quantitative and part subjective.

Finally, the development of an expert system in construction schedule analysis could lead to the identification of new theory, or develop deep knowledge in the field, by formalizing the existing state of knowledge. In particular, the object-oriented representational approach may provide new and better ways to integrate cost quality and schedule information that to date has been so elusive. In this way, expert systems technology can provide heuristic answers to today's problems while suggesting research to develop and use new heuristics as well as new algorithmic solutions in the future.

Many other researchers are working quite hard to develop KBES tools for project management. Some of the more prominent and accessible work is documented in references 4, 5, 6 and 7.

REFERENCES AND OTHER READINGS

1. De La Garza, J.M., and Ibbs, C.W., A Knowledge Engineering Approach to the Analysis and Evaluation of Vertical Construction Schedules, Proceedings of the 10th Triennial Congress of the International Council for Building Research, Studies and Documentation, Vol. 2, pp. 683-691, Washington, D.C., September, 1986.

2. Ibbs, C.W., and De La Garza, J.M., Knowledge Engineering for a Construction Scheduling Analysis System, Expert Systems in Construction and Structural Engineering, edited by Hojjat Adeli, Chapman and Hall Publishing Co., forthcoming, 1987.

3. O'Connor, M.J., De La Garza, J.M., and Ibbs, C.W., An Expert System for Construction Schedule Analysis, Proceedings of the First Symposium on Expert Systems in Civil Engineering, edited by Celal Kostem and Mary L. Maher, ASCE, pp. 67-77, Seattle, WA, April 1986.

4. Levitt, R.E. and Kunz, J.C., "Using Knowledge of Construction and Project Management for Automated Schedule Updating," Project Management Journal. Vol. 16, No. 5, December 1985.

5. Gray, C. and Little, J. "Expert System Development for Predicting Time and Cost of Construction During Initial Design," 1st International Expert System Conference, London, 1986.

6. Hendrickson, C., Martinelli, D. and Rehak, D. "Hierarchical Rule-Based Duration Estimation," Dept. of Civil Engineering Working Paper, Carnegie-Mellon University, 1986.

7. Ashley, D. and Perny, Y-H. "An Intelligent Construction Risk Identification System." Department of Civil Engineering Working Paper, University of Texas at Austin, 1986.

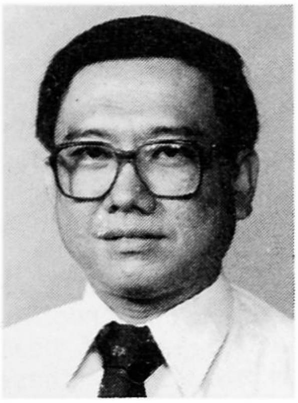
Leere Seite
Blank page
Page vide

Special Techniques for Construction of Viaducts in Singapore

Techniques spéciales pour la construction de viaducs à Singapour

Spezielle Bauverfahren für Brücken in Singapur

Ewe Chye LIM
Senior Lecturer
Nanyang Technol. Inst.
Singapore



Ewe Chye Lim obtained his Civil Engineering degree from University of London. He worked for five years with Consulting Engineers and has spent the last ten years as an academic. His main interest is in Civil Engineering Construction, in particular bridges, tunnels, high-rise buildings and deep basements.

SUMMARY
This paper describes techniques adopted in the construction of viaducts using precast concrete post-tensioned longitudinal beams and examines the use of different types of purpose-built erection equipment to suit various site constraints. Methods used in the construction of viaducts for the recently built Singapore Mass Rapid Transit system are discussed. Emphasis is on the use of special equipment to transport precast beams from casting yards onto viaducts, installation of beams into their final positions and the forward advance of launching girders.

RÉSUMÉ
Ce travail décrit des techniques adoptées dans la construction du métro de Singapour, le Singapore Mass Rapid Transit, pour le montage des viaducs utilisant des poutres longitudinales en béton préfabriquées, et avec posttension. Il examine l'emploi de différents équipements de montage en fonction de contraintes locales. L'attention est portée sur le systéme de transport des poutres préfabriquées du chantier à l'emplacement des viaducs, ainsi que leur mise en place définitive avec la poutre de lancement.

ZUSAMMENFASSUNG
Der Aufsatz beschreibt das Verfahren der Brückenkonstruktion aus vorfabrizierten Teilen. Die Eignung verschiedener Montagesystme wurde speziell untersucht. Die Methoden, die für die Brückenerrichtung von Singapores Transit System angewendet wurden, werden diskutiert. Besonders wichtig ist die Verwendung von speziellen Maschinen zum Transport von vorfabrizierten Balken für deren Versetzen in die endgültige Lage.

1. INTRODUCTION

The building of viaducts for roadways and rail systems is an important aspect of Civil Engineering Construction. With advances in technology, engineers are building viaducts in shorter times by the use of precast concrete elements. However, the use of long span precast concrete beams will give rise to transportation problems should these units be carried by articulated vehicles and launched by mobile cranes. The construction of flyovers which comprise several spans and require the installation of up to about fifty precast beams, is manageable by the above technique, especially if these units can be transported during off-peak hours. Where many kilometres of viaducts are to be constructed, Engineers must device special purpose-built erection equipment to enable hundreds of precast beams to be installed without interruption to existing road traffic. Advanced launching techniques are available for "off-the-road" transportation and erection of viaduct beams to great satisfaction of all parties involved.

A spectacular feature is the viaduct construction for the Singapore Mass Rapid Transit System, in which over 3,300 precast beams were concreted and launched within a three-year period from mid-1985. These precast beams make up almost the entire 42 km length of elevated viaduct, which forms some 64% of the total 66 km route of the Singapore Mass Rapid Transit network.

2. STRUCTURAL CONCEPTS

In building precast concrete viaducts, the precast components are of significant numbers and most large contracts have precasting yards adjoining the viaduct under construction. Purpose-built gantry cranes are normally chosen to lift and transport the heavier units within the site, although mobile track or wheel mounted cranes are frequently used to handle smaller precast beams.

Where the location of the casting yard and the viaduct are advantageously positioned, it is possible to design the casting yard crane so that it can lift a beam directly from its mould onto the viaduct for direct delivery to the erection point. This combines the functions of the casting yard gantry and the transfer gantry. The latter is so named because it is used to transfer the precast beam to the viaduct.

The erection gantry, more commonly known as the launching gantry, is the most complicated member of the family of equipment needed on major projects. The launching gantry has not only to install beams onto cross-heads with high accuracy, it has also to launch itself between cross-heads, up and down slopes, manoeuvre curves and has frequently to offer stability to the viaduct structure.

3. PURPOSE-BUILT ERECTION EQUIPMENT

3.1 The Casting-yard Gantry

Precast concrete beams are manufactured in specially planned casting yards for various contracts and transported onto the viaducts. Location of the casting yard determines the method to be used in transporting the precast members. The arrangement of the beams on sites are divided into two main categories:

(i) casting yard with individual casting beds parallel to the viaduct,
(ii) casting yard with individual casting beds perpendicular to the viaduct.

Sites separated from the viaduct by a road pose a challenge in that the beams have to be moved over the road with minimal interruption to vehicular traffic.

Several alternatives are available:

(i) a rail-mounted gantry (Fig. 1) for the yard and a transfer gantry (Fig. 2) to lift the beam onto the viaduct.

(ii) a long-rail girder to serve both the casting yard and to load the beams onto the viaduct (Fig. 3).

(iii) C-type frame to serve both the casting yard and to load the beams onto the viaduct (Fig. 4).

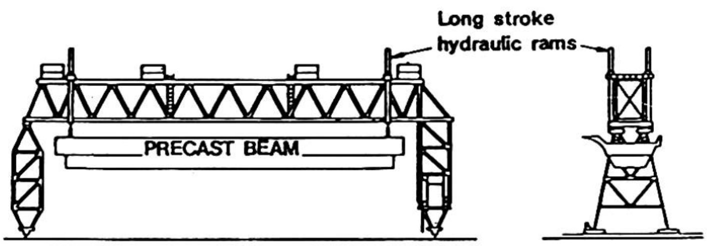


Fig.1 CASTING YARD GANTRY

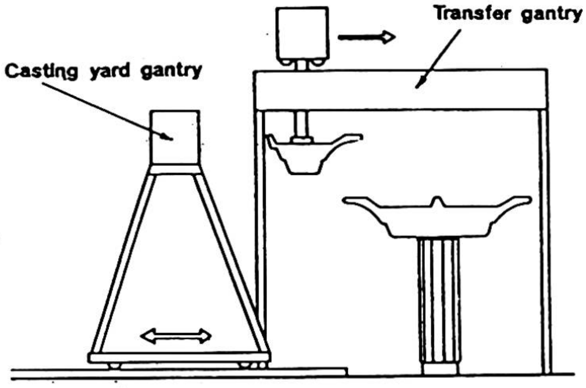


Fig.2 TRANSFER GANTRY

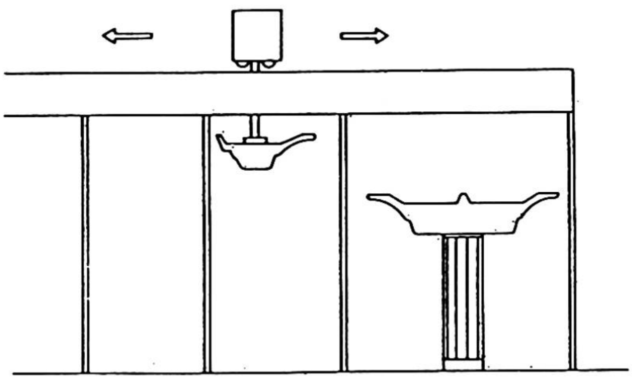


Fig.3 LONG-RAIL GIRDER

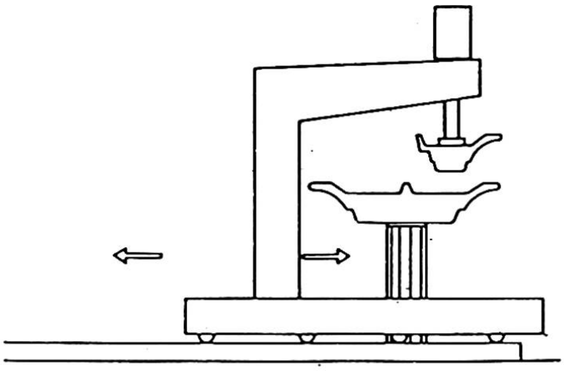


Fig.4 C-FRAME CASTING YARD GANTRY

The typical casting yard gantry mentioned in (i) above is a simple pinned portal frame with a lifting height capacity sufficient to lift a beam element out of and clear of its mould. The usual lifting height is about 5 m and the operation is executed inexpensively using long stroke hydraulic rams as opposed to electric or hydraulic winches. Beams that are concreted on casting beds perpendicular to the viaduct have to be rotated 90^0 on a turntable to bring them parallel to the viaduct.

The transfer gantry is a massive piece of fabrication and has to provide clearance for the casting yard gantry, precast beams and the beam launching gantry. The transfer gantry usually comprises a pair of elevated truss or plate girders supporting a mobile overhead crane beam transporting the precast components. The lifting mechanism on the transfer gantry is usually expected to carry beams at heights in excess of 10 m.

The long-rail girder serves both the function of the casting yard gantry and the transfer gantry. It is basically an extension of the transfer gantry in that it covers the whole precasting yard and does away with the casting yard gantry.

Where the casting yard is adjacent to and casting beds are parallel to the viaduct, C-type gantries can be mobilised to lift the precast units directly onto the superstructure. To perform this task, the gantry must cantilever over the superstructure and place the beam on a transport vehicle on the viaduct. This is the most economical way of lifting the beams and transferring them onto the viaduct.

3.2 Launching Gantry

Various types of beam launching gantries are used in different countries and generally they are expected to place four or more beams side by side. Within each span the beams are parallel but the gantry has to alter horizontal alignment between spans to cater for horizontal curvature.

4. SINGAPORE MASS RAPID TRANSIT VIADUCT CONSTRUCTION

4.1 Viaduct Structure

The viaduct configuration generally adopted consists of two lines of post-tensioned precast concrete box-girders (Fig. 5) supported by reinforced concrete cross-heads which cantilever from single columns. Half-joints are introduced to carry the beams on the cross-heads and the box-girder profile is maintained through the cross-heads. Horizontal curves are possible by profiling the top side cantilevers of the beams to the required geometry. The box-girder soffit is kept to a straight profile between supporting cross-heads to keep construction costs to a minimum. The ends of the box-girders with the highly stressed half-joints and the tendon anchorages are solid.

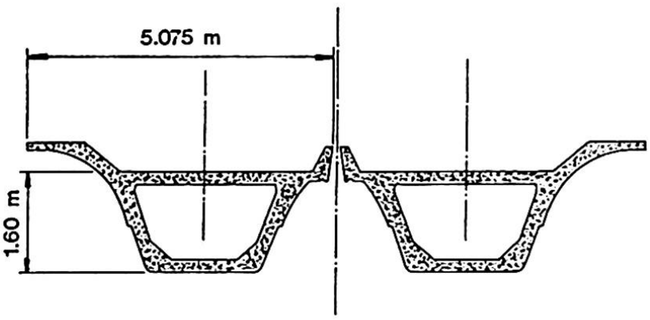


Fig.5 TYPICAL VIADUCT CROSS-SECTION FOR SINGAPORE MRT SYSTEM

The average precast box-girder weighs 170 tonnes, has an overall depth of 2100 mm and its top flange cross-sectional width is 5075 mm. The viaduct is typically situated either in the median of a dual carriageway road or alongside a road. In the median, the support structure is restricted to the space available between the carriageway gauges.

4.2 Construction Configuration

The substantial numbers and large sized precast beams to be transported daily to the various installation points would cause major traffic disruptions. In addition very large beam loads on roadways would need examination of existing bridges, culverts and drains along the viaduct route. The acceptable solution was to transport beams on a temporary rail track along the newly installed viaduct and place the beams into position using a self-travelling launching gantry mounted on the viaduct itself. This method allowed for the rapid building of the viaduct to meet tight construction schedules.

Casting yard sites were strategically located alongside viaduct routes to facilitate the launching gantry techniques. The most appropriate casting yard layout was to provide beam casting beds parallel to the adjoining viaduct. At casting yards where the beams were manufactured perpendicular to the viaduct, turntables were provided before they were placed onto the viaduct.

4.3 Launching Techniques

The launching system consisted of basically three sets of equipment:

(i) a loading system to transport the beams from the casting yard onto the viaduct,

(ii) a rail transport system to deliver the beams to the point of launching,

(ii) a launching gantry which lifted the beams from the rail cars, conveyed them longitudinally into the next span, lowered them to their final position, and advanced itself to the next span.

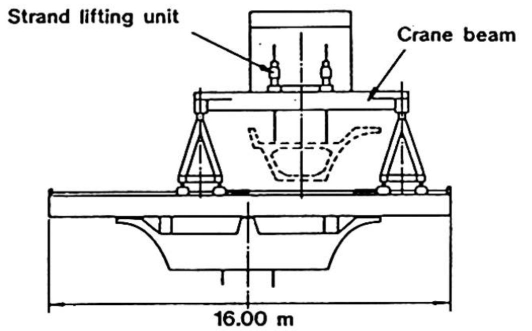


Fig.6(a) SECTION THROUGH TYPICAL LAUNCHING GANTRY

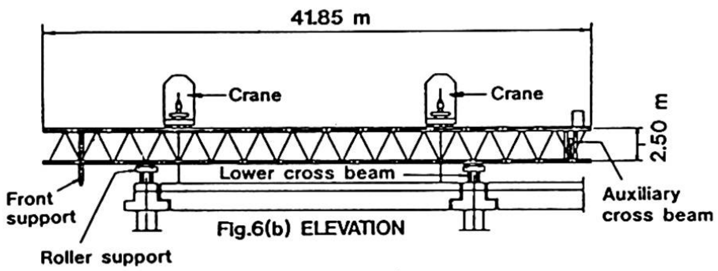


Fig.6(b) ELEVATION

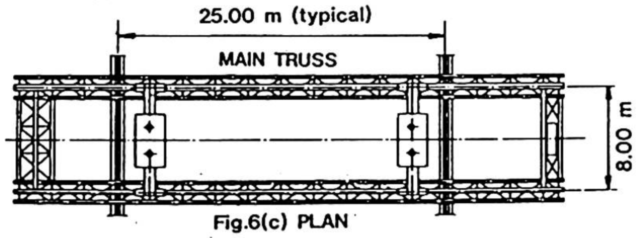


Fig.6(c) PLAN

TYPICAL LAUNCHING GANTRY FOR SINGAPORE MRT SYSTEM

In the Singapore MRT system, precast beams were erected singly or in pairs. The launching girder had to be able to manoeuvre and operate safely along a minimum 400 m radius and a gradient up to 2.5%. From records obtained from completed sections of the MRT system, a launching girder could comfortably place one beam per day within normal working hours. Faster rates of placement were also achieved and on exceptional occasions up to three beams were launched in one day, with long working hours and night work.

One type of purpose-built launching gantry used on several viaduct contracts is illustrated in Fig. 6. Each launching gantry consists of two main trusses which are able to move longitudinally and laterally on two lower cross-beams. Two crane beams which support the lifting equipment move on top of the main trusses. The launching gantry lifts the precast beam off the rail cars, transports it longitudinally into the next span, lowers and keeps the beam suspended until the load can be transferred to the permanent bearings.

When the launching girder advances itself into another span, it is firmly connected to the beam which rests on the rail cars. The beam acts as a counter-weight for the free cantilever of the launching gantry while the rail cars provide the driving force for the forward longitudinal advance. The principle of using the beam as a counter-weight while advancing the launching girder longitudinally is to allow a reduction in the total length of the gantry to a little over 40 m. The gantry is able to move forward with all its equipment without any assistance of a mobile crane.

The launching gantry is also able to install beams for the parallel viaduct (i.e. two beams side by side) by sliding laterally on its own lower cross-beams. In moving longitudinally, the launching girder relies on roller supports which rest on the lower cross-beams.

The average cycle time is as follows:

o	Loading of beam from casting yard onto railcars	2.5 hrs
o	Rail transport (speed 400 mm/sec; say 1 km to launching gantry and same distance back to loading installation)	1.5 hrs
o	Beam launching	2.0 hrs
o	Advance of launching girder	4.0 hrs

5. CONCLUSIONS

The use of precast concrete beams and the adoption of purpose-built construction equipment have facilitated speed of construction of viaducts. This method of construction has permitted installation of beams with minimum traffic disruption and excellent safety records. A variety of purpose-built erection equipment is available to the engineer and the contractor. The final choice of equipment must depend on contract period, location of casting yard, route of the viaduct and configuration of the superstructure.

ACKNOWLEDGEMENT

The author would like to thank the Singapore Mass Rapid Transit Corporation for permission to publish information on the MRT system.

REFERENCES

1. BHOGAL, S. S., ROBINSON, S. A. and TAYLOR, R. D., Singapore Mass Rapid Transit System: Viaduct Design. Singapore Mass Rapid Transit Conference, April 1987, Singapore.

2. GEE, G. A. and YARWOOD, N. G. A., The Economical Use of Purpose-Built Erection Equipment in Precast Concrete Bridge Structures. International Conference on Modern Techniques in Construction, September 1987, Singapore.

3. POTTER, L. A. C., Precasting for Viaduct Beams. Singapore Mass Rapid Transit Conference, April 1987, Singapore.

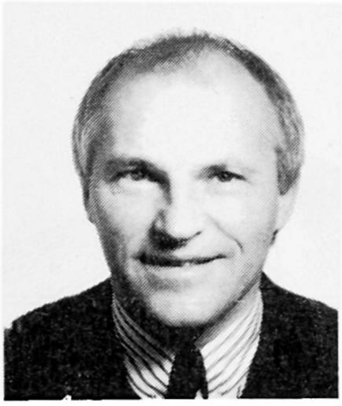
4. RAMASAMY, G., Launching Systems for Viaduct Precast Beams. Singapore Mass Rapid Transit Conference, April 1987, Singapore.

Rotation: Mode d'exécution original du pont de Ben-Ahin

Drehung: Einzigartige Bauweise der Ben-Ahin Brücke

Rotation: Original Mode of Erection of the Ben-Ahin Bridge

Jean-Marie CREMER
Ingénieur Civil
Bureau d'Etudes Greisch
Liège, Belgique



J. M. Cremer, né en 1945, a obtenu son diplôme d'ingénieur civil des constructions à l'ULG, Liège en 1968. Pendant 4 ans, il dirige des chantiers de génie civil. En 1973, il entre au bureau Greisch où il est actuellement responsable des études des ouvrages d'art.

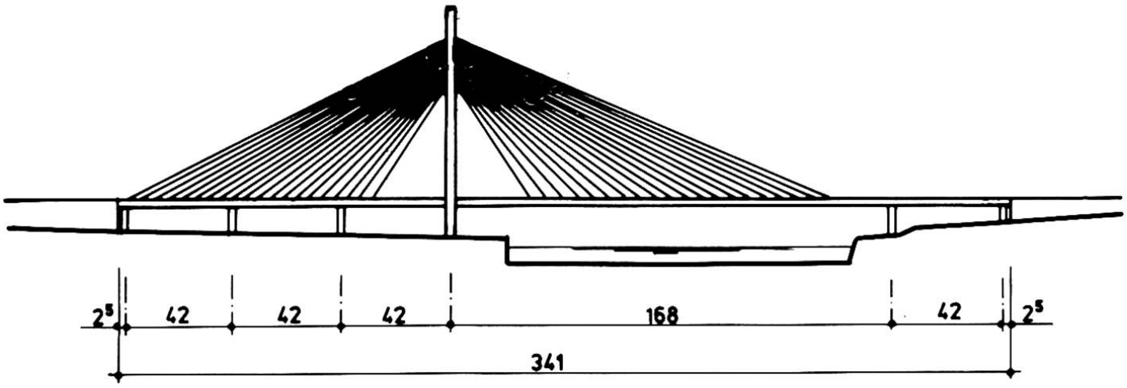
RÉSUMÉ
Le pont de Ben-Ahin par son mode d'exécution tout à fait original, la rotation, fait figure d'ouvrage d'avant-garde. A notre connaissance, jamais un pont de poids aussi élevé (16000 T.) et de portée aussi grande n'a été mis en place par ce système. Les avantages de ce mode d'exécution sont un gain de temps et de coût grâce à la construction complète de l'ouvrage sur la terre ferme et l'absence de nuisance pour le trafic fluvial pendant les travaux.

ZUSAMMENFASSUNG
Die Ben-Ahin Brücke stellt wegen ihrer einzigartigen Bauweise, der Drehung, ein zukunftsweisendes Bauwerk dar. Unseres Wissens wurde noch nie eine so schwere Brücke (16000 T.) mit einer solchen Tragweite durch diese Methode über einen Fluss gespannt. Die Vorteile dieser Bauweise sind Zeit- und Kostenersparnis, da das Bauwerk vollständig auf dem Festland fertiggestellt wird und der Schiffsverkehr während den Arbeiten nicht unterbrochen wird.

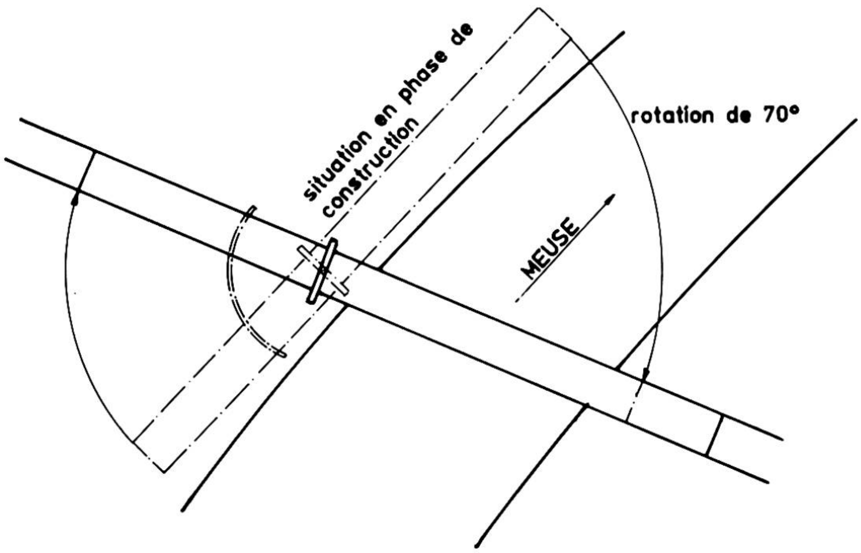
SUMMARY
Due to its quite original mode of erection, rotation, the Ben-Ahin bridge is an outstanding work. To the author's knowledge, it is the first time that such a heavy bridge (16000 T.) with such a large span was rotated by about 70 degrees across a river. This mode of erection permits time and cost savings because the whole structure can be built on dry land. In addition, the river traffic is not interrupted during the construction works.

1. DESCRIPTION GENERALE

L'ouvrage qui franchit la Meuse à environ 2 kilomètres en amont de la ville de Huy permettra de relier dans des conditions favorables la ville de Huy au réseau d'autoroutes belges en évitant le centre de la ville souvent encombré.
C'est un pont haubané à un seul pylône avec une nappe centrale de 40 haubans (20 de chaque côté du pylône) supportant un tablier en béton partiellement précontraint.
La longueur totale du pont est de 341 m. Il se compose d'un fléau d'équilibrage de 128,5 m reposant sur 3 appuis en rive gauche, d'un fléau de 168 m au-dessus de la Meuse et d'une travée de 42 m en rive droite prolongée par un porte-à-faux de 2,5 m.



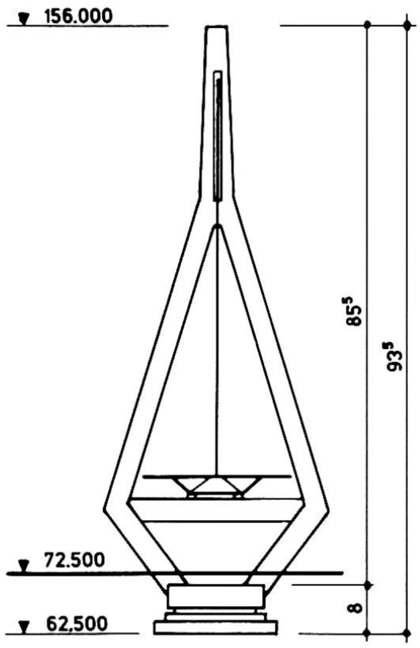
L'ensemble des 2 fléaux soit 296,5 m de long a été construit sur la rive gauche de la Meuse, parallèlement à la berge, sur cintre complet. Après montage et règlage des haubans, l'ensemble a subi une rotation de 70° autour de l'axe du pylône qui a amené l'ouvrage en position définitive et réalisé la continuité avec la travée de 42 m construite en rive droite.



Ce procédé de mise en place a déjà été utilisé notamment en France pour des ouvrages plus petits (de l'ordre de 4000 to). A Ben-Ahin les charges déplacées sont supérieures à 16000 to.

2. DESCRIPTION DES DIFFERENTS ELEMENTS DE LA STRUCTURE

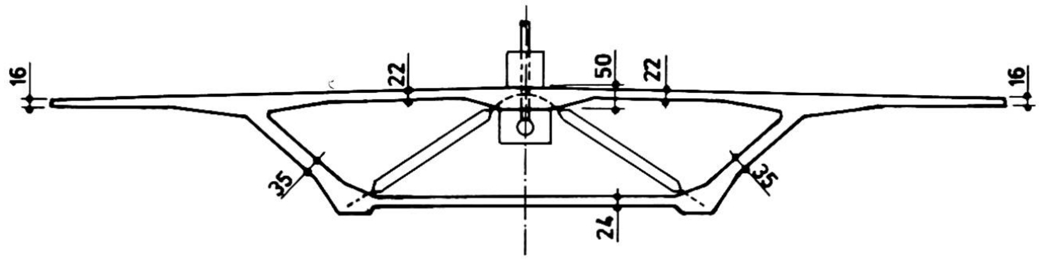
2.1. Pylône



Il a une hauteur totale de 93,5 m. Il a une forme d'Y renversé avec les jambes inférieures retroussées et encastrées dans une semelle unique. Au niveau de la cassure des jambes, une traverse horizontale reprend les efforts de poussée au vide. Elle est précontrainte par 42 câbles 19T15 soit un effort d'environ 12000 to. Elle sert également de point d'appui pour le tablier. Dans la tête du pylône se trouve une cage métallique de 20 m de haut et 70 cm de large où sont ancrés les haubans.

2.2. Tablier

C'est un caisson en béton de 21,8 m de large et de 2,9 m de haut avec 2 âmes inclinées, des encorbellements de 4,5 m et un fond de caisson de 8,7 m de large. A l'intérieur, des bracons en béton ou des tirants métalliques liaisonnent le centre de la dalle de plattelage au bas des âmes.



La forme intérieure de la coupe transversale permet de définir deux sections différentes: une section légère (11 m2) qui existe sur la plus grande partie de l'ouvrage (250 m) et une section lourde (16 m2) qui existe sur environ 100 m du fléau d'équilibrage en rive gauche.
La longueur des fléaux en rotation étant dissymétrique (168 m d'un côté et 126m de l'autre), cette différence de section était nécessaire pour équilibrer en partie les charges.
Pour égaliser parfaitement les masses en rotation de part et d'autre du pylône le fléau le plus court a été lesté sur appuis.
Ce lest est également nécessaire en service pour éviter le soulèvement des appuis sous l'effet des surcharges sur la travée en Meuse.

2.3. Haubans

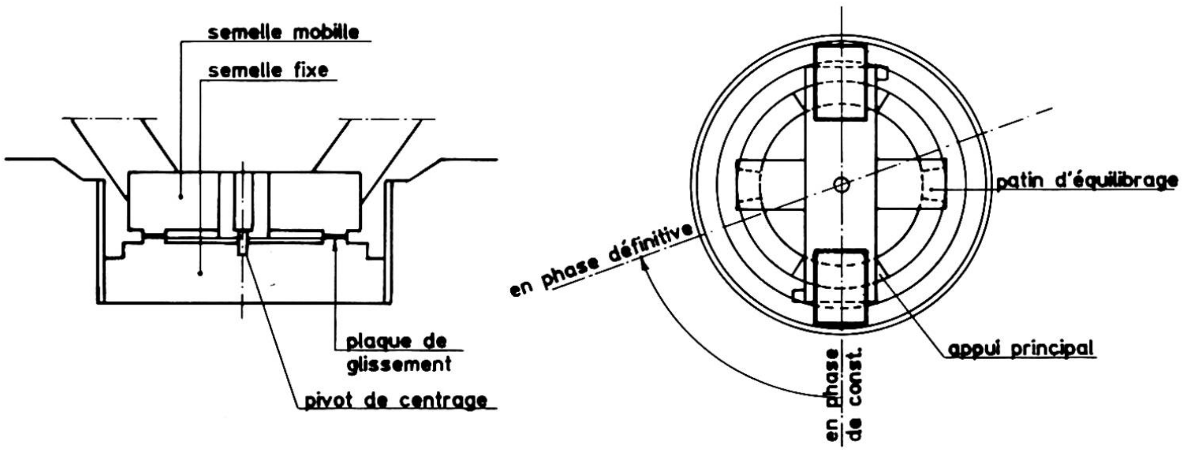
Au nombre de 40, ils constituent une nappe centrale de type semi-harpe. Ils sont composés de torons à fils parallèles. Le nombre de torons dans un hauban varie de 47 à 73.

Ils sont attachés au pylône par l'intermédiaire d'une boîte métallique logée dans la tête de celui-ci et solidarisés au béton au moyen de goujons connecteurs.
Ils viennent s'ancrer dans le tablier au moyen de bossages en béton dans lesquels sont noyés une plaque d'appui et un tube métallique.

3. DESCRIPTIONS DES ELEMENTS SPECIAUX POUR LA ROTATION

3.1. Semelle du pylône

C'est l'élément essentiel de la rotation. En effet, pendant celle-ci, toute la masse de l'ouvrage est reportée en un point unique: le pylône.
La fondation a donc été particulièrement bien soignée. Elle est composée de 2 semelles: 1 fixe et 1 mobile.



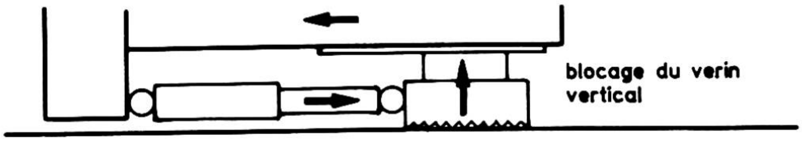
La partie fixe de 18 m de diamètre et de 4,5 m d'épaisseur moyenne repose sur le rocher calcaire. Elle est surmontée d'une couronne qui sert de piste de glissement sur laquelle sont déposés des appuis en néoprène-teflon.

La partie mobile a une forme de croix: sur la branche principale viennent s'encastrer les 2 jambes du pylône; l'autre sert à reprendre un moment longitudinal éventuel de déséquilibre pendant la rotation. Les extrémités de la croix sont garnies d'inox pour faciliter le glissement (le coefficient de frottement inox-teflon est de l'ordre de 5% au démarrage et 2% pendant la suite du mouvement) ce qui représente des efforts de frottement variant de 800 à 300 to.

Au centre, un tube en acier rempli de béton matérialise l'axe de rotation de l'ouvrage.

A l'extérieur de la couronne de glissement, sous les extrémités de la semelle mobile, se trouvent deux groupes de vérins diamétralement opposés. Ce sont eux qui fournissent l'effort moteur de rotation.
Chaque groupe est composé de vérins verticaux qui en se soulevant viennent se coincer entre la semelle fixe et la semelle mobile et de vérins horizontaux prenant appui sur une excroissance de la semelle mobile d'un côté et sur les vérins verticaux de l'autre. Le mouvement étant courbe, il a été nécessaire d'intercaler une rotule entre les deux types de vérins.

Ce système par vérins a été préféré à des câbles tendus pour éviter les mouvements brusques dus à la restitution d'énergie brutale lors de la mise en mouvement du système et du relachement des câbles.



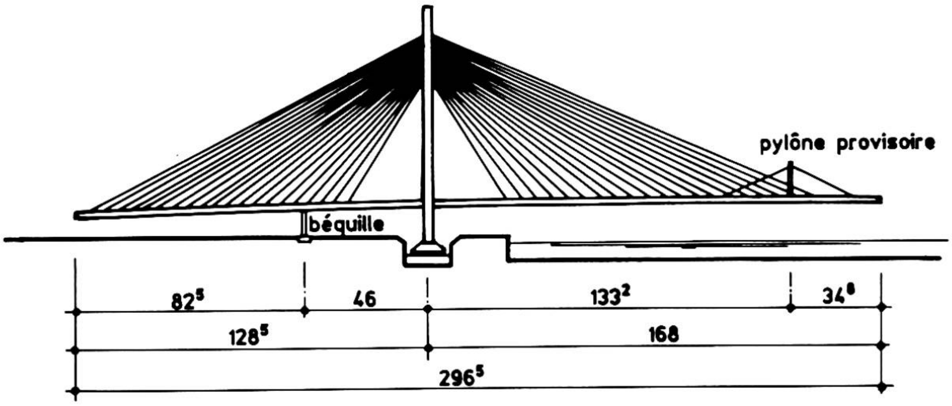
Chaque action des vérins provoque une rotation de 20 cm au niveau des poussées donc de 6 m au bout du fléau de 168 m. Une quarantaine de poussées ont été nécessaires pour effectuer la rotation complète de 70°. Celle-ci a été terminée en une seule journée.

3.2. Béquille d'équilibrage

Celle-ci a été placée à 46 m du pylône en rive gauche. Elle est destinée à reprendre les éventuelles charges de déséquilibre pendant la rotation.
Formée de profilés métalliques soudés, tirée par un treuil électrique, elle glisse sur une piste circulaire recouverte de teflon. Pour éviter de créer un trop grand moment de torsion dans le pylône, l'effort moteur de rotation est exercé simultanément au pylône et à la béquille. L'effort à la béquille est d'environ une quinzaine de tonnes.

3.3. Pylônes provisoires

La partie non haubanée du tablier de 22,5 m de long à droite du dernier hauban donnant par son poids propre un moment non acceptable dans le tablier, nous avons été obligé de placer deux petits pylônes provisoires de 12 m de haut audessus de chaque âme du caisson.
Ces pylônes sont haubanés chacun par 2 câbles pouvant reprendre un effort de traction de 1200 to. Ils ont été démontés après rotation de l'ouvrage.



3.4. Haubans surtendus

Le règlage de rotation des haubans a été étudié pour être le plus proche possible du règlage de service et ainsi limiter au maximum les manipulations.
Seuls les 3 haubans d'extrémité de chaque côté ont été surtendus pour la rotation à des efforts dépassant 1200 to., c'est-à-dire 75% de leur charge de rupture. Cela était nécessaire pour éviter des flèches de fléaux trop grandes et pour pouvoir passer en rive gauche au-dessus des installations du chemin de fer.

3.5. Point fixe

Pour solidariser le tablier aux jambes du pylône pendant la rotation et éviter ainsi un retard de mouvement d'un élément par rapport à l'autre, on a construit 4 excroissances à l'extrémité des porte-à-faux du tablier.
Entre chaque excroissance et la jambe du pylône est placé un vérin capable de reprendre un effort de 150 to.
Le moment de torsion autour du pylône pouvant être repris par ce système s'élève à environ 4000 tm.

4. ETUDES SPECIALES

L'étude dynamique de l'ensemble en rotation a donné tant horizontalement que verticalement des fréquences d'environ 0,20 Hertz pour les premiers modes de vibration. Une étude aérodynamique a montré que même à cette fréquence faible les risques d'instabilité étaient inexistants.
La courbe de vitesse du déplacement des vérins a été étudiée pour être la plus douce possible et éviter les chocs en début et fin de course de ceux-ci. On a finalement retenu une courbe de vitesse sinusoïdale en fonction du temps.
Les vibrations verticales et horizontales des extrémités des fléaux enregistrées pendant la rotation n'ont pas dépassé 1 ou 2 cm ce qui est très faible relativement à la longueur de l'ouvrage.

5. OPERATION DE ROTATION

La présence du soleil et une température anormalement élevée en cette période de l'année (septembre) a quelque peu compliqué les opérations de décollement du tablier par rapport à ses appuis de construction. L'augmentation de température ambiante entraînant un allongement des haubans et un gradient thermique dans le tablier, a provoqué une courbure dans celui-ci faisant reposer les extrémités des deux fléaux sur leurs appuis de construction. Des règlages additionnels de haubans ont été nécessaires pour résoudre ce problème.
La force nécessaire aux vérins moteurs de rotation a été beaucoup plus faible que prévu: le frottement inox-teflon a atteint 4% au démarrage pour redescendre rapidement jusqu'à 1,5%.
Pendant la rotation, des capteurs ont été placés sur les vérins et la visualisation de leurs déplacements était faite sur un écran graphique de manière à déceler un éventuel retard d'un verin par rapport à l'autre. Les déplacements des extrémités des deux fléaux étaient constamment enregistrés. Ceux-ci n'ont pas dépassé 1 à 2 cm et la vitesse de rotation prévue au départ a pu être augmentée.

6. AVANTAGES DU SYSTEME

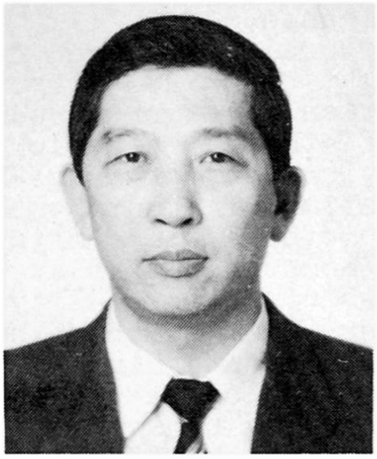
La construction du tablier a pu s'effectuer sur terre ferme dans des conditions idéales ce qui a permis des rendements et des coûts réduits.
La construction du tablier a pu se faire à un rythme de 3 tronçons de 18 m par mois. Le pylône et le tablier ont été construits en même temps et la mise en place des haubans a duré 2 mois.
Pendant toute la durée du chantier, même pendant la rotation, il n'y a eu aucune entrave à la circulation automobile, fluviale ou ferroviaire.
Les études et la réalisation de cet ouvrage auront duré exactement deux ans, de décembre 85 à décembre 87, ce qui est un délai particulièrement court.

Rapid Erection Method for Steel Stacks

Méthode de montage rapide pour des cheminées en acier

Schnellmontageverfahren für Stahlkamine

V. G. KIM
Civil Engineer
VNIPI Promstalkonst.
Moscow, USSR



V. G. Kim, born in 1941, graduated from the Moscow Civil Engineering Institute in 1964. Now he is the head of a department and responsible for the design of heavy industrial buildings.

SUMMARY
This paper describes the influence of a stacks structural parameters on erection labour expenditure, the estimating procedure of stacks' adaptability for erection, technical-and-economic index of different erection methods, erection-site-process of stack hoist squeezing out with tackle block equalizing system.

RÉSUMÉ
L'article traite de la relation entre les caractéristiques techniques d'une cheminée et les frais en personnel pour le montage, de l'évaluation du type de montage approprié sur la base d'indices technico-économomiques. Il présente le montage de la cheminée selon la méthode de la poussée vers le haut au moyen de vérins.

ZUSAMMENFASSUNG
Der Artikel behandelt den Einfluss der technischen Eigenschaften von Stahlkaminen auf die Personalkosten für die Montage, die Evaluation der besten Montagemethode auf Grund verschiedener technisch-wirtschaftlicher Bestimmungsgrössen, sowie die Montage der Stahlkamine nach der Methode des Taktaufziehverfahrens mit Takelwerken.

Steel tower type exhaust stacks in the industrial construction present a separate group of tower structures characterized by a specific design and certain difficulties of erection especially at operating plants and those under reconstruction. Intensification and growth of ferrous and non-ferrous metallurgy, power, chemical and some other industries caused an increase of exhaust stack construction in order to protect the environment from noxious and corrosive gases. That is why shortening duration of stacks erection, raising labour productivity and improving safety of works at the construction site became matter of scientific and industrial significance.

Great variety of structurally-arranged designs of steel frame exhaust stacks of height up to 200 m brought to life numerous methods of their erection. That provided additional difficulties in application of standart erection rigging and equipment and questioned the rationality of large-block erection. In spite of permanent modernization of traditional build-up and turning around hinge erection methods their major drawbacks remained the same: large amount of mounting works at height, use of expensive equipment, difficulties of joint quality control, necessity of special safety measures, limitation of height of stackswhich are to be erected by turning around hinge method-not higher than 100...120m. The development of new hoist squeezing out methods with tackle block equalizing system entailed changes of stacks' structurally-arranged designs.Different project firms worked out steel stack designs without taking into consideration their adaptability for erection because of simple engineering methods of estimating, such points were not yet elaborated. Structures of analogous stacks possessed different numbers of structural elements,different masses, the joints of the stacks differed in quantity of bolts and masses of weld metal. That was the reason why labour expenditure on construction sites differed 1.2...1.8 times for analogous stacks erected by the same method and with the same equipment.

Researches conducted in VNIPI Promstalkonstructsia on the basis of 50 stack designs permitted to determine the influence of stack structural parameters on the labour expenditure and express this dependance by multiple regression equations [1]:

$$T_1=-2.276+0.267M+0.197N_{el}+0.007N_b+0.051G \quad (1)$$

$$t_{bl}^i=-0.339+0.239M+0.163N_{el}+0.018N_b+0.09G \quad (2)$$

where : T_1-labour expenditure of stack pyramidal part assembly, man-day;

$t_{bl}i$ - labour expenditure of assembly of stack prismatic part i - block, man - day;

M - mass of corresponding part of stack frame, ton ;

N_{el}- number of dispatched elements, pcs ;

N_b - number of bolts in assembling joints, pcs ;

G - mass of weld metal in joints , kgs ;

Multiple determination ratio of equation (1) is equual to 99.34 and equation (2) - 98.34. Labour expenditure on assembly of stack prismatic part T_2 is determined by the formula :

$$T_2 = \sum_{i=1}^{n} t_{bl}i \quad (3)$$

Thus the total labour expenditure of assembly works is determined by summation T_1 and T_2. The obtained data may be compared with the indexes of the basic variant. In that way it is possible to choose a profitable type of stack structurally-arranged design. To execute the procedure it is necessary to calculate the stack weight (mass), number of dispatched elements, bolts in assembling joints as well as mass of weld metal. To simplify the determination of labour expenditure on assembly works of pyramidal and prismatic parts blocks nomographs are developed on the basis of multiple regression equations (1) and (2). One of them is shown in fig. 1.

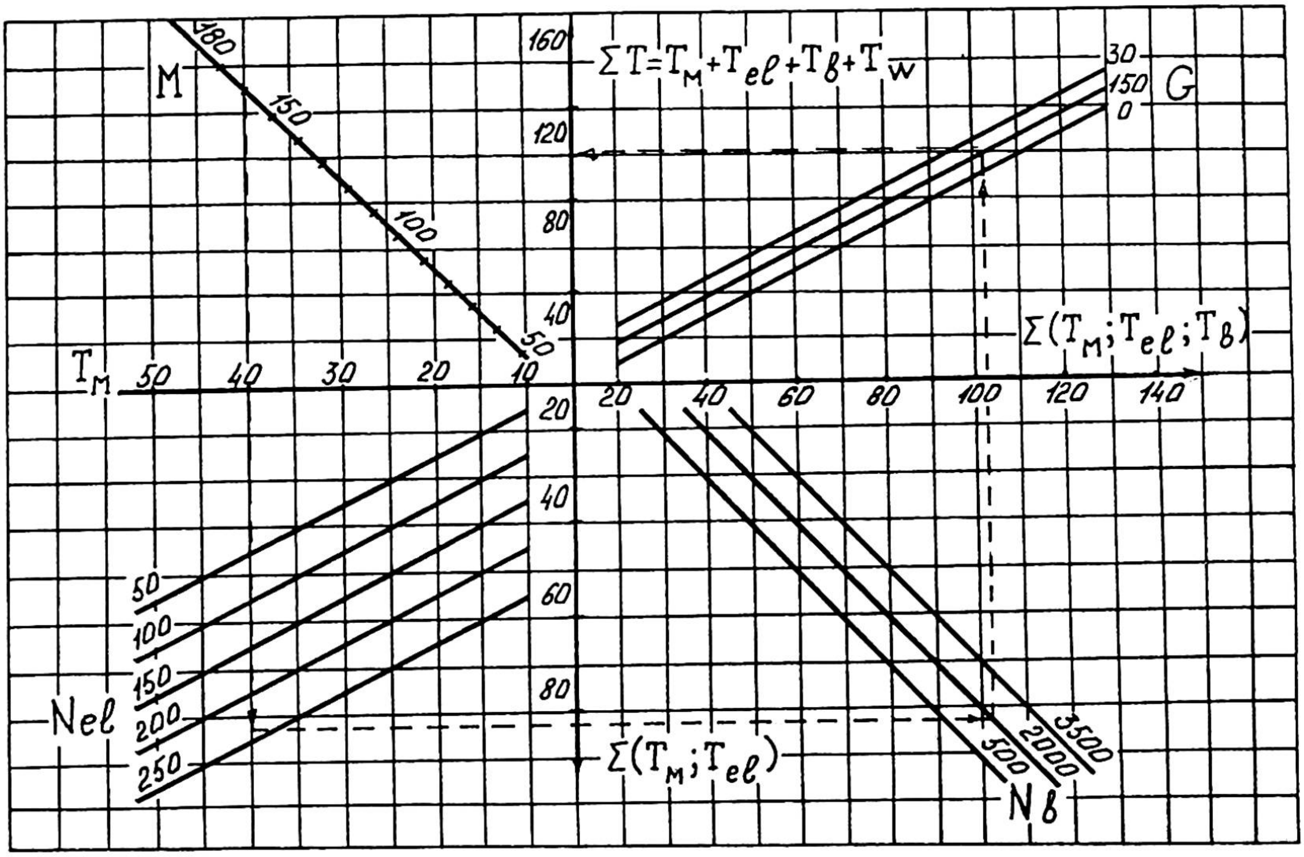


Fig 1. Determination nomograph of stack pyramidal part assembly labour expenditure.

The procedure of quantity estimation of stack design adaptability for erection was used for choosing profitable standard structurally-arranged designs of exhaust stacks with heights of 90, 120, 150 and 180 m. Such designs permitted to reduce the value and number of structural parameters. That provided reducing labour expenditures to 12...15% of traditional structural designs indexes. For example, using in structure triangular lattice instead of cross or rhombus one permits to decreas erection labour expenditure to 1.6 times. The rewiew of home and foreign experience of stack design and construction as well as the analysis of published original sources showed a wide range of variation of labour expenditure and duration of erection works. Determination of effective methods of stack erection if based on separate criteria does not always correspond to real practice. That is why technical-and-economic analysis of

the most wide spread stack erection methods in the USSR was carried out by means of multifactors estimation procedure. The procedure includes expert and quantity estimates of erection works safety level. Safety level is determined from time of mounting works at height accounting for probabilistic influence of traumatic factors.
Analysis of technical-and-economic indexes of stack erection processes showed the method of stack squeezing out with tackle block equalizing system in comparis on with traditional methods of stack erection (table 1) ensured the following advantages: raising labour productivity to 25...53%, shortening erection time to 18...31% (duration of erection), decreasing erection cost to 23...41%, improving erection works safety level to 45... 120% and significant improvement of working conditions at the expense of carrying out erection process at low height on stationary scaffolds, raising quality control **reliability** of mounting joints fulfilment, creating production conveyer line of assembly and installation of stack prismatic part blocks, reducing volume of mounting works height to 2...2.5 times, exception of application of expensive and deficit erection rigging and equipment, etc. [2,3].

Indexes	Methods of erection				
	Build up methods			Hoist	Turning
	self-claiming crane on the cylinder	self-crawling gantry	tower crane with attachments	squeezing out with tackle block equalizing system	around hinge
Mass, t	253	255	253	265	262
Cost, %	79	100	118	77	118
Cost of 1 ton of mounted steel structure, %	80	100	119	74	114
Duration of erection, %	131	100	139	85	107
Labour expenditure of erection works, %	107	100	134	76	106
Output, %	93	100	75	137	98
Safety level of erection works, %	85* 81**	100* 100**	150* 172**	200* 261**	185* 209**

* - expert estimate [4]
** -quantity estimate by VNIPI Promstalkonstructsia procedure

Table 1. Technical-and-economic indexes of erection methods.

Video-recording equipment with automatic data processing were used to analyze actual labour expenditure of different assembly and installation processes, operation elements and labour techniques.

That permitted to work out an optimum model of assembly and installation of steel stacks structures. Introduction of such models reduced labour expenditure of erection works to 10...12%.
The results of the conducted researches allowed to improve the erection-site-process of stack hoist squeezing out method, which contained:
- standard assembly of spatial frame blocks with exhaust cylinder blocks of the equal height on special stand;
- block on the stand transportation from assembling site to the place of installation by rails;
- connecting the block to the structures of the stack prismatic part have been put into position before;
- hoist squeezing out of stack prismatic part with exhaust cylinder by means of tackle block equalizing system at the block's height;
- lowering the stand on the rails and transporting it back to the blocks assembling site to assemble a new block.

Such erection-site-processes are repeated until squeezing-up part of the exhaust stack reaches its design elevation. Simultaneous installation of stack steel frame with exhaust cylinder permitted to reduce labour expenditure of erection works to 7...9% additionally.

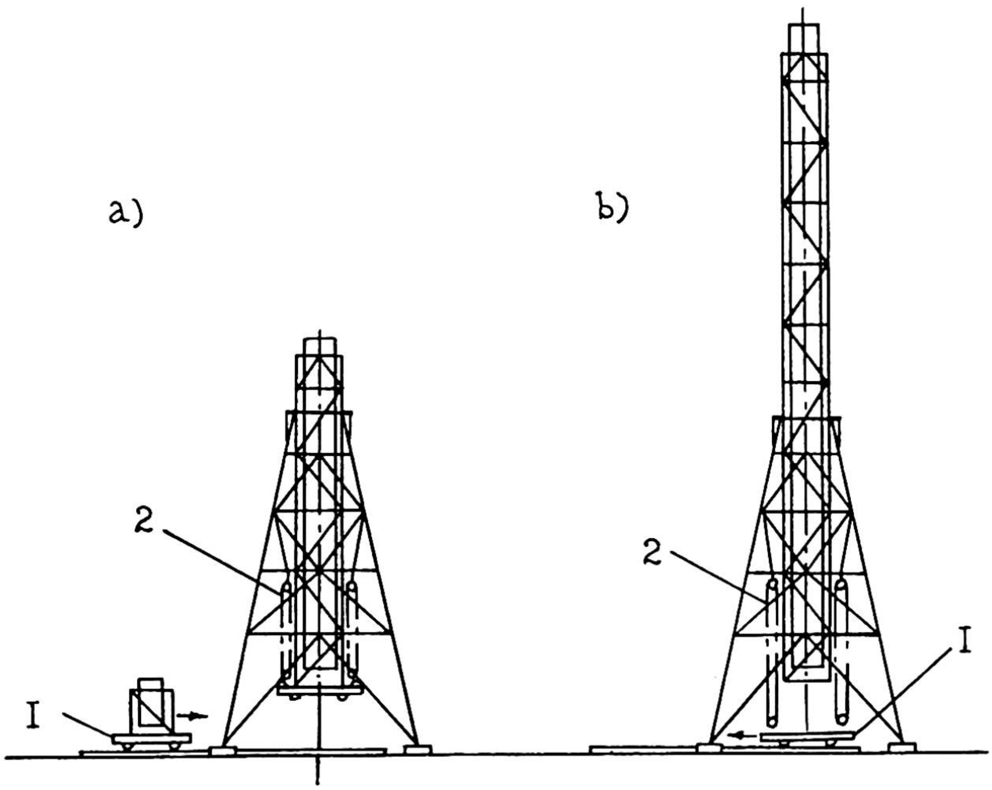


Fig.2 Scheme of erection: a -first step of squeezing out; b - intrmediate position; 1 - stand with block on; 2 -tractive tackle block.

Tractive tackle block system consists of separate tackle blocks Their quantity is equal to the number of stack's sides. Special equalizing system includes dynamometers which are provided for control forces in the ropes going to the winches. There are guiding devices inthe pyramidal part of stack to stabilize the pri-

zmatic part during squeezing out.
Experience of designing and erection of different types of stacks was generalized and specifications were formulated. They permitted eliminating unwarranted multiformity of stack types as well as multimodification of ineffective erection methods and to work out new structurally-arranged designs of exhaust stacks. Erection of tower structures of such designs with due regard for the above mentioned developments permitted to reduce labour expenditure and duration of erection in 1.5...1.7 times.

REFERENCES

1. KIM V.G., FRENKEL V.M. Metodika otsenki montazhnoi tekhnologitch nosti vityazhnikh bashen po kriteriyu trudoemkosti/ Montazhnie i spetsialnie raboti v stroitelstve, 1986.N 8, pg. 22-24.

2. KIM V.G., VISCHINIS A.D. Montazh vityazhnoi bashni podraschivaniem na Kedainyajskom khimzavode,-M. 1986. - pg. 15-19.-/Montazhnie i spetsialnie stroitelnie raboti. Seria YII, Izgotovlenie metallicheskikh i montazh stroitelnikh konstructsi /TSNTI Minmontazhspetsstroya SSSR; vipusk 3/

3. KIM V.G. Povishenie effectivnosti montazha vityazhnikh bashen-trub.- M., 1987. - 44. -(Montazhnie i spetsialnie stroitelnie raboti. Informatsionnoe obespechenie otraslevikh programm i osnovnikh napravleni razvitiya otrasli. : Obzornaya informatsiya/ TSBNTI Minmontazhspetsstroya SSSR; vipusk 3)

4. KIM V.G., LUKJYANOV K.I., POLUYANOV E.P. Recomendatsii po viboru effectivnikh metodov montazha vityazhnikh trub /TSBNTI Minmontazh spetsstroya SSSR. - M., 1987. - 24 pg.