

MAIN ASPECTS OF THE DESIGN OF A SUPPORT STRUCTURE OF A LMFBR WITH PARTICULAR REFERENCE TO THE EXPLOSIVE ACCIDENT CONSEQUENCES

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SUMMARY

The aim of this paper is a review of the main aspects of the design of a support structure of a LMFBR tank, with particular reference to the analysis of the non-linear dynamic behaviour of the structure in the plastic range under the effect of an explosive accident within the tank. The structure is composed by a L-shaped flange, which supports the tank, connected by means of nine square beams to a rigid box-type ring, fixed to the concrete. The plug of the tank is connected to the L-shaped flange by means of a group of SS bars.

The analysis of the loads acting on the structure, including seismic loads but excluding the explosive accident, has been carried out on an elastic basis and on a beam model. An integrated computer programs procedure, which presents as general static solutor SAP IV code, has been used. The procedure allows not only the solution of the structural problem but also assesses the compliance of all the structural components to the requirements of ASME code for a linear type support for all the operating conditions.

The beam model analysis is completed with 2D and 3D F.E.M. analyses, carried out in order to control either the accuracy of the beam scheme used for some structure components, as L-shaped flange and the box-type ring, either for the local analysis of complex structure components, as 3D solid connection of the square beams to the ring fixed to the concrete.

The non-linear dynamic analysis of the explosive accident has been carried out on a lumped mass model, with elastic-plastic elements which simulate main components of the support structure and tank. The impulsive load connected to the explosive accident has been modelled (on the basis of extensive comparative studies carried out) as two triangular pressure impulses acting on the plug and on the bottom of the tank. The time phase of such impulses has been the object of a parametric evaluation. The dynamic transient on the support structure during and after the explosive accident for each couple of pressure impulses has been analyzed by means of modified version of the NON SAP code running on a CDC 7600 computer. A large amount of results, which describe displacements, velocities and accelerations of the plug, of the tank, and of the support structure, together with the forces and stresses acting on the main structural components are presented and discussed, with particular reference to the influence of the various parameters involved in the analysis. The global non-linear elastic-plastic lumped mass model has been completed with 2D and 3D elastic-plastic analyses carried out, on the basis of the results obtained for the global model, for the main structural components. In the paper results of a 2D isoparametric variable node f.e. dynamic elastic-plastic analysis, based on Von Mises yield condition with isotropic hardening, are presented and discussed for the L-shaped flange with particular emphasis to the propagation in the flange of the plastic deformations.

1. Introduction

The aim of this paper is a review of the main aspects of the design of a particular support structure of a LMFBR tank.

The support structure is a part of the PEC project, owned by CNEN-DRV and designed by NIRA; it will be manufactured by CMI.

Particular emphasis has been given to the analysis of the non linear dynamic behaviour of the structure in the plastic field under the effect of an explosive accident within the tank (HCDA) since this accident, due to the large amount of potential mechanical energy released, is strongly influent on the design of the structure [1].

The analysis of the other loads acting on the support structure including seismic loads has been performed on an elastic basis. In order to assess the compliance of all the structural components to the requirements of the ASME code [2] for a linear type support, an integrated computer programs procedure, which uses SAP IV code [3] as general static and dynamic solutor, has been extensively used.

2. General description of the support structure

The support structure at the up to day stage of the design (fig.1) is composed by a L shape flange, on which the tank of the LMFBR is supported, and by nine square beams, which connect the flange to a rigid box type ring, fixed to the concrete.

The plug of the tank is connected to the L shape flange by means of a group of 36 stainless steel bars. The conceptual design of the structure has been carried out on the basis of the applied loads, in particular the explosive accident within the tank (HCDA), and of the analytical procedures which are described in the companion paper [1].

The basic resistant members of the support structure are the nine square beams which connect the L flange to the box type ring; due to the relatively low stiffness presented by the L flange, these members have been analyzed as short cantilevers; a very large numbers of section types have been analyzed and compared, by means of fast but comprehensive analytical procedures [1] and finally a square section was selected.

In order to assess the compliance of all the structural components to the ASME code requirements, the structure has been considered as a "linear type" support and ASME III NF, ASME III NA App. XVII App. F have been used.

Moreover a large amount of 2D and 3D F.E.M. analyses have been carried out in order to control either the beam scheme used for some structural components, as the L shape flange and the box type ring, and the local distribution of the stresses in complex structural components, e.g. the 3D connection of the square beams to the ring fixed to the concrete.

The need of transporting the support structure from the manufacture shop to the installation site, has forced the designer to introduce some mechanical attachments, which have required a very careful evaluation in order to assure not only the integrity of the structure under the action of the analyzed loads but also the correct installation at the reactor site.

In the final stage of the design a very complex model based on 3D isoparametric elements will be analyzed by means of a modified version of NON SAP code [5] in order to determine the linear and non linear behaviour of the structure under the action of all the loads, including the HCDA.

Here the integrated computer program procedure necessary to comply with the requirements of the ASME code will be briefly reviewed and some particular results, related to the local analyses and to the evaluation of the non linear response of the structure to the HCDA, will be presented and discussed.

3. Integrated computer programs procedure

The flow chart of the integrated computer program is depicted in tab. 1.

The SAP IV code is the general static solutor; the results of each calculation run in terms of displacements and end forces are stored on tape. The GECS code [6] on the basis of the results of the SAP IV generates two files in terms of end forces and element lengths; the first one is related only to select families of members, characterized by the same inertial and material properties and by maximum values of the end forces and lengths, the second one is related to all the members.

The first file is used for a "quick" verification, the failure of which automatically forces the choice of the second file.

Program TETRA [7], on the basis of the results of GECS code and of cards read related to the properties of the sections, reduces the end forces in stresses and generates two files of the same type as GECS code.

The ANATRA [8] code controls the compliance of the calculated stresses to the requirements of ASME code.

At the up to day stage of the procedure three different families of calculation runs, each up to 30 loading cases, may be analyzed.

Choice between successful and unsuccessful runs is possible.

The loading cases are combined as required by the design specifications and on the basis of allowable stresses for each type of loading condition (design, normal, upset, emergency and faulted) the compliance to the ASME code requirements is controlled.

In tab. 1 a typical output of TETRA code is presented.

4. Non linear elastic-plastic analyses

The impulsive loading due to the HCDA in the tank of the reactor is characterized, as described in the companion paper [1], by very large forces developed in very short time. Then it is impossible to absorb the effects of the HCDA with responses in the elastic field; the only way of absorbing the released energy is to allow a plastic consequently large deformation of the support structure. In particular upwards-forces acting on the plug of the tank will be absorbed by the plastic elongation of 36 stainless steel bars, while downwards forces due to the tank supported on the L shape flange will be absorbed by plastic deformation of the square beams.

The analysis of the behaviour of the support structure during and after the HCDA has been performed in the time domain by means of step by step integration of the non linear equation of the motion. This has required the solution of the main following problems.

- simple characterization of the impulse and choice of the time to which to extend the computation
- characterization of mass and stiffness distribution of the support structure by means of a simple but realistic model
- choice of a reliable and quick non linear code in order to performe time integration without prohibitive CPU computer times.

For the first point [1] extensive analyses, carried out by means of NON SAP code [4] have produced substantially equivalent results either by characterizing the time histories of the impulsive load due to HCDA as from experimental registrations either as a somewhat regularized impulse .

The structure natural period is much larger than the impulse duration; then it is obvious that the actual shape of the impulse is not very important on the determination of the structural response but the only parameters necessary are the total momentum and duration of the impulse. For all these reasons in the calculations performed a ITSI (idealized triangular shape impulse) has been used [1] .

The analyses carried out with CAT code [9] for the solution of a one degree of freedom non linear system have shown that a total integration time of 20 times the impulse duration is sufficient for a comprehensive analysis of the transient after the HCDA.

For the characterization of the stiffness distribution of the support structure the basic resistant members, i.e. square beams, have been analyzed in the plastic field by means of an "ad hoc" code named CARPA [1], [10] and a formulation of the non linear stiffness has been obtained. The effect of L shape flange, analyzed either in the elastic either in the plastic field, as it will be shown, and of the box type ring has been

taken into account.

The S.S. bars have been simulated as elastoplastic members . For the mass distribution , due to the typology of the "short" impulsive loading applied and following "slow" response of the system, only global masses need to be simulated and a lumped mass scheme has been found realistic. For the integration of the equation of the motion NON SAP code has been chosen ; the need of simulating elastic-plastic materials has forced the designer to modify to some extent the original version of the code [5]; moreover in order to minimize the CPU computer time a new version running on the CDC 7600 of the CINECA at Bologna has been used rather than the standard version running on the CDC 6600, which has a speed roughly four times lower [4].

The model shown in fig. 2 has been supposed realistic and used for the analyses of the response of the support structure during and after the HCDA.

In the fig. 2 member I models the support structure and presents a non linear elastic-plastic formulation, with Drucker Prager kinematic hardening.

Member II models the tank: two different material formulation have been used. The first elastic, simulates a rigid connection (up and down) between tank and L shape flange, the second, non linear elastic, with resistance only for traction forces, simulates a simple support (down) of the tank on the L shape flange.

Member III simulates the connection members between S.S. bars and L shape flange and are linear elastic.

Member IV simulates S.S. bars and presents an elastic plastic formulation with Drucker Prager Kinematic hardening for the material.

M1 is the mass of the tank and M2 is the mass of the plug. The ITSI is applied upwards to the plug and downwards to the tank; the influence of the time difference between the two ITSI has been analyzed parametrically.

An updated Lagrangian Formulation with equilibrium iterations has been used in the solution of the equations in all the performed calculations.

Typical time histories in terms of displacements of the plug and forces absorbed by the S.S. bars are shown in fig. 3 and fig. 4.

In fig. 5 the maximum displacement of the plug after the HCDA is shown as function of the time difference between the two ITSI, while in fig. 6 maximum force on the S.S. bars is presented.

In fig. 7 the maximum displacement of the support structure at level of the L shape flange during and after the HCDA is shown as a function of the time difference between the two ITSI, while in fig. 8 and fig. 9 maximum up and down forces absorbed by the square beams are presented.

As previously mentioned in the final stage of the design the behaviour of the support stru

cture will be analyzed also by means of a 3D model and of a modified version of NONSAP code, actually under test, in order to check the results obtained with the described model. In order to investigate the influence of the behaviour in the plastic field of the L shape flange on the absorption of energy as plastic deformation, an axisymmetric model of the L flange has been extensively analyzed.

Elastoplastic formulation with Von Mises isotropic hardening has been assumed for the material and total lagrangian formulation with equilibrium iterations has been used in the solution of the problem.

In fig. 10 the rotation of the thinner flange and the moment of the elements which connect the S.S. bars to the L flange are presented as function of the moment due to the square beams. In figs.11 spatial distribution of the plastic zone is plotted as function of the applied moment.

In fig. 12 the radial displacement, rotation of the thinner flange and rotation at level of the elements which connect the S.S. bars to the flange are presented as a function of the radial forces. due to the square beams.

In figs.13 spatial distribution of the plastic zone is plotted as function of the applied radial force.

5. Conclusion

The main aspects of the design of a particular support structure of a LMFBR have been briefly described and reviewed with particular reference to the response of the structure under the impulsive loads due to the HCDA in the tank.

Some significant results obtained in terms of response of the structural components during and after the HCDA and 2D, 3D elastic and elastic-plastic stress analyses have been presented and discussed.

The compliance of the structural components to the requirements of the ASME code has been achieved by means of an integrated computer program procedure, which has been briefly discussed.

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- [2] ASME III - Nuclear Components - Ed. 1974.
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- [4] K.J. Bathe, E.L. Wilson, R.H. Iding - NON SAP, a structural analysis program for static and dynamic response of non linear systems - Report UCSESM 74-3.
- [5] V. Giuliano - " A modified version of NON SAP code". SAIGE Technical note.
- [6] "GEGCS" - Theoretical and user manual - SAIGE Technical note.
- [7] "TETRA"- Theoretical and user manual - SAIGE Technical note.
- [8] "ANATRA" Theoretical and user manual - SAIGE Technical note.
- [9] "CAT" - Theoretical and user manual - SAIGE Technical note.
- [10] "CARPA"- Theoretical and user manual - SAIGE Technical note.

 * - SAISE-S.P.A. - *
 * PROGRAMMA *
 * TETRA *

TABLE 1

--- ANFLLO A L -CASO A ---DATA 28/10/76 --- VPAG 5

CARATTERISTICHE SOLLECITAZIONF TRAVI (TON/CM)

TRAVE	F1	F2	F3	M1	M2	M3
104	-414.00	-3.00	1.00	-39.00	36290.00	2592.00
111	-373.00	151.00	-153.00	10040.00	27520.00	-4752.00
121	-382.00	125.00	-161.00	8882.00	27280.00	-2782.00
111	-373.00	151.00	-153.00	10040.00	27520.00	-4752.00
104	-414.00	-3.00	1.00	-39.00	36290.00	2592.00
111	-373.00	151.00	-153.00	10040.00	27520.00	-4752.00

TENSIONI (TON/CM2)

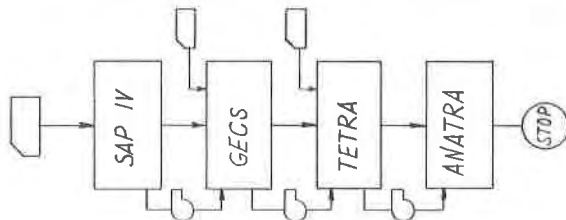
TRAVE	S1	T2	T3	TT	S2	S3
104	-.27	-.00	.00	-.00	1.95	.56
111	-.24	.16	-.25	1.01	1.49	-1.02
121	-.25	.13	-.26	.89	1.47	-.60
111	-.24	.16	-.25	1.01	1.49	-1.02
104	-.27	-.00	.00	-.00	1.95	.56
111	-.24	.16	-.25	1.01	1.49	-1.02

CONDIZIONE DI MASSIMA FORZE F MOMENII

F1	F2	F3	M1	M2	M3
-414.00	151.00	-161.00	10040.00	36290.00	-4752.00

CONDIZIONE DI MASSIMA TENSIONE

S1	T2	T3	TT	S2	S3
-.27	.16	-.26	1.01	1.95	-1.02



FLOW CHART

Table 1 Typical TETRA output and flow chart of the calculation procedure

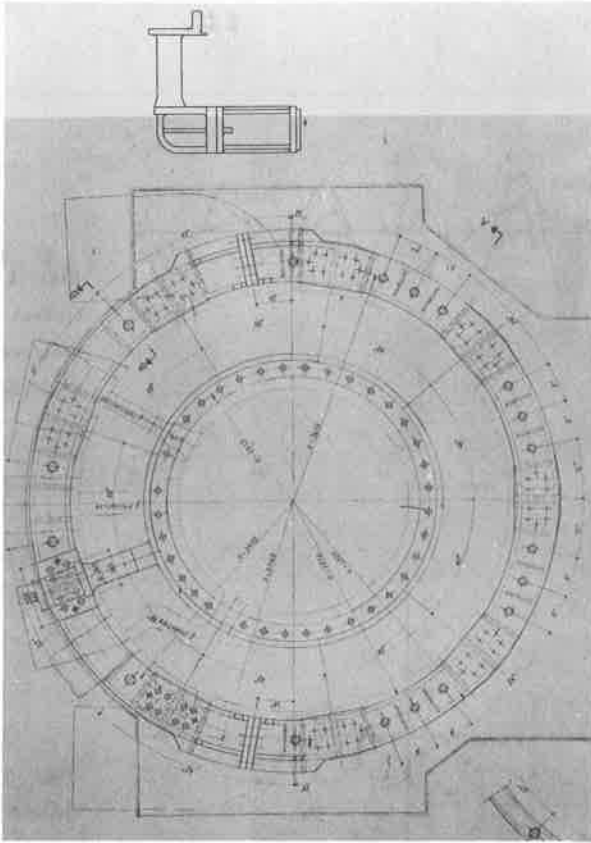


Fig. 1 Support structure general arrangement and beam model

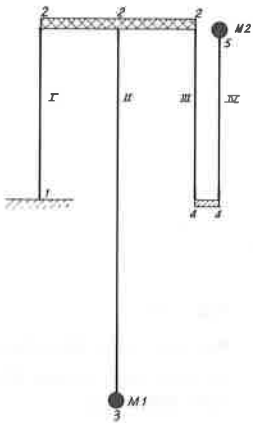


Fig. 2 Elastic plastic model of the support structure

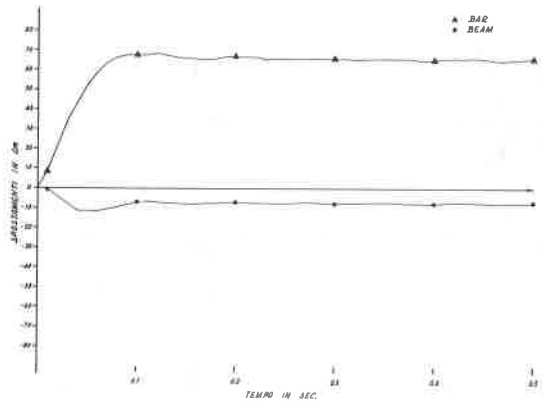


Fig. 3 Typical time history of the plug displacement

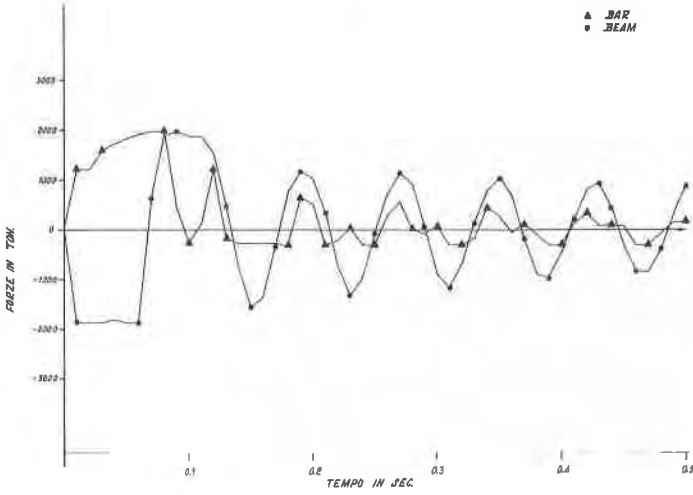


Fig. 4
Typical time history of the force absorbed by the S.S. bars

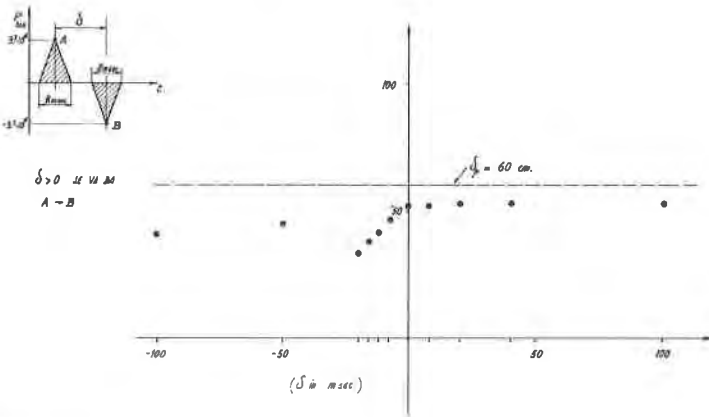


Fig. 5
Maximum plug displacement versus ITSI time difference

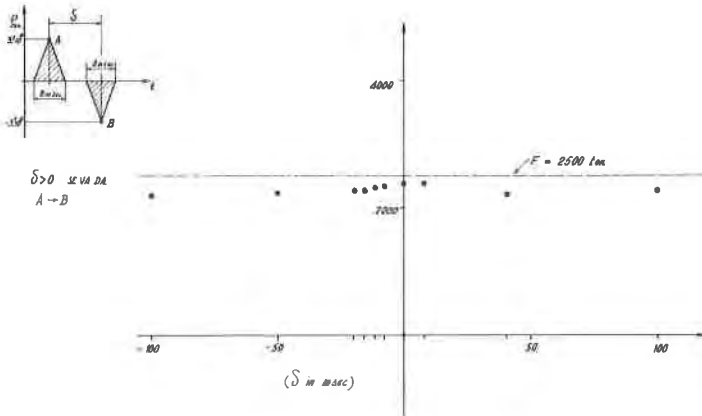


Fig. 6
Maximum force absorbed by S.S. bars versus ITSI time difference

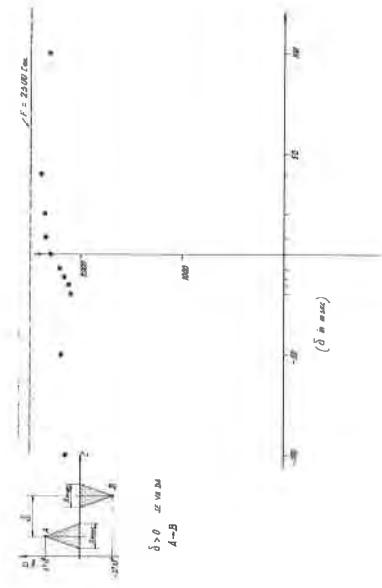


Fig. 8 Maximum upwards force on the support structure versus time difference

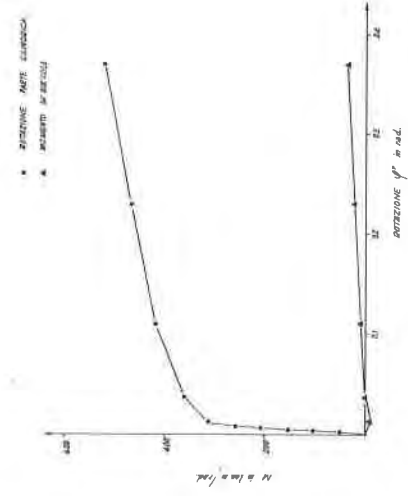


Fig. 10 Rotation of L thinner flange and moment on S.S. bar connection versus applied moment

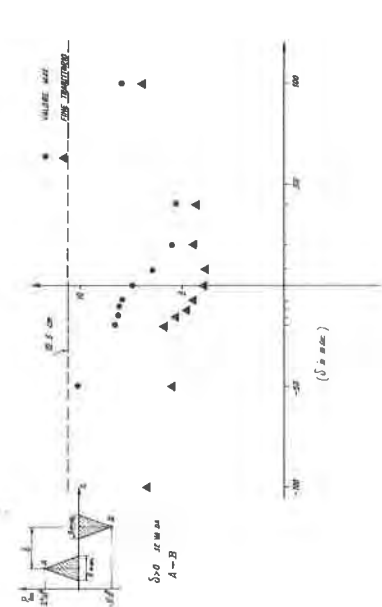


Fig. 7 Maximum L flange downwards displacement during (●) and after (▲) HCDA versus ITSI time difference

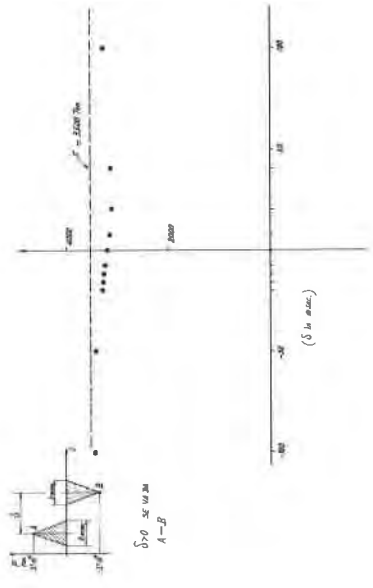


Fig. 9 Maximum downwards force on the support structure versus time difference

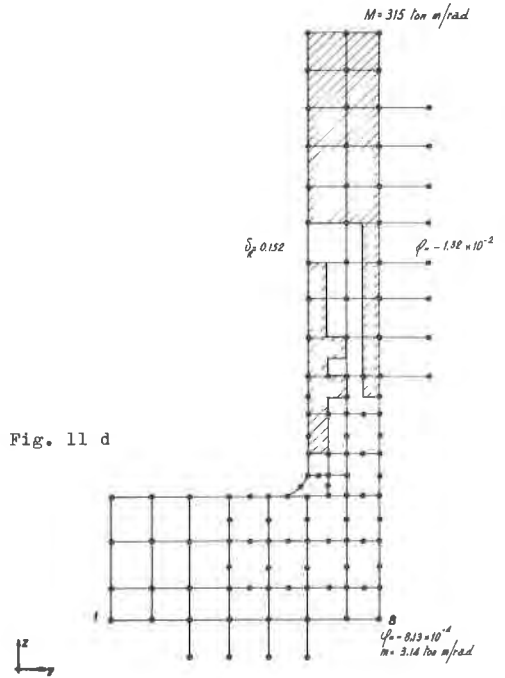
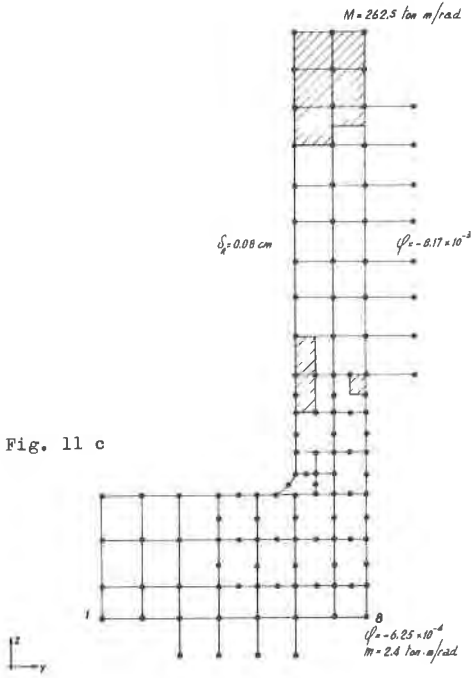
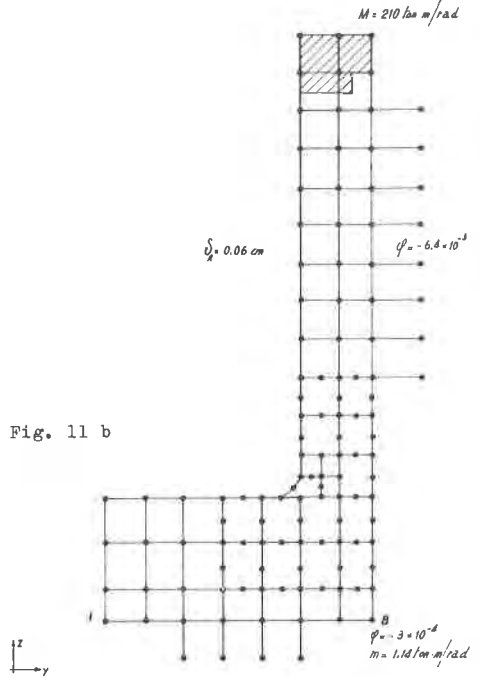
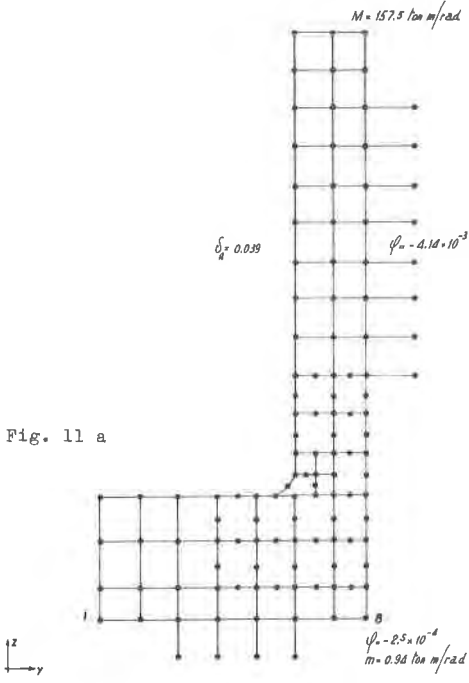
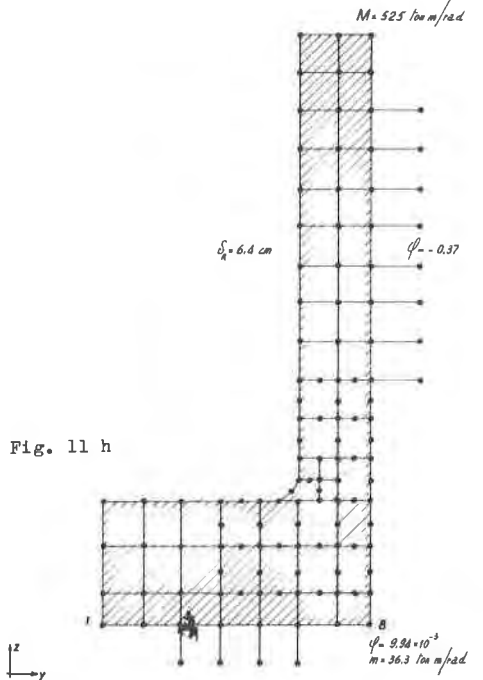
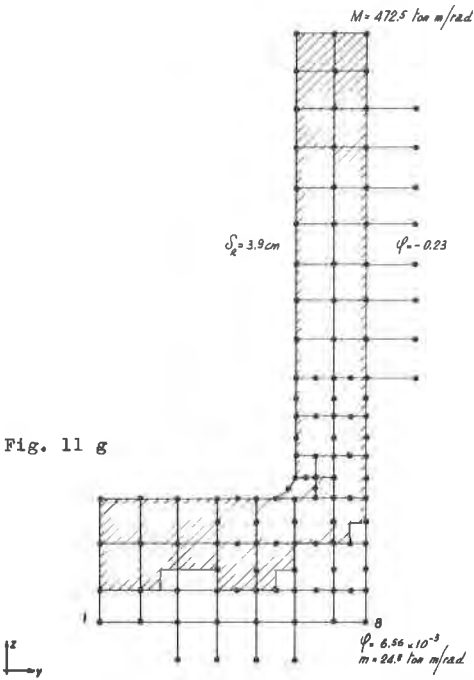
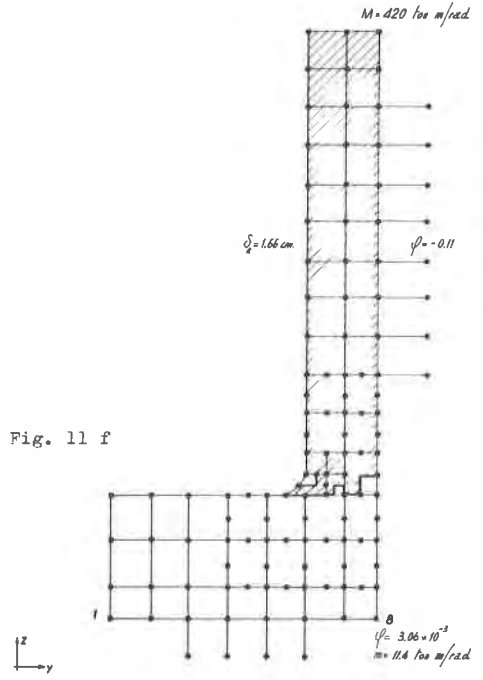
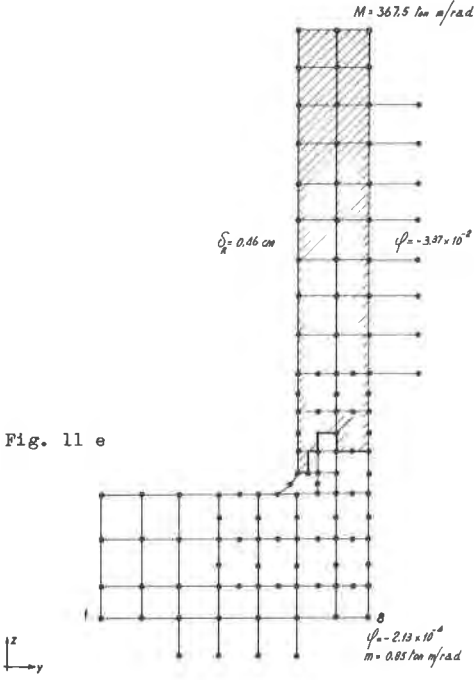


Fig. 11 a, b, c, d, e, f, g, h Elastic zone spatial distribution versus applied moment



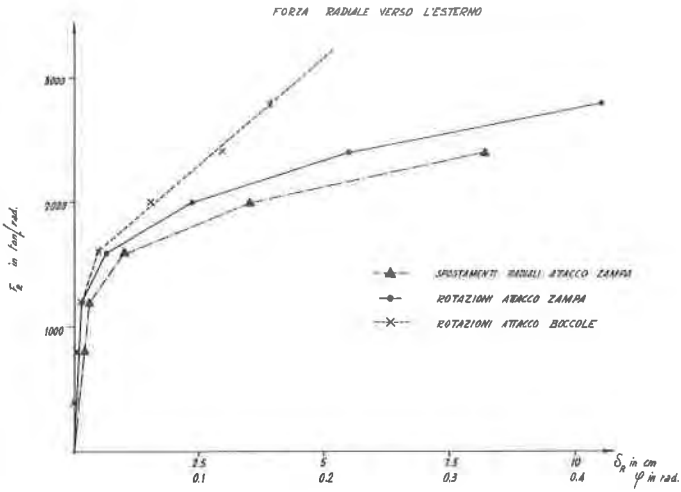


Fig. 12 Radial displacement (\blacktriangle), rotation of thinner flange (\bullet), rotation of thicker flange (\times) versus applied radial force

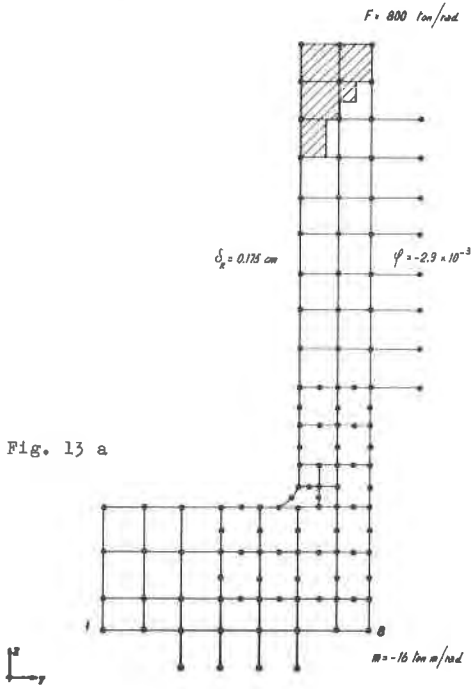


Fig. 13 a

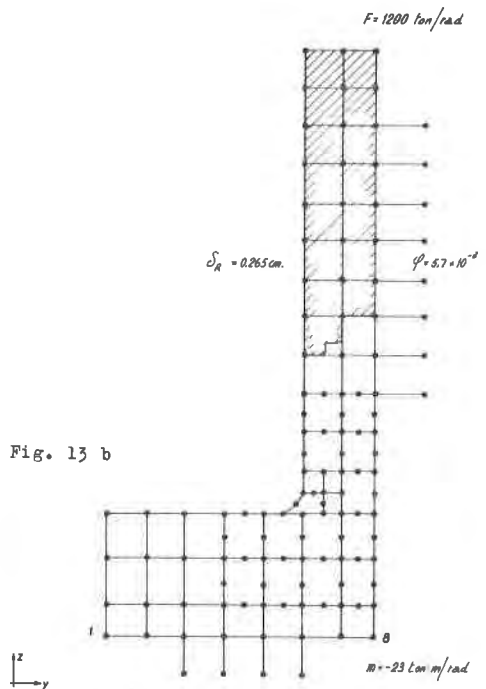


Fig. 13 b

Fig. 13 a, b, c, d, e, f Plastic zone spatial distribution versus applied radial force

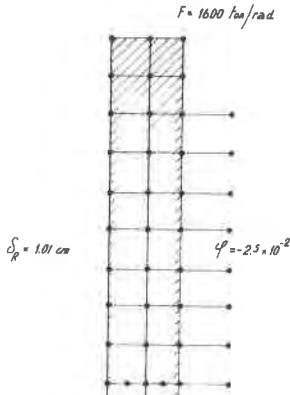


Fig. 13 c

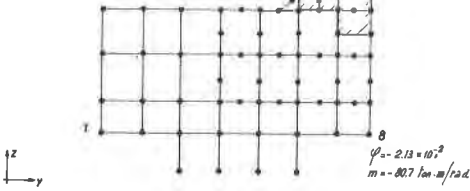


Fig. 13 d



Fig. 13 e



Fig. 13 f

