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Autor(en): **Scotto, F.L.**

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I-7

Triaxial State of Stress "Tiny Walled" PCPV for HTGR. Comparison with a Conventional "Thick Solution"

Etat de contrainte triaxiale dans un PCPV pour un HTGR à parois minces. Comparaison avec la solution conventionelle à parois épaisses

Multiaxialen Spannungzuständen in dem PCPV für HTGR Typ Reaktor. Vergleich zwischen die Dünn- und Dickwandigenlösungen

Dr. Ing. F. L. SCOTTO, ENEL - CPN (Nuclear Design and Construction Center) Rome, Italy

1. INTRODUCTION

In the field of the civil nuclear engineering work design stand up the prestressed concrete pressure vessels (PCPV), structures typically subjected to a triaxial state of stresses.

Considering that for the different types of "PCPV filière" a quantity of concrete of the order of 3, 000 to 20, 000 m^3 and of prestressing steel from 500 to 3, 000 ton can be involved, the economical implications arising in fitting a more or a less degree of conservatism in the design hypothesis clearly appear.

In addition, the high values of the ground basis acceleration (that for many Nuclear Plant sites is notable (Caorso, Italy $a = 0.24\,g$)) push the designers to re-examine in deeper detail the margins adopted for the analysis of such structures in order to reduce the imposing masses to be stabilized under the seismic event and, of course, the relevant additional costs.

This paper is related to the Italian contribution to such efforts that involve different research branches and laboratories.

The research is sponsored by the DSR (Research and Development Department) of ENEL (Italian Generating Electricity Board) and devised and coordinated by CPN (Nuclear Design and Construction Center) of ENEL - Rome with the cooperation of ISMES (Experimental Institute for Models and Structures) Bergamo, and CRIS (Hydraulic and Structural Research Center) of ENEL - Milan, with the aim to give a contribution to the development of more advanced and economical solutions in the topics of the Nucleothermoelectrical plants.

The PCPV that represent the objective of this research are not built in Italy at the present or envisaged in the near future, but they are considered in perspective for the high interest of the problems involved that they represent as structures typically subjected to a triaxial state of stress.

This topic requires in fact the development of the more advanced design tools and basic researches on materials, thus giving a contribution on a better understanding and approaching on the behaviour of the great family of the structures under triaxial state of stresses. For instance, remaining in the nuclear field, the containement buildings.

In this perspective, I have proposed at the 1st and 2nd Conference in Berlin on Reactor Technology (1, 2) a so-called "tiny-walled" solution of a PCPV for a high temperature gas reactor (whose thickness is not less than the limit required for a biological shielding of about 2.5 m) in which, in my opinion, the resources of the concrete triaxially stressed are better utilized that in the conventional solution, called from now on "thick solution".

In line with the topic of this Seminar and as an additional supporting contribution to the proposal, I will give in the following a comment on the design tools selected for the analysis and a comparison between the "thick" and the "thin" solutions.

As far as the general considerations and the collapse state analysis are concerned, I refer to the report that I have presented at the above-said conferences.

This comparison concerns the triaxial state of stress of both the solutions for the typical loading combinations in the working range, that is, in the so-called quasi elastic or linear elastic field of behaviour.

The same comparison was made for the local safety factors calculated on the basis of the Mohr-Caquot method envisaged by the French Code.

Some design philosophy aspects connected with the proposal are also herewith outlined.

2. DESIGNING TOOLS

The true problem for the designer of a PCPV is to define the limits of acceptability of the stress of state of the structure, once satisfactorily defined; these limits, in their turn, will affect the cost.

The stress values, as accepted in the existing codes and standards, impose the construction of oversized structures as proved by the built prototypes and as experienced in our models. In order to elapse from these limitations and better utilize the materials resources, it was necessary to dispose of adequate designing tools able to fill the gap existing in the field of the information on the behaviour of the materials adopted for PCPV in the triaxial stress state.

The first problem consisted in selecting and defining reliable tools to be used easily, rapidly and economically.

Our designings tools are the physical and the mathematical models of the structure, and the rheological model of materials.

More detailed information on these are provided in the Reports (3, 4, 5) which are to be considered an extension of this Report and which are also been presented at the Seminar.

From the complex recycling of the information provided by each of these tools, it was possible to obtain the calibration of each of them and consequently, the check on the reliability and then the quality control of the design.

Both the mathematical and the physical models become essential and complementary design means: the first, to cover the structural design phase (geometries) and the linear behaviours; the second, with the help of the first one (supplying a global information of the elastic phase) to cover the ultimate states, that is, all the non-linear (short time) aspects up to the collapse.

2.1 Physical model

As far as the physical model is concerned, we wish to point out that we should cope with relevant problems to meet the envisaged goals, that is, one model of the same material of the prototype able to provide in short time with limited costs and at the top of the representativity the larger number of information for the whole range of performances from the elastic field to the structural collapse.

These conflicting requirements have been, in my opinion, fully satisfied by our small-scale models equipped with a copper bag liner.

Just to give a feeling about these models, we can say that in nine months we have been able to design, build, and test two models at a cost of the order of 150,000 $.

2.2 Mathematical model

The finite-element method available at the present is a very satisfactory tool to be applied for designing the PCPV structures.

The real problem lies in providing the analyst with the rheological inputs of the material.

From our part, we have tried to solve this problem calibrating the mathematical model on the physical small-scale model, suitably devised for this purpose (axisymmetric model without penetrations (3)). Of course, also the physical models allow the simulation of the reality within certain limits.

The simulation of the actual prototype behaviour for a correct and safe design represent infact the principal problem to be solved. For the constructional stage, for instance, the difficulties arise in modelling the condition of non monolithicity of the structure poured in different steps and portions and along extended periods of time and seasonal variations (of the order of one year and more). This generates problems of differential ageeing for the different portions and, because of the specific dimensions under consideration, problems of shrinkage and thermal effects caused by the hydration heat which impress an indelible mark that will affect all the following behaviours. No to speak of hidden defects of fabrication and their effects on the failure mechanisms.

The problem becomes more and more complex when we would try to simulate the prestressing stage that, for technological reasons, is made in sequences necessarily not axisymmetric involving long periods of time and problems related to the definition of the real friction coefficient and its circumferential variation, obviously again not axisymmetric.

Just to give another example of the design modelling difficulties to be over-come, we know from our small-scale models that in order to obtain stable measurements we must recycle the pressure many times, that means that we need to obtain a structural assessment including for instance some frictional redistributions. Looking at the operational stages, for instance, we should know in advance the heating and cooling, pressurization and depressurization schedule, both in operating and accidental conditions, and what is more important, we should know point by point the time depending governing laws of creep for the different stress state conditions.

We must recognize that the above at now represents, let me say, a topic.

We are therefore obliged to operate a series of choices and simplifications which will enable us to utilize at better all the available calculation tools, making a general synthesis with the scope to sum-up and interconnect all the aspects of the problem, on the safe side, and in the most economic way.

Said design interconnections are going ahead for our research per steps, with the realistic aim to apply the more advanced available tools or/and to devise some new ones in the full respect of an engineeristic and, therefore, productive view of the problem.

For instance, coming back to the mathematical model, the computer programs should provide the designer with an immediate survey of the tensional and deformational state of the whole structure and relevant safety margins, point by point, and step by step.

The computer programs set up at ISMES are in this respect very efficient as it can be checked from the figures as shown in our papers obtained directly on the plotter.

These plots give an immediate sight of the critical areas to be reinforced, for instance, by appropriate steel reinforcement and, in its turn, the relevant modifications to be applied to the local stiffness and behaviour of materials whose characteristics in the triaxial stress state conditions cannot be analized as per the remaining of the structure.

Stating a design philosophy requiring a so-called elastic behaviour for all the phases of structural performance related to the operating and accidental conditions, we have found that the adoption of a linear semplified model, i. e. a constant elastic modulus E it is already more than sufficient to define in a satisfactory way the probable behaviour of the real structure (as checked on physical models).

We can say, moreover, that the results seem to be also moderately conservative.

2.3 Rheological model

Once derived from the mathematical model the structural state of stress, it is very important to perform a further calibration of this tool, taking into account the results of triaxial test on concrete samples, drawn from the physical model during the pouring stage (3).

At the ENEL laboratories of Niguarda (Milan) a basic research on the behaviour of the concrete subjected to triaxial stress (5) is under development.

In the frame of this general research, said laboratory was asked to cooperate to our research qualifying, at first, the concrete selected for the small-scale physical models (maximum size aggregate 8 mm).

The results of this first investigation has shown that this particular undersized type of conglomerate behaves under triaxial stresses like the full-scale concrete (maximum size aggregate 3 cm), especially as regards the safety aspects, thus confirming the validity of the behaviour of the small-scale models and than their reliability in reproducing the actual structural conditions.

At the present, the cooperation, at its preliminary stage, consists in the application of the advanced know-how developed by the laboratory for the evaluation of the local safety related to the local state of stress of the structure. From this evaluation it is possible to control, per spots, the validity of the safety "maps" computed on the basis of the simplified Mohr-Caquot method (cfr. fig. 5).

In turn, where possible, this information has been recycled to the small-scale models for judgements. It must be remembered that the triaxial tests on sample are carried out on cubic specimens under an uniform stress distribution state, while in the actual structure the stress distribution is variable.

The complexity of the problems involved in trying to simulate on samples the structural conditions (fairly described in the paper (5)) in order to draw "the constitutive relations" for the given material, asks for a long and very expensive experimental work.

This means that in the future we have to expect supplementary improvements in our design from this research.

3. COMPARISON BETWEEN "THICK" AND "THIN" SOLUTIONS

The following refers to a PCPV solution for high temperature Gas Reactor that will be called "thick", to which design I attended within an international Joint Group, and to my proposal of alternative solution that will be called "thin". For both the solutions, some elements of comparison are herewith given, in order to allow a judgement about the validity of said proposal that seems better utilize the resources of the concrete under triaxial state of stresses.

In the following table some costs relevant to the two solutions are compared showing the great cut-down of the costs and the relevant economical interest arising from this proposal.

	Quantity	Solution		Δ	Costs drop $
		thick	thin		
1 - Concrete					
- Volume	m^3	14, 800	5, 440	9, 360	800, 000
- Load	ton	37, 000	13, 600	23, 400	
2 - Prestressing steel	ton	2, 700	CPS 3/2 1, 000	1, 700	3, 500, 000
			CPS 3/3 1, 200	1, 500	3, 100, 000
3 - Reactor Building Volume	m^3	75, 400	57, 800	17, 600	1, 500, 000

In addition we must consider, the costs drop in: foundations, penetrations, seismic aspects etc. that can lead to total cost - drop amount of the order of 5 - 8 million dollars.

3.1 Aspects of interconnection between mathematical and physical model. Design philosophy for the elastic phase.

Fig. 1 shows the geometrical characteristics of both the solutions and of the four physical 1 : 20 (small) scale models supporting the research.

The general section across the reactor and turbine buildings shows the importance of the seismic problems to be solved.

The reference design inputs data are:

- working pressure $p_w = 40\ \mathrm{Kg/cm^2}$
- design pressure $pf_c = p_d = 44\ \mathrm{Kg/cm^2}$
- accident pressure $p_a = 48\ \mathrm{Kg/cm^2}$
- ΔT across the walls $\Delta = 20^{\circ}\mathrm{C}$

Fig. 2 shows a comparison, for the four models, with respect to the equatorial and axial deflections, as resulted from the average of symmetrical points examined.

This information, arising from the physical model, allows to perform the calibration of mathematical model and therefore autorize us to give credit to its results for the pressure range p at least between:

$$0 < p \leqslant 1.5\ p$$

This behaviour, that appears from the plot to be "quasi linear" and that is as much valid for the "tick" as for the "thin" **structures**, comes from the adopted design philosophy to have the structure "fully compressed" for a value of internal pressure:

$$pf_c = 1.1\ p_w = p_d$$

This pressure is normally considered the design pressure for Gas Reactors. As for as the light water reactors B.W. type are concerned, my opinion is that such a value $p_d = pf_c$ shall match with the pressure value corresponding to the opening of the last safety valve, that is:

$$pf_c = p_d \cong 1.25\ p_w$$

3.2 Comparison of the state of stresses in the structure for the constructional and operational phase.

Fig. 3 shows a comparison of the state of stress of structure (principal stresses) between the "thick" and "thin" solutions.

In particular, fig. 3 points out the different specific level of stress values which, in general, are higher, as we have to expect for the "thin" solutions.

On the contrary, it can be noted that both the structures show the same problems of local intensifications for the peculiar points (gussets).

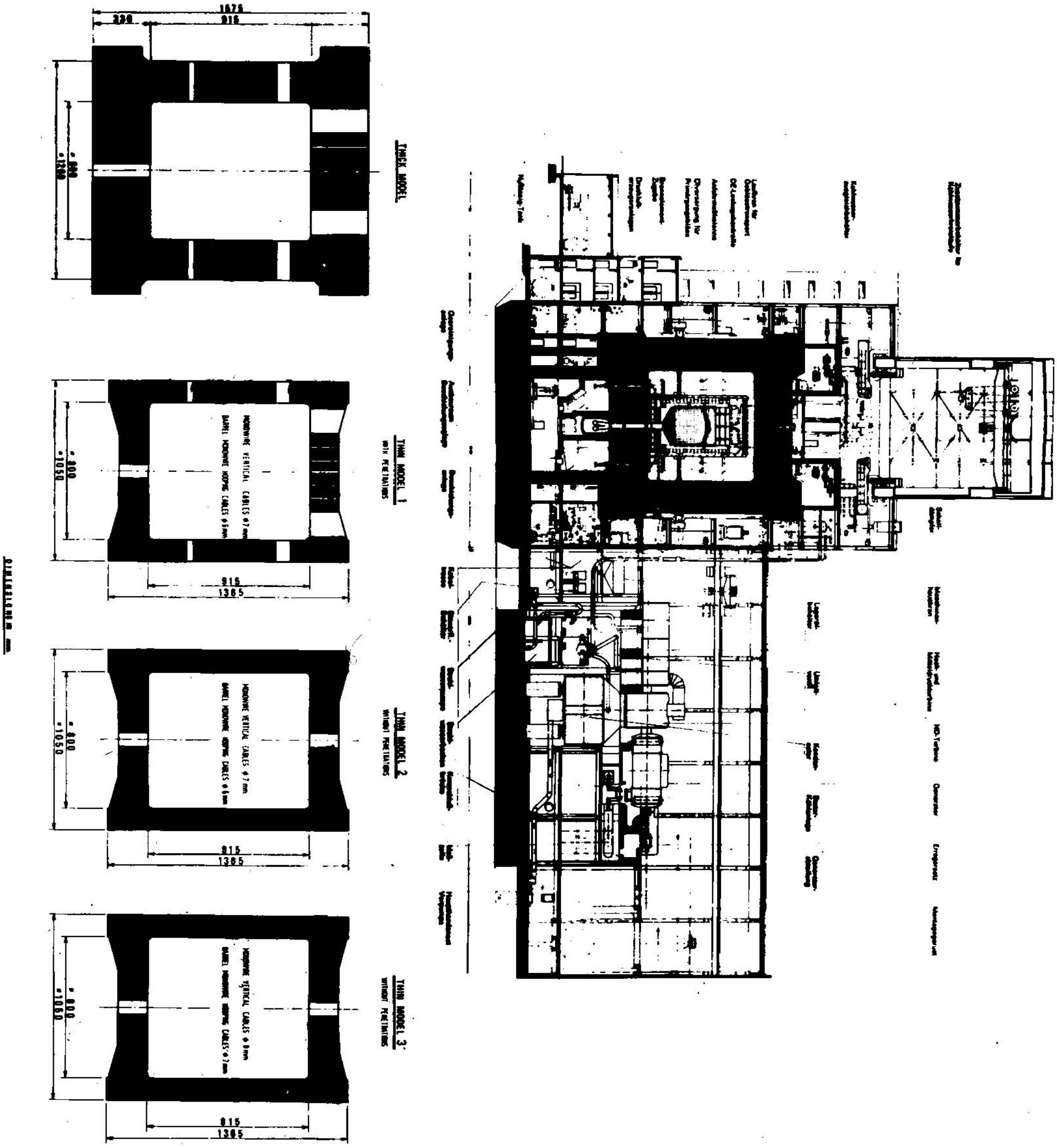
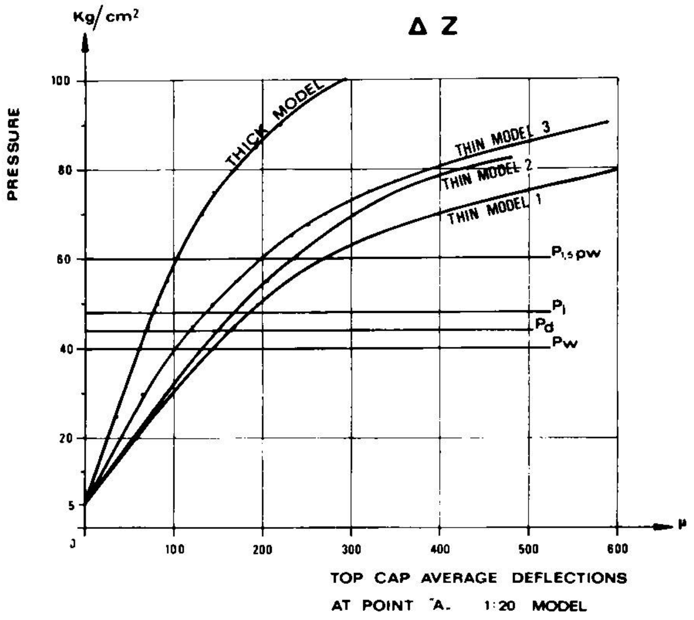


FIG. 1
Geometrical data of "thick" and "thin" solutions.
Données géométriques pour la solution épaisse et mince.
Abmessung beider Lösungen.

P.C.P.V. FOR H.T.R.



EQUIVALENT PROTOTYPE DEFLECTIONS IN μ AT WORKING PRESSURE (40 Kg/cm²)

Deflection type	THICK model	THIN model 1	THIN model 2	THIN model 3
ΔR eq. μ	1422	2252	2280	2162
ΔZ μ	1520	3280	2816	2774

P_w - working pressure 40 kg/cm²

P_d - design pressure 44 kg/cm²

P_i - upper bound pressure 48 " (incident condition)

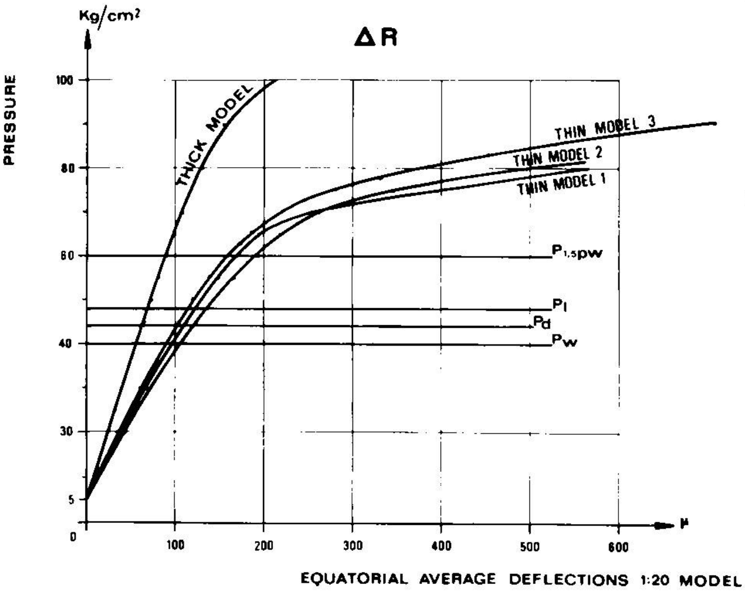
P_f - first clearly visible cracks pressure

THIN MODELS
- 1) 70 kg/cm² – (with penetrations)
- 2) 82,5 " – (without ")
- 3) 90 " – (" ")

THICK MODEL 90 "

P_r - testing reversibility limit pressure

thin 82.5 kg/cm²
thick 116



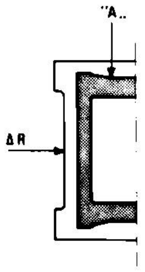


FIG. 2
Deflectionscomparison between the four 1 : 20 scale model.
Comparaisons des flèches des quatre modèles en échelle 1 : 20.
Verschiebungsvergleich zwischen den vier Modellen Massstab 1 : 20.

PRESTRESSING ONLY

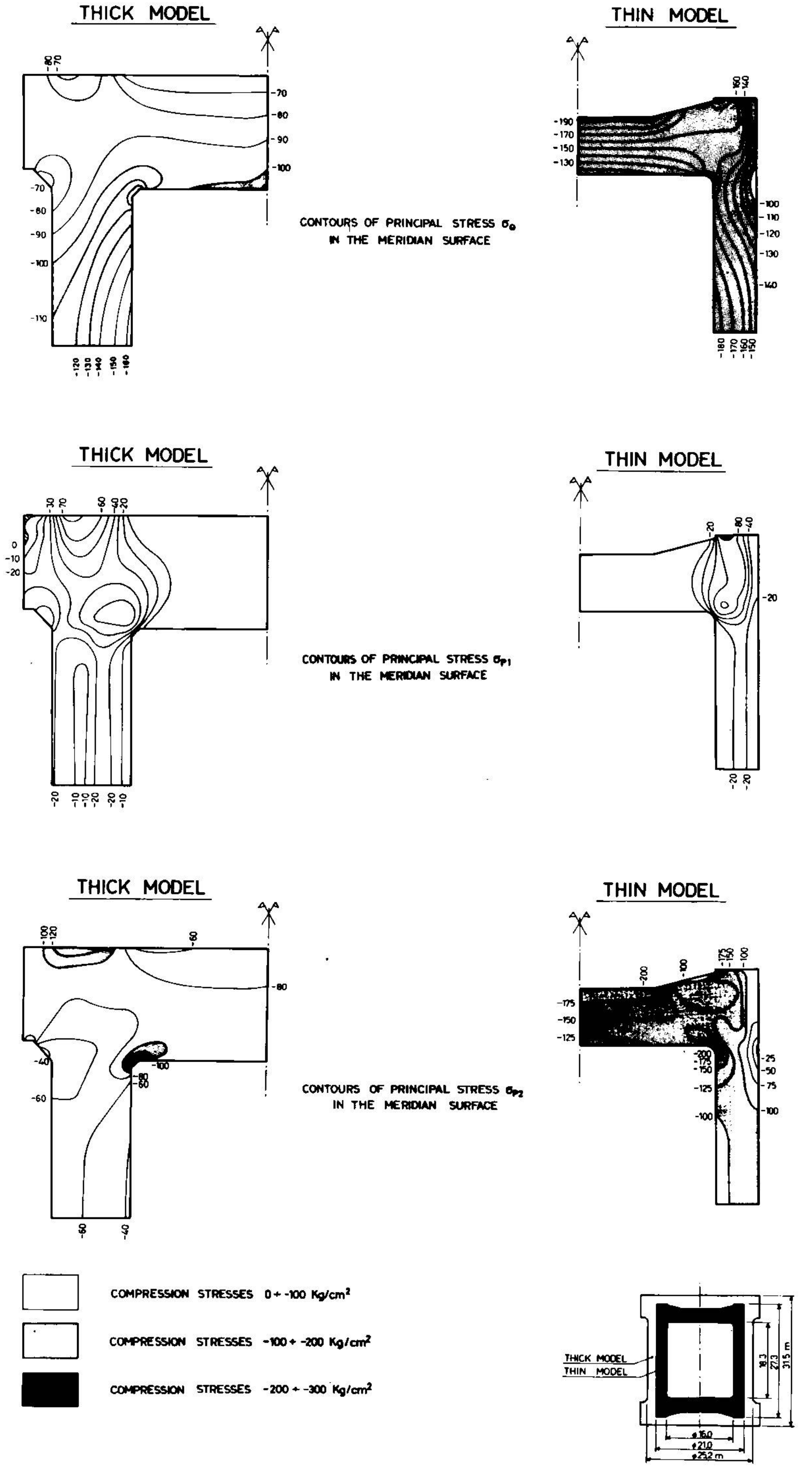


FIG. 3
Comparison between the "thick" and the "thin" solution.
Comparaisons entre la solution épaisse et mince.
Vergleich zwischen der "Dick und Dünnwandigen" Lösung.

The physical models evidenced that the concrete, also at the above-said two different levels of stress perfectly responds to the imposed stress conditions showing a perfect elastic reversibility.

Fig. 4 indicates the same comparison in the normal operating conditions that refer to an equivalent medium-term value of $\Delta t = 10^{o}C$; halved with respect to the design input in order to take into account the medium-term cut-down of thermal stress due to creep (about 1 year).

The thermal loads represent another input that is very difficult to simulate either on the physical or on the mathematical model. On the contrary their effects, are noticeable.

The heating and cooling thermal cycling that can take place during the plant life are theoretically capable even of causing in sequence, due to the creep effects, the inversion of the sign of the thermal stresses.

It is not in my knowledge whether some specific researches have been carried out to ascertain if the known creep laws can be reapplied at any time, in the sense if these laws are still valid even if the creep phenomena have developed their effect for some time, in addition also if the above said creep governing laws are applicable for every combination of the stress ratio in a triaxial state of stresses.

In order to reduce these effects and the problems associated to a correct evaluation versus time of the creep, in my opinion, it is advisable to:

- reduce the wall tickness
- preheat the structure before the pressurization (during the commissioning phase) by means of the liner water cooling system adequately switched to be a water-heating system
- never permit the cooling of the concrete structure during the shut - down conditions in order to exclude inverted thermal gradients across the walls (by means of the said preheating system).

Coming back to the comparison of the state of stresses, it appears from fig. 4 that, even if a certain difference in the specific stress values is maintened between "thick" and "thin" solutions (in the thin solution the specific values are higher), the general trend is practically the same for both structures and the differences are less large.

This is, besides, the prevaling stress condition for more than 90% of structural life, that the physical model warrants to be perfectly stable and satisfactory for both the solutions.

3.3 Safety factors.

Fig. 5 shows the map of the safety factors in the structure defined following the Mohr-Caquot method (3).

From the comparison, it clearly appears that both the "thick"

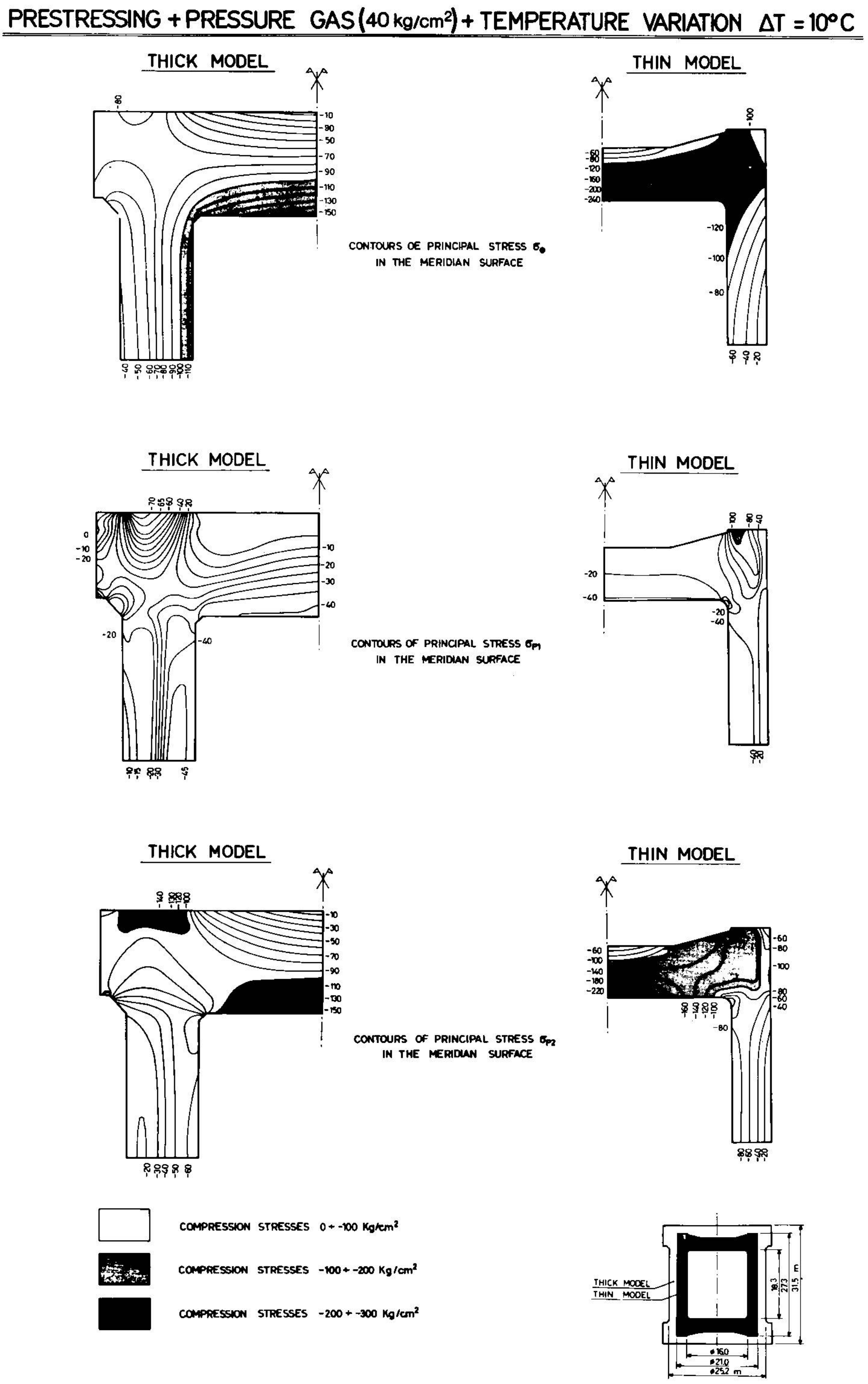
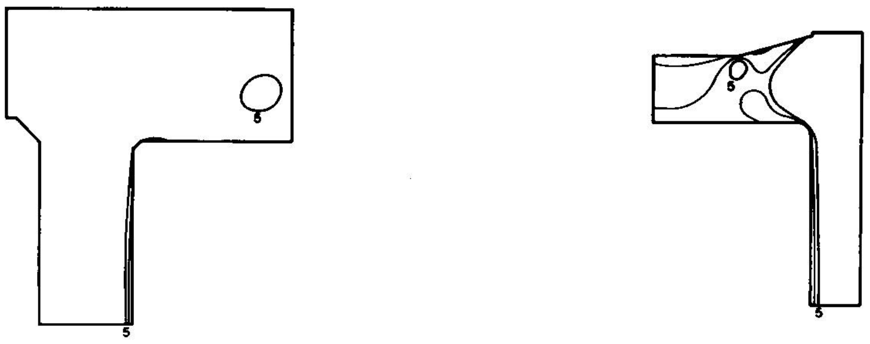


FIG. 4
Comparison between the "thick" and the "thin" solution.
Comparaisons entre la solution épaisse et mince.
Vergleich der "Dick und Dünnwandigen" Lösung.

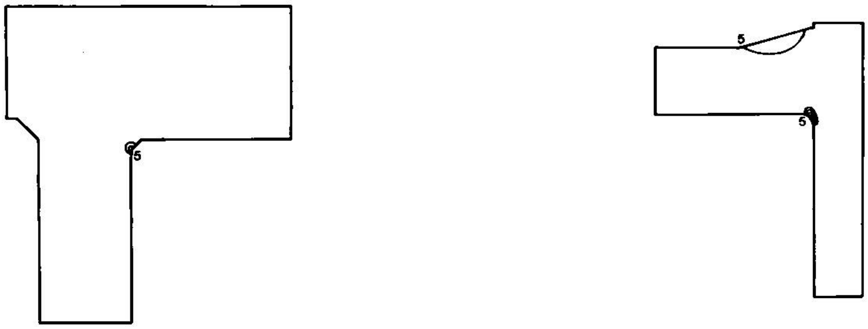
PRESTRESSING ONLY

THICK MODEL

THIN MODEL

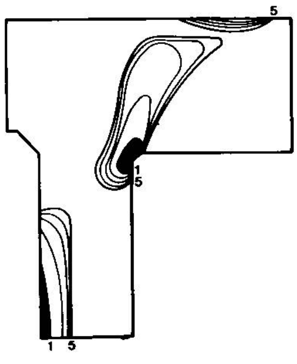


PRESTRESSING + GAS PRESSURE (40 kg/cm²) + TEMPERATURE VARIATION DT = 10°C



PRESTRESSING + GAS PRESSURE (60 Kg/cm²) + TEMPERATURE VARIATION DT = 10°C

PRESTRESSING + GAS PRESSURE (77 kg/cm²) + TEMPERATURE VARIATION DT = 10°C



■ SAFETY FACTOR < 1

SAFETY FACTORS CALCULATED

BY MOHR CAQUOT METHOD

FIG. 5
Comparison between the "thick" and the "thin" solution.
Comparaisons entre la solution épaisse et mince.
Vergleich der "Dick und Dünnwandigen" Lösung.

and the "thin" solutions are provided with large safety margins in the operating conditions, practically the same margins in the barrel for the "prestressing only" condition and a margin, more reduced but always perfectly acceptable, for the cap slabs for the "thin solution" case.

Taking into account what is evidenced in fig. 7, that both the physical model presents cracks in the external equatorial cortical area of the barrel for pressure values that are in the range of 70 - 90 Kg/cm^2 for the "thin" solution and 90 Kg/cm^2 for the "thick" solution, and the possibility, shown in fig. 2, to accept and extrapolate the elastic behaviour results for pressure of the order of 1.5 times the working pressure and over, we have shown in fig. 5 also the plotter outputs of the safety factors according to the following pressure values:

- thin structure $p_c = 1.5\ p_w = 60\ Kg/cm^2$
- thick structure $p_c = 90/70 \cdot 1.5\ p_w = 77\ Kg/cm^2$

These values were selected in order to make comparable the two solutions considering the behaviour of the physical model.

Taking into account both the plotted values of the fig. 5 and fig. 6, we can notice that:

- the barrel crack pattern in the equatorial area is, topographically speaking, denounced fairly well and, as far as the specific local values are concerned, in a conservative way;
- the "tick" structure is provided with larger margins than the "thin" one, but the relative difference is modest;
- the Mohr-Caquot method is conservative and, at any rate, adequate.

It must be specified that the above-said results refer to the work developed until 1973.

We are now carrying out our safety analysis on the basis of the results acquired from the rheological model and on more advanced methods proposed in the literature which consider also the principal intermediate stress (3).

From the first results in our hands, this check analysis shows that the safety conditions, in the critical areas, are improved (the dimension of the critical areas is restricted and safety factors improve). We consider critical areas those where the safety factor is less than 1.

Moreover, the behaviour checked on physical models is better than the calculated one, in that, the margins in the models look higher.

This is due to the fact that in the reality a stress redistribution occurs, in the sense that a stress migration arises from the critical plastic overstressed areas towards to those (largely predominant in this phase $p \geqslant 1.5\ p_w$) behaving in a linearly elastic way.

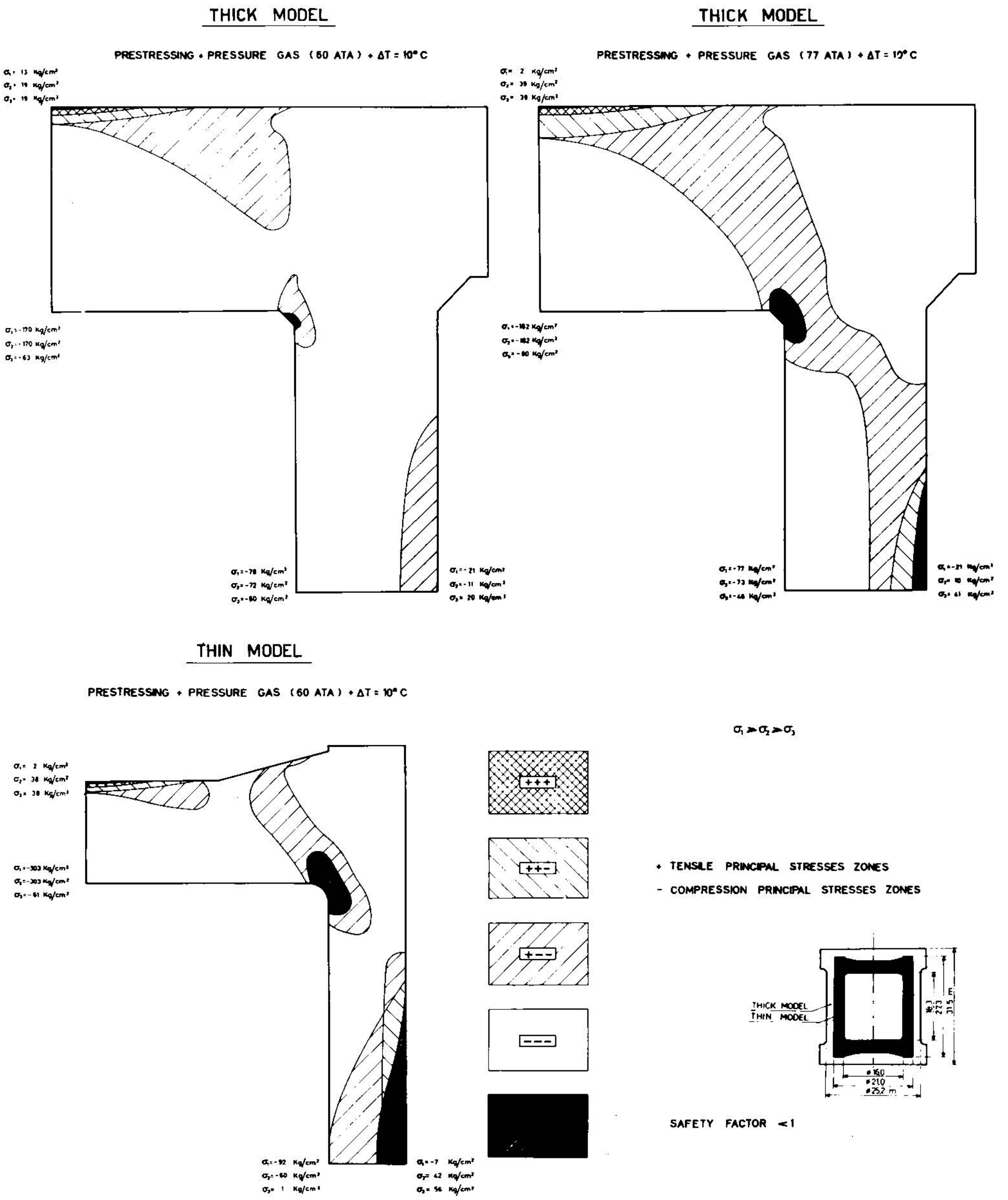
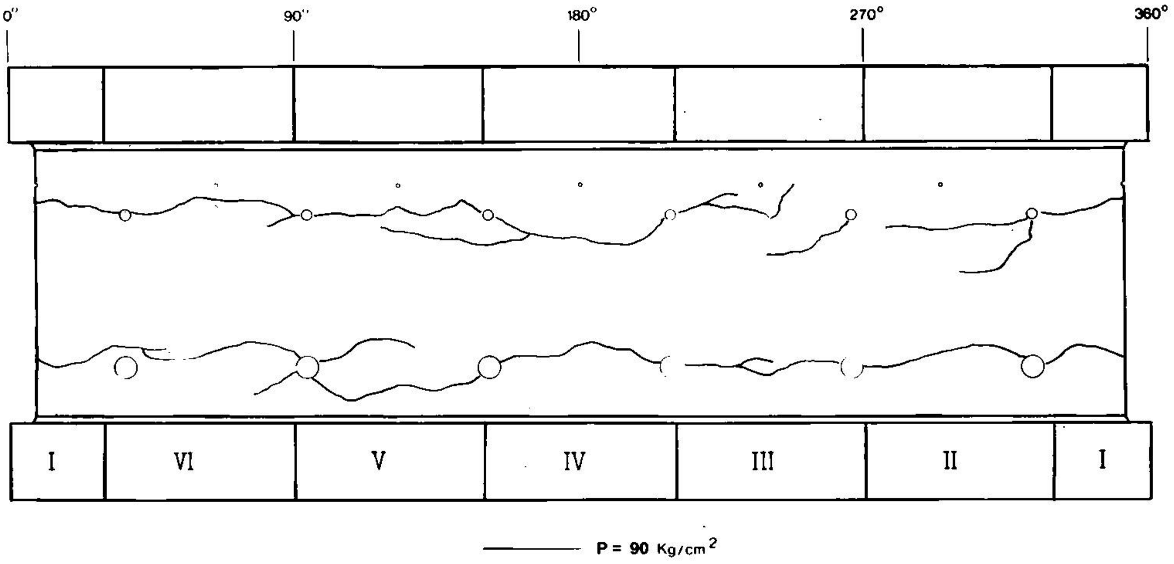


FIG. 6
Comparison between the "thick" and the "thin" solution.
Comparaisons entre la solution épaisse et mince.
Vergleich der "Dick und Dünnwandigen" Lösung.

FIRST CLEARLY VISIBLE CRACKS

THICK MODEL

external surface



THIN MODEL

external surface

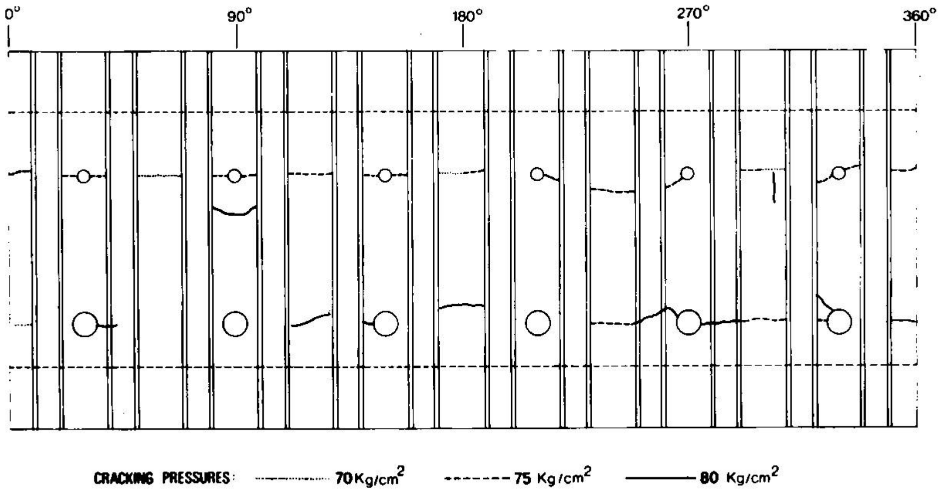


FIG. 7
Comparison between the "thick" and the "thin" solution.
Comparaisons entre la solution épaisse et mince.
Vergleich der "Dick und Dünnwandigen" Lösung.

Very significant in this respect is the behaviour of the cap slabs in the ultimate conditions (as checked on our models) where we assist to the building up of an inverted compressed resistant dome for subsequent partializations per layers (onion type), in the critical plastic tensile areas without impairing the structural integrity.

4. FINAL CONSIDERATIONS

From this necessarily synthetic survey we can, in my opinion, draw the following considerations:

- a problem of a "thick" or a "thin" solution does not exist;
- for a given structure only one design, reliable and satisfactory under all respects. can be provided.

The first point to be considered carefully for an economical viewing of the problem is to try to avoid the superposition of the degrees of conservatism coming from the different technical and safety choices. At first, the design philosophy, shall be stated not only on the basis of a pondered knowledge of all the operating and accidental conditions and their relevant degree of probability, but it must be perfectly acquainted with the structural behaviour so to avoid to ask to the designer unfeasible requirements. One typical example of this is, for instance, offered by the permissible collapse safety factor. This factor is normally stated around 2-2.5 while in the reality it results automatically, at least, higher than 4. For the "thin" solution we were not able to reduce it to less than 3. But the meaningless of this requirements must be sought in the wording "collapse". If we state that for "safety factor" we intend to refer to the value of the ratio between the structural collapse pressure and the working pressure, we do not interpret correctly the safety problem. Indeed we know from our models, on which we experienced the true structural collapse of cables or concrete that, by the point of view of the safety we have to consider a lower pressure level, that is, that level at which the liner integrity (tightness) is lost.

The corresponding pressure level is located in the pressure range of the big deformations (big structural cracks). The theoretical lower bound of this range, in turn, corresponds to the pressure level at which at first the first wire of the prestressing system overcomes its yield limits. Moreover, the true collapse limits are a function of the overpressurization speed that, from our experience, plays a fundamental role in an anticipation of this limit.

When we refer to the PCPV for boiling water reactors, in my opinion, this safety factor can lose at all any significance in case we would size adequately the prestressing cable system.

This sizing must be capable to withstand, within the elastic limits and adequate margins, the pressure levels corresponding to the relief of the safety valves system or/and, because of the high involved cost, justifying the reasons of such choice, to the higher pressure values, like for instance the pressure at which the leakage through the top lid coupling system begins. Another important point that involves directly the design philosophy of the structure is the problem of the gas permeation through the concrete vessel walls due to accidental liner leakages.

This item can ask for a terrible amount of prestressing and cable layout problems and in my opinion must be, as soon as possible solved and clarified. The more logical proposal is to equip the liner of an efficient suitable gas purging system. At the present, for instance, a triangular distribution of gas pressure across the walls (or rectangular) is envisaged by designers.

Our research has not taken into consideration this kind of phenomena up to now: we intend to consider it in the future. This problem can in fact modify in a drastic way the design and the safety aspects of the structures triaxially stressed.

As far as the permissible stress limits in the structure are concerned, I believe that we shall be prudent and make use of our good engineering feeling considering that this matter is not yet fully explored. In fact, both the so-called "thick" and "thin" structures, present limited regions that would be off-limits under a firm application of the codes. These critical situations are evidenced by the calculation tools, but the physical models prove that these critical areas do not affect at all the overall safety of the structure and, least of all, when a suitable reinforcement is envisaged, thus providing us of the required judgement to accept such conditions.

These considerations must be particularly applied to the cap slab regions grouted of hundreds of penetrations, for which the conventional tools and rules cannot be applied and only the experiments can give us an answer.

5. CONCLUSIONS

Well aware of the present limits of our research work, at any rate, I believe that the results acquired have given evidence to the fact that in the PCPV structures, the strenght reserve, intrinsic of the triaxial state of stresses, can be better utilized. Therefore, I believe that the research work has accomplished our primary objective that was to give a contribution in promoting important cost reductions in the field of nuclear energy and more advanced design methods.

Along these necessarily fragmentary and synthetic paper descriptions, I have tried to put in evidence the importance of defining a suitable design philosophy adequate and aware of the structural behaviour modes.

At the present, our research is oriented towards the PCPV for Boiling Water Reactors, and we will try to apply our experience and improve our techniques on this subject for the future.

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SUMMARY

The paper is related to a proposal made by the Author at the 1st and 2nd Conferences on Reactor Technology held in Berlin concerning a tiny walled solution of a PCPV for HTGR. With this solution, on the opinion of the Author, the resources of concrete in the triaxial state of stress is better utilized than with the conventional "thick" solution normally adopted.

A comment on the design tools selected for the analysis and a comparison among the triaxial state of stress and relevant punctual safety factors of the "thick" and the "thin" solutions are presented in order to give the possibility to judge about the reliability of the proposed "tiny-walled" solution.

RESUME

Dans ce rapport on décrit une proposition faite par l' Auteur à la 1^{e} et 2^{e} Conférence sur la technologie des Réacteurs Nucléaires tenue à Berlin concernante une solution à parois minces pour un PCPV d' une filière HTGR. Avec cette solution, à l' opinion de l' Auteur, les resources du béton dans l' état de contrainte triaxiale sont mieux utilisées qu'avec la solution conventionnelle à parois épaisses normalement adoptée.

Un commentaire sur les instruments de projet adoptés pour la analyse et une comparaison établie entre l' état d' effort triaxial et les relatifs coéfficients de sécurité de la solution à parois minces et de celle à parois épaisses sont soumises pour donner la possibilité de juger la fiabilité de la solution proposée.

ZUSAMMENFASSUNG

In diesem Bericht illustriert man einen Vorschlag schon in der ersten und, zweiten Konferenz über die Reaktortechnologie in Berlin von dem Verfasser gemacht. Der Vorschlag betrifft eine Dünnwandigenlösung eines PCPV für HTGR Typ Reaktor. Nach dem Verfasser, ist der Beton in den zu multiaxialen Spannungszustanden untergezogenen Strukturen besser als in Dickwandigenlösung nutzbar gemacht.

Der Beitrag behandelt die Berechnungtechniken fur die Analysen und beschriebt einen Vergleich zwischen Dünn- und Dickwandigenlösung unter multiaxialen Spannungzuständen und die bezuglichen Sicherheitfaktoren.