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EUROPEAN ATOMIC ENERGY COMMUNITY — EURATOM

EXPERIMENTAL STUDY OF THE STRESS DISTRIBUTION IN THE ESSOR REACTOR VESSEL WALL

by

P.S. WELTEVREDEN and J.F.G. BLANCKENBURG

1966

ORGEL Program

Joint Nuclear Research Center
Ispra Establishment - Italy

Engineering Department
Technology

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Summary

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This report contains a description of the experimental stress analysis of this discontinuity-stress problem. Its primary scope is to demonstrate, by means of a practical example, the usefulness of the experimental stress analysis techniques regarding safe and economic design of important constructions. In addition it presents a rather detailed view of the various existing techniques and their characteristics.

C O N T E N T S

LIST OF FIGURES

1. INTRODUCTION

The ESSOR reactor (ESSOR = ESSAI ORGEL) which is now under construction at the Euratom Research Centre at Ispra has a large, relatively thin walled primary reactor vessel. For several reasons it was required that the upper cylindrical part of this vessel be larger in diameter than the lower cylindrical part, i.e. the outer diameter of the upper part should be 2,560 mm compared to 2,404 mm for the lower part. In addition, this reduction of diameter should be realized within a certain axial length for reasons of space and fabrication.

Concerning the fabrication it is evident that the only way to construct such a vessel is to build it up out of two cylinders and a transition ring, having principally a conical form. The latter part can be forged and subsequently welded to the two rolled cylinders.

In view of this rather unconventional geometry and the requirement that the primary reactor vessel must be able to withstand an accidental static overpressure of 12 atm., it was decided that a detailed study of the vessel, with special regard to the transition ring, was indispensable for safety reasons.

Moreover, as the axial length of the transition piece should be as small as possible, such a study would be necessary to investigate the optimum location of the circumferential weldings with respect to discontinuity stresses.

On request of G.A.A.A. a proposal was made for a test program of experimental stress analysis, the results of which are summarized in this paper.

Manuscript received on August 26, 1966

2. OBJECTIVES

A cross-section of the primary vessel is given in Fig. 1, in which only those dimensions are indicated regarding the transition ring, henceforth called "stricture".

Internal pressure loading of this vessel will develop high axial bending moments throughout and in the vicinity of the stricture. At first it was considered as the scope of the experimental work to establish the attenuation of these bending moments and their corresponding stresses along an axial generatrix. Based on such data, it should have been possible to determine the location of the weldings.

In the course of the experimental work, however, it was found that the maximum occurring bending stresses were higher than expected. Consequently, the geometry of the stricture had to be changed in such a way as to reduce these values. A series of four different stricture geometries were studied, comprising the original one. The first part of the work was performed by means of a 1:10 scale model of the reactor vessel. A systematic approach, including stress-coat technique, photoelasticity and strain gauge measurements resulted in quantitative data on stress distribution. The second part, i.e. the optimization study of the stricture geometry, was performed by means of a series of two-dimensional photoelastic models of the stricture section 4. As a result of this test series a stricture geometry could be selected, acceptable both from the point of view of stress level and bending moment distribution.

In the following sections a detailed description is given of the experimental work (section 3 and 4). In section 5 a short description is given of a test on the actual reactor vessel and a comparison is made with the data obtained from the model tests.

3. EXPERIMENTAL STRESS ANALYSIS ON MODEL-VESSEL

From the size of the reactor vessel (see Fig. 1) it follows that a scale model is indispensable for this kind of work. As a compromise between ease of fabrication and required accuracy a scale factor 1:10 was selected. In order to obtain higher strain sensitivity an aluminium alloy was chosen for the model vessel. The alloy was tested in our laboratories and showed the following mechanical properties:

Young's modulus:	6,790 kg/mm^2
Shear modulus:	2,525 kg/mm^2
Poisson's ratio:	0.34
Yield Stress ($\sigma_{0.2}$):	25 kg/mm^2
Rupture stress:	36 kg/mm^2

As only the stricture and its vicinity was of interest from the point of view of stress analysis, the upper and lower cylindrical parts of the vessel were closed at such a distance that the closures did not show any influence on the stress distribution near the stricture. The relaxation length of discontinuity stresses being $0.778\sqrt{r.t}$, which corresponds to about 12 mm for the model vessel, an axial cylinder length of 50 mm thus reduces the discontinuity stresses to 4% of their initial values. The upper part of the vessel was thus scaled down according to the real vessel design whereas the bottom closure was realized at a distance of about 100 mm from the stricture.

Fig. 2 gives a drawing of the model vessel.

Fig. 3 shows a picture of the experimental set-up. To pressurize the vessel up to the required gauge pressure of 12 atm. a hydraulic screw-pump was constructed, enabling to give a very exact and stable pressure. The picture shows the set-up as used for the experiments which will be described now. Clearly visible are: water filled model vessel, screw-pump and pressure gauge.

3.1. Stresscoat

Although the stresscoat technique does not have a high exactitude regarding magnitude of stresses, it has regarding its location. In our case the location being very important it was thought useful to start the experiments with a stresscoat analysis.

The area of interest for the analysis could be restricted, due to the cylindrical geometry, to a small part of the vessel wall incorporating a part of the outside stricture surface, about 10 cm square.

The stresscoat equipment of the Magnaflux Corporation was used for this experiment. Fig. 4 gives a picture of the overall equipment.

The coating was applied simultaneously on the vessel and five calibration bars. The spraying set-up is illustrated in Fig. 5. The spraying was performed in a large hall under rather bad spraying conditions: cold and drawing. The conditions in the laboratory, where the test was to be performed, at the moment of the selection of the coating were characterized by respectively a dry - and wet-bulb temperature of 72.5°F and 55°F. From the Coating Selection Chart (Fig. 6) it follows that coating No.1203 should be used. As this coating was not available it was obtained by mixing equal proportions of Coating No. 1204 and 1202.

Immediately after spraying, the model vessel and calibration bars were transferred to the laboratory and allowed to dry for 18 hours. On testing the calibration bars for the determination of the threshold strain, once more the temperature and humidity of the atmosphere were measured and were found to correspond to coating No. 1204. Next, the calibration bars were loaded (loading time 1 sec) which gave the following threshold values:

TABLE 1

Calibration Values - Threshold Strain

bar	threshold strain (μ/m)
1	1080
2	1080
3	1010
4	1000
5	980

The average value of 1030 μ/m was taken as a basis for the analysis of the experiment of the model vessel. It should be noted that reproducibility within 5% of stress magnitude was found on the calibration bars.

Actually the coating No. 1203 should have shown a threshold value of $\pm$ (800 + 100) μ/m, due to the fact that it was loaded under the circumstances fit for coating No. 1204. That the actual threshold strain turned out to be 1030 μ/m is most probably due to the fact that spraying was performed in a very humid and cold atmosphere. However, given the good reproducibility, this does not influence the results.

Immediately after the calibration tests, the test on the model vessel was started. The loading was performed in a relatively short time in order to avoid excessive creep of the coating. The results of the test are summarized in table 2.

TABLE 2

EXPERIMENTAL VALUES

time to load (sec)	time to inspect (sec)	total time (sec)	test pressure (atm)	crack location	creep corrected strain (μ/m)
19	36	55	5.4	A	1210
70	20	90	7.0	A grows	
109	46	155	8.2	A grows B added	1300
180	35	215	9.5	A grows B grows	
240	60	300	11.3	A grows B grows C added	1380
322			12.4	A,B and C growing	

The values in the last columns were determined by means of the creep correction chart as given in Fig. 7, and can thus be used assuming elastic behaviour, for the determination of the stress at the design pressure of 12 atm.

For instance, at location A, the value of the strain at the test pressure of 12 atm. amounts to:

$$\epsilon_A = 1210 \cdot \frac{12}{5.4} = 2670\ \mu/m$$

corresponding to a stress value of

$$\sigma_A = \epsilon_A \cdot E = 2670 \cdot 10^{-6} \cdot 6790 = 18.2\ kg/mm^2$$

In Fig. 8 a detail-picture is given of the stresscoat crack pattern after completion of the test. The surface was treated with dye-etchant in order to improve visual inspection. The first crack (A) appeared in tangential direction, pointing towards a steep axial bending-stress peak. The location of this peak could be determined with an accuracy better than 0.1 mm. The subsequent appearance of pattern B indicated tangential discontinuity stresses. Pattern C appeared near the top flange of the vessel (not visible on the picture) and indicated discontinuity stresses near the flange, which are not discussed here.

Summarizing the results of the stresscoat experiment: an exact indication of the point of highest axial stress concentration was obtained, together with an estimation of the magnitude of the stress in this point (about 18 kg/mm^2 at 12 atm inner pressure).

3.2. Photostress

Following the stresscoat experiment the so-called photostress-technique was applied. This experiment served first of all to check the stresscoat values and to obtain additional information regarding the distribution of the surface stresses in the vicinity of the stricture.

The photostress-technique is a method of stress analysis in which the model to be analyzed is coated with a photoelastic plastic. When the model is loaded, surface-strains are transmitted to the plastic coating, which then becomes birefringent. If a reflective surface is provided at the interface of the structure and the plastic, this birefringence can be observed and measured by means of a reflection polariscope. Like a transmitting polariscope the reflection polariscope contains resp. a light source, polarizer, quarter-wave plates and analyzer. At normal incidence, i.e. with the incident light perpendicular to the coating, isoclines and isostatics can be determined, giving a complete view of the stress-intensity distribution over the surface.

Using an oblique-incidence attachement, it is possible to determine separate values of the principal stresses. Detailed description of this technique is presented in several textbooks on experimental stress analysis. In the following we will only mention some special features of the technique which are relevant to this specific experiment.

As the surface to be analyzed was rather irregular, the plastic was applied by the so-called contoured sheet method. A flat sheet of plastic is poured and allowed to polymerize partially and is subsequently formed over the surface. After the sheet is formed it is allowed to continue polymerization at room temperature until it is hardened completely. Next, it is cemented to the model by means of a reflective cement. After cementing the sheet is analysed for residual stresses, which can never be avoided completely, due to the fact that after forming of the sheet a small amount of contraction will still occur.

Before forming the sheet a strip was cut from it which served to determine the K-factor of the sheet. This strip, cemented to a prismatic beam and calibrated in bending, gave a strain-optical-coefficient of K = 0.075 m/m.

In the area of interest the stress-situation through the vessel-wall is a combination of bending and traction (or compression). Due to the relatively high thickness of the coating with respect to the wall thickness, correction of the measured stress values is necessary in order to account for the reinforcement effect. The amount of correction depends on the ratio of plastic-to-wall thickness and the type of material. Fig. 9 represents a correction-chart for the cases of tension and bending. As the material of the model-vessel is an aluminium-alloy, a thickness-ratio of 1.47 was selected. For this ratio the correction factors for bending and tension just cancel each other, so that for a plastic thickness of 2.94 mm (wall thickness 2 mm) no correction of the measured stress values is necessary in this specific case, assuming that the bending and the tension stresses are of the same level. If not, the maximum error introduced by this assumption is only ± 5% (see Fig. 9).

Once the preformed plastic sheet cemented in place and the cement cured, the sheet was checked for residual stresses at the vertical mid-section. The optical retardation was measured at normal and oblique incidence.

Next, the model was loaded and the strain pattern as shown in Fig. 10 appeared. The first thing to remark is a rather strong boundary effect in the plastic. This had been expected and for this reason the plastic section had been taken relatively wide. The bubble pattern at the left corner of the sheet can not be avoided when working with the contoured sheet technique. However, when taking care that it does not cover the points of interest, it will not influence the accuracy. Analysing the strain pattern, the locations of maximum bending stresses could easily be determined (indicated in Fig. 10 by two crosses). In these points and some other points in their vicinity, a complete analysis of the stress-situation was made. I.e. in each point the value of the optical retardation was determined under normal and oblique incidence and corrected for residual stress. Subsequently, these values (α_n and α_o) were substituted in the following formula:

$$\sigma_1 = 3.8 \frac{E}{1+\mu} \frac{f}{d} (0.856\ \alpha_o - 0.73\ \alpha_n) \cdot \frac{1}{c}$$

$$\sigma_2 = 3.8 \frac{E}{1+\mu} \frac{f}{d} (0.856\ \alpha_o - \alpha_n) \cdot \frac{1}{c}$$

in which

f = fringe value = $\frac{\lambda}{2tK}$

λ = wave length monochromatic light source (= 5750 Å)

t = thickness of plastic (= 2.94 mm)

K = strain optical coefficient (= 0.075 m/m)

d = instrument constant (= 180°)

c = correction coefficient (= 1)

REMARK: The numerical constants in the formula are given by the angle of oblique incidence.

Table 3 summarizes the stress values obtained in this way.

T A B L E 3

code number	reference height (mm)	α_n corrected (degrees)	α_o corrected (degrees)	σ_{axial} (kg/mm^2)	$\sigma_{tangential}$ (kg/mm^2)
1	151.8	2	45	5.61	5.52
2	133.0	165	180	-16.7	-5.9
3	122.3	0	40	5.0	5.0
4	116.5	200	340	19.5	11.3
5	108.7	0	50	6.5	6.5
6	92.7	138	170	1.5	7.0

Although a general appreciation of these data will be made later (section 5), it should be noted here that the maximum bending stresses measured by means of the photostress technique (resp. -16.7 and 19.5 kg/mm^2) are in good agreement with the stresscoat value (18 kg/mm^2).

3.3. Strain-Gauges

On the basis of the stresscoat and the photostress experiments a clear picture was obtained of the general stress situation in the vicinity of the stricture. To check the quantitative values of the obtained results, it was considered useful to complete the data with strain-gauge measurements on a few specific locations, i.e. those corresponding to code numbers 1-2-4- and 6 of table 3.

Fig. 11 shows the disposition of the gauges on the model vessel. The SR-4 type wire-gauges were used, with a grid size of 3 mm square.

The strain data obtained from a test-run at 12 atm gauge pressure are summarized in table 4.

TABLE 4

code number	ϵ_a (μ/m)	ϵ_t (μ/m)	σ_a (kg/mm^2)	σ_t (kg/mm^2)
1	478	488	4.97	5.03
2	-1680	-47	-17.6	-6.5
4	1575	1365	15.6	14.6
6	-137	953	1.47	7.0

Comparing these values with the values of table 3 it is seen that good agreement is obtained for all measuring points except number 4, showing a difference of almost

25% between photostress and strain-gauge values. Although no satisfactory explanation can be given for this anomaly, it should be mentioned that the gauges of measuring point 4 are the only ones which are applied in a location with a re latively strong curvature (see also Fig. 12, where the gaug are drawn in scale on the cross section of the vessel wall) It is possible that during application of these gauges - th application requires a curing of the cement under homogeneo pressure - a non-perfect bonding has been achieved. For thi reason the strain values of these gauges must be considered with care.

Concluding this section, the general stress distribution along the stricture is represented in Fig. 12. The drawn line gives the stress distribution as resulted from the photostress measurements.

The position of the weldments, determined on the basis of this stress distribution by the manufacturer of the vessel, is also indicated in this figur and is clearly shown not to interfere with the position of the maximum bending stresses

4. TWO DIMENSIONAL PHOTOELASTIC MODEL OF THE STRICTURE

In item 2 it was indicated that an optimization of the stricture geometry was necessary as the stresses in the stricture as designed were considered too high (addendum I)

On the basis of the results obtained in section 3, three modified stricture contours were designed, henceforth calle "Variant 1, 2 and 3" (see Fig. 13).

In order to obtain full information on the stress situation in these variants it would have been necessary to construct 3 model vessels of the type as indicated in section 3 and repeat the experimental stress analysis of the original model vessel three times. HOwever, for reasons of fabrication planning of the actual reactor vessel, it was decided that it would be sufficient to determine the amount and location of the maximum bending stresses in the variants with respect to the original stricture contour.

To this extent the four stricture contours (original and three variants) were cut from an Araldite plate of 10 mm thickness in full scale. These models were subsequently mounted in the loading frame of a transmission polariscope by means of a special fixture which guarantees pure axial loading of the model (Fig. 14). In this way only axial bending stresses are introduced in the stricture models, not accompanied by tangential stresses which actually occur in a cylindrical vessel due to the "beam on elastic foundation" effect. However, the stress analysis on the model vessel indicated a.o. that the maximum tangential stresses are only about 60% of the maximum axial stresses. As the 3 variants had a contour which deviated only slightly from the original one, it is justified to suppose that in non of the variants the tangential stresses would increase so much as to become larger than the axial stresses, the axial stresses thus remaining critical in all cases.

Analysis of the results of this test-series gave the following data (Table 5).

TABLE 5

stricture contour	peak stress value with respect to original	location peak stress (distance from centre of stricture in mm)
original	1	80
variant 1	1.01	88
variant 2	0.79	95
variant 3	0.82	72

From Table 5 it follows that maximum reduction of the peak stress is obtained with variant 2. However, this peak stress occurs at relatively large distance from the centre of the stricture, requiring increased distance between the two circumferential weldments. The second-best variant (no. 3) reduces the stress peak with 18% and moreover the location of the stress peak moves over 8 mm towards the centre of the stricture. Variant 3 shows thus the best compromise and was selected for the definite design.

5. TESTS ON ACTUAL REACTOR VESSEL AND COMPARISON WITH MODEL

In october 1965 the construction of the reactor vessel was completed and hydraulic testing was performed at the manufacturer's site. Apart from a number of other measurements, required for acceptance of the vessel, this occasion was utilized to check the results of the model-stricture analysi

For this purpose a number of 9 strain-gauges were applied in the area where the maximum bending stresses should occur, as predicted by the model tests. The disposition of the strain-gauges is shown in Fig. 15.

The test conditions during hydraulic testing differed from the test conditions during the model tests at two points:

a) hydraulic pressure of 10 atm gauge with respect to 12 atm gauge for the model tests,

b) the actual vessel was tested with the upper shielding cover in place. The weight of this cover amounts to 32.000 kg which is equivalent, at least for the axial force on the stricture, to an internal pressure of - 0.7 atm gauge. Consequently the axial stresses in the stricture are due to a net internal pressure of 10 - 0.7 = 9.3 atm gauge.

Several test-runs were performed showing good proportionality of strain signals and test pressure and good reproducibility. The result of a typical test-run is graphically shown in Fig. 16.

Gauge 6 shows a maximum strain value which should have been repeated at gauge 7. Actually the dotted line indicates what should have been the strain signal of gauge 9. That gauge 9 indicated a strain different from this value could not be explained satisfactorily, however, this gauge was suspected as it showed a rather high instability during preliminary tests. On the other hand it is possible that local deviations of the nominal geometry give rise to locally higher strain values. But even in this case the left hand branch of the curve (gauges 3-5-7-9) has a rather strong curvature, indicating that the maximum value should be close to gauge position 9.

Considering representative the right hand branche of the curve, it follows that the maximum strain value occurs at 75 mm from the centre of the stricture (see also Fig. 15, gauge position 6). This agrees well with the predicted value of 72 mm (see table 5, variant 3).

Concerning the value of the maximum axial stress at gauge position 6, unfortunately no tangential strain measurement was performed at this location. It is thus possible only to make an estimation of the axial stress value by estimating the tangential stress at this location. To this extent it is recalled that the tangential stress at the location of the maximum axial stress during the model tests was about 1.5 times the tangential membrane stress (see also Fig. 12). Assuming that this is valid also for the actual vessel, one arrives at the following value of the tangential stress:

$$\sigma_t = 1.5 \cdot \frac{p.r}{t}$$

$$\sigma_t = 1.5 \cdot \frac{0,1 \cdot 1250}{20} = 9.4 \text{ kg/mm}^2$$

Substituting this value in the following equation:

$$\sigma_a = \epsilon_a E + \nu \sigma_t$$

with

$$\epsilon_a = 370 \mu/m \text{ (strain signal gauge 6)}$$

$$E = 2 \cdot 10^4 \text{ kg/mm}^2 \text{ (st.st.)}$$

$$\nu = 0.33$$

one obtains:

$$\sigma_a = 10.5 \text{ kg/mm}^2$$

Comparing this value with the value obtained from the model tests, one proceeds as follows:

The maximum axial bending stress for the original stricture follows from Table 3, and amounts to 19.5 kg/mm^2. From Table 5 one finds the maximum bending stress in variant 3 to be 0.82 . 19.5 = 16 kg/mm^2.

Next, it is taken into account that the net test pressure of the actual vessel amounted to 9.3 atm. gauge compared to 12 atm. gauge pressure for the model vessel. Consequently, one finally finds as maximum bending stress predicted by the model test:

$$\sigma_a = \frac{9.3}{12} \cdot 16 = 12.4 \text{ kg/mm}^2$$

Comparing the real and the predicted value, resp. 10.5 and 12.4 kg/mm^2, it follows that the model tests have resulted in an overestimation of 18% of the maximum axial bending stress.

In order to explain this difference an exact metrology was made of the vessel wall thickness of the model vessel after completion of the tests. At several locations along the circumference axial sections were cut from the vessel wall (see Fig. 17).

As a matter of fact, the nominal maximum thickness of the stricture being 3 mm, an average value of 2.84 mm was measured. Although this amounts to a reduction of only 5.5%, it should be taken into account that the bending stresses vary with the square of the thickness. Thus overestimation of the order of

$$\frac{3^2 - 2.84^2}{3^2} \cdot 100 = 10\%$$

should reasonably be expected.

ADDENDUM

GAAA

GROUPEMENT ATOMIQUE ALSACIENNE ATLANTIQUE

SOCIÉTÉ ANONYME AU CAPITAL DE 4.000.000 F.

DATE 11/5-64. N° 7046
CLASSEMENT
CIRCULATION

LE PLESSIS-ROBINSON
100. AV. EDOUARD-HERRIOT
TEL. ROB. 53-44

Bruyères-le-Châtel, le 28 avril 1964

EURATOM
C.C.R. - ISPRA
Service Technologie

B.P. n° 1

Province de VAREZE (ITALIE)

N/Réf. : EA 177 64 2390 OR/120
JA/ES

Objet : ESSOR - Décrochement de cuve

à l'attention de Monsieur WELTEVREDEN

[redacted]

Messieurs,

Après examen des résultats que vous avez obtenus sur la maquette du décrochement de cuve, nous estimons que les contraintes maxima que l'on obtiendra lors des essais à 12 bars sont élevées pour un acier inoxydable austénitique du type 18.8 à bas carbone.

Nous envisageons deux modifications possibles de la forme du décrochement. Elles figurent sur le croquis ci-joint. La première pourrait être obtenue par augmentation du rayon de raccordement, la deuxième par augmentation de l'épaisseur du décrochement dans la zone des contraintes maxima. Dans les deux cas les soudures seraient éloignées au maximum de la zone fléchie.

Pensez-vous que ces modifications entraîneraient une diminution des contraintes dans la zone critique ou que d'autres types de tracés du décrochement pourraient conduire à de tels résultats.?

Veuillez agréer, Messieurs, l'expression de nos sentiments distingués.

GROUPEMENT ATOMIQUE ALSACIENNE ATLANTIQUE
Le Chef du Département Applications Nucléaires

J.P. CRETTE

4 P.J.

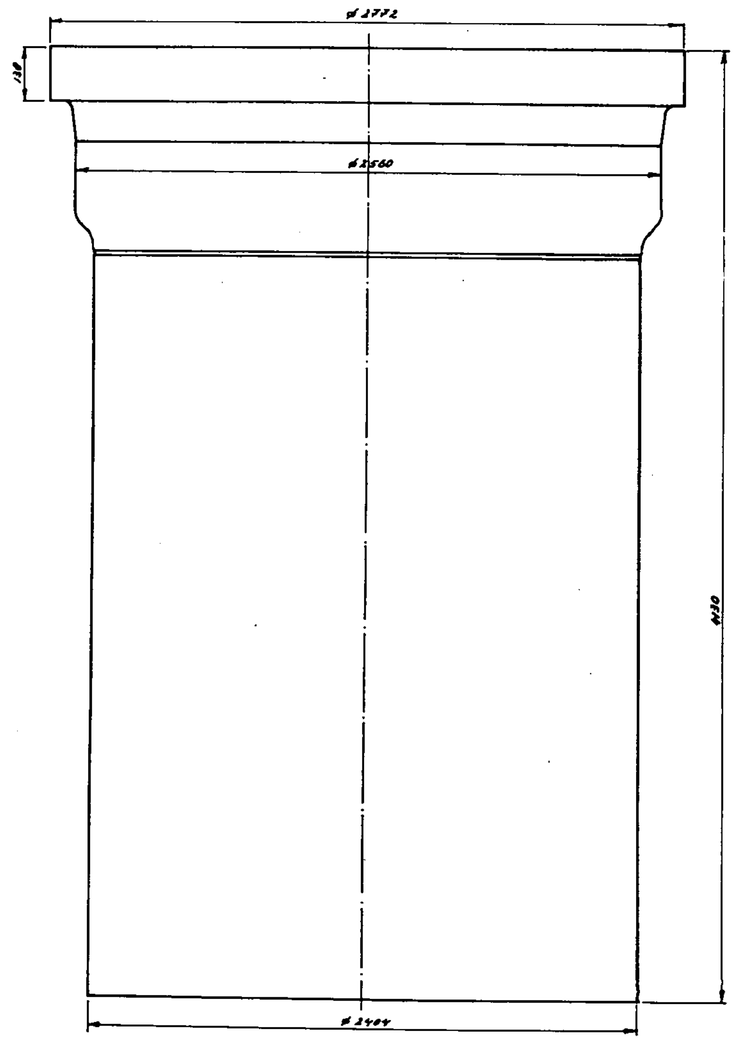
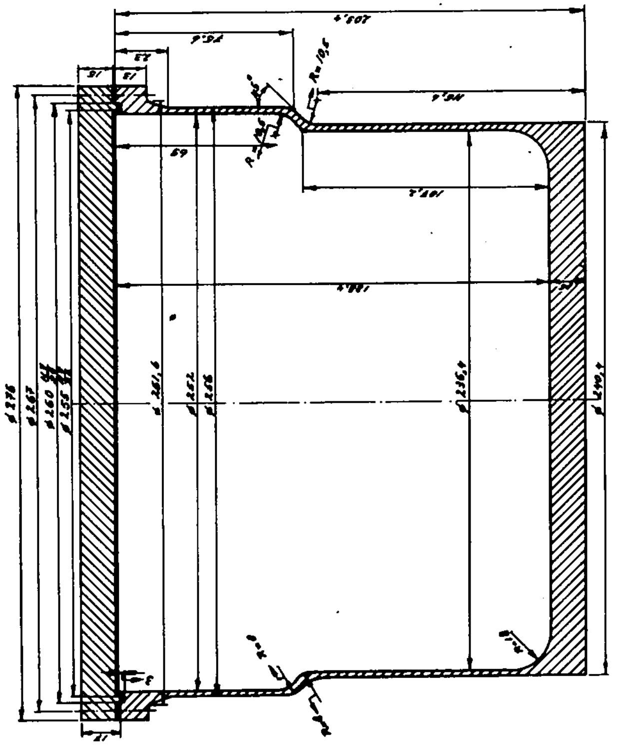


fig. 1



N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORME E OSSERVAZIONI
				Anticorodal		

SCALA: 1:2

MODIFICAZIONE

EURATOM
C.C.R. ISPRA

FINITURA: ▽▽

DESIGNAZIONE: ESSOR

SERVIZIO: DTB
N.
GRUPPO

– fig. 2

TOLLERANZE GENERALI:

TITOLO: Model vessel

per Servizio:
Prog. N.: E

	DATA	NOME
DISEGNATO		
VERIFICATO		
CAPO DI GRUPPO		

FABBRICAZ. N.: F

NOMENCLATURA N.: N —

INSIEME N.: —

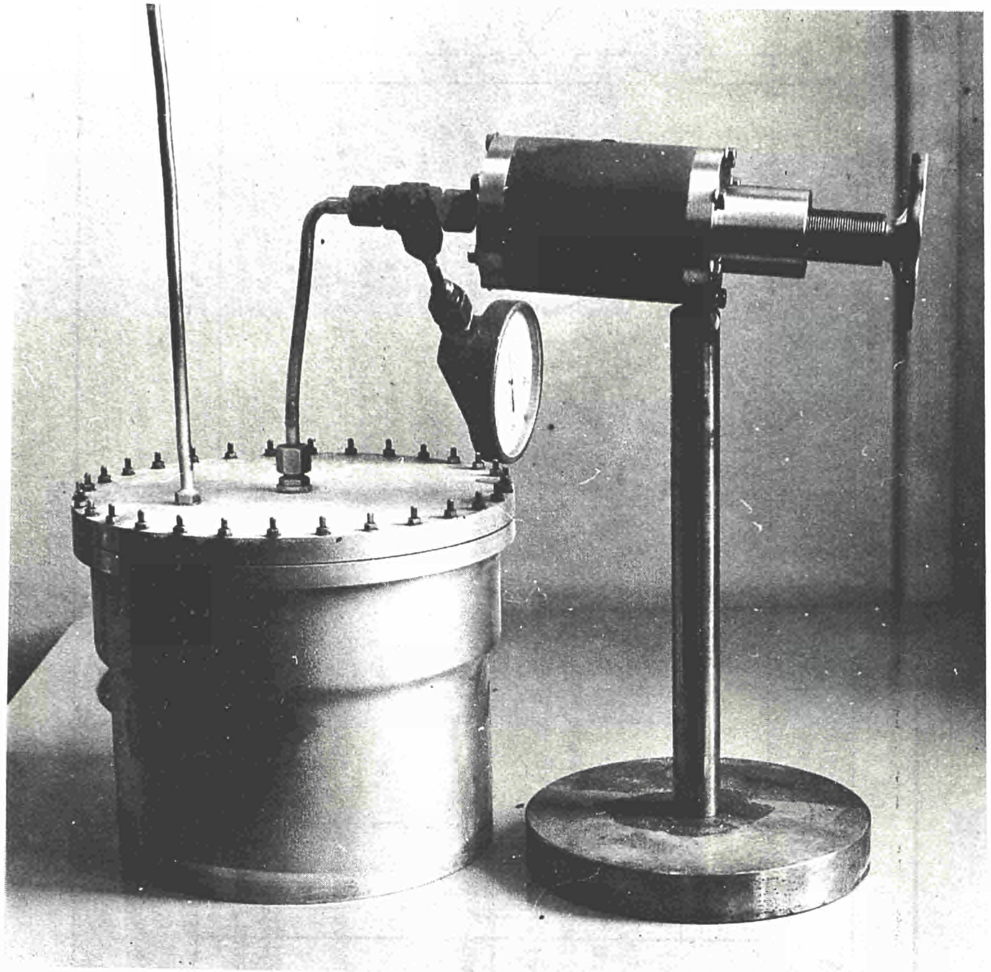


Fig. 3

EXPERIMENTAL SET-UP

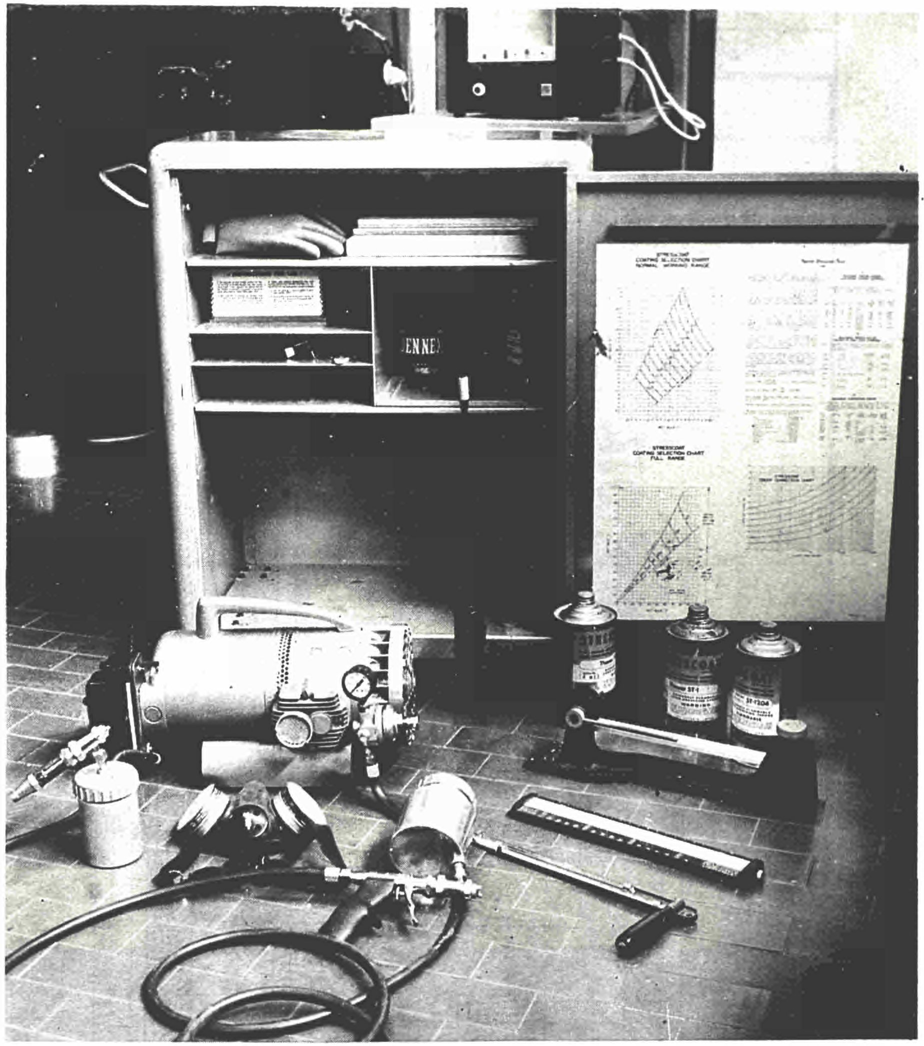


Fig. 4

STRESSCOAT EQUIPMENT

SPRAYING SET-UP

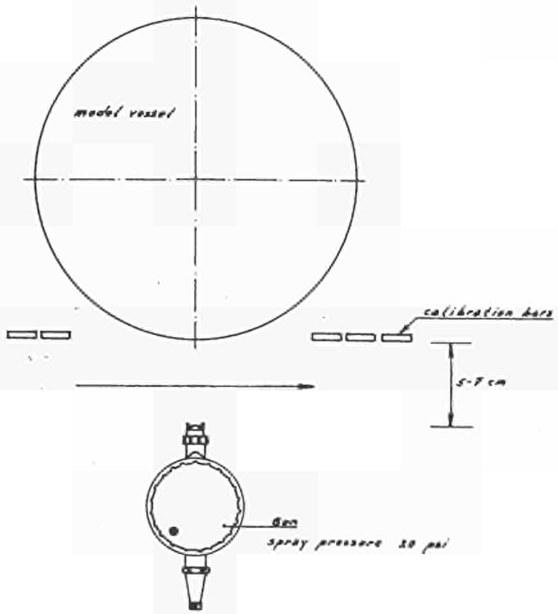


fig. 5

Coating Selection

Normal Working Range

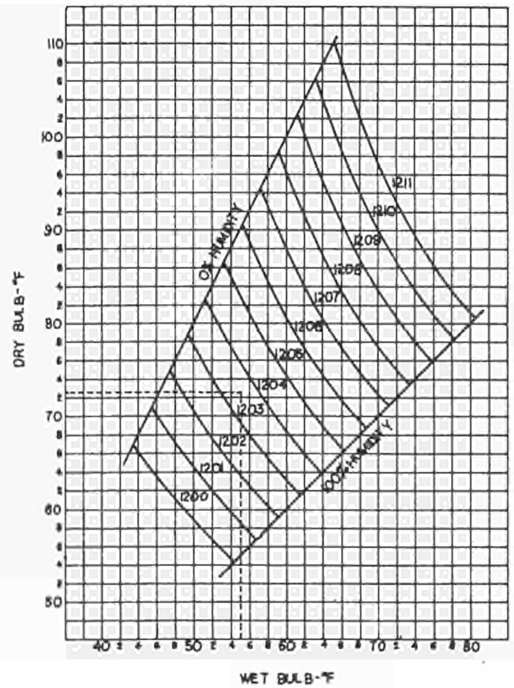


fig. 6

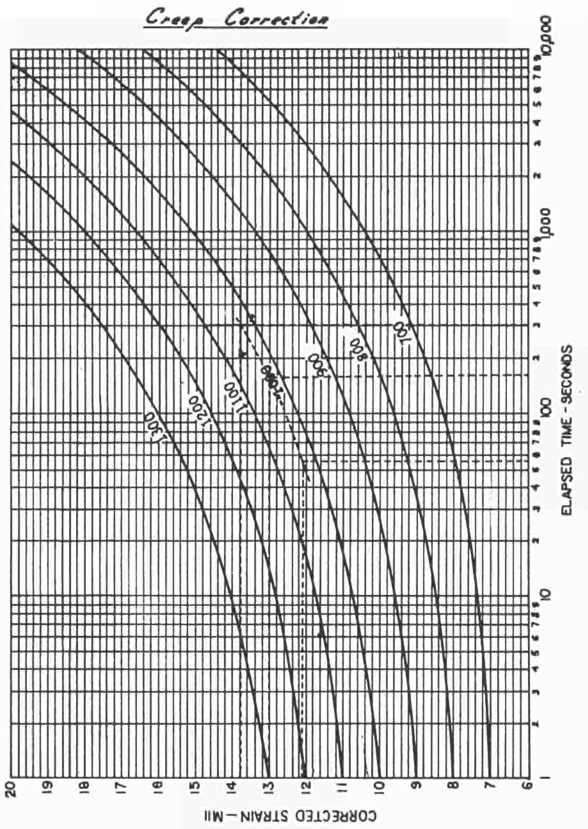


fig. 7

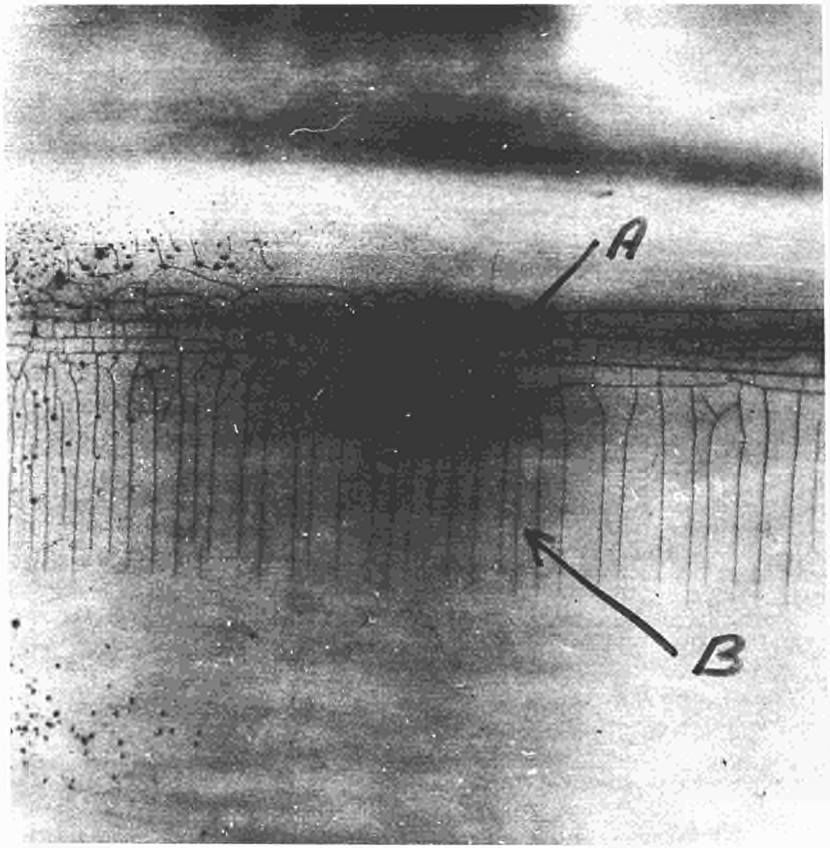


Fig. 8

CRACK PATTERN STRESSCOAT

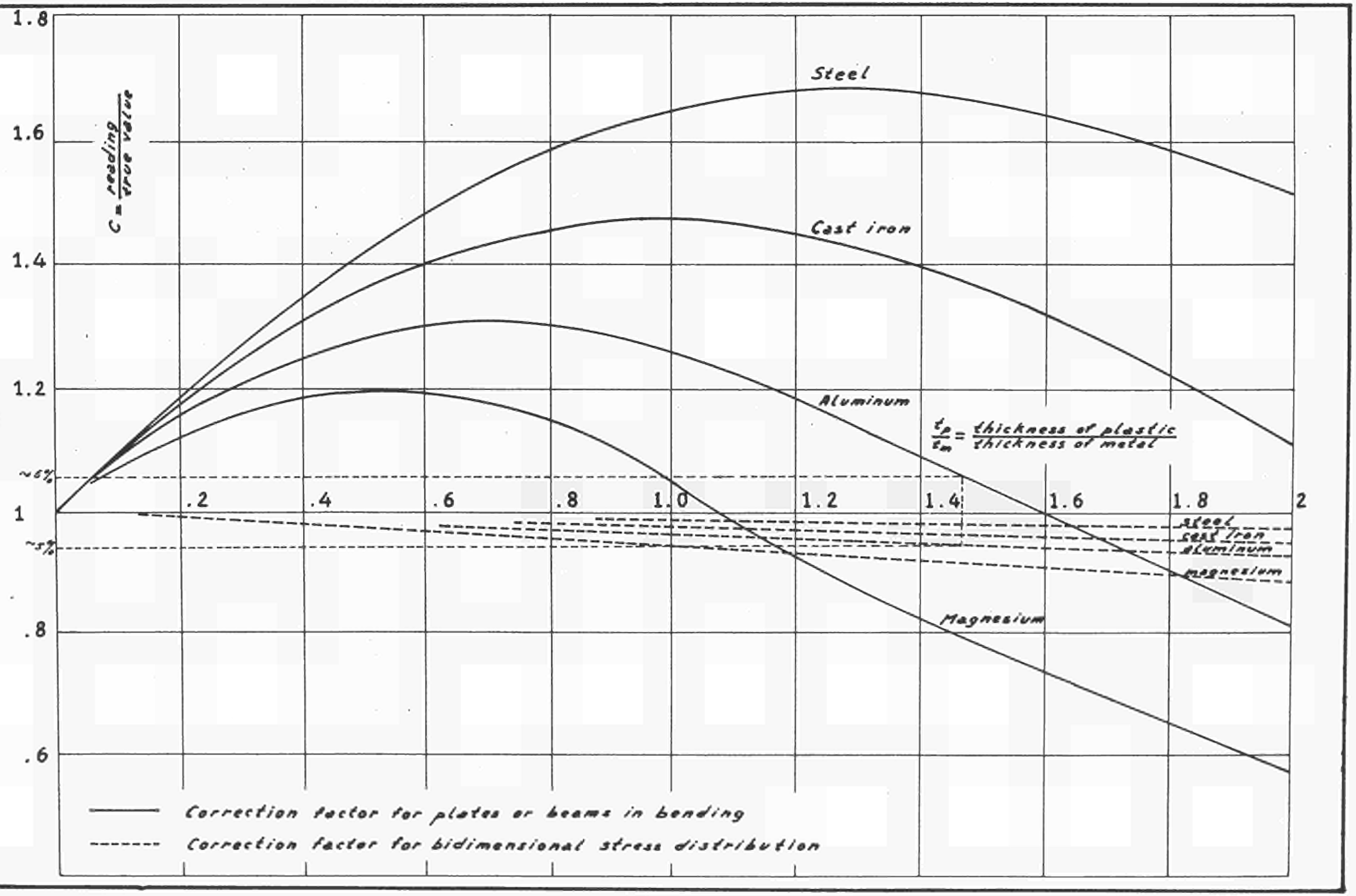

1.8
1.6
1.4
1.2
1
.8
.6
~6%
~5%
$C = \frac{reading}{true\ value}$
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2
Steel
Cast iron
Aluminum
Magnesium
$\frac{t_p}{t_m} = \frac{thickness\ of\ plastic}{thickness\ of\ metal}$
steel
cast iron
aluminum
magnesium
Correction factor for plates or beams in bending
Correction factor for bidimensional stress distribution

fig. 9

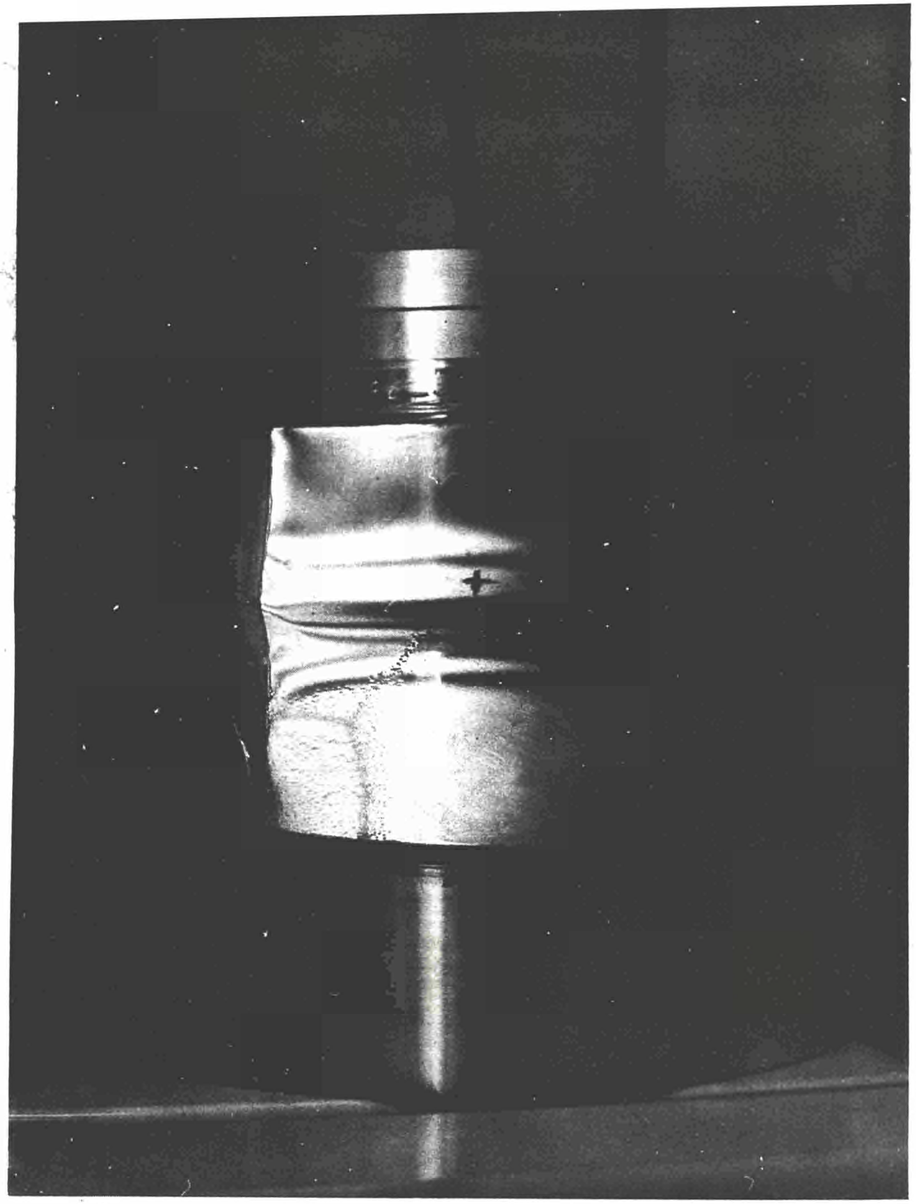


Fig. 10

STRAIN PATTERN PHOTOSTRESS

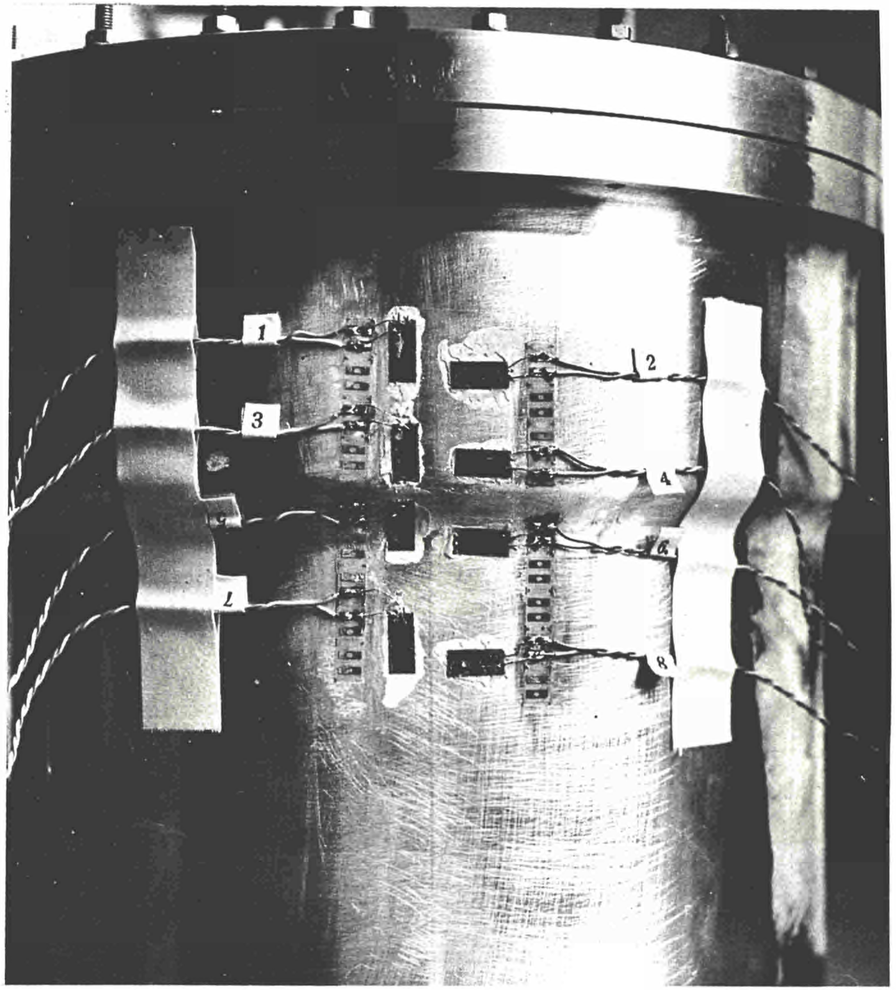


Fig. 11

STRAIN-GAUGES ON MODEL VESSEL

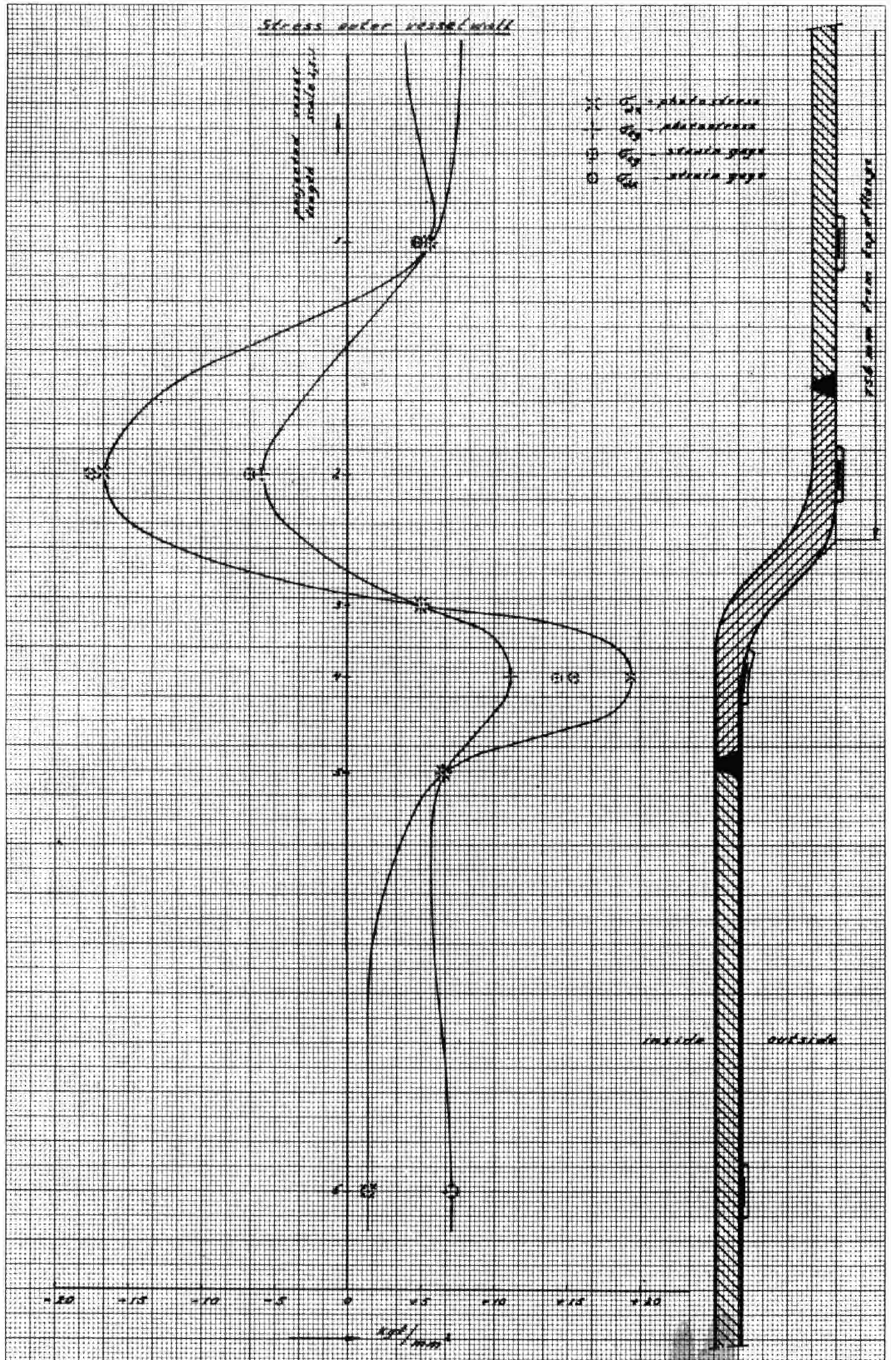
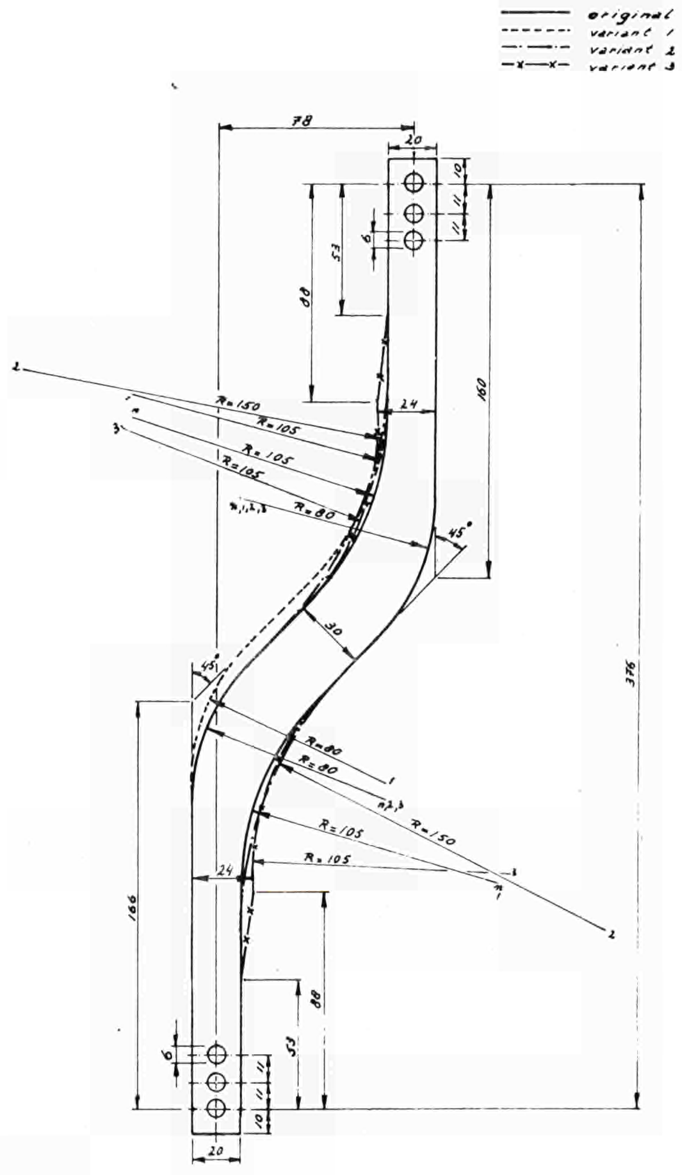


fig 12



material: araldite
scale: 1:2

fig. 13

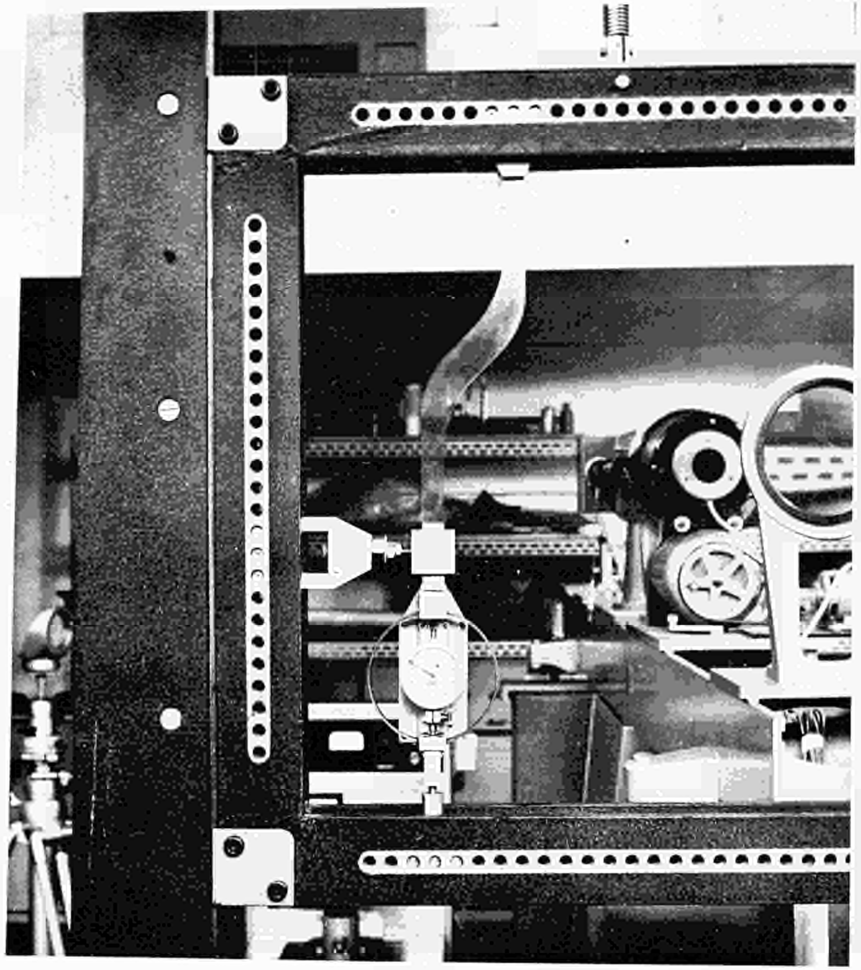


Fig. 14

TWO-DIMENSIONAL STRICTURE MODEL IN LOADING FRAME

Position of 1 direction strain gages on the exterior of the stricture

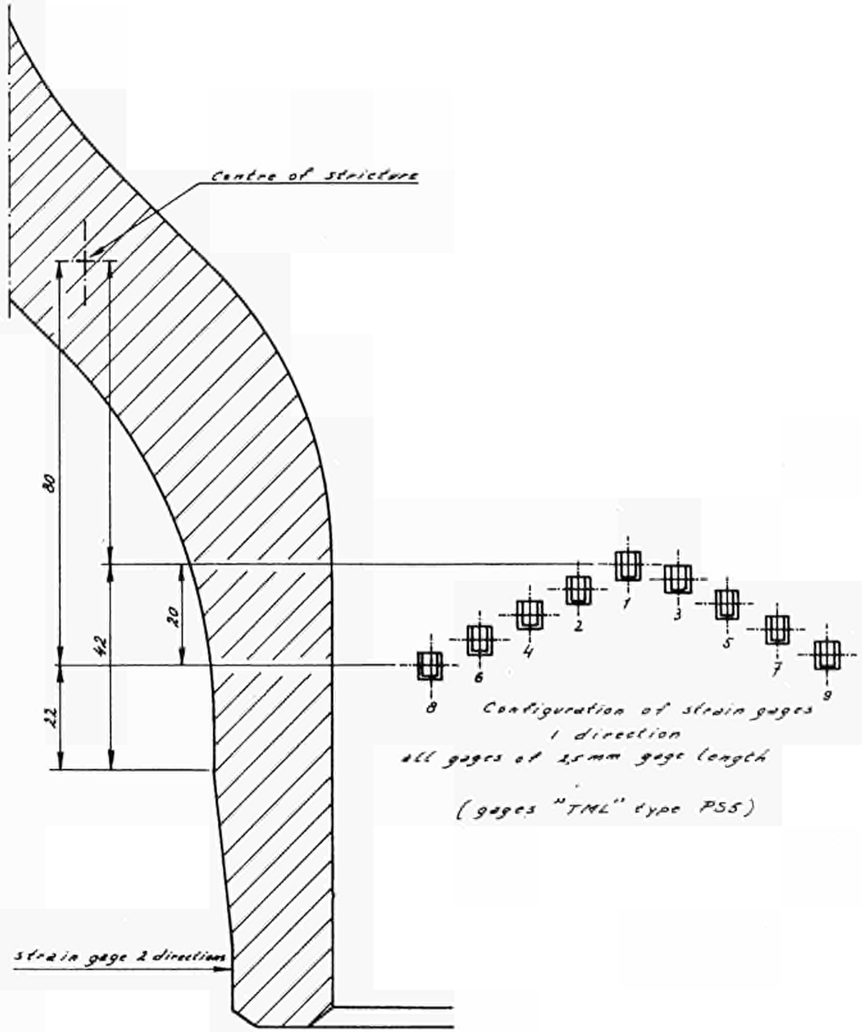


fig. 15

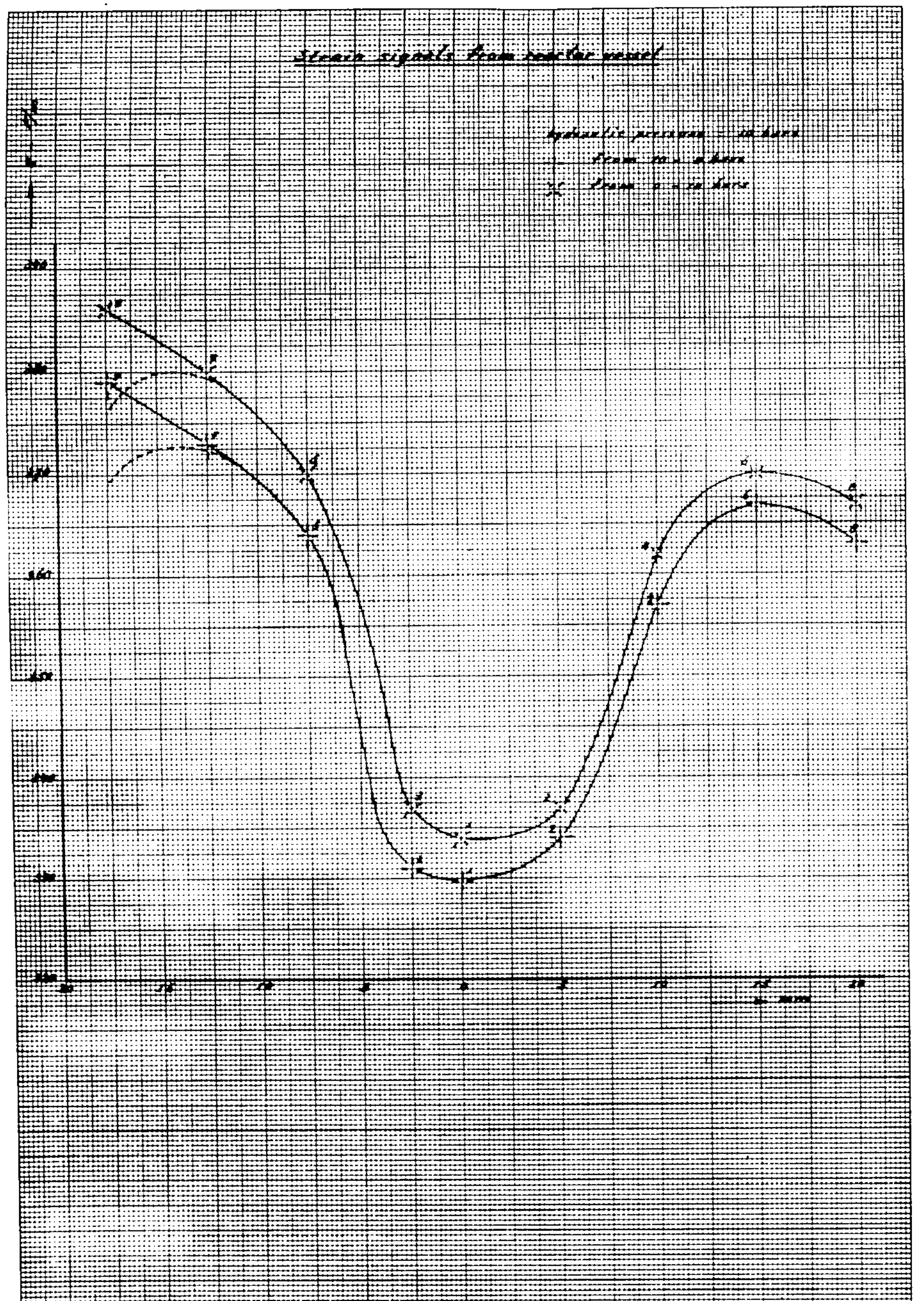
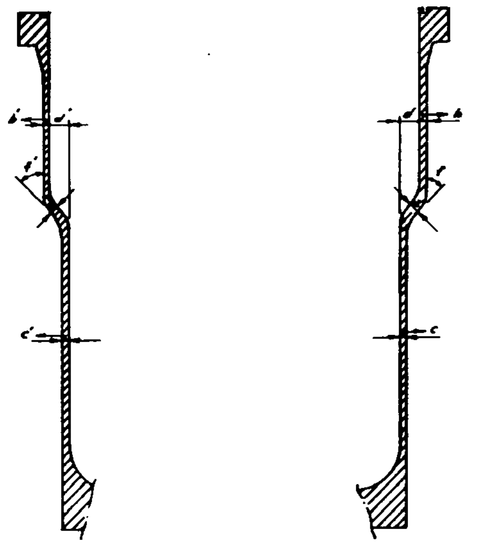


fig. 16



a' –	2,78	a –	2,84
	2,77		2,83
	2,70		2,84
b' –	1,98	b –	2,05
	1,97		2,06
	1,96		2,06
c' –	2,06	c –	1,87
	2,07		2,00
	2,07		2,00
d' –	7,10	d –	6,65
f' –	42°	f –	42°

fig. 17

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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