ANCHORAGE BOND IN CONCRETE BASES

BY

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DECLARATION OF CANDIDATE

I, Willem Jacobus Vermaak, hereby declare that this thesis is my own work and that it has not been submitted for a degree at another university.

April, 1981.

I wish to dedicate this thesis to my wife.

CONTENTS

SYNOPSIS

Five series of tests were performed to investigate the anchorage bond stresses in concrete bases. In Series I to IV concrete base specimens were loaded and column starter bar strains measured for different supporting conditions of the base. Curves indicating the distribution of steel compressive stresses and bond stresses in the columns and base slabs are given. Results from these tests indicate that the conventional design approach towards bond stresses in concrete bases is conservative and that the allowable bond stresses in BS CP110 seem to be too low while the maximum stresses specified in ACI 318-71 and the CEB-FIP Recommendations seem to be more acceptable.

In Series V pull-out tests were made on 60 concrete cube specimens subjected to biaxial normal pressure. The ultimate bond strength was found to increase with applied normal pressure in proportion to the square root of the normal pressure and square root of the concrete strength.

A comparative finite element stress analysis was done on a typical concrete base specimen and the results were found to be in accordance with the results of the tests in Series I to IV.

ACKNOWLEDGEMENTS

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LIST OF SYMBOLS

A_c	Area of concrete
A'_s	Area of compression reinforcement
A_s	Area of tension reinforcement
b	Width of section
d	Effective depth of tension reinforcement
E_c	Static secant modulus of elasticity of concrete
E_s	Modulus of elasticity of steel
F	Total load
$F_{sc\ col}$	Theoretical compression force in column starter bars above base slab
f_{bs}	Bond stress
f_c	Concrete stress
f_{cu}	Characteristic concrete cube strength
f_n	Normal pressure
f_{sc}	Steel compression stress
$f_{sc\ col}$	Theoretical compressive stress in column starter bars above base slab
f_y	Characteristic strength of reinforcement
K	A constant
l	Embedded length of bar
l_a	Anchorage length of bar
M	Bending moment
x	Neutral axis depth
z	Lever arm
α_e	Modular ratio
ε_c	Concrete strain
ε_s	Steel strain
ϕ	Bar size
ρ	Tension steel ratio (A_s/bd)

1. INTRODUCTION

The design of reinforced concrete column bases, particularly with regard to bond stresses in column starter bars, seems to vary widely. In pracetice two basic approaches to the design of concrete bases exist, namely :

(a) to consider bending and shear only to determine base thicknesses and to ignore compression bond stresses, and

(b) to consider the need for the base thickness to be sufficient to ensure a safe bond stress for the column starter bars.

The British[1] and American Codes[2] call for both bending and shear to be considered in the design of concrete bases. The ACI Code[2], however, requires in addition that where transfer of force is accomplished by reinforcement, the development length to be sufficient to ensure safe bond stresses. In BS CP110 allowable, bond stresses for compression bars are given but the consideration of bond stresses in the design of column bases is not mentioned in the relative clauses.

Astill and Al-Sajir[6] illustrated through a comparison that a thinner base is obtained if the base thickness is determined by shear than when a bond stress criteria for fully stressed column bars is used.

Astill and Martin[3] emphasise that bond stress should be considered while Allen[4] ignores compression bond stresses in the design of column bases to BS CP110.

Since many bases have been designed in which compression bond has been ignored with no ill effects or failures, it seems that the traditional, theory regarding the calculation of compression bond stresses in column bases may be conservative.

The aim of this investigation was therefore to gather more information on the distribution of bond stresses in reinforced concrete column bases.

2. LITERATURE SURVEY

2.1 Bond

Bond is defined[10] as "that property which causes hardened concrete to grip an embedded steel bar in such a manner as to resist forces tending to slide the bar longitudinally through the concrete" or[9] as "the adhesion of concrete or mortar to reinforcement" and bond strength as "the resistance to separation of mortar and cement from reinforcing steel". The intensity[10] of the resistance offered or the tangentail inter-surface stress between the concrete and the steel, is called the bond stress.

The bond stresses[13] between steel and concrete are brought about by changes in the tensile force in the steel caused by external loadings or by the layout of the reinforcement and depend on a number of parameters. The stresses may change rapidly along the bars and for this reason the idea of "conventional bond stresses" corresponding to average values along the lengths in question, was introduced. These average values are the design values for bond stresses.

2.2 Mechanism of Bond

Bond, as discussed by several investigators,[9, 10, 12] may be regarded as consisting of three components :

(a) chemical adhesion or glueing by the cement gel

(b) friction between bar and concrete caused by lateral internal forces, and

(c) mechanical interaction between concrete and steel or the keying between the concrete and bar deformations which depends on the bearing and shearing resistance of concrete.

The bond of plain bars depends mainly on the first two elements. For deformed bars, bond depends primarily on mechanical interlocking while friction and adhesion are secondary.

2.3 Anchorage Bond

To prevent bond failure an adequate anchorage length for a reinforcement bar must be provided for the development of the design stress of the bar, subject to maximum allowable bond stresses.

The anchorage length[13] of a bar depends on its surface properties, quality of the concrete, the position of the bar at concreting, the tensile force in the bar and the form of the mechanical anchorage device, if any.

2.4 Current Code Provisions for Anchorage Length

2.4.1 British Code of Practice 110 : 1972[1]:

The anchorage length required in terms of this Code is given by the equations

$$l_a \text{ (bar in tension)} = \frac{0{,}87 f_y \phi}{4 f_{bs}}$$

$$l_a \text{ (bar in compression)} = \frac{0{,}72 f_y \phi}{4 f_{bs}} \qquad (2,1)$$

and the maximum value of the average bond stress f_{bs} over the anchorage length is limited for different concrete grades and for plain and deformed bars in tension and compression. These values vary from 1,2 N/mm² for a plain bar in tension and grade 20 concrete to 3,2 N/mm² for a deformed bar in compression and concrete grade of 40 or more.

2.4.2 CEB-FIP Recommendations[13]:

The anchorage length specified is

$$l_a = \frac{0{,}87 f_y \phi}{4 f_{bs}} \qquad (2.2)$$

where $f_{bs} = 0{,}242 \sqrt{f_{cu}}$ for plain bars

and $f_{bs} = 0{,}338 \sqrt[3]{f_{cu}^2}$ for deformed bars.

Where the actual steel area (As actual) is greater than that required in the design (As calc.), the anchorage length may be reduced in the ratio $\frac{A_s \text{ calc}}{A_s \text{ actual}}$ but should not be less than the largest of 1/3l_a, 10ϕ or 150 mm.

2.4.3 ACI Code 318-71[2]:

This Code requires the anchorage length for deformed bars in compression to be

$$l_a = \frac{0{,}276 f_y \phi}{\sqrt{f_{cu}}} \qquad (2,3)$$

but not less than $0{,}0427 f_y \phi$

Where excess bar area is provided the l_a length may be reduced by the ratio of required area to area provided and may also be reduced by 25% when the reinforcement is enclosed by links.

2.4.3 Comparison of Anchorage Lengths:

The anchorage length requirements according to the above-mentioned Codes in order to develop the design ultimate stress of compression reinforcement with a characteristic yield strength of 410 N/mm² are shown in Table 2.1.

2.5 Compression Anchorage of Bars

Arthur and Cairns[11] concluded from research done on compression laps of deformed bars in columns that force is transferred from the bar in compression partly by bond stresses and partly by end-bearing of the bar on the concrete. Both these effects exert bursting forces on the surrounding concrete and the ultimate strength in bond is thus dependent on the resistance available to counteract these forces.

Compression reinforcement qualifies for higher average bond stresses than are permitted for tension steel. Roberts[14] and Astill and Al-Sajir[6] are of the opinion that the reasons for this could be to account for the elastic expansion of the compressed bar in the concrete and the additional load capacity of

TABLE 2.1

	Required Anchorage Length in Terms of Diameter of Bar l_a		
Concrete Grade	20	30	40
BS CP110 : 1972[1]	36 *	28 *	23 *
CEB Recommendations[13]	36	28	23
ACI - 318 - 71[2]	26	21	18

* These values may be divided by 1,3 when using deformed reinforcement of Type 2.

a compression bar due to end-bearing on to the concrete. Roberts indicates that the reduction in anchorage length can be expressed as a function of the concrete cube strength, bar diameter, concrete cover and yield stress of the steel.

2.6 Compression Bond in Column-to-Base Joints

Three series of tests were performed by Astill and Al-Sajir[6] on concrete base models with stub columns to investigate the strength of column-to-base joints. The following conclusions were drawn from the results :

(a) The total load carrying capacity of the column-to-base joint increased linearly with the base thickness.

(b) It also appeared from the results that the lower 200 mm of the column contributed to bond length in addition to the base thickness. In these cases the breadth of the column stubs was also 200 mm.

(c) Increases in the quantity of reinforcement in the base lead to approximately proportional increases in the joint strength.

(d) An increase in the ratio area of base to area of column lead to increased joint capacity.

(e) It appeared that the allowable bond stresses in CP110 are too low and that the bond lengths obtained by applying the general clauses of this Code would be excessive.

(f) It was proposed that a portion of the column length be included into the bond length adopted.

Anchor[5] indicates through a calculation that it is possible to consider local bond rather than average bond as the limiting stress in the calculation of anchorage lengths for column starter bars. If it is assumed that the zone of compressive stress disperses through the base at 45° and that the steel takes the compressive force which is in excess of that taken by the concrete, it is shown that the concrete in the base is always capable of taking up load quicker than the starter bars are of shedding it. If this method of calculation is adopted the bond length required may therefore be shortened.

2.7 Influence of Normal Pressure on Bond Strength

Tests were made by Untrauer and Henry[9] on 37 pull-out specimens with deformed high yield reinforcing bars. All specimens had an embedment length of 150 mm. The normal pressure was applied to two parallel faces of the bond specimens and varied from zero to approximately 16 N/mm². The following could be found from the results :

(a) The bond strength increased with normal pressure in proportion to the square root of the normal pressure when other factors are constant and with the square root of the concrete cube strength. The ultimate bond strength of all the specimens can be represented by the equation

$$f_{bs\ ult} = 1{,}29\sqrt{f_{cu}} + 0{,}39\sqrt{f_{cu}f_n} \qquad (2.4)$$

(b) The normal pressure increased the bond strength more at ultimate than at lower slip values of the reinforcing bar. This can be contributed to the fact that adhesion furnish the main bond resistance at low slip values on which normal pressure has little effect.

(c) The results show that the diameter of the reinforcing bar has little effect on the ultimate bond strength as influenced by normal pressure.

(d) The slip of the reinforcing bar increased with increased normal pressure.

3. DESCRIPTION OF EXPERIMENTS AND TESTING PROCEDURE

Five series of tests were undertaken to investigate some aspects of and factors influencing bond stresses in concrete bases. In series I to IV strains were measured at different levels in the starter bars for concrete bases varying in plan dimensions and thickness and for varying column loads and support conditions.

In series V pull-out tests on 60 concrete cube specimens varying in strength from 20-75 MPa were conducted measuring the pull-out force for a 16 mm diameter deformed bar under varying biaxial normal pressures applied to the parallel faces of the concrete cubes.

3.1 Series I to IV : Tests on Concrete Bases

3.1.1 Details of Concrete Bases and Reinforcement :

Details of Concrete Bases I to IV are given in Table 3.1 referring to Figures 3.1 and 3.2.

Bases I and II were existing bases previously used for a similar series of tests[7] while Base III was newly designed and constructed for testing.

Base I was designed for an ultimate column load of 310 kN to satisfy the requirements of BS CP110 in all respects. Base II was designed for the same ultimate column load but in terms of the requirements of BS CP110 inadequate anchorage bond length was allowed for the column starter bars.

Base III was designed for an ultimate column load of 394 kN with inadequate anchorage bond length allowed as for Base II but smaller in base area.

Base IV was obtained from Base III through cutting off strips 325 mm wide on both sides of the column in one direction only to reduce one plan dimension from 1200 mm to 550 mm. Transverse reinforcement was unavoidably cut through and was exposed on the sides.

3.1.2 Details of Strain Gauges on Starter Bars :

Type KFC-5-C1-11 (5 mm gauge length) electrical strain gauges in conjunction with a Huggenberger Resistance Meter were used

TABLE 3.1

Base	Dimensions * (mm)					Concrete Cube Strength @ 28 days (N/mm^2) f_{cu}		Reinforcement *				Cover to Reinforcement (mm)		Ultimate Design Load (kN)
								Columns			Bases			
	A	B	C	D	E	Column	Base	a	b	c	d	Column	Base	
I	1600	1600	440	150	470	38	31	4Y12	4Y12	4R8	10Y12	30	25	310
II	1600	1600	250	150	470	36	43	4Y12	4Y12	4R8	8Y12	30	25	310
III	1200	1200	250	150	440	24	26	4Y12	4Y12	6R8	6Y12	30	25	394
IV	1200	550	250	150	440	24	26	4Y12	4Y12	6R8	2Y12+	30	25	394

* Refer to Figures 3.1 and 3.2
\+ Refer to Cl. 3.1.1

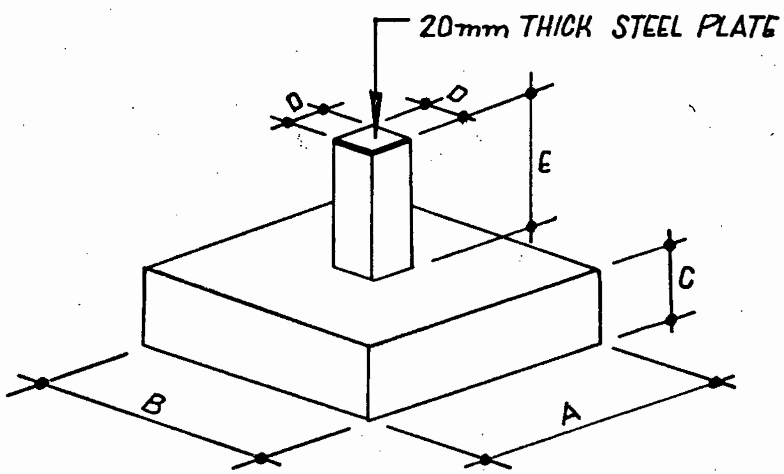


Figure 3.1

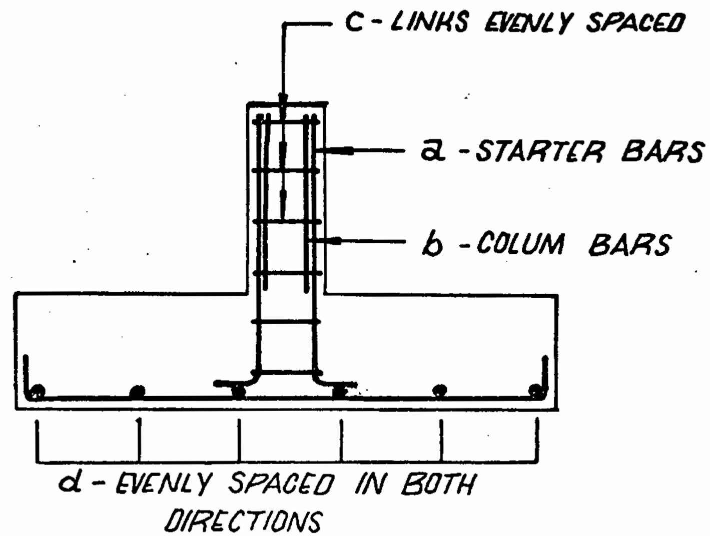


Figure 3.2

for strain measurement on the starter bars.
Positions in relation to the top of the footing where the gauges were attached to the reinforcing bars are given in Table 3.2 and 3.3 referring to Figures 3.3 and 3.4 respectively. Each gauge was attached to the bar using CC-15A gauge cement on a small area of approximately 5 x 20 mm filed smooth to remove irregularities and finally protected with C5 waterproofing. The terminal leads were positioned to project at right angles from the reinforcement and the leads from gauges in the column and base were bundled separately and taken to the surface of the concrete via the shortest route.

3.1.3 Testing Procedure :

The support conditions for the different tests performed on each base were varied in order to simulate varying support conditions in practice as well as to investigate the influence of the stresses in the base due to that particular condition on the anchorage bond stresses. The following support conditions were considered :

(a) Base supported on a uniform elastic foundation.

(b) Base supported on an in-elastic foundation.

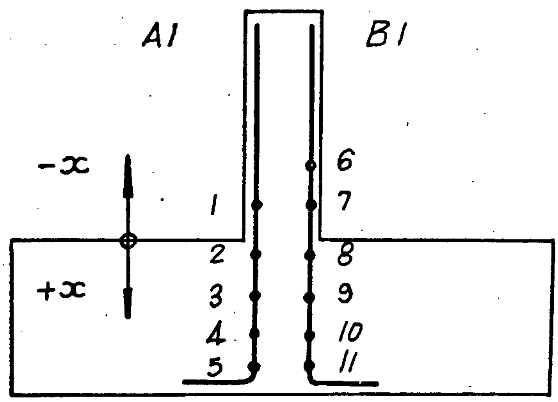
Condition (a) permits bending moments to develop uniformly in two directions in the base slab while condition (b) permits no bending moment in the base slab.

In addition to the abovementioned conditions, the same bases were tested for an eccentric column load with the base supported on an in-elastic foundation. Base IV was specifically made to be tested for the case where bending moment would develop in only one direction in the base slab.

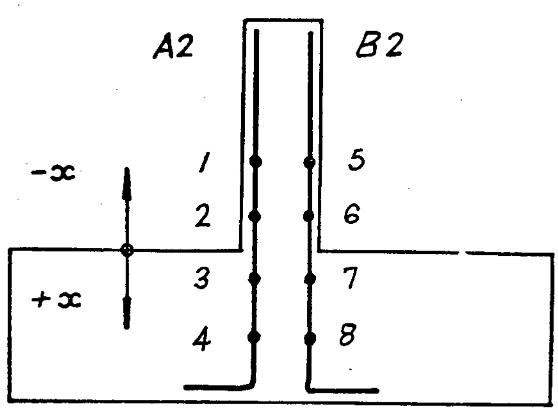
TABLE 3.2

Base	Bar No.	x - Values * (mm)										
		Gauge No.										
		1	2	3	4	5	6	7	8	9	10	11
I	A_1	- 66	+41	+135	+236	+336						
	B_1						−163	−65	+35	+137	+235	+346
II	A_2	−160	−63	+ 36	+130							
	B_2					−165	- 63	+35	+134			

* Refer to Figure 3.3



(a) Base I



(b) Base II

Figure 3.3

Position of Gauges on Diagonally Opposite Bars.

TABLE 3.3

Base	Bar No.	x - Values * (mm)								
		Gauge No.								
		1	2	3	4	5	6	7	8	9
III & IV	1a	-288	-188	-88	+12	+112				
	1b	-288	-188	-88	+12	+112				
	2a						-240	-140	-40	+60
	2b						-233	-133	-33	+67

* Refer to Figure 3.4

Bases III & IV.

(a) (b)

Figure 3.4

3.1.3.1 Tests Performed on Bases.

The tests performed on the bases in each Series are given in Table 3.4.

Column loads were applied in increments of generally 40 kN to a total load between 400 kN and 500 kN for each condition and the starter bar steel strains were noted after each increment in load.

3.1.3.2 Testing Equipment and Loading Systems.

The concrete bases were loaded in a test bed equipped with vertically mounted overhead hydraulic jacks of 200 t and 500 t capacities respectively. Loads were transmitted axially to the bases through a system of ball hinges built into the jacks. The hydraulic jacks were elctrically operated with application rate control facilities.

A uniform elastic foundation was simulated by 16 equally spaced support points over the base slab. To ensure, however, that the support reactions at each of the 16 points were equal, the bases were loaded upside down i.e. the load was actually applied over the base slab and the specimen supported on the stub column. Handling and setting up of the specimens were furthermore eased through using this loading system. Details of the system are shown in Figure 3.5.

Two 200 t jacks were used to apply the 16 equal point loads to the base slab through simply supported steel beam systems, each system comprising of two parallel I-beams transmitting 2 point loads each through 50 mm diameter flat washers and connected with a cross beam. The load from each jack was equally distributed to two of the systems thus described through a simply supported connecting beam. The layout of the 16 point loads on the bases is shown in Figure 3.6.

For the case of no bending in the base slabs the specimens were loaded with a single 500 t jack positioned concentrically over

TABLE 3.4

Series	Base	Condition			
		No Bending in Base Slab	Bending in Two Directions in Base Slab	Bending mainly in One Direction in Base Slab	Eccentric Column Load
I	I	X	X		X
II	II	X	X		X
III	III	X	X		X
IV	IV	X		X	

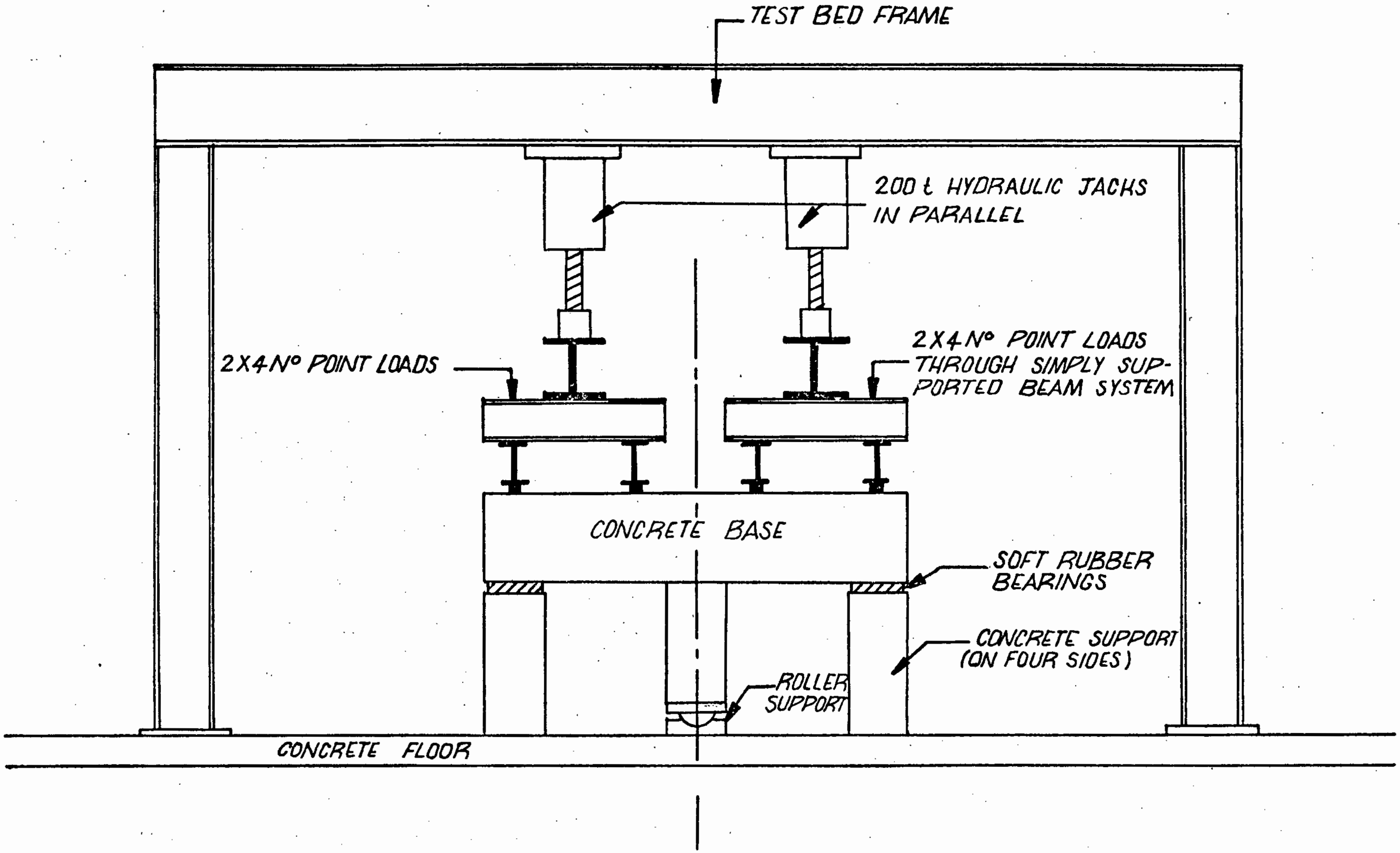
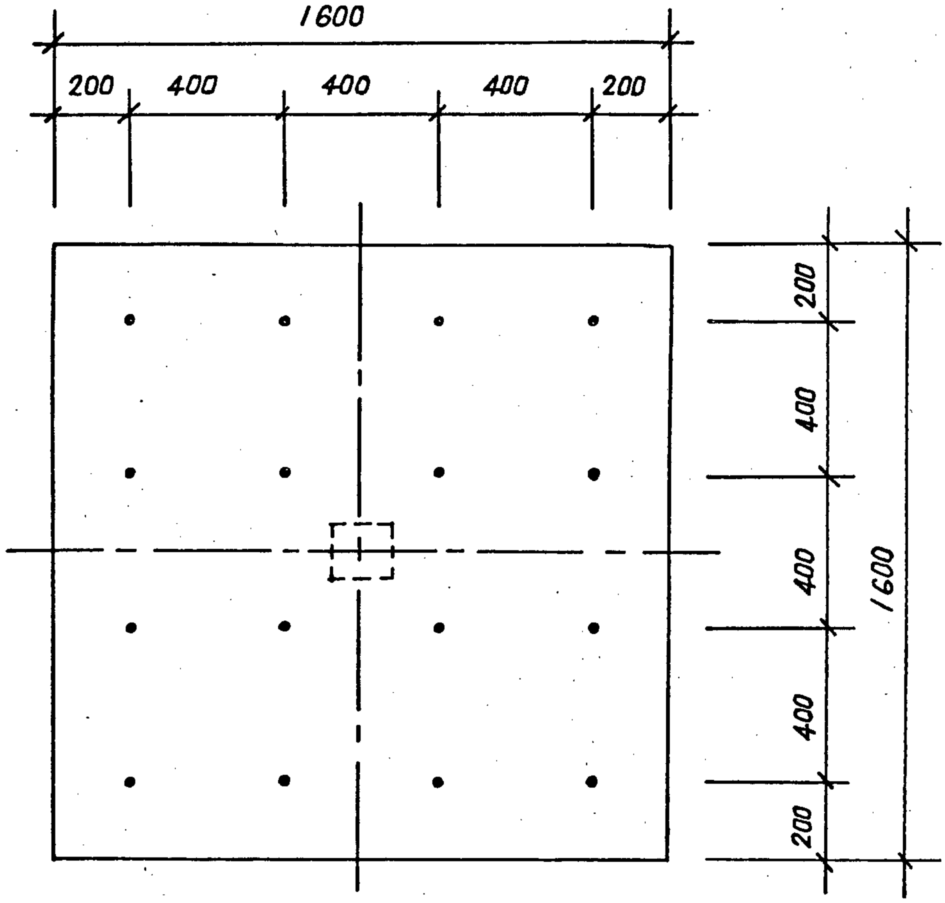
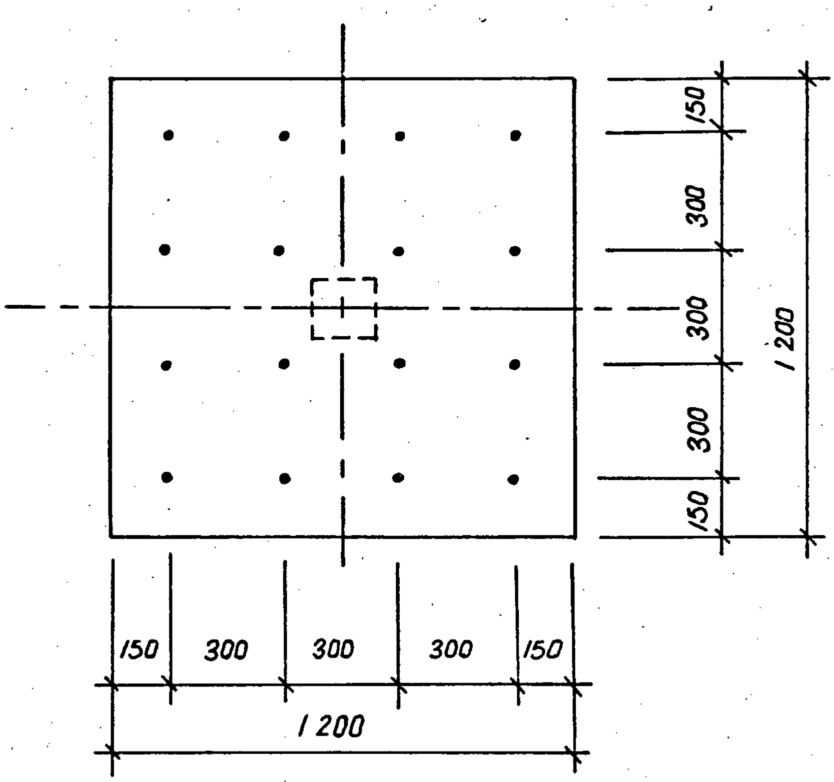


Figure 3.5

Loading System for Simulated Uniform Elastic Foundation



(a) Bases I & II

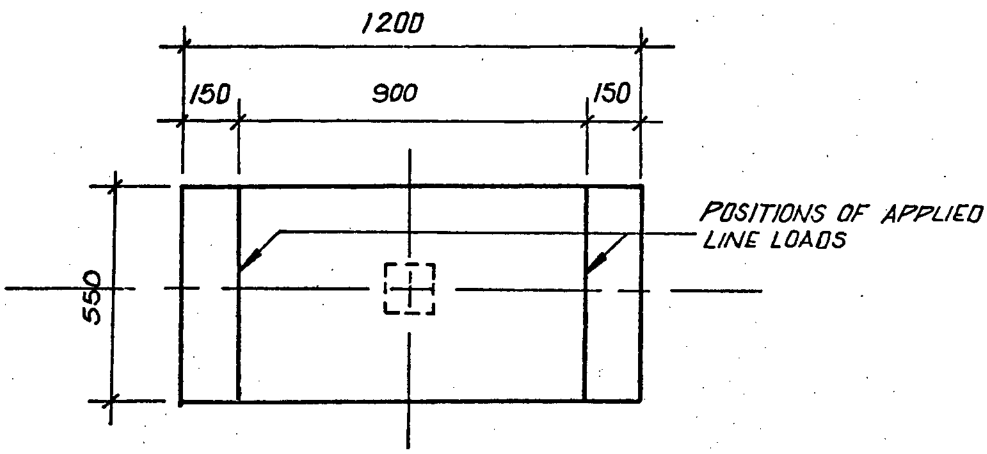


(b) Base III

Figure 3.6
Layout of 16 Point Load on Bases

the column support on the base slab. Eccentric column loads were similarly applied except that the jack was eccentrically positioned over the column and the column accordingly supported. The eccentricity in the two main perpendicular directions was 12,5 mm.

For the case of bending mainly in one direction (Base IV) use was made of two 200 t jacks to apply line loads through steel beams on the base slab at the positions indicated in Figure 3.7.



Base IV

Figure 3.7

Due to the system of ball hinges in the line of loading, problems were experienced in some instances with the stability of the system. In such cases use was made of a horizontal bracing system of wooden struts clamped diagonally to the base and four supporting columns of the test bed respectively. During setting up operations ~~the~~ concrete bases were supported on 20 mm soft rubber bearing pads on concrete block supports as shown in Figure 3.5. Use was also made of dial gauge deflection meters on the four sides of the base slab to monitor the relative deflection of the slab during loading.

3.2 Series V : Pull-out Tests

The object of the pull-out tests was to determine the influence of biaxial normal pressure on the bond strength between steel and concrete.

3.2.1 Description of Specimens and Preparation :

Sixty specimens were prepared, each consisting of a 16 mm diameter deformed high yield reinforcing bar embedded in a 150 x 150 x 150 mm concrete cube. Details are shown in Figure 3.8.

For each specimen cast, a control cube was cast and tested for cube strength after 28 days. The specimens and control cubes were damp cured at room temperature. Concrete cube strengths varied uniformly with approximately 10 specimens having cube strengths falling in each of 6 ranges between 20 - 75 N/mm². Cube strengths of each specimen are given with the test results in Appendix 6.

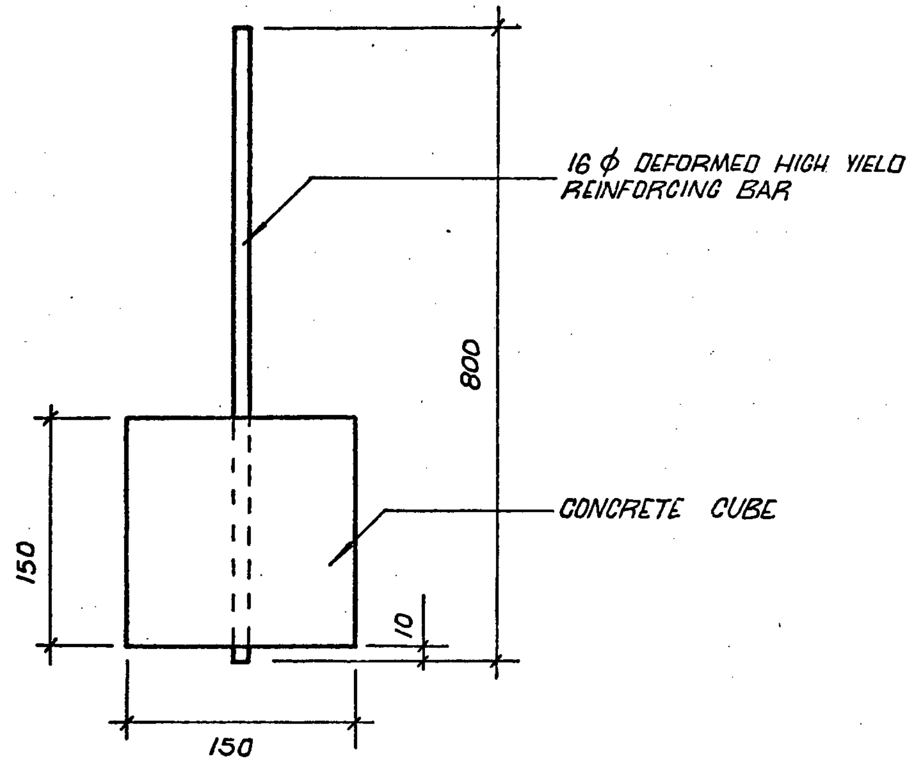


Figure 3.8

Details of Pull-out Test Specimen

3.2.2 Testing Procedure.

Nine out of the ten specimens per concrete strength range were tested with an applied constant biaxial normal pressure varying from approximately 0,6 to 6,0 N/mm² for the different specimens while one specimen per range was tested with zero normal pressure. The ultimate pull-out force for each specimen was measured and recorded.

3.2.3 Testing Equipment and Loading System.

A special steel frame was manufactured to apply a constant uniformly distributed and equal normal pressure in the two perpendicular directions of the concrete cube by means of two 20 t manually operated hydraulic jacks coupled in parallel. The planes of application of the normal pressures are shown in Figure 3.9. Details of the steel frame are given in Appendix 6.

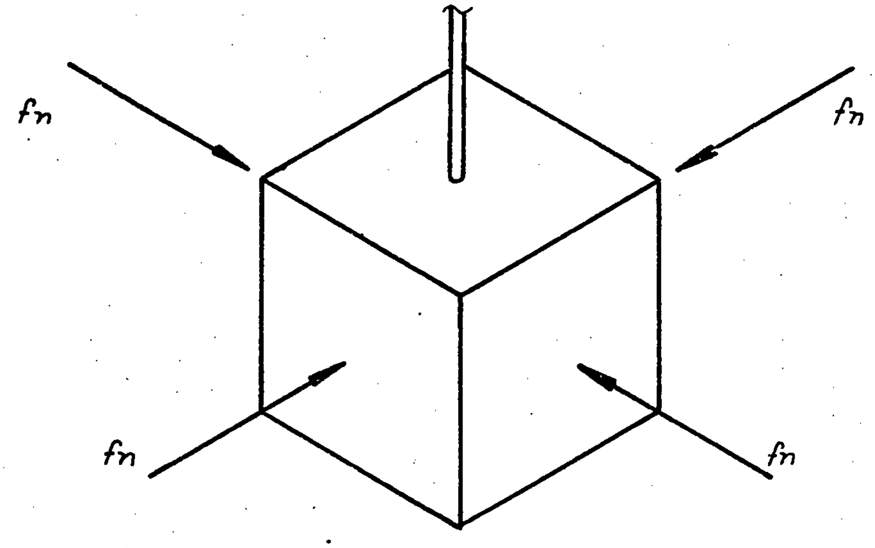


Figure 3.9
Planes of Application of Normal Pressure

An hydraulic testing machine with 500 kN capacity was used to apply the pull-out force. The specimen was placed in the steel frame which was mounted on the bed of the testing machine and the normal pressure applied to the concrete in the directions indicated above.

Softboard, 10 mm thick, was placed between the concrete cube and the 150 mm outside diameter bearing ring used to transmit the load to the concrete.

The load was then applied to the reinforcing bar and increased at a constant rate until the ultimate bond was reached while the normal pressure was kept constant throughout the test.

4. FINITE ELEMENT STRESS ANALYSIS

A linear analysis of the stresses in Base III for the loading case of bending in two directions in the base slab was done on a Univac 1100 computer using PAFEC75 three dimensional finite element analysis.

4.1 Model

All reinforcement was ignored and the concrete modelled as an elastic material with the following constants :

Modulus of Elasticity E_c = 30 kN/mm²
Poisson's ratio = 0,20

Only one quarter in plan of the base was analysed due to symmetry and rectangular 8-node elements were used to represent the base as shown in Figure 4.1.

4.2 Loading

Three loading conditions were analysed viz.:

(a) Self weight
(b) 16 Point loads applied on base slab
(c) Combination of (a) and (b)

The 16 point loads of 1 kN each were applied at the corresponding nodes at the positions indicated in Figure 3.6(b).

4.3 Stresses

The average stresses in the column and column core through the base in the x-, y- and z- directions were calculated from the node stresses for a total column load of 200 kN. These stresses are shown in Figures 4.2 and 4.3 plotted against the depth of the column and base.

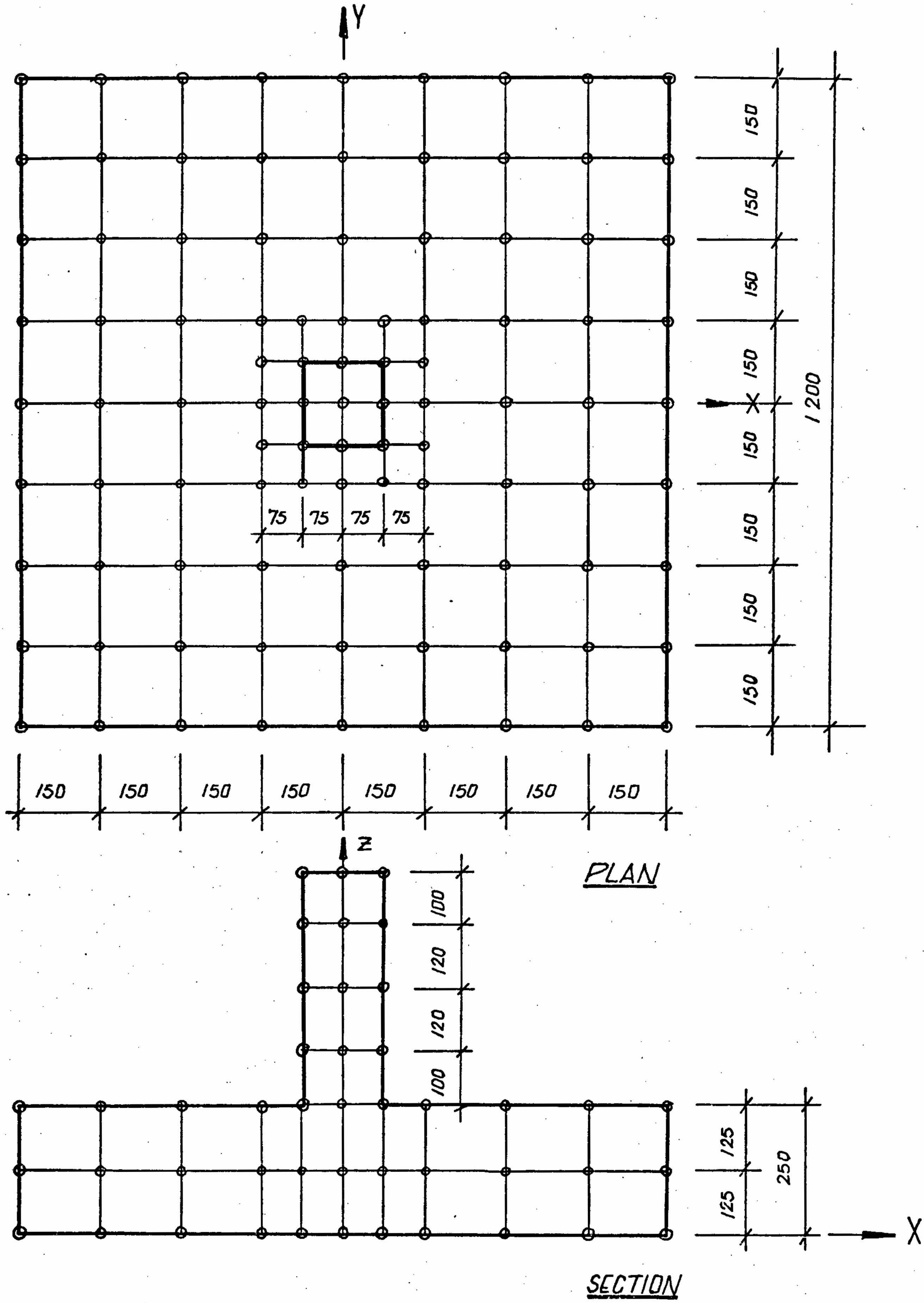
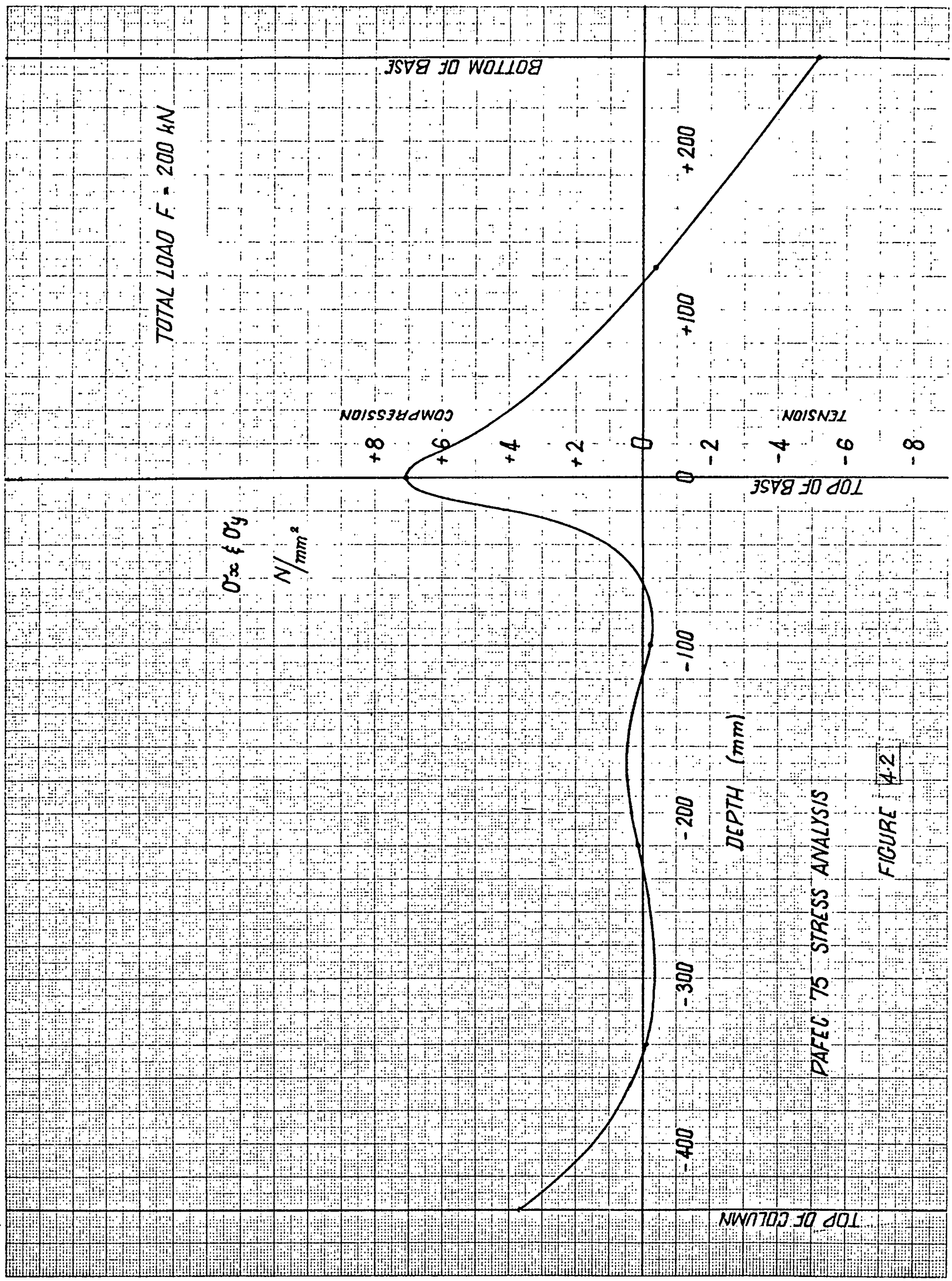
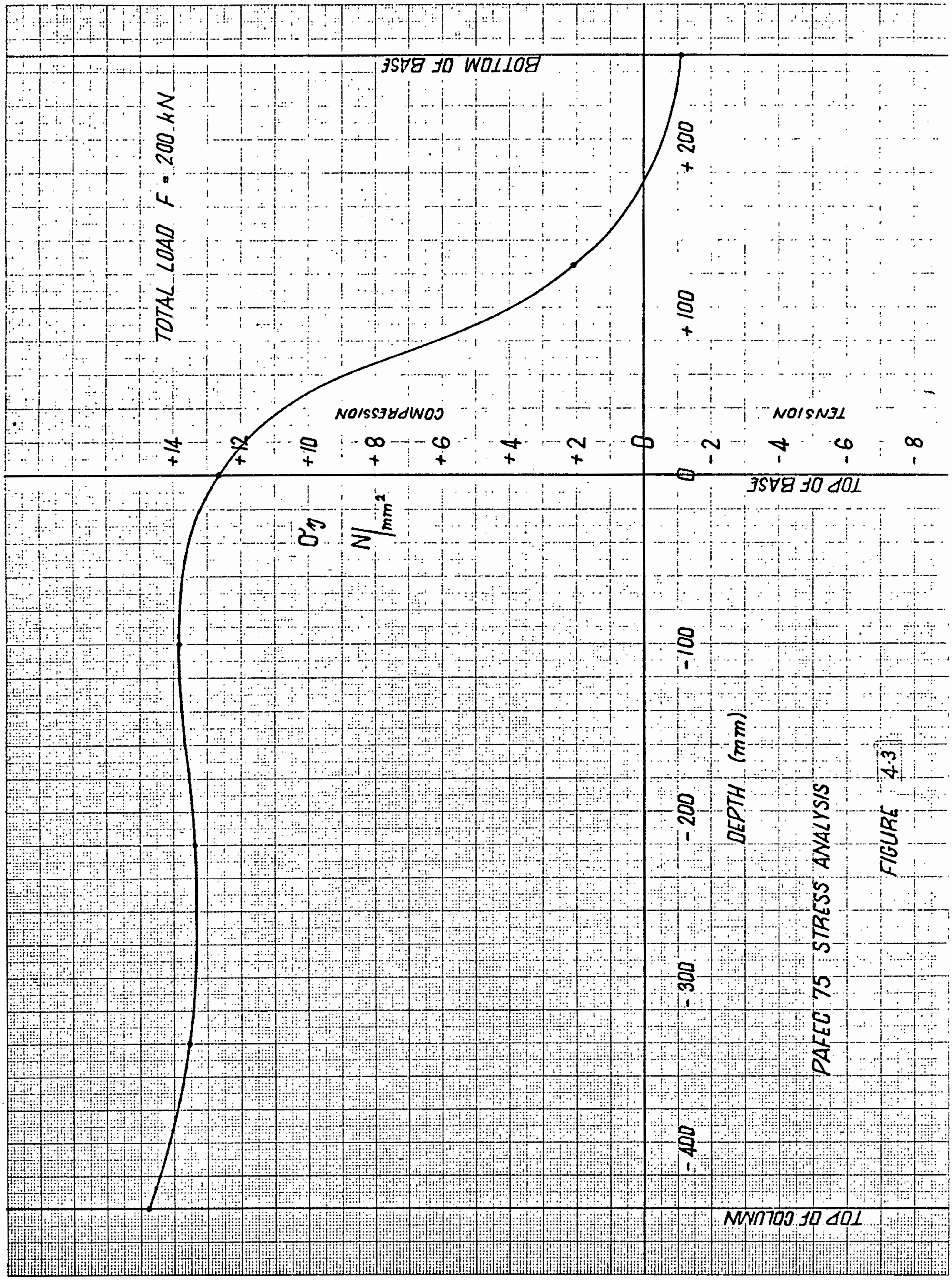

Y
150
150
150
150
150
150
150
150
1 200
X
75
75
75
75
150
150
150
150
150
150
150
150
Z
PLAN
100
120
120
100
125
125
250
X
SECTION

Figure 4.1


TOTAL LOAD F = 200 kN
BOTTOM OF BASE
COMPRESSION
TENSION
+8
+6
+4
+2
0
-2
-4
-6
-8
TOP OF BASE
σ_x & σ_y
N/mm²
+200
+100
0
-100
-200
-300
-400
DEPTH (mm)
TOP OF COLUMN
PAFEC 75 STRESS ANALYSIS
FIGURE 4.2



PAFEC 75 STRESS ANALYSIS

FIGURE 4.3

5. RESULTS AND CALCULATIONS

5.1 Results from Series I to IV

5.1.1 Steel Strains :

The steel strains at the positions and for the different loading conditions for each base as described in section 3 were measured and recorded. A typical example of the strains measured are given for Base I in Appendix 1.

5.1.2 Bond Stresses :

Bond stresses were obtained from the above results by considering the forces that act on the portion of bar between two strain gauges.

Considering the equilibrium of forces acting on the portion of bar shown in Figure 5.1 :

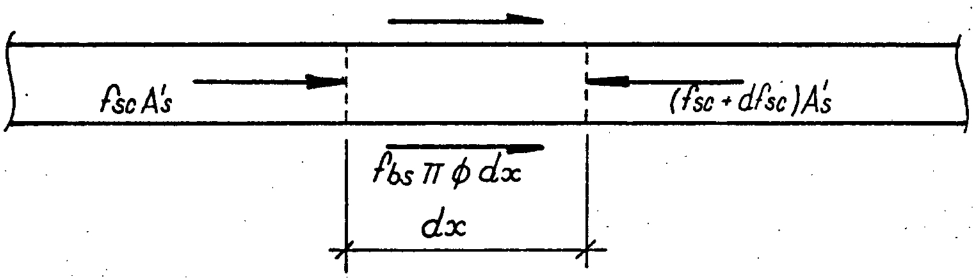


Figure 5.1

$$f_{bs}\ \pi\phi\, dx + A'_s f_{sc} = A'_s(f_{sc} + df_{sc})$$

Hence

$$f_{bs} = K \frac{df_{sc}}{dx} \qquad (5.1)$$

Where $K = \dfrac{A'_s}{\pi\phi}$

From equation (5.1) it follows that the bond stress is proportional to the slope of the steel stress curve for the bar. An example of a typical steel stress curve is given in Appendix 2.

Bond stresses along starter bars in each base for the different loading conditions were calculated from equation (5.1) substituting the appropriate values for K and

$df_{sc} = d\,\varepsilon_s\,E_s$ taking $E_s = 200$ kN/mm²

The calculated bond stresses for each base are also given in Appendix 2.

5.1.3 Steel Stresses :

The compression stresses in the starter bars at the levels of the gauges were calculated from the equation

$$f_{sc} = \varepsilon_s\,E_s \qquad (5.2)$$

taking E_s as above.

The theoretical compression stresses in the starter bars above the base slab may be calculated from

$$F = f_c A_c + f_{sc\ col} A'_s$$

rearranging and introducing the elastic modular ratio

$$f_{sc\ col} = \frac{\alpha_e\,F}{A_c + \alpha_e\,A'_s} \qquad (5.3)$$

The calculated values for $f_{sc\ col}$ for the incremental loads on the columns are given in Appendix 3.

Average values of $\dfrac{f_{sc}}{f_{sc\ col}}$ at the corresponding positions on the starter bars in each base were subsequently plotted against the depth in the base with reference to the top of the base slab, for each loading condition. A typical curve is shown in Figure 5.2 and the curves for each base are given in Appendix 4.

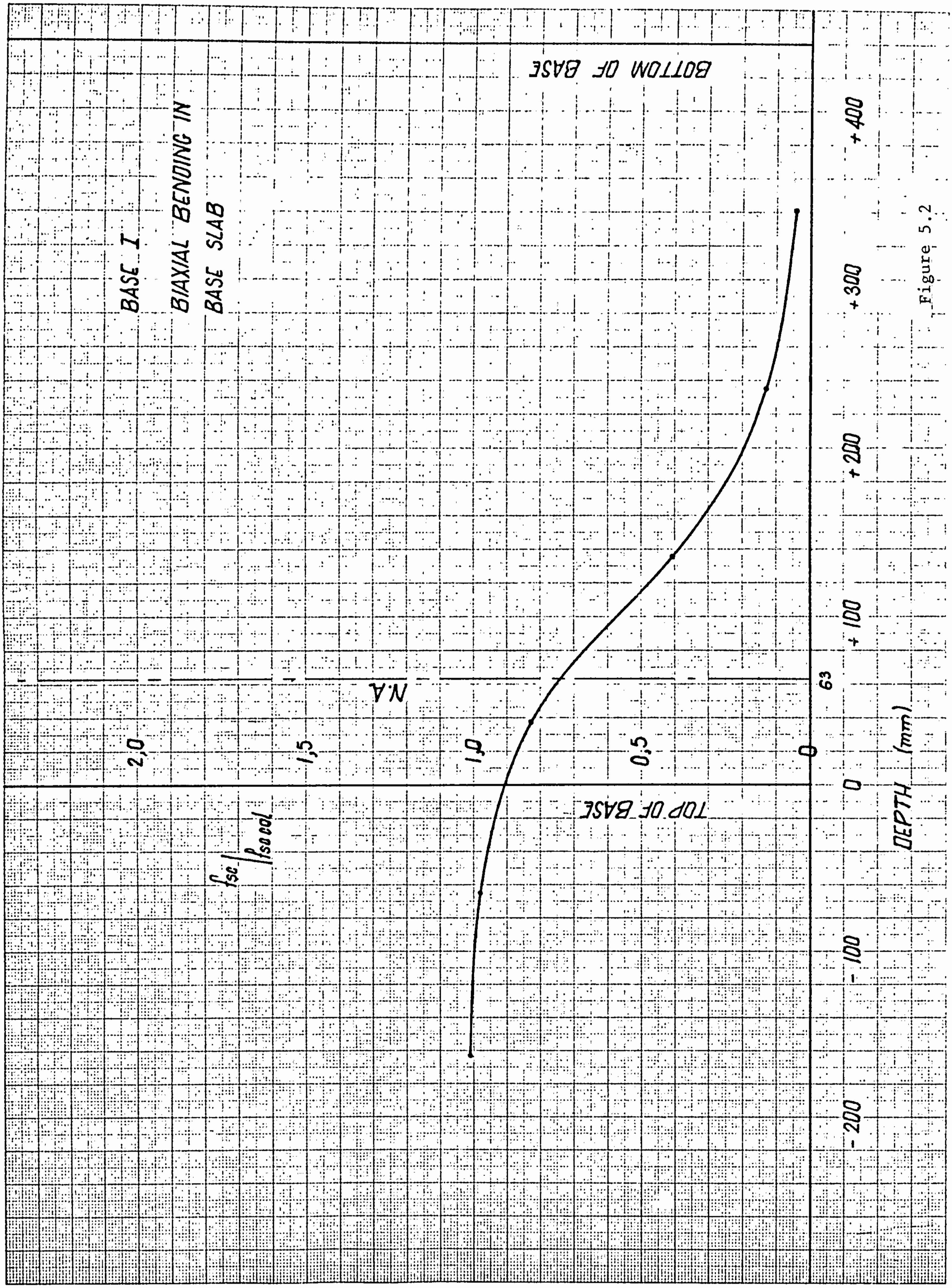

BASE I
BIAXIAL BENDING IN
BASE SLAB
BOTTOM OF BASE
TOP OF BASE
N.A.
63
2,0
1,5
1,0
0,5
0
$f_{sc}/f_{sa\,cal}$
DEPTH (mm)
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400

Figure 5.2

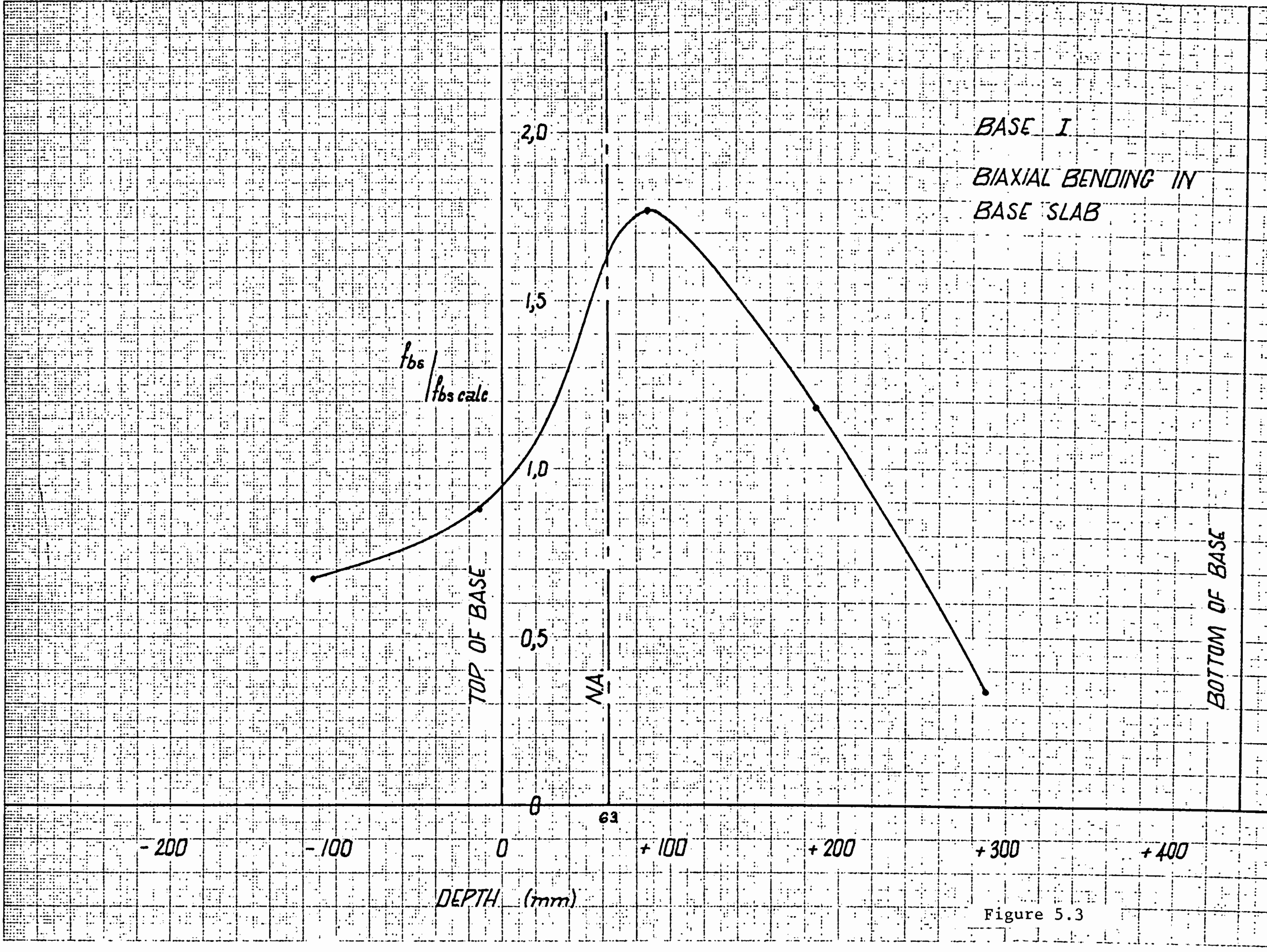

BASE I
BIAXIAL BENDING IN
BASE SLAB
fbs / fbs calc
2,0
1,5
1,0
0,5
0
63
TOP OF BASE
N.A.
BOTTOM OF BASE
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

Figure 5.3

5.1.4 Bond Stress Distribution in Base :

To indicate the distribution of bond stresses in the bases for the different loading conditions, the average values of $\frac{f_{bs}}{f_{bs\ calc}}$ were also plotted against the depth in the base where f_{bs} is calculated from equation (5.1) and $f_{bs\ calc}$ is the calculated bond stress from the equation

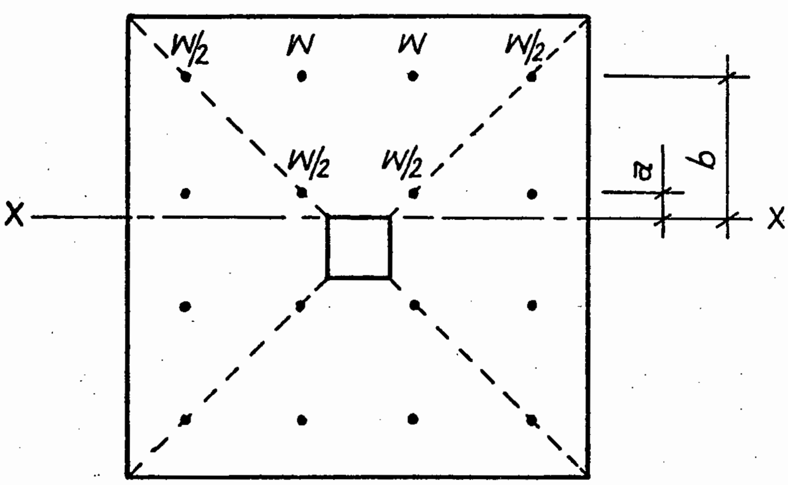
$$f_{bs\ calc} = \frac{F_{sc\ col}}{\pi\ \phi\ l_a} \qquad (5.4)$$

$F_{sc\ col}$ is the calculated force in the starter bar and the anchorage length l_a is taken as the depth of the base minus concrete cover. A typical curve is shown in Figure 5.3 and the curves for each base are given in Appendix 5.

5.1.5 Bending Moments in Base Slabs :

Bending moments in the bases due to the 16 point loads on the base slabs may be calculated as follows :

Bases I to III



Plan on Base Slab

Figure 5.4

$M_{xx} = 3Wb + Wa$ Where $W = \frac{F}{16}$

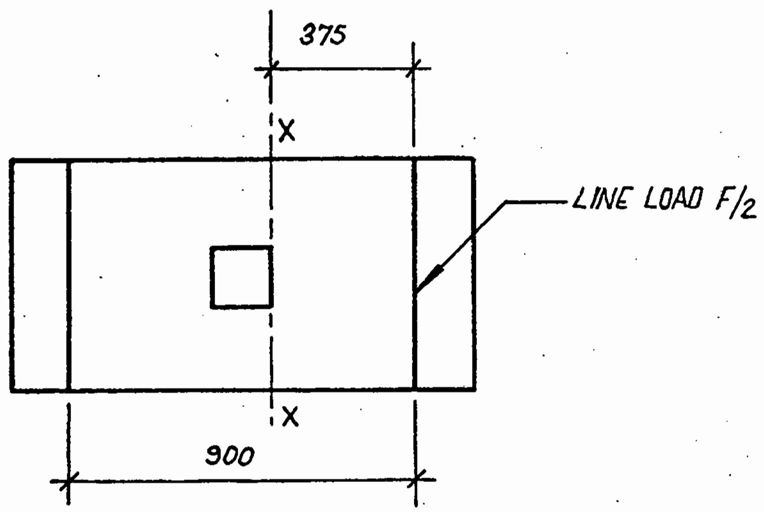
For Bases I and II

a = 0,125 m and b = 0,525 m

and for Base III

a = 0,075 m and b = 0,375 m

Base IV



Plan on Base Slab

Figure 5.5

$M_{xx} = 0{,}375\ F/_2$

The calculated bending moments in each base for all the values of F are given in Appendix 3.

5.1.6 Compressive Stresses in Concrete due to Bending :
The maximum compressive stresses in the concrete due to the bending of the base slabs were calculated according to the classical elastic theory from the equation

$$f_{c\ max} = \frac{M_{xx}}{I_c} x \tag{5.5}$$

where $x = d(-\alpha_e \rho + \sqrt{\alpha_e^2 \rho^2 + 2\alpha_e \rho})$

and I_c = second moment of area of equivalent section

$= \frac{1}{3} bx^3 + \alpha_e \rho bd(d-x)^2$

The calculated values of $f_{c\ max}$ are tabulated for each base slab in Appendix 3.

5.2 Results from Series V

The ultimate pull-out force, applied normal pressure and the 28 day concrete cube strength for each specimen tested were recorded.

5.2.1 Ultimate Bond Stress :

The ultimate bond stress reached for each specimen is given by the equation

$$f_{bs\ ult} = \frac{F\ ult}{l\pi\ \phi} \tag{5.6}$$

where F_{ult} = ultimate pull-out force

and l = embedded length of bar.

5.2.2 Bond Stress, Cube Strength and Normal Pressure Relationship :

As it was found earlier[9] that the bond stress increases approximately in proportion to the square root of the cube strength and the square root of the normal pressure, the ratio $\frac{f_{bs\ ult}}{\sqrt{f_{cu}}}$ was plotted against $\sqrt{f_n}$ A linear relationship of the form $f_{bs} = (A + B\sqrt{f_n})\sqrt{f_{cu}}$ was found and the constants determined by least squares as

A = 1,39 and B = 0,35

The relationship is shown in Figure 5.6 and the measured and calculated values of the abovementioned variables for each specimen are given in Appendix 6.

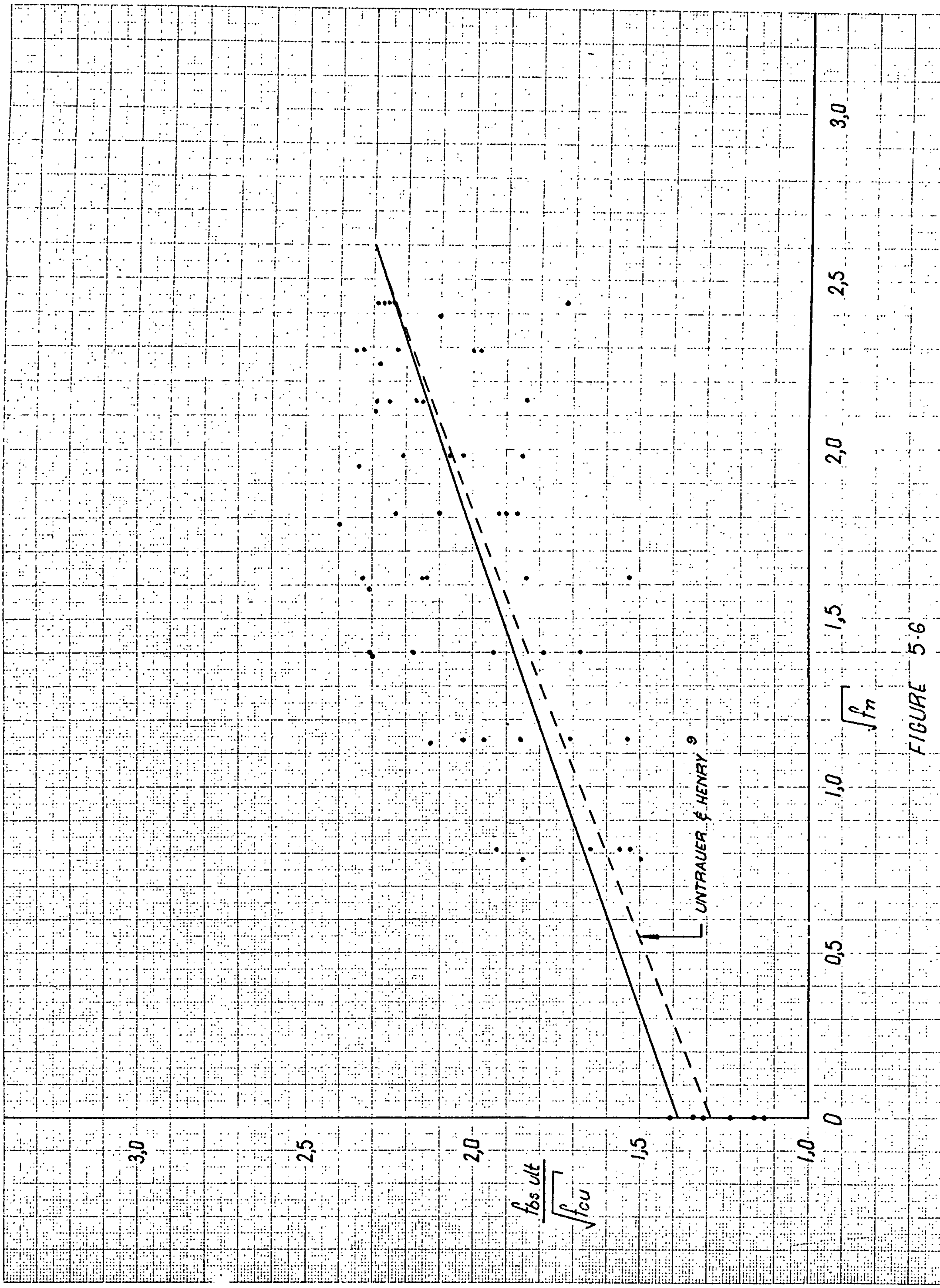

UNTRAUER & HENRY 9
0
0,5
1,0
1,5
2,0
2,5
3,0
1,0
1,5
2,0
2,5
3,0
$\frac{f_{bs\ ult}}{\sqrt{f_{cu}}}$

FIGURE 5·6

The relationship found by Untrauer and Henry[9] from pull-out tests on specimens with normal pressure in one direction is also shown in Figure 5.6.

6. DISCUSSION OF RESULTS

6.1 Finite Element Stress Analysis

6.1.1 Transverse Stresses in Column and Column Core through Base : From the distribution of these stresses shown in Figure 4.2 it can be seen that the transverse stresses in the column is approximately zero except at the top of the column where compression stresses exist where the load is applied. From about 60 mm above the top of the base compression stresses develop to reach a maximum along the top of the base and then decreases uniformly to the neutral axis of the base to develop maximum tension stresses at the bottom of the base.

The distribution of the stresses shown would not apply directly to a concrete base since an elastic material was assumed in the analysis. However, it is clear that the maximum normal compression stresses on the column starter bars develop in the lower region of the column and upper part of the base for the condition of biaxial bending in the base slab.

6.1.2 Axial Stresses in Column and Column Core through Base : The distribution of these stresses are shown in Figure 4.3. An approximately uniform axial compression stress occurs in the column to the top of the base from where it decreases rapidly to approximately zero over 2/3 of the depth of the base slab. It is thus clear that the axial stress in the column is dispersed at a fairly high rate through the base slab on reading the top of the base. As mentioned above, these stresses apply for the case of biaxial bending in the base slab.

6.1.3 It can therefore be stated from the results in Figures 4.2 and 4.3 that :

(a) The lower approximately 100 mm of the column and upper 2/3 of the base slab is in a state of triaxial compression.

(b) The maximum biaxial normal pressure on the column starter bars occurs over this region.

(c) The axial stresses in the column are dispersed rapidly into the base slab to zero over approximately 2/3 of the depth of the base slab.

6.2 Series V - Pull-out Tests

(Refer to Appendix 6)

6.2.1 In the majority of specimens tested with normal pressure, the bar was pulled out of the concrete cube without splitting the concrete. The concrete failed in bearing on the lugs of the deformed bar and the concrete between the lugs was powdered and displaced in the direction of the applied load.

In the specimens tested without normal pressure, tension cracks developed radially from the bar and split the cube into several pieces. The concrete did not fail in bearing on the lugs as the pattern of the bar was almost undisturbed in the concrete after failure.

6.2.2 The applied force in a pull-out test must cause some slip for stress-strain compatibility of the steel and concrete. The adhesion part of bond will thus dominate at low applied loads and as the load increases and loss of adhesion progresses along the bar, friction between the bar and concrete and the bearing forces against the lugs will provide the bond resistance at ultimate. It would therefore be expected that these mechanical actions be improved with the addition of normal pressure to provide a higher bond strength.

6.2.3 In Figure 5.6 it can be seen from the relationship between $\sqrt{f_n}$ and $f_{bs\ ult}/\sqrt{f_{cu}}$ plotted for the results obtained from the pull-out tests, that the ultimate bond strength increases with increased normal pressure and that the increase is proportional to the product of the square root of the normal pressure and square root of the compressive strength of the concrete.

6.2.4 It is also evident from Figure 5.6 that the increase in ultimate bond stress was more, by a small margin, with the application of normal pressure in two perpendicular directions than with the normal pressure applied only in one direction on the cube as found by Untrauer and Henry[9]. It would, however, be expected that the ultimate bond stress for the case of zero normal pressure be the same for both series of tests, but the discrepancy may be attributed to the fact that the pull-out tests by Untrauer and Henry[9] were performed on specimens with varying bar sizes as opposed to the constant bar size used in this series. This is confirmed by the values plotted by Untrauer and Henry[9] for the individual bar sizes tested.

6.2.5 Considering the above, it is of importance to note that the rate of increase in bond stress is practically the same for both cases of applied normal pressure. It thus appears as if the application of normal pressure in an additional direction did not influence the increase in bond strength significantly. This phenomenon may be explained if it is assumed that the bearing of the concrete on the lugs of the bar is the limiting factor at ultimate for the bond strength and that the applied normal pressure does not affect the bearing significantly at ultimate. On these assumptions it appears furthermore that the increase in friction resistance between the concrete and the bar constitutes a major part of the increased bond strength at working stresses.

6.2.6 It can be calculated from the relationship shown in Figure 5.6 that the increase in bond strength for a bar under biaxial normal pressure of 8 N/mm^2 embedded in concrete of 25 N/mm^2 strength is approximately 71% and for a normal pressure of 2 N/mm^2 the increase in bond strength is approximately 36%.

6.3 Series I to IV - Tests on Bases

The maximum total load applied on any one base during testing was 500 kN and in no case could any signs of bond failure of the starter bars be observed. It can therefore be assumed that the bond stresses measured and given in Appendix 2 are lower than the ultimate bond stresses for the column starter bars.

6.3.1 Distribution of Compression Stress in Column Starter Bars : (Refer to Appendix 4)

(a) No bending in base slab.

The compression stress measured in the starter bars for Base I is approximately equal to the calculated stress $f_{sc\ col}$ above the base slab and decreases from the top of the base to a value of approximately 0,25 $f_{sc\ col}$ at ½ depth of the base slab. The increase in compression stress may be attributed to the influence of the stress concentration in the region where the load was applied on the bottom of the base for the case of no bending in the base slab.

For Bases II and III the compression stresses in the starter bars above the base slab are well above the calculated stresses and decrease upon entering the base slab to an average value of approximately 0,65 $f_{sc\ col}$ at ½ depth of the base slab. This value is considerbly higher than the value for Base I. If a constant rate of dispersion of the stress in the base is assumed and the reduced thickness of the slab considered, the higher value would be expected as the values compared are not at the same depth from the top of the base. This may also be influenced significantly by the induced stresses in the concrete due to application of the load on the base slab due to the thinner base slab.

The high stresses in the starter bars in Base IV can be attributed to the limiting of the dispersion of the column stresses in the base slab through the reduction of the plan area of the base.

(b) Bending in Base Slab.

The measured compression stress for Base I again equals the calculated stress in the column and reduces rapidly from approximately the neutral axis depth to a value of 0,05 $f_{sc\ col}$ at 0,77 depth of the base slab.

The stresses for Base III follow approximately the same pattern except that a minimum value of 0,25 $f_{sc\ col}$ is reached at 0,44 depth of the base slab.

In Bases II and IV stresses considerably higher than the calculated stresses occur in the column above the base slab but drop sharply over the lower region of the column and region above the neutral axis in the base slab to an average value of 0,33 $f_{sc\ col}$. Below the neutral axis a minimum value of 0,15 $f_{sc\ col}$ is reached at 0,44 depth of the base slab.

The stresses in Base III may be compared with the axial stresses found through the finite element stress analysis and are found to follow the same pattern of distribution along the starter bars.

In general it is of importance to note that the high starter bar compression stresses in the column reduce rapidly over approximately ½ depth of the base to low stresses of the order of 0,64 $f_{sc\ col}$ for the case of no bending in base slab and 0,18 $f_{sc\ col}$ for the case of biaxial bending in base slab.

The high rate of dispersion of the column stresses in the base slab found in this series of tests confirms the findings of Anchor[5] that the concrete in the base slab would be expected to be capable of taking up load quicker than the starter bars be of shedding it.

6.3.2 Distribution of Column Starter Bar Bond Stresses :

(Refer to Appendix 5)

As shown earlier, the bond stresses are proportional to the slope of the steel stress curves discussed above and maximum bond stresses will occur where maximum rates of change in starter bar stresses occur.

(a) No bending in base slab.

In Base I a maximum bond stress of 1,75 $f_{bs\ calc}$ occurs at a depth of 0,2 depth of base slab and then decreases to approximately 0,55 $f_{bs\ calc}$ at 0,65 depth of base slab.

For Bases II and IV maximum bond stresses are reached in the lower ± 100 mm of the column above the base slab whereafter the stresses decrease to a minimum of the order of 0,3 $f_{bs\ calc}$ at 0,24 depth of base slab.

In Base III, however, a maximum bond stress again occurs in the lower 100 mm of the column, decreases to a minimum at the top of the base slab but then increases to a maximum value at 0,24 depth of base slab. Due to the lack of information on steel stresses deeper in the base, it is impossible to predict exactly the distribution of the bond stresses in that region, but it would be expected that a maximum be reached whereafter the stress would decrease rapidly to a minimum value.

As previously mentioned, Astill and Al-Sajir[6] found that the bottom part of the column approximately equal to the width of the column contributed to bond length in addition to the base thickness and the development of high bond stresses in the lower region of the columns in this series of tests seems to confirm their findings.

(b) Bending in base slab.

As for the case of no bending in base slab, maximum bond stresses are reached in the lower 100 mm of the column and top 1/4 depth of the base slab. In Bases I and III these maximums are approximately at the depths of the neutral axis and for Bases II and IV the maximums are reached in the column just above the base slab.

The maximum bond stresses for the case of bending in the base slab are higher on the average than the maximum bond stresses for the case of no bending in base slab. This phenomenon is further discussed in Section 6.3.3.

Upon reaching the maximum values discussed above, the stresses again decrease sharply to an average value of approximately 0,42 $f_{bs\ calc}$ still within the upper half of the base slab except for Base III where, again due to the lack of information, it is impossible to predict the distribution of the bond stress deeper in the base.

In general it can be stated that maximum bond stresses occur in the lower 100 mm of the column and upper region of the base slab (from approximately the neutral axis depth upwards) and that these stresses rapidly decrease to low values within the upper half of the base slab. Higher bond stresses are also reached when bending occurs in the base slab.

6.3.3 Comparison of stresses with results from Series V - Pull-out tests : (Refer to Appendices 5 and 6).

It is clear from the bond stress curves in Appendix 5 that the maximum bond stress in the region where the base slab is in a state of triaxial compression as indicated by the finite element stress analysis (Figures 4.2 and 4.3), due to bending, is considerably higher than for the case of no bending. The percentage increase in bond stress is given in Table 6.1.

	% Increase in Maximum Bond Stress
Base I	1%
Base II	91%
Base III	75%
Base IV	90%

TABLE 6.1
Increase in Maximum Bond Stresses due to Bending in Base.

The compressive stresses due to bending which develop in the concrete of Base I are low compared to the stresses developed in the remaining bases mainly due to the excessive depth of the base slab. This can be seen from the calculated values given in Appendix 3. The normal pressure on the starter bars is therefore very low and does not affect the bond stress significantly as shown in Section 6.2.6.

The increase in the bond stresses in Bases II, III and IV corresponds favourably with the findings of the pull-out tests.

6.3.4 Comparison of measured maximum bond stresses with allowable bond stresses specified in Codes of Practice : (Refer to Appendix 2).

The maximum stresses measured and limiting stresses are given in Table 6.2.

Considering that the maximum stresses measured are not ultimate stresses, it appears that the allowable bond stresses in accordance with BS CP110 could be too low and that the values specified in ACI 318-71 and the CEB-FIP Recommendations would be in better agreement as was also found by Astill and Al-Sajir[6]. Testing of the bases till bond failure will have to be undertaken before finality on this matter can be reached.

TABLE 6.2

	Loading Case	Max. Bond Stress Measured (N/mm²)	Limiting Stresses (N/mm²)		
			BS CP110	ACI 318-71	CEB-FIP Recommendaions
Base I	Eccentric loading on column.	2,22	2,7+ (3,51)	4,32*	3,26
Base II	Biaxial bending in base slab.	3,06	3,2+ (4,16)	5,17*	4,15
Base III	Biaxial bending in base slab.	4,66	2,4+ (3,12)	3,94*	2,89
Base IV	No bending in base slab.	3,07	2,4+ (3,12)	3,94*	2,89

+ These values may be increased by 30% if deformed reinforcement of Type 2 is used (increased values given in brackets).

* These values calculated from specified anchorage lengths.

7. CONCLUSIONS

7.1 Tests on Bases I to IV

The results of the tests performed and described herein on Bases I to IV show that :

7.1.1 The compressive stresses in column starter bars decrease rapidly upon entering the base slab due to the dispersion of the compressive stresses in the column into the base slab. The stresses are significantly reduced over the top half of the base slab to a value of $\pm$ 0,64 $f_{sc\ col}$ when no bending occurs in the base slab and $\pm$ 0,18 $f_{sc\ col}$ for the case of biaxial bending in the base slab.

7.1.2 Maximum bond stresses occur in the lower $\pm$ 100 mm of the column above the base slab and the upper region of the base slab to approximately the depth of the neutral axis whereafter the stresses reduce to low values of the order of 0,42 $f_{bs\ calc}$ within the upper half of the base slab.

7.1.3 Higher bond stresses are reached in the region mentioned above for the case of biaxial bending in the base slab. The increase in bond stress is attributed to the influence of the normal pressure on the starter bars and is also confirmed by the results from the pull-out tests in Series V. The percentage increases were as high as 91% for Base II.

7.1.4 It appears as if a length of the column above the base slab approximately equal to the width of the column contributes to bond length in addition to the base thickness.

7.2 Pull-out Tests in Series V

The following was found from the results of the pull-out tests performed on bars under biaxial normal pressure :

7.2.1 The bond strength increases with increase in normal pressure. The increase is approximately in proportion to the product of the square root of the normal pressure and the square root of the compressive strength of the concrete.

The ultimate bond strength for all the specimens tested can be represented by the equation :

$$f_{bs\ ult} = (1,39 + 0,35\sqrt{f_n})\sqrt{f_{cu}}$$

7.2.2 The rate of increase in bond stress due to biaxially applied normal pressure seems to be practically the same as for normal pressure applied in one direction as found by Untrauer and Henry[9].

7.2.3 The percentage increase in bond stress is as high as 71% for an applied normal pressure of 8 N/mm².

7.3 Finite Element Stress Analysis

The distribution of the axial and lateral stresses in the column and column core through the base slab correspond to the measured distributions in the bases tested and serves as confirmation of the results.

7.4 Design Procedure and Allowable Stresses

7.4.1 It appears from the results of the tests in Series I to V that the conventional design approach to provide an anchorage length for the column starter bars in the base measured from the top of the base slab, is a conservative approach. The increase in bond strength due to the bending in the base slab and the contribution to anchorage length of the lower part of the column is ignored in this approach and it therefore seems advisable that the consideration of these factors be introduced in the different Codes of Practice.

7.4.2 Ultimate bond stresses were not measured in the tests on Series I to IV but it appears from the values obtained that the allowable stresses in BS CP110 would be too low while the limiting stresses according to ACI 318-71 and the CEB-FIP Recommendations would be in better agreement.

7.5 Factors Affecting Bond not Considered

The following factors have not been considered in these tests and may have a further influence on the bond stresses in the base :

7.5.1 The effect of providing a 90° hook in the starter bar at the bottom of the base. However, Anchor[5] is of the opinion that it is unlikely that such bars can transmit compression through the bend since there is little to restrain the bar from punching out at the corner, apart from the bond developed before the bend is reached.

7.5.2 The affect of elastic expansion of the compressed bar in the concrete which in effect will be equivalent to a further increase in the normal pressure on the bar.

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APPENDICES

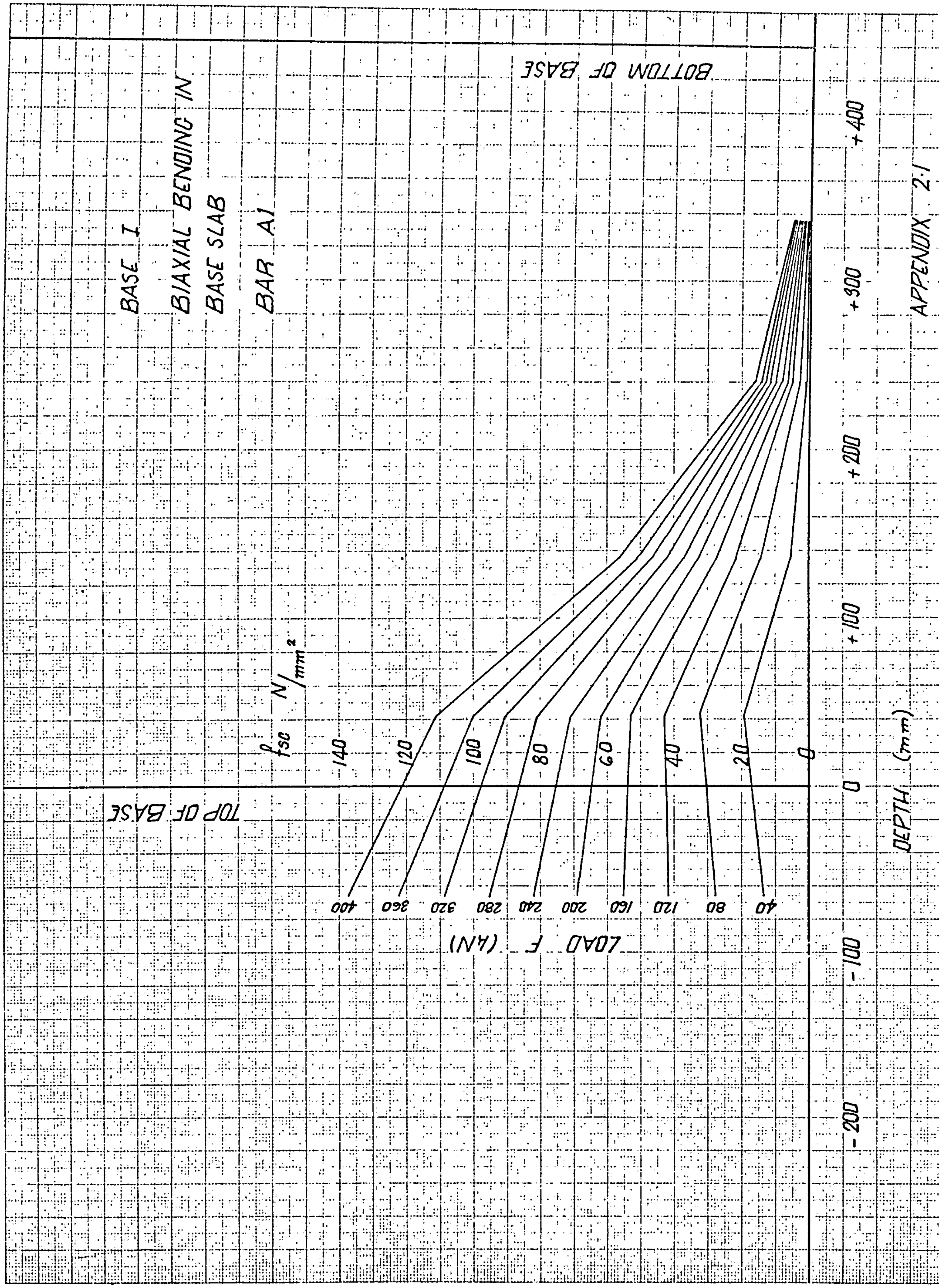
APPENDIX 1

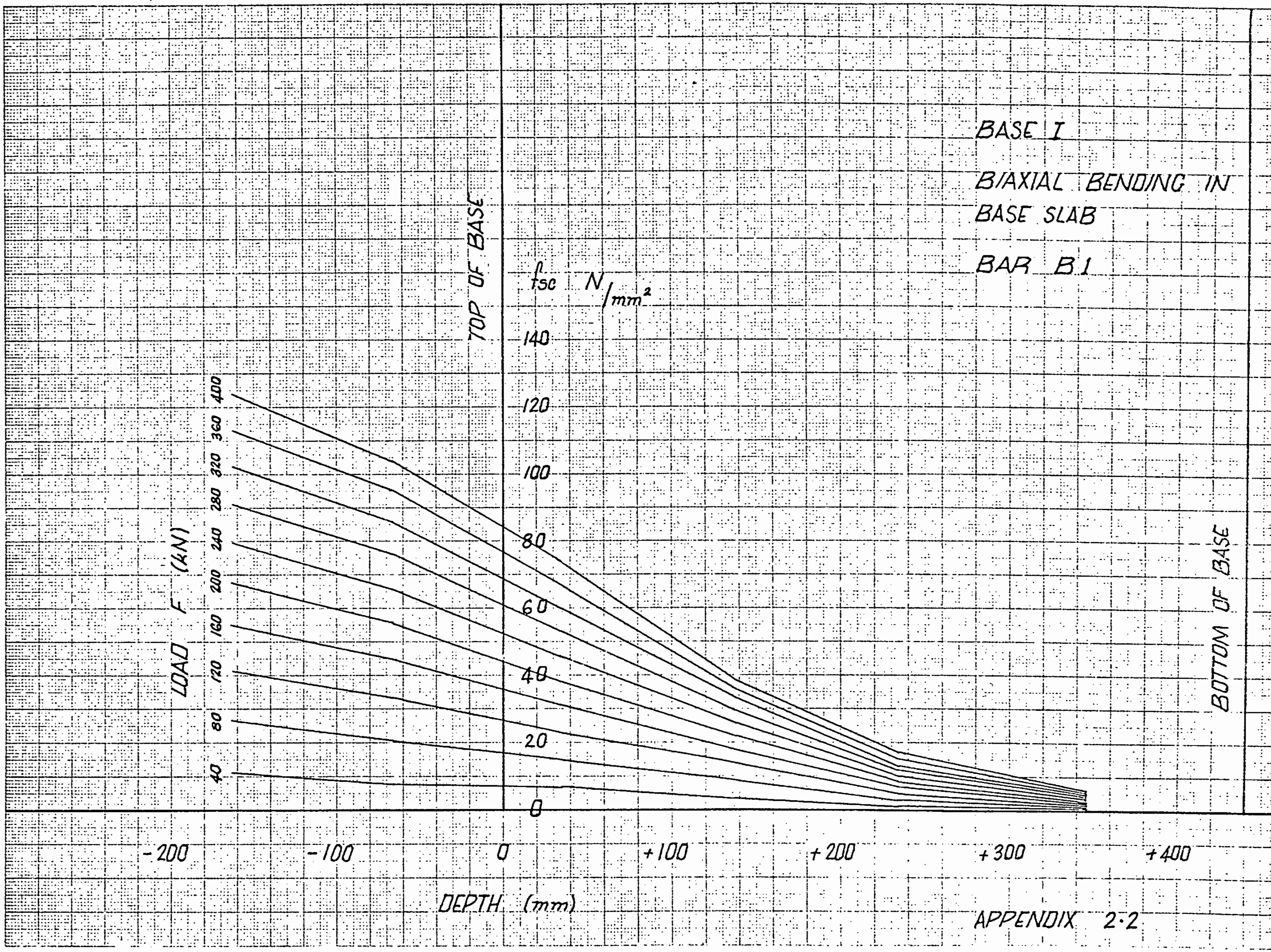
TOTAL STRAINS MEASURED.

BASE I : BIAXIAL BENDING IN BASE SLAB
TOTAL STRAIN $(\times 10^{-3})$

GAUGE Nº	TOTAL LOAD (kN)									
	40	80	120	160	200	240	280	320	360	400
1	0,067	0,139	0,208	0,276	0,343	0,410	0,476	0,542	0,610	0,685
2	0,096	0,161	0,214	0,263	0,309	0,356	0,404	0,452	0,500	0,555
3	0,027	0,070	0,106	0,135	0,160	0,184	0,207	0,230	0,252	0,279
4	0,005	0,014	0,023	0,030	0,038	0,046	0,054	0,061	0,069	0,079
5	0,004	0,007	0,010	0,013	0,015	0,017	0,019	0,020	0,018	0,016
6	0,050	0,127	0,201	0,269	0,331	0,391	0,449	0,504	0,559	0,612
7	0,041	0,105	0,168	0,227	0,280	0,331	0,382	0,430	0,478	0,523
8	0,031	0,072	0,112	0,152	0,189	0,225	0,263	0,298	0,334	0,373
9	0,016	0,043	0,068	0,089	0,109	0,127	0,145	0,163	0,180	0,189
10	0,008	0,017	0,027	0,036	0,044	0,051	0,060	0,069	0,077	0,086
11	0,002	0,005	0,007	0,009	0,011	0,014	0,015	0,016	0,018	0,020

APPENDIX I


BASE I
BIAXIAL BENDING IN
BASE SLAB
BAR A1
BOTTOM OF BASE
TOP OF BASE
fsc N/mm²
140
120
100
80
60
40
20
0
LOAD F (kN)
400
360
320
280
240
200
160
120
80
40
DEPTH (mm)
+400
+300
+200
+100
0
-100
-200
APPENDIX 2:1


BASE I
BIAXIAL BENDING IN
BASE SLAB
BAR B1
fsc N/mm²
140
120
100
80
60
40
20
0
TOP OF BASE
BOTTOM OF BASE
LOAD F (kN)
400
360
320
280
240
200
160
120
80
40
-200
-100
0
+100
+200
+300
+400
DEPTH (mm)
APPENDIX 2·2

APPENDIX 2

STEEL STRESS CURVES

AND

CALCULATED BOND STRESSES.

BASE I : NO BENDING IN BASE SLAB : BOND STRESSES (N/mm²)

GAUGE Nº	TOTAL LOAD (kN)									
	40	80	120	160	200	240	280	320	360	400
1										
	0,163	0,090	0,006	0,095	0,174	0,230	0,292	0,359	0,409	0,477
2										
	0,287	0,440	0,568	0,715	0,862	1,015	1,168	1,309	1,449	1,589
3										
	0,184	0,327	0,422	0,481	0,529	0,558	0,600	0,630	0,659	0,695
4										
	0,036	0,072	0,114	0,144	0,180	0,204	0,252	0,270	0,300	0,324
5										
6										
	0,086	0,208	0,269	0,324	0,349	0,380	0,429	0,441	0,471	0,496
7										
	0,060	0,216	0,354	0,444	0,540	0,600	0,648	0,690	0,732	0,756
8										
	0,165	0,300	0,412	0,529	0,641	0,753	0,853	0,959	1,053	1,141
9										
	0,043	0,129	0,196	0,245	0,288	0,318	0,361	0,392	0,422	0,459
10										
	0,054	0,124	0,315	0,254	0,319	0,378	0,438	0,497	0,546	0,605
11										

APPENDIX 2.3.1

APPENDIX 2·3·2

BASE I : BIAXIAL BENDING IN BASE SLAB

BOND STRESSES (N/mm²)

GAUGE Nº	TOTAL LOAD (kN)									
	40	80	120	160	200	240	280	320	360	400
1	0,163	0,123	0,034	0,073	0,191	0,303	0,404	0,505	0,617	0,729
2	0,440	0,581	0,689	0,817	0,951	1,098	1,257	1,417	1,583	1,762
3	0,131	0,333	0,493	0,624	0,725	0,820	0,909	1,004	1,087	1,188
4	0,006	0,042	0,078	0,102	0,138	0,174	0,210	0,246	0,306	0,378
5										
6										
7	0,055	0,135	0,202	0,257	0,312	0,367	0,410	0,453	0,496	0,545
8	0,060	0,198	0,336	0,450	0,546	0,636	0,714	0,792	0,864	0,900
9	0,088	0,171	0,259	0,371	0,471	0,576	0,694	0,794	0,906	1,082
10	0,049	0,159	0,251	0,324	0,398	0,465	0,520	0,576	0,651	0,631
11	0,032	0,065	0,108	0,146	0,178	0,200	0,243	0,286	0,319	0,357

APPENDIX 2·3·3

BASE I : ECCENTRIC COLUMN LOAD
BOND STRESSES (N/mm^2)

GAUGE No	TOTAL LOAD (kN) 50	100	150	200	250	300	340	380	410	440	470	500
1	0,381	0,667	0,875	1,060	1,200	1,340	1,424	1,536	1,609	1,688	1,783	1,867
2	0,460	0,638	0,817	0,989	1,194	1,398	1,557	1,736	1,864	1,979	2,100	2,215
3	0,154	0,309	0,440	0,552	0,636	0,701	0,766	0,790	0,832	0,861	0,891	0,915
4	0,054	0,102	0,150	0,204	0,252	0,288	0,330	0,354	0,390	0,396	0,396	0,384
5												
6	0,061	0,202	0,355	0,441	0,484	0,520	0,557	0,569	0,588	0,600	0,624	0,631
7	0,462	0,330	0,150	0,006	0,126	0,234	0,300	0,354	0,378	0,408	0,432	0,468
8	0,118	0,159	0,206	0,271	0,341	0,406	0,459	0,535	0,594	0,635	0,706	0,759
9	0,337	0,392	0,459	0,508	0,557	0,594	0,637	0,667	0,692	0,716	0,735	0,753
10	0,086	0,124	0,097	0,059	0,016	0,022	0,135	0,114	0,151	0,178	0,205	0,243
11												

APPENDIX 2.4.1

BASE II: NO BENDING IN BASE SLAB

BOND STRESSES (N/mm^2)

GAUGE No	TOTAL LOAD (kN)						
	40	100	160	220	280	340	400
1	0,074	0,241	0,384	0,501	0,575	0,631	0,668
2	0,212	0,630	0,970	1,242	1,491	1,703	1,885
3	0,019	0,038	0,109	0,185	0,268	0,351	0,409
4							
5	0,088	0,300	0,494	0,629	0,729	0,812	0,929
6	0,104	0,373	0,661	0,967	1,255	1,524	1,806
7	0,109	0,267	0,388	0,479	0,576	0,673	0,776
8							

APPENDIX 2-4-2

BASE II : BIAXIAL BENDING IN BASE SLAB

BOND STRESSES (N/mm^2)

GAUGE No	TOTAL LOAD (kN)								
	40	80	120	160	200	240	280	320	360
5 / 6	0,047	0,173	0,359	0,465	0,582	0,682	0,747	0,818	0,865
6 / 7	0,380	0,796	1,169	1,512	1,849	2,149	2,431	2,731	3,061
7 / 8	0,139	0,188	0,242	0,267	0,291	0,309	0,327	0,339	0,333

APPENDIX 2·4·3

BASE II : ECCENTRIC COLUMN LOAD
BOND STRESSES (N/mm²)

GAUGE Nº	TOTAL LOAD (kN)											
	50	100	150	200	250	300	340	380	410	440	470	500
1												
	0,260	0,192	0,093	0,012	0,099	0,155	0,179	0,198	0,173	0,186	0,167	0,148
2												
	0,448	0,776	0,976	1,127	1,212	1,315	1,364	1,406	1,430	1,430	1,430	1,448
3												
	0,096	0,172	0,217	0,274	0,306	0,326	0,364	0,364	0,389	0,402	0,409	0,434
4												
5												
	0,206	0,459	0,629	0,759	0,841	0,906	0,982	1,135	1,294	1,424	1,594	1,735
6												
	0,496	0,949	1,255	1,506	1,708	1,867	2,039	2,210	2,363	2,559	2,773	3,049
7												
	0,164	0,267	0,370	0,473	0,576	0,691	0,800	0,909	1,018	1,115	1,212	1,297
8												

APPENDIX 2·5·1

BASE III : NO BENDING IN BASE SLAB
BOND STRESSES (N/mm^2)

GAUGE No	TOTAL LOAD (kN)										
	40	80	120	160	200	240	280	320	360	400	440
1a	0,042	0,162	0,234	0,282	0,354	0,426	0,456	0,492	0,528	0,570	0,630
2a	0,054	0,054	0,066	0,084	0,018	0,012	0,024	0,042	0,072	0,108	0,132
3a	0,018	0,270	0,432	0,552	0,648	0,762	1,026	0,924	1,008	1,098	1,236
4a	0,150	0,276	0,354	0,438	0,486	0,540	0,564	0,606	0,660	0,720	0,726
5a											
6a	NO	READINGS									
7a	0,192	0,336	0,462	0,558	0,624	0,726	0,786	0,882	0,942	1,038	1,122
8a	0,204	0,354	0,438	0,450	0,540	0,540	0,564	0,558	0,546	0,540	0,540
9a											
1b	0,258	0,498	0,558	0,570	0,582	0,612	0,600	0,600	0,618	0,642	0,690
2b	0,042	0,108	0,090	0,042	0,072	0,060	0,072	0,066	0,078	0,060	0,060
3b	0,036	0,018	0,024	0,006	0,012	0,042	0,018	0,024	0,024	0,066	0,156
4b	0,288	0,540	0,708	0,840	0,936	1,020	1,110	1,218	1,350	1,506	1,704
5b											
6b	0,066	0,054	0,048	0,108	0,108	0,132	0,150	0,144	0,102	0,078	0,006
7b	0,240	0,350	0,468	0,714	1,080	1,272	1,338	1,422	1,530	1,626	1,632
8b	0,018	0,066	0,162	0,138	0,150	0,168	0,198	0,204	0,186	0,192	0,258
9b											

APPENDIX 2.5.2

BASE III : BIAXIAL BENDING IN BASE SLAB
BOND STRESSES (N/mm^2)

GAUGE No	TOTAL LOAD (kN)									
	40	80	120	160	200	240	280	320	360	400
1a	0,048	0,090	0,126	0,162	0,180	0,246	0,348	0,438	0,570	0,786
2a	0,054	0,084	0,096	0,096	0,102	0,114	0,048	0,030	0,132	0,324
3a	0,294	0,198	0,072	0,066	0,246	0,570	1,242	2,316	3,192	4,236
4a	0,630	0,870	1,050	1,224	1,410	1,650	1,494	1,116	0,972	0,636
5a										
6a	NO READINGS									
7a	0,042	0,006	0,042	0,120	0,204	0,330	0,486	0,708	0,990	1,398
8a	0,258	0,456	0,612	0,816	0,918	1,164	1,476	1,920	2,304	2,748
9a										
1b	0,144	0,240	0,276	0,306	0,312	0,378	0,426	0,444	0,492	0,522
2b	0,012	0,012	0,006	0,000	0,012	0,024	0,006	0,060	0,042	0,036
3b	0,066	0,036	0,012	0,066	0,120	0,222	0,366	0,600	0,762	0,996
4b	0,378	0,630	0,780	0,936	1,098	1,248	1,314	1,344	1,500	1,674
5b										
6b	0,018	0,021	0,042	0,096	0,138	0,162	0,216	0,270	0,342	0,384
7b	0,126	0,156	0,240	0,306	0,342	0,486	0,720	0,960	1,038	0,912
8b	0,210	0,372	0,504	0,648	0,786	1,122	1,836	2,610	3,444	4,656
9b										

APPENDIX 2·5·3

BASE III : ECCENTRIC COLUMN LOAD
BOND STRESSES (N/mm²)

GAUGE Nº	TOTAL LOAD (kN)										
	40	80	120	160	200	240	280	320	360	400	430
1a	0,006	0,030	0,084	0,138	0,210	0,264	0,312	0,360	0,378	0,396	0,384
2a	0,042	0,078	0,120	0,090	0,072	0,072	0,060	0,048	0,018	0,024	0,030
3a	0,198	0,234	0,174	0,108	0,024	0,072	0,174	0,246	0,324	0,372	0,402
4a	0,150	0,270	0,330	0,366	0,408	0,426	0,426	0,450	0,420	0,420	0,366
5a											
6a	NO READINGS										
7a	0,072	0,210	0,318	0,432	0,522	0,618	0,690	0,762	0,852	0,930	0,966
8a	0,228	0,282	0,306	0,318	0,330	0,348	0,360	0,366	0,366	0,396	0,414
9a											
1b	0,510	0,666	0,750	0,744	0,714	0,786	0,804	0,834	0,948	1,218	1,554
2b	0,126	0,126	0,060	0,042	0,048	0,042	0,024	0,048	0,036	0,006	0,012
3b	0,228	0,402	0,564	0,666	0,732	0,810	0,906	0,984	1,134	1,416	1,704
4b	0,468	0,804	1,080	1,272	1,470	1,620	1,770	1,908	2,082	2,274	2,472
5b											
6b	0,024	0,042	0,036	0,048	0,096	0,162	0,198	0,204	0,198	0,162	0,210
7b	0,156	0,090	0,426	0,798	1,266	1,692	2,004	2,214	2,412	2,622	2,796
8b	0,060	0,096	0,144	0,186	0,228	0,264	0,294	0,330	0,384	0,468	0,576
9b											

APPENDIX 2·6·1

BASE IV : NO BENDING IN BASE SLAB
BOND STRESSES (N/mm²)

GAUGE No	TOTAL LOAD (kN)										
	40	80	120	160	200	240	280	320	360	400	440
1a											
	0,396	0,618	0,738	0,816	0,906	1,002	1,086	1,116	1,176	1,212	1,248
2a											
	0,186	0,366	0,432	0,474	0,522	0,576	0,630	0,630	0,636	0,636	0,570
3a											
	0,228	0,456	0,636	0,714	0,780	0,858	0,900	0,954	0,996	1,008	1,044
4a											
	0,060	0,120	0,144	0,186	0,210	0,222	0,228	0,111	0,150	0,066	0,012
5a											
6a											
	NO READINGS										
7a											
	0,516	0,810	0,972	1,074	1,182	1,242	1,290	1,344	1,356	1,350	1,290
8a											
	0,102	0,180	0,228	0,288	0,354	0,426	0,486	0,522	0,540	0,492	0,522
9a											
1b											
	0,432	0,816	0,990	1,074	1,110	1,152	1,206	1,266	1,302	1,314	1,308
2b											
	0,090	0,312	0,456	0,516	0,594	0,618	0,636	0,672	0,708	0,738	0,996
3b											
	NO READINGS										
4b											
	NO READINGS										
5b											
6b											
	NO READINGS										
7b											
	0,192	0,492	0,822	1,260	1,566	1,848	2,142	2,424	2,742	2,982	3,072
8b											
	0,060	0,228	0,366	0,420	0,372	0,288	0,174	0,060	0,300	0,420	0,372
9b											

APPENDIX 2·6·2

BASE IV : BENDING IN BASE SLAB
BOND STRESSES (N/mm²)

GAUGE Nº	TOTAL LOAD (kN)							
	20	40	60	80	100	120	140	160
1a	0,096	0,240	0,318	0,402	0,498	0,582	0,648	0,726
2a	0,030	0,072	0,108	0,150	0,216	0,282	0,396	0,630
3a	0,192	0,486	0,702	0,942	1,224	1,584	2,436	2,964
4a	0,018	0,018	0,048	0,036	0,096	0,024	0,498	1,188
5a								
6a	NO READINGS							
7a	0,252	0,576	0,768	0,918	1,086	1,302	1,764	2,394
8a	0,072	0,192	0,300	0,390	0,522	0,684	1,350	1,938
9a								
1b	0,114	0,420	0,672	0,774	0,864	0,942	1,002	1,038
2b	0,006	0,108	0,240	0,318	0,378	0,438	0,534	0,684
3b	NO READINGS							
4b	NO READINGS							
5b								
6b	NO READINGS							
7b	0,060	0,246	0,420	0,648	0,942	1,242	1,716	2,946
8b	0,150	0,420	0,660	0,924	1,200	1,578	2,070	1,914
9b								

APPENDIX 3

CALCULATED MOMENTS AND STRESSES.

BASE I: MOMENTS & STRESSES

TOT. LOAD (kN)	M_{xx} (kNm)	$f_c max$ (N/mm^2)	f_{sc} col (N/mm^2)	f_{bs} calc (N/mm^2)
40	4,25	0,22	12,47	0,09
80	8,50	0,44	24,94	0,18
120	12,75	0,66	37,41	0,27
160	17,00	0,87	49,88	0,36
200	21,25	1,09	62,34	0,45
240	25,50	1,31	74,81	0,54
280	29,75	1,53	87,28	0,63
320	34,00	1,75	99,75	0,72
360	38,25	1,97	112,22	0,81
400	42,50	2,19	124,69	0,90
440	46,75	2,41	137,16	0,99
500	53,13	2,73	155,86	1,13

BASE II : MOMENTS & STRESSES

TOT. LOAD (kN)	Mxx (kNm)	fc max (N/mm²)	fsc col (N/mm²)	fbs calc (N/mm²)
40	4,25	0,64	12,47	0,17
80	8,50	1,28	24,94	0,33
100	10,63	1,61	31,17	0,42
120	12,75	1,93	37,41	0,50
160	17,00	2,57	49,88	0,67
200	21,25	3,21	62,34	0,83
220	23,38	3,53	68,58	0,91
240	25,50	3,85	74,81	1,00
280	29,75	4,49	87,28	1,16
320	34,00	5,13	99,75	1,33
340	36,13	5,45	105,99	1,41
360	38,25	5,77	112,22	1,50
400	42,50	6,41	124,69	1,66
440	46,75	7,05	137,16	1,83
500	53,13	8,01	155,86	2,08

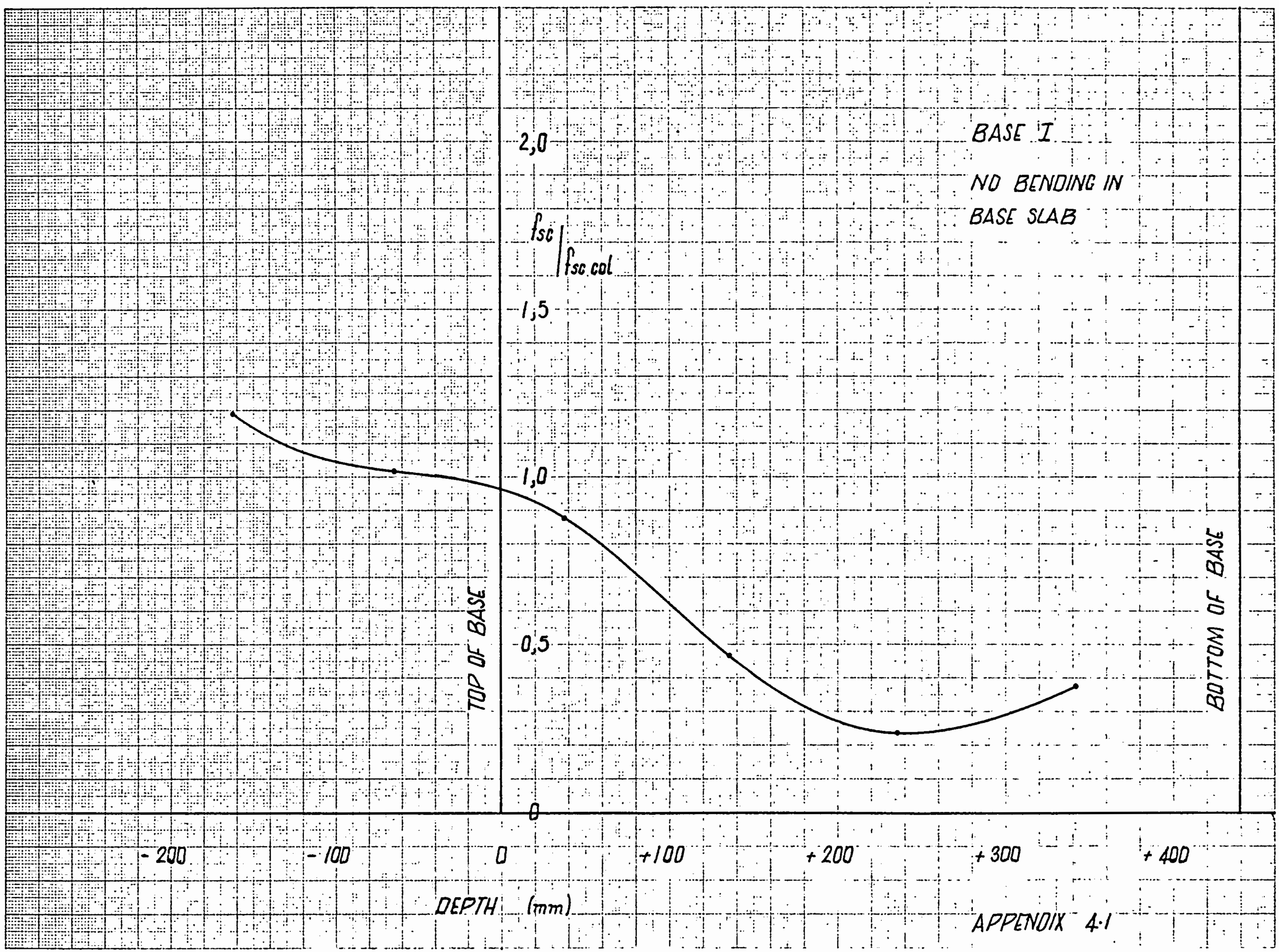
BASE III : MOMENTS & STRESSES				
TOT. LOAD (kN)	Mxx (kNm)	fc max (N/mm^2)	fsc col (N/mm^2)	fbs calc (N/mm^2)
40	3,00	0,63	12,05	0,17
80	6,00	1,26	24,10	0,33
120	9,00	1,88	36,15	0,50
160	12,00	2,51	48,21	0,67
200	15,00	3,14	60,26	0,83
240	18,00	3,77	72,31	1,00
280	21,00	4,40	84,36	1,16
320	24,00	5,03	96,41	1,33
360	27,00	5,65	108,46	1,50
400	30,00	6,28	120,51	1,66
440	33,00	6,91	132,57	1,83

APPENDIX 3·4

BASE IV : MOMENTS & STRESSES				
TOT. LOAD (kN)	Mxx (kNm)	fc max (N/mm²)	fsc col (N/mm²)	fbs calc (N/mm²)
20	3,75	1,11	6,23	0,08
40	7,50	2,21	12,47	0,17
60	11,25	3,32	18,70	0,25
80	15,00	4,42	24,94	0,33
100	18,75	5,53	31,17	0,42
120	22,50	6,63	37,41	0,50
140	26,25	7,81	43,64	0,58
160	30,00	8,84	49,88	0,67
200			62,34	0,83
240			74,81	1,00
280			87,28	1,16
320			99,75	1,33
360			112,22	1,50
400			124,69	1,66
440			137,16	1,83

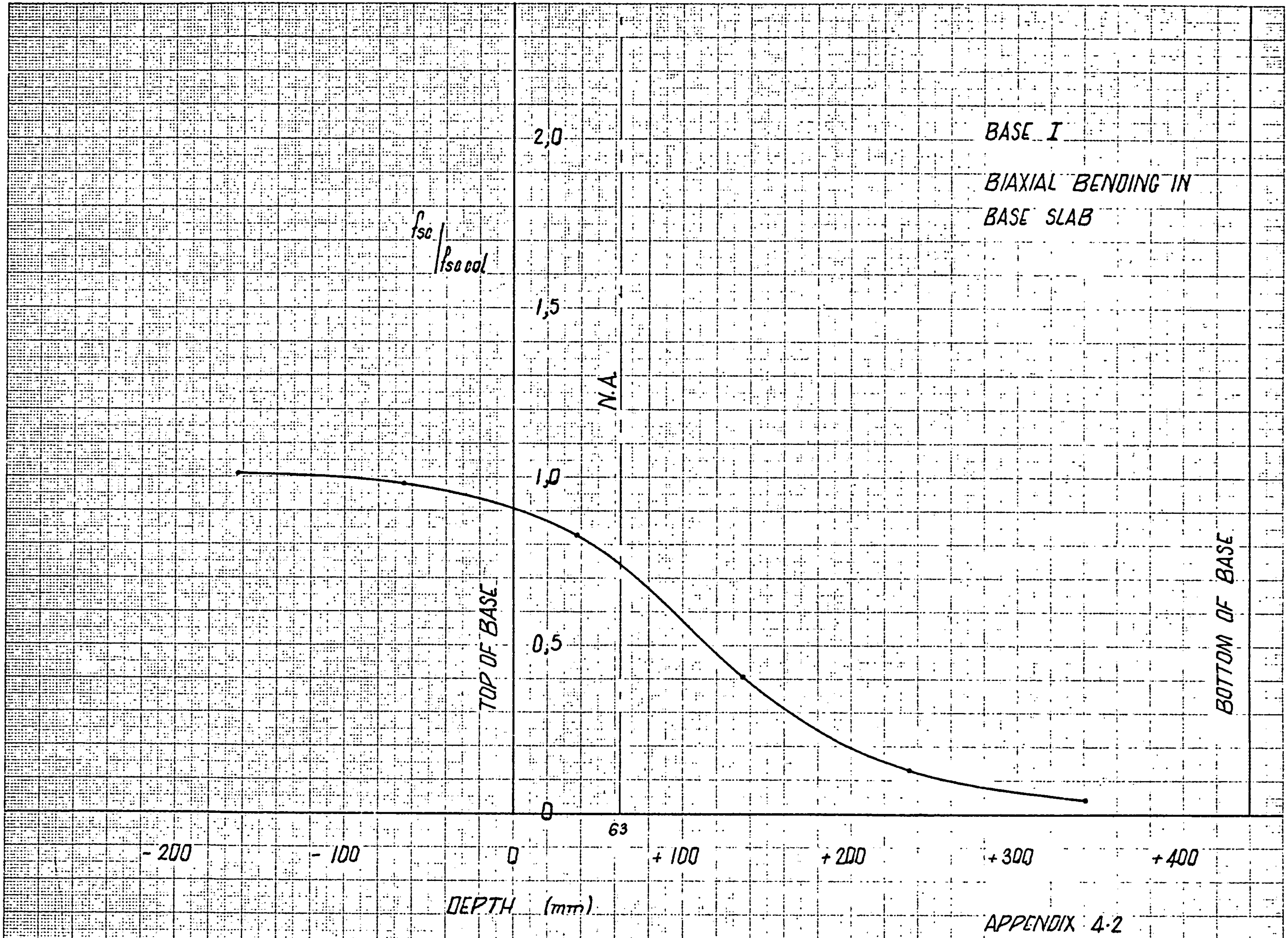
APPENDIX 4

$\frac{f_{sc}}{f_{sc\ col}}$ CURVES.



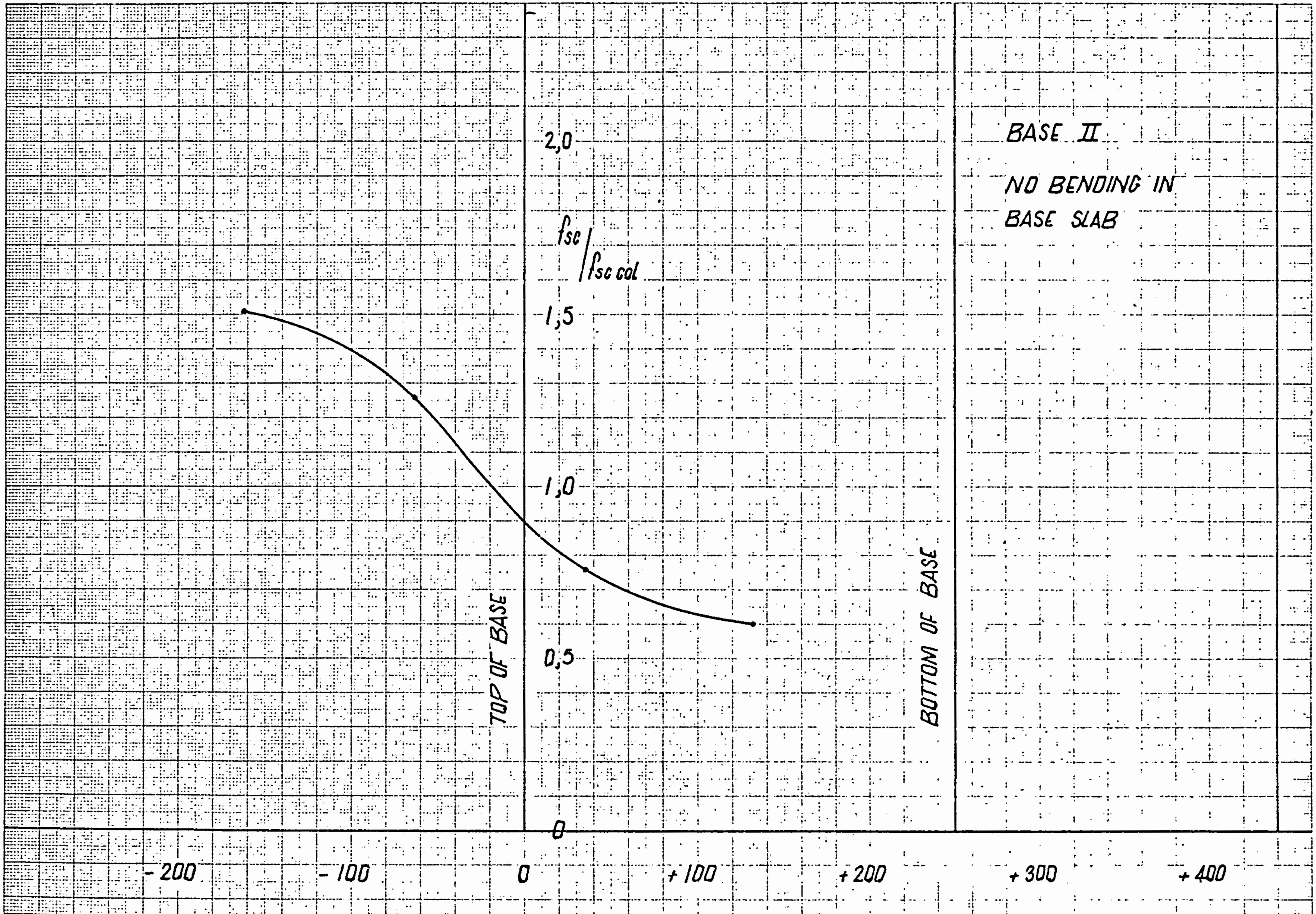
BASE I
NO BENDING IN
BASE SLAB
$f_{sc} / f_{sc\,col}$
2,0
1,5
1,0
0,5
0
TOP OF BASE
BOTTOM OF BASE
- 200
- 100
0
+100
+ 200
+ 300
+ 400
DEPTH (mm)

APPENDIX 4·1

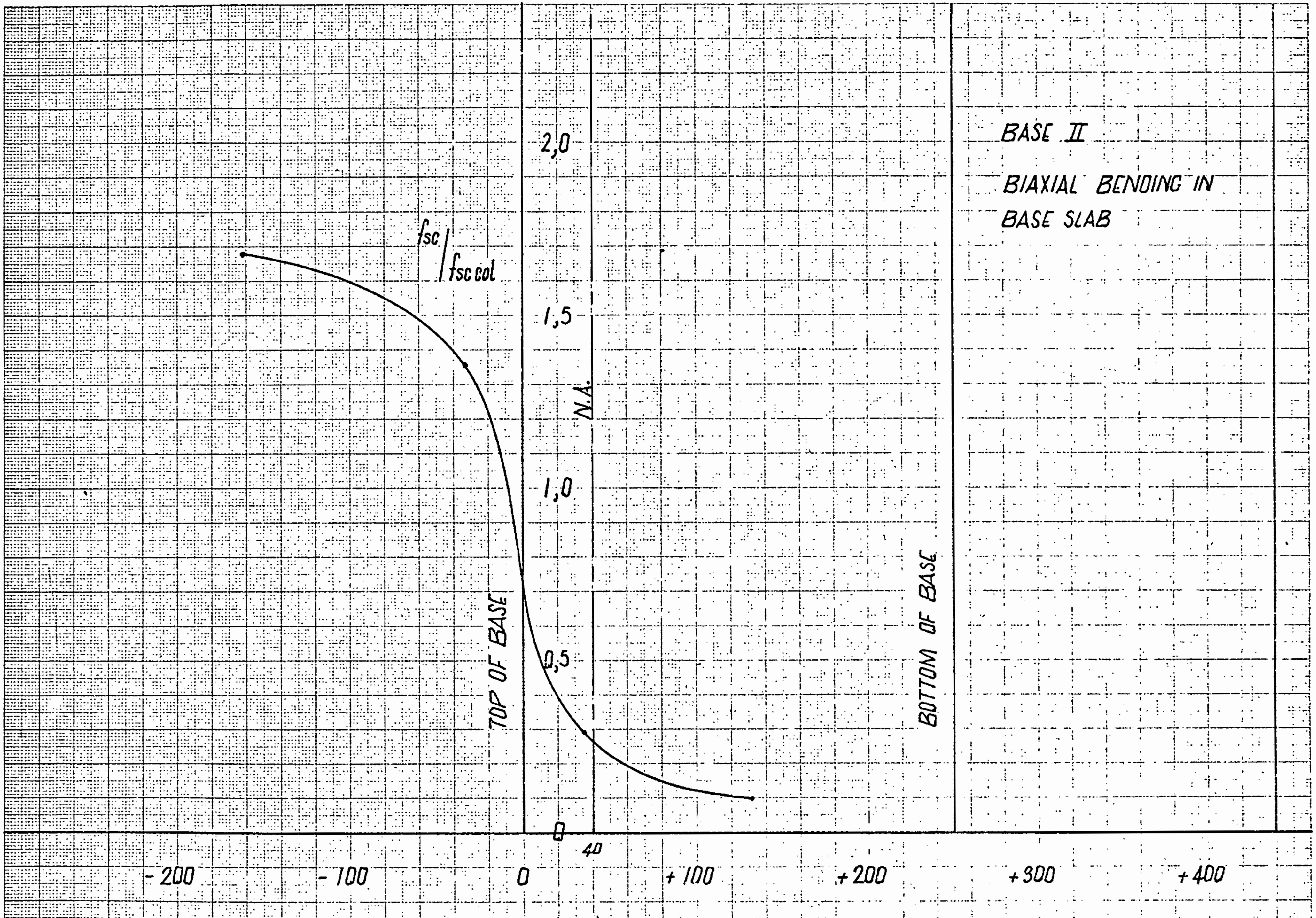


BASE I
BIAXIAL BENDING IN
BASE SLAB
fsc / fsc col
2,0
1,5
1,0
0,5
0
N.A.
TOP OF BASE
BOTTOM OF BASE
63
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

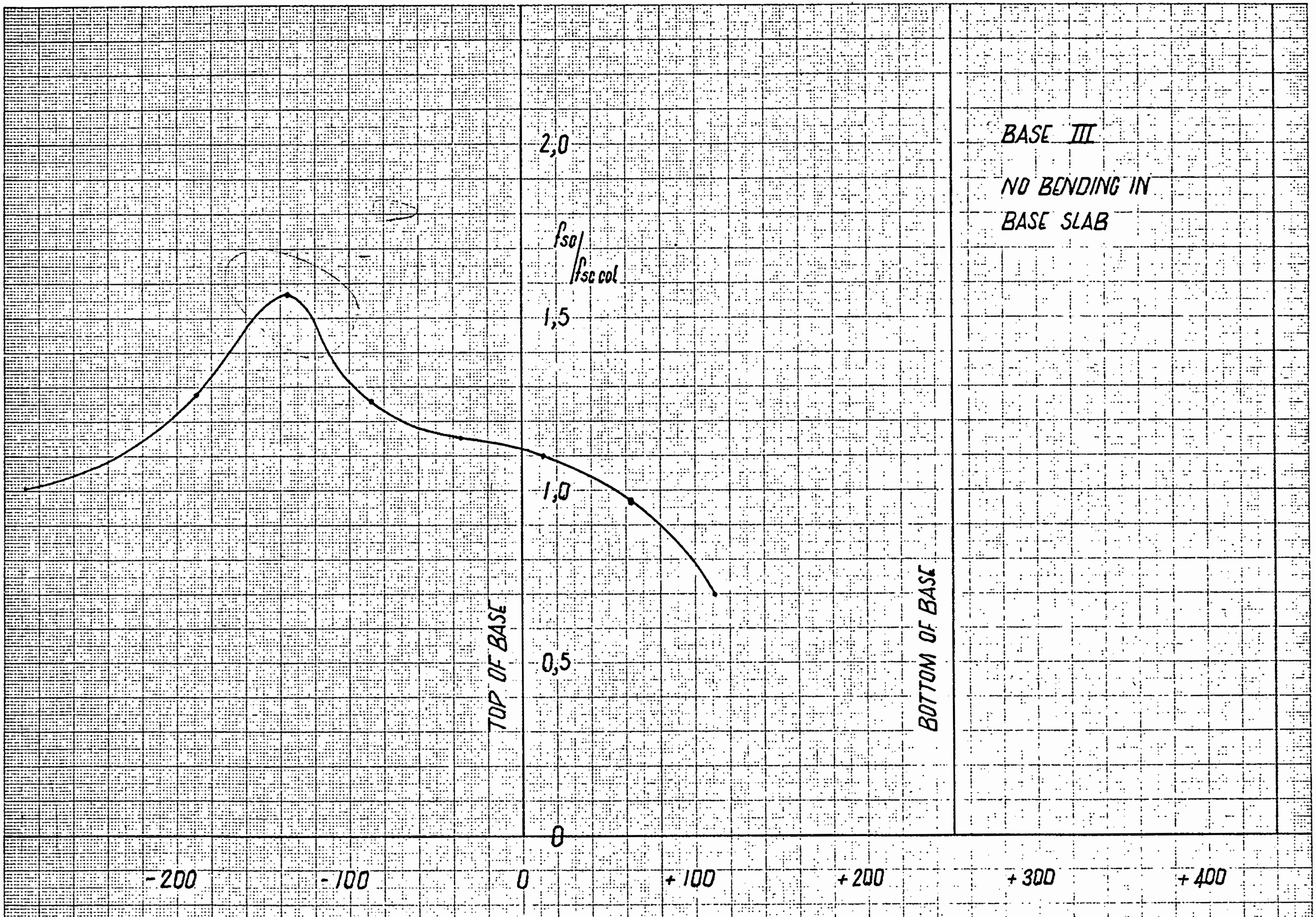
APPENDIX 4·2


BASE II
NO BENDING IN
BASE SLAB
$f_{sc}/f_{sc\,col}$
2,0
1,5
1,0
0,5
0
TOP OF BASE
BOTTOM OF BASE
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

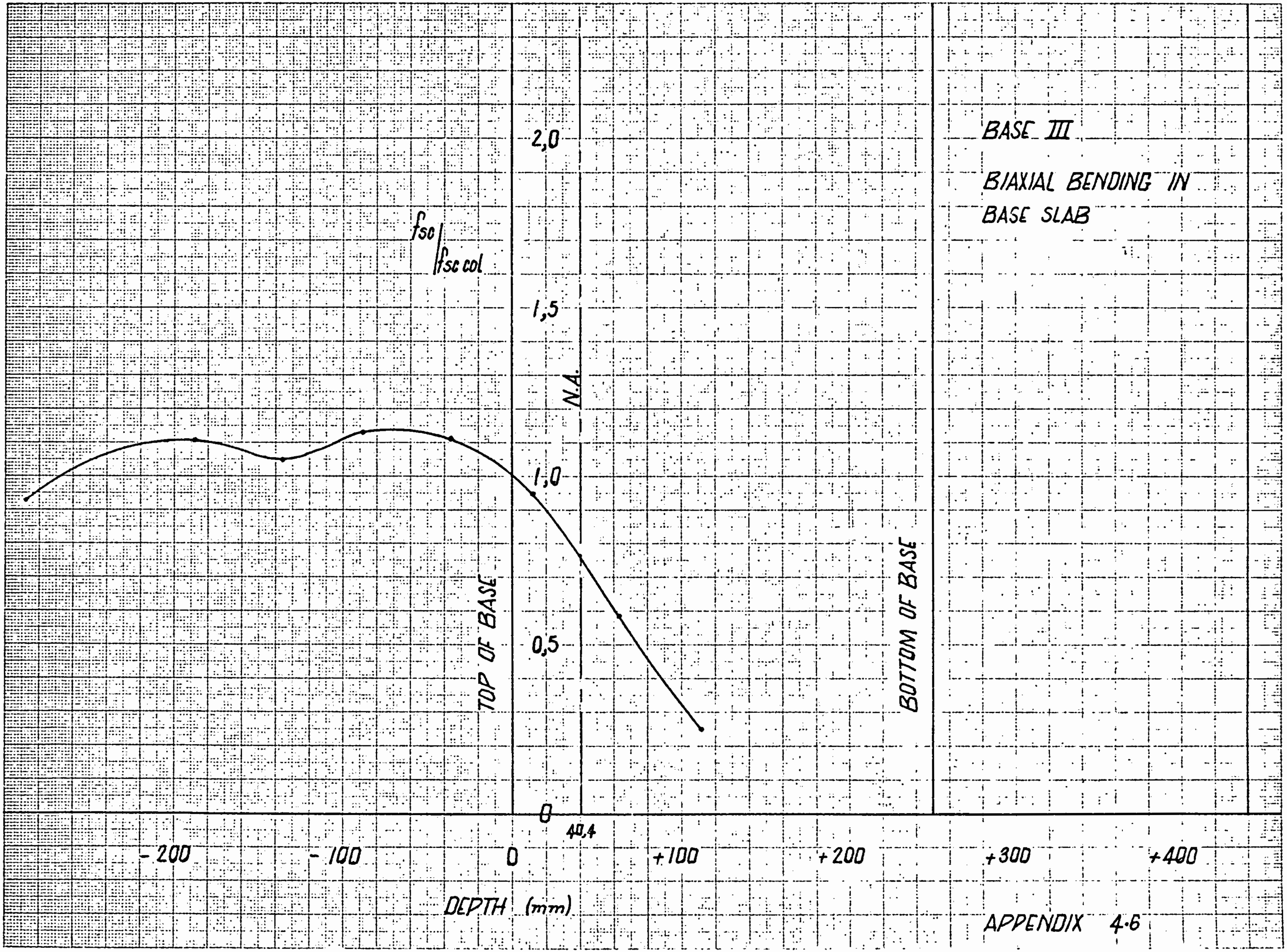
APPENDIX 4·3


BASE II
BIAXIAL BENDING IN
BASE SLAB
fsc / fsc col
2,0
1,5
1,0
0,5
0
N.A.
TOP OF BASE
BOTTOM OF BASE
40
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

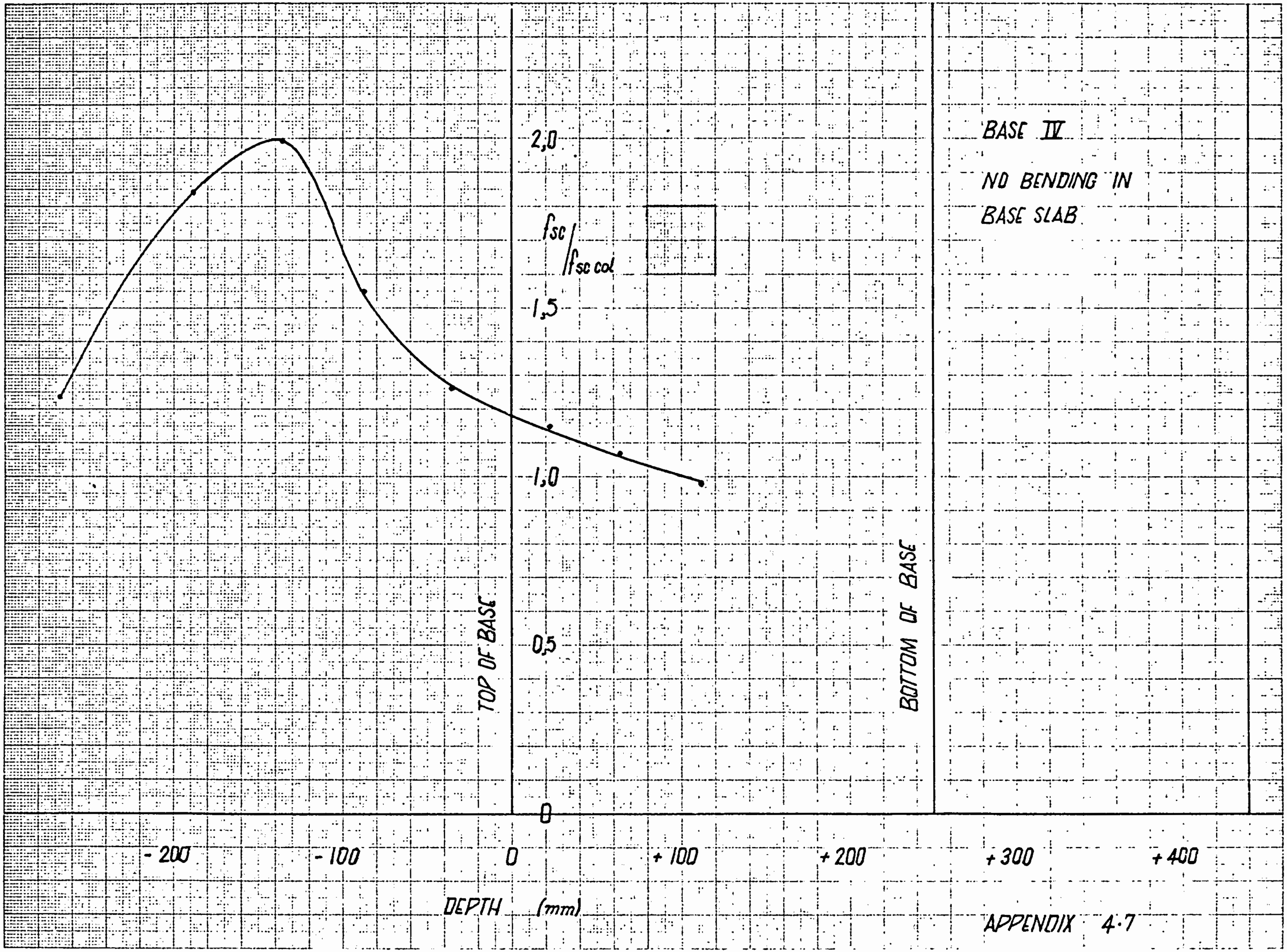
APPENDIX 4.4


BASE III
NO BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
$f_{so} / f_{sc\,col}$
TOP OF BASE
BOTTOM OF BASE
-200
-100
0
+100
+200
+300
+400
DEPTH (mm)

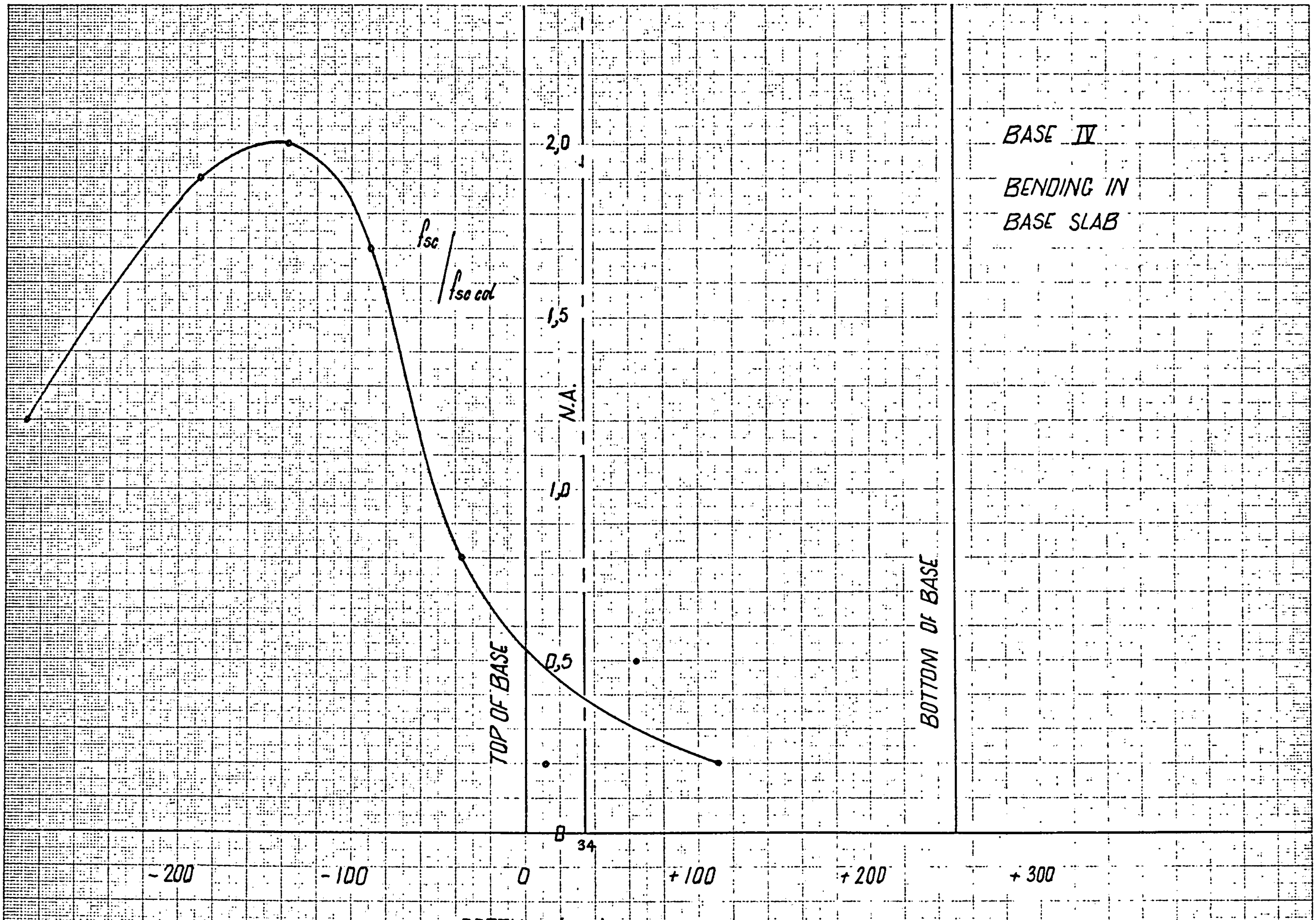
APPENDIX 4.5


BASE III
BIAXIAL BENDING IN
BASE SLAB
fsc/fsc col
2,0
1,5
1,0
0,5
0
N.A.
TOP OF BASE
BOTTOM OF BASE
40,4
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

APPENDIX 4·6


BASE IV
NO BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
fsc/fsc col
TOP OF BASE
BOTTOM OF BASE
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

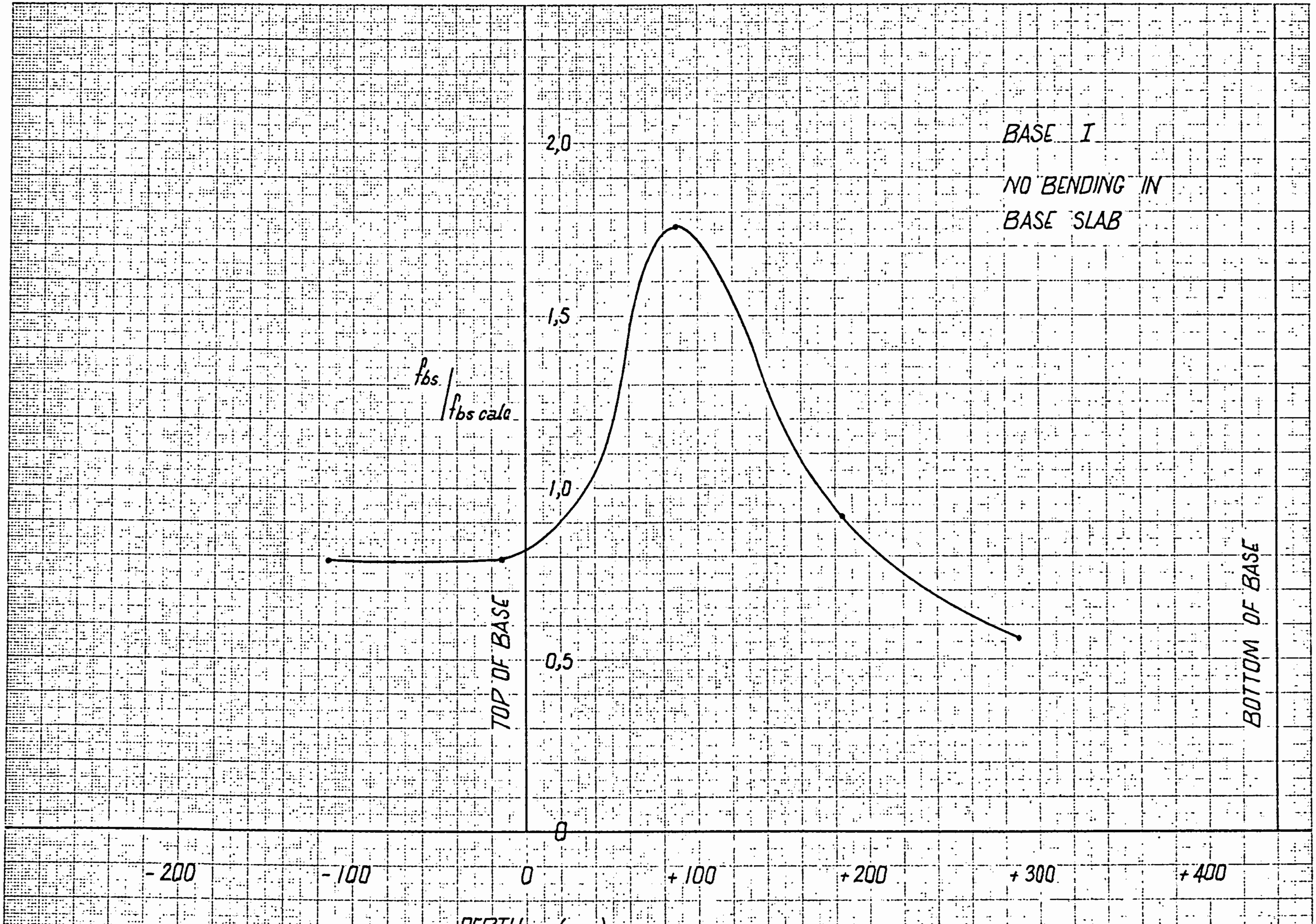
APPENDIX 4·7


BASE IV
BENDING IN
BASE SLAB
fsc / fsc cal
2,0
1,5
N.A.
1,0
0,5
0
34
TOP OF BASE
BOTTOM OF BASE
-200
-100
0
+100
+200
+300
DEPTH (mm)

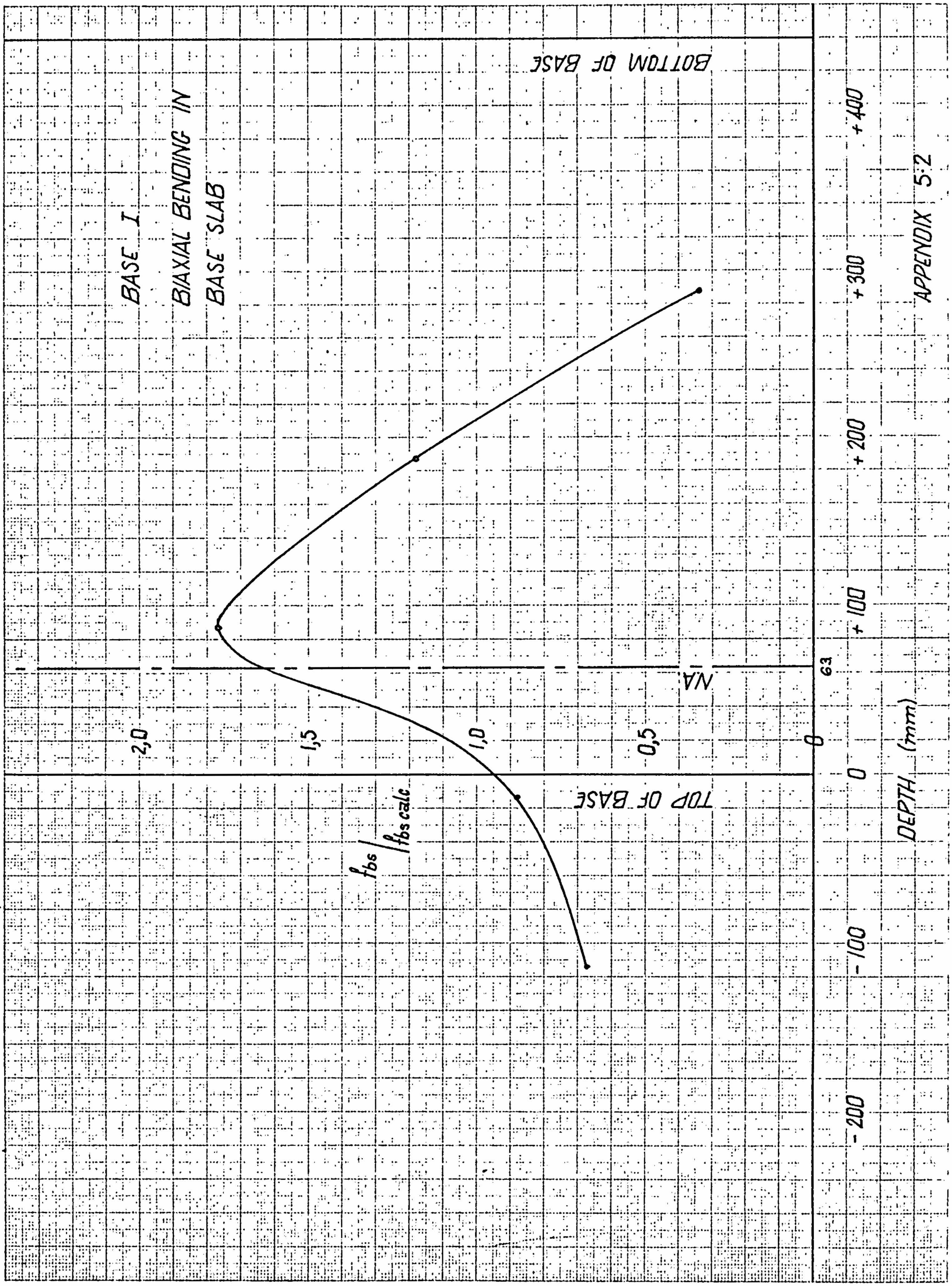
APPENDIX 4·8

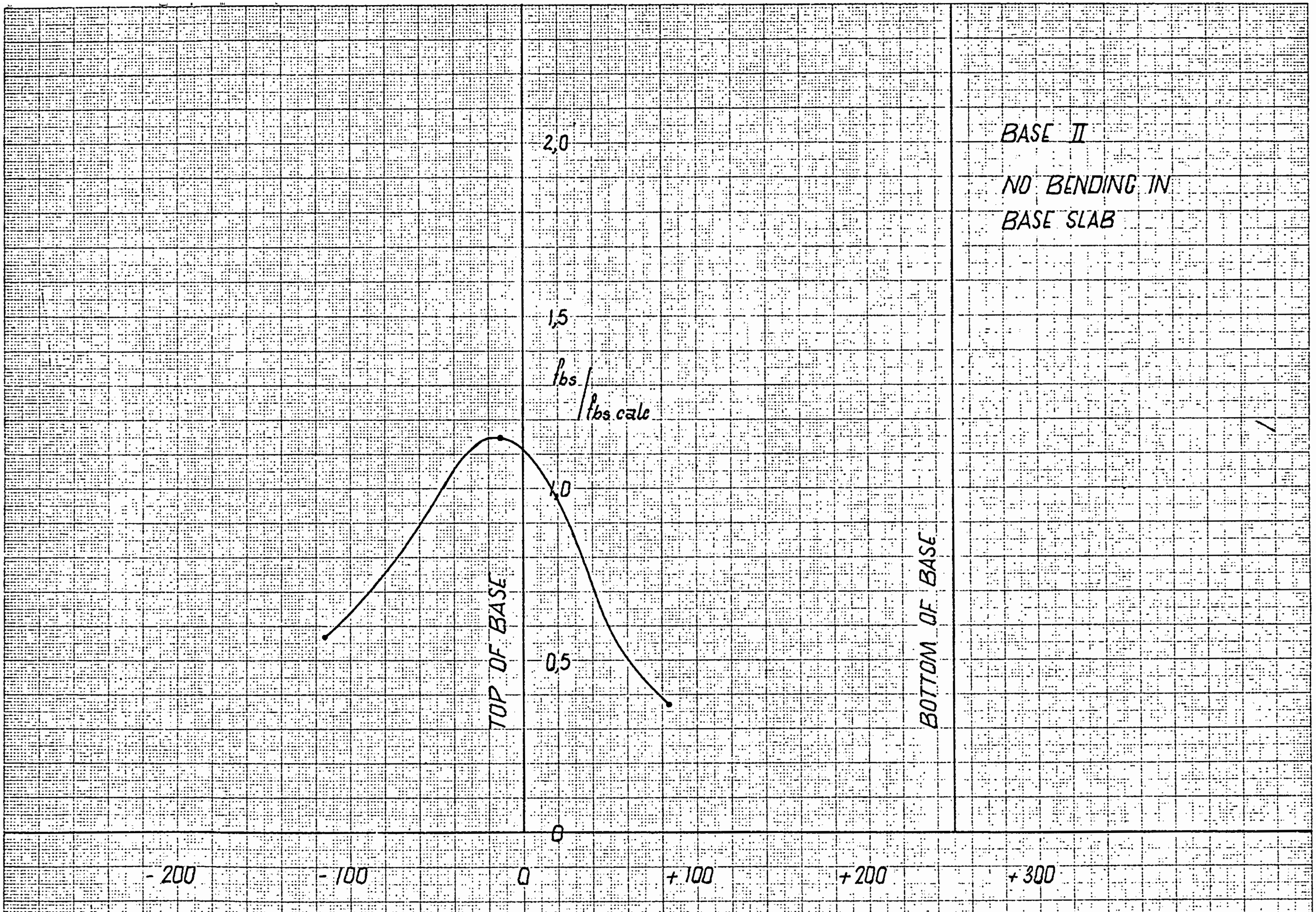
APPENDIX 5

$\frac{f_{bs}}{f_{bs\ calc}}$ CURVES.

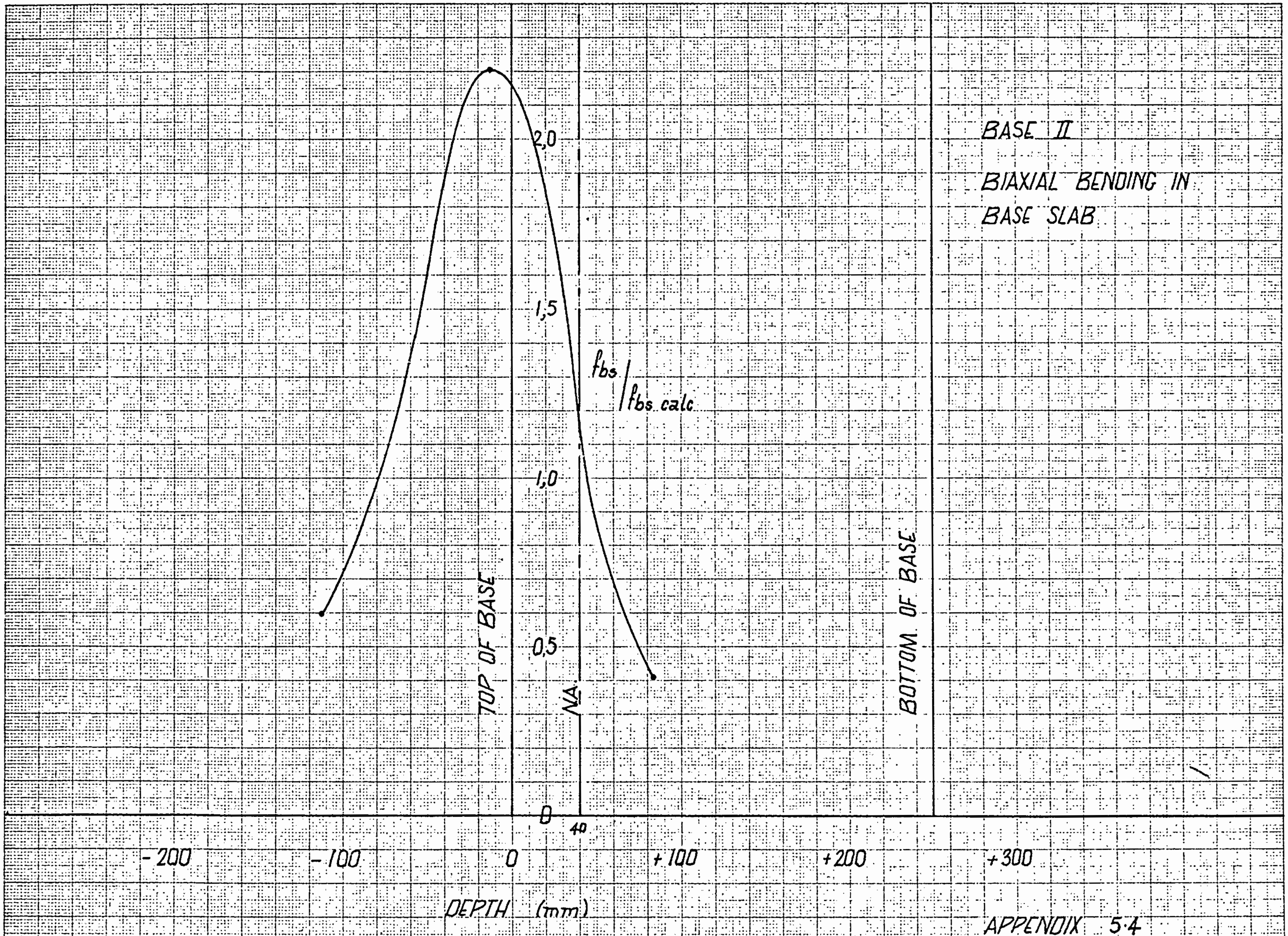

BASE I
NO BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
fbs / fbs calc
TOP OF BASE
BOTTOM OF BASE
- 200
- 100
0
+ 100
+ 200
+ 300
+ 400
DEPTH (mm)

APPENDIX 5·1


BASE I
BIAXIAL BENDING IN
BASE SLAB
BOTTOM OF BASE
TOP OF BASE
N.A.
63
$f_{bs}/f_{bs\,calc}$
2,0
1,5
1,0
0,5
0
-200
-100
0
+100
+200
+300
+400
DEPTH (mm)
APPENDIX 5:2

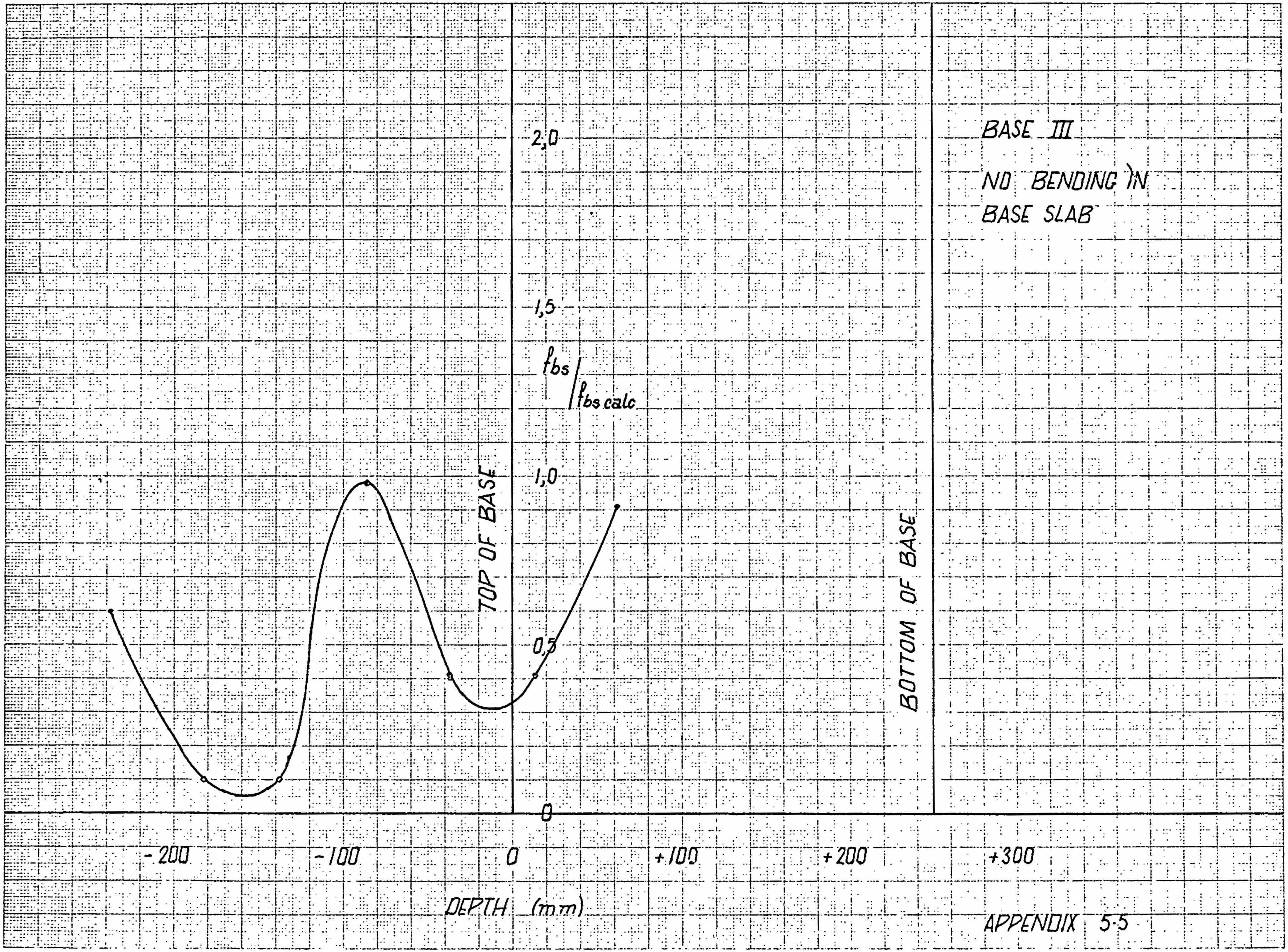

BASE II
NO BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
f_{bs} / $f_{bs.calc}$
TOP OF BASE
BOTTOM OF BASE
- 200
- 100
0
+ 100
+ 200
+ 300
DEPTH (mm)

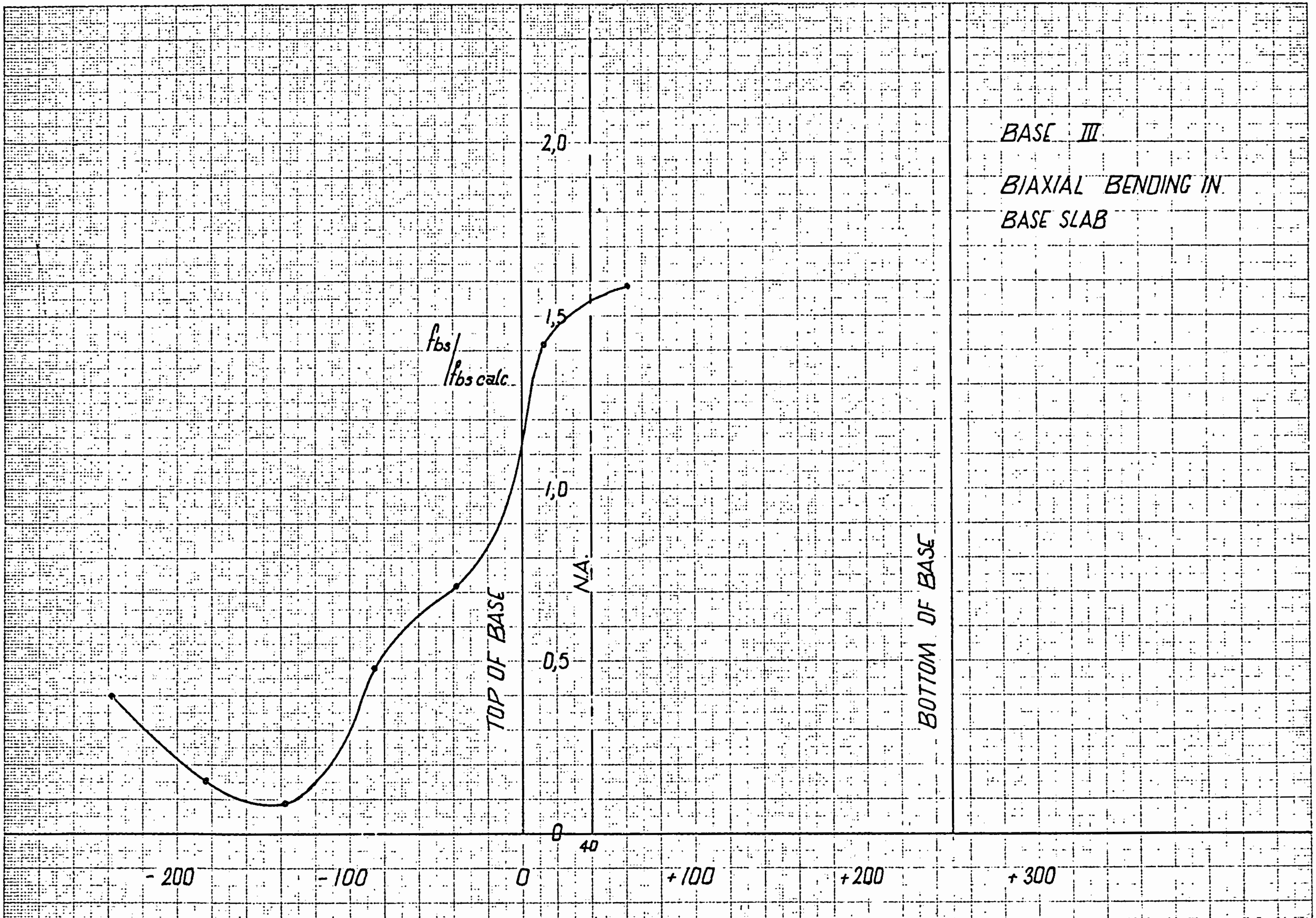
APPENDIX 5·3



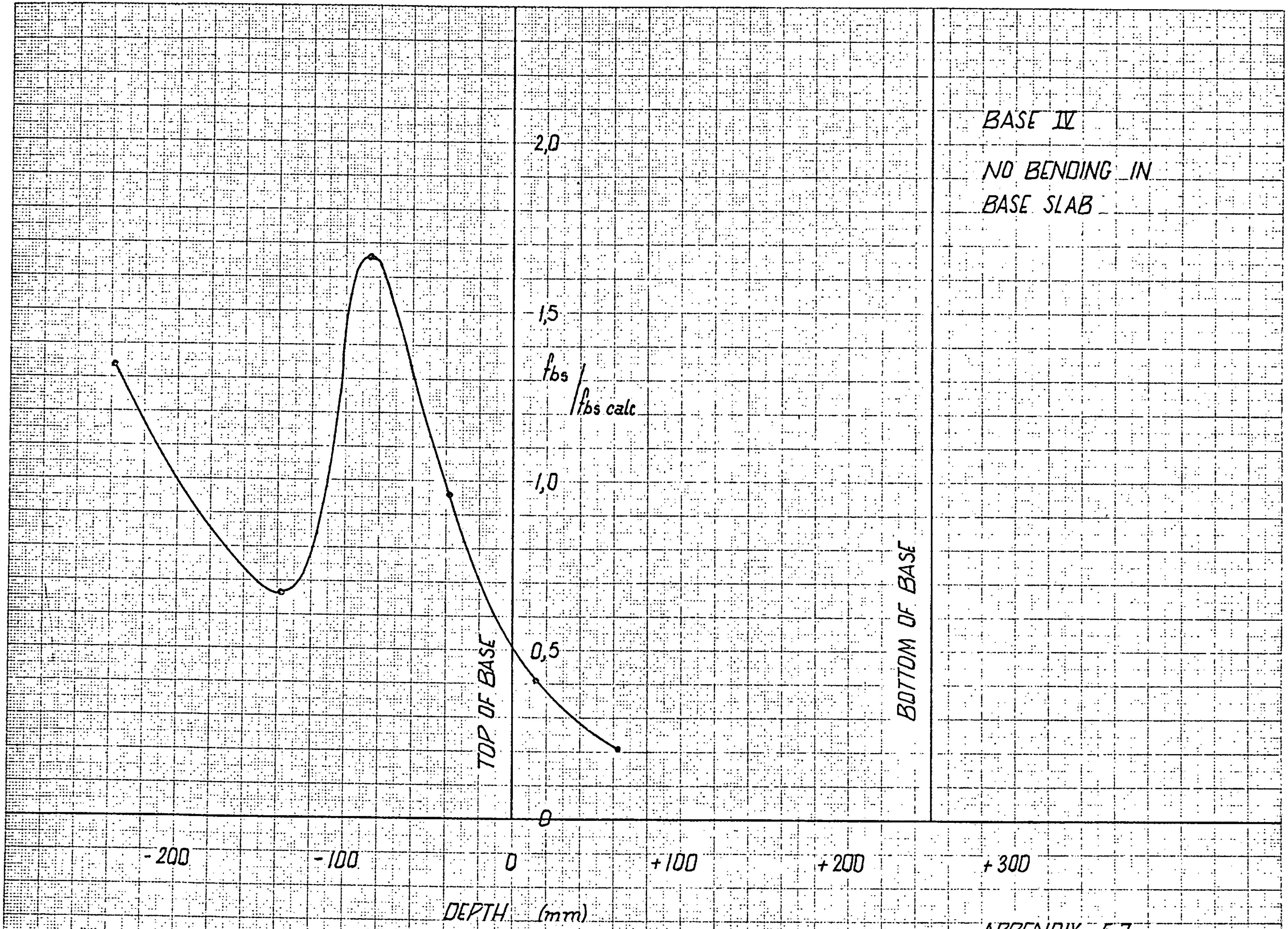
BASE II
BIAXIAL BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
fbs / fbs.calc
TOP OF BASE
NA
BOTTOM OF BASE
40
-200
-100
0
+100
+200
+300
DEPTH (mm)

APPENDIX 5·4

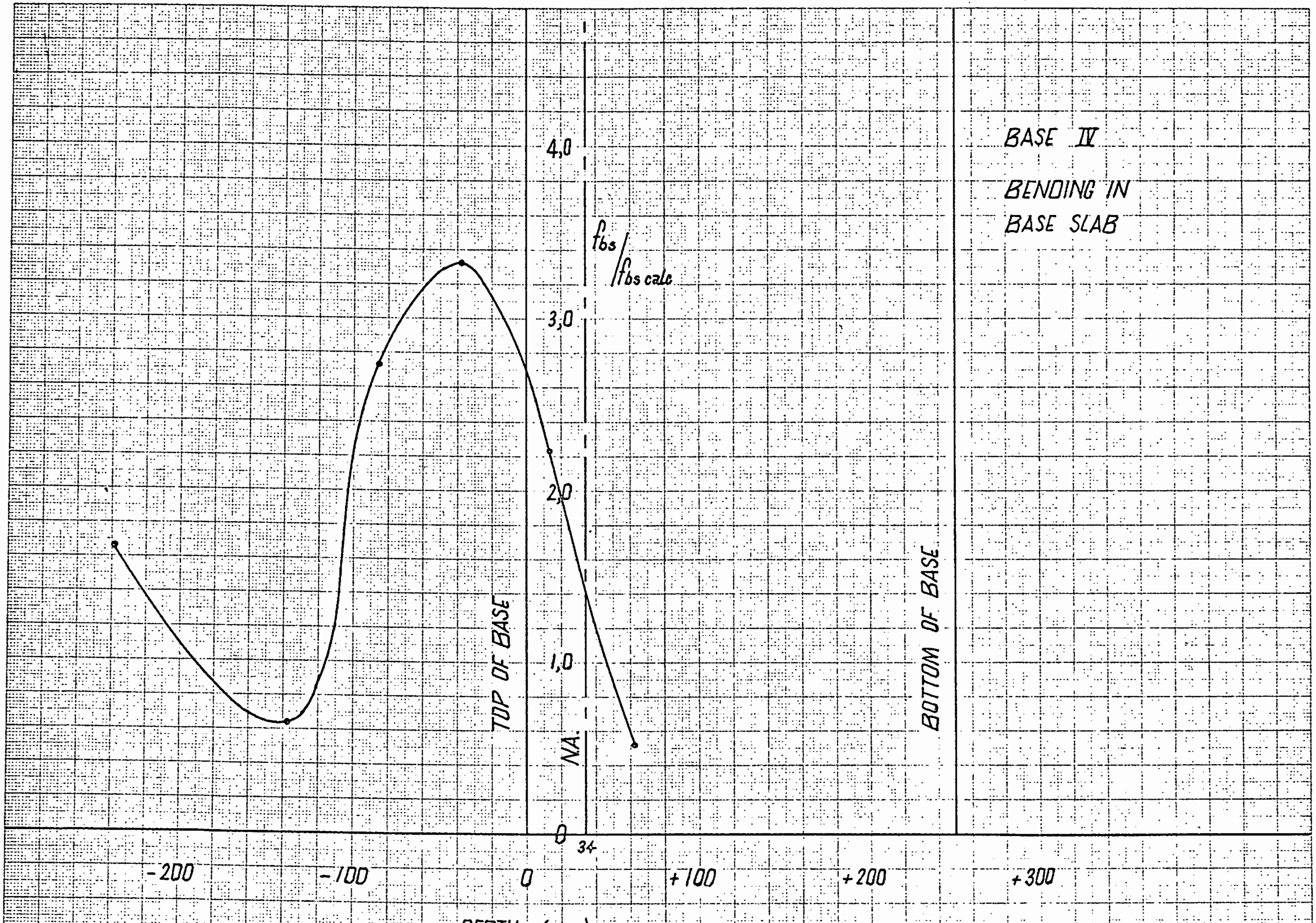

BASE III
NO BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
fbs / fbs calc
TOP OF BASE
BOTTOM OF BASE
-200
-100
0
+100
+200
+300
DEPTH (mm)
APPENDIX 5·5


BASE III
BIAXIAL BENDING IN
BASE SLAB
fbs/fbs calc
2,0
1,5
1,0
0,5
0
TOP OF BASE
N.A.
BOTTOM OF BASE
- 200
-100
0
40
+100
+200
+300
DEPTH (mm)

APPENDIX 5·6


BASE IV
NO BENDING IN
BASE SLAB
2,0
1,5
1,0
0,5
0
$f_{bs}/f_{bs\ calc}$
TOP OF BASE
BOTTOM OF BASE
-200
-100
0
+100
+200
+300
DEPTH (mm)

APPENDIX 5·7


BASE IV
BENDING IN
BASE SLAB
4,0
3,0
2,0
1,0
0
$f_{bs}/f_{bs\,calc}$
TOP OF BASE
BOTTOM OF BASE
N.A.
34
-200
-100
0
+100
+200
+300
DEPTH (mm)

APPENDIX 5·8

APPENDIX 6

RESULTS FROM PULL-OUT TESTS

SERIES V.

APPENDIX 6.1.1

SERIES V : PULL-OUT TESTS			
SPEC. NO.	fbs ult (N/mm^2)	fcu (N/mm^2)	fn (N/mm^2)
4501	12,87	73,6	0,61
4502	16,18	75,8	1,31
4503	18,90	74,9	1,97
4504	18,44	73,6	2,63
4505	18,24	75,1	3,29
4506	18,63	71,3	3,94
4507	18,60	73,6	4,60
4508	19,10	73,1	5,26
4509	19,66	73,6	5,92
4510	12,14	74,0	0
4001	13,53	53,7	0,61
4002	16,31	58,9	1,27
4003	17,18	55,9	1,93
4004	16,84	53,2	2,54
4005	17,34	52,2	3,16
4006	17,27	54,7	3,81
4007	16,94	54,9	4,47
4008	16,88	54,9	5,08
4009	16,08	58,4	5,70
4010	9,62	53,6	0

APPENDIX 6.1.2

SERIES V : PULL-OUT TESTS

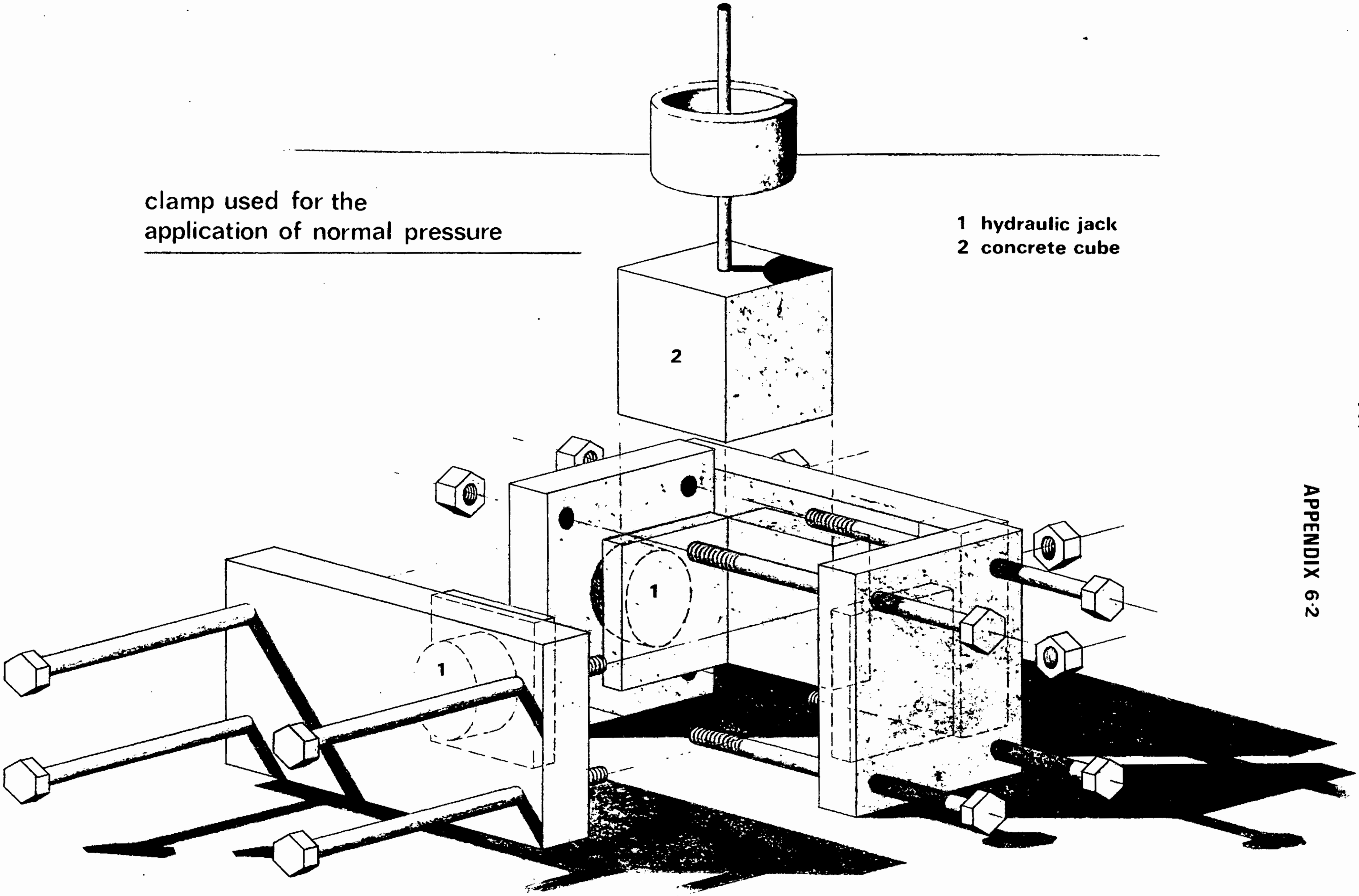
SPEC. NO.	fbs ult (N/mm^2)	fcu (N/mm^2)	fn (N/mm^2)
3001	11,41	55,8	0,66
3002	14,85	57,1	1,31
3003	14,46	55,6	1,97
3004	15,42	51,8	2,63
3005	13,93	52,7	3,29
3006	15,05	54,9	3,94
3007	16,81	53,8	4,60
3008	14,09	49,8	5,26
3009	16,08	50,2	5,92
3010	9,48	49,8	0
2501	12,23	40,9	0,66
2502	13,10	41,6	1,31
2503	15,02	42,4	1,97
2504	14,92	40,9	2,63
2505	13,56	37,1	3,29
2506	13,33	41,6	3,94
2507	14,26	40,3	4,60
2508	14,85	40,6	5,26
2509	14,46	40,9	5,92
2510	7,43	40,7	0

APPENDIX 6·1·3

SERIES V : PULL-OUT TESTS

SPEC. NO.	fbs ult (N/mm^2)	fcu (N/mm^2)	fn (N/mm^2)
2001	8,42	29,0	0,66
2002	8,72	25,9	1,31
2003	8,82	27,4	1,97
2004	10,01	29,6	2,63
2005	10,41	30,9	3,29
2006	10,48	32,2	3,94
2007	10,78	25,1	4,60
2008	11,87	25,6	5,26
2009	12,27	30,0	5,92
2010	6,53	28,3	0
1501	7,15	18,7	0,66
1502	6,62	18,5	1,31
1503	8,09	20,4	1,97
1504	6,95	20,7	2,63
1505	8,46	19,9	3,29
1506	4,55	19,8	3,94
1507	7,92	18,6	4,60
1508	8,70	19,4	5,26
1509	7,75	20,4	5,92
1510	5,29	22,0	0

clamp used for the application of normal pressure



1 hydraulic jack
2 concrete cube

COURSES COMPLETED IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE M.Sc.(ENG.) DEGREE AT THE UNIVERSITY OF CAPE TOWN

COURSE		DATE CREDITED	CREDIT VALUE
CE 515	- Surface Structures	1976	5
CE 519	- Steel Structures	1976	3
CE 533	- Bridge Engineering	1977	4
CE 525	- Coastal Engineering	1977	5
CE 532	- Contracts Administration	1978	3
CE 516	- Prestressed Concrete	1978	5
		TOTAL	25

Total credit requirements for the M.Sc.(Eng.) Degree = 40

Course Credits	:	25
Thesis	:	20
TOTAL		45