Budagov J. a.o.

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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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ДЕПОНИРОВАННАЯ ПУБЛИКАЦИЯ

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ATLAS Hadron Calorimeter
Mechanical Design
Strength and Stiffness Design

Prepared by:

J. Budagov, I. Chirikov-Zorin, V. Kolomoets, A. Lebedev, Yu. Lomakin, D. Pantea[1], V. Romanov, N. Russakovich, A. Schelchkov, A. Sissakian, V. Teterin, N. Topilin, V. Utkin (JINR)

with participation of:

G. Akopian, E. Mnatsakanian (EREVAN, Inst.of Physics.),
Yu. Kulchitski (MINSK, Inst. of Phys., and JINR),
G. Chlachidze (TBILISI, IHEP - TSU, and JINR)

Abstract

In this document we present a variant of submodules and modules production. The basic idea is to use the hot rolled steel without some selection of sheet thickness. The submodule and module design use positive ideas of all projects what we have. The strength and stiffness design, assembly recommendations, economic and other information are also presented.

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[1] On leave of absence from Institute of Atomic Physics, Bucharest, ROMANIA

Contents

1 INTRODUCTION.

ATLAS hadron calorimeter production option is considered. When technology developing the experience of designing of five prototypes of hadron calorimeter (57 periods 18 mm long each with 2 flanges 20 mm thick each) was taken into account. The International Seminar on hadron calorimeter design (21 — 28 June, 1994, CERN) also was taken into account.

Experience in design development together with technological experience in assembling showed that the geometry of primary steel sheets and their manufacturing precision are of principal significance.

The proposed 1 m submodule design and assembling technology intends on the use of the hot rolled steel, which can be produced by any technically developed country.

For the 1 m submodule assembling convenience and for achieving of geometry demands to the 6 m submodule this guessing is using the master plates locating datum system together with special fixtures.

Here we present the calculation results for the welded 1 meter submodule and 6 meter module.

For the glued option the submodule calculations were done by Jacek Blocky. The results obtained show that the submodule and module are enough stiff and strong for lifting, moving & transporting operations and assembly operations.

But calculations additionally show that not for all submodule and module positions they are enough stiff and strong.

What are the positions to be avoided are shown below.

2 STEEL MANUFACTURING

2.1 The steel manufacturer choosing in Russia.

As one of the main potential steel manufacturer for hadron calorimeter the NOVOLIPETSK METALLURGICAL PLANT (the NLMK, Lipetsk-city) was taken.

The NLMK's steel is satisfying in the most complete way to the project technical demands and has a large demand on the world market. The NLMK steel sheets thickness tolerance is not worse than ± 0.15 mm. Practice shows that after same amount of steel with some steel thickness (about 60 ÷ 90 metric tons) was rolled, the stabilization of rolling process parameters is ESTABLISHING. When rolling at this stabilized regime the steel sheets thickness tolerances is not worse than ± 50 micron for 90% of the rolled steel and not worse than ± 100 micron for the remaining 10%. The exceptions are 1 ÷ 2 sheets at the every end and beginning of roll (1 roll is 15 tons heavy bobbin or 250 m for 5 mm thick and 1500 mm wide steel sheet). In its cross-section the sheet has a lens-form: smooth 50 ÷ 100 microns sheet thickness decreasing from the center to the sheet salvage.

W. European rolling mills are equipped by additional rolls for steel sheet thickness smoothing in transverse direction. German (Siemmens) equipment will be established at NLMK later, in 1995 for same purposes.

The steel sheets delivered to JINR (Dubna) for 5th prototype manufacturing had the nonflatness [1] not worse than $0.3 \div 0.5$ mm per 1 m sheet's length for 4 m long sheet. The exceptions are 300 mm long edges of sheet. Here one observes local, smooth sheet curving up to 6 mm per 1 m of length. However this curvings escapes completely with little load on sheet. Hot rolled steel sheets roughness at NLMK is not worse $R_a = 3.2$ microns.

During rolling the steel obtains 10 microns thick covering scale film strongly connected to main metal. If slightly oiled this film protects the metal against corrosion temporarly.

2.2 Steel cost dependence upon tolerances.

If rolled steel sheets selection is excluded, then NLMK steel cost does not depend on tolerances and estimated by NLMK financial Dept. on the 0.28$/kg level. This is June 1994 price and it may change with time.

When ordering of steel with high but realistic thickness tolerances demands the steel price will be + 25% larger.

Conclusion: It is more economically beneficial to order some excess (+ $10 \div 15\%$) amount of steel with NO severe thickness tolerances demands. If ordering the steel mainly with "minus" allowances then the presence of some amount of "plus" allowances steel sheets will positively affect on reaching of 1 m and of 6 m modules nominal parameters.

2.3 Material specification.

The base material for the hadron calorimeter production is hot rolled **steel 10** (Russia state standard is GOST 1050-74), or **Fe 360**, or equivalent steel determined by European Norms **EN 10025**

This steel chemical composition (max): C = 0.14%, P = 0.035%, S = 0.04%.

The mechanical parameter: R_e (yield strength) = 190 MPa; R_m (tensile strength) = 340 MPa. This steel magnetic properties (the permeability mainly) are quite acceptable.

Steel sheets geometry parameters are on the Table 1.

2.4 Steel quality control.

For fast operative obtaining of information about the steel quality during its rolling and for being able to introduce corrections into production process it is necessary to create a quality group. This quality group must contain the participating Institutions representatives and the representatives of spacer & master plates producing plant(s).

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[1] For more details see Appendix 1: "The Novolipetsk Metallurgical Plant steel sheets geometry measurement results. JINR, Dubna, 12 August, 1994"

Table 1: Steel sheets geometry parameters

thickness measured along the axis line:	3.9 mm ± 0.05 mm; 4.9 mm ± 0.05 mm
difference in thickness within one sheet limits:	not worse 0.10 mm
flatness of sheets:	1 mm per 1 m sheet's length (and 5 mm / 1 m for 300 mm wide band at the each sheet edge side)
roughness of surface:	R_a = 3.2 micron
sheets dimensions (mm):	4 × 1500 × 4000 and 5 × 1500 × 3200 (or 4800)

Type & amount of control, the duties & rights of the **quality group** members, report-form etc. must be described in **Quality Program**. The **Quality Program** must be agreed and approved by steel & plates producers as well as by all other interested parties. The **Quality Program** can be written separately by each participating side and then agreed by all the producers collaboration participants.

2.5 Conditions of steel storage and its delivery to 1 m submodule manufacturer.

Hot rolled steel band after it was cut into sheets has very good sheet's flatness and free from rust. On all the stages of steel transporting from producer to user these sheets must be reliably protected against the moisture.

When sheets loading / unloading it is desirably to use the magnetic capture for steel pack sheets and vacuum capture for one steel sheet. All the sheets must be stored in dry warm area with no air admixtures able to cause the danger for the steel. The amount of gaskets should enough to avoid the sheets curvatures during their storage.

3 Choosing of manufacturer.

When choosing of plates manufacturing plant we were taking into account that the choosen plant must fabricate spacer (see Fig. 1)& master(see Fig. 2) plates with a desired precision using the most cheap their production technology: stamping or/and laser pattern cutting.

Besides that the spacer & master plates manufacturer(s) must have a possibilities:

1. to make the 2 datum surfaces of master plates with a 0.05 mm precision;
2. to fabricate the module's girder;
3. to assemble the submodule (see Fig. 3);
4. to assemble the module (see Fig. 4);
5. to fabricate the barrel support structure;
6. to make the barrel test assembling directly on the manufacturer's shop areas.

In Russia the manufacturers with such a possibilities are:

1. The ATOMMASH plant (Volgodonsk-city) is a very large, modern factory. ATOMMASH is producing high precision, very large size heavy-weight facility. ATOMMASH's possibilities were, particulary, demonstrated in a vary convincing way when designing & fabricating of SDC muon magnet barrel toroid. ATOMMASH has excelent Q/A and Q/C systems based on modern test tooling & equipment. ATOMMASH is recognized by International Engin. Union as a plant able to manufacture high tolerances modern equipment.
2. IZHORA — plant (Sankt-Petersburg). This is a highly experienced large plant producing succesfully for many years period the high precision large size equipment. IZHORA had manufactured large magnets for DELPHI (CERN) and for DESY (Hamburg).
3. The KIROV-PLANTS UNION (St.-Petersburg) is one of the largest St.-Petersburg plants. It has many years successfull experience of large size military and civil technique manufacturing.

COMMENT:

- IZHORA and KIROV have the possibilities to manufacture the dies for spacer & master plates production by necessary precision cutting.
- ATOMMASH has the possibility of master & spacer plates laser precutting.

Preliminary, unofficial price estimates by potential fabricators, (in US k$):

- material – 420
- spacer and master plates production:
  - by laser – 220
  - by dying – 250
- submodules and modules assembly – 1300

To estimate the price of assembling and of production tooling more correctly, the plants request for more detailed technical documentation concerning submodules & modules production and assembling. The another possiblity is to sign contract with plant(s) to develop such a documentation.

4 Module assembling.

We have studied the CERN, Barcelona, Chicago, Protvino projects on barrel hadron calorimeter submodules and modules fabrication and propose the following design and production technology.

Module consists of six submodules placed on carrying girder. The two edge submodules are fabricated by gluing of spacer & master plates by epoxy glue. The thickness of the glue layer is 0.1 mm. This two submodules give necessary stiffness to the module and unload the studs going through the whole module. Compressing force along the block axis is accepted by girder and by narrow plate $10\times100mm^2$ located at wedge narrow part.

Four central submodules are fabricated with use only of welding. In these welded submodules 4 strips, connecting spacer & master plates in one submodule, are giving to this submodule the necessary stiffness and strength when transporting of submodule or its assembly on girder. At the same time such a submodule design gives to it some flexibility which allows one to connect the submodules with not more than 0.5 mm gap between them.

The strip surfaces are the neighbouring modules contact surfaces. The strips presence at the submodule corners allows one to keep the gap between the modules not more than 0.5 mm.

Steel plates — for spacers manufacturing — are planned to be fabricated of (3.9±0.05) mm thickness; plates for master will have initial thickness of (4.9±0.05) mm.

For glued submodules the length of one period, which is consisting of 2 spacer layers and of 2 master plates, is equal to 18mm; for the welded submodules one period length is 17.6 mm.

The edge submodules will each contain 54 periods of 18 mm each and their length is (972±0.5) mm. The 3 middle submodules will also contain 54 periods each with 17.6 mm of period length. These submodules length is (952±0.5) mm.

One central submodule contains 55 periods and its length is (970±0.5) mm.

So the total module periods quantity is 325; its length (5900±2.5) mm. (see Fig. 3 and Fig. 4)

The preliminary plan of prototype 6 meter module production is presented in the Table 2.

The 0.1 mm glue layer thickness will be achieved by fixed depth center-punch craters on the spacers surface; the plate's metal, pressed out these craters, will determine the above quoted 0.1mm gap. By changing the crater depth one can regulate this gap within (0.05÷0.15) mm limits and — in this manner — the one period length can be increased from 0.05 mm up to 0.6 mm.

By using such a method one can achieve the submodule production with a length precision ±0.5 mm.

Module endface flange plates (their thickness is 65 mm) allow the reliable and precise connecting of module's faces by M24 bolts and ø 60mm pins (see Fig. 5).

When barrel assembling each module is supported by the previous one around all its perimeter, what allows to achieve high barrel stiffness and its dimensions minimal change due to gravitational forces.

Preliminary calculations show that in this case the barrel vertical dimension decrease due to gravitational force will be om 1mm level.

Table 2: The plan of prototype 6-m module production.

	Work type	1994			1995												1996			
		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
1.	Financing (beginning) of works	●																		
2.	Signing of contracts		●	●	●															
3.	1-m submodule shopdrawing production		●	●	●															
4.	6-m module shopdrawing production			●	●	●														
5.	Tooling and fixtures designing			●	●	●	●													
6.	Tooling and fixtures production						●	●	●	●	●									
7.	Steel production				●	●														
8.	Master and spacer plates production						●	●	●	●	●	●								
9.	Stripplates production							●												
10.	Endplates production								●											
11.	Girder production									●	●	●								
12.	1-m submodules assembling, Q/C								●	●	●	●	●	●						
13.	6-m module assembling, Q/C														●	●				
14.	6-m module transporting in CERN																●			
15.	Tiles insert																	●	●	
16.	6-m module test																			●

5 Calculations for 1 meter submodule.

5.1 Case one.

After assembling 1 meter submodule is located in a staple-type fixture. Submodule's absorber plates are all horizontal. Four submodule angle strips are welded as well as one key on the wide wedge side. There are no submodule compressing studs (see Fig. 6).

The calculation scheme of plates loading by their weight when submodule is lifted with its strip is given on Fig. 7.

Table 2: The plan of prototype 6-m module production.

Work type		1994			1995												1996			
		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
1.	Financing (beginning) of works	•																		
2.	Signing of contracts		•	•	•															
3.	1-m submodule shopdrawing production		•	•	•															
4.	6-m module shopdrawing production			•	•	•														
5.	Tooling and fixtures designing			•	•	•	•													
6.	Tooling and fixtures production						•	•	•	•	•									
7.	Steel production				•	•														
8.	Master and spacer plates production						•	•	•	•	•	•								
9.	Stripplates production							•												
10.	Endplates production								•											
11.	Girder production									•	•	•								
12.	1-m submodules assembling, Q/C								•	•	•	•	•	•						
13.	6-m module assembling, Q/C														•	•				
14.	6-m module transporting in CERN																•			
15.	Tiles insert																	•	•	
16.	6-m module test																			•

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		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
1.	Financing (beginning) of works	•																		
2.	Signing of contracts		•	•	•															
3.	1-m submodule shopdrawing production		•	•	•															
4.	6-m module shopdrawing production			•	•	•														
5.	Tooling and fixtures designing			•	•	•	•													
6.	Tooling and fixtures production						•	•	•	•	•									
7.	Steel production				•	•														
8.	Master and spacer plates production						•	•	•	•	•	•								
9.	Stripplates production							•												
10.	Endplates production								•											
11.	Girder production									•	•	•								
12.	1-m submodules assembling, Q/C								•	•	•	•	•	•						
13.	6-m module assembling, Q/C														•	•				
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The calculation scheme of plates loading by their weight when submodule is lifted with its strip is given on Fig. 7.

For this case

$$M_A = M_B = \frac{ql^2}{12}$$

where $q = bH\gamma = 30 \cdot 0.7 \cdot 7.8 \cdot 10^{-3} = 0.164$ *kG/cm*, $l = 155$ *cm*, $M_A = M_B = 328$ *kg·cm*.

At the submodule's narrow side two strips are connected with each master plate by four welding seams with cathetus side dimension $\Delta h = 0.5$ *cm*.

The welding seams tensions are

$$\sigma = \frac{M}{nW} = \frac{328 \cdot 6}{4 \cdot 0.5 \cdot 0.5^2} = 3936\ kG/cm^2.$$

These tensions are significantly higher than allowed ones

$$[\sigma] = 1500\ kG/cm^2 < \sigma = 3936\ kg/cm^2.$$

Therefore submodule lifting in such position is forbidden. The submodule together with its staple-type fixture must be turned on 90° to the position indicated in Fig. 8. When the submodule is turning the force causad by its weight is accepted by fixture's basement and staple's wall. In such position the submodule absorber plates are located vertically.

5.2 Case two.

Let us consider the possibility of lifting & transporting of a submodule in the position indicated on Fig. 8.

For submodule lifting it will be used the crossrail (as a lifting fixture) connected — by eight M12 bolts — to the submodule. The calculation scheme for this loading case is given on Fig. 9.

The load per one bolt when submodule lifting will be

$$F_b = \frac{kG}{n},$$

where $k = 1.33$ is the dynamic coefficient, $G = 3000$ *kG* is the module weight, $n = 8$ is the amount of the bolts.

$$F_b = \frac{1.33 \cdot 3000}{8} = 500\ kG.$$

This load is less than allowed one:

$$F_b = 500\ kG < [F_b] = 1200\ kG.$$

The sheets relative displacement will be prevented by welding seams between strips and master plates. These seams total cross section is $S_s = 2\ cm^2$.

Tangential tension appeared in those welding seams due to cutting off forces is

$$\sigma_{W.S.} = \frac{1.33 \cdot G}{5S_s} = \frac{1.33 \cdot 3000}{5 \cdot 2} = 400\ kG/cm^2.$$

This tension is less than allowed one.

5.3 Case three.

The submodule position is defined on Fig. 10.

This case one could meet when module assembling. The submodule elasticity along the acting force allows to the submodule to get such position when inter-submodules gaps will be minimal.

Let us determine the narrow submodule's part displacement relatively to wide one caused by 100 kG loading. The scheme of calculations is shown on Fig. 11.

This displacement is equal to

$$f = 2f' = 2 \cdot \frac{Pl^3}{3EJn} =$$
$$2 \cdot \frac{100 \cdot 75^3}{3 \cdot 2 \cdot 10^6 \cdot 30 \cdot 0.5^3 \cdot 108} = 0.4\ cm,$$

where $n = 108$ is the number of master plates.

5.4 Case four.

The submodule is lying on one of its side surface. Two strips along their full length serve as the support (see Fig. 12). The calculation scheme for the master plates deflections is given on Fig. 13.

$$f = \frac{5}{384} \cdot \frac{0.164 \cdot 155^4 \cdot 12}{2 \cdot 10^6 \cdot 0.5 \cdot 30^3} = 0.0006\ cm.$$

Master plates deflection when supported on two strips (master plates surfaces are vertical) are practically absent. In such submodule position it can be lifted, moved, transported and stored.

6 Module calculations

6.1 Case one.

The assembled module position is shown in Fig. 14. From such position the module can be lifted and transported providing the uniform lifting force distribution between the modules. This case is equivalent to 5.2 case. The load on bolts and tangential tensions in welds are 10% higher because of girder's additional weight. These tensions are significantly smaller then the allowed ones.

6.2 Case two.

In Fig. 15 position the submodule can be easily stored or transported. The cutting force caused by the submodules weight is accepted by the girder.

Normal tensions in the 10×100 mm band due to bending will be unsignificant:

$$\sigma = \frac{F}{S} = \frac{1000}{10} = 100\ kG/cm^2,$$

which is much less than permissible stress.

6.3 Case three.

Module is lying on one of its side surfaces being supported by 2 flanges, see Fig. 16. In this case the maximal stress due to bending will occur in the 10×1000 (mm^2) steel band.

These stresses are equal to

$$\sigma = \frac{ql^2 2}{8SH} = \frac{7 \cdot 600^2 \cdot 2}{8 \cdot 10 \cdot 10} = 6300\ kG/cm^2,$$

which is significantly larger then permissible stresses. Therefore the module storage and transportation in the Fig. 16 position are not allowed. When transporting it will be rather difficult to create around the perimeter support. The allowed module transportation position is shown on Fig. 15.

6.4 Mounting operation.

The module's lifting, movement and positioning when first half barrel assembling can be done with help of crossrail shown in Fig. 17.

The crossrail distributes uniformly the lifting force on the loading fixtures in the module's narrow part. The gird is stiff and strong enough to accept the concentrated load when module lifting.

After the first barrel's half is assembled the cryostates will be inserted in. It will not be possible to use the loading fixtures on the wedge narrow side. For the barrel second half assembly it will be possible to use the magnet crossrail as indicated on Fig. 18.

7 Barrel strength design

When barrel assembly the last module is contacting to neighbouring module around the perimeter and the contact surfaces are: wedge narrow & wide side strips and 65 mm thick edge plates.

For such module design the bending stresses appear only in master plates whose stresses and deflection — as it is shown in 5.4 — can be ignored. Stresses due to cutting forces which are acting in the barrel, between the modules, will mainly be accepted by ø 60 mm pins placed in edge plates.

The tangential tensions in the pins are

$$\tau = \frac{Q}{nS} = \frac{201000}{6 \cdot 6 \cdot 5} = 1116\ kG/cm^2.$$

These stresses are smaller than permissible ones for the pin's material.

The stresses due to the compressing forces acting in the barrel, will be accepted by strips and by edge plates.

We assume that all compressing load is accepted only by strips with 10 × 5900 mm² contacting area.

Compressing stresses in these strips are

$$\sigma = \frac{N}{S} \cdot \cos 2.812^\circ = \frac{376000}{590} \cdot \cos 2.812^\circ = 637\ kG/cm^2.$$

which is less than allowable stresses.

The barrel vertical dimension change due to gravitation forces will appear due to strips compressing, master plates compressing and compressing of the 10 × 1000 mm² plates in the barrel's part.

The total decreasing of the primary 2000 mm vertical size of ten narrow (inside the barrel!) sides of ten assembled modules is

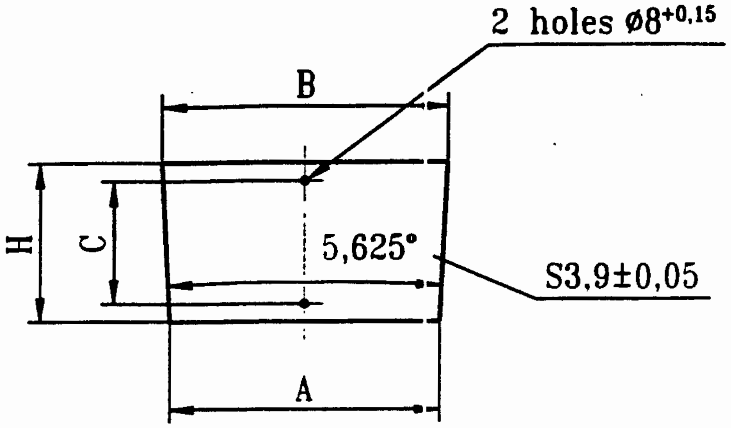
$$\Delta l = \frac{\sigma \cdot L}{E} = \frac{637 \cdot 200}{2 \cdot 10^6} = 0.0637\ cm,$$

(Note: these 10 modules are assembled symmetrically: — 5 + 5 — relatively to barrel middle plane).

Barrel vertical size change due to its weight is

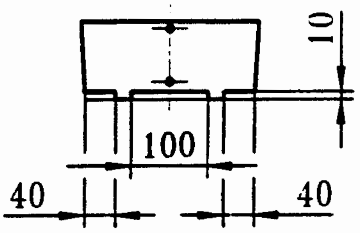
$$f = k \cdot \Delta l = 2.1 \cdot 0.0637 = 0.13\ cm = 1.3\ mm,$$

what is allowed for the design considered.

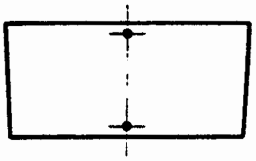


N	A	B	C	H
1	217.86	227.78	73±0.1	101
2	227.58	237.59	72±0.1	102
3	237.40	247.41	72±0.1	102
4	247.21	260.17	102±0.1	132
5	259.98	272.94		
6	272.74	285.70		
7	285.50	300.43	122±0.1	152
8	300.23	315.15		
9	314.96	329.88		
10	329.69	348.54	162±0.1	192
11	348.34	369.06	162±0.1	211

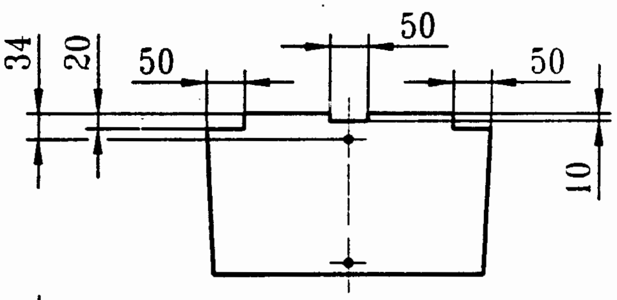
Spacer N1



Spacers N2÷10



Spacer N11



Spacer N0

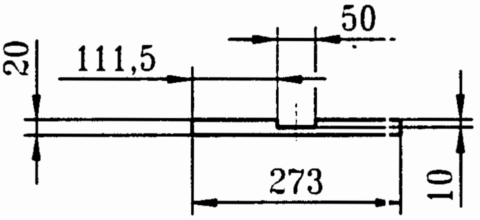


Fig. 1

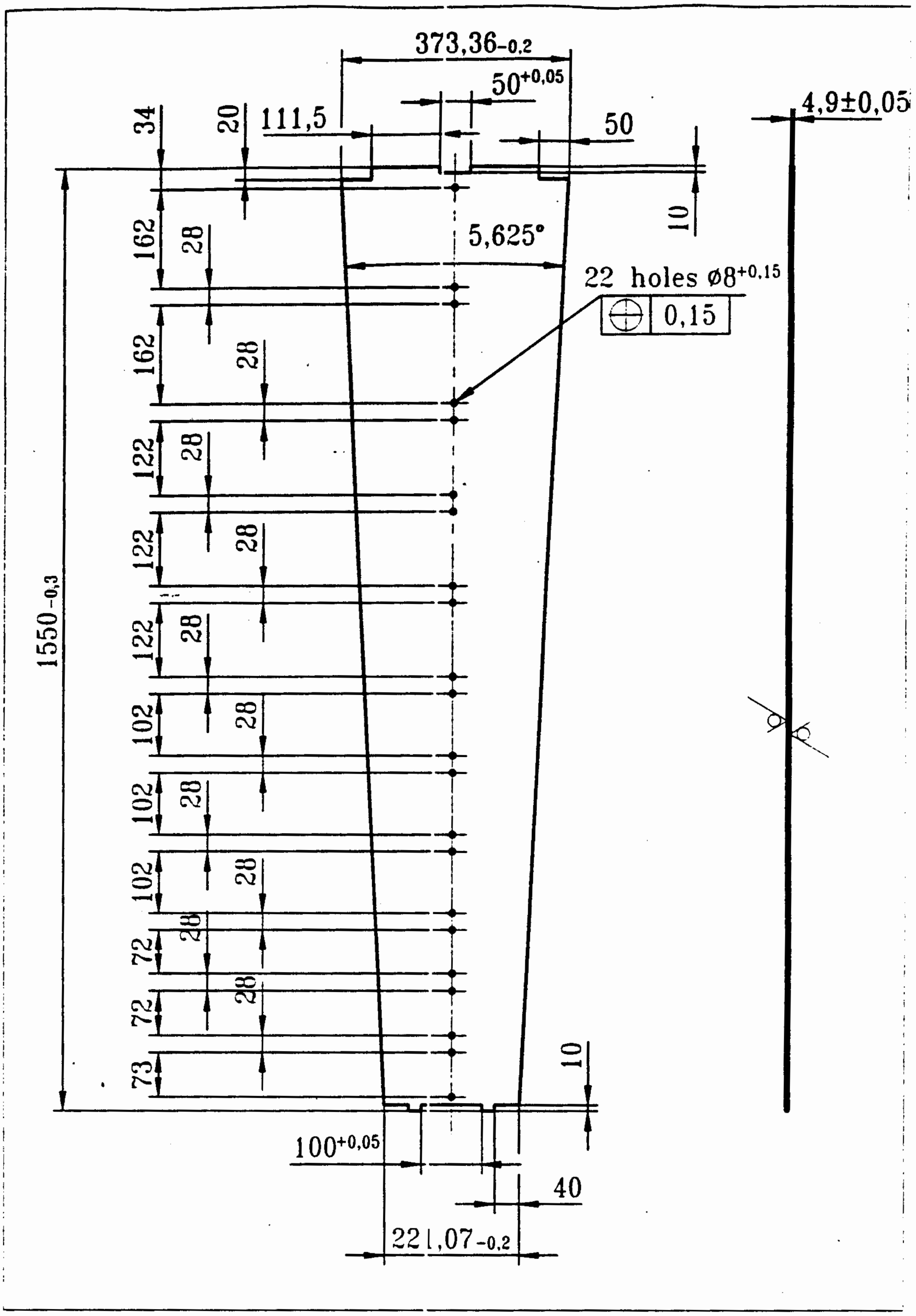
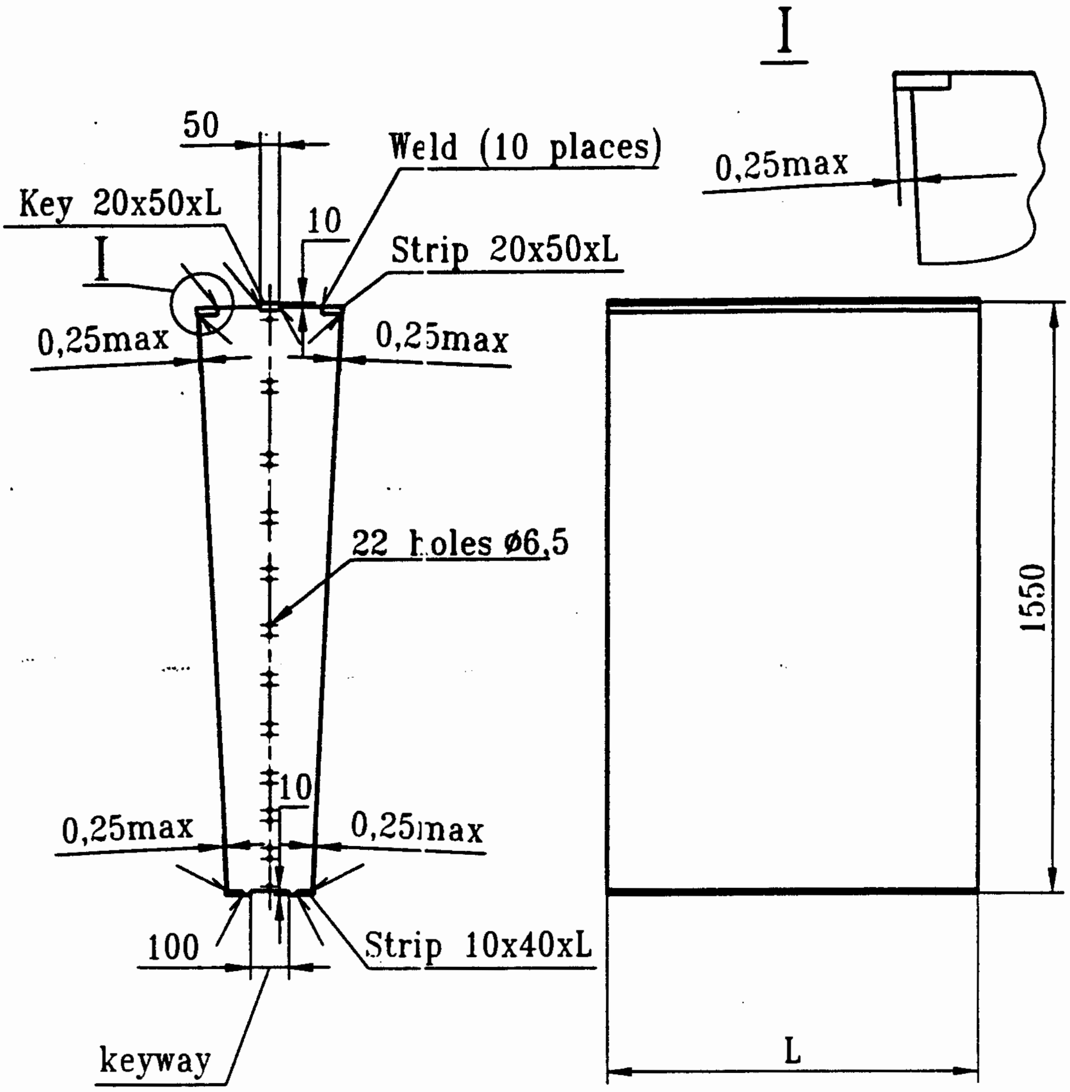

373,36-0,2
50+0,05
111,5
50
34
20
10
162
28
5,625°
22 holes Ø8+0,15
0,15
162
28
122
28
122
28
122
28
102
28
102
28
102
28
72
28
72
28
73
10
1550-0,3
4,9±0,05
100+0,05
40
221,07-0,2

Fig. 2



Module number	Periods quantity	L,mm	Kind of joint
1	54	972	weld+glue
2	54	952	weld
3	54	952	weld
4	54	952	weld
5	55	970	weld
6	54	972	weld+glue

Fig. 3

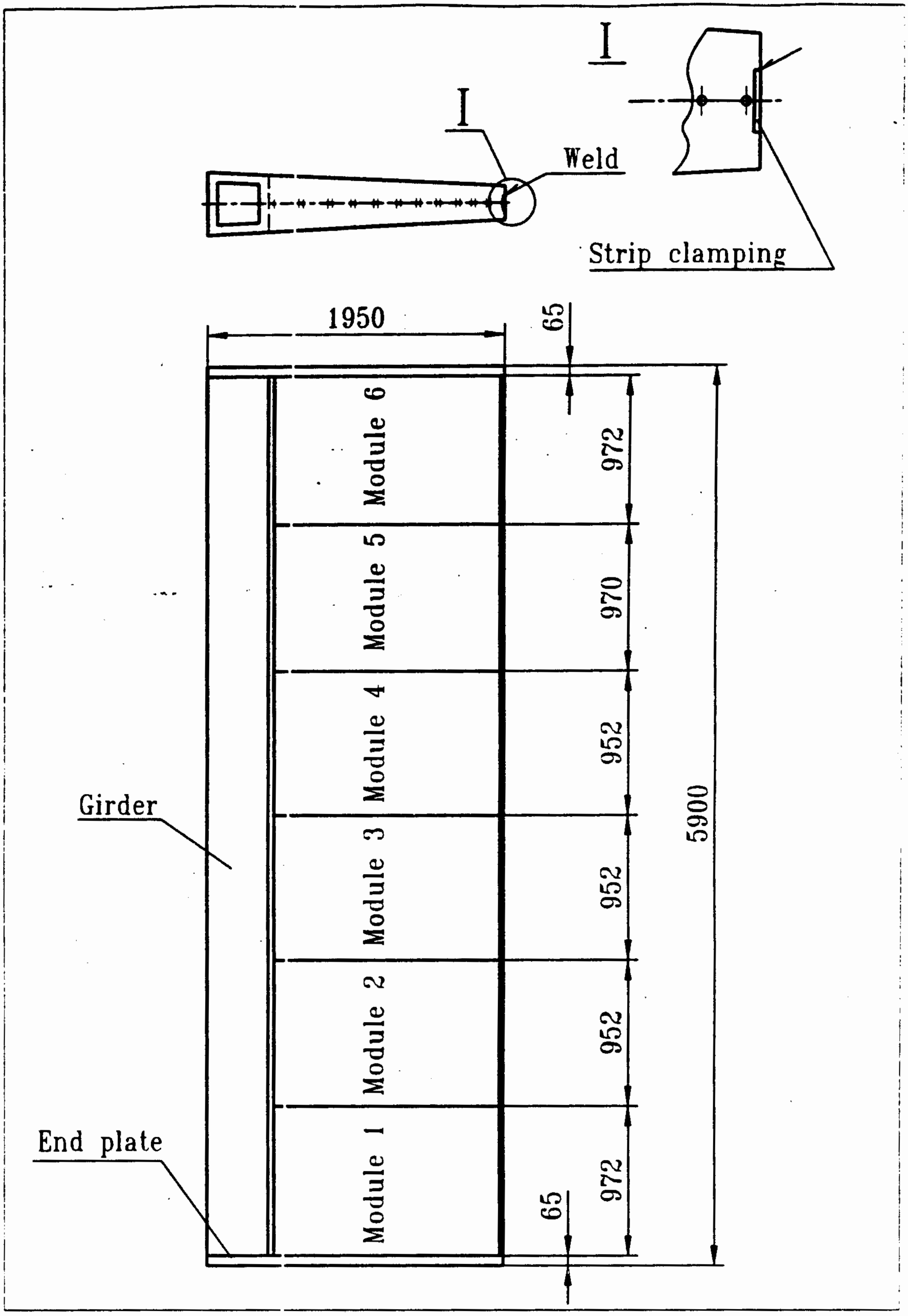

I
I
Weld
Strip clamping
1950
65
Module 6
Module 5
Module 4
Module 3
Module 2
Module 1
972
970
952
952
952
972
5900
65
Girder
End plate

Fig. 4

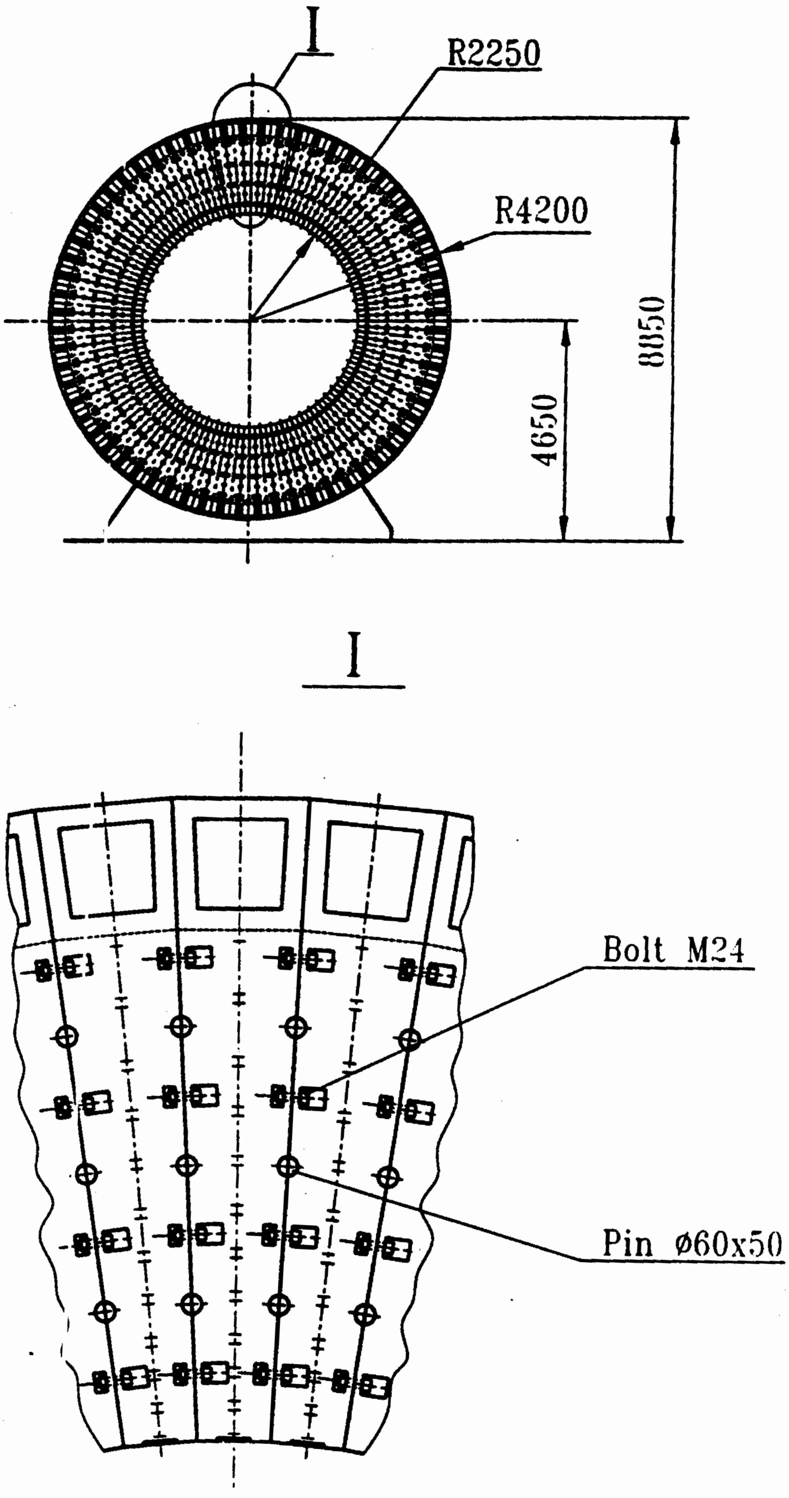


Fig. 5

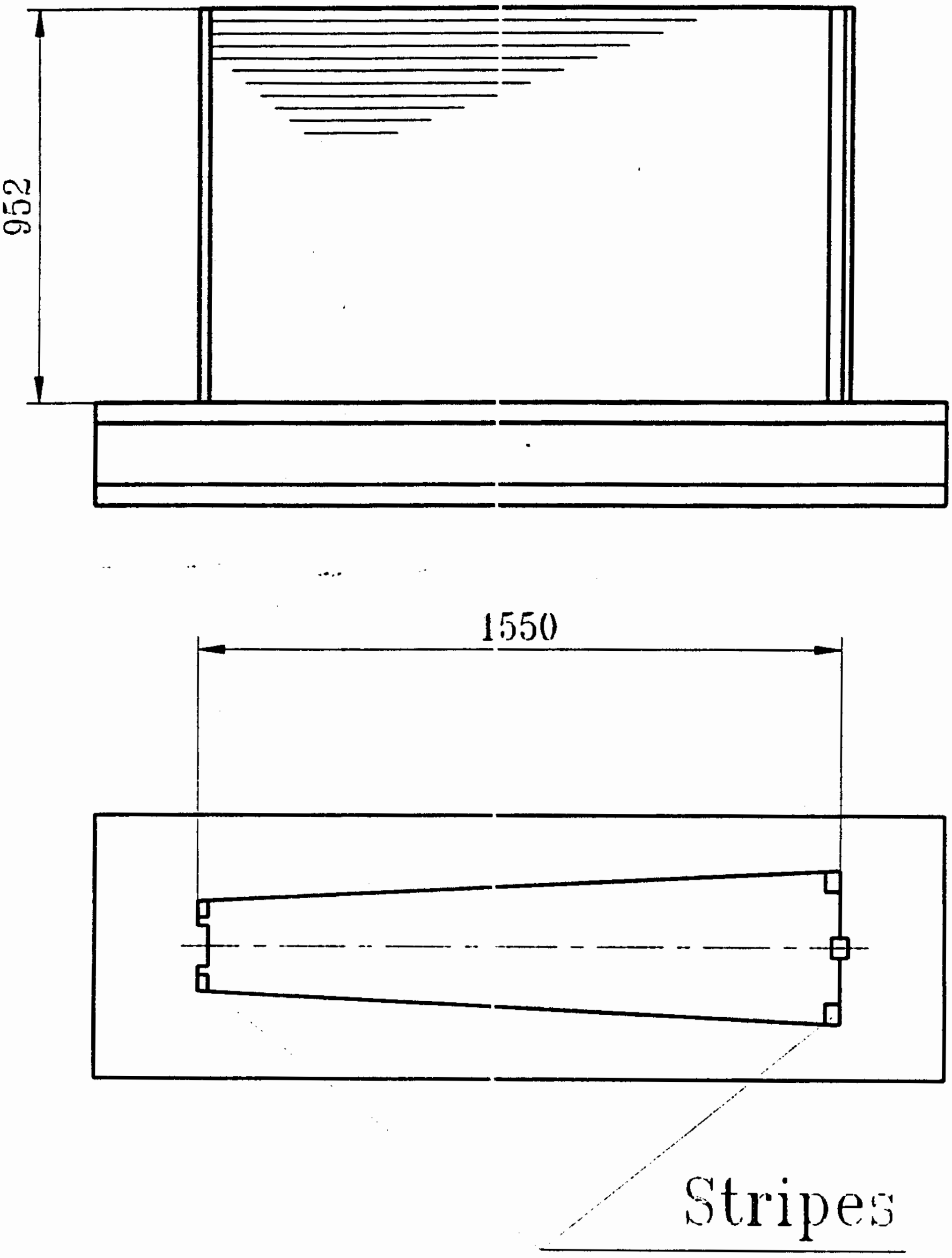


Figure 6

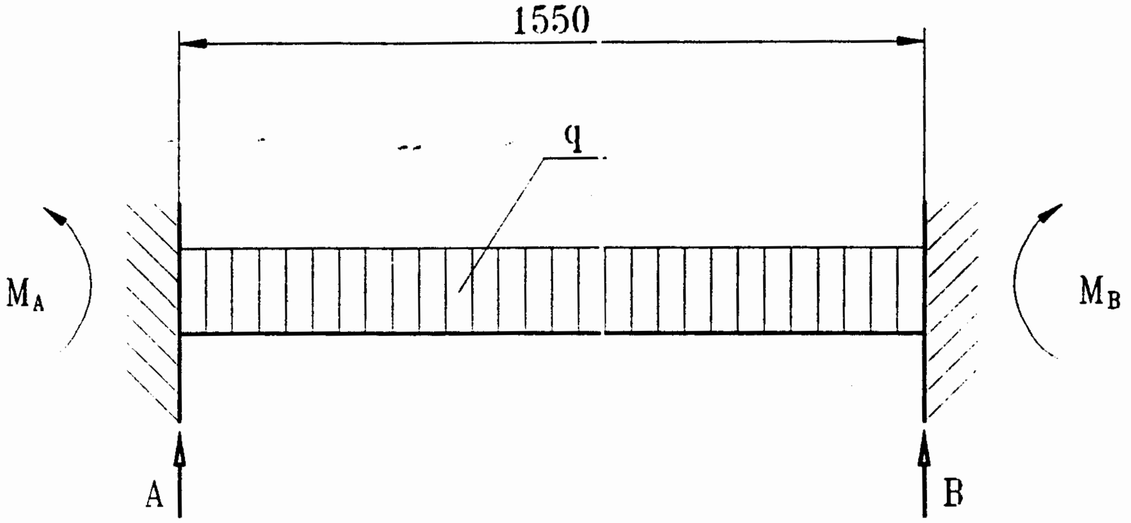


Figure 7

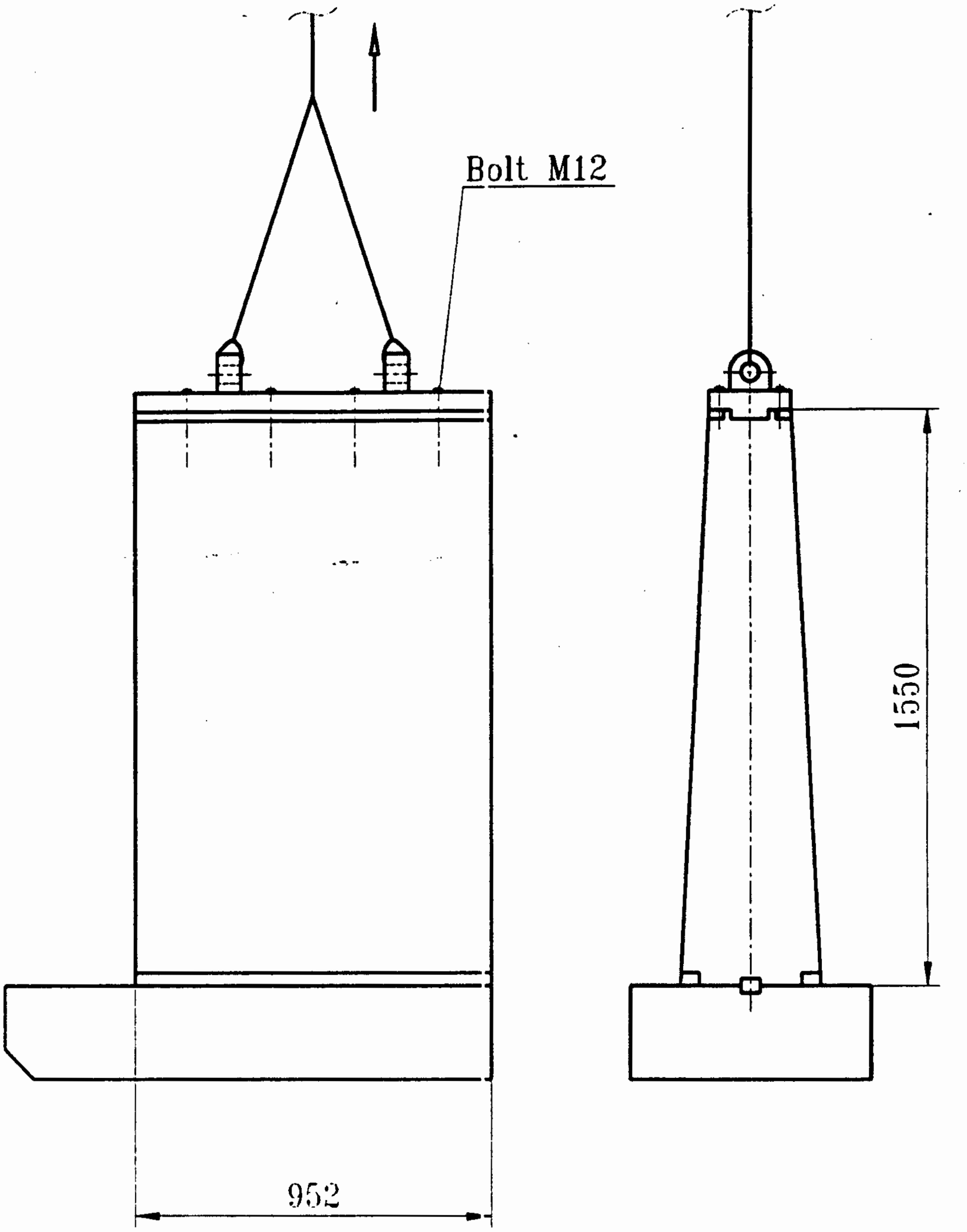


Figure 8

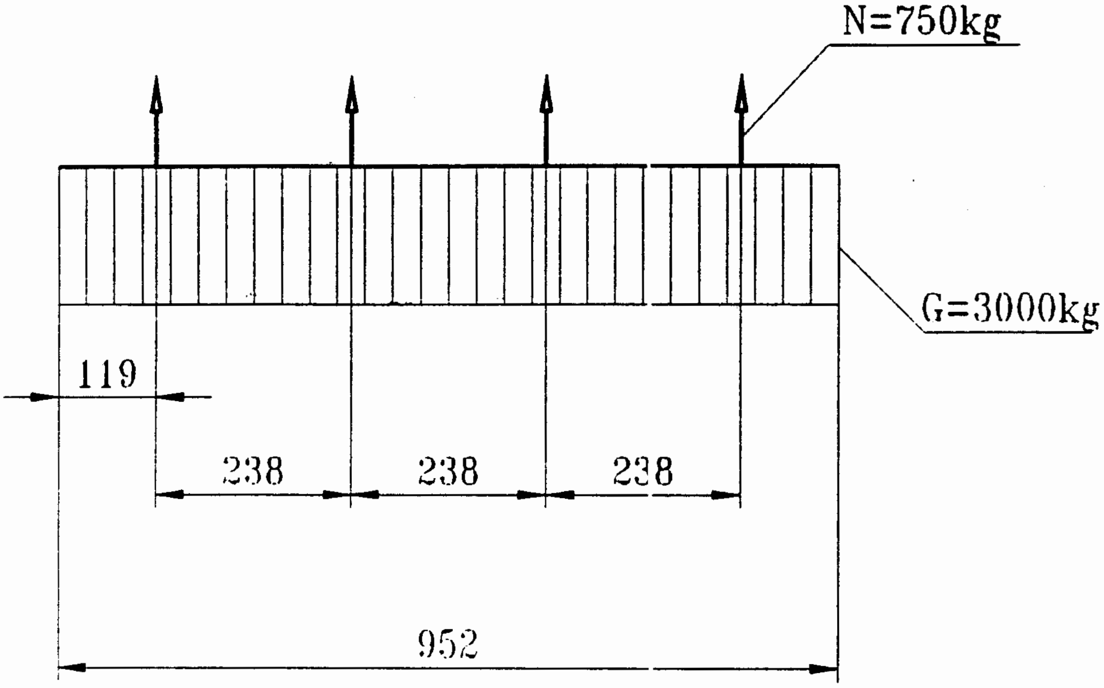


Figure 9

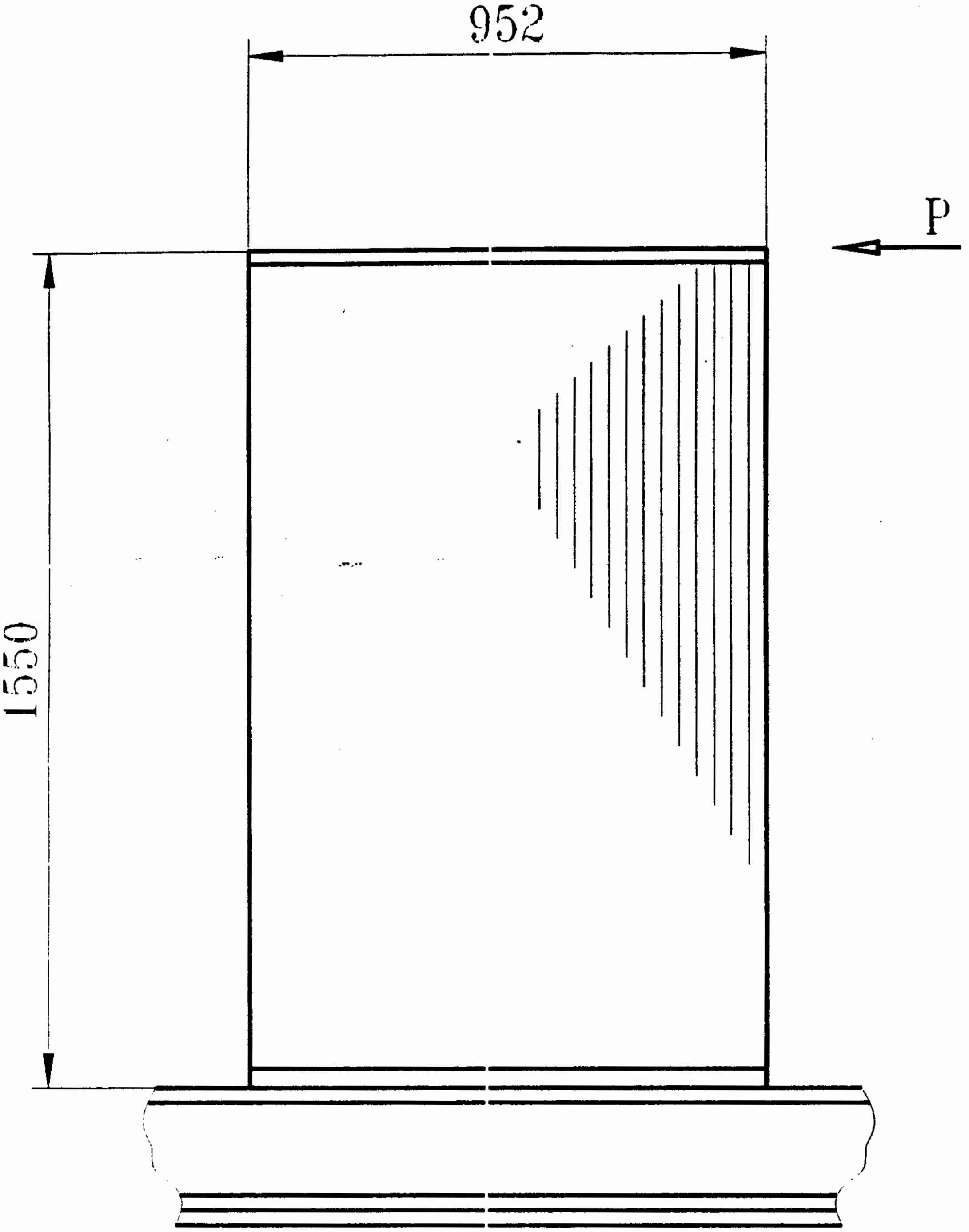


Figure 10

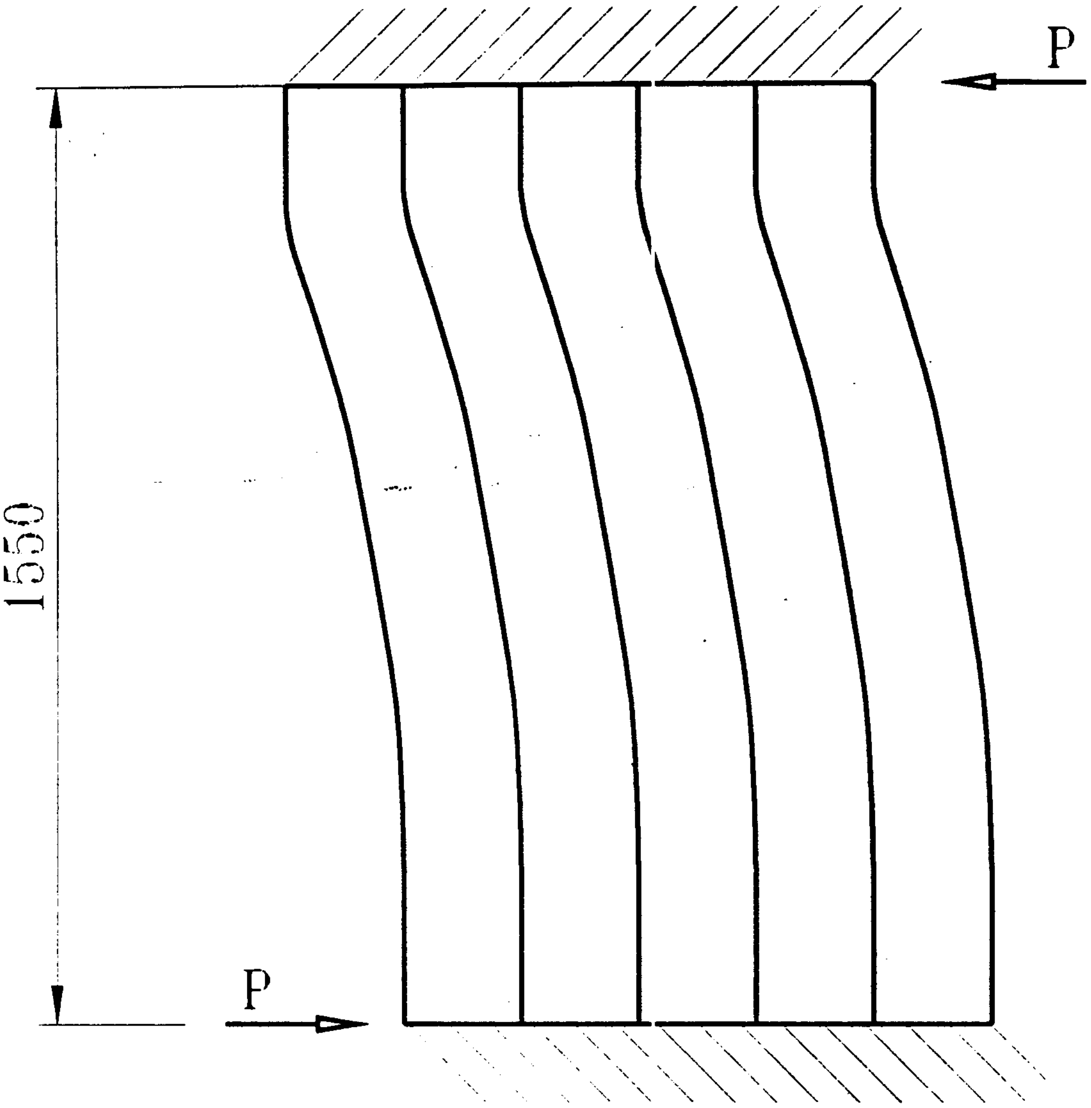


Figure 11

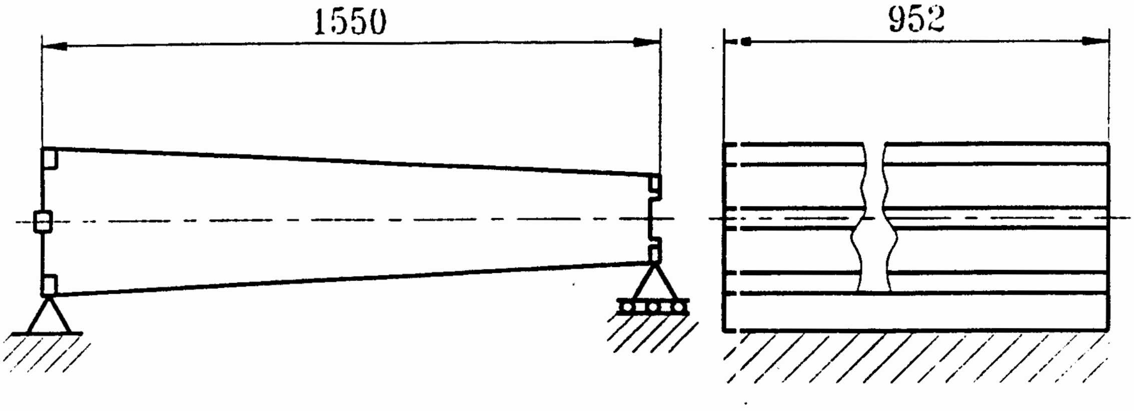


Figure 12

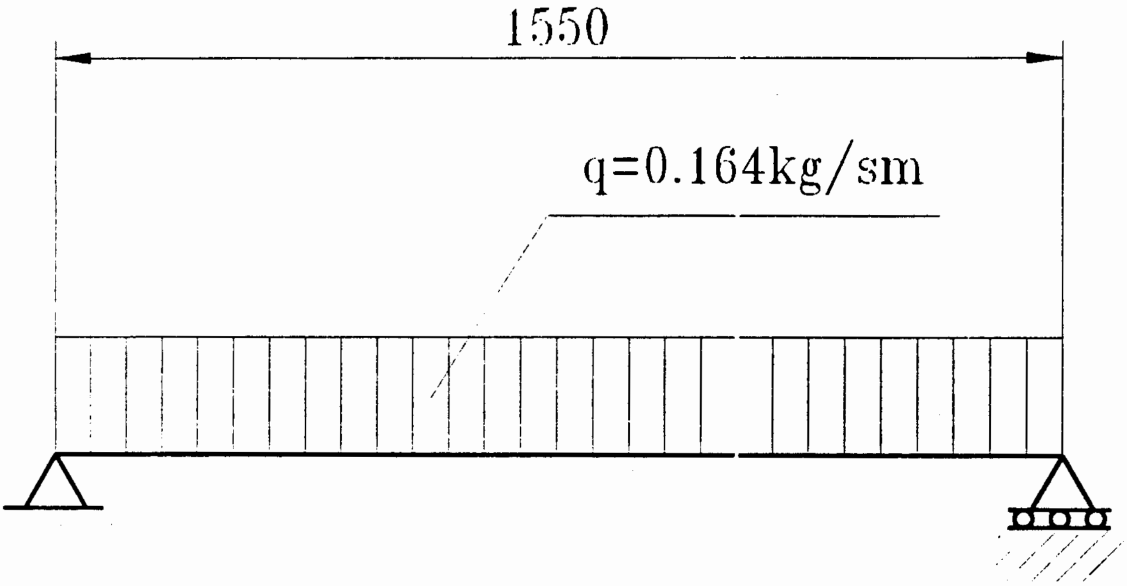


Figure 13

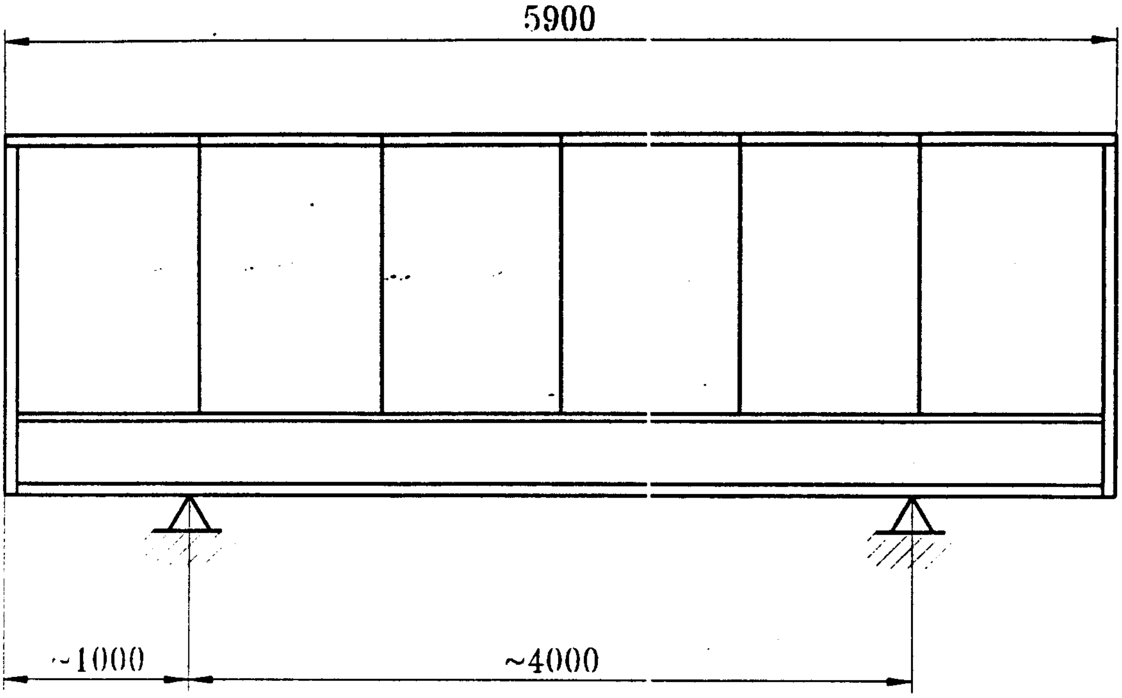


Figure 14

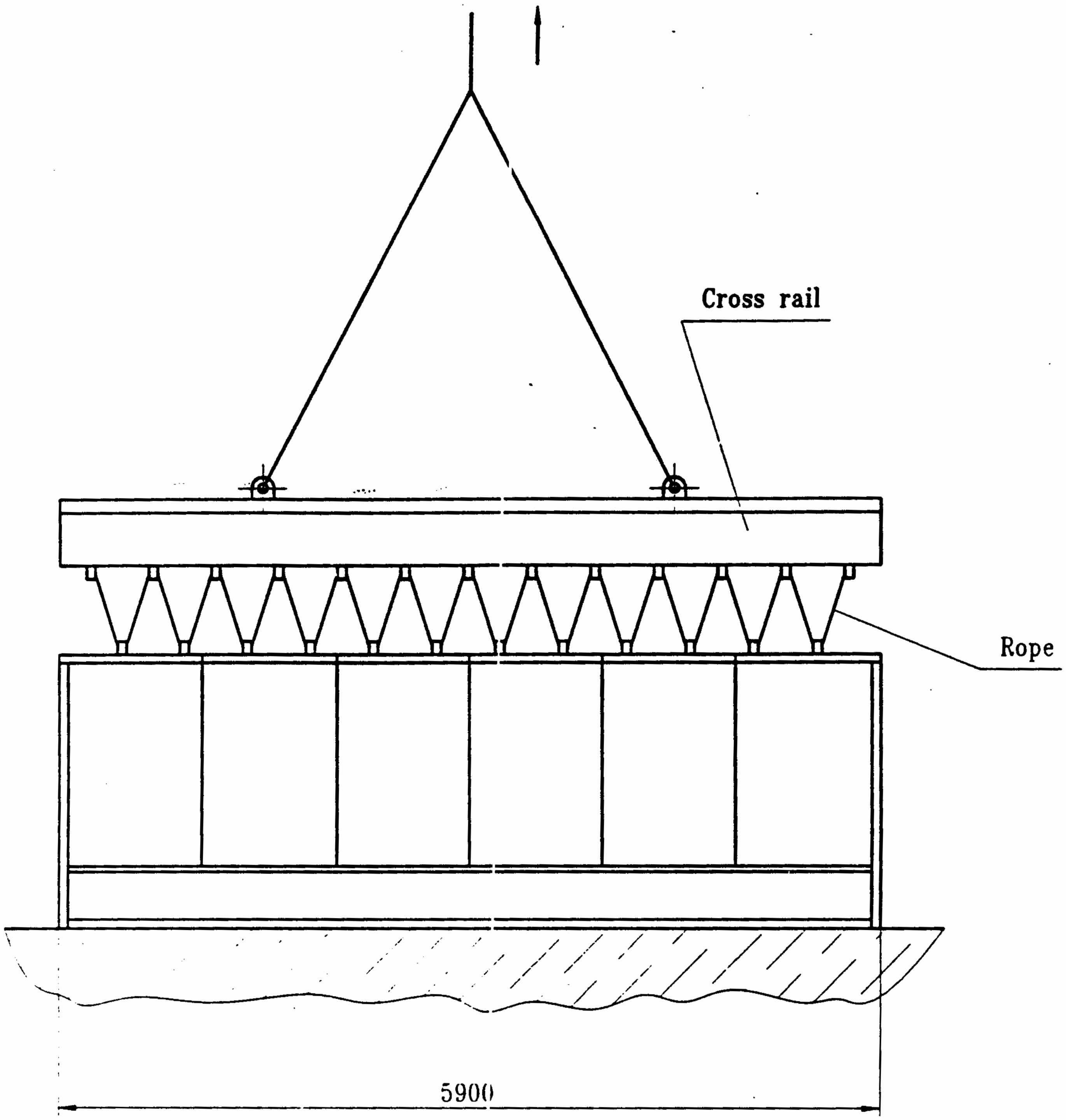


Fig. 15

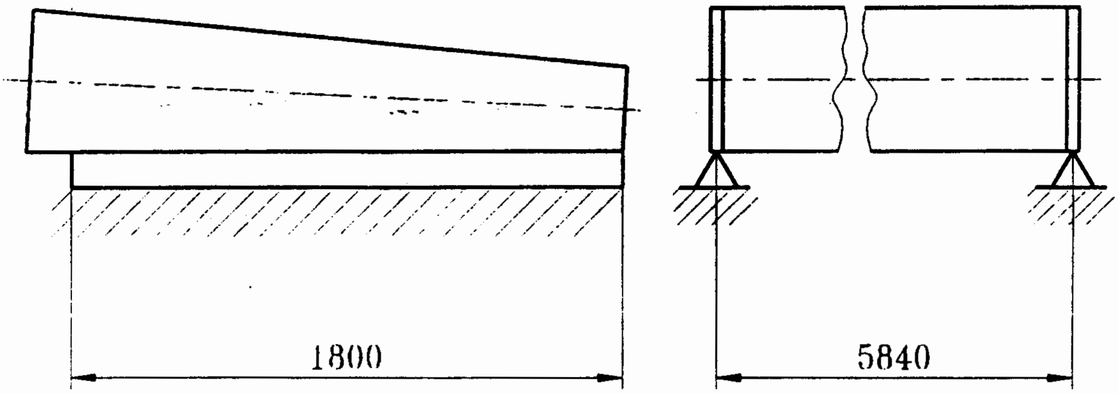


Figure 16

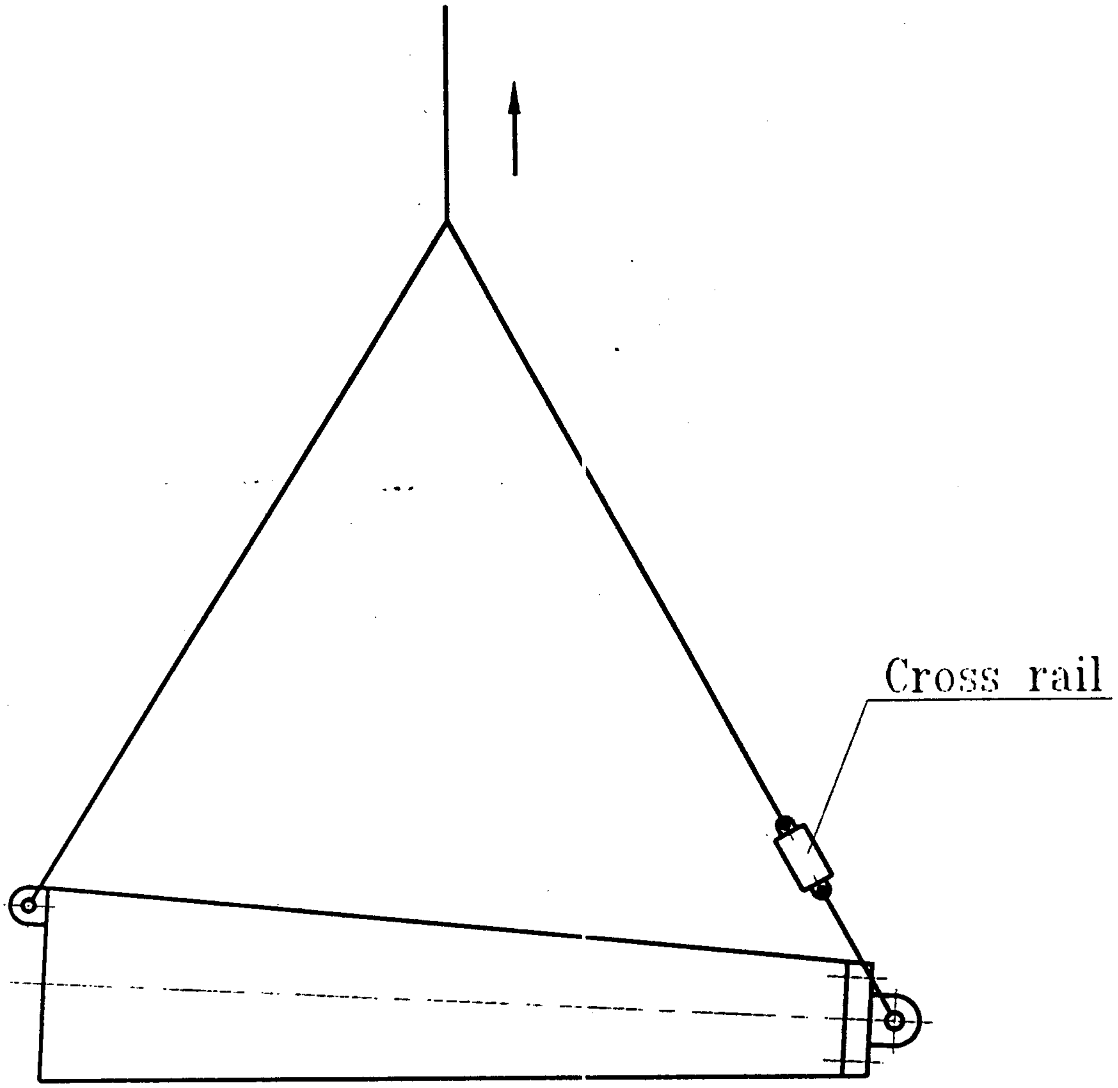


Figure 17

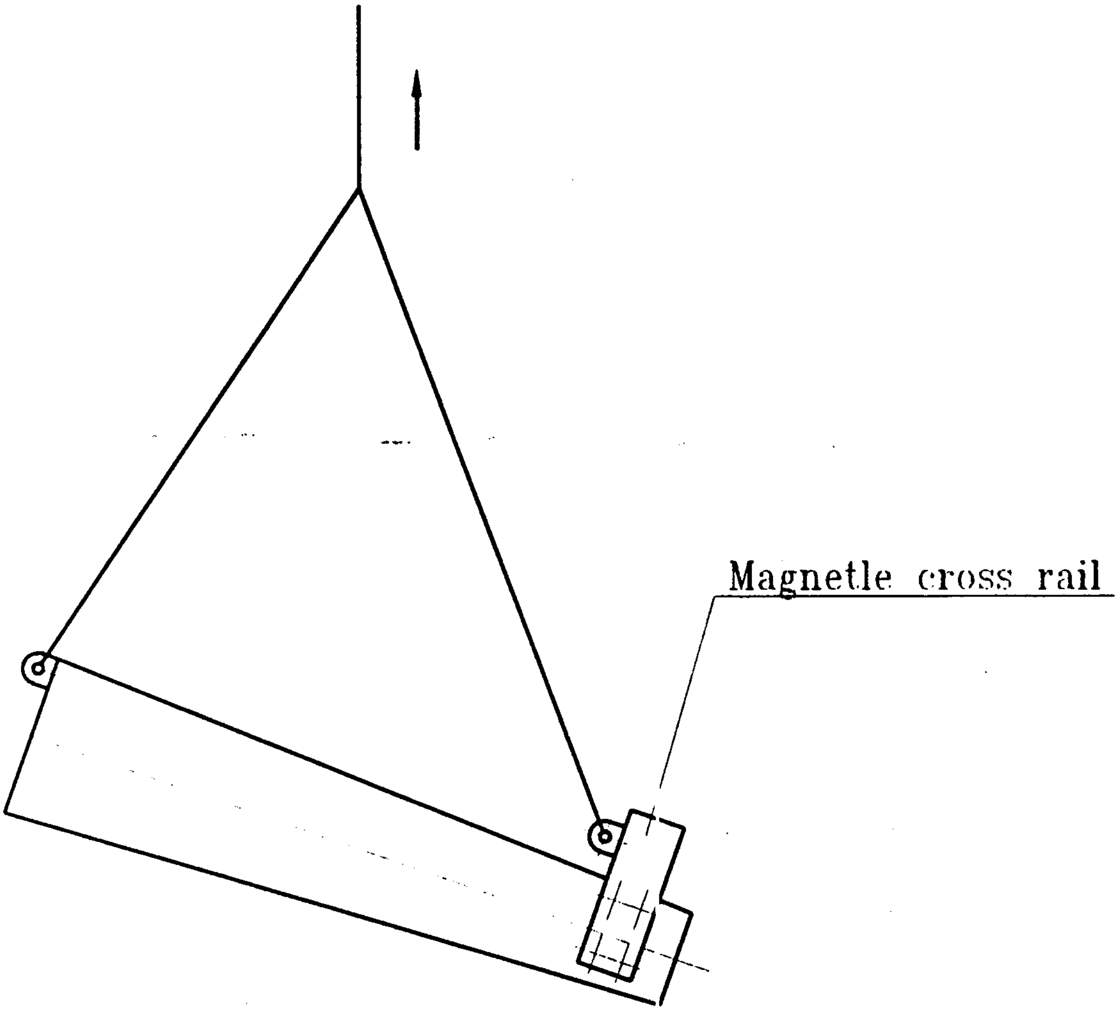


Figure 18

The Novolipetsk Metallurgical Plant steel sheets geometry measurement results.

by: Yu.Zhadnov, A.Novikov, V.Romanov, N.Topilin
JINR, Dubna, 12 August 1994

Subject of measurements.

The steel sheets samples remained after 5th hadron calorimeter prototype submodule production were chosen for measurements. The steel was rolled on March 18 1994 at NLMK. The steel was rolled in nonstabilized regime after rolls (in 4 rolls set) were replaced by new ones. 5 mm thick sheet was obtained from the slab $N\,3$; 4 mm thick sheet was obtained from the slab $N\,5$. The standard (regular) NLMK rolling technological procedure was used for the steel preparation.

Purpose of measurements.

1. Steel sheets surface real flatness determination.
2. Steel sheets transversal thickness variation ("lens-shape" of steel sheet in its cross-section) determination.
3. Steel sheet thickness variation determination in the direction of rolling.

Steel sheet flatness deviations from plane surface were determined by maximal value of saggita between surface of the sheet placed on the flat table and attached to sheet 1 m long linear template. As a flat table surface we used the ø 6 m face plate of vertical boring & turning shop machine. The (steel sheet $\sim$ linear template) gaps were determined by set of standard measuring feeler gauges.

For the steel sheets thickness measurement the micrometer was used. The flatness and the "lens-shape" degree measurements were made on three 5 mm thick sheets and three 4 mm thick ones.

Transverse direction steel sheet thickness measurements were done for each sheet end 20 mm away of sheet's edge. The flatness measurement scheme and the measurement results are presented on Fig. 1 and Fig. 2. The transverse direction steel sheets thickness measurement scheme and the results of measurements are presented on Fig. 3.

The steel sheets thickness measurements in the direction of rolling were done for 8 master plates billets cut out of the same original steel sheet. For measurement purposes each billet was cut along the long side by guillotine. Corresponding scheme and the measurement results are presented on Fig. 4.

CONCLUSIONS.

1. The hot rolled steel production technology allows to obtain the very high flatness sheets. Generally speaking the steel sheets nonflatness — for all the surface in any direction — is not more than $0.3 \div 0.5$ mm per 1 meter of sheet length. The exceptions are 300 mm long zones from the each sheet's edge. Here the observed sheet nonflatness is reaching up to 6 mm per 1 m length in the direction of rolling.

   By accepting of such steel sheets for spacer & masters fabrication one can significantly reduce the studs tightening force when submodule and module assembly.

2. The sheets "lens-shape" profile is 0.1 mm. This observation has to be taken into account either when billets cutting or one must foresee smaller "lens-shape" profile when steel ordering.
3. Along the rolling direction steel sheet thickness is changing arbitrarily. However the maximal steel sheet thickness changing of one billet is not larger 0.05 mm.

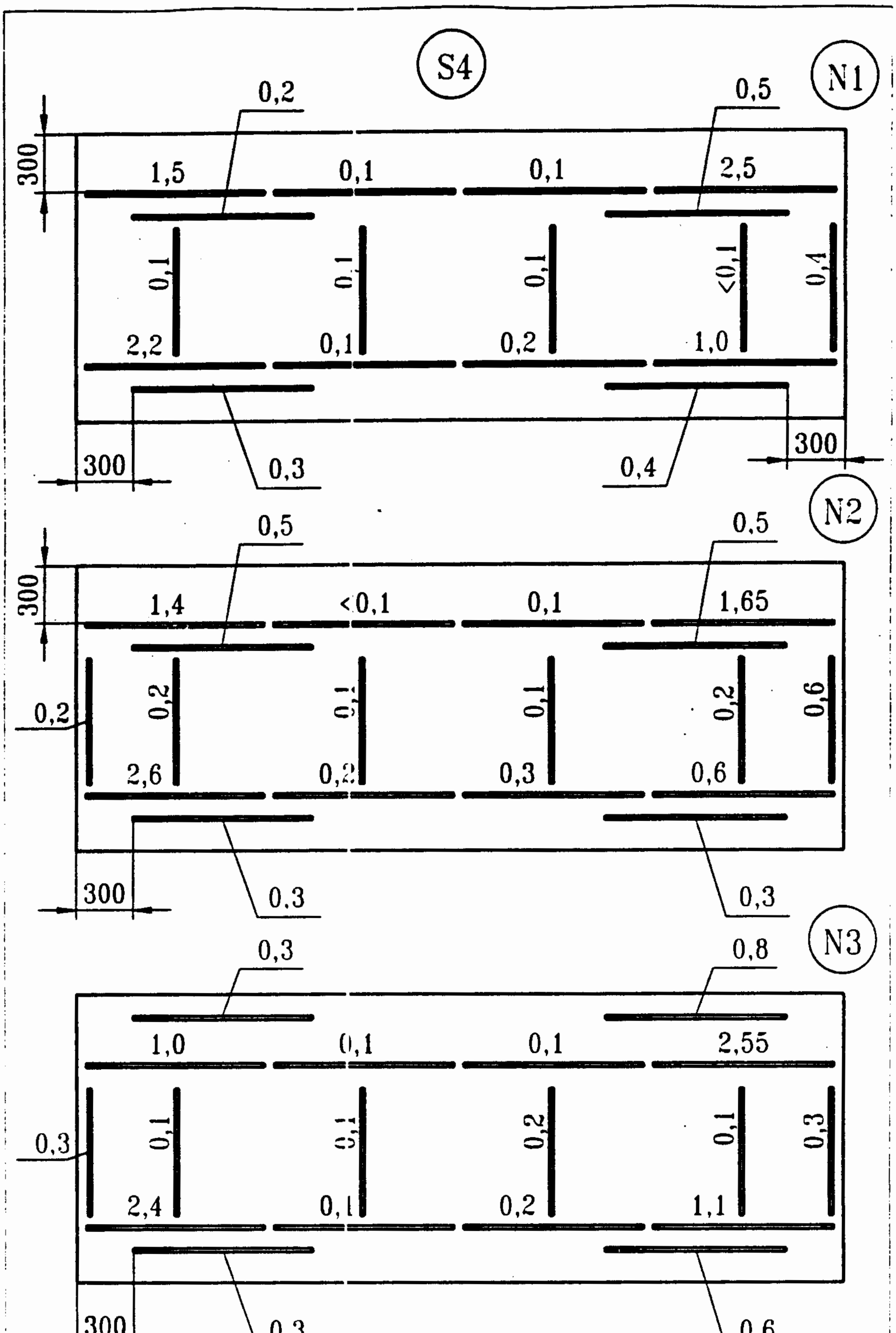

S4
N1
0,2
0,5
300
1,5
0,1
0,1
2,5
0,1
0,1
0,1
<0,1
0,4
2,2
0,1
0,2
1,0
300
0,3
0,4
300
N2
0,5
0,5
300
1,4
<0,1
0,1
1,65
0,2
0,2
0,1
0,1
0,2
0,6
2,6
0,2
0,3
0,6
300
0,3
0,3
N3
0,3
0,8
1,0
0,1
0,1
2,55
0,3
0,1
0,1
0,2
0,1
0,3
2,4
0,1
0,2
1,1
300
0,3
0,6

Fig. 1.

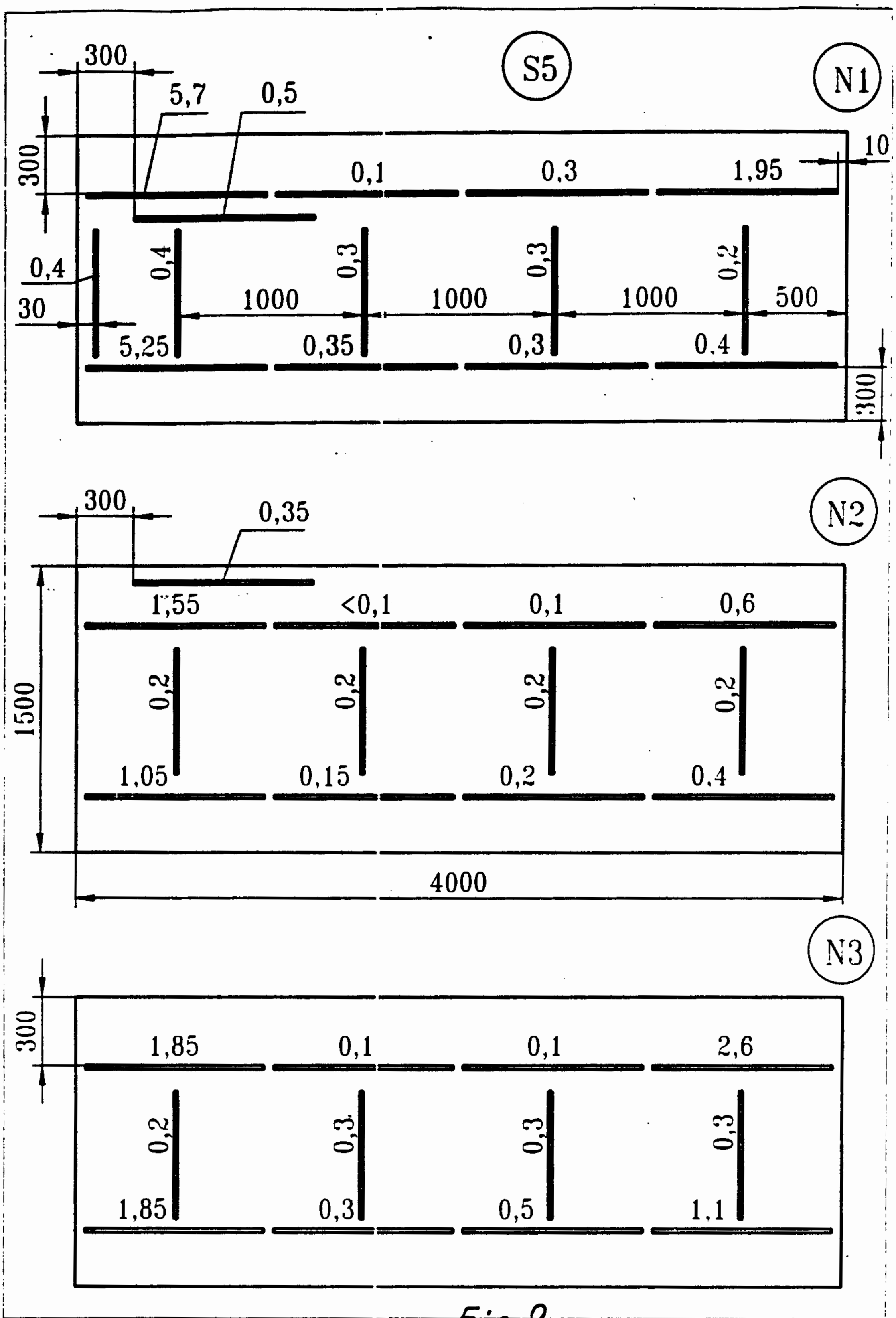
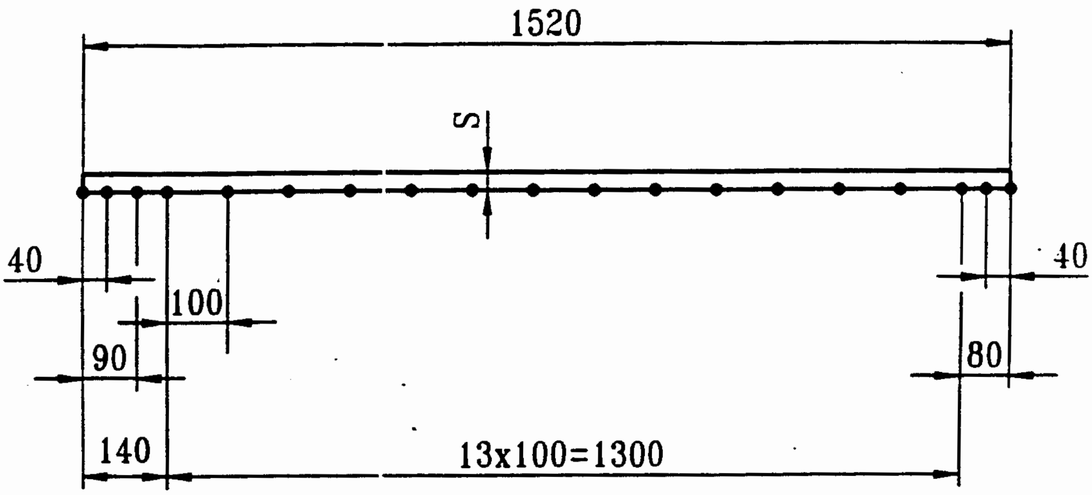

S5
N1
300
5,7
0,5
300
0,1
0,3
1,95
10
0,4
0,4
0,3
0,3
0,2
30
1000
1000
1000
500
5,25
0,35
0,3
0.4
300
N2
300
0,35
1,55
<0,1
0,1
0,6
1500
0,2
0,2
0,2
0,2
1,05
0,15
0,2
0.4
4000
N3
300
1,85
0,1
0,1
2,6
0,2
0,3
0,3
0,3
1,85
0,3
0,5
1.1

Fig. 2



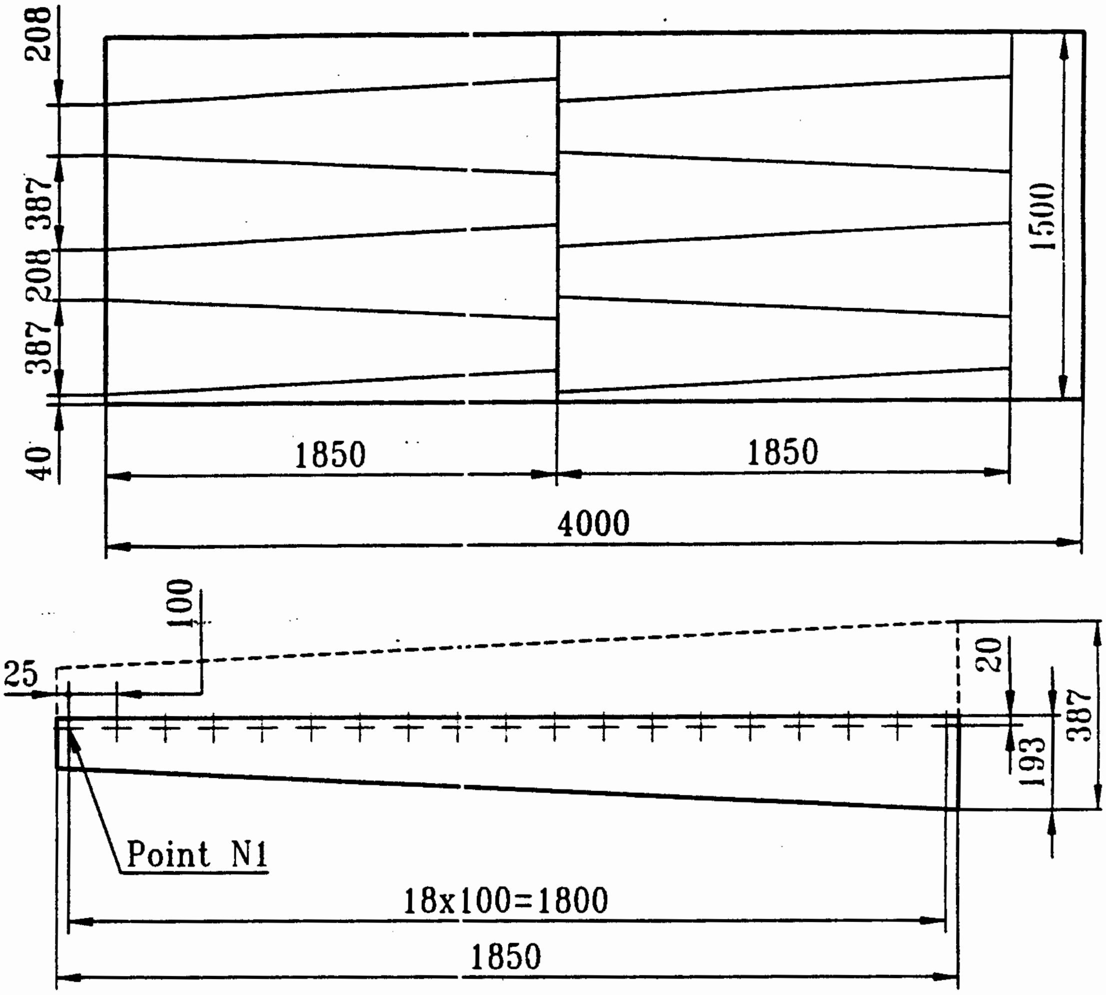
S=4

N	40	90	140	240	340	440	540	640	740	840	940	1040	1140	1240	1340	1440	1480
1.1	4.02	4.03	4.06	4.08	4.09	4.09	4.09	4.10	4.10	4.10	4.11	4.09	4.09	4.09	4.06	4.03	4.02
1.2	3.99	4.00	4.02	4.08	4.07	4.08	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.05	4.03	4.00	3.98
2.1	4.00	4.01	4.04	4.05	4.07	4.07	4.07	4.07	4.08	4.08	4.07	4.06	4.06	4.05	4.04	4.00	3.98
2.2	4.00	4.02	4.03	4.10	4.08	4.09	4.08	4.08	4.08	4.08	4.08	4.08	4.08	4.07	4.05	4.02	4.00
3.1	4.00	4.01	4.03	4.08	4.08	4.08	4.08	4.08	4.09	4.08	4.08	4.07	4.06	4.06	4.04	4.01	4.00
3.2	3.98	4.00	4.02	4.07	4.06	4.06	4.07	4.07	4.07	4.08	4.07	4.07	4.07	4.06	4.05	4.01	4.00

S=5

N	40	90	140	240	340	440	540	640	740	840	940	1040	1140	1240	1340	1440	1480
1.1	5.05	5.05	5.09	5.11	5.13	5.12	5.12	5.12	5.13	5.15	5.13	5.13	5.12	5.11	5.11	5.06	5.04
1.2	5.06	5.06	5.09	5.16	5.16	5.14	5.14	5.15	5.15	5.15	5.15	5.14	5.15	5.14	5.11	5.07	5.07
2.1	5.05	5.05	5.13	5.14	5.15	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.13	5.13	5.11	5.07	5.06
2.2	5.05	5.07	5.09	5.13	5.13	5.14	5.14	5.15	5.15	5.16	5.16	5.15	5.13	5.13	5.12	5.08	5.07
3.1	5.04	5.05	5.07	5.16	5.14	5.11	5.10	5.12	5.12	5.11	5.11	5.11	5.11	5.10	5.07	5.03	5.02
3.2	5.06	5.07	5.09	5.12	5.14	5.14	5.14	5.14	5.14	5.15	5.15	5.14	5.14	5.13	5.10	5.07	5.07

Fig. 3.



N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	5.11	5.11	5.11	5.11	5.11	5.11	5.11	5.11	5.10	5.11	5.12	5.12	5.12	5.12	5.13	5.14	5.14	5.15	5.15
2	5.09	5.10	5.10	5.10	5.09	5.09	5.09	5.10	5.11	5.11	5.11	5.11	5.11	5.12	5.13	5.13	5.14	5.14	5.14
3	5.15	5.15	5.14	5.13	5.12	5.12	5.12	5.12	5.12	5.11	5.10	5.09	5.10	5.10	5.09	5.10	5.10	5.10	5.10
4	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.13	5.13	5.13	5.13	5.13	5.14	5.14	5.14	5.15	5.15
5	5.14	5.14	5.13	5.13	5.13	5.13	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.13	5.13	5.13	5.12	5.13	5.13
6	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.12	5.13
7	5.14	5.14	5.14	5.14	5.13	5.12	5.12	5.11	5.11	5.11	5.10	5.10	5.10	5.10	5.09	5.10	5.10	5.10	5.10
8	5.16	5.16	5.15	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.13

Fig. 4.

Appendix 2

The results of steel samples technical measurements for the ATLAS TILECAL.

by: Yu.Zhadnov, A.Novikov, V.Romanov, N.Topilin
JINR, Dubna, 12 August 1994

Subject of measurements.

2 cylindrical ø 58 mm, L = 50 mm samples were taken for the tests. Samples were fabricated from low carbon steel. Each sample had 4 milled 10 mm × 10 mm channels along the sample length, as indicated on Fig. 5. The sample length was measured by micrometer frame at 5 points: 0, 1, 2, 3, 4 (see Fig. 5). After that the angular welding seams were made in the channels up to their total filling. After metal cooled the samples lengths were measured in the same points.

Purpose of measurement.

To obtain the indirect estimation of welding seams affect on 1 m module after 4 longitudinal plates were welded to the module on its corners side.

The measurement results are presented on Fig. 6.

CONCLUSIONS.

1. The equivalent effect of welding seams on the samples is equal to longitudinal sample compressing force of about 60 tons.
2. The longitudinal plates welded to 1 m module will press the set of spacer and master plates to each other.
3. The necessity of using of high strength material for studs is removed.

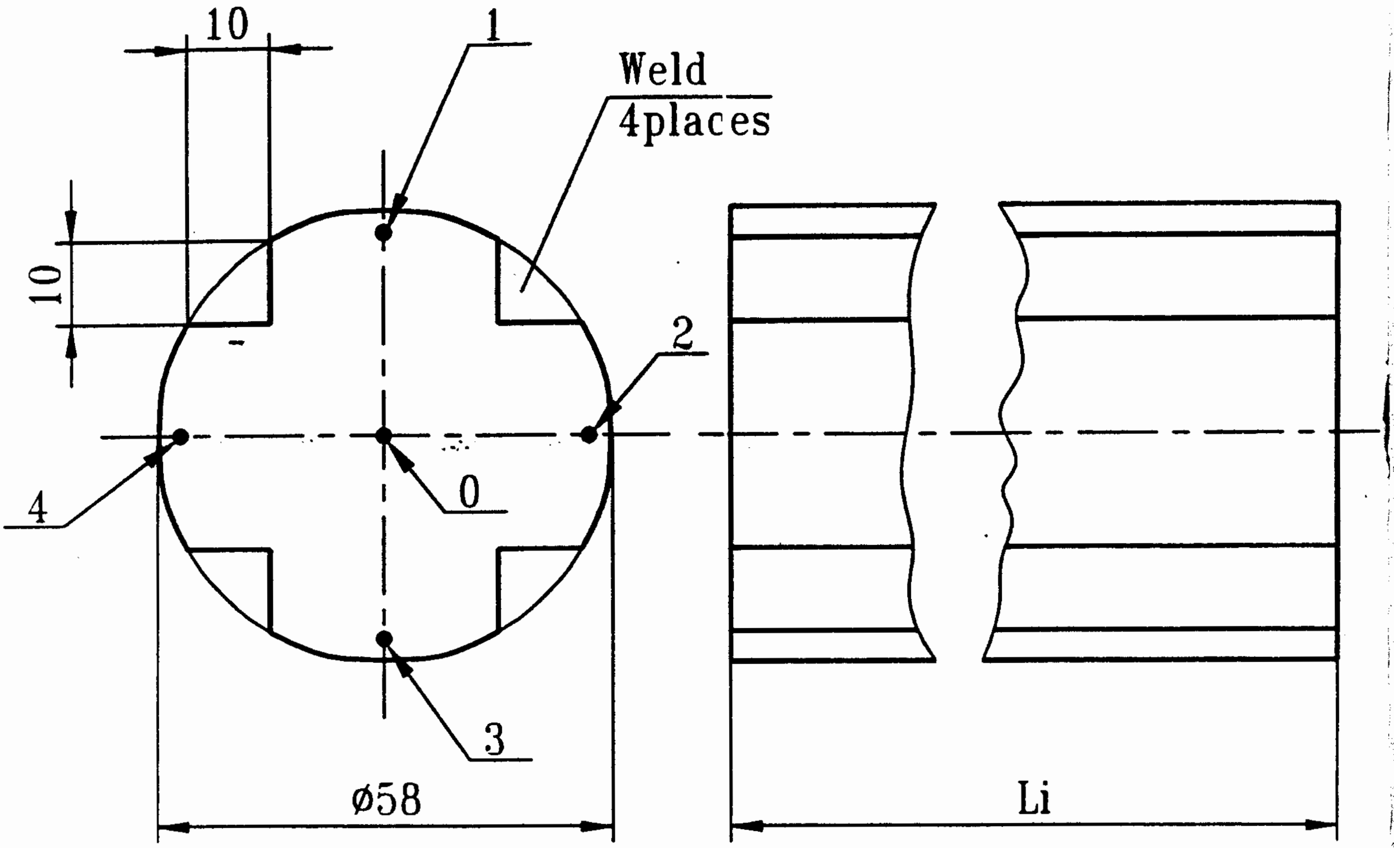


Fig. 5.

	Specimen N1			Specimen N2		
	Before welding	After welding	△Li	Before welding	After welding	△Li
L0	248.75	248.34	0.41	249.75	249.17	0.58
L1	248.66	248.17	0.49	249.77	249.26	0.51
L2	248.61	248.08	0.53	249.74	249.21	0.53
L3	248.71	248.20	0.51	249.76	249.03	0.73
L4	248.69	248.21	0.48	249.78	249.02	0.76

Fig. 6.