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GOVERNMENT OF INDIA
ATOMIC ENERGY COMMISSION

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60	**Abstract :** In Pressurised Heavy Water Reactor (PHWR), on-power refuelling is done by use of fuelling machine. Before refuelling sealing plug assembly is removed from the end-fitting of the coolant channel and after refuelling the sealing plug is reinstalled back into the end-fitting. The seal disc is a part of sealing plug assembly. Its function is to create sealing action for the heavy water inside the coolant channel. A systematic developmental work is done to arrive at a final configuration of the seal disc. This is done to minimise the stresses in the body of the seal disc and at the same time to obtain required seating reaction to avoid heavy water leakage. It is observed that stresses computed for the final configuration by linear elastic analysis are more than the allowable value as per ASME Section III, Division 1. This calls for Elasto-plastic analysis to find out collapse load to satisfy ASME codal limits as per spectial provision of NB-3228.1(1986). The Elasto-plastic analysis showed that the seal disc meets ASME codal limits for all stages of loading.	
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INTRODUCTION

Pressurised Heavy Water Reactors (PHWR) have special feature of on-power refuelling. Remotely operated automatic fuelling machines are used for this purpose. At the each end of a coolant channel, there is a sealing plug assembly. Before refuelling, the fuelling machine interacts with the sealing plug assembly and removes it from the end fitting of the coolant channel. After the refuelling, the sealing plug is re-installed back in to the end-fitting.

The Seal disc is a metallic disc and is a part of sealing plug assembly. The function of seal disc is to create sealing action such that leakage of heavy water from the coolant channel should be minimum.To achieve the sealing action an annular nickel layer is electro deposited on one face of the seal disc at its outer periphery. This nickel gasketing in conjunction with the 'Seating surface' in the end-fitting of the coolant channel forms the pressure boundary for the heavy water inside the channel. To obtain the effective sealing force between nickel gasket and end-fitting seating surface, a specific loading and locking arrangement is used. This loading causes very high stresses in the seal disc body. A failure of seal disc may cause loss of coolant in a channel. This calls for a detailed stress analysis of seal disc to satisfy ASME Section III Division 1 codal limits.

The present report describes how a proper geometry of the seal disc for 500MWe PHWR is evolved. In the first section we describe the properties of the proposed material, the loading sequence and necessary seating reactions for a leak proof sealing. To arrive at a proper geometry various alternatives have been tried. This work is summerised in the second section. The final geometry, its finite element stress analysis and a comparison of stresses with the corresponding ASME limits are described in the third section. It is seen that a linear elastic analysis fails to satisfy the ASME codal limits. Hence an elasto-plastic analysis is done to determine the collapse load. This analysis is also described in the third section. In the fourth section we draw the conclusion on this work.

1.0 MATERIAL PROPERTIES, LOADING SEQUENCE AND REQUIRED SEATING REACTIONS

1.1 The proposed material for the seal disc of 500MWe reactor is Inconel 718. At annular periphery of 0.88 mm thick nickel is coated on one of the face. The maximum design temperature is 310 degree centigrade. The properties of this material at room temperature and at design temperature are listed in Table-I. From the Table-I it can be seen that the allowable membrane stress is governed by the one-third ultimate tensile stress criterion as per article III 2110(1986).

1.2 Just before the installation or removal of seal disc the fuelling machine is clamped with coolant channel. Thus fluid pressure on both the sides of seal disc remains same till the fuelling machine is unclamped. During installation and operation seal disc is supported by the end-fitting seating surface at its nickel gasketted annular periphery. The loads applied on seal disc for installation/operation can be categorised in to four stages.

(a) During the first stage of loading, a load (p1) is applied on the central boss of the seal disc such that a differential displacement of 0.8107 mm is obtained between the centre and the rocker point of the seal disc.

(b) In the second stage of loading both the centre and the rocker points are loaded such that the differential displacement of 0.8107 mm is maintained and sum of both the loads is equal to 1814 Kg. At the end of second stage of loading the rocker point gets deflected by 0.27 mm, which is the basis for determining the differential displacement to be achieved in first stage of loading.

(c) In the third stage of loading, the deflection 0.27 mm (obtained in second stage of loading) is locked by extending the jaw into the corresponding groove in the end-fitting. After the locking, externally applied loads at centre and at rocker point are removed. Fluid pressure continues to be same on both the sides as the fuelling machine is still in clamped position with the coolant channel.

(d) Fourth stage of loading is the operational stage of seal disc. After third stage, the fuelling machine is unclamped from the coolant channel. This causes removal of fluid pressure on the fuelling side of the seal disc. In other words, the fourth stage corresponds to a channel design pressure of 1.26 Kg/mm^2 on the seal disc, while rocker point is locked at the displacement of 0.27 mm.

Above sequence of loading makes it possible to install the seal disc with the available load capacity in fuelling machine and also to reduce the stresses induced in the seal disc to the minimum possible.

1.3 For all the stages of loading mentioned above, the stresses induced in the seal disc body should be within ASME Section III, Division I codal limits. To obtain an effective sealing, the seating reactions at the nickel gasket should be 8.9 Kg/mm and 30.4 Kg/mm of periphery at the end of third and fourth stage of loading respectively<1>.

2.0 SUMMARY OF THE PREVIOUS WORK TO ARRIVE AT THE PROPOSED GEOMETRY OF THE SEAL DISC

2.1 For the seal disc of 500MWe PHWR, a new geometry was suggested <1>. This geometry had a special feature of having central boss and hump at the rocker point in the direction of coolant channel. It was expected that this new geomtrical configuration will eliminate many manufacturing difficulties. Preliminary analysis of this geometry was done by using axisymmetric two noded thin shell elements. Maximum stresses and reactions were computed for all the stages of loading <2>. Reactions obtained at the seating radius were found to be sufficient but stresses were much more than allowable value. Optimisation of this new configuration was tried by one dimensional finite element model. This is done by varying the bore diameter and various thicknesses. However it was found that the dimensions are impossible to optimise to meet both the seating reaction as well as stresses within limits <3>.

2.2 As an alternative, the 600MWe export model seal disc geometry (figure 1) was suggested for 500MWe reactor. A series of 1-D finite element analyses were carried out. The conclusion obtained from these studies were that it is possible to modify the seal disc configuration used in 600MWe export model to suit 500MWe reactor <3>.

2.3 As a follow up action, two-dimensional axisymmetric finite element discretization of 600MWe export model seal disc was done by using 258, eight noded isoparametric elements and 909 nodes having two degrees of freedom per node. Analysis of this model was done with the support on nickel gasket corresponding to 500MWe end-fitting configuration. Though the stresses were found to be below the yield stress and also the seating reaction in third stage was meeting the required value, the seating reaction in the fourth stage was much below the required value of 30.4 Kg/mm. A number of changes in the dimensions were done to optimise the required seating reactions and stresses<4>. It was found possible to arrive at a geometry which meets the required seating reactions and bending stresses below yield stress of the material. However for the present material since the allowable membrane stress was one-third of the ultimate stress instead of two-third of yield stress, these stresses were not meeting the ASME codal limits.

2.4 In parallel to the above analysis, it was decided to check whether finite radius of curvature(25mm) of closure cap which is in contact with rocker seat can give rise to interference with seal disc body during various loading conditions. Deformed shapes of the rocker seat for different stages of loading showed that due to large stiffness the rocker seat only rotates towards centre of seal disc and its top surface remains a plane. This means that for any finite radius of curvature of closure cap, there will be a change in the radius of rocker-point-loading to avoid interference. A number of iterations were carried out to find the true location of contact point of closure cap with rocker seat for all stages of loading and corresponding stresses and seating reactions<5>. The conclusion from these analyses are:

(a) the maximum shift of rocker-point-loading is 0.687 mm outward.

(b) there is no significant change in stresses due to this change in rocker-point-loading radius.

(c) there is a tendency of increase in seating reaction by 10 %.

3.0 THE FINAL GEOMETRY, FINITE ELEMENT MODEL AND RESULTS OF STRESS ANALYSIS

3.1 As mentioned in the previous section, it was found possible to modify the geometry of 600MWe export model seal disc to suit 500MWe reactor. The modifications were done by changing different dimensions in a planned manner. The final geometry which gives the required seating reactions and also stresses are minimum, is shown in figure 2. In comparison to 600MWe export model seal disc, the following changes may be noted:-

(i) Rocker seat thickness is increased by 0.5 mm.

(ii) Rocker seat is shifted by 0.65 mm outward.

(iii) A groove having a radius of 3.5 mm is introduced at the junction of central boss and horizontal plate to relieve the stress at the junction.

(iv) The central boss of seal disc is made longer. This is done as per the suggestion from designer to meet some fuctional requirements.

3.2 Figure 3 shows the two-dimensional finite element model of this proposed seal disc geometry. The mesh includes 258, eight noded isoparametric elements and 909 nodes. Each node has two degrees of freedom. The problem is treated as an axisymmetric case. When seal disc is supported by end-fitting, the nickel gasket makes contact with end-fitting seating surface. It is difficult to establish the location and width of the contact analytically. Exact location and width of contact is decided experimentally. Mean radius and width of the support are selected as 56.864 mm and 0.508 mm respectively.

3.3 RESULTS OF THE LINEAR ELASTIC ANALYSIS

Four linear elastic computations(correspond to four stages of loading) were done to obtain displacements and stresses by using computer code 'PLAXIS'<7>. The displacements and reactions at the salient points have been shown in figure 4. These computations show that 1294.7 Kg load is applied at the centre in the first stage of loading. The loads in the second stage are 1157.9 Kg at the centre and 656.1 Kg at the rocker point. The reactions at the nickel gasket are 11.54 kg/mm and 30.5 Kg/mm of periphery in third and fourth stage of loadings respectively.

The components of the stresses have been computed at different points in the mesh with respect to given coordinate system. These stresses are classified in terms of membrane, bending and peak as per NB-3217-1(1986). These classifications are done along different planes. The planes are identified such that points of large stresses should fall onto these planes. Figure 5 shows these planes for four stages of loading. Table 2A through 2D show the stresses as compared with corresponding allowable values for all the planes and different loading cases. These tables show that membrane plus bending stresses cross the allowable value of 58 Kg/mm^2. This fails to satisfy NB-3217-1(1986) for number of planes and various stages of loading.

3.4 RESULTS OF ELASTO-PLASTIC ANALYSIS

It was found necessary to invoke the special provision of NB-3228.1(1986) to satisfy ASME codal limit<6>. This requires computation of collapse channel pressure for this component. An Elasto-plastic analysis is done by computer code 'THESIS'<8>. Finite element model shown in figure 3 was used for this purpose. Material is treated to behave elastic-perfectly plastic as per NB-3213.27(1986). Figures 6A through 6E show progress of plastic front as channel pressure is increased beyond design value. These figures show that yielding is mainly due to bending stresses. At 250 % of design pressure a cross section at rocker seat yields through thickness (fig 6E). Since no strain hardening has been considered for this analysis, component fails to sustain any more pressure beyond this value.

Figures 7a, 7b and 7c show the variation of centre line deflection as a function of percentage of original loading for all the three stages of loadings (stage I, II, and IV). In all the three cases it may be seen that corresponding collapse loads are much more than the ASME codal limits (which is 150 % of the actual applied load). Hence as per NB 3228.1(1986) the proposed seal disc geometry satisfies the ASME codal limits for all the four stages of loading.

4.0 CONCLUSIONS

A new seal disc geometry has been evolved to suit our 500MWe PHWR. The geometry is similar to that of the seal disc used in 600MWe export model. Some changes in dimensions have been done to obtain the required seating reactions and also to minimize the stresses. The linear elastic calculations show that though the membrane plus bending stresses are below yield limit they cross the allowable value as per ASME article III 2110 (1986), for various stages of loading. This is because the membrane allowable stress for the present material is one-third of ultimate rather than two-third of yield stress. However elasto-plastic analyses show that collapse loads for all the stages of loading are much more than 150 %. So as per special provision given in NB-3228.1(1986), the proposed seal disc geometry meets ASME codal limits for all stages of loading.

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TABLE-I

Material of 500MWe reactor seal disc	Inconel 718
Gasket material	Nickel
Poison's ratio for Inconel 718	0.3
Poison's ratio for Nickel	0.33
Modulus of elasticity of Inconel 718 at RT	2.08E04 Kg/mm²
Modulus of elsaticity of Nickel at RT	2.11E04 Kg/mm²
At room temperature(RT) for Inconel 718	
ultimate stress	130.28 Kg/mm²
yield stress	105.64 Kg/mm²
allowable stress (Sm)	42.25 Kg/mm²
allowable stress for bending (1.5Sm)	63.37 Kg/mm²
Operating temperature	310°C
Modulus of elasticity of Inconel718 at 310°C	1.887E04 Kg/mm²
Modulus of elasticity of Nickel at 310°C	1.96E04 Kg/mm²
At temterature 310 C for Inconel718	
ultimate stress	116.0 Kg/mm²
yield stress	95.2 Kg/mm²
allowable stress (Sm)	38.7 Kg/mm²
allowable stress for bending (1.5Sm)	58.0 Kg/mm²

TABLE 2A : Finite element stress classification as per ASME Section III for stage 1 loading.

Line no.	Stress Category	Stress Intensity (Kg/mm^2)	Allowable value (Kg/mm^2)	Remark
1-1	Pm	2.68	38.7	Satisfied
	Pm + Pb	42.96	58.0	Satisfied
	Pp	68.02	---	Unclassified +
2-2	Pm	7.45	38.7	Satisfied
	Pm + Pb	70.03	58.0	Not satisfied *
	Pp	83.56	---	Unclassified +
3-3	Pm	9.05	38.7	Satisfied
	Pm + Pb	70.59	58.0	Not satisfied *
	Pp	73.27	---	Unclassified +
4-4	Pm	9.31	38.7	Satisfied
	Pm + Pb	63.01	58.0	Not satisfied *
	Pp	64.01	---	Unclassified +
5-5	Pm	10.10	38.7	Satisfied
	Pm + Pb	59.75	58.0	Not satisfied *
	Pp	60.65	---	Unclassified +
6-6	Pm	11.60	38.7	Satisfied
	Pm + Pb	50.84	58.0	Satisfied
	Pp	50.84 $	---	Unclassified +
7-7	Pm	6.88	38.7	Satisfied
	Pm + Pb	35.01	58.0	Satisfied
	Pp	35.01 $	---	Unclassified +

Pm - Membrane; Pb - Bending; Pp - Peak

* - However an elasto-plastic collapse load analysis showed that stage-1 loading is safe.

\+ - Not classified in ASME Section III for this geometrical configuration.

$ - Pp is same as Pm+Pb, which shows that peaking of stresses is not there.

TABLE 2B : Finite element stress classification as per ASME Section III for stage 2 loading.

Line no.	Stress Category	Stress Intensity (Kg/mm^2)	Allowable value (Kg/mm^2)	Remark
1-1	Pm Pm + Pb Pp	2.61 40.51 63.66	38.7 58.0 ---	Satisfied Satisfied Unclassified
2-2	Pm Pm + Pb Pp	6.75 66.09 78.95	38.7 58.0 ---	Satisfied Not satisfied Unclassified
3-3	Pm Pm + Pb Pp	8.31 67.44 69.89	38.7 58.0 ---	Satisfied Not satisfied Unclassified
4-4	Pm Pm + Pb Pp	8.63 61.52 62.30	38.7 58.0 ---	Satisfied Not satisfied Unclassified
5-5	Pm Pm + Pb Pp	9.42 59.05 59.95	38.7 58.0 ---	Satisfied Not satisfied Unclassified
6-6	Pm Pm + Pb Pp	11.00 55.61 55.61 $	38.7 58.0 ---	Satisfied Satisfied Unclassified
7-7	Pm Pm + Pb Pp	7.04 35.55 35.55 $	38.7 58.0 ---	Satisfied Satisfied Unclassified

Pm - Membrane; Pb - Bending; Pp - Peak

* - However an elasto-plastic collapse load analysis showed th stage-2 loading is safe.

\+ - Not classified in ASME Section III for this geometr configuration.

$ - Pp is same as Pm+Pb, which shows that peaking of stresses not there.

TABLE 2C : Finite element stress classification as per ASME Section III for stage 3 loading.

Line no.	Stress Category	Stress Intensity (Kg/mm^2)	Allowable value (Kg/mm^2)	Remark
1-1	Pm	1.80	38.7	Satisfied
	Pm + Pb	25.39	58.0	Satisfied
	Pp	25.49	---	Unclassified +
2-2	Pm	1.88	38.7	Satisfied
	Pm + Pb	28.40	58.0	Satisfied
	Pp	28.40 $	---	Unclassified +
3-3	Pm	2.35	38.7	Satisfied
	Pm + Pb	32.37	58.0	Satisfied
	Pp	32.82	---	Unclassified +
4-4	Pm	2.90	38.7	Satisfied
	Pm + Pb	36.45	58.0	Satisfied
	Pp	37.01	---	Unclassified +
5-5	Pm	5.17	38.7	Satisfied
	Pm + Pb	46.02	58.0	Satisfied
	Pp	46.02 $	---	Unclassified +
6-6	Pm	1.27	38.7	Satisfied
	Pm + Pb	31.16	58.0	Satisfied
	Pp	31.16 $	---	Unclassified +
7-7	Pm	6.05	38.7	Satisfied
	Pm + Pb	37.30	58.0	Satisfied
	Pp	38.65	---	Unclassified +

Pm - Membrane; Pb - Bending; Pp - Peak

\+ - Not classified in ASME Section III for this geometrical configuration.

$ - Pp is same as Pm+Pb, which shows that peaking of stresses is not there.

TABLE 2D : Finite element stress classification as per ASME Section III for stage 4 loading.

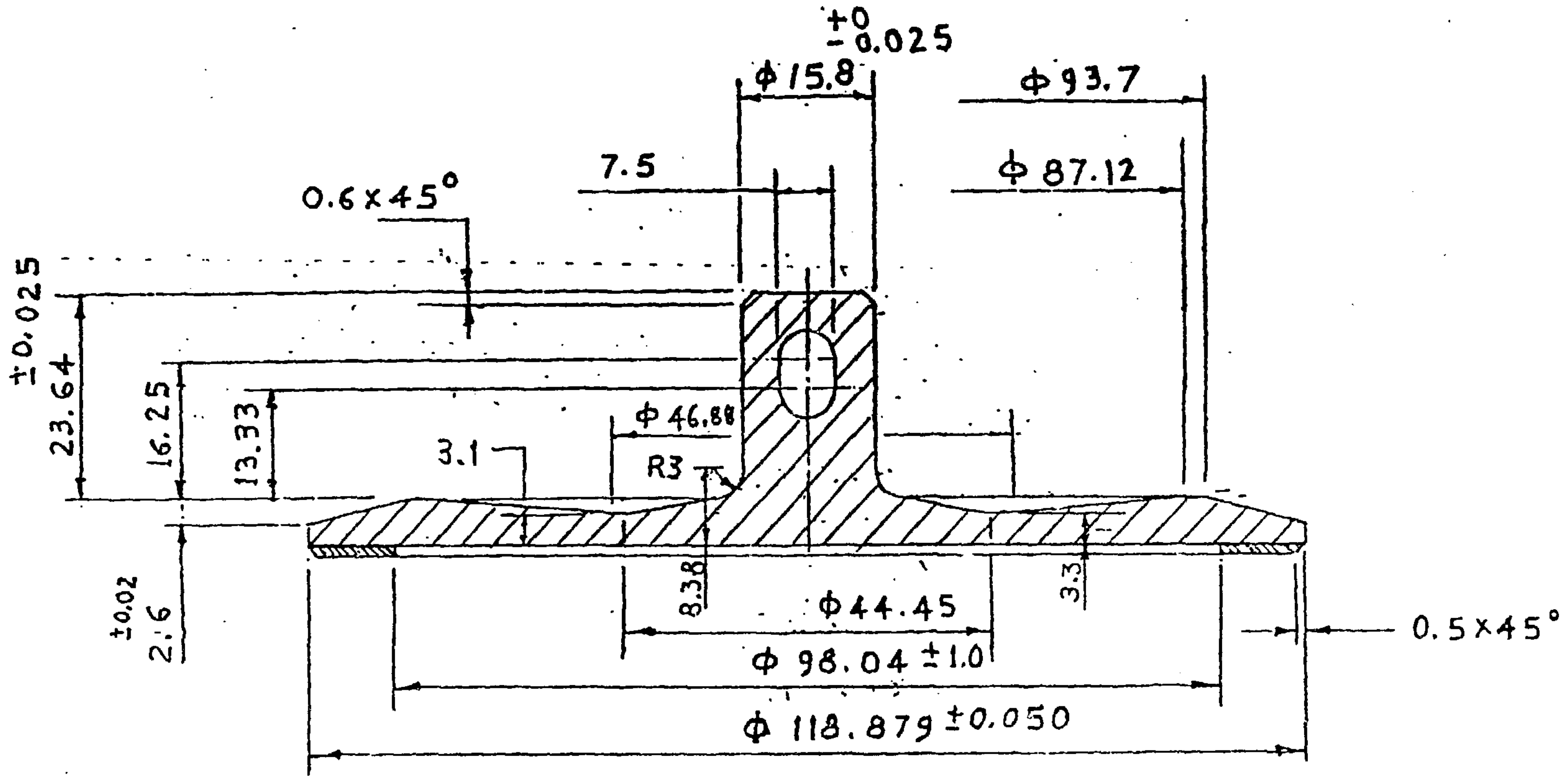
Line no.	Stress Category	Stress Intensity (Kg/mm^2)	Allowable value (Kg/mm^2)	Remark
1-1	Pm	2.72	38.7	Satisfied
	Pm + Pb	39.38	58.0	Satisfied
	Pp	43.64	---	Unclassified +
2-2	Pm	10.30	38.7	Satisfied
	Pm + Pb	18.24	58.0	Satisfied
	Pp	18.24 $	---	Unclassified +
3-3	Pm	10.60	38.7	Satisfied
	Pm + Pb	46.05	58.0	Satisfied
	Pp	46.05 $	---	Unclassified +
4-4	Pm	10.80	38.7	Satisfied
	Pm + Pb	70.84	58.0	Not satisfied *
	Pp	70.84 $	---	Unclassified +
5-5	Pm	13.10	38.7	Satisfied
	Pm + Pb	92.16	58.0	Not satisfied *
	Pp	92.16 $	---	Unclassified +
6-6	Pm	15.50	38.7	Satisfied
	Pm + Pb	88.41	58.0	Not satisfied *
	Pp	88.41 $	---	Unclassified +
7-7	Pm	23.20	38.7	Satisfied
	Pm + Pb	59.64	58.0	Not satisfied *
	Pp	59.64 $	---	Unclassified +

Pm - Membrane; Pb - Bending; Pp - Peak

* - However an elasto-plastic collapse load analysis showed that stage-4 loading is safe.

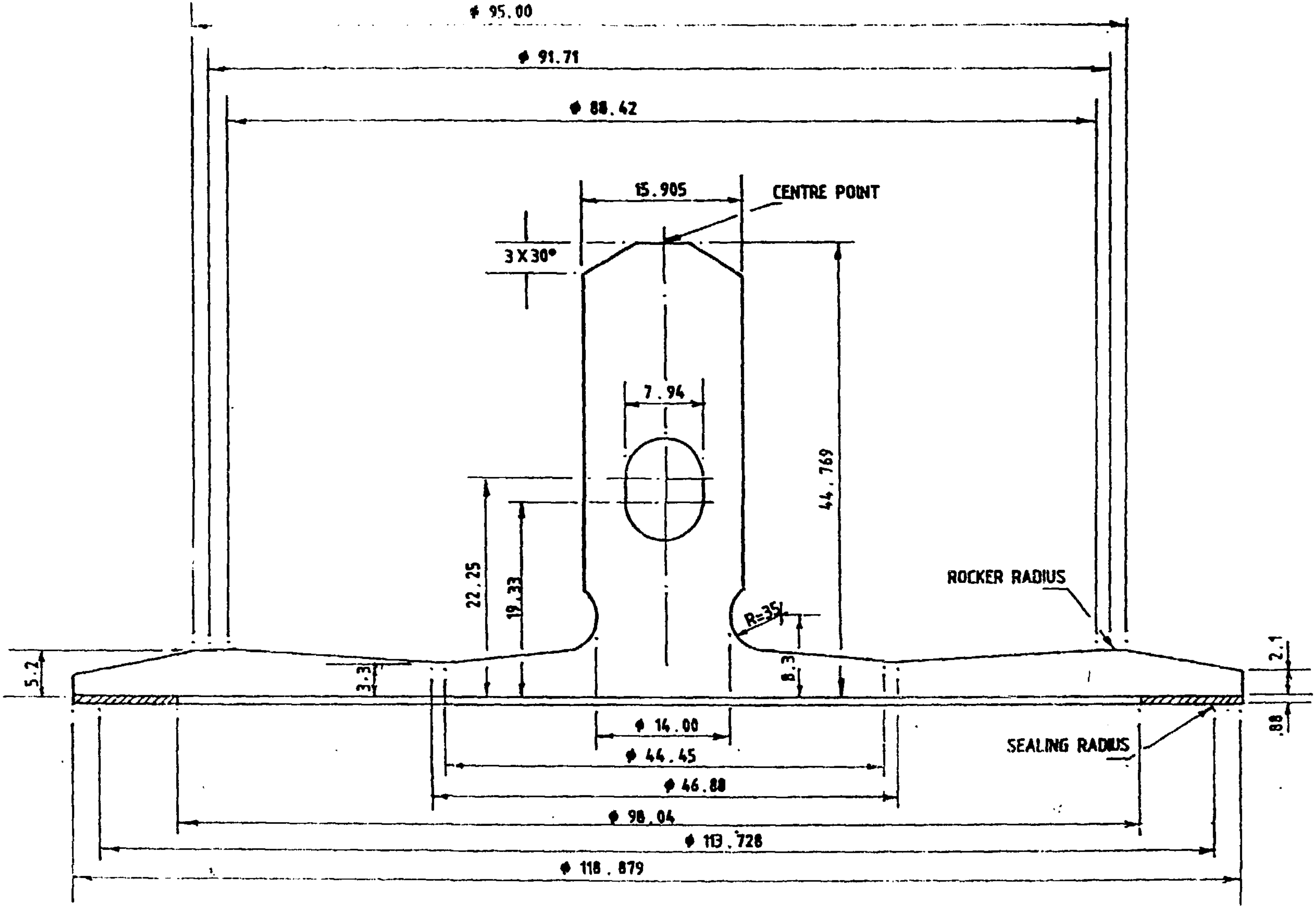
\+ - Not classified in ASME Section III for this geometrical configuration.

$ - Pp is same as Pm+Pb, which shows that peaking of stresses is not there.



All Dimensions are in mm

FIG. 1 SEAL DISC GEOMETRY USED IN 600 MWe EXPORT MODEL REACTOR SYSTEM



ALL DIMENSIONS ARE IN mm

FIG. 2 PROPOSED SEAL DISC GEOMETRY FOR 500 MWe REACTOR

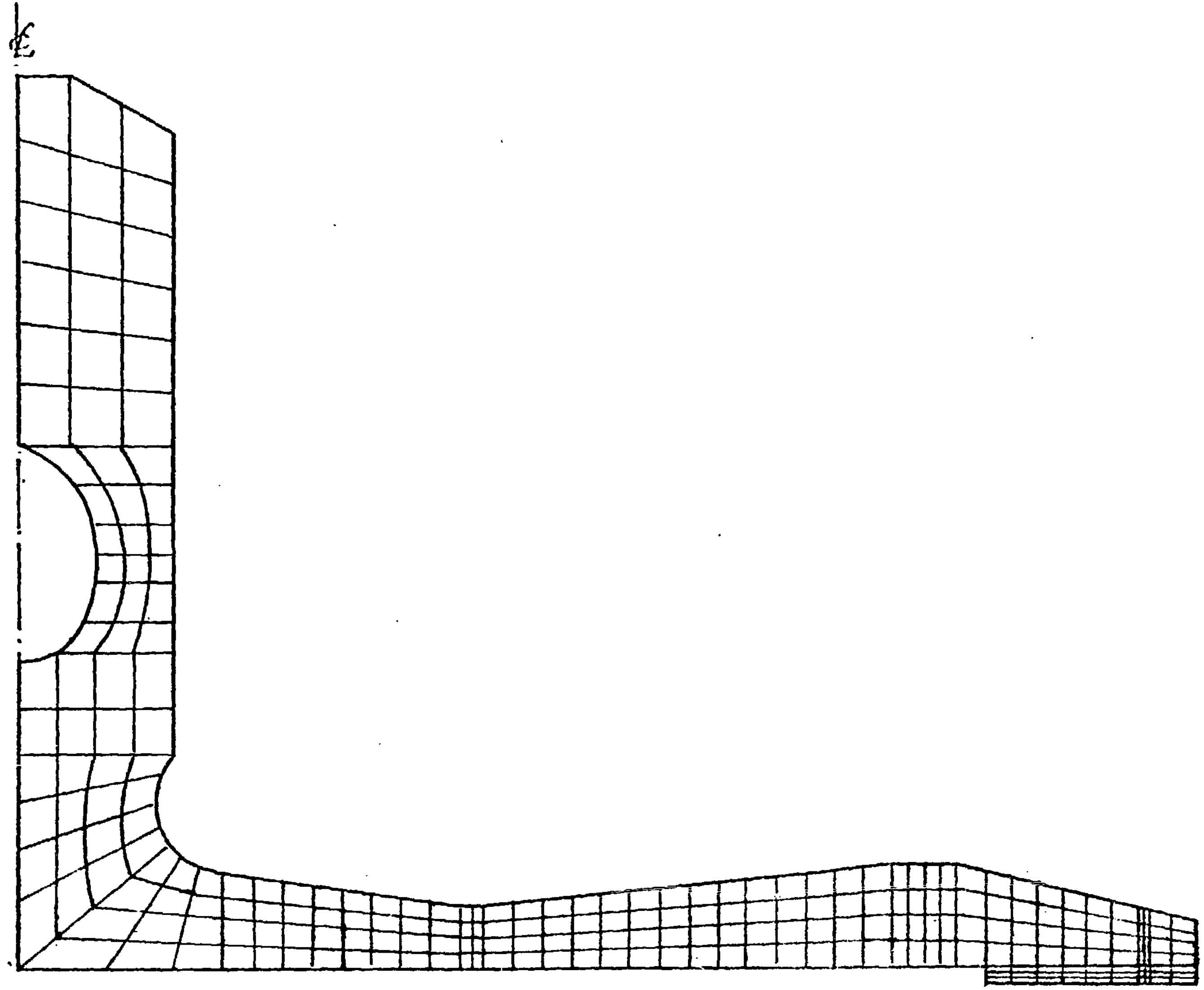
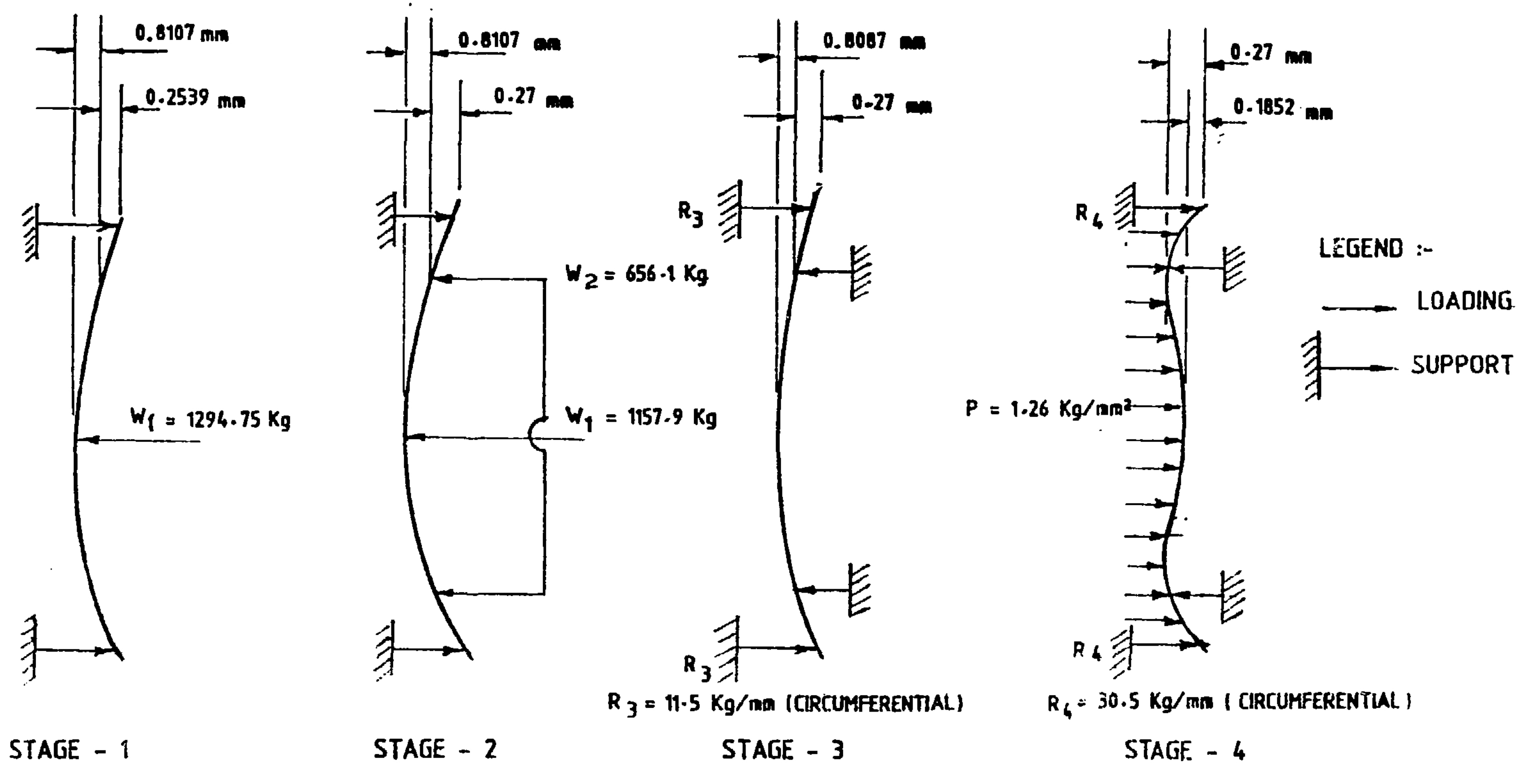


FIG. 3 FINITE ELEMENT MESH OF 500 MWe SEAL DISC



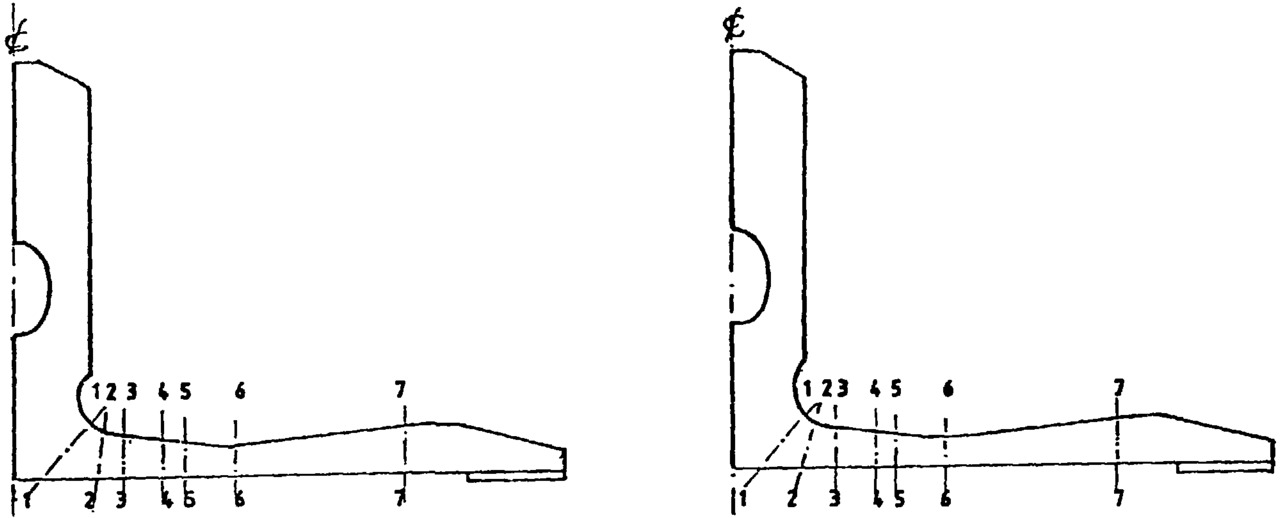
STAGE - 1

STAGE - 2

STAGE - 3

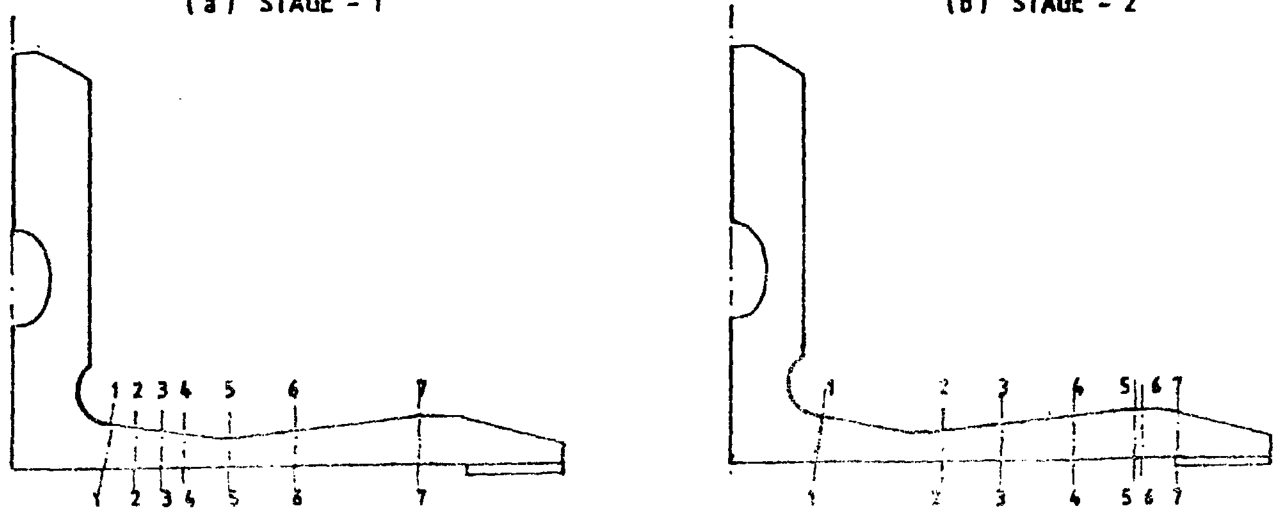
STAGE - 4

FIG. 4 DEFLECTION PATTERN FOR VARIOUS STAGES OF LOADING IN 500 MWe REACTOR SEAL DISC



(a) STAGE - 1

(b) STAGE - 2



(c) STAGE - 3

(d) STAGE - 4

[illegible] 6 IDENTIFICATION OF VARIOUS PLANES USED FOR STRESS CLASSIFICATIONS

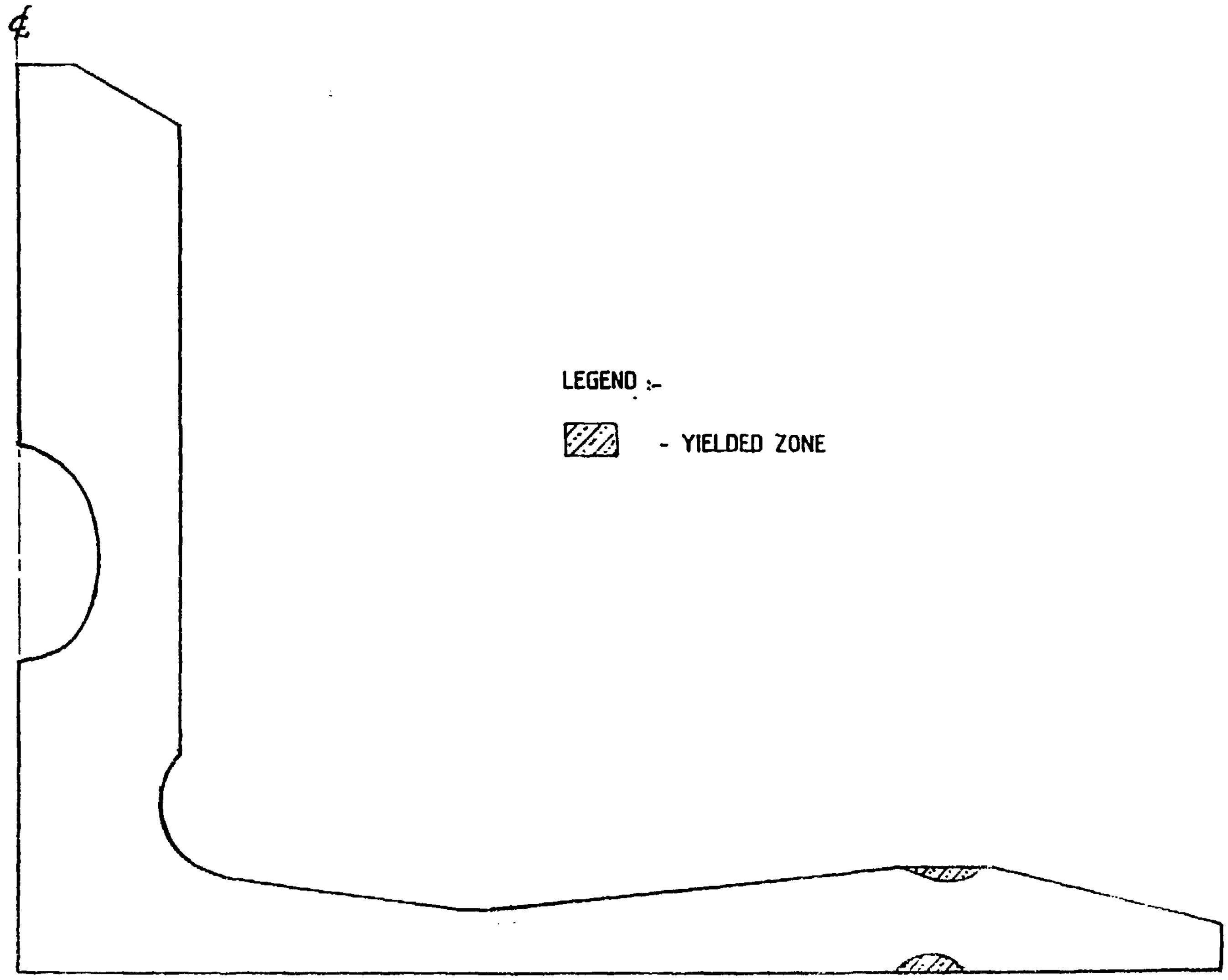


FIG 6A - PROGRESS OF PLASTIC FRONT FOR 150 % OF DESIGN PRESSURE

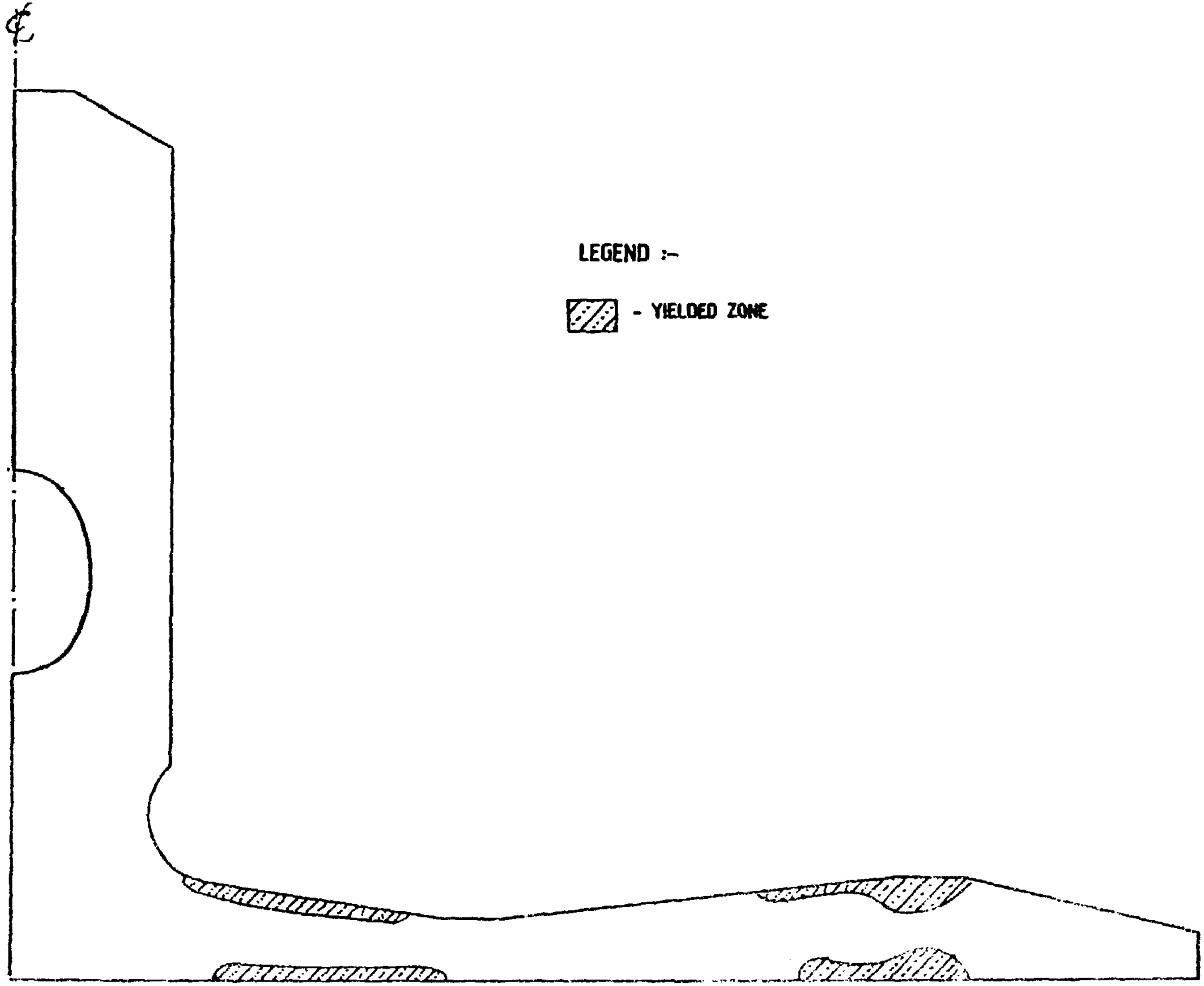


FIG. 6B PROGRESS OF PLASTIC FRONT FOR 200 % OF DESIGN PRESSURE

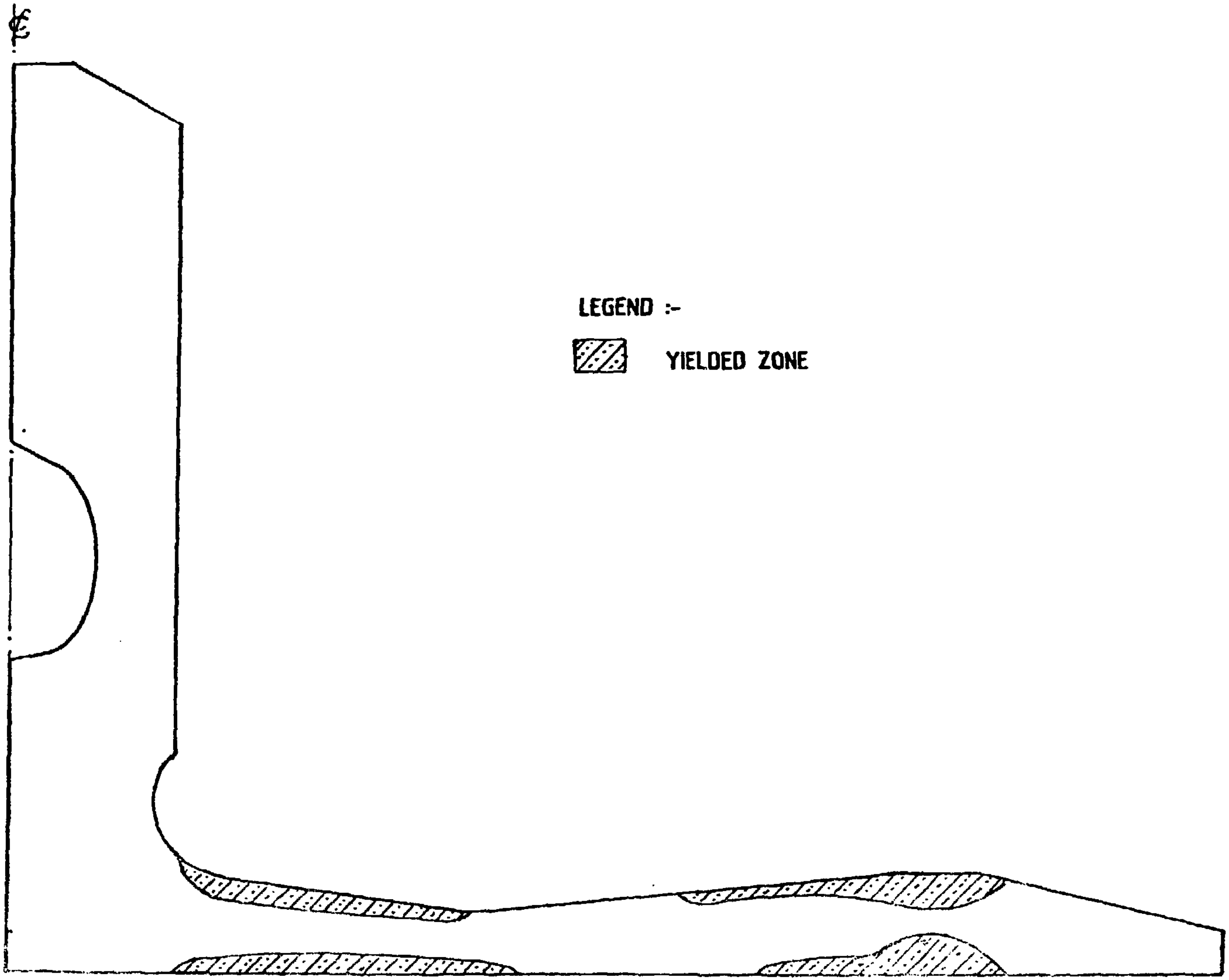


FIG. 6C PROGRESS OF PLASTIC FRONT FOR 220 % OF DESIGN PRESSURE

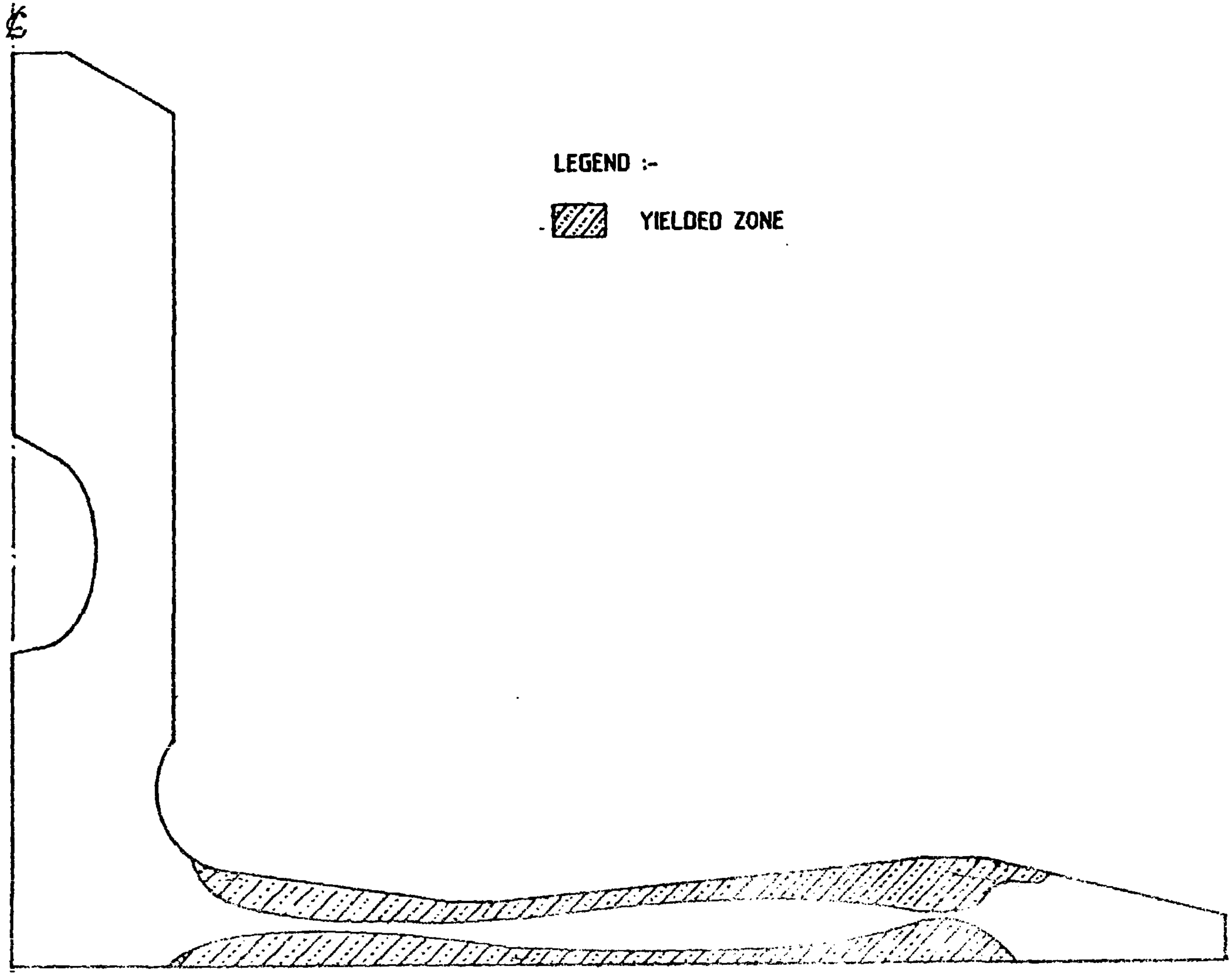


FIG. 6D PROGRESS OF PLASTIC FRONT FOR 240 % OF DESIGN PRESSURE

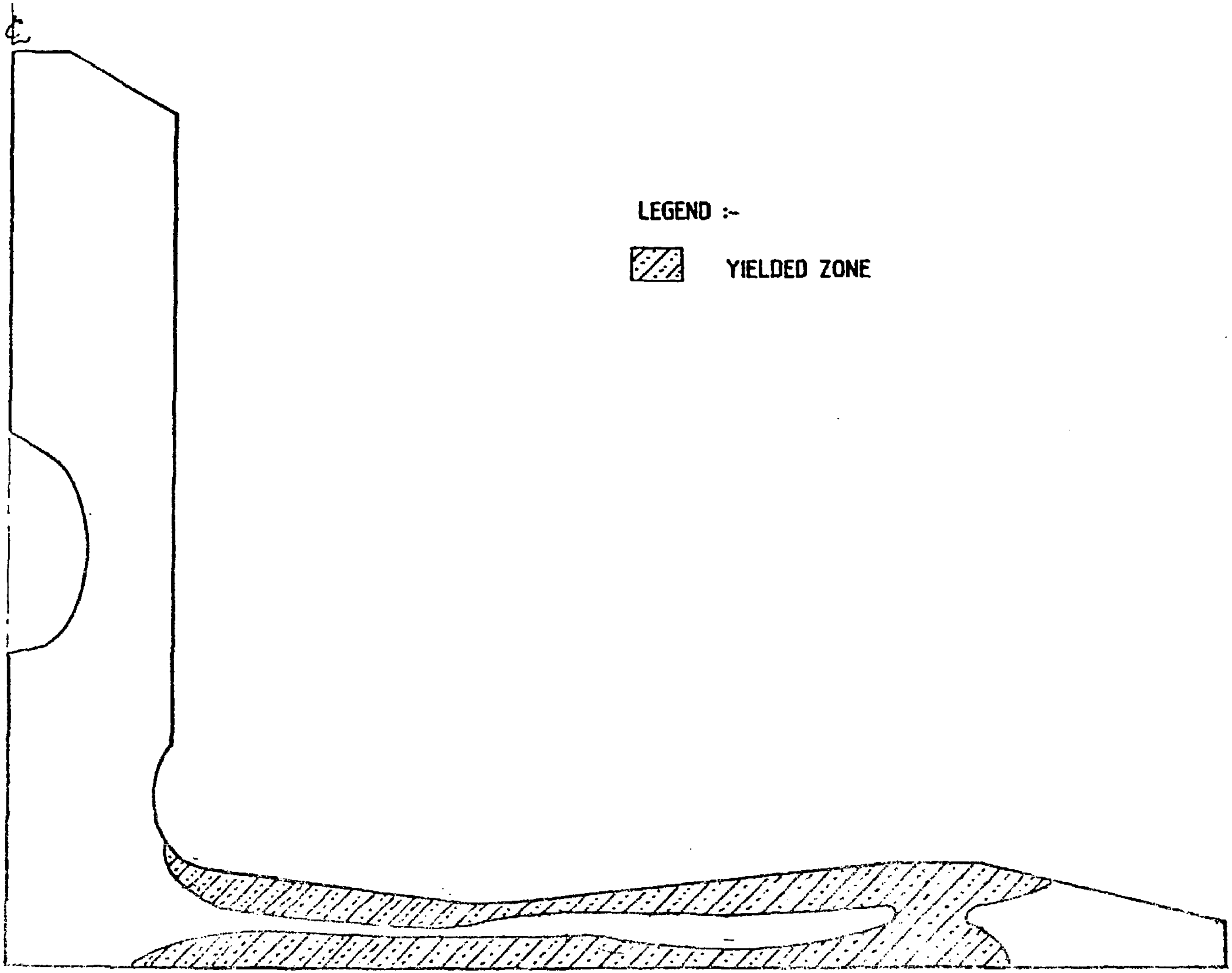


FIG. 6E PROGRESS OF PLASTIC FRONT FOR 250 % OF DESIGN PRESSURE

(COLLAPSE OCCURS)

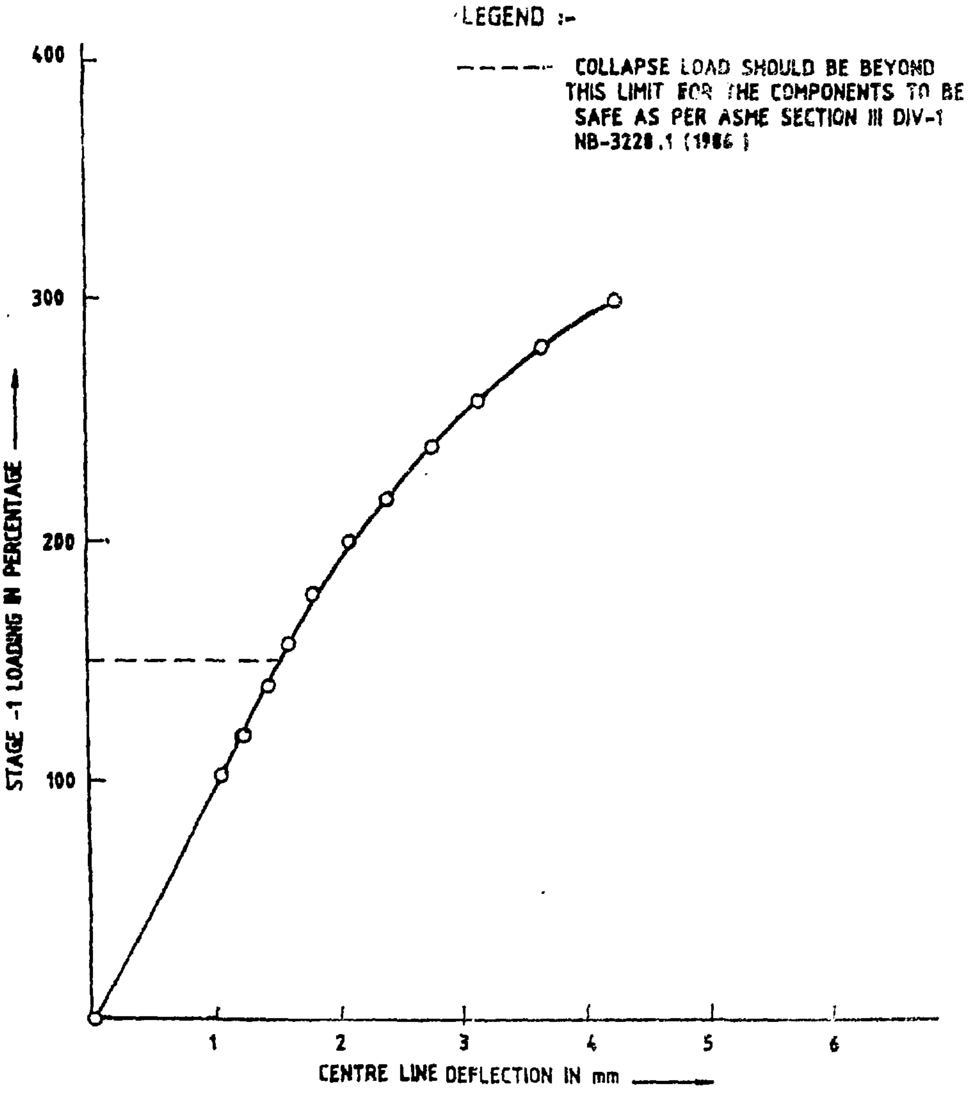


FIG. 7A VARIATION OF CENTRE LINE DEFLECTION FOR STAGE-1 LOADING (COLLAPSE LOAD ANALISIS)

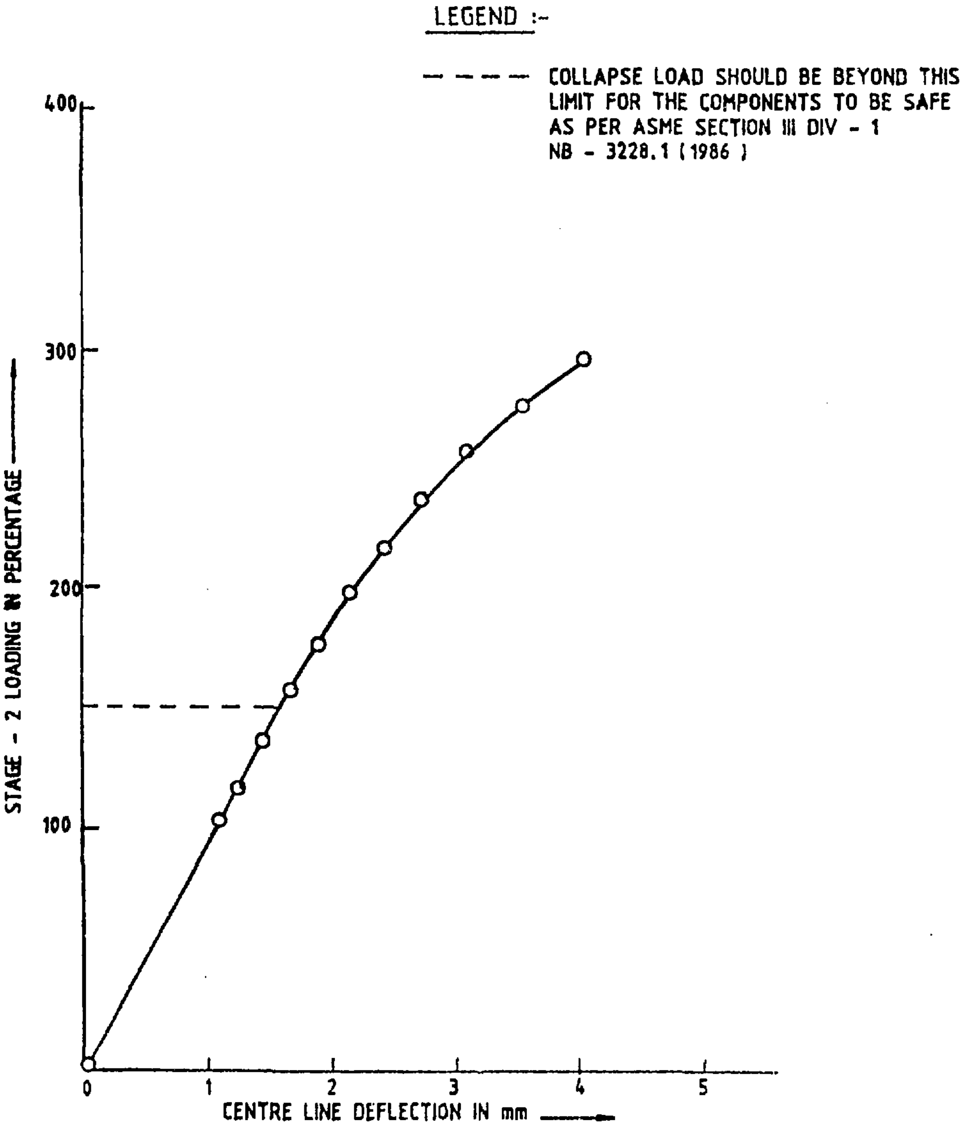


FIG. 7B VARIATION OF CENTRE LINE DEFLECTION FOR STAGE-2 LOADING (COLLAPSE LOAD ANALYSIS)

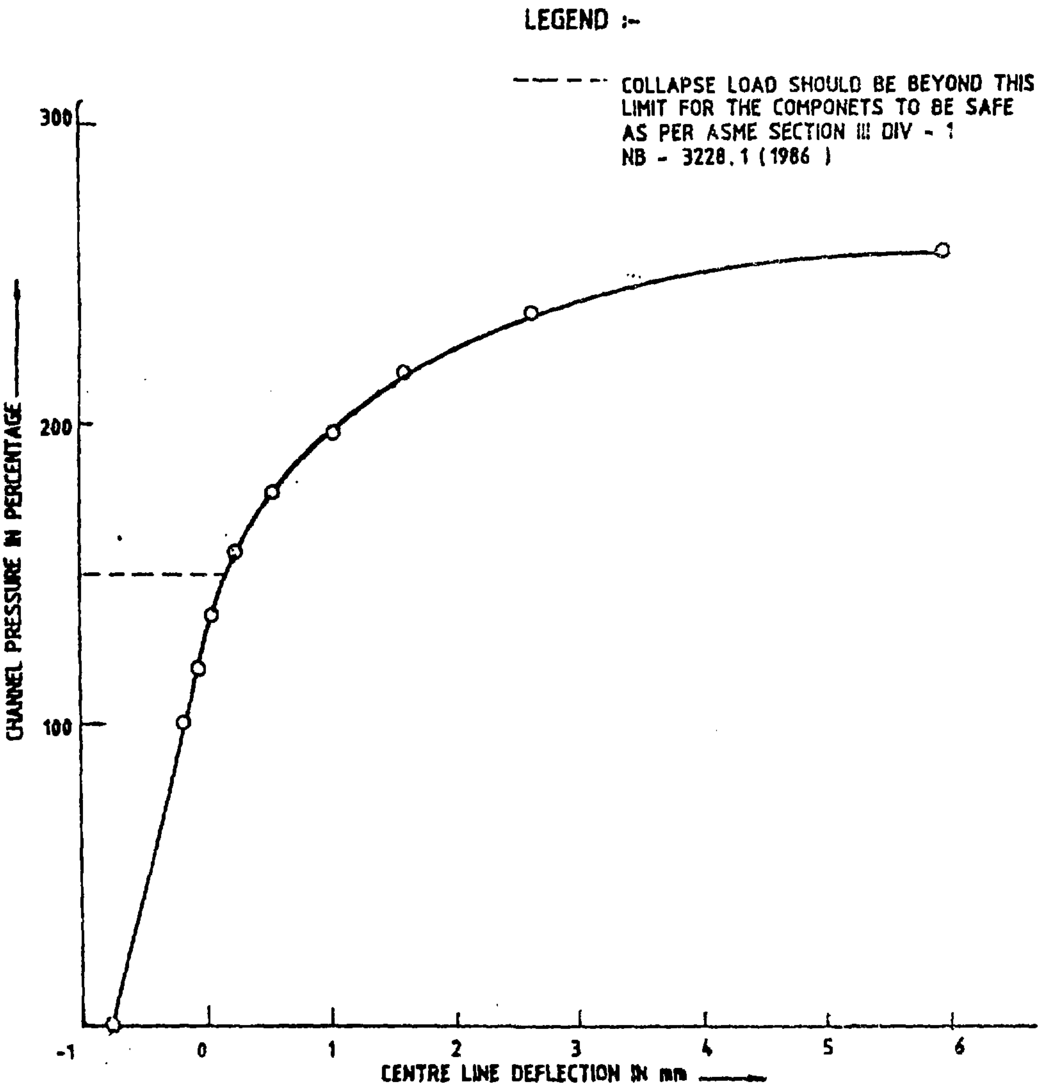


FIG. 7C VARIATION OF CENTRE LINE DEFLECTION FOR INCREASING CHANNEL PRESSURE (COLLAPSE LOAD ANALYSIS)

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