Investigation And Performance Of Surface Bonded Sparfil Block Walls

Elie Alkhoury

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ABSTRACT

Elie Alkhoury

INVESTIGATION AND PERFORMANCE OF SURFACE BONDED SPARFIL BLOCK WALLS

Surface bonded Sparfil block walls enjoy two special features. First, these insulating light-weight blocks provide adequate insulation and structural capabilities for many building applications. Second, the simple and fast construction method, in which the blocks are dry-stacked in a running bond pattern and surface bonded with fibre glass reinforced mortar.

Comparable to sandwich construction, the thin faces of the wall, about 3 mm (1/8") thick, provide overall structural integrity, while the light-weight concrete core stabilizes the faces and gives the wall ample overall rigidity.

Walls were investigated in three different loading conditions, bending, compression with eccentricity, and impact. Bending and impact strengths are controlled by the skin material's tensile strength. In compression, the wall capacity is governed by the compressive strength of the blocks.

The performance of this wall system might be improved by increasing the block strength, grinding block surfaces to give uniform dimensions, and better field quality control of the surface bonding.

ACKNOWLEDGEMENTS

The author expresses his gratitude to Professor Cedric Marsh for his guidance in supervising the project. Many thanks are due to Mr. Joseph Zilkha at the building materials laboratory and Mr. Louis Stanke at the structural laboratory of Concordia University. Recognition is due to Sparfil Quebec Inc. for originally sponsoring the project and supplying all materials needed to make this research possible.

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NOMENCLATURE

a = Distance from neutral axis to extreme fibres in compression

A_c = Net area of core material

A_s = Transformed area of skin material

b = Width of section

B = Length of failure line of a section in bending inclined to bed joints

c = Distance from neutral axis to extreme fibres in tension

C_c = Compression force in core

C_s = Compression force in skin

d = Total depth of section

d' = Thickness of core blocks

e = Eccentricity of applies axial load P

E_{cs}, E_{ts}, E_c = Modulii of elasticity of skin in compression, skin in tension and core material respectively

f'_c, f_t = Compressive and tensile strengths of skin

h = Height of drop of load W for impact loading

I = Moment of inertia of wall section in bending about its centroidal axis

I_{eff} = Effective moment of inertia of wall section in combined bending and compression about its centroidal axis

L = Span

M = Applied static bending moment

n = $E_{cs}/E_c = 10$

t_1, t_2 = Compression and tension skin thicknesses

U = Total impact energy

U_c, U_s = Core and skin strain energies

α = Ratio of net to gross area of core block

γ = Experimentally obtained ratio of bending strain energy to total impact energy on wall

Δ = Deflection of wall at mid-span

σ_r = Modulus of rupture

σ_{cc} = Compressive stress in core

$\sigma_{ts}, \epsilon_{ts}, \sigma_{cs}, \epsilon_{cs}$ = Tensile and compressive stresses and strains in skin

CHAPTER 1

INTRODUCTION

This work investigated the behaviour of surface bonded Sparfil block walls. The wall construction is simple, with only two elements: the insulating concrete core blocks and structural, fibre glass reinforced mortar facings.

Research covered the properties of the individual elements and the performance of full scale walls under different loading conditions up to failure. Proposed theoretical expectations were verified by the experimental work. Results were analysed ~~and an~~ understanding of wall behaviour obtained. From this, design criteria were derived and a design procedure established.

In its present form, the wall system is suitable for limited load bearing applications. Its bending strength is high and controlled by the tension face thickness. The capacity to absorb impact energy is more than adequate for normal use.

This wall system is a competitive candidate in construction of two storey residential units, industrial buildings, warehouses and as infill walls in mutli-storey buildings.

Experiments were conducted on walls built with 200 mm (8") and 250 mm (10") blocks. These thicknesses are the most commonly used due to their stability and the level of insulation they provide.

CHAPTER 2

SPARFIL CONCRETE

2.1 INTRODUCTION

Sparfil is a lightweight concrete made from cement, sand, expanded polystyrene beads and water. The expanded beads are spherical in shape and contain about 98% air. Hence they are regarded as water tight pre-packaged air. Figure (2.1) shows a section through a sample of this material. The incorporation of polystyrene into the concrete mix has several advantages which include:

1) A considerable reduction in weight; densitites as low as 400 kg/m^3 (25 pcf) are practicable.
2) A major increase in the thermal resistance of the concrete rendering it a good and constant thermal insulator.
3) A high resistance to severe weather conditions, such as freezing and thawing, due to the low water absorption, as most of the air is contained within the closed cells of the polystyrene.

Further advantages are low drying shrinkage, reduced curing time, fire resistance and good sound attenuation.

The size of the beads, about 2 mm in diameter, is chosen to give a reasonable compressive strength in addition to the above characteristics. The compressive strength of Sparfil is inversely proportional to the bead diameter and ranger from 1.5 MPa to 8.5 MPa (200 to 1200 psi), corresponding to densities of 400 kg/m^3 (25 pcf) to 900 kg/m^3 (60 pcf) respectively.

2.2 PREPARATION OF MAIN AGGREGATES

The fine beads of polystyrene contain an agent that, when heated in steam, expands them up to fifty times their original volume. Figure (2.2) shows polystyrene beads before and after expansion to a density of 12 kg/m^3 (0.75 pcf).

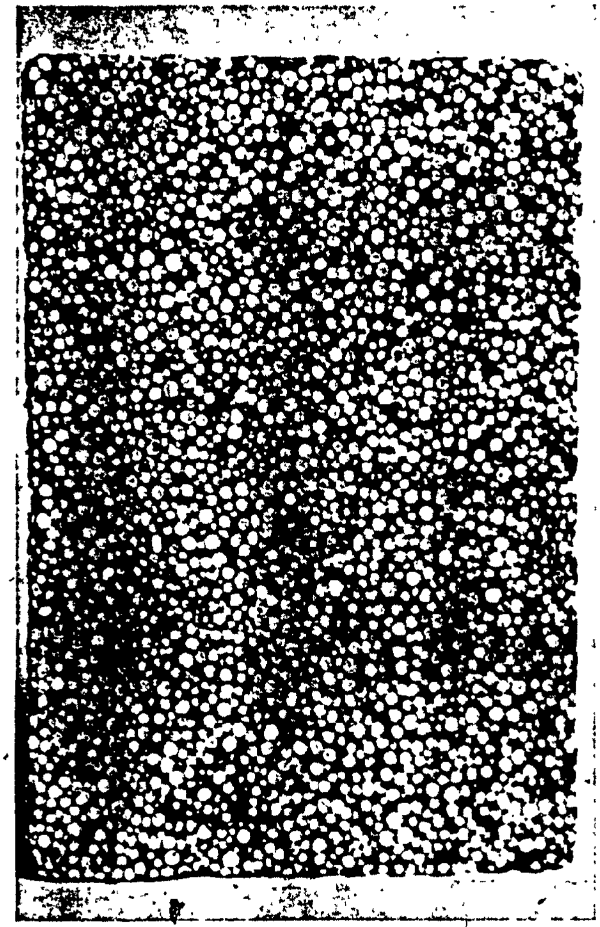

Figure (2.1): Section through Sparfil Concrete.

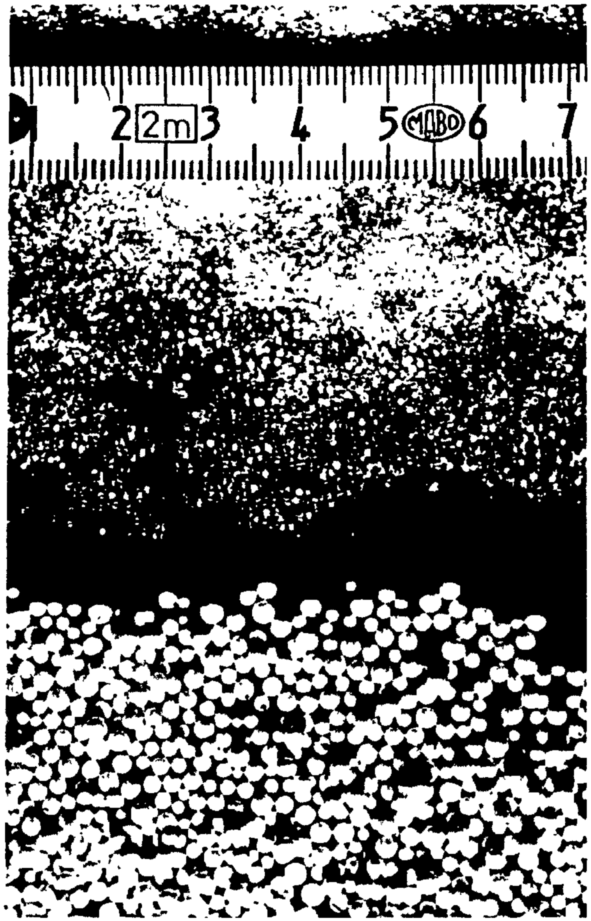

Figure (2.2): Unexpanded and expanded polystyrene beads.

After expansion, the beads are allowed to cool in large holders. Any residual expanding agent is eventually replaced by air.

2.3 PREPARATION OF BEADS SURFACE

To make the polystyrene beads bond to the cement matrix, they are coated with a bonding agent. Plastic dispersions or adhesive resins are the most widely used as bonding agents. These materials do not attack the bead surface nor interfere with the hydration of the cement. A 50% aqueous dispersion of polyvinyl-propionate has been found suitable for this purpose.

Figure (2.3) shows samples of Sparfil concrete made with and without bonding additives after a rupture test. In the absence of a bonding additive, the beads separate from the matrix, consequently, this sample has a low rupture strength.

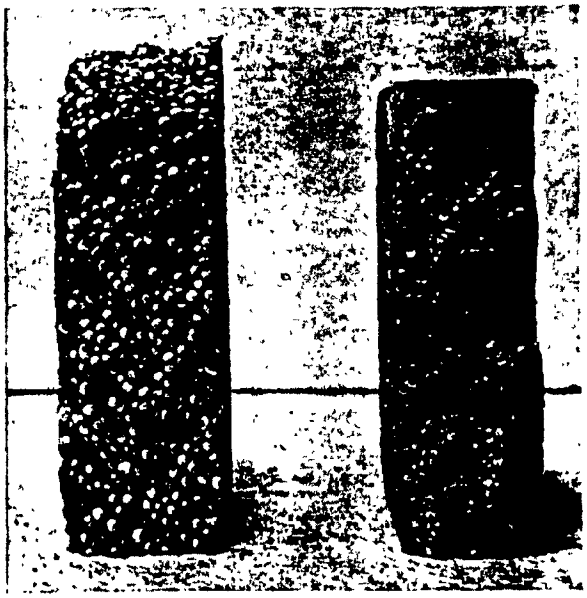

Figure (2.3): Break surfaces of Sparfil Concrete specimens with (right) and without (left) bonding additive

2.4 MIXING

Mixing of Styropor Concrete requires special attention in order to produce a homogeneous mix. Polystyrene beads are very light compared with the other ingredients of the mix. this creates problems as the beads tend to float on the mixing water, but any commercially available mixer that provides positive displacement and folding action is suitable. Rotating drum mixers do not provide such a mixing action and will not produce a uniform, homogeneous concrete.

2.5 CASTING AND CURING

Sparfil concrete lends itself to conventional casting and curing methods employed with normal Portland cement concretes. Precast panels and slabs are currently produced and marketed. Panels are reinforced with steel. Cast-in-place Sparfil Concrete is also gaining popularity. Applications range from insulating roof fills to frost protecting and load spreading beds for highways and railroads.

However, the most popular Sparfil Concrete elements on the market today are the masonry blocks seen in Figure (2.4). Aside from the inherent properties of Styropor Concrete, these masonry blocks offer many advantages in the building industry such as simplicity, speed of construction and labour efficiency leading to a substantial overall economy.

Sparfil Concrete blocks are produced by conventional masonry block machines. The elements are compacted with intense vibration and pressure and instantaneously released from their molds. Fresh Sparfil Concrete blocks are quite fragile when they leave the machine. Curing takes place at ambient temperature or with steam similar to methods employed with regular masonry blocks.

If cured in air, frequent wetting is required initially in order to completely hydrate all the cement.

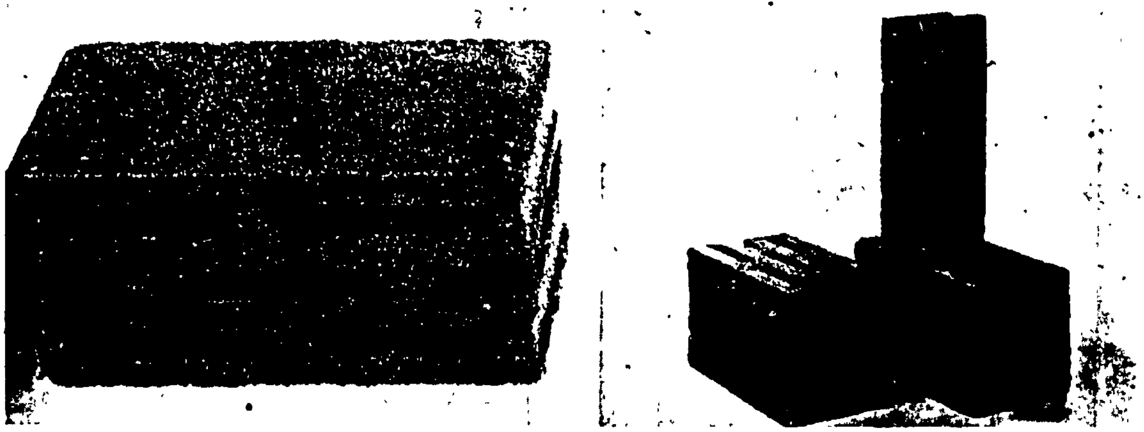

Figure (2.4): Sparfil Concrete masonry building blocks

CHAPTER 3

SURFACE BONDING CEMENT (SBC)

Surface bonding cement, more precisely, a surface bonding mortar will be referred to as "SBC". It is a mixture of white Portland Cement, sand and chopped glass fibres with additives to improve the workability and other properties required for a protective coating for exterior walls. For increased bonding strength to concrete blocks, latex emulsion is added to the mixing water.

The presence of glass fibres improves impact resistance and arrests the formation and propagation of cracks under normal service loading conditions. The quantity of fibres must be carefully controlled as excess fibres create workability problems in mixing and application of the mortar. The fibres must also resist the alkalinity of the fresh cement, which tends to embrittle the fibres and adversly affect their bond to mortar.

In designing a surface bonding mortar mix, the considerations are:

1) Type of glass fibre used in order to resist the medium alkalinity of cement.
2) Fibre length, or in particular, the fibre aspect ratio, diameter to length ratio, in order to maximize their pull out force.
3) Fibre quantity, to ensure there are enough of them per unit area of the coated surface.

4. Incorporation of an inert filling material, usually fines, to eliminate stresses induced from drying shrinkage.
5. The addition of a water reducing agent to improve workability of the mix at a reduced water/cement ratio. The presence of "unwanted water" creates many problems. Aside from reducing overall strength, excess water bleeds out to the surface and deposits the fines it carries, causing "dusting". Also, the passages left behind the bleeding water remain as "open pores", which make the protective coating more permeable to moisture and dirt, thus reducing significantly the durability and especially the resistance to cyclic freezing and thawing.

Surface bonding mortar can be applied by either trowelling or shooting it under pressure onto a clean, dust free surface.

CHAPTER 4

WALL CONSTRUCTION

The simplicity of the wall system makes its construction easy and rapid. Starting at foundation level, the first course of blocks is levelled in a full bed of mortar. Then, the remaining courses are stacked from the corners in a running bond pattern. Mortar is not required in head and bed joints. Openings are left for doors and windows.

Since mortar is not used in joints, care must be taken to eliminate burrs from block surfaces. This is acheived by sliding the blocks over each other. The wall is checked for plumbness and level every fourth or fifth course. Plastic shims or galvanized brick ties can be used for levelling while stacking. Gaps larger than 6 mm (¼") are filled prior to coating the wall.

SBC is prepared by adding water to the ready-to-use dry mix, which contains all the ingredients, additives and glass fibres, in the appropriate proportion. The final mixture has a creamy, easy-to-trowel consistency.

Dampening the clean surface of the wall aids in spreading the SBC and improves the bonding to the blocks. The mix is spread into open joints and completely over the block. A minimum surface thickness of 3 mm (1/8") is used. Only one coat is needed on each side of the wall. (See Figure (4.1)).

Figure (4.1): Construction of a surface bonded block wall

CHAPTER 5

MECHANICAL PROPERTIES OF MATERIALS

5.1 INTRODUCTION

In order to gain some insight into what to expect from the wall system in terms of structural performance, a series of mechanical tests were run on the individual components. Strengths were assessed under idealized loading conditions by testing small samples in pure compression, tension and bending. The results obtained were used to design full scale testing on complete wall sections.

5.2 SPARFIL IN COMPRESSION

Several tests were made on sparfil to determine its compressive strengths:

(a) Three cylinders 15 cm (6") in diameter and 30 cm (12") high, having a density of 720 kg/m^3 (45 pcf). These were tested without being capped.

After failure, the cylinder continued to creep while carrying about 80% of the ultimate load.

Table (5.1) gives sample dimensions and the ultimate compressive strength. Fig. (5.1) shows a typical load-deformation curve of a Sparfil cylinder.

Table (5.1): Compressive Strength of Sparfil Cylinders

Sample #	Dimension diaxheight mm x mm	area 10^3mm^2	Ultimate load P_u kN	Compressive strength f'_c MPa
1	153 x 301	18.4	65.0	3.54
2	150 x 302	18.4	64.0	3.47
3	155 x 305	18.5	69.0	3.73

(b) Samples of rectangular cross section cut from a 250 mm (10") standard block of Sparfil having a density of 720 kg/m^3. (45 pcf). These were tested in compression in the direction of loading of the actual block. Table (5.2) contains the results obtained from this test.

Table (5.2): Compressive Strength of Sparfil prisms

Sample #	Average width mm	Average length mm	Area 10^3mm^2	Ultimate load P_u, kN	Ultimate comp. strength f'_c (MPa)
1	40	118	4.7	4.76	1.0
2	39	116	4.5	6.65	1.5
3	40	117	4.7	6.80	1.4

(c) Standard 4",8" and 10" blocks of Sparfil. These were tested individually in compression. Each block was capped with a lean mix of cement and fine sand. Table (5.3) gives the dimensions and ultimate compressive strengths of the blocks.

(d) Nominally 70 mm cubes cut from a standard 4" x 16" x 24" solid Sparfil block, having density of 720 kg/m^3 (45 pcf). Table (5.4) gives values of the compressive strengths obtained. Table (5.5) lists the average values of the strengths from the various compression tests.

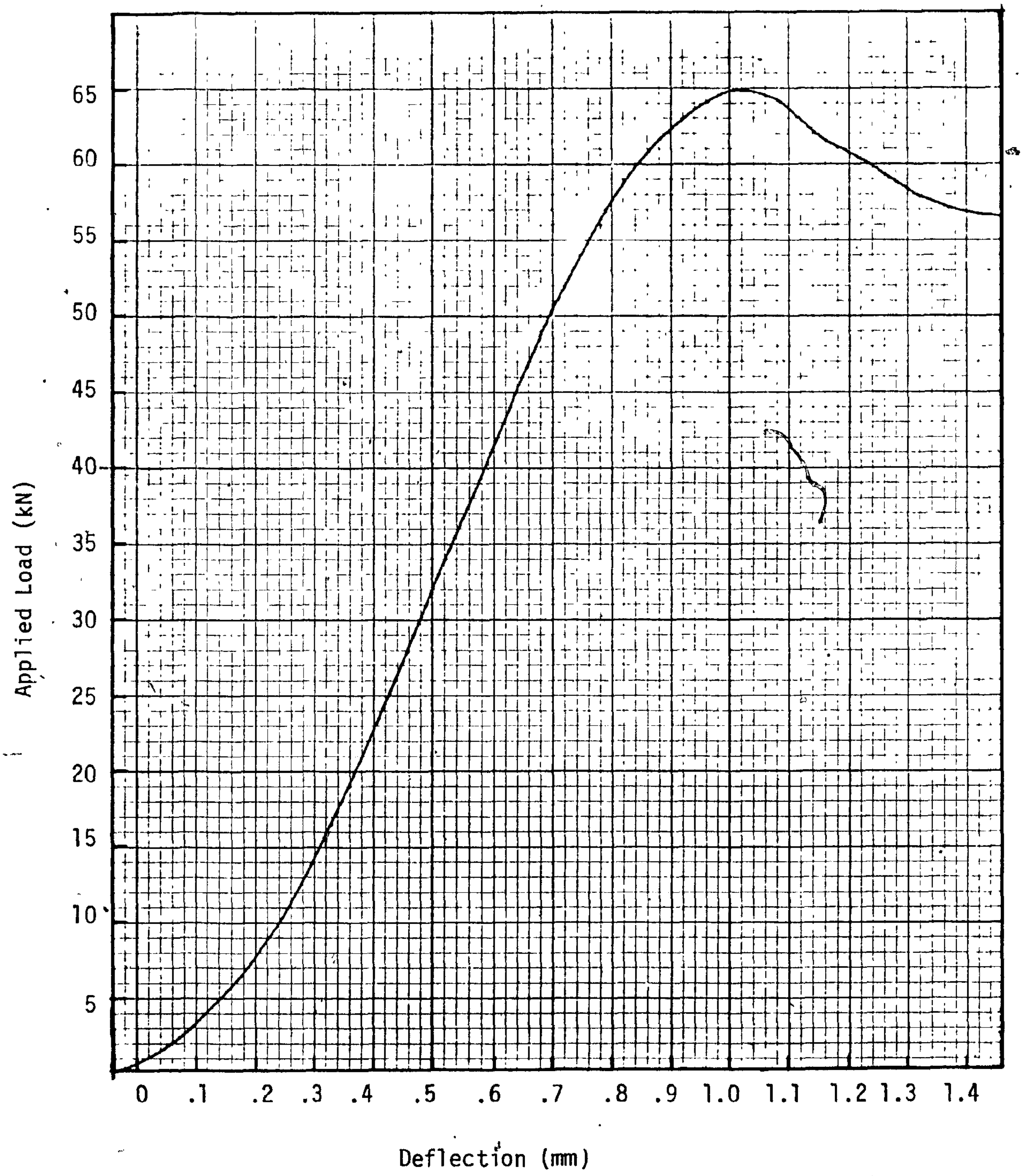

Figure (5.1): Load deflection curve for Sparfil Concrete cylinder in compression.

Table (5.3): Compressive Strength of Sparfil Blocks

Nominal block size (in) mm	Net area (in^2) $10^3 mm^2$	Test #	Ultimate load (lbs) kN	Ultimate compress. strength (psi) MPa	Average compress. strength (psi) MPa
(4) 100	(45.52) 29.4	1	(4950) 22.02	(109) 0.75	(116) 0.80
		2	(5375) 23.91	(118) 0.81	
		3	(5525) 24.58	(121) 0.84	
(8) 200	(82.14) 53.0	4	(11400) 50.71	(139) 0.96	(168) 1.16
		5	(12575) 55.94	(153) 1.05	
		6	(15000) 66.72	(183) 1.26	
		7	(14750) 65.51	(180) 1.24	
		8	(15025) 66.83	(183) 1.26	
(10) 250	(107.25) 96.2	9	(30275) 134.67	(282) 1.94	(265) 1.83
		10	(27750) 123.44	(259) 1.79	
		11	(23550) 104.76	(220) 1.52	
		12	(30500) 135.67	(284) 1.96	
		13	(30250) 134.56	(282) 1.94	

Table (5.4) Compressive Strength of Sparfil concrete cubes

Sample #	Cross-section dimensions mm x mm	Ultimate Load (kN)	Ultimate Compressive Strength (MPa)
1	75.1 X 69.5	17.2	3.26
2	73.5 X 70.2	15.6	3.03
3	71.7 X 74.3	15.7	2.95

Table (5.5): Average Compressive Strengths of Sparfil obtained from various tests

Test #	Types of sample tested	Least thickness mm	Average net compressive strength f_c' MPa (Psi)
1	3 - Cylinders 25 cm dia., 30 cm high	150	3.58 (519)
2	3 - prisms 4 X 10 cm, 10 cm high	40	1.46 (213)
3	3 - 4" blocks	33*	0.80 (116)
4	5 - 8" blocks	25*	1.16 (168)
5	5 - 10" blocks	40*	1.83 (265)
6	3 - 7 cm cubes	70	3.1 (449)

* Thickness of an interior wythe of block, See Appendix (D)

5.3 SPARFIL IN BENDING

Three prisms of Sparfil with a density of 720 kg/m^3 (45 pcf) were cast and tested, after 28 days, in bending. At the point of loading at midspan, SBC was used to prevent crushing. Shear failure was prevented at the supports by reinforcing the sides of the prism with SBC. Table (5.6) contains sample dimensions and the corresponding experimental modulus of rupture. The low value obtained for sample #3 was due to localized failure at ½ span due to some imperfections in molding.

Table (5.6): Calculation of Modulus of Rupture of Sparfil (σ_r)

prism #	Clear span L mm	Width b mm	Depth d mm	Ultimate load P N	M = PL/4 N.mm	S = bd^2/6 mm^3	σ_r = M/S MPa
1	573.1	78.0	77.7	422.6	61,000	78,000	0.8
2	577.9	77.9	78.2	367.0	53,000	79,000	0.7
3	584.2	78.1	78.2	255.8	37,000	80,000	0.5

5.4 SBC IN COMPRESSION

Test cubes were cut from a prism of SBC 5cm x 5cm (2½" x 2½") in cross-section. This particular size was chosen to eliminate excessive shrinkage cracking that may occur in a large sample. The results obtained are listed in Table (5.7). Fig. (5.2) shows a typical load deformation curve of SBC in compression.

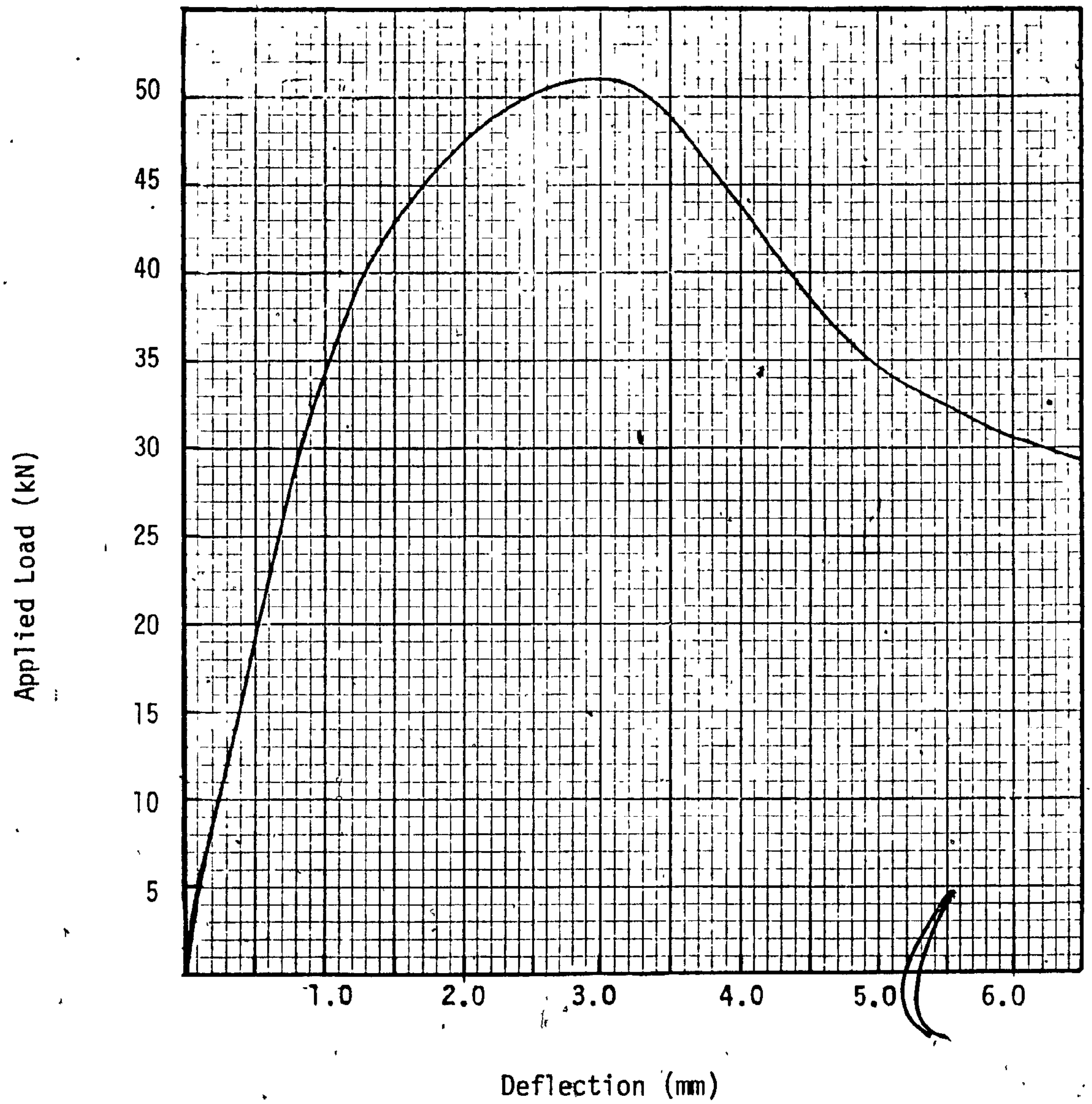

Figure (5.2): Load-deflection curve for SBC cube in compression.

The compressive strength of SBC is about the same as that of normal concrete. It depends on the water/cement ratio which is chosen to give a workable mix that can be easily trowelled on to the surface of a wall. The calculated average of the SBC compressive strengths given in Table (7) is $f'_c = 25.3$ MPa. (3670 psi).

Table (5.7): Compression Test Data on SBC Cubes

Sample #	x-section dimensions mm x mm	Ultimate load, P_u kN	Compressive strength, (f'_c) MPa
1	45.2 X 46.0	54.3	26.1
2	46.7 X 51.0	61.2	25.7
3	46.4 X 51.0	55.8	23.6
4	45.7 X 46.5	51.2	24.1
5	45.4 X 44.8	54.5	26.8

5.5 SBC IN TENSION

The tensile strength of SBC governs the wall bending strength when resisting lateral loads. The modulus of elasticity in tension is required to predict the deflection due to lateral loads.

Direct tension tests were conducted on nine samples having rectangular cross sections of 50 x 12 mm (2" x ½") and nominally 200 mm (6") long. Extensiometers were attached to test samples to measure extensions over a 100 mm (4") gauge length during loading. Test results are given in Table 5.8. the modulus of elasticity in tension was calculated for each sample using the stress-strain curves plotted by the testing machine. A typical stress-strain curve for SBC in tension is shown in Figure (5.3).

SBC has an average direct tensile strength of 4.5 MPa (653 psi) and a modulus of elasticity of 12,500 MPa (1813 ksi). The average ultimate strain is about 3.6×10^{-4} mm/mm.

Table (5.8): Tension test results for SBC specimen

Sample	Area mm^2	Ultimate Load, N	Tensile Strength MPa	Ultimate Strain $\times 10^{-4}$ mm/mm	Modulus of Elasticity MPa
1	605	2500	4.1	3.5	11,000
2	612	2700	4.4	3.9	12,000
3	610	2900	4.7	3.4	13,000
4	623	2500	4.0	4.0	11,000
5	564	2800	4.9	3.3	15,000
6	621	3000	4.9	3.6	13,000
7	619	3100	5.0	3.5	15,000
8	635	2700	4.3	3.2	12,000
9	627	2900	4.6	3.7	12,000

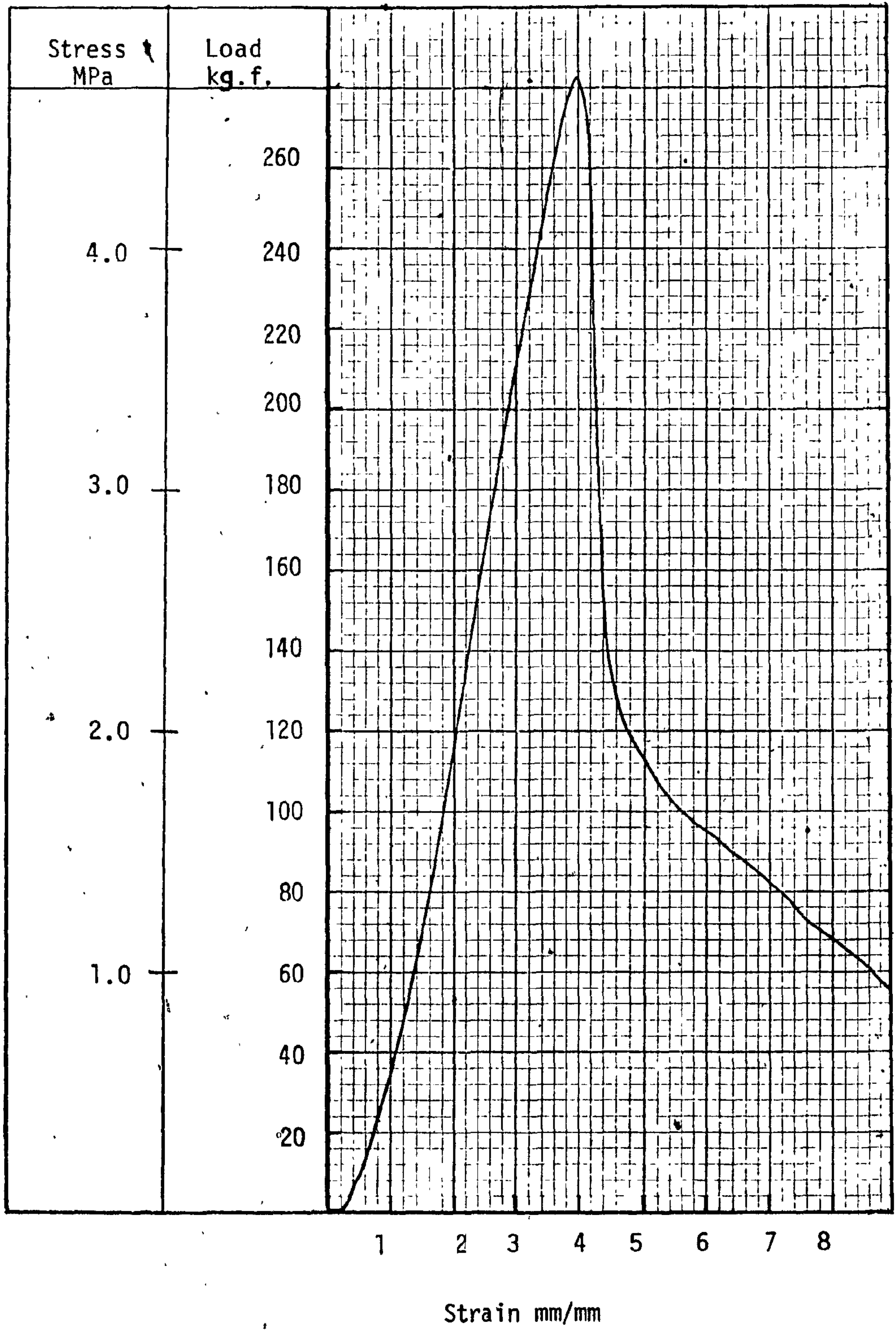

Figure (5.3): Stress-strain curve for SBC in tension.

5.6 SBC IN TENSION DUE TO BENDING

(a) Prisms of SBC of 50 x 50 x 450 mm were cast and tested in bending under one concentrated load applied at midspan. The modulus of rupture obtained for each sample is listed in Table (5.9) along with the corresponding dimensions.

Table (5.9): Calculation of Modulus of Rupture of SBC

prism #	Clear span, L mm	Width b mm	Depth d mm	Ultimate load, P N	$M = PL/4$ N.mm	$\sigma_r = M/S$ MPa
1	440	50.1	50.9	1820	201,000	9.3
2	432	48.0	52.3	1620	175,000	8.0
3	432	48.5	51.5	1620	175,000	8.2
4	440	49.0	50.1	1900	210,000	10.2
5	439	48.7	50.2	1990	218,000	11.7

(b) Prisms were made from 70 mm cubes of Sparfil surface bonded with SBC on two opposite faces to form a sandwiched beam 600 mm long. Three such beams were tested in bending. The computed tensile stress in the skin is given in Table (5.10) for samples 1, 2 and 3.

(c) Three beams 1200 mm (4') long were cut from actual wall sections and tested in bending with two-point loading at ¼ of span. In all tests, failure occured at the joint closest to the line of loading. (See figure (5.4)). Tests results are given in Table (5.10) for samples 4, 5 and 6.

Table (5.10): Calculation of tensile stresses in SBC skins

Test #	Clear span L mm	Total depth d mm	Width b mm	Skin thickness		P_u N	Moment arm $a = d-(t_1 + t_2)$ mm	Ultimate moment 10^3 N.mm	$T = M/a$ N	$\sigma_{ts} = T/bt_2$ MPa
				bot-tom t_2 mm	top t_1 mm					
1	559	83.9	72.5	5.23	8.76	600.5	76.9	84	1100	2.88
2	559	81.1	70.1	4.98	9.45	578.3	73.9	81	1100	3.14
3	562	82.2	71.3	5.56	8.75	585.5	67.9	82	1200	3.05
4	1130	200.8	125.5	4.14	3.61	2444	196.9	326.3	1700	3.66
5	1118	200.5	123.5	3.28	3.23	1555	197.2	286.1	1500	3.64
6	1125	200.1	124.5	3.51	3.42	2375	193.2	334.0	1700	3.96
7	1105	201	570	3.75	3.50	9326	193.7	2576	13 300	4.4
8	1100	202	565	4.00	3.95	10131	193.7	2786	14 400	4.5
9	1110	201	585	3.80	3.70	9434	193.7	2618	13 500	4.3
10	1100	251	560	3.20	3.61	10364	244.5	2850	11 700	4.6
11	1112	251	550	3.65	3.25	10486	244.5	2915	11 900	4.2
12	1113	251	555	3.21	3.47	9520	244.5	2649	10 800	4.3

(d) Six beams 1200 mm (4') long and 600 mm (24") wide were cut from actual wall sections. Three beams were 200 mm deep cut from 8" - walls. The other three were 250 mm deep cut from 10" - walls. all beams were cut at an angle of 45° to the joints. They were tested in bending, one point loading.

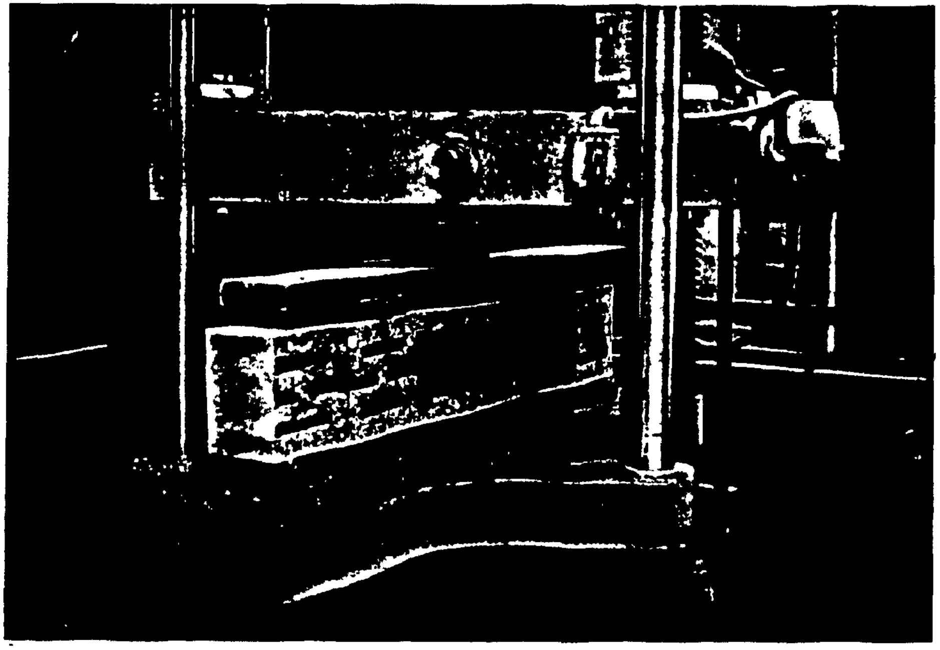

Fig. (5.4) Test set-up to determine tensile strength of SBC

Failure of the six beams occured in the tension face along the block joints. No failure was seen in the core. Figure (5.5) shows the bending direction relative to the bed joints and the line of failure. Test results are given in Table (5.10). Samples 7,8 and 9 were 200 mm deep; samples 10, 11 and 12 were 250 mm deep.

To compute the stress in the SBC skin, the portion of the core below the neutral axis is neglected since the core is not continuous. The elastic modulus of the core, E_c, is approximately one tenth of that of the skin ($E_s/E_c = 10$) and furthermore, it is effectively reduced due to the discontinuity of the core. For analysis the moment arm is approximated as the distance between C_s and T. See figure (5.6).

From simple equilibrium: Applied moment = Resisting moment, or $M = T.d'$ where T = tensile force carried by the skin, and d' = resisting moment arm. The tensile stress developed in the skin $\sigma_{ts} = M/S$ where S is the section modulus provided by the skins = $b\ t_2\ d'$. The computed skin tensile stress is given in Table (5.10). The average tensile stress in the skins of samples 1, 2 and 3 is 3.0 MPa compared to 3.8 MPa for those of samples 4, 5 and 6. This discrepancy may be attributed to the way the SBC was applied. The application of SBC to a large surface, as in test C, section 5.4 is accomplished with less manipulation than when it is applied to a small surface such as used in test B. Over manipulating leads to bleeding of mortar water to the surface carrying with it the very fine particles of sand. This eventually reduces the overall strength.

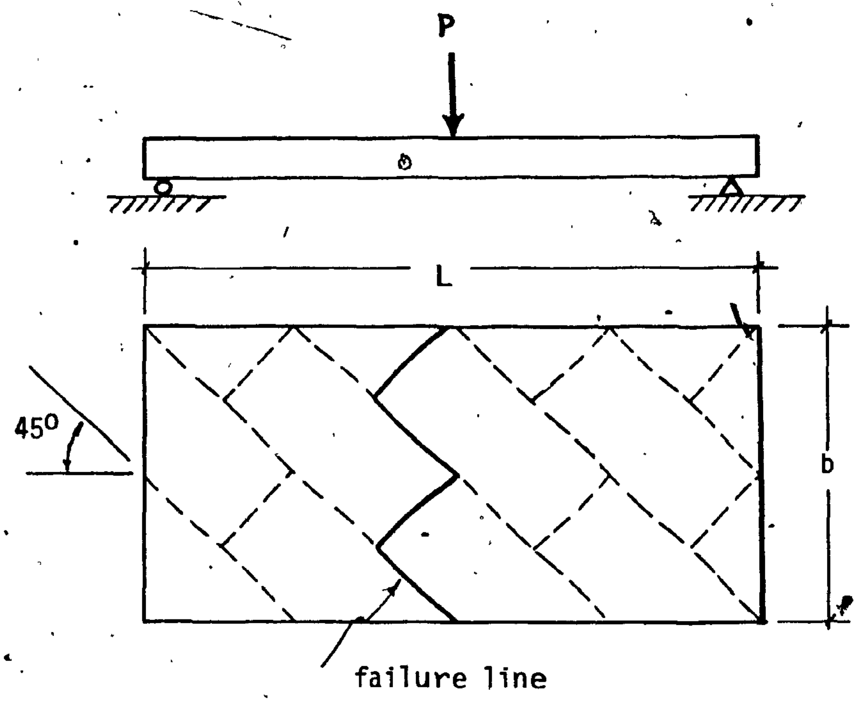

Figure (5.5): Wall section in bending at 45° to bed joints.

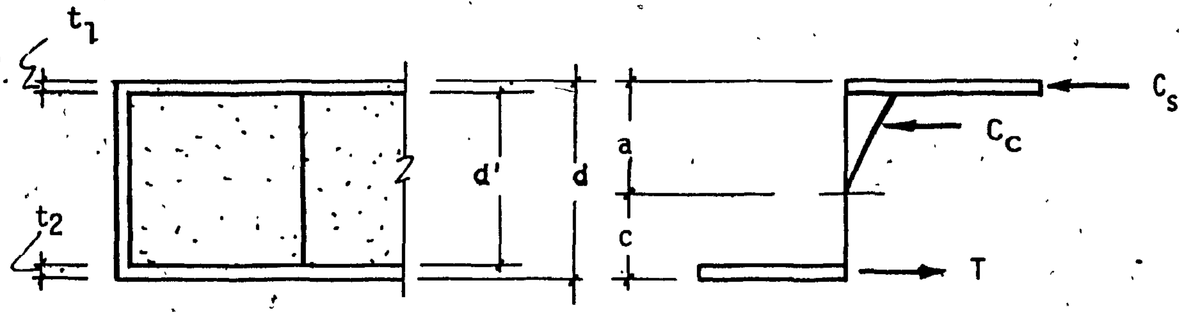

Figure (5.6): Stress distribution in a sandwiched beam section.

5.7 ANALYSIS OF RESULTS

Various values were obtained for the ultimate compressive stength of Sparfil Concrete. These range from 0.8 MPa for a 100 mm (4") block to 3.6 MPa for a standard 250 mm (6") diameter cylinder. By examining table (5.5) it is seen that the strength obtained, for a given density, depends on two factors. First, the test sample's least dimension plays a significant role in the ultimate strength. The self-confining effect of a large sample produces values three times greater than those obtained for the thinest specimen. Second, the specimen's cross sectional geometry is found to affect the overall ultimate strength. This is evident by examining results obtained for tests 2 and 5 found in table (5.5). Webs within the block provide a positive bracing action and some stability against any lateral dimensional changes. Figure (5.7) shows the dependence of compressive strength on the factors mentioned.

Test performed on SBC produced more consistent resuls. For prisms, the material is assumed to behave in a non-linear manner. The ultimate compressive strength and modulus of rupture are 25.3 MPa and 9.3 MPa respectively. As an approximate analysis, consider a section under bending load having a plastic stress distribution as shown in figure (5.8). From equilibrium:

$$\sigma_c(d-c) = \sigma_t c$$

or:

$$c = \frac{\sigma_c d}{\sigma_t + \sigma_c}$$

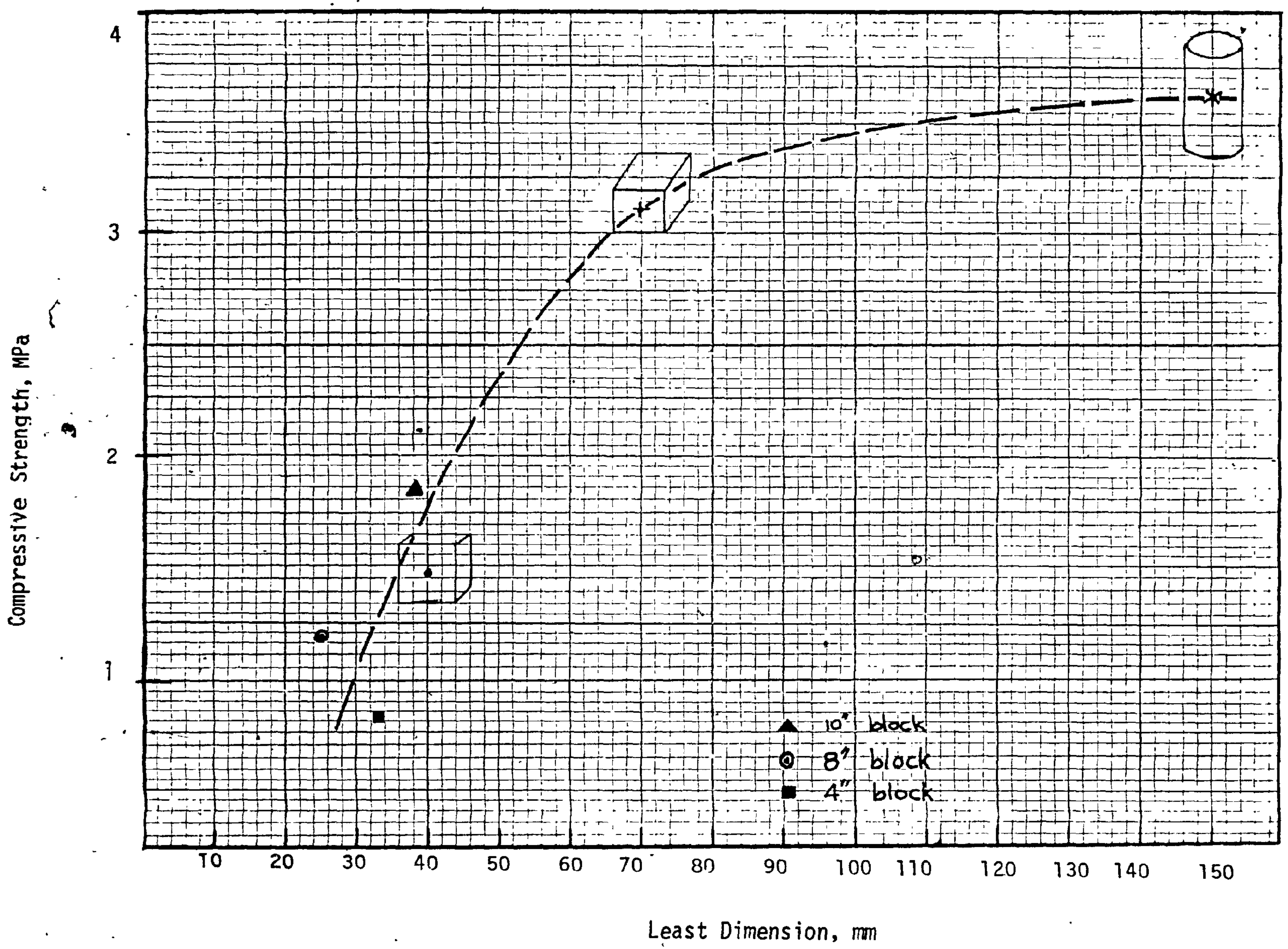

Figure (5.7): Compressive strength of Sparfil Concrete versus sample least dimension then: $$a = d(1 - \frac{\sigma c}{\sigma t + \sigma c})$$

Taking moments about C:

$$M = \sigma_t \; c \; (\frac{d}{2}), \text{ per unit width}$$

Substituting the value of c:

$$M = \frac{d^2}{2} \left(\frac{\sigma c \; \sigma t}{\sigma c + \sigma t}\right)$$

The modulus of rupture is given by: $\sigma_r = M/_S$, $S = bd^2/6$

or: $$\sigma r = \frac{3\sigma c \; \sigma t}{\sigma c + \sigma t}$$

by manipulation, we get:

$$\sigma_t = \frac{\sigma c \quad \sigma r}{3 \; \sigma c - \sigma r}$$

This equation gives the tensile stress reached at full plastic condition for a material of given ultimate compressive and flexural strengths. By substituting values obtained for SBC, we get:

$$\sigma_t = \frac{25.3 \times 9.3}{3 \times 25.3 - 9.3} = 3.5 \text{ MPa}$$

The average experimental tensile strength obtained for SBC of 4.5 MPa indicates that the section approaches the "fully plastic" condition at failure.

SBC's modulus of elasticity in tension is found to be one half of its value in compression. According to other research work done by an independent firm$^{(1)}$, an average value for SBC modulus of elasticity was found to be 25,200 MPa (3.65 x 10^6 psi). The modulus of elasticity of Sparfil concrete in compression is 2520 MPa (365 ksi) $^{(2)}$.

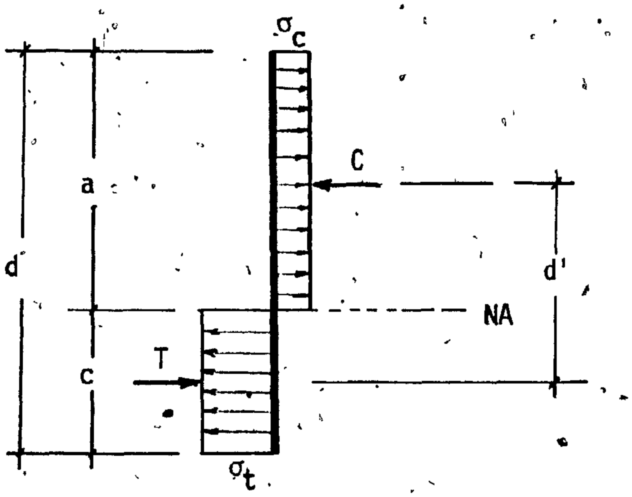

Figure (5.8): Stress distribution across a fully plastic section in bending.

CHAPTER 6

THEORY AND ANALYSIS OF WALL BEHAVIOUR

6.1 INTRODUCTION

The wall system combines the stiffness and lightness characterised by a sandwich construction. The thick low density core is sandwiched between two thin, stiff faces. The faces carry most of the bending stresses, their action being similar to the flanges of an I-beam. The core provides the shear strength of the wall, and stablizes the thick compression face against buckling. The bond between face and core is called upon to resist shear stress and also tension from the wrinkling tendency of the compression face. This behaviour has been verified by the failure modes for the different loading conditions.

6.2 WALL IN BENDING

6.2.1 General

In bending, the two faces of the wall are assumed to provide the whole resisting couple, because the core is discontinuous at the bed joints. Even when bending occurs at 45° to the joints, the skins provide the total resistance.

Only two cases will be considered in the analysis and experiments. First, when bending is perpendicular to bed joints, because of its obvious governing influence. Second, when bending is at 45° to the bed joints.

6.2.2. Bending Perpendicular to Bed Joints

Referring to figure (5.6), section 5.6, and neglecting the small contribution of core, the location of neutral axis can be found by geometry to be:

$$c = d \frac{t_1}{t_1+t_2} \tag{6.1}$$

where c = distance from the neutral axis to the extreme fibres in tension mm,

t_1 = thickness of compressive face,

t_2 = thickness of tension face,

Neglecting moment of inertia of the skins about their own axes, the moment of inertia about its centroidal axis is given by:

$$I = bd^2 t_1 t_2/(t_1+t_2) \tag{6.2}$$

where b = the width of the section, and

d = the depth of the section measured between centres of skin thicknesses.

The moment carrying capacity of the section is given by:

$$M = f_t . t_2 d \tag{6.3}$$

where f_t is the ultimate tensile strength of SBC.

These equations will be used to calculate the bending capacity of test walls. Values obtained will be compared with experimental figures in a following section.

6.2.3 Bending Inclined to Bed Joints

Experiments conducted in section 5.6 (d) indicate that failure occurred in SBC skin and no failure was evident in the core. This verifies our assumption made earlier that skin alone provides resistance to lateral loads.

For bending at 45° to the bed joints, see figure (5.6), one might consider the "extended" failure path B along the block joints in calculating the bending capacity of a section.

For example the lateral load capacity of sample #7, of table (10), was 9326 N and:

$L = 1105$ mm $d = 198$ mm

$t_1 = 3.50$ mm $t_2 = 3.75$ mm

$b = 570$ mm

$$M = \frac{PL}{4} \quad \frac{9326 \times 1105}{4} = 2.576 \times 10^6 \text{ N.mm}$$

$$\sigma = \frac{2.576 \times 10^6}{570 \times 198 \times 3.75} = 6.1 \text{ MPa}$$

For forces normal to the joint line, the ultimate strength is 4.5 MPa.

The ratio of 6.1/4.5 = 1.35 is approximately 2. i.e. the ratio of the relative length of the failure path to the actual width of the section.

6.3 WALL IN COMPRESSION

6.3.1 General

The axial load carrying capacity of our wall is shared between the stabilized SBC skin and the Sparfil concrete core blocks. Which governs depends on the ratio of the strengths and elastic moduli. In the present tests $\sigma_C/\sigma_S < E_C/E_S$, so the core governs. Once the ultimate strength of the block is exceeded, its edges start to crumble accompanied by noticeable lateral expansion at the block edges. This in turn forces the SBC skin to buckle outwards under the imposed compressive stress. Skin buckling begins at the bed joints.

The compressive strength of sparfil concrete is found to be dependent on the least dimension and general shape of the tested samples. Different values obtained in section 5.1 make the task of determining the "true" ultimate strength difficult. Furthermore, the presence of SBC skin provides a certain "confinement" which may alter the ultimate core stress. Local failure at sample edges may not affect the strength in a testing machine, but it has the most influence on inducing skin buckling in wall failures.

A general stress distribution within a wall section is shown in figure (6.1). To compute the core compressive stress σ_{CC}, the area of skin is transformed into an equivalent area of core material.

Strain and stress distributions across a transformed section are shown in figure (6.2). In locating the neutral axis, the following assumptions are made:

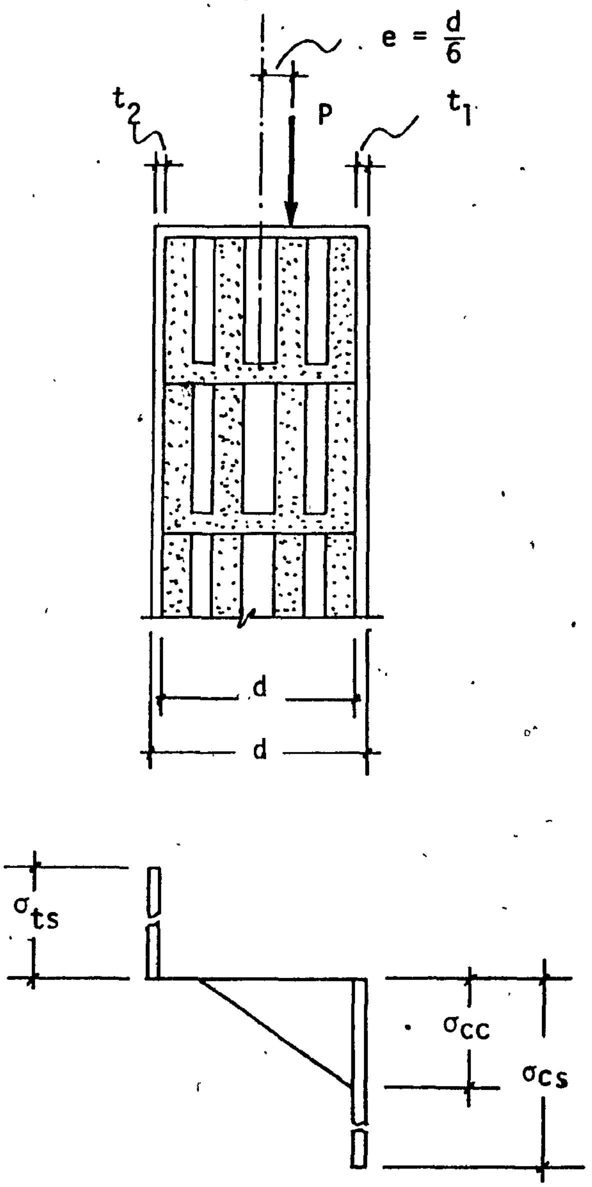

Figure (6.1) : Stress distribution across wall section under axial force P with eccentricity e.

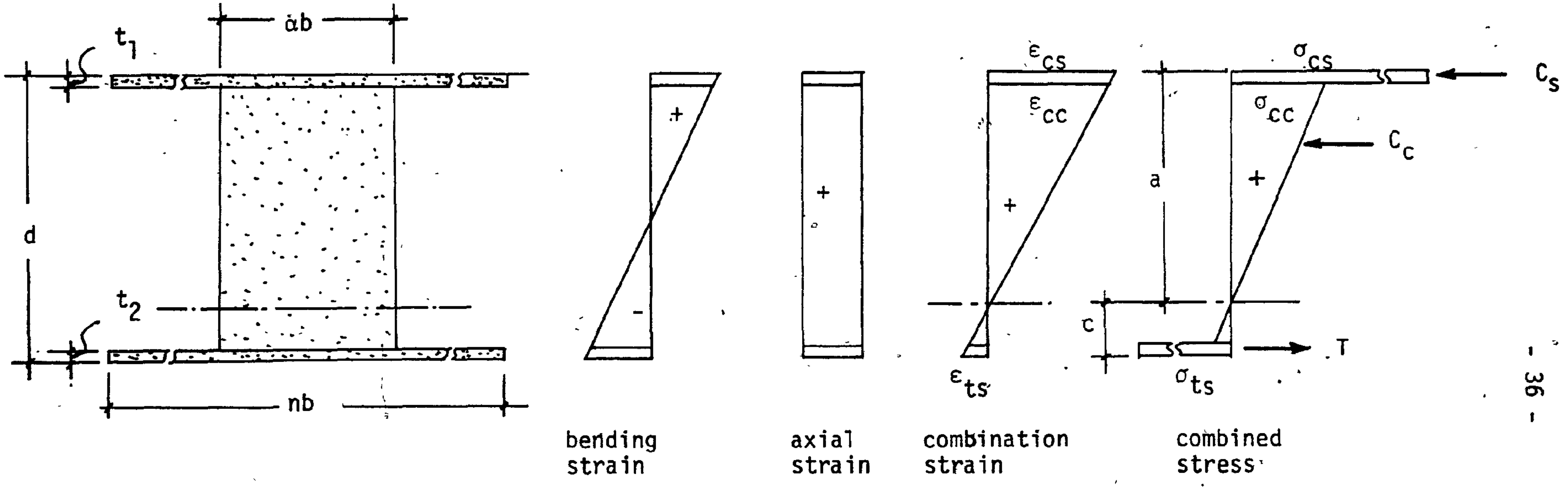

Figure (6.2): Strain and Stress distribution for a transformed section.

1) The core behaves in an elastic manner until it starts crumbling and the skin buckles.
2) The ultimate compressive strength of the core, σ_{cc}, is assumed to be 1.4 MPa. This value is less than that for the complete block because of the edge effect. Hence the ultimate compressive strain in the core σ_{cc} is 1.4/2500 = 5.6×10^{-4} mm/mm.
3) The moment of inertia of the thin face about its own axes is neglected.

Referring to figure (6.2), from geometry the tensile strain in the skin is:

$$\epsilon_{ts} \approx \epsilon_{cc} \left(\frac{d-a}{a}\right) = 5.6 \times 10^{-4} \left(\frac{d}{a} - 1\right)$$

The tensile stress in the skin is:

$$\sigma_{ts} = \epsilon_{ts} E_{ts} = 7 \left(\frac{d}{a} - 1\right) \text{ where } E_{ts} = 12{,}500 \text{ MPa}$$

from which the tensile force in the skin, $T = bt_2 \sigma_{ts}$, becomes:

$$T = 7\ bt_2 \left(\frac{d}{a} - 1\right)$$

The compressive force in the core is $C_c \approx \alpha a b \sigma_{cc}$ where α is the ratio of the net to gross area of the core block. α = 0.69 and 0.71 for the 8" and 10" blocks respectively.

$$C_c \approx 1.4\ \alpha ab$$

The compressive force in the skin is $C_s = nb\,(1-\alpha)\ t_1\ \sigma_{cc}$

$$C_s \approxeq 14\ bt_1\ (1-\alpha)$$

From equilibrium: $T = C_c + C_s$

or $7\ t_2\ (\frac{d}{a} - 1) = 1.4\alpha\ a + 14\ t_1\ (1-\alpha)$

solving for a, we find:

$$a = \frac{1}{2\alpha}\ (Q + \sqrt{Q^2 + 40\ dt_2}) \tag{6.4}$$

where $Q = 10[t_2 + 2t_1\ (1-\alpha)]$ (6.5)

The effective moment of inertia of the section is approximated by:

$$I = b\ (\frac{\alpha\, a^3}{3} + nt_1\, a^2 + nt_2\ c^2) \tag{6.6}$$

6.3.2.2 Calculation of Stresses in Wall

For an axial load P applied with an eccentricity e, the general stress formula is:

$$\sigma = \frac{P}{A} \mp \frac{Pey}{I}$$

where A is the area of the transformed section and is given by:

$$A = b\ [\alpha\ d + n\ (t_1 + t_2)] \tag{6.7}$$

Compressive stress in core: $\sigma_{cc} = P(\frac{1}{A} + \frac{ea}{I})$ (6.8)

Compressive stress in skin: $\sigma_{cc} = nP(\frac{1}{A} + \frac{ea}{I})$ (6.9)

Tensile stress in skin: $\sigma_{ts} = nP(\frac{1}{A} - \frac{ec}{I})$ (6.10)

Equations (6.4) through (6.10) will be used in a later section to calculate stresses in the experimental walls. Combined with equations (6.1) through (6.3), they will form the basis for wall design by finding the required SBC thickness to support a given loading condition.

6.4 WALL UNDER IMPACT

Apart from resisting higher statically applied lateral loads, the resistance of sparfil walls to suddenly applied loads is substantially higher than that of mortared normal weight concrete masonry walls, and the more flexible core imparts larger damping effects.

A load, W, falling from a height, h, onto the centre of the wall possesses a kinetic energy, U = Wh. On impact, this energy will be absorbed by strain energies due to bending, U_b, and due to shear, U_s.

From the relationship of strain energy for pure bending:

$$U_b = 2 \int_0^{L/2} \frac{M^2\,dx}{2\,EI}$$

where M is the bending moment at midspan of the wall, given by M = Px/2. Substituting the value of M and evaluating the integral gives:

$$U_b = \frac{P^2L^3}{96\,EI} = \frac{M^2L}{6\,EI} \qquad (6.11)$$

or $U_b = \frac{P\,\Delta}{2}$, where Δ is the wall deflection at midspan at failure, given by $\Delta = \frac{PL^3}{48\,EI}$.

Knowing that U_b is a fraction γ of the total kinetic energy U, the tensile stress in the skin could now be found from equation (6.11).

$$\gamma Wh = \frac{(\sigma_{ts} S)^2 L}{6\ EI} = \frac{\sigma_{ts}^2\ IL}{6\ E\ c^2}$$

Hence $$\sigma_{ts} = c \sqrt{\frac{6E\ \gamma Wh}{IL}} \qquad \text{- - - - - - -} \qquad (6.12)$$

The fraction γ will be determined in a later section from the results obtained experimentally.

CHAPTER 7

FULL SCALE TESTS ON WALL SECTIONS

7.1 INTRODUCTION

The purpose of these tests was to study the compatibility in behaviour of skin and core materials of full size wall panels. An equation describing the bending behaviour of walls is developed in the following sections. The overall compression strength of the wall is assessed along with an explanation of the mode of failure under the eccentric applied load. The behaviour of the walls subjected to impact loads is also investigated.

Bending, compression and impact tests were performed on a total of 18 walls in accordance with ASTM E (72). All walls were of the same surface area of 122 cm (4') wide and 244 cm (8') high. Nine of the walls were 20 cm (8") thick and nine were 25 cm (10") thick. Walls were constructed by dry-stacking and with surface layers of SBC, about 3 mm (1/8") thick, trowelled onto both faces of the wall and left 28 days before testing began.

7.2 BENDING TESTS

Bending tests were performed on six Sparfil walls in a horizontal position. Loads were applied from underneath the wall by means of a hydraulic ram and a manual pump connected to a pressure gauge, as shown in figure (7.1). The wall was loaded against two reaction steel beams connected to a rigid frame. Temporary supports were used to position

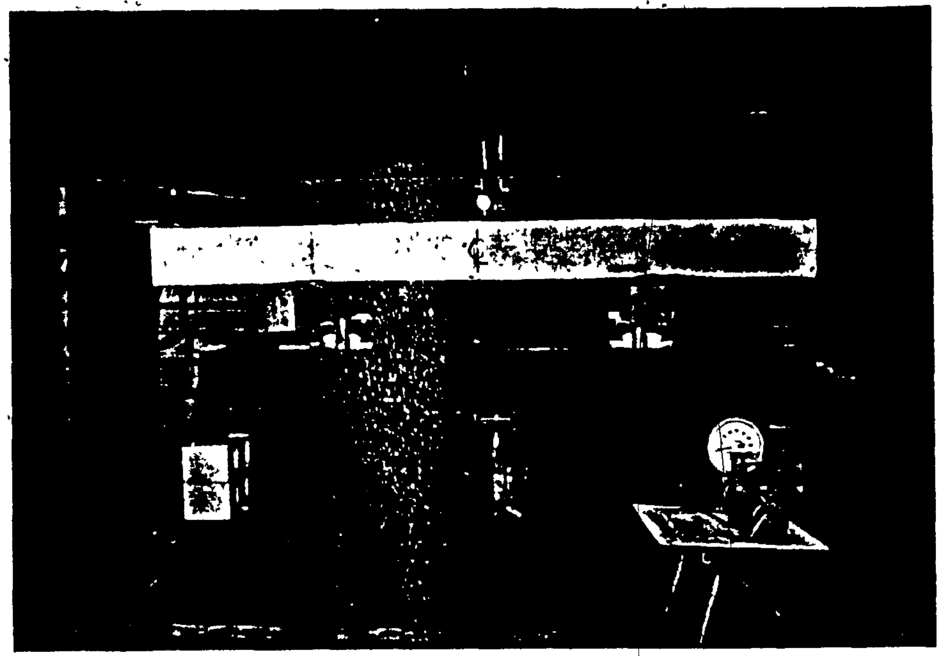

Figure (7.1): Full scale bending test.

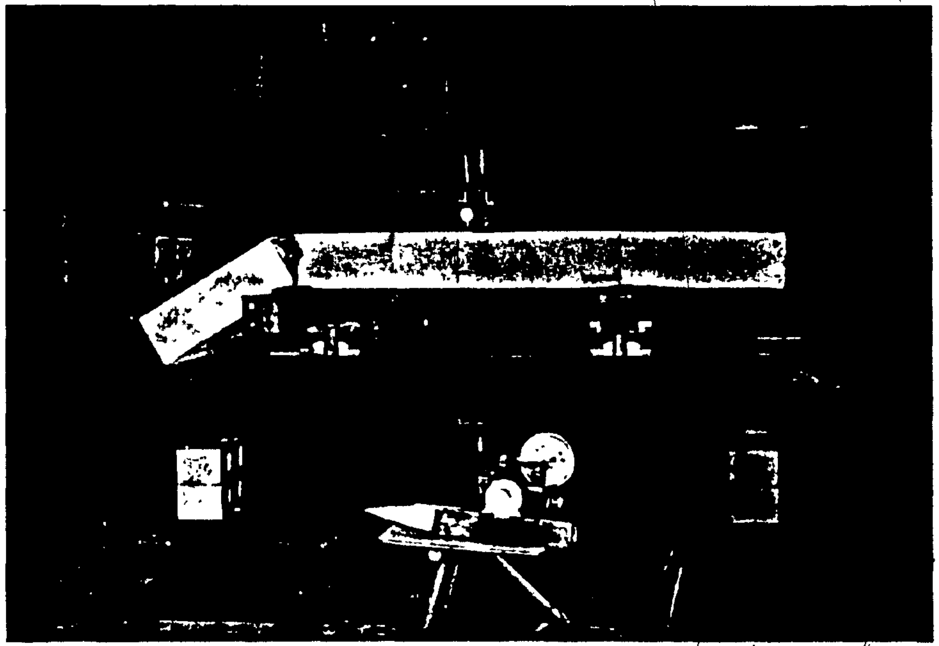

Figure (7.2): Wall section after failure in bending.

the wall above a rigid H beam. The H beam served to divide the ram load into two line loads acting on the test wall. Once in position, the wall was raised by the ram until it touched both reaction beams above. The weight of wall and fixtures resting on the ram was subtracted from the final reading to obtain the net load applied on the wall. Two dial guages to read deflections at the centre of wall were installed at 1/4 width from the edge of the wall. Load was applied in several increments. Deflection readings were taken immediately after each loading. Each load increment was maintained for about 5 minutes after which another deflection reading was taken. Failure of the walls was always along one of the joints between the lines of loading, (see figure 7.2)). Readings obtained on 20 cm and 25 cm walls are given in Appendix A. Readings obtained in British units were converted into SI units and are summarized in Table (7.1). Skin thicknesses at the failure planes are also listed in the same table. The average skin thickness is converted into SI units and used in the analysis. In Figures (7.3) and (7.4), deflections are plotted versus the applied loads for both the 25 cm and 20 cm thick walls, respectively.

Table (7.1): Full Scale Bending Tests Results

Test #	Nominal wall thickness (in) mm	Applied net load (lbs) kN	Maximum deflection (in) mm	Average skin thickness		Average Cross-sectional dimensions mm	Applied bending moment (ft. lb.) N.m.
				Tension face t_2 (in) mm	Compression face t_1 (in) mm		
B1	(10) 250	(4375) 19.46	(0.205) 5.21	(0.156) 3.89	(0.159) 4.05	253 x 1207	(4374) 5931
B2	(10) 250	(3560) 15.84	(0.074) 1.88	(0.155) 3.94	(0.156) 3.96	253 x 1201	(3561) 4828
B3	(10) 250	(3550) 15.79	(0.113) 2.87	(0.158) 4.02	(0.177) 4.49	251 x 1206	(3561) 4828
B4	(8) 200	(2605) 11.59	(0.108) 2.74	(0.129) 3.27	(0.149) 3.78	225 x 1199	(2606) 3533
B5	(8) 200	(2790) 12.41	(0.097) 3.46	(0.120) 3.05	(0.148) 3.75	220 x 1196	(2790) 3783
B6	(8) 20	(3290) 14.63	(0.143) 3.63	(0.136) 3.44	(0.142) 3.60	220 x 1199	(3289) 4459

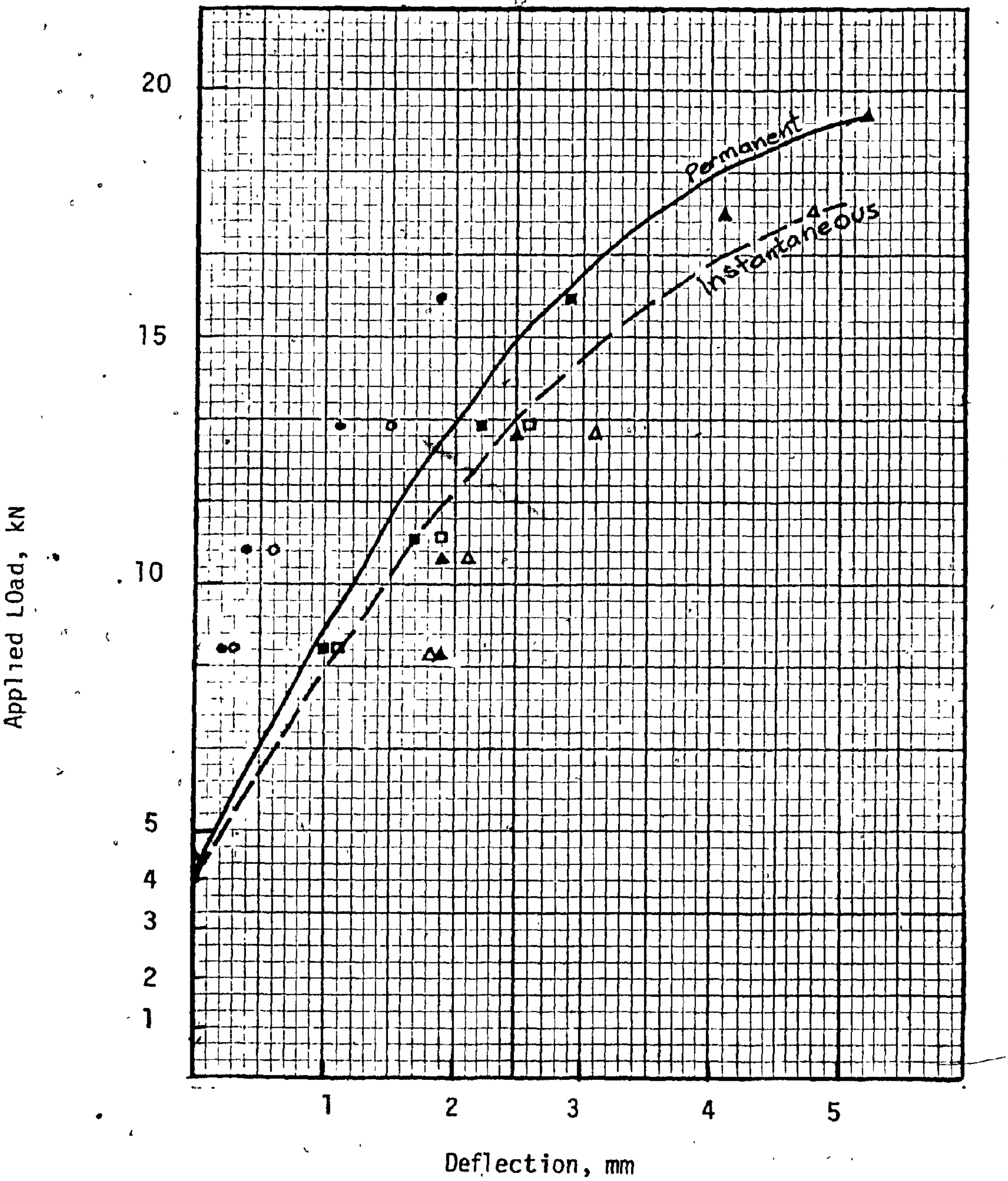

Figure (7.3): Load - deflection curves for 250 mm thick walls in bending.

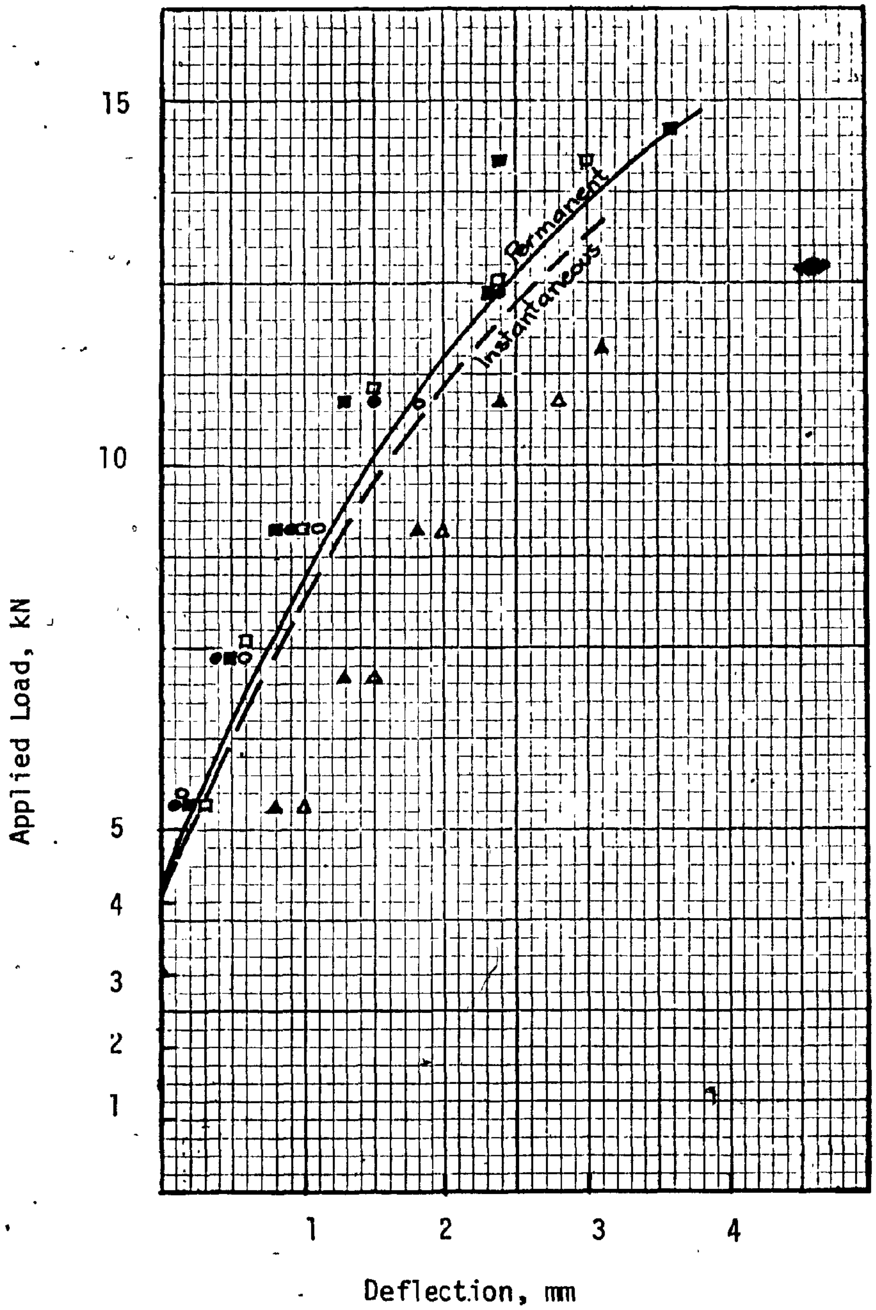

Figure (7.4): Load - deflection curves for 200 mm thick walls in bending.

7.3 COMPRESSION TESTS

Six walls were tested in compression under eccentric loading, in accordance with ASTM E(72). The compressive load was applied in increments and maintained for about five minutes for each. Axial and lateral deflections were measured both at the beginning and at the end of each load increment duration. Figure (7.5) shows the compression test set-up. Failure of the walls was characterized by skin buckling. See Figure (7.6). Readings obtained from the compression tests are included in Appendix (B) and summarized in Table (7.2). The instantaneous and permanent axial deflections are plotted versus the applied loads for both the 25cm and 20cm walls, as shown in Figures (7.7 and 7.8), respectively.

Table (7.2): Full-Scale Compression Tests Results

Test #	Nominal Wall Thickness (in) mm	Applied Net Load (K) kN	Average Skin Thickness		Average Cross-Sectional Dimensions mm
			Tension Face t_2 mm	Compression Face t_1 mm	
C1	(10) 250	(50) 222	2.56	2.74	255 x 1205
C2	(10) 250	(45) 200	2.39	2.34	253 x 1198
C3	(10) 250	(50) 222	3.35	3.17	251 x 1201
C4	(8) 200	(45) 200	2.82	3.94	220 x 1198
C5	(8) 200	(45) 200	2.77	3.40	225 x 1202
C6	(8) 200	(40) 178	2.49	2.90	220 x 1206

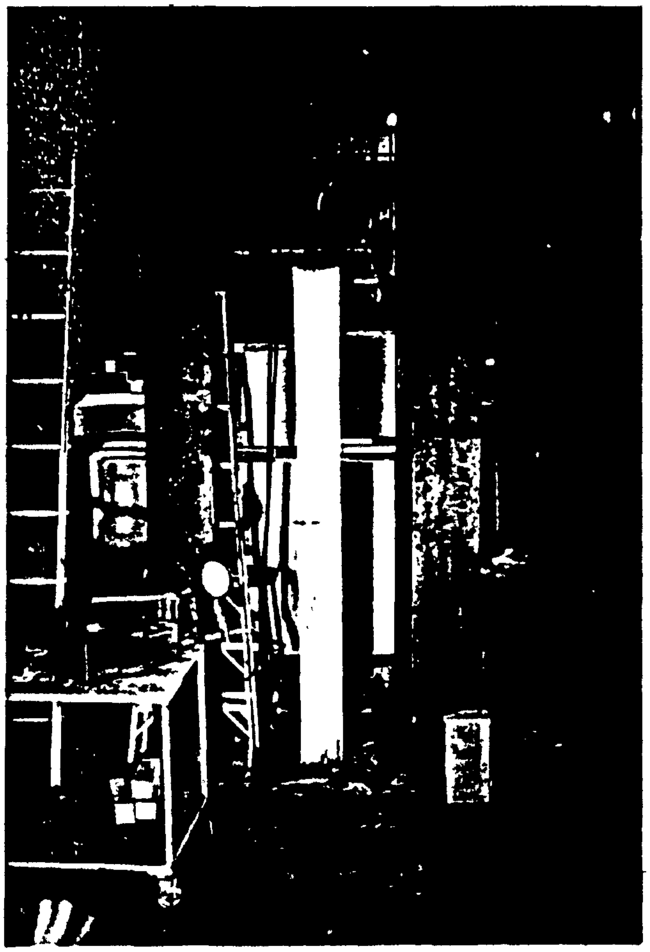

Fig. (7.5): Full scale compression test set-up

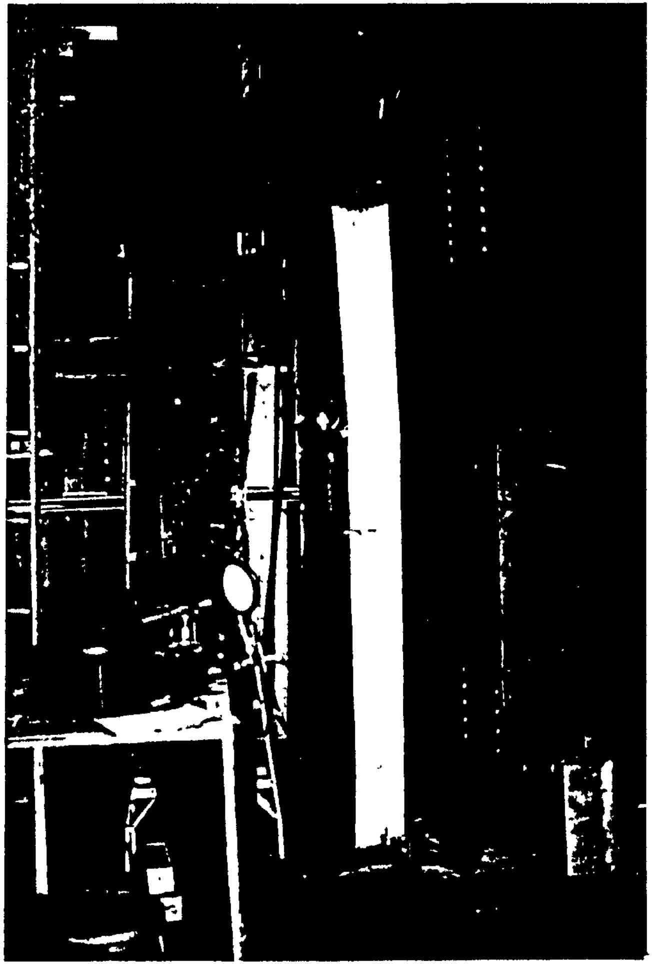

Fig. (7.6): Test wall after failure in compression
Note skin buckling on left side of wall

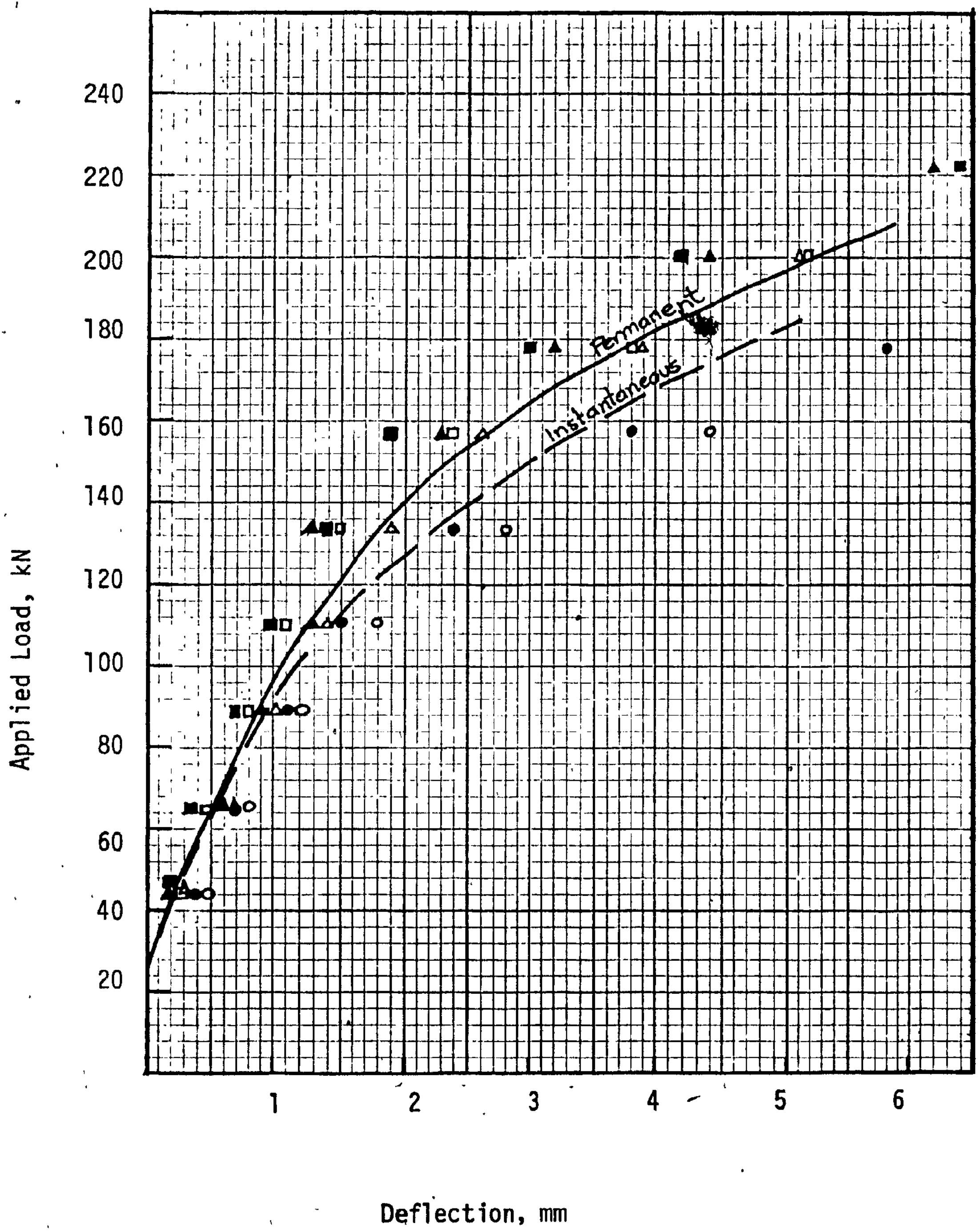

Figure (7.7) : Load - axial deflection curves for 250 mm thick walls in compression.

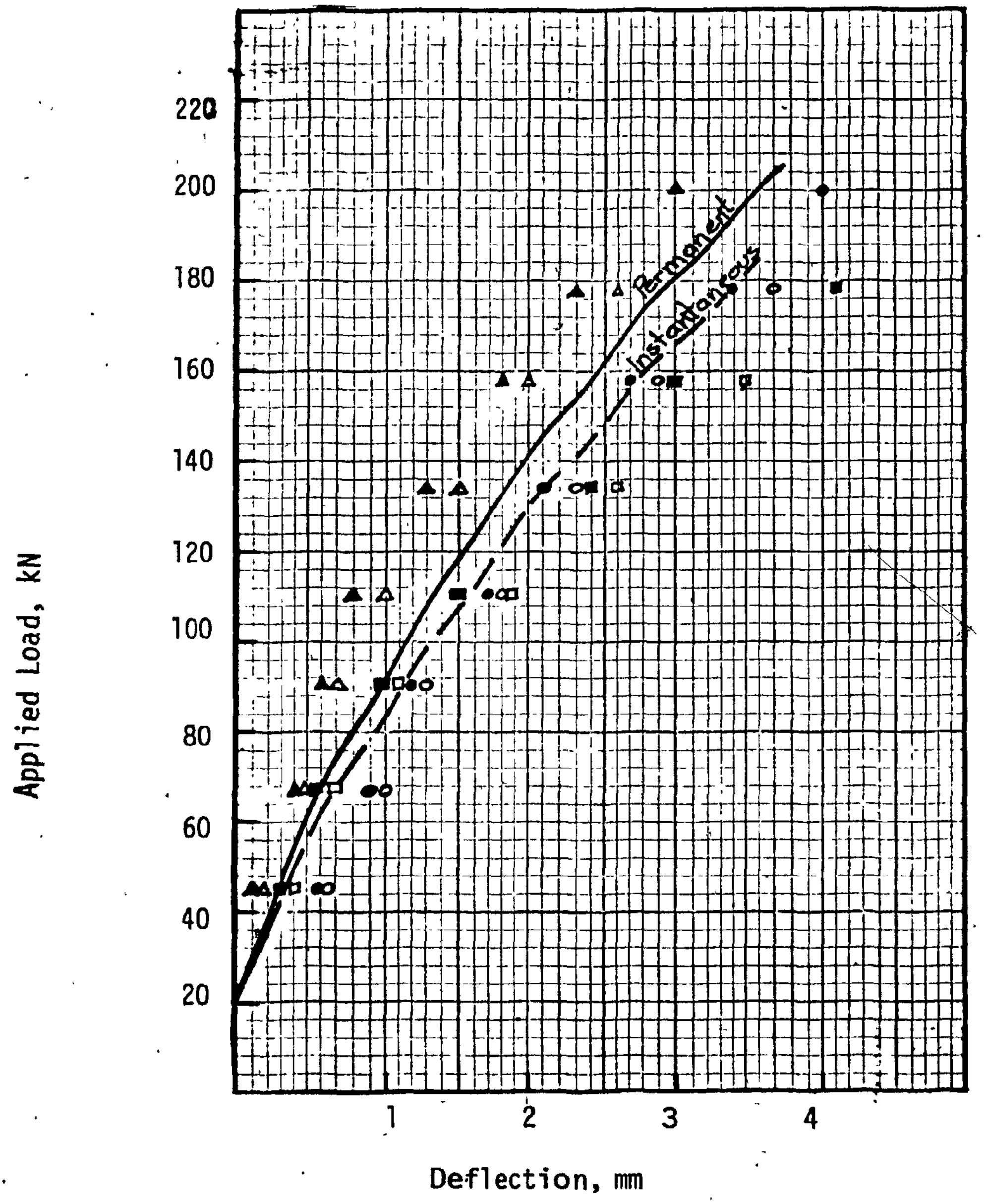

Figure (7.8): Load - axial deflection curves for
200 mm thick walls in compression.

7.4 IMPACT TESTS

Six walls were subjected to impact loads from a sandbag released from different elevations. Except for the bag's weight and its release mechanism, the test was conducted in accordance with ASTM E(72). The wall span was 2.4 m (8').

The 60-pound sandbag prescribed in the ASTM standards did not impart enough energy to cause the dry stacked, surface bonded Sparfil block wall to fail, even at the largest practical drop height, so a 100-pound bag was used in all the tests. The sand bag was raised to the desired elevation by means of an overhead crane and released by cutting the supporting string. Swinging freely, the bag hit the centre of the wall when it reached the lowest point of its path. See figure (7.9).

Deflection and set of the wall were measured instantly after each hit by means of modified dial gauges.

Data obtained from all the impact tests on three 250 mm and three 200 mm walls are included in Appendix (C) and summarized in Table (7.3). The instantaneous deflection versus the impact energy is shown in Figure (7.10). The measured set in the walls was negligible. Failure occurred generally at the central horizontal joint, but, in some walls, was in the two adjacent horizontal joints closest to the centre.

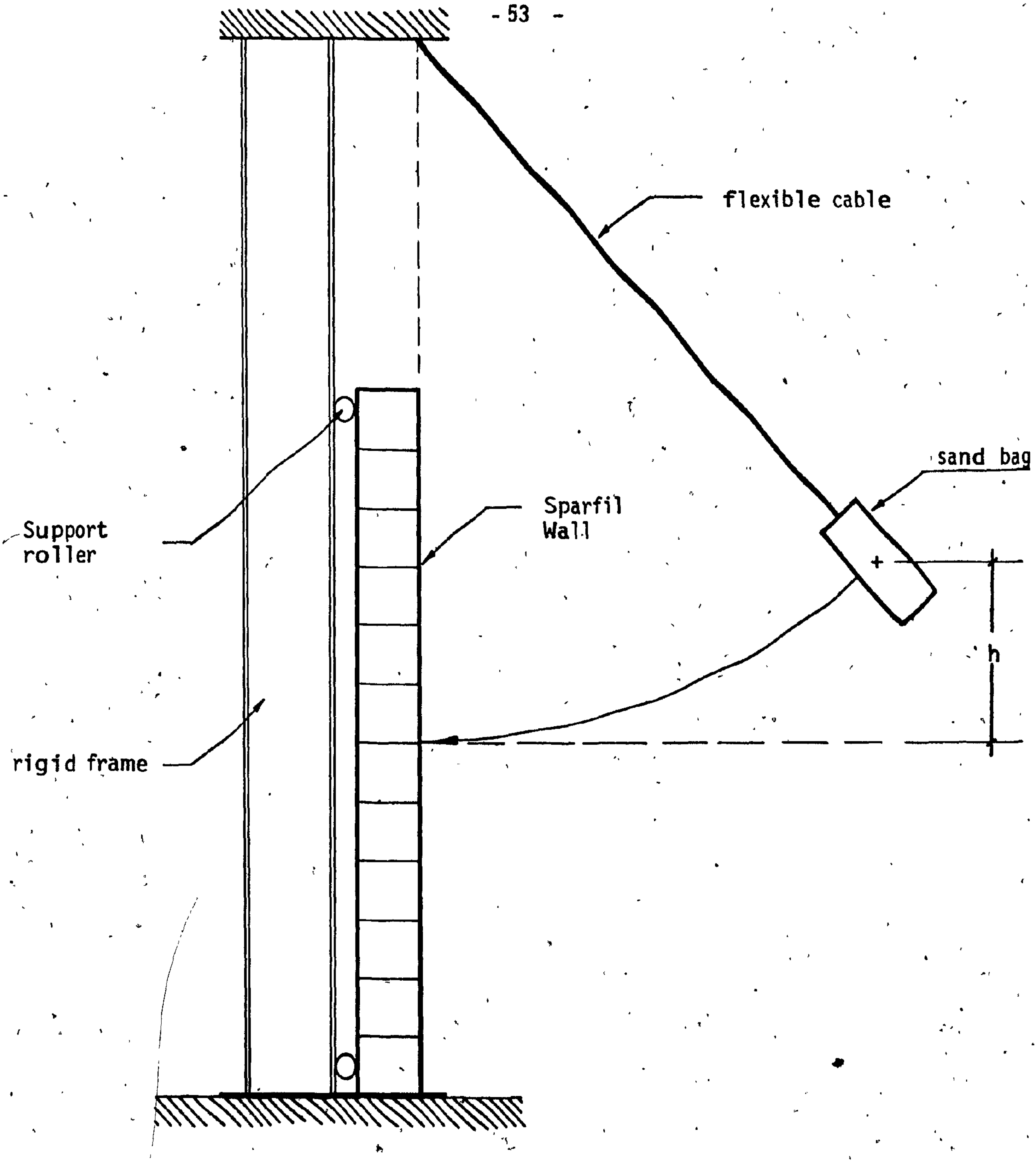

Figure (7.9): Full scale impact test set-up

Table (7.3): Full-Scale Impact Tests Results

Test #	Nominal Wall Thickness (in) mm	Applied Impact Load (ft.lb) N.m	Maximum Deflection mm	Average Skin Thickness mm		Average Cross-Sectional Dimensions mm
				Tension face t_2 mm	Compression face t_1 mm	
I1	(10) 250	(558) 757	7.9	4.71	3.91	254 x 1205
I2	(10) 250	(500) 678	6.8	4.85	3.21	251 x 1200
I3	(10) 250	(517) 701	7.0	4.57	3.87	256 x 1195
I4	(8) 200	(425) 576	5.9	3.47	4.01	220 x 1201
I5	(8) 200	(450) 610	4.9	3.76	4.22	225 x 1191
I6	(8) 200	(400) 542	4.2	4.09	3.93	230 x 1201

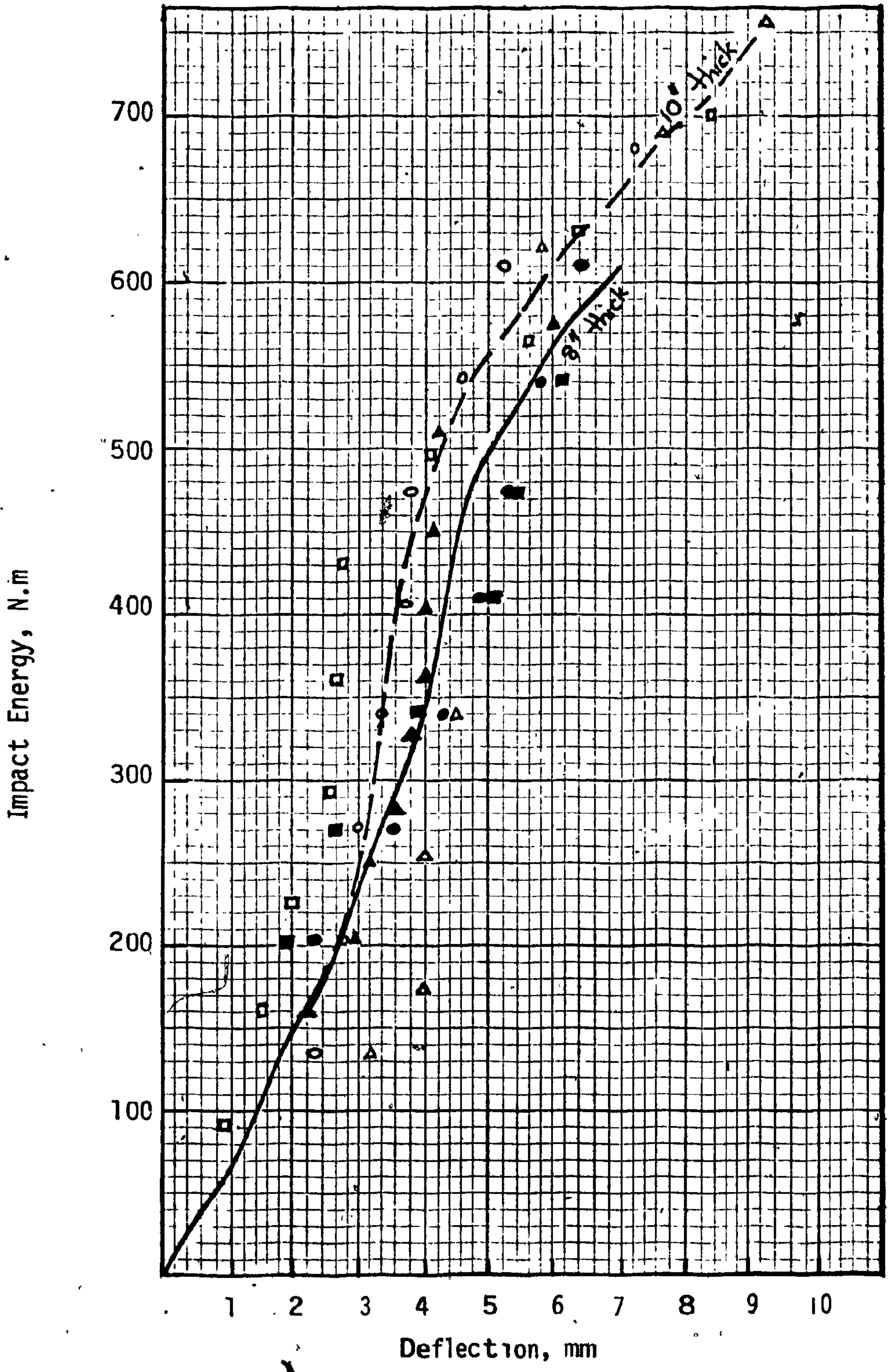

Figure (7.10): Impact energy - deflection curves for test walls

CHAPTER 8

ANALYSIS OF TEST RESULTS

8.1 INTRODUCTION

In this chapter correlations are made between experimental results and the theoretical analysis established in chapter 6. The results from the impact experiments are used to derive the empirical constants needed to simplify the analysis.

8.2 WALL IN BENDING

The data in Table 7.1, obtained from the bending tests, is used to find the maximum tensile stress in the skin at failure, which is compared with the ultimate value of 4.5 MPa obtained from direct tests on the SBC. The results are summarized in Table (8.1).

The following typical calculation is made for test specimen B1, for which:

$d = 253$ mm $\qquad b = 1207$ mm

$t_1 = 4.05$ mm $\qquad t_2 = 3.89$ mm

$M = 5931$ N.m

Equation (6.1) gives: $c = d \dfrac{t_1}{t_1+t_2}$

$$c = 253 \frac{4.05}{4.05 + 3.89}$$

$$c = 129 \text{ mm}$$

$$a = 253 - 129 = 124\text{mm}$$

Equation (6.2) gives: $I = bd^2\, t_1 t_2 / (t_1+t_2)$

$$I = \frac{1207 \times 253^2 \times 4.05 \times 3.89}{4.05 + 3.89} = 153.3 \times 10^6 \text{ mm}^4$$

Then $$\sigma_{ts} = \frac{Mc}{I} = \frac{5931 \times 10^3 \times 129}{153.3 \times 10^6} = 5.0 \text{ MPa}$$

The tensile stressses in the skins are seen to be close to the ultimate tensile strength of SBC of 4.5 MPa.

Table (8.1): Tensile stresses in skins in bending tests

Sample #	Applied Moment N.m	c mm	I x 10^6 mm^4	Tensile Stress in skin, MPa
B1	5931	129	153.3	5.0
B2	4828	127	151.8	4.0
B3	4828	132	161.1	4.0
B4	3533	120	106.4	4.0
B5	3783	121	97.4	4.7
B6	4459	112	102.1	4.9

8.3 WALL IN COMPRESSION

Substituting data obtained from Table (7.2) into the equations of Section 6.2 gives all the stresses in the test walls. Results of these calculations are given in Table 8.2.

Using wall C1 as an illustration:

$d = 255$ mm $\qquad b = 1205$ mm

$t_1 = 2.74$ mm $\qquad t_2 = 2.56$ mm

$P = 222$ kN $\qquad = 0.71$

$e = d/6 = 42$ mm

Equation (6.4) gives $a = \frac{1}{2\alpha}\ (Q + \sqrt{Q^2 + 40\ dt_2})$

where $Q = 10\ [t_2 + 2t_1\ (1-\alpha)] = 10[2.56 + 2\text{x}2.74\ (1-0.71)] = 41.5$ mm

$$a = \frac{1}{2\text{x}0.71}\ (41.5 + \sqrt{41.5^2 + 40 \text{ x } 255 \text{ x } 2.56})$$

$$a = 147 \text{ mm} \quad , c = 255-147 = 108 \text{ mm}$$

The effective moment of inertia is found from equation (6.6):

$$I = b(\frac{a^3}{3t} + t_1\ a^2 + t_2 c^2)$$

$$I_{eff} = 1205\ [\ \frac{0.71 \text{ x } 147^3}{3} + 10 \text{ x } 2.56 \text{ x } 108^2 + 10 \text{ x } 2.74 \text{ x } 147^2]$$

$$I_{eff} = 1.98 \text{ x } 10^9 \text{ mm}^4$$

The area of the transformed section is given by equation (6.7)

$$A = b[\alpha d + n\ (t_1+t_2)]$$

$$A = 282000\ \text{mm}^2$$

Compressive stress in the core is given by equation (6.8) as:

$$\sigma_{cc} = P(\frac{1}{A} + \frac{e.a}{I})$$

$$\sigma_{cc} = 222 \times 10^3\ (\frac{1}{282000} + \frac{42\text{x}147}{1.98 \times 10^9})$$

$$\sigma_{cc} = 1.48\ \text{MPa}$$

Compressive stress in the skin is then:

$$\sigma_{cs} = n\ \sigma_{cc}$$

$$\sigma_{cs} = 14.8\ \text{MPa}$$

The stress in the far skin is found by evaluating equation (6.10)

$$\sigma_{ts} = nP(\frac{1}{A} - \frac{ec}{I})$$

$$\sigma_{ts} = 10\text{x}222\text{x}10^3\ (\frac{1}{282000} - \frac{42\text{x}108}{1.98\text{x}10^9})$$

$$\sigma_{ts} = 3.09\ \text{MPa (compression)}$$

The calculated stresses in this particular wall indicate that the core blocks just started to crumble at σ_{cc} = 1.4 MPa. Failure of this wall is characterized by skin buckling due to core failure at bed joints.

Table (8.2): Stresses in walls under axial loading with eccentricity of d/6

Sample #	Applied Load kN	a mm	I $10^9 mm^4$	Compressive stresses MPa		
				Core σ_{cc}	Skin 1 σ_{cs}	Skin 2 σ_{ts}
C1	222	147	1.98	1.49	15.14	3.09
C2	200	139	1.69	1.44	14.65	1.46
C3	222	171	2.76	1.34	13.64	4.76
C4	200	158	2.38	1.24	12.58	6.78
C5	200	155	2.16	1.30	13.22	6.04
C6	178	143	1.71	1.27	12.86	4.84

8.4 WALL IN IMPACT

The strain energy due to bending is calculated for each wall at failure using the equation $U_b = \frac{P\Delta}{2}$, where P is the ultimate static load applied at the centre of the wall, this is also given by :

$$U_b = \frac{2M\Delta}{L} = \frac{2f_t \; I\Delta}{Lc}$$

for f_t = 4.5 MPa

$$= \frac{U_b}{U} = \frac{9 \; I \Delta}{Wh \; Lc} \times 100$$

Values of γ are calculated and listed in table (8.3) for all walls. The average span length for each wall is 2440 mm. Other data are obtained from table (7.3).

Table (8.3): Derivation of γ for impact walls

Sample #	U N.m	I 10^6 mm^4	c mm	Δ mm	γ %
I1	757	166.1	116	7.9	5.5
I2	678	146.1	102	6.8	5.3
I3	701	164.1	118	7.0	5.1
I4	576	108.1	117	5.9	3.5
I5	610	119.9	118	4.9	3.0
I6	542	127.3	113	4.2	3.2

Using wall I1 as an example :

$d = 254$ mm $\qquad b = 1205$ mm

$t_1 = 3.91$ mm $\qquad t_2 = 4.71$ mm

$U = 757$ N.m $\qquad \Delta = 7.9$ mm

$L = 8'\text{-}0'' = 2440$ mm $\qquad E = 12500$ MPa

Equation (6.1) gives: $c = d\,\frac{t_1}{t_1+t_2}$

$$c = 254\,\frac{3.91}{3.91+4.71} = 116 \text{ mm}$$

Equation (6.2) gives: $I = bd^2\,t_1t_2/(t_1+t_2)$

$$I = 1205\,(254)^2(3.91)(4.71)/(3.91+4.71) = 166.1\times10^6\text{mm}^4$$

Then $$\gamma = \frac{9\times166.1\times10^6\times7.9\times100}{757\times1000\times2440\times116} = 5.5\%$$

Only 5.5% of the total kinetic energy is absorbed in the form of bending strain energy. The average values of 5% and 3% for 250 mm and 200 mm thick walls will be used respectively.

CHAPTER 9

RECOMMENDED DESIGN PROCEDURE

In designing SBC walls with thin faces, there are two considerations: First, bending and compressive capacities of the wall are governed by the strength of the skin in tension or compression and the core in compression. Second, effective area and moment of inertia of the cross section depend on the loading condition of the wall. The limiting extremes are:

1) Wall in pure bending: The skin alone provides the required resistance and the core is not considered.

2) Wall in pure compression: The core provides part of the compressive resistance. The transformed area and moment of inertia of the core, along with those of the faces, are considered. This is also the case in the general loading condition of compression combined with bending.

Axial loading provides positive contact between the blocks at bed joints and the core is considered to be continuous in the compression zone.

The design task is to find the required skin thickness for each side of a wall. The experiments indicate that core stresses at failure are 1.42 MPa and 1.27 MPa for 250 mm and 200 mm thick walls respectively. Consequently, characteristic stress of 1.2 MPa for 200 mm walls instead of 1.4 MPa is recommended.

Table (9.1) lists the ultimate capacities, under axial compressive load, of a 200 mm (8") wall for all combinations of skins thicknesses from 3 to 24 mm. The given values are for one meter wide section without any bending. Similar values are given for a 250 mm (10") wall in table (9.2). A diagonal line across the tables replaces values equal to those found at its top end. For example, the axial load carrying capacity of a (6,12) - 200 mm wall, where the thickness of compression skin (t_1) is 6 mm and that of the tension skin, (t_2) is 12 mm, is 402 kN/m. This is found by tracing the diagonal line passing through location (6,12) read the value indicated at its upper end.

Table (9.1): Axial Load Carrying Capacity of 200 mm Thick Wall, kN/m

t_2 t_1	3	6	9	12	15	18	21	24
3	237	278	320	361	402	444	485	526
6	/	/	/	/	/	/	/	556
9	/	/	/	/	/	/	/	589
12	/	/	/	/	/	/	/	622
15	/	/	/	/	/	/	/	656
18	/	/	/	/			/	692
21	/	/	/	/			/	726
24	/	/	/	/		/	/	761

Table (9.2): Axial Load Carrying Capacity of 250 mm Thick Wall, kN/m

t_2 t_1	3	6	9	12	15	18	21	24
3	333	382	430	480	529	578	627	676
6								709
9								746
12								784
15								824
18								864
21								905
24								946

CHAPTER 10

CONCLUSION

Surface bonded Sparfil concrete masonry blocks offer certain advantages to the construction industry, the light weight and inherent insulating properties, the strength and weather resistance of SBC skins, and a rapid erection procedure.

The structural capacity is governed by the compressive strength of core blocks, and at failure the edges of the Styropor concrete block crumble causing the wall skin to buckle at bed joints. An increase in the overall capacity of the wall could be achieved by improving the blocks strength and their dimensional uniformity.

Sparfil block walls with a nominal skin thickness of 3 mm provide adequate strength for many applications with limited load carrying requirements and the walls performance in bending although controlled by the skin is superior to that of a conventional masonry block wall with mortared joints.

The ability of SBC wall system to absorb impact energy is substantial. Due to the damping property of Sparfil concrete, much of the impact energy is dissipated in the core.

Since SBC skins provide all the bending resistance and some axial load carrying capacity, rigid quality control in preparing the mix and good workmanship in the application are essential. In particular care must be taken to avoid cold joints, due to work interruption, at any bed joint level.

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4. Nichollos, Robert, Composite Construction Material Handbook, Prentice-Hall, Inc. 1976.

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APPENDIX "A"

Bending Tests Data on
200 mm (8") and 250 mm (10") Walls

Table (A1): Bending Test Data on 10" Surface Bonded Sparfil Block Walls

Sample # weight (lbs)	Applied Load (lbs)	Deflections				Remarks *	Skin Thickness at Failure Plane	
		Instantaneous		Permanent			Tension Face (in)	Compression Face (in)
		1 (in)	2 (in)	1 (in)	2 (in)			
B1	1000	0.000	0.000	0.000	0.000		0.150	0.132
	1925	0.082	0.064	0.084	0.065		0.154	0.155
	2375	0.086	0.066	0.090	0.075		0.154	0.173
47.25"x2.93"	2925	0.104	0.095	0.125	0.120			
l = 96.75"	3925	0.165	0.157	0.195	0.180			
(1200)	4375	0.205				Failure (1)	Average 0.153	Average 0.153
B2	1000	0.000	0.000	0.000	0.000		0.150	0.155
	1950	0.005	0.010	0.009	0.015		0.165	0.157
47.50"x9.94"	2400	0.014	0.021	0.020	0.029		0.149	0.157
l = 96.25"	2950	0.035	0.052	0.047	0.068			
(1177)	3560	0.061	0.086			Failure (2)	Average 0.155	Average 0.157
B3	890	0.000	0.000	0.000	0.000		0.117	0.167
	1940	0.034	0.044	0.045	0.045		0.164	0.178
47.40"x10.00"	2440	0.060	0.070	0.069	0.079		0.194	0.185
l = 96.10"	2940	0.081	0.092	0.102	0.105			
(1185)	3550	0.110	0.115			Failure (2)	Average 0.158	Average 0.177

* (1) At Centre Joint
(2) At Joint Directly Under Line of Loading

Table (A2): Bending Test Data on 8" Surface Bonded Sparfil Block Walls

Sample # weight (lbs)	Applied Load (lbs)	Deflections				Remarks *
		Instantaneous		Permanent		
		1 (in)	2 (in)	1 (in)	2 (in)	
B4	1200	0.030	0.035	0.035	0.043	
	1600	0.050	0.056	0.055	0.063	
48.10"x7.90"	2050	0.067	0.075	0.074	0.085	
l = 97.20"	2450	0.090	0.100	0.105	0.112	Failure
(920)	2605	0.115	0.126			(1)
B5	1200	0.005	0.005	0.007	0.006	
	1640	0.017	0.017	0.024	0.024	
48.50"x7.90"	2040	0.037	0.035	0.045	0.045	
l = 97.50"	2440	0.059	0.059	0.069	0.069	Failure
(935)	2790	0.095	0.098			(2)
B6	1200	0.009	0.010	0.011	0.012	
	1640	0.019	0.019	0.022	0.023	
	2040	0.035	0.035	0.040	0.039	
48.70"x7.90"	2440	0.051	0.052	0.060	0.059	
l = 96.70"	2790	0.075	0.072	0.077	0.075	
	3190	0.095	0.097	0.115	0.122	Failure
(935)	3290	0.135	0.150			(2)

Skin Thickness at Failure Plane	
Tension Face (in)	Compression Face (in)
0.120	0.137
0.135	0.153
0.131	0.157
Average	Average
0.129	0.149
0.115	0.141
0.121	0.147
0.124	0.155
Average	Average
0.120	0.148
0.130	0.130
0.135	0.145
0.142	0.150
Average	Average
0.136	0.142

* (1) At Centre Joint
(2) At Joint Directly Under Line of Loading

APPENDIX "B"

Compression Tests Data on 200 mm (8") and 250 mm (10") Walls.

Table (B1): Compression Test Data on 10" Surface Bonded Sparfil Block Wall
Sample C1

Applied Load kips	Instantaneous Deflection				Permanent Deflection				Remarks
	Axial		Lateral		Axial		Lateral		
	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	
10	0.011	0.007	0.8	0.0	0.014	0.011	0.8	0.0	
15	0.026	0.021	0.8	0.0	0.028	0.023	0.8	0.0	
20	0.039	0.033	0.8	0.0	0.042	0.035	0.8	0.0	
25	0.058	0.046	0.8	0.5	0.061	0.050	0.9	0.5	
30	0.075	0.063	1.0	0.6	0.080	0.067	1.1	1.0	
35	0.099	0.082	1.3	1.2	0.108	0.094	1.5	1.5	Hissing sound
40	0.129	0.121	2.0	2.0	0.159	0.145	2.8	2.6	
45	0.175	0.170	3.5	3.7	0.205	0.200	4.0	4.5	
50	0.250	0.241	4.5	5.0					Skin buckles.

Skin thicknesses at failure plane :

Tension Face :		Compression Face :	
	0.100"		0.118"
	0.106"		0.102"
	0.098"		0.091"
			0.121"

Wall Cross-Section Area : Top : 10.75" x 47.5"
Bottom : 10.0" x 47.75"

Table (B2): Compression Test Data on 10" Surface Bonded Sparfil Block Wall
Sample C2

Applied Load kips	Instantaneous Deflection				Permanent Deflection				Remarks
	Axial		Lateral		Axial		Lateral		
	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	
10	0.019	0.010	0.0	0.0	0.022	0.013	0.0	0.0	
15	0.035	0.021	0.2	0.2	0.037	0.023	0.5	0.5	
20	0.051	0.034	0.6	0.8	0.056	0.037	1.0	1.0	
25	0.072	0.050	1.2	1.3	0.085	0.058	1.2	1.3	
30	0.110	0.078	2.2	2.2	0.126	0.092	2.8	3.0	
35	0.175	0.123	4.0	4.0	0.195	0.150	4.0	5.0	Hissing sound
40	0.250	0.205	5.0	5.0	0.270	0.255	5.5	6.0	
45	0.295	0.273	6.0	7.0					Skin buckles

Skin thicknesses at failure plane :

Tension Face :	Compression Face :
0.085"	0.108"
0.106"	0.100"
0.092"	0.081"
0.094"	0.077"
	0.092"

Wall Cross-Section Area : Top : 10.5" x 47.0"
Bottom : 10.0" x 47.25"

Table (B3): Compression Test Data on 10" Surface Bonded Sparfil Block Wall
Sample C3

Applied Load	Instantaneous Deflection				Permanent Deflection				Remarks
	Axial		Lateral		Axial		Lateral		
kips	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	
10	0.007	0.009	0.0	0.0	0.008	0.010	0.1	0.0	
15	0.015	0.018	0.5	0.1	0.018	0.019	0.5	0.2	
20	0.026	0.029	0.8	0.8	0.030	0.030	0.8	0.8	
25	0.040	0.040	1.0	0.8	0.045	0.043	1.0	1.0	
30	0.055	0.054	1.0	1.0	0.062	0.059	1.2	1.1	
35	0.075	0.071	1.8	1.5	0.102	0.082	2.1	2.0	
40	0.118	0.115	2.5	2.5	0.155	0.150	3.0	3.0	Hissing sound
45	0.170	0.165	3.5	3.0	0.205	0.200	5.0	5.0	
50	0.255	0.250	6.5	6.0					Skin buckles

Skin thicknesses at failure plane :

Tension Face :	0.123" 0.129" 0.145"	Compression Face :	0.168" 0.170" 0.155"

Wall Cross-Section Area : Top : 11.0" x 47.5"
Bottom : 10.0" x 47.5"

Table (B4): Compression Test Data on 8" Surface Bonded Sparfil Block Wall
Sample C4

Applied Load kips	Instantaneous Deflection				Permanent Deflection				Remarks
	Axial		Lateral		Axial		Lateral		
	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	
5	0.000	0.000	0.0	0.0	0.000	0.000	0.0	0.0	
10	0.006	0.000	0.0	0.0	0.008	0.002	0.0	0.0	
15	0.015	0.014	0.0	0.0	0.017	0.017	0.0	0.0	
20	0.025	0.022	0.0	0.0	0.027	0.026	0.0	0.0	
25	0.035	0.032	0.1	0.0	0.041	0.042	0.1	0.0	
30	0.050	0.050	0.1	0.0	0.059	0.057	0.2	0.3	Hissing sound
35	0.070	0.069	0.5	0.6	0.079	0.078	0.6	0.8	
40	0.091	0.092	0.8	0.9	0.100	0.107	0.9	1.0	
45	0.118	0.119	1.0	1.2					Skin buckles

Skin thicknesses at failure plane :

Tension Face : 0.130"
0.149"
0.151"

Compression Face : 0.127"
0.195"
0.154"

Wall Cross-Section Area :

Top : 8.13" x 48.40"
Bottom : 7.75" x 47.35"

Table (B5): Compression Test Data on 8" Surface Bonded Sparfil Block Wall Sample C5

Applied Load	Instantaneous Deflection				Permanent Deflection				Remarks
	Axial		Lateral		Axial		Lateral		
kips	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	
5	0.012	0.011	0.0	0.0	0.013	0.012	0.0	0.0	
10	0.024	0.022	0.0	0.0	0.025	0.024	0.2	0.0	
15	0.037	0.035	0.5	0.2	0.041	0.038	0.5	0.4	
20	0.053	0.045	0.8	0.8	0.056	0.051	1.0	1.0	
25	0.068	0.061	1.2	1.1	0.075	0.066	1.5	1.2	
30	0.088	0.077	2.0	1.9	0.097	0.085	2.2	2.0	Hissing sound
35	0.113	0.100	2.5	2.5	0.120	0.107	3.0	3.0	
40	0.140	0.125	3.8	3.7	0.154	0.137	4.1	4.0	
45	0.165	0.150	7.0	6.9					Skin buckles

Skin thicknesses at failure plane :

Tension Face : 0.185"
0.134"
0.175"

Compression Face : 0.136"
0.141"
0.160"
0.120"

Wall Cross-Section Area : Top : 8.50" x 48.75"
Bottom : 7.50" x 47.75"

Table (B6): **Compression Test Data on 8" Surface Bonded Sparfil Block Wall Sample C6**

Applied Load	Instantaneous Deflection				Permanent Deflection				Remarks
	Axial		Lateral		Axial		Lateral		
kips	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	(1) (in)	(2) (in)	(1) (mm)	(2) (mm)	
5	0.004	0.005	0.0	0.0	0.008	0.009	0.0	0.0	
10	0.010	0.013	0.0	0.0	0.012	0.016	0.0	0.0	
15	0.021	0.021	0.3	0.1	0.027	0.025	0.8	0.3	
20	0.038	0.039	1.0	0.6	0.044	0.046	1.0	0.9	
25	0.059	0.064	1.2	1.0	0.070	0.075	1.6	1.2	Hissing sound
30	0.085	0.094	2.0	2.0	0.100	0.106	2.1	2.3	
35	0.116	0.124	3.0	3.0	0.135	0.141	3.2	3.5	
40	0.160	0.165	4.5	4.7					Skin buckles

Skin thicknesses at failure plane :

Tension Face :		Compression Face :	
	0.150"		0.118"
	0.137"		0.136"
	0.121"		0.096"
			0.104"

Wall Cross-Section Area :
Top : 8.25" x 48.13"
Bottom : 7.75" x 47.75"

APPENDIX "C"

Impact Tests Data on 200 mm
(8") and 250 mm (10") Walls

Table (C1): Impact Test Data on 10" Surface Bonded Sparfil Block Walls

Test # & Date	Height of Drop (in)	Impact Load (ft.lb)	Deflections		Average Skin Thickness at Failure Plane (mm)
			Midspan (in)	Support (in)	
I 1	12.0	100	0.125		4.28
	15.6	130	0.154		4.86
	22.8	190	0.158		5.00
	30.0	250	0.178		
	55.0	458	0.227		
	61.0	508	0.305		Average
	67.0	558	0.365	0.054	4.71
I 2	12.0	100	0.092		4.72
	18.0	150	0.107		4.84
	24.0	200	0.120		5.00
	30.0	250	0.135		
	36.0	300	0.142		
	42.0	350	0.150		
	48.0	400	0.180		
	54.0	450	0.205		Average
	60.0	500	0.285	0.017	4.85
I 3	8.0	67	0.035		4.28
	14.0	117	0.058		4.70
	20.0	167	0.078		4.72
	26.0	217	0.098		
	32.0	267	0.102		
	33.0	317	0.108		
	44.0	367	0.161		
	50.0	417	0.221		
	56.0	467	0.251		Average
	62.0	517	0.326	0.050	4.57

Average Walls dimensions: 4'- 0"x8'- 0"x10"

Table (C1): Impact Tests Data on 8" Surface Bonded Sparfil Block Walls

Test # & Date	Height of Drop (in)	Impact Load (ft.lb)	Deflections		Average Skin Thickness at Failure Plane (mm)
			Midspan (in)	Support (in)	
I 4	14.0	117	0.086		3.60
	18.0	150	0.114		3.34
	22.0	183	0.127		3.46
	25.0	208	0.140		
	29.0	242	0.151		
	32.0	267	0.156		
	36.0	300	0.159		
	40.0	333	0.161		
	45.0	375	0.166		Average
	51.0	425	0.235	0.003	3.47
I 5	18.0	150	0.090		3.44
	24.0	200	0.140		3.78
	30.0	250	0.170		4.06
	36.0	300	0.191		
	42.0	350	0.209		
	48.0	400	0.230		Average
	54.0	450	0.251	0.058	3.76
I 6	18.0	150	0.075		4.00
	24.0	200	0.102		4.08
	30.0	250	0.155		4.18
	36.0	300	0.195		
	42.0	350	0.210		Average
	48.0	400	0.239	0.074	4.09

Average walls dimensions: 4'- 0"x8'- 0"x8"

APPENDIX "D"

Section Properties of Sparfil Concrete Blocks

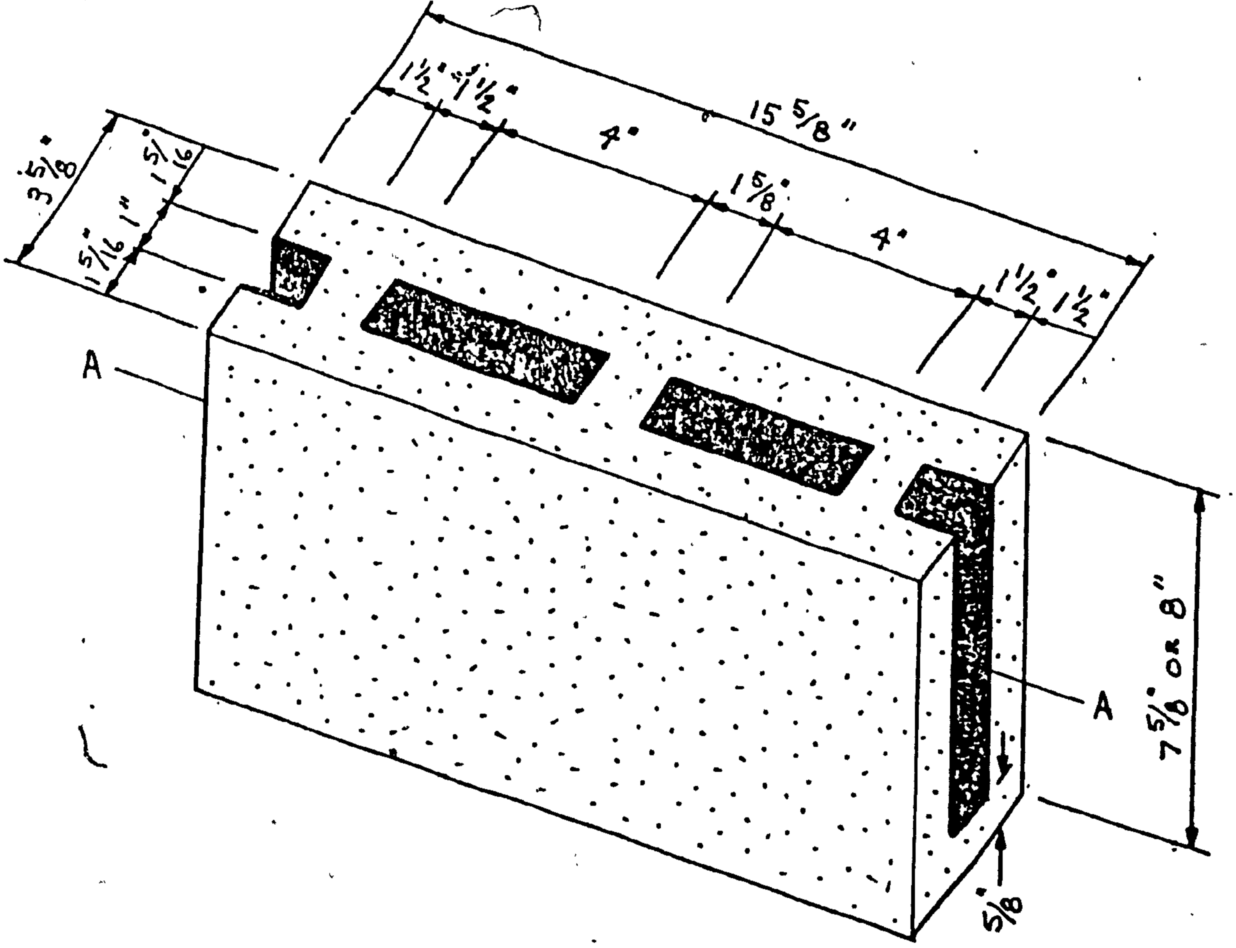

Fig. (D1): 4" SPARFIL Block

Gross Area: 56.64 in^2
Net Area: 45.64 in^2
Nominal Weight: 10 lbs.
Moment of Inertia of Horizontal cross section: 61 in^4

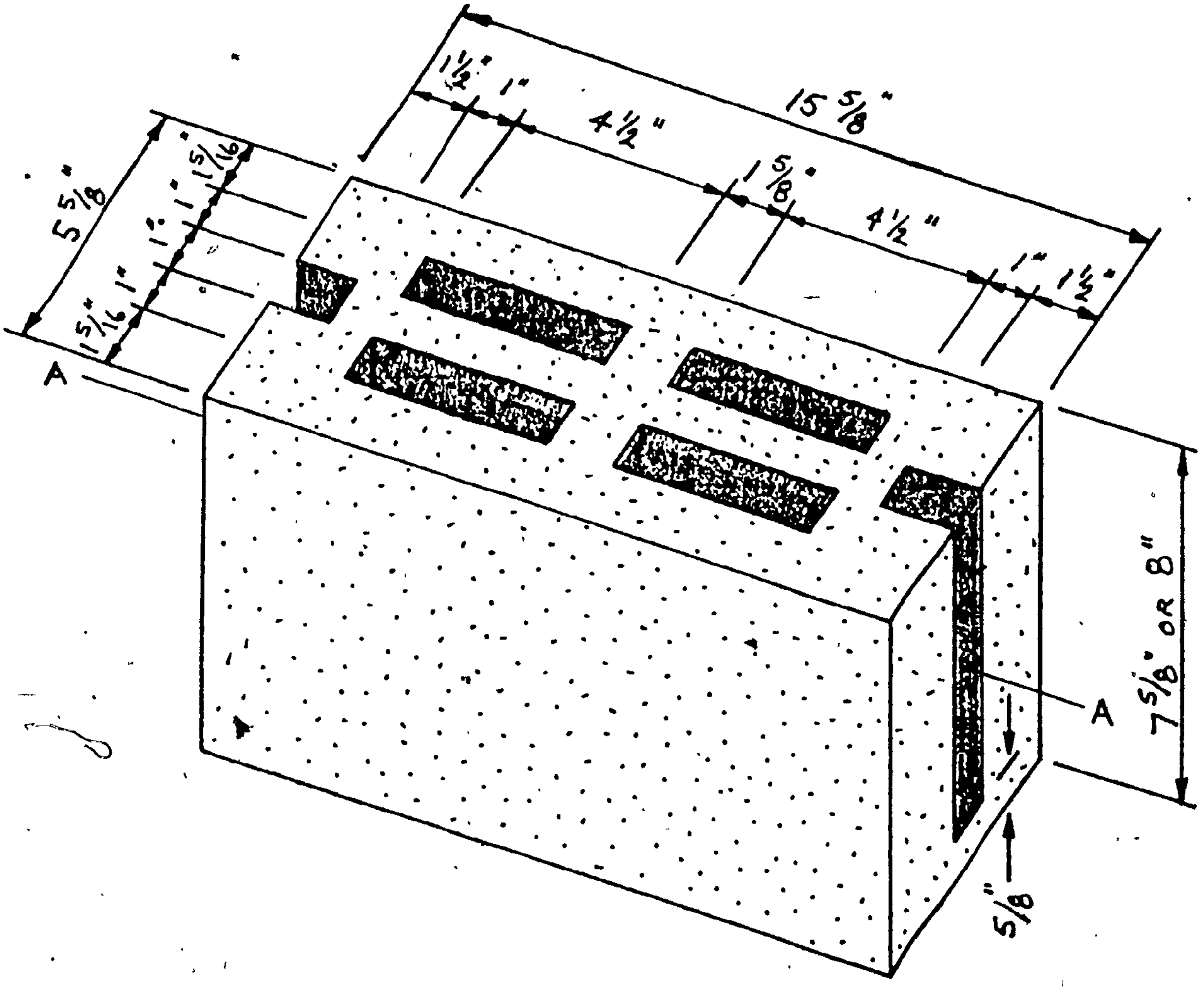

Fig. (D2): 6" SPARFIL-Block

Gross Area: 87.89 in^2
Net Area: 66.89 in^2
Nominal Weight: 15 lbs
Moment of Inertia of horizontal cross section:
212 in^4

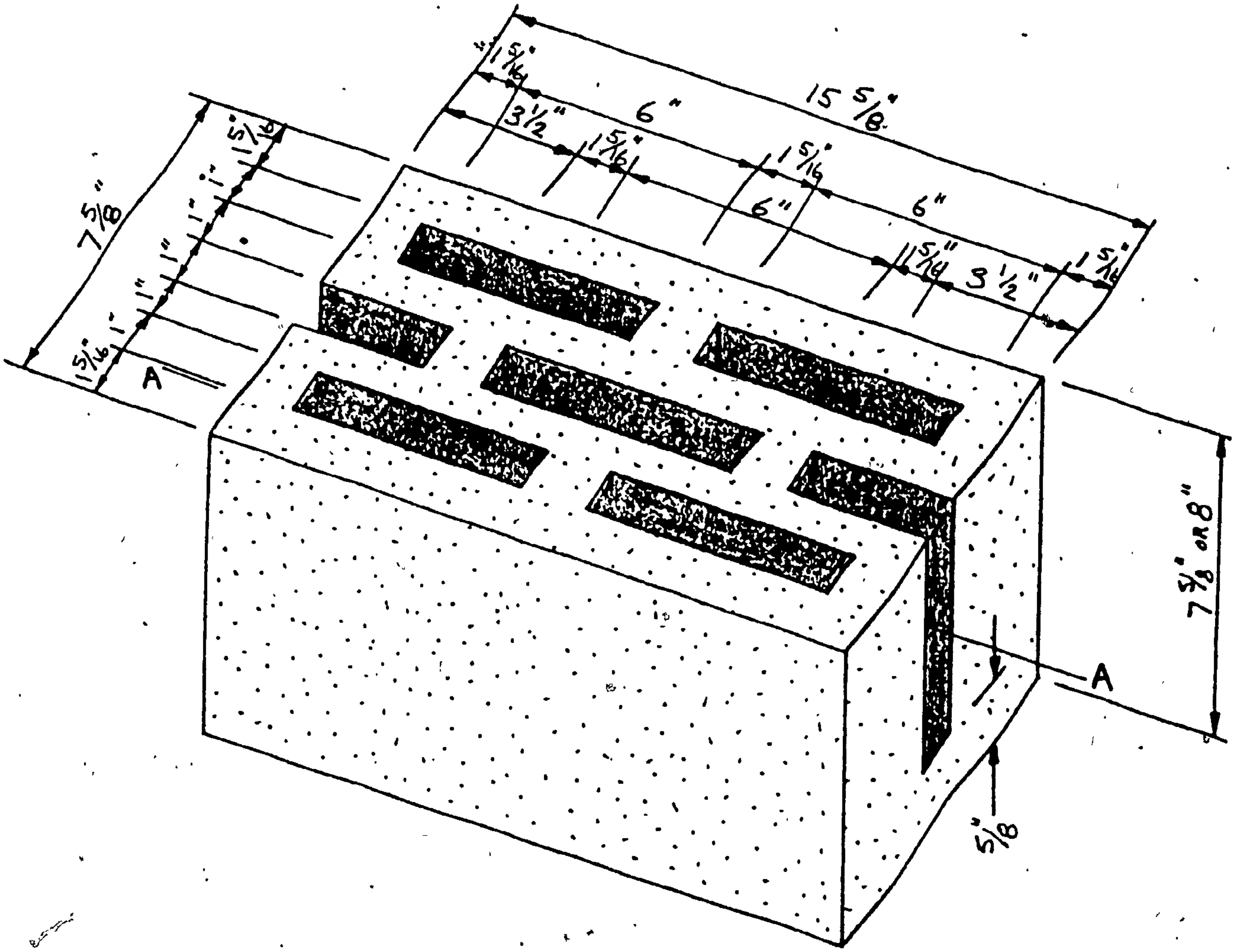

Fig. (D3): 8" SPARFIL Block

Gross Area: 119.14 in^2
Net Area: 82.14 in^2
Nominal Weight: 20 lbs.
Moment of Inertia of horizontal cross section:
478 in^4

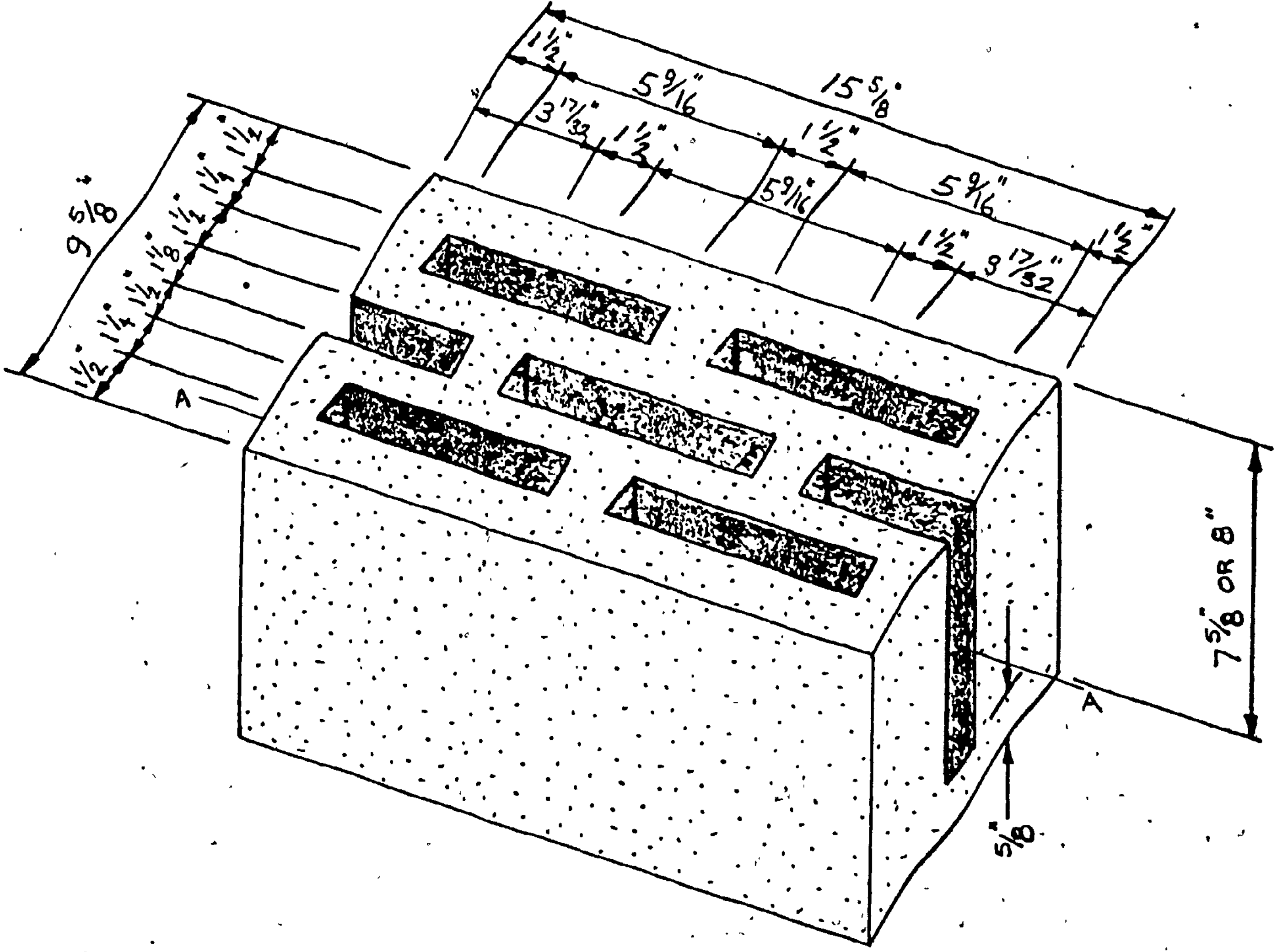

Fig. (D4) : 10" SPARFIL Block.

Gross Area: 150.39 in²
Net Area: 107.25 in²
Nominal Weight: 25 lbs
Moment of Inertia horizontal cross section:
922 in⁴