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AN INVESTIGATION INTO REINFORCED BRICKWORK BEAMS USING QUETTA BOND

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AN INVESTIGATION INTO REINFORCED BRICKWORK BEAMS USING QUETTA BOND

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Volume 2
Appendices

VOLUME 2

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APPENDIX 1

Results of experimental material tests

1.0 BRICKS

Four tests:

(a) dimensional tolerance
(b) compressive strength
(c) water absorption
(d) initial suction rate

1:1 DIMENSIONAL TOLERANCE, CLAUSE 27, BS3921

Limits of size based on a random sample of 24 bricks.

	Nominal Size (mm)	Mean (mm)	Max (mm)	Min (mm)
Length	215.0	5160	5235	5085
Width	102.5	2460	2505	2415
Height	65.0	1560	1605	1515

1:1:1 Results

Brick Type	Length (mm)	Width (mm)	Height (mm)	
1	5141	2464	1592	OK within limits
2	5168	2415	1568	
3	5119	2436	1555	

1:1:2 Mean

Brick Type	Length (mm)	Width (mm)	Height (mm)
1	214.2	102.7	66.3
2	215.3	100.6	65.3
3	213.3	101.5	64.8

1:2 COMPRESSIVE STRENGTH

1:2:1 Brick Type 1

No	On bed (N/mm^2)	On face (N/mm^2)	On end (N/mm^2)
1	39.1	17.7	8.4
2	42.2	21.5	12.9
3	44.6	20.0	13.4
4	30.6	19.0	12.2
5	37.4	22.4	14.1
6	42.7	18.7	11.9
7	40.2	15.4	7.6
8	29.2	17.6	10.0
9	29.5	20.8	14.2
10	46.3	14.7	10.6

Orientation	Mean compressive strength (N/mm^2)	Standard deviation (N/mm^2)	Coefficient of variation
bed	38.2	6.35	16.62%
face	18.9	2.51	13.28%
end	11.5	2.31	20.09%

Ratio of orientation to bedface

face/bed 0.5

end/bed 0.3

1:2:2 Brick Type 2

No	On bed (N/mm^2)	On face (N/mm^2)	On end (N/mm^2)
1	27.9	11.6	4.7
2	28.3	13.9	6.7
3	47.8	13.0	7.7
4	32.0	13.3	7.7
5	37.5	13.7	7.2
6	31.6	11.8	8.3
7	26.1	13.3	8.0
8	29.5	11.1	10.3
9	27.1	13.3	4.1
10	32.0	13.9	8.8

Orientation	Mean compressive strength (N/mm^2)	Standard deviation (N/mm^2)	Coefficient of variation
bed	32.0	6.46	20.19%
face	12.9	1.01	7.83%
end	7.3	1.84	25.20%

Ratio of orientation to bedface

face/bed 0.4

end/bed 0.23

1:2:3 Brick Type 3

No	On bed (N/mm^2)	On face (N/mm^2)	On end (N/mm^2)
1	99.5	24.1	11.3
2	113.7	10.6	13.0
3	117.4	18.6	10.2
4	106.8	12.3	6.4
5	112.9	20.7	7.7
6	104.8	22.7	6.8
7	111.3	12.9	10.6
8	94.5	20.1	9.4
9	103.4	22.7	9.1
10	114.3	17.0	11.7

Orientation	Mean compressive strength (N/mm^2)	Standard deviation (N/mm^2)	Coefficient of variation
bed	107.9	7.32	6.79%
face	18.2	4.80	26.37%
end	9.6	2.16	22.50%

Ratio of orientation to bedface

face/bed 0.17

end/bed 0.09

1:3 WATER ABSORPTION TEST (BY 5 HOUR BOILING)

1:3:1 Brick Type 1

No	Dry Weight (g)	Wet Weight (g)	Water Absorption (%)
1	2312	2577	11.46
2	2272	2489	9.55
3	2265	2513	10.95
4	2295	2552	11.20
5	2274	2506	10.20
6	2347	2603	10.91
7	2282	2522	10.52
8	2251	2480	10.17
9	2302	2534	9.90
10	2298	2561	11.44

Mean water absorption = 10.63%

Standard deviation = 0.66%

Coefficient of variation = 6.21%

$$\text{Water absorption} = \frac{100\,(\text{wet mass} - \text{dry mass})}{\text{dry mass}}$$

1:3:2 Brick Type 2

No	Dry Weight (g)	Wet Weight (g)	Water Absorption (%)
1	2091	2440	16.67
2	2117	2475	16.90
3	2015	2221	10.22
4	2045	2366	15.70
5	2047	2333	13.97
6	2060	2366	14.85
7	2085	2448	17.41
8	2070	2427	17.25
9	2043	2399	17.42
10	2089	2428	16.23

Mean water absorption = 15.66%

Standard deviation = 2.23%

Coefficient of variation = 14.24%

$$\text{Water absorption} = \frac{100\ (\text{wet mass - dry mass})}{\text{dry mass}}$$

1:3:3 Brick Type 3

No	Dry Weight (g)	Wet Weight (g)	Water Absorption (%)
1	2467	2594	5.15
2	2470	2594	5.02
3	2473	2603	5.26
4	2476	2603	5.13
5	2482	2604	4.91
6	2476	2605	5.21
7	2485	2615	5.23
8	2475	2609	5.41
9	2483	2616	5.36
10	2477	2604	5.13

Mean water absorption = 5.18%

Standard deviation = 0.15%

Coefficient of variation = 2.90%

Water absorption $= \frac{100\,(\text{wet mass} - \text{dry mass})}{\text{dry mass}}$

1:4 INITIAL SUCTION RATE

1:4:1 Brick Type 1

No	Dry Weight (g)	Wet Weight (g)	Suction Rate (%)
1	2437	2458	1.111
2	2422	2433	0.582
3	2448	2473	1.323
4	2392	2411	1.058
5	2405	2425	1.111
6	2438	2461	1.270
7	2483	2504	1.164
8	2485	2500	0.847
9	2481	2497	0.900
10	2455	2472	0.953

Mean initial suction rate = 1.032 $kg/m^2/min$

Standard deviation = 0.219 $kg/m^2/min$

Coefficient of variation = 21.220%

Initial Suction Rate = $\frac{1000\ (\text{mass of wet - mass of dry})}{\text{gross area of immersed surface in } mm^2}$

1:4:2 Brick Type 2

No	Dry Weight (g)	Wet Weight (g)	Suction Rate (%)
1	2426	2444	0.904
2	2310	2327	0.853
3	2342	2356	0.703
4	2385	2398	0.653
5	2363	2377	0.703
6	2402	2414	0.602
7	2396	2411	0.753
8	2296	2317	1.054
9	2369	2385	0.803
10	2431	2442	0.552

Mean initial suction rate = 0.758 $kg/m^2/min$

Standard deviation = 0.150 $kg/m^2/min$

Coefficient of variation = 19.791%

Initial Suction Rate $= \dfrac{1000\ (\text{mass of wet - mass of dry})}{\text{gross area of immersed surface in } mm^2}$

1:4:3 Brick Type 3

No	Dry Weight (g)	Wet Weight (g)	Suction Rate (%)
1	2495	2500	0.260
2	2485	2490	0.260
3	2567	2571	0.208
4	2484	2489	0.260
5	2597	2603	0.312
6	2485	2490	0.260
7	2572	2576	0.208
8	2481	2486	0.260
9	2563	2567	0.208
10	2606	2611	0.260

Mean initial suction rate = 0.250 $kg/m^2/min$

Standard deviation = 0.033 $kg/m^2/min$

Coefficient of variation = 13.200%

Initial Suction Rate = $\dfrac{1000\ (\text{mass of wet - mass of dry})}{\text{gross area of immersed surface in } mm^2}$

2:0 SIEVE ANALYSIS OF SAND AND FINE AGGREGATE

Sieve Sizes (mm)	Sieve Sizes (mm)	Sieve Sizes (mm)	Sieve Sizes (mm)
10	0	100	100
5	31	98	100
2.36	273	80	90-100
1.18	453	51	70-100
0.60	363	27	40-80
0.30	206	14	5-40
0.15	122	6	0-10
RESIDUE	94	0	

3:0 MORTAR TEST RESULTS

3:1 COMPRESSION CUBES

Beam Number	Density (kN/m^3)	Area x10^4(mm^2)	Load (kN)	Stress (N/mm^2)	Mean (N/mm^2)
1/220	22.36	1.00	268	26.8	
	22.55	1.00	292	29.2	
	22.87	1.01	312	30.9	
	22.56	1.00	332	33.2	30.02
1/221	23.00	1.00	349	34.9	
	22.91	1.00	270	27.0	
	22.70	1.00	318	31.8	31.23
1/230	22.60	1.00	316	31.6	
	22.52	1.00	264	26.4	
	22.88	1.00	317	31.7	
	22.82	1.00	357	35.7	31.35
1/231	22.76	1.00	327	32.7	
	22.38	1.00	312	31.2	
	22.63	0.99	250	25.2	
	22.95	1.00	407	40.7	
	22.27	1.01	400	39.6	33.88
1/240	22.89	1.00	270	27.0	
	22.72	0.98	277	28.3	
	22.75	1.00	210	21.0	
	22.62	1.00	203	20.3	24.15
1/241	22.86	1.00	390	39.0	
	22.74	1.00	376	37.6	
	22.80	1.00	376	37.6	
	22.75	1.00	386	38.6	38.20
1/120	22.59	1.00	243	24.3	
	22.39	0.99	269	27.0	25.65
1/121	22.31	0.99	238	24.0	24.00
1/130	22.84	1.00	360	36.0	
	22.78	1.00	357	35.7	
	22.58	1.00	344	34.4	
	22.60	0.99	353	35.5	35.40

3:1 COMPRESSION CUBE CONTD

Beam Number	Density (kN/m³)	Area x10⁴(mm²)	Load (kN)	Stress (N/mm²)	Mean (N/mm²)
1/131	22.42	1.00	321	32.1	
	23.01	1.00	347	34.7	
	22.91	1.00	377	37.7	34.33
1/140	22.43	1.00	231	23.1	
	22.31	1.00	316	31.6	
	22.63	1.01	298	29.5	
	22.39	1.00	259	25.9	27.52
1/141	22.75	1.00	258	25.8	
	22.73	0.99	248	25.0	
	22.70	0.99	246	24.8	
	22.64	0.99	267	26.9	25.62
1/320	22.52	1.00	352	35.2	
	22.68	1.00	340	34.0	34.60
1/321	22.28	1.00	350	35.0	
	22.60	1.00	325	32.5	
	22.72	1.00	338	33.8	33.77
1/330	22.83	1.00	329	32.9	
	22.34	1.00	338	33.8	
	22.48	1.01	319	31.6	
	22.57	1.01	395	39.1	34.35
1/331	22.48	1.01	317	31.4	
	22.52	1.01	287	28.4	
	22.37	1.01	370	36.6	
	22.43	1.00	362	36.2	33.15
1/340	23.15	1.01	389	38.5	
	22.89	1.00	368	36.8	37.65
1/341	22.86	0.99	265	26.8	
	21.98	1.00	205	20.3	23.55

Overall mean cube stress = 31.44 N/mm²

Standard deviation = 5.28 N/mm²

Coefficient of variation = 16.79%

Mean density = 22.64 kN/m³

3:1 COMPRESSION CUBE CONTD

Beam Number	Density (kN/m^3)	Area x10^4(mm^2)	Load (kN)	Stress (N/mm^2)	Mean (N/mm^2)
2/140	22.86	0.99	336	33.9	36.40
	23.02	1.00	414	41.4	
	22.46	1.02	323	31.7	
	22.60	1.01	390	38.6	
2/141	22.82	1.01	434	43.0	41.77
	22.87	0.99	418	42.2	
	22.81	1.02	406	39.8	
	22.90	1.01	425	42.1	
2/240	22.70	1.02	368	36.1	35.27
	22.81	1.01	353	34.9	
	22.71	1.00	352	35.2	
	22.63	1.00	349	34.9	
2/241	22.36	1.03	408	39.6	35.80
	22.57	1.02	351	34.4	
	22.63	1.01	348	34.4	
	22.51	1.02	355	34.8	
2/340	22.75	1.02	342	33.5	34.95
	22.61	1.02	350	34.3	
	22.79	1.02	366	35.9	
	22.44	1.03	372	36.1	
2/341	22.84	1.01	343	34.0	38.40
	22.48	1.01	391	38.7	
	22.34	1.02	421	41.3	
	22.51	1.01	400	39.6	

Overall mean cube stress = 37.10 N/mm^2

Standard deviation = 3.32 N/mm^2

Coefficient of variation = 8.95%

Mean density = 22.67 kN/m^3

Mean stress for all mortar cubes = 33.08 N/mm^2

Standard deviation = 5.43 N/mm^2

Coefficient of variation = 16.41%

3:2 TENSION CYLINDER

Specimen Number	Height (mm)	Density (kN/m^3)	P (kN)	Tensile Stress
1/1	297	22.15	186	2.65
1/2	298	21.98	160	2.29
1/3	298	22.07	174	2.48
1/4	296	21.94	154	2.21
1/5	297	21.87	200	2.86
1/6	296	22.04	202	2.89
1/7	295	22.11	202	2.91
2/1	300	22.20	220	3.11
2/2	300	22.20	204	2.89
2/3	300	22.20	214	3.03
2/4	303	21.76	180	2.52

Series1, Mean tensile stress = 2.61 N/mm^2
Standard deviation = 0.29 N/mm^2
Coefficient of variation = 11.19%
Mean density = 22.02 kN/m^3

Series 2, Mean tensile stress = 2.89 N/mm^2
Standard deviation = 0.26 N/mm^2
Coefficient of variation = 9.03%
Mean density = 22.09 kN/m^3

Mean tensile stress for all specimens = 2.71 N/mm^2
Standard deviation = 0.30 N/mm^2
Coefficient of variation = 11.07%
Mean density = 22.05 kN/m^3

4:0 INFILL CONCRETE TEST RESULTS

4:1 COMPRESSION CUBES

Beam Number	Density (kN/m³)	Area x10⁴(mm²)	Load (kN)	Stress (N/mm²)	Mean (N/mm²)
1/120	22.95	0.99	113	11.5	
1/121	22.98	1.00	120	12.0	11.75*
1/130	23.58	1.00	265	26.5	
	23.88	1.00	231	23.1	24.80
1/131	23.99	1.00	308	30.8	
	23.16	1.00	266	26.6	28.17
1/140	22.55	0.99	314	31.7	
	23.37	0.98	318	32.4	32.05
1/141	22.59	1.00	338	33.8	
	22.26	1.00	206	20.6	27.20
1/220	23.98	1.00	349	34.9	34.90
1/221	23.42	1.00	294	29.4	29.40
1/230	23.83	1.01	210	20.8	
	23.79	1.00	259	25.9	23.35
1/231	23.20	1.00	295	29.5	
	23.19	0.97	163	16.8	23.15
1/240	21.95	1.00	317	31.7	
	22.63	1.01	340	33.6	32.65
1/241	23.21	0.99	282	28.5	
	23.22	1.00	326	32.6	
	23.18	1.02	298	29.2	
	23.73	1.00	292	29.2	
	23.25	1.00	281	28.1	
	23.15	0.99	270	27.3	29.15
1/320	23.82	1.01	268	26.5	26.50
1/321	22.16	0.97	167	17.2	17.20

*denotes specimens did not have plasticiser added

4:1 COMPRESSION CUBES CONTD

Beam Number	Density (kN/m^3)	Area $x10^4(mm^2)$	Load (kN)	Stress (N/mm^2)	Mean (N/mm^2)
1/330	23.16	1.00	353	35.3	
	22.30	0.97	253	26.1	30.70
1/331	22.70	0.99	302	30.5	30.50
1/340	23.78	0.98	202	20.8	
	23.26	1.00	328	32.8	26.80
1/341	23.26	1.00	362	36.2	
	23.10	1.00	300	30.0	33.10
2/140	23.67	1.01	156	15.4	
	23.23	1.01	157	15.5	
	23.51	1.00	167	16.7	
	24.00	1.01	167	16.5	16.02
2/241	23.27	1.02	233	22.8	
	23.20	1.02	192	18.8	
	23.48	1.01	188	18.6	20.07
2/240	23.25	1.00	131	13.1	
	23.20	1.00	143	14.3	
	23.04	0.98	137	14.0	
	23.49	1.00	137	13.7	13.77
2/241	22.45	1.01	162	16.0	
	22.80	1.00	158	15.8	
	22.89	0.99	168	17.0	
	22.86	0.99	179	18.1	16.72
2/340	23.05	1.01	144	14.3	
	22.91	1.00	139	13.9	
	22.75	1.01	144	14.3	
	23.04	0.99	142	14.3	
	22.95	1.01	143	14.2	14.20
2/341	23.05	1.00	115	11.5	
	22.89	1.00	137	13.7	
	22.72	1.00	126	12.6	
	23.20	1.00	133	13.3	12.62

Series1,
Mean compressive stress = 28.33 N/mm^2
Standard deviation = 5.13 N/mm^2
Coefficient of variation = 18.06%
Mean density = 23.20 kN/m^3

Series 2,
Mean compressive stress = 15.35 N/mm^2
Standard deviation = 2.46 N/mm^2
Coefficient of variation = 16.00%
Mean density = 23.12 kN/m^3

Mean stress for all specimens with plasticiser = 22.67 N/mm^2
Standard deviation = 7.70 N/mm^2
Coefficient of variation = 33.99%
Mean density = 23.16 kN/m^3

4:2 TENSION CYLINDER

Specimen Number	Height (mm)	Density (kN/m³)	P (kN)	Tensile Stress
1/1	295	22.58	108	1.55
1/2	294	22.56	144	2.08
1/3	297	22.80	107	1.53
1/4	263	22.90	107	1.73
1/5	300	22.94	163	2.31
1/6	299	22.74	165	2.34
1/7	296	22.69	167	2.39
1/8	300	23.13	170	2.40
2/1	298	22.58	81	1.15
2/2	300	22.76	109	1.54
2/3	300	22.17	186	2.63
2/4	300	22.37	190	2.69
2/5	300	22.70	95	1.34
2/6	297	22.68	98	1.40
2/7	298	22.43	123	1.75
2/8	299	22.74	131	1.86
2/9	300	24.08	141	1.99

Series 1, Mean tensile stress = 2.04 N/mm^2
Standard deviation = 0.38 N/mm^2
Coefficient of variation = 18.63%
Mean density = 22.79 kN/m^3

Series 2, Mean tensile stress = 1.82 N/mm^2
Standard deviation = 0.55 N/mm^2
Coefficient of variation = 30.22%
Mean density = 22.72 kN/m^3

Mean tensile stress for all specimens = 1.92 N/mm^2
Standard deviation = 0.47 N/mm^2
Coefficient of variation = 24.48%
Mean density = 22.75 kN/m^3

5:0 STEEL CHARACTERISTICS

Diameter (mm)		Condition	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Modulus of Elasticity (kN/mm^2)
25	1	unslot	468.4	606.9	195.7
25	2	unslot	458.3	604.9	198.9
	mean		463.4	605.9	197.3
25	1	slot	477.0	621.0	196.8
25	2	slot	473.0	618.0	199.4
	mean		475.0	619.5	198.1
16	1	unslot	487.3	556.6	196.7
16	2	unslot	472.4	554.5	199.3
	mean		479.9	555.5	197.8
16	1	unslot	475.0	612.0	195.9
	2	unslot	478.0	617.0	197.1
	3	unslot	475.0	612.0	195.9
	mean		476.0	614.0	196.3
16	1	slot	471.5	586.0	195.5
	2	slot	473.5	580.4	190.5
	3	slot	477.0	579.9	192.1
	mean		474.0	582.0	192.7

Diameter (mm)	Mean Yield (N/mm^2)	Ultimate (N/mm^2)	E (kN/mm^2)
25	469.2	612.7	197.7
20	465.4	584.7	201.2
16	476.2	587.3	195.4
8	290.5	405.8	242.4
6	385.5	509.3	227.4

6:0 COMPRESSION ZONE PRISM TESTS

6:1:1 Westbrick Prism Test 1

Load (kN)	Stress (N/mm^2)	Strain (μs)				
		e_1	e_2	e_3	e_4	e_{av}*
0.0	0.00	0.0	0.0	0.0	0.0	0.0
48.6	1.06	48.3	64.4	96.6	96.6	76.5
97.2	2.12	-16.1	129.0	161.0	129.0	100.7
145.8	3.18	113.0	209.0	258.0	193.2	193.3
194.4	4.24	257.6	273.7	305.9	209.3	261.6
243.0	5.30	273.7	338.1	386.4	257.6	314.0
291.6	6.36	305.9	418.6	450.8	289.8	366.30
340.2	7.42	418.6	499.1	547.4	338.1	450.8
388.8	8.48	483.0	595.7	627.9	370.3	519.2
437.4	9.54	547.4	676.7	724.5	418.6	591.8
485.6	10.59	644.0	788.9	821.1	483.0	684.3
534.2	11.65	740.6	885.5	933.8	515.2	768.8
582.8	12.71	788.9	1014.3	1062.6	579.6	861.4
631.4	13.77	869.4	1110.9	1175.0	611.8	941.8
680.0	14.83	901.6	1191.4	1304.1	676.2	1018.3
728.6	15.89	998.2	1304.0	1417.0	708.4	1106.9
777.2	16.95	1143.0	1385.0	1562.0	788.9	1219.7
825.8	18.01	1175.0	1497.0	1739.0	885.5	13240.1
874.4	19.07	1239.7	1578.0	1867.0	949.9	1408.7
923.0	20.13	1400.7	1658.0	2045.0	1095.0	1549.7
971.6	21.19	1497.0	1706.6	2286.0	1224.0	1678.3
Specimen Failed						

$$*e_{av} = e_1 + e_2 + e_3 + e_4$$

6:1:2 Westbrick Prism Test 2

Load (kN)	Stress (N/mm^2)	Strain (µs)					
		e_1	e_2	e_3	e_4	e_3+e_4	e_1+e_2
0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
48.6	1.06	80.5	48.3	80.5	112.7	96.6	64.4
97.2	2.12	144.9	96.6	128.8	193.2	161.0	120.8
145.8	3.18	209.3	144.9	225.4	225.4	225.4	177.1
194.4	4.24	273.7	193.2	305.9	338.1	322.0	233.5
243.0	5.30	338.1	241.5	402.5	418.6	410.6	289.8
291.6	6.36	418.6	257.6	531.3	531.3	531.3	338.1
340.2	7.42	466.9	289.8	611.8	611.8	611.8	378.4
333.8	8.48	547.4	322.0	708.4	692.3	700.4	434.7
437.4	9.54	595.7	338.1	805.0	821.1	813.1	466.9
485.6	10.59	676.2	402.5	885.5	966.0	925.8	539.4
534.2	11.65	756.7	418.6	998.2	1095.0	1046.6	587.7
582.8	12.71	821.1	450.8	1095:0	1256.0	1175.5	636.0
631.4	13.77	901.6	515.2	1191.0	1385.0	1288.0	708.4
680.0	14.83	1030.4	563.5	1352.0	1594.0	1473.0	797.0
728.6	15.89	917.7	450.8	1240.0	1401.0	1320.5	684.3
777.2	16.95	853.3	370.3	1240.0	1369.0	1304.5	611.8
825.8	18.01	821.0	354.2	1095.0	1401.0	1248.0	587.6
874.4	19.07	821.0	338.1	1352.0	1481.0	1416.5	579.6
923.0	20.13	805.0	322.0	1626.0	1562.0	1594.0	563.5
971.6	21.19	837.2	330.0	1882.0	1674.4	1778.2	583.6
Specimen failed							

6:1:3 Westbrick Prism Test 3

Load (kN)	Stress (N/mm^2)	Strain (μs)			
		e_1	e_2	e_3	e_2+e_3
0.0	0.00	0.0	0.0	0.0	0.0
48.6	1.06	80.5	64.4	48.3	56.4
97.2	2.12	0.0	161.0	128.8	144.9
145.8	3.18	-193.2	209.3	241.5	225.4
194.4	4.24	-289.8	289.8	322.0	305.9
243.0	5.30	-273.7	370.3	402.5	386.4
291.6	6.36	-255.4	466.9	499.1	483.0
340.2	7.42	-177.1	531.3	595.7	563.5
388.8	8.48	-144.9	627.9	708.4	668.2
437.4	9.54	-96.6	740.0	740.6	740.3
485.6	10.59	-64.4	837.2	869.4	853.3
534.2	11.65	-32.2	901.6	949.9	925.8
582.8	12.71	0.0	982.1	1063.0	1022.6
631.4	13.77	48.3	1079.0	1159.0	1119.0
680.0	14.83	80.5	1196.0	1288.0	1242.0
728.6	15.89	144.9	1336.0	1433.0	1384.5
777.2	16.95	161.0	1433.0	1530.0	1481.5
825.8	18.01	209.3	1546.0	1642.0	1594.0
874.4	19.07	289.8	1658.0	1787.0	1722.5
923.0	20.13	305.9	1771.0	1932.0	1851.5
971.6	21.19	370.3	1916.0	2093.0	2004.5
Specimen failed					

6:1:4 Westbrick Prism Test 4

Load (kN)	Stress (N/mm²)	Strain (με)			
		e_1	e_2	e_3	e_4
0.0	0.00	0.0	0.0	0.0	0.0
48.6	1.06	76.5	96.6	56.4	120.0
97.2	2.12	100.7	161.0	144.9	180.0
145.8	3.18	193.3	225.4	225.4	245.0
194.4	4.24	261.6	322.0	305.9	340.0
243.0	5.30	314.0	410.6	386.4	440.0
291.6	6.36	366.3	531.3	483.0	520.0
340.0	7.42	450.8	611.8	563.5	665.0
388.8	8.48	519.2	700.4	668.2	755.0
437.4	9.54	591.9	813.1	740.3	705.0
485.6	10.59	684.3	925.8	853.3	810.0
534.2	11.65	768.8	1046.6	925.8	987.0
582.8	12.71	861.4	1175.5	1022.6	1100.0
631.4	13.77	941.8	1288.0	1119.0	1200.0
680.0	14.83	1018.3	1473.0	1242.0	1284.0
728.6	15.89	1106.9	1320.5	1384.5	1305.0
777.2	16.95	1219.7	1304.5	1481.5	1420.0
825.8	18.01	1324.1	1248.0	1594.0	1640.0
874.4	19.07	1408.7	1416.5	1722.5	1875.0
923.0	20.13	1549.7	1594.0	1851.5	2070.0
971.6	21.19	1678.3	1778.2	2004.5	2248.0
Specimen failed					

6:1:5 Westbrick Non-Dimensional Stress Strain Plot

Load (kN)	Stress (N/mm^2)	f/f_m	e_1/e_m	e_2/e_m	e_3/e_m	e_4/e_m
0.0	0.00	0.000	0.000	0.000	0.000	0.000
48.6	1.06	0.043	0.022	0.028	0.016	0.034
97.2	2.12	0.086	0.029	0.046	0.042	0.052
145.8	3.18	0.129	0.056	0.065	0.065	0.070
194.4	4.24	0.172	0.075	0.093	0.088	0.098
243.0	5.30	0.215	0.090	0.118	0.111	0.126
291.6	6.36	0.258	0.105	0.153	0.139	0.149
340.2	7.42	0.300	0.130	0.176	0.162	0.191
388.8	8.48	0.343	0.149	0.201	0.192	0.217
437.4	9.54	0.386	0.170	0.234	0.213	0.203
485.6	10.59	0.429	0.197	0.266	0.245	0.233
534.2	11.65	0.472	0.221	0.301	0.266	0.284
582.8	12.71	0.515	0.248	0.338	0.294	0.316
631.4	13.77	0.558	0.271	0.370	0.322	0.345
680.0	14.83	0.601	0.293	0.423	0.357	0.369
728.6	15.89	0.644	0.318	0.379	0.398	0.375
777.2	16.95	0.687	0.350	0.375	0.426	0.408
825.8	18.01	0.730	0.380	0.359	0.458	0.471
874.4	19.07	0.773	0.405	0.407	0.495	0.539
923.0	20.13	0.815	0.445	0.458	0.532	0.595
971.6	21.19	0.858	0.482	0.511	0.576	0.646

6:1:6 Westbrick Non-Dimensional Parabolic Plot

strain (μs)	f/f_m	e/e_m
0	0.000	0.000
400	0.207	0.115
800	0.407	0.230
1200	0.571	0.345
1600	0.708	0.460
2000	0.819	0.575
2400	0.904	0.690
2800	0.962	0.805
3200	0.994	0.920
3600	0.999	1.034
4000	0.978	1.149

$e_m = 3480\ \mu s$
$f_m = 25.2\ N/mm^2$

6:2:1 Coatham Prism Test 1

Load (kN)	Stress (N/mm²)	Demec gauge strain (µs)							
		1	2	3	4	5	6	7	8
0.0	0.00	0	0	0	0	0	0	0	0
48.6	1.06	-40	-40	-466	-243	20	40	81	121
97.2	2.12	-101	-284	-850	-466	61	162	266	202
145.8	3.18	-243	-607	-1050	-809	202	263	506	466
194.4	4.24	-385	-870	-1619	-1052	223	364	789	789
243.0	5.30	-587	-1316	-2348	-1376	769	466	1903	3036
291.6	6.36	-668	-1579	-2672	-1957	3198	2449	6173	7813
340.2	7.42	-830	-1700	-3259	-2503	7307	5375	11320	13844
368.0	8.03	Specimen failed							

Average concrete cube strength = 26.7 N/mm^2

Average mortar cube strength = 44.3 N/mm^2

Cross-sectional area = 45850 mm^2

Length = 611.3mm

Remarks

Specimen loaded in 50kN increments, cracking noises started at 120kN, visible cracking started at 230kN and occurred at interface between grout and brickwork and through bricks at top and bottom of specimen.

6:2:2 Coatham Prism Test 2

Load (kN)	Stress (N/mm²)	Demec gauge strains (µs)							
		1	2	3	4	5	6	7	8
0.0	0.00	0	0	0	0	0	0	0	0
48.6	1.06	-20	-284	-344	-263	20	40	20	20
97.2	2.12	-142	-344	-506	-405	61	61	40	20
145.8	3.18	-284	-445	-668	-567	101	81	101	142
194.4	4.24	-425	-466	-891	-809	202	345	101	243
243.0	5.30	-627	-926	-1133	-972	263	870	344	466
291.6	6.36	-809	-1050	-1194	-1215	668	1653	547	749
340.2	7.42	-1155	-1324	-1805	-1459	4809	6753	3173	5222
388.8	8.48	-1306	-1538	-2097	-1859	10383	11651	7470	8137
439.0	9.57	Specimen failed							

Average concrete cube strength = 26.7N/mm^2

Average mortar cube strength = 44.2 N/mm^2

Cross-sectional area = 45850 mm^2

Length = 611.3 mm

Remarks
Initial crack noise started at 200kN, visible cracking at 280kN. At 340kN cracks between interface to brickwork and grout. Failure not explosive at 439.0kN.

6:2:3 Coatham Prism Test 3

Load (kN)	Stress (N/mm²)	Strain (µs)		
		e_1*	e_3**	e_3/e_1
0.0	0.00	0	0	0.000
48.6	1.06	-243	65	0.267
97.2	2.12	-466	173	0.371
145.8	3.18	-830	359	0.433
194.4	4.24	-1051	541	0.515
243.0	5.30	-1498		
291.6	6.36	-2153		
340.2	7.42	-2588		

* = demec gauges 3 and 4

** = demec gauges 5,6,7 and 8

6:2:4 Coatham Prism Test 4

Load (kN)	Stress (N/mm²)	Strain (µs)		
		e_1*	e_3**	e_3/e_1
0.0	0.00	0	0	0.000
48.6	1.06	228	25	0.110
97.2	2.12	349	45	0.129
145.8	3.18	491	106	0.216
194.4	4.24	648	223	0.344
243.0	5.30	915	358	0.391
291.6	6.36	1067		
340.2	7.42	1436		
388.8	8.48	1700		

* = demec gauges 1,2,3 and 4

** = demec gauges 5,6,7 and 8

6:2:5 Coatham Plot Prism Test 5

Load (kN)	Stress (N/mm²)	Strain (μs)			
		e_1	e_2	e_3	e_4
0.0	0.00	0	0	0	0
48.6	1.06	240	220	121	180
97.2	2.12	460	355	400	282
145.8	3.18	840	485	440	545
194.4	4.24	1045	530	720	560
243.0	5.30	1500	915	818	760
291.6	6.36	2140	1065	1205	925
340.2	7.42	2580	1315	1642	1240
388.8	8.48	-	1700	2283	1480
Failure load		368	439	422	431

6:2:6 Coatham Non-Dimensional Stress Strain Plot

Load (kN)	Stress (N/mm^2)	f/f_m	e_1/e_m	e_2/e_m	e_3/e_m	e_4/e_m
0.0	0.00	0.000	0.000	0.000	0.000	0.000
48.6	1.06	0.123	0.110	0.101	0.055	0.083
97.2	2.12	0.245	0.211	0.163	0.183	0.129
145.8	3.18	0.369	0.385	0.222	0.202	0.250
194.4	4.24	0.492	0.479	0.243	0.330	0.257
243.0	5.30	0.615	0.688	0.420	0.375	0.348
291.6	6.36	0.738	0.981	0.488	0.552	0.421
340.2	7.42	0.860	1.183	0.603	0.753	0.569
388.8	8.48	0.983	-	0.779	1.047	0.679

6:2:7 Coatham Non-Dimensional Parabolic Plot

Strain (μs)	f/f_m	e/e_m
0	0.000	0.000
400	0.333	0.183
800	0.599	0.367
1200	0.798	0.550
1600	0.929	0.734
2000	0.993	0.917
2400	0.990	1.100
2800	0.919	1.284

$e_m = 2181\ \mu s$

$f_m = 8.8\ N/mm^2$

6:3:1 Waingrove Prism Test 1

Load (kN)	Stress (N//m m^2)	Demec Gauge Strains (μs)							
		1	2	3	4	5	6	7	8
0.0	0.00	0	0	0	0	0	0	0	0
48.6	1.06	-142	+40	-223	0	40	364	0	-61
97.2	2.12	-324	-101	-284	-20	0	81	223	-81
145.8	3.18	-526	-162	-344	0	263	344	0	-81
194.4	4.24	-749	-223	-445	-40	20	20	0	-81
243.0	5.30	-607	40	-364	142	20	263	0	-61
300.0	6.54								

Average concrete cube strength = 26.7 N/mm^2

Average mortar cube strength = 44.2 N/mm^2

Cross-sectional area = 45850 mm^2

Length = 611.3 mm

Remarks

Specimen loaded in 50kN increments, no cracking until 150kN - then slight noises occurred. At 243kN cracking was observed passing through the brickwork and grout interface. At 250kN cracks widened and spread through brickwork and grout, some spalling of the faces occurred until the specimen failed at 300kN. Failure mode was vertical splitting - tension failure.

6:3:3 Waingrove Prism Test 3

Load (kN)	Stress (N/mm²)	Demec gauge strains (μs)				
		e_1	e_2	e_3	e_4	e_5
0.0	0.00	0	0	0	0	0
48.6	1.06	120	20	110	60	40
97.2	2.12	180	20	230	120	73
145.8	3.18	223	40	350	180	120
194.4	4.24	331	80	470	240	160
243.0	5.30	400	140	-	240	270
291.6	6.36	500	170	-	320	270
340.2	7.42	570	250	-	370	320
388.8	8.48	680	280	-	500	410
437.4	9.54	780	380	-	540	460
485.6	10.59	850	470	-	590	540
534.2	11.65	950	530	-	650	700
582.8	12.71	1080	610	-	740	800
Failure load		650	628	300	615	643

6:3:4 Waingrove Non-Dimensional Stress Strain Plot

Load (kN)	Stress (N/mm^2)	f/f_m	e_1/e_m	e_2/e_m	e_3/e_m	e_4/e_m	e_5/e_m
0.0	0.00	0.000	0.000	0.000	0.000	0.000	
48.6	1.06	0.076	0.111	0.019	0.102	0.056	0.037
97.2	2.12	0.152	0.167	0.019	0.213	0.111	0.068
145.8	3.18	0.229	0.206	0.037	0.324	0.167	0.111
194.4	4.24	0.305	0.306	0.074	0.435	0.222	0.148
243.0	5.30	0.381	0.370	0.130	-	0.222	0.250
291.6	6.36	0.457	0.463	0.157	-	0.296	0.250
340.2	7.42	0.533	0.528	0.231	-	0.343	0.296
388.8	8.48	0.609	0.630	0.259	-	0.463	0.380
437.4	9.54	0.685	0.722	0.352	-	0.500	0.426
485.6	10.59	0.762	0.787	0.435	-	0.546	0.500
534.2	11.65	0.838	0.880	0.491	-	0.602	0.648
582.8	12.71	0.914	1.000	0.565	-	0.685	0.741

6:3:5 Waingrove Non-Dimensional; Parabolic Plot

Strain (μs)	f/f_m	e/e_m
0	0.000	0.000
200	0.336	0.185
400	0.604	0.370
600	0.802	0.556
800	0.933	0.741
1000	0.995	0.926
1200	0.988	1.111
1400	0.912	1.296

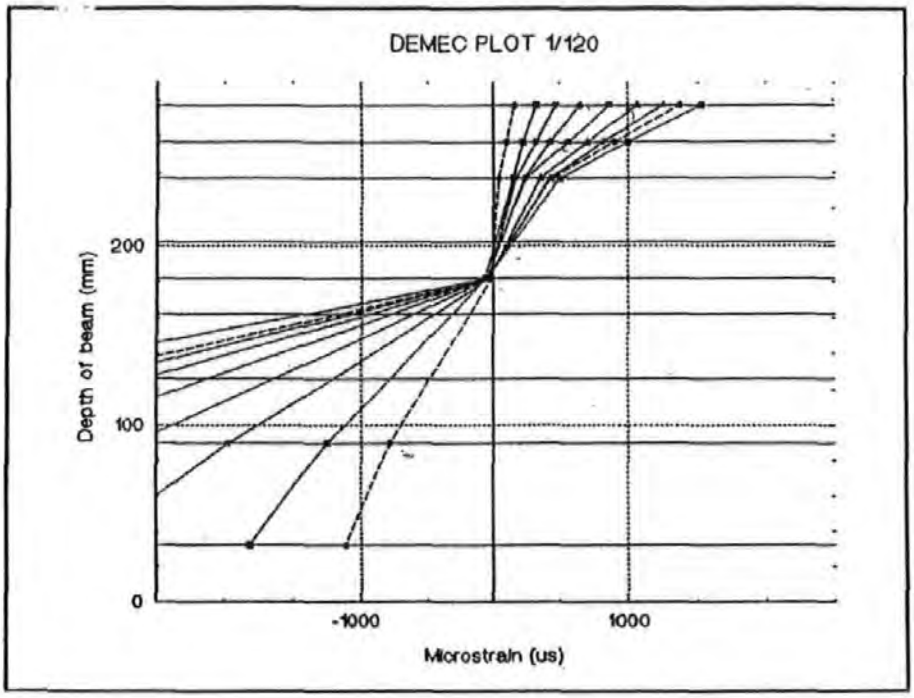
e_m - 1080 μs

f_m = 14.2 N/mm^2

APPENDIX 2

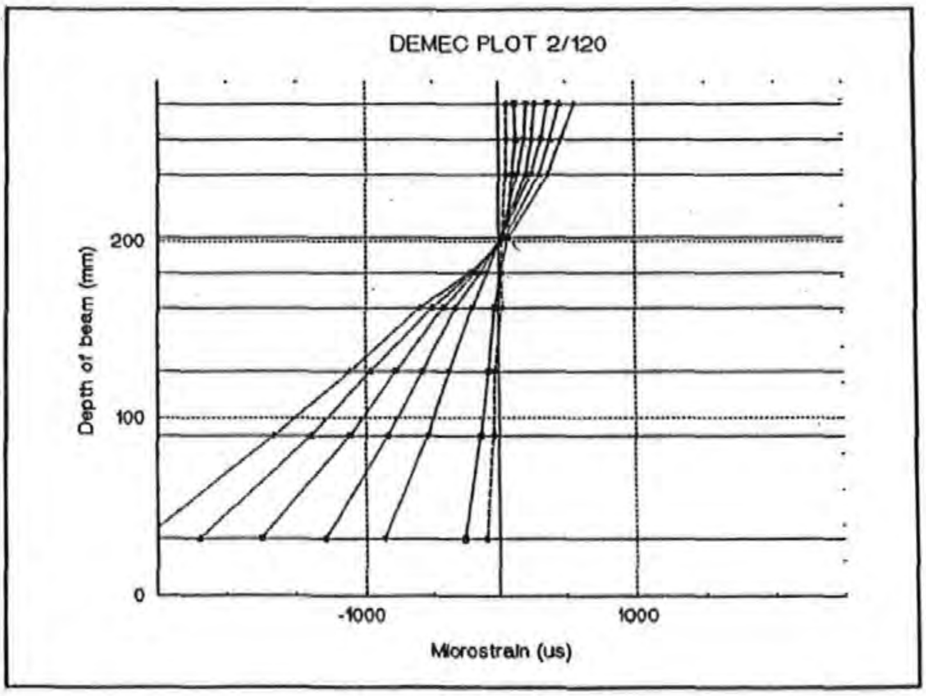
APPENDIX 2

Graphs



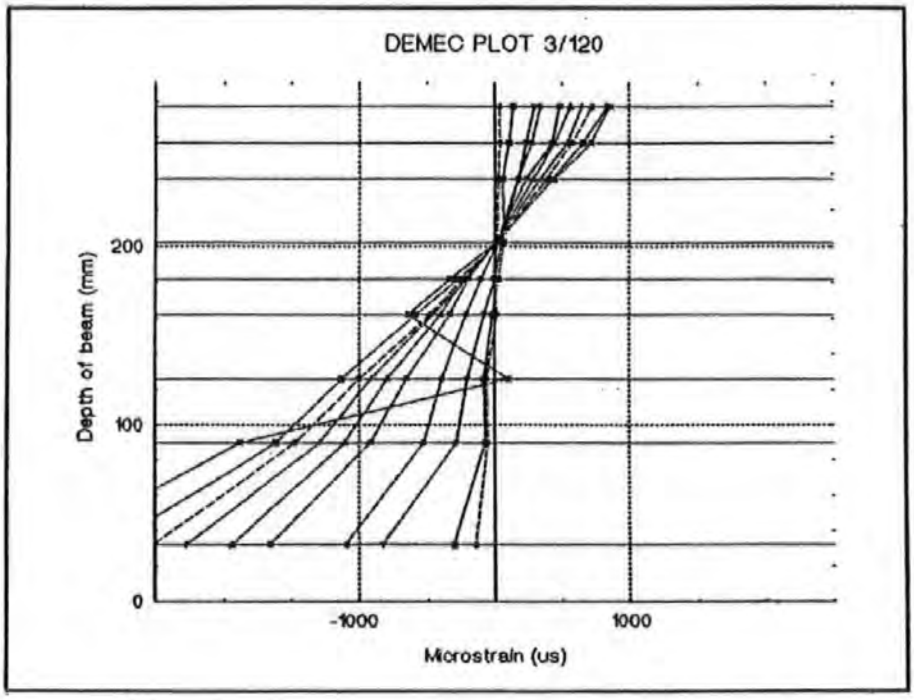
Demec plot 1/120

Graph 1



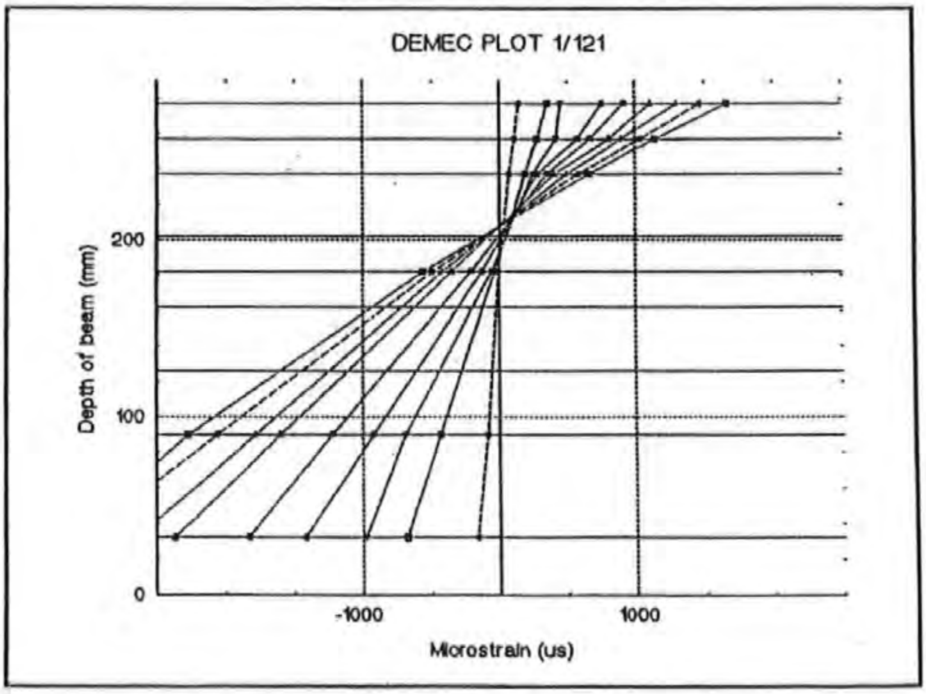
Demec plot 2/120

Graph 2



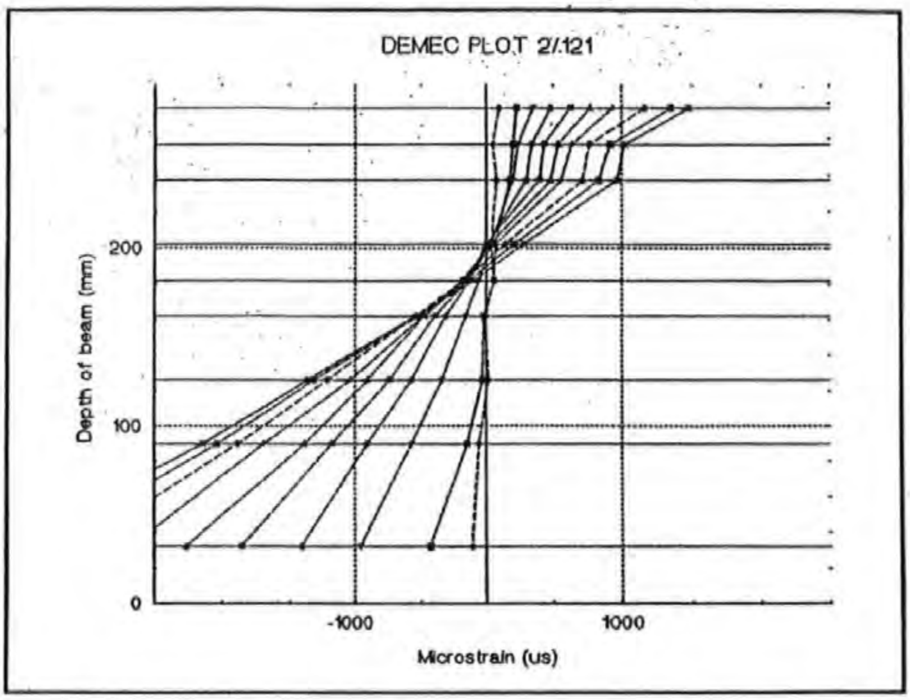
Demec plot 3/120

Graph 3



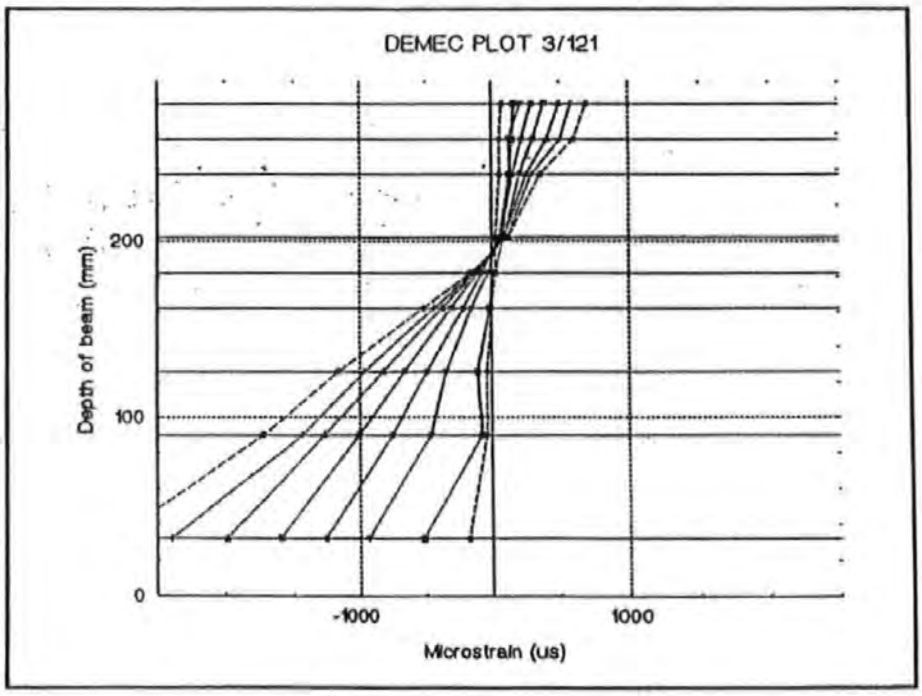
Demec plot 1/121

Graph 4



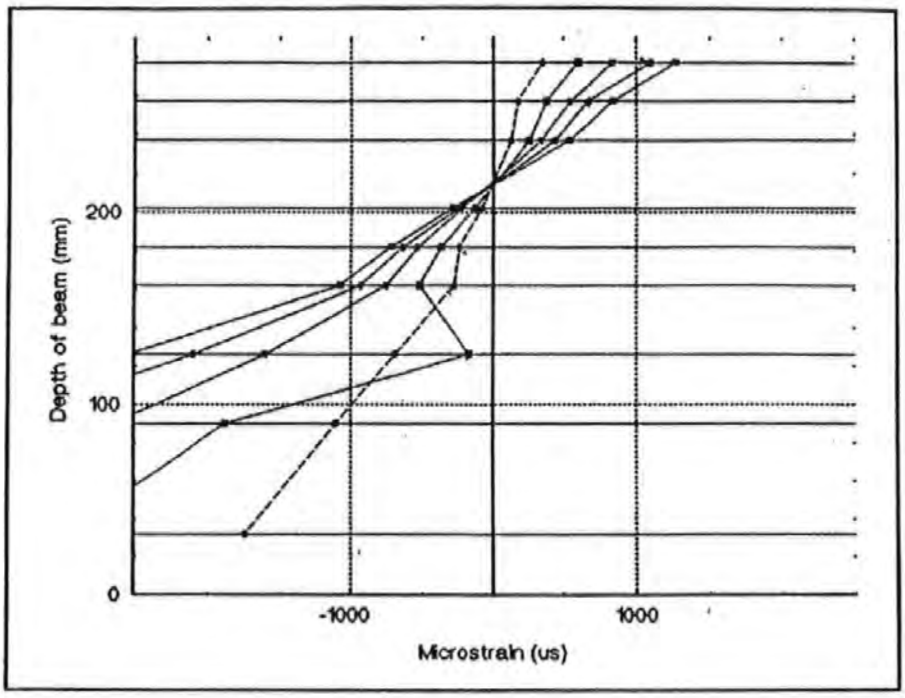
Demec plot 2/121

Graph 5



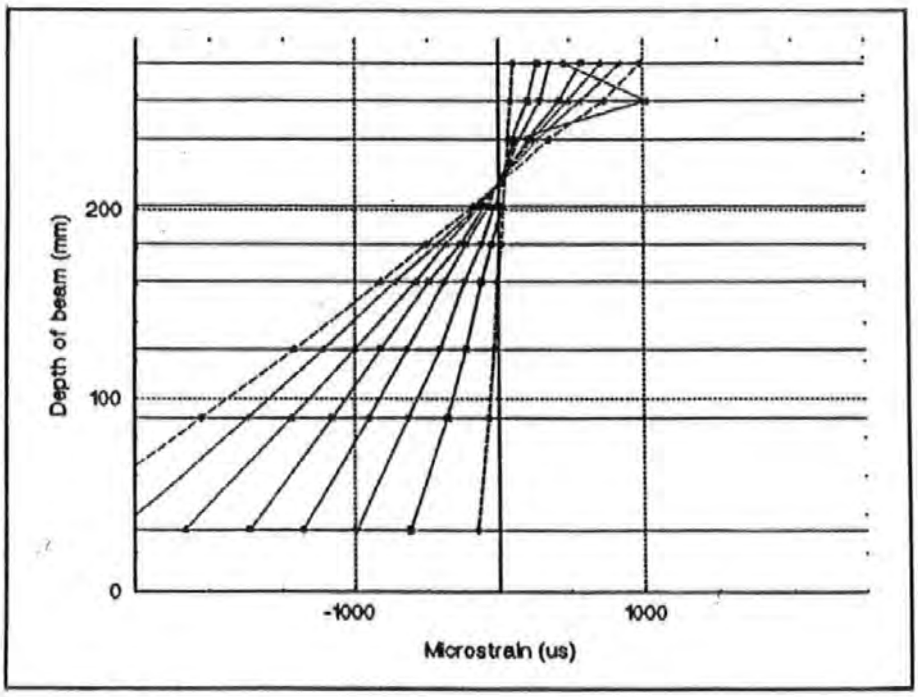
Demec plot 3/121

Graph 6



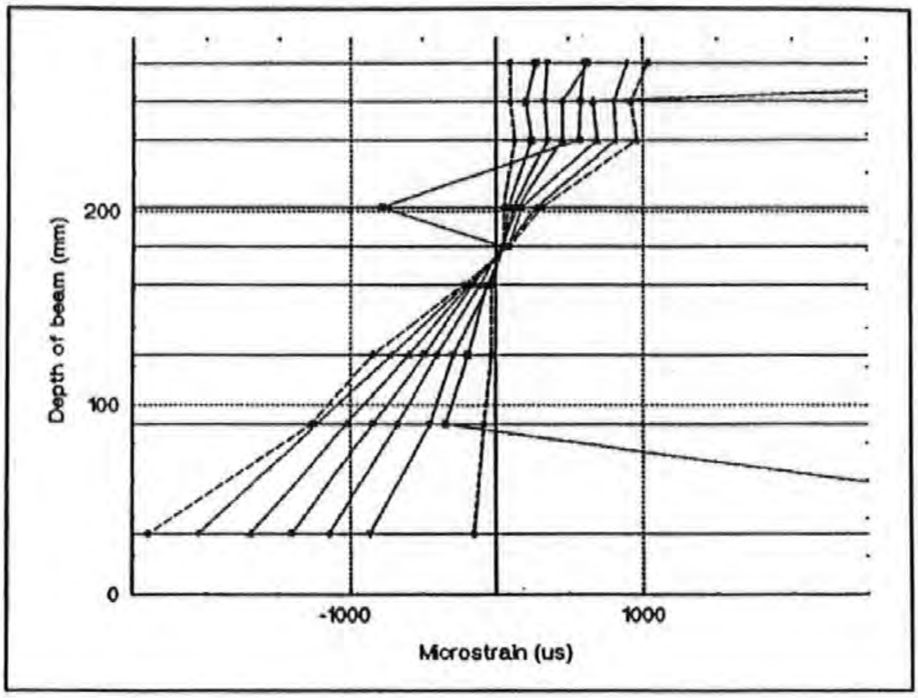
Demec plot 1/130

Graph 7



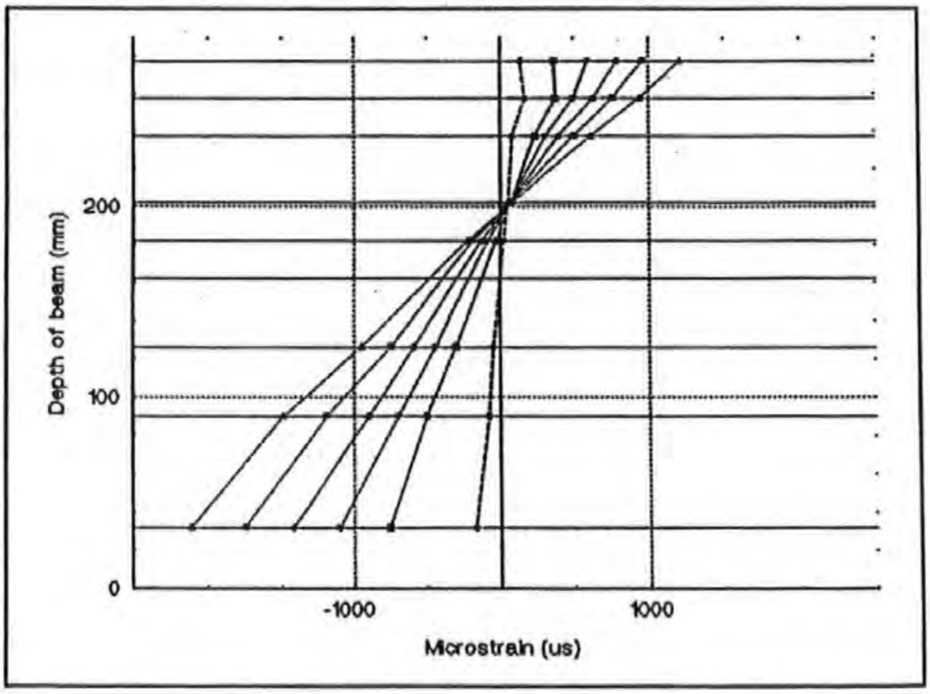
Demec plot 2/130

Graph 8



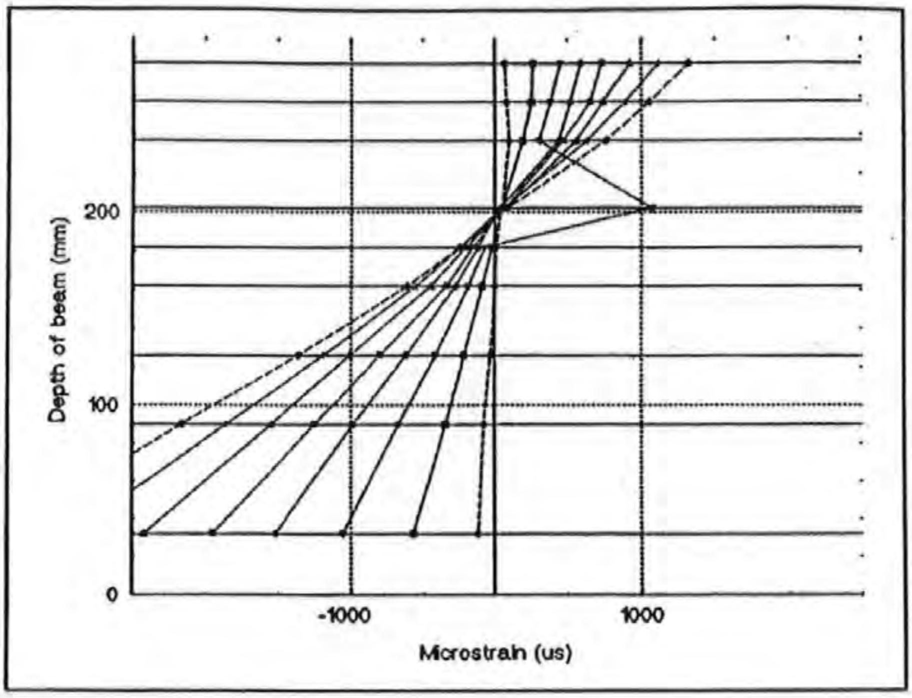
Demec plot 3/130

Graph 9



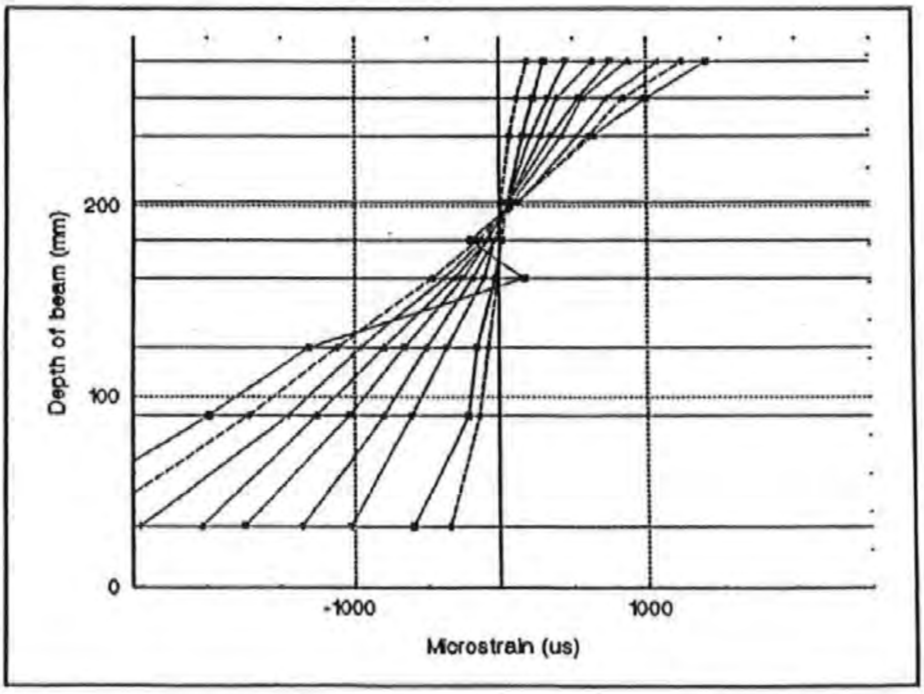
Demec plot 1/131

Graph 10



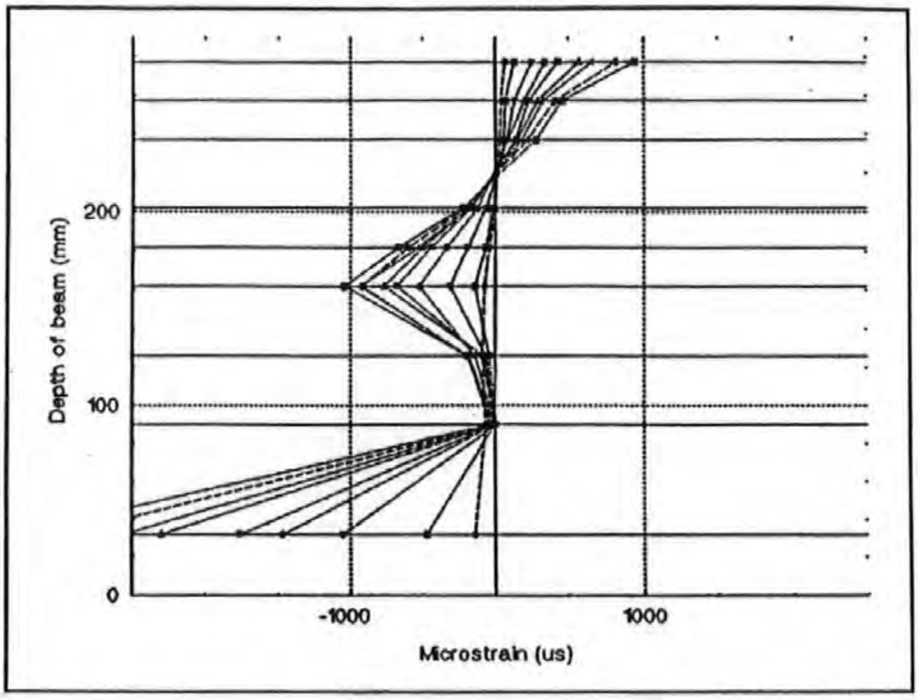
Demec plot 2/131

Graph 11



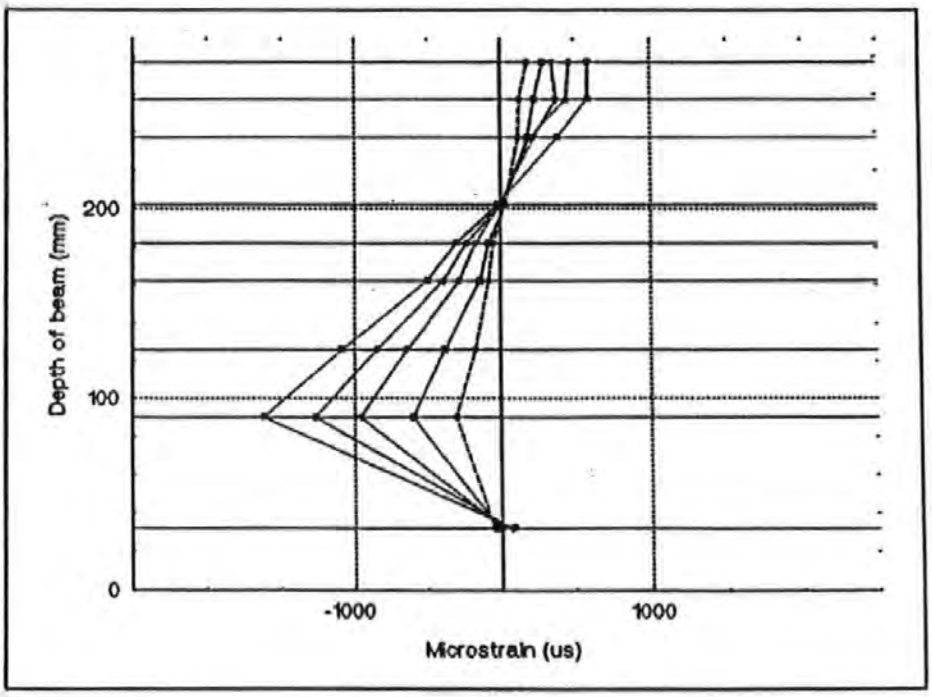
Demec plot 3/131

Graph 12



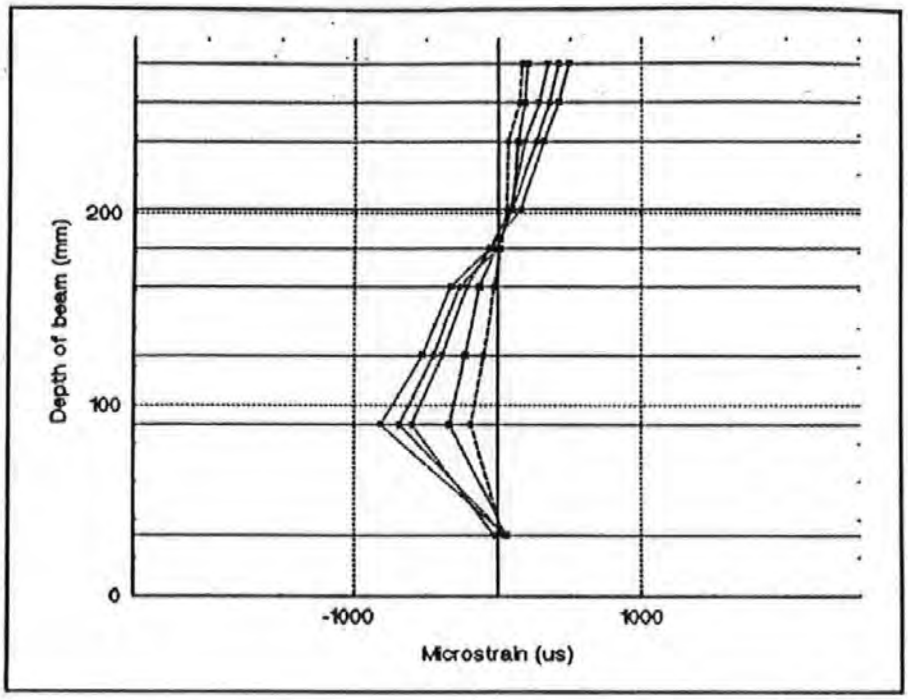
Demec plot 1/140

Graph 13



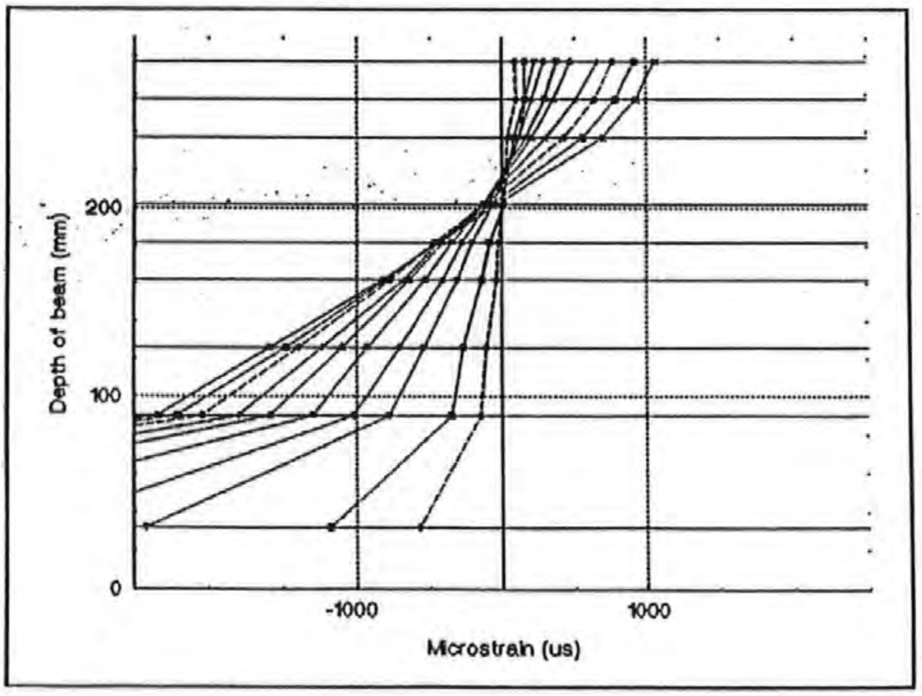
Demec plot 2/140

Graph 14



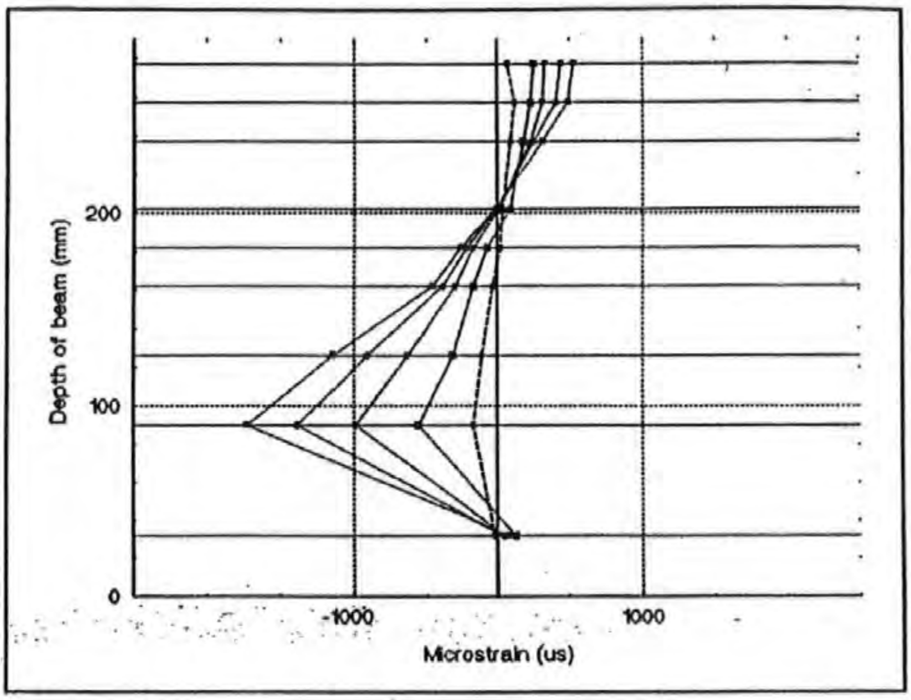
Demec plot 3/140

Graph 15



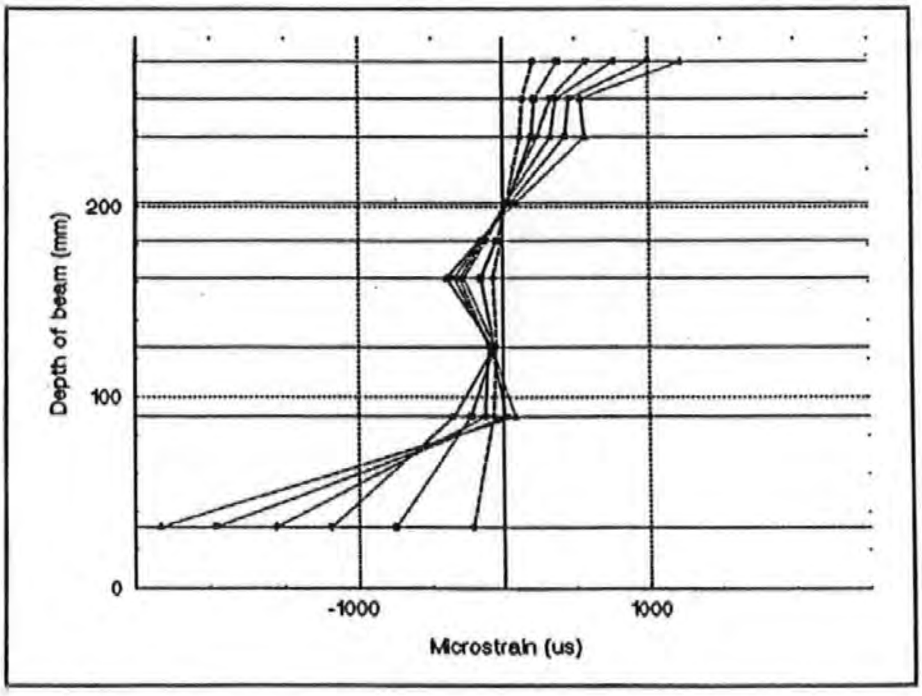
Demec plot 1/141

Graph 16



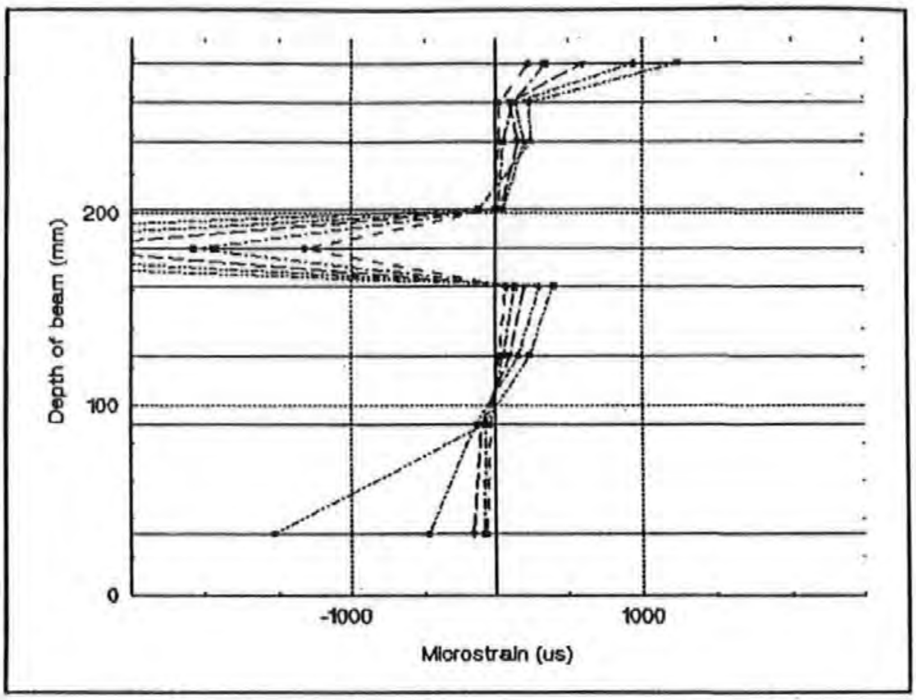
Demec plot 2/141

Graph 17



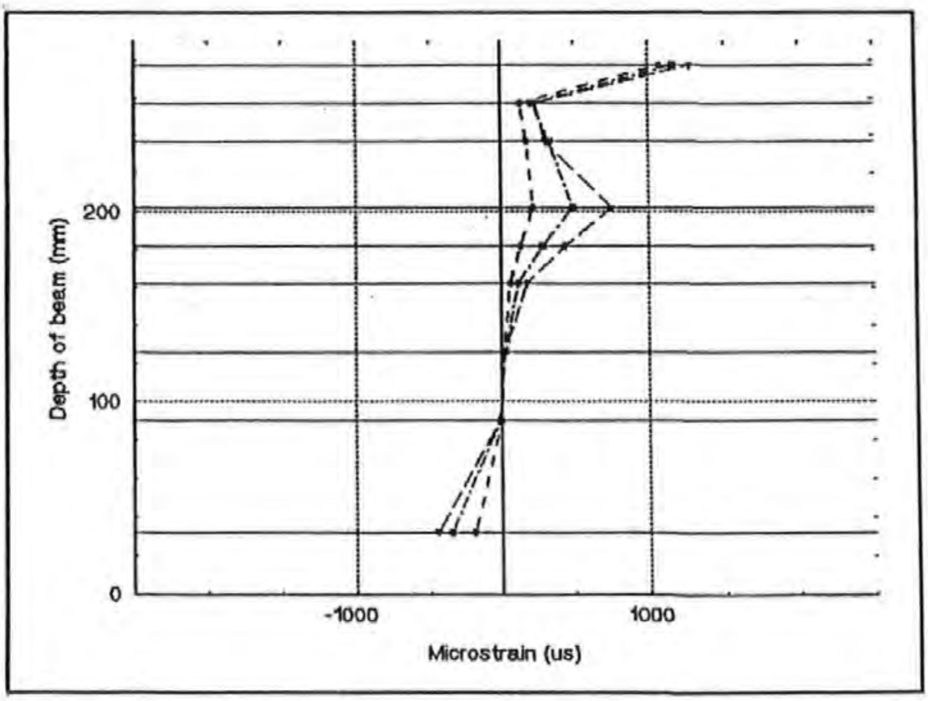
Demec plot 3/141

Graph 18



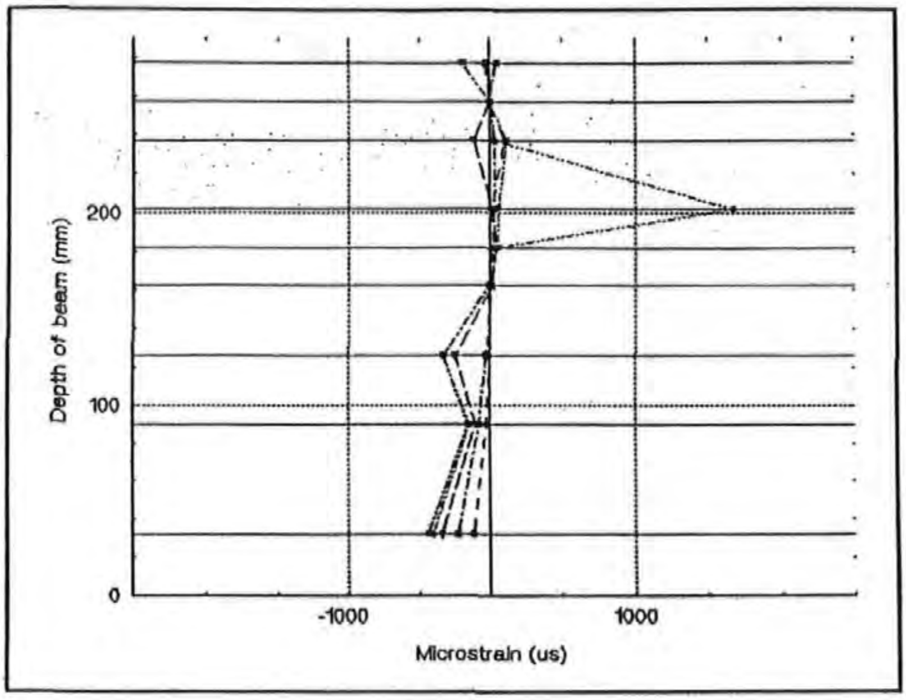
Demec plot 1/220

Graph 19



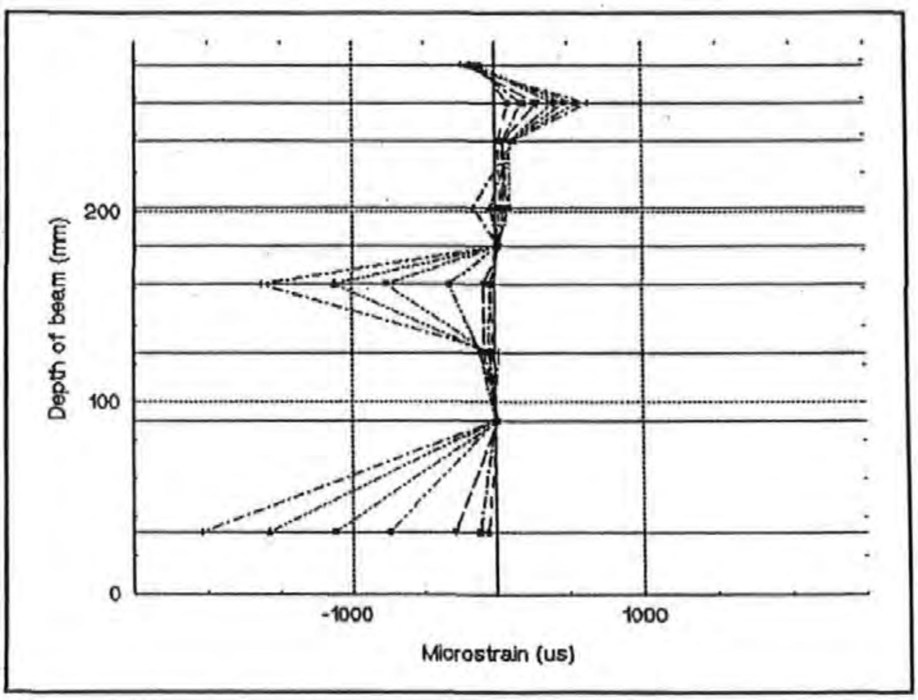
Demec plot 2/220

Graph 20



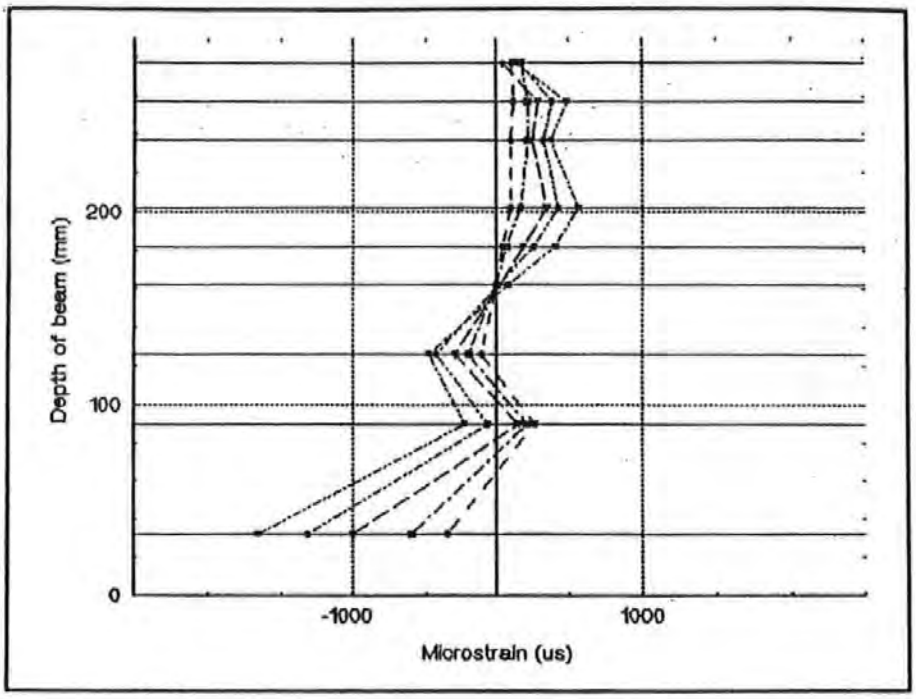
Demec plot 3/220

Graph 21



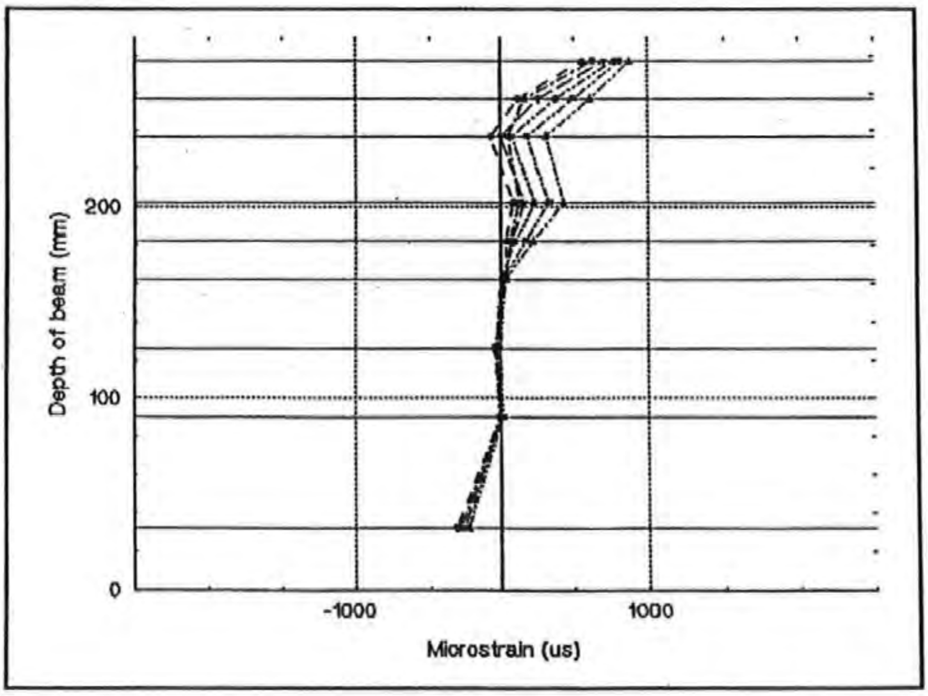
Demec plot 1/221

Graph 22



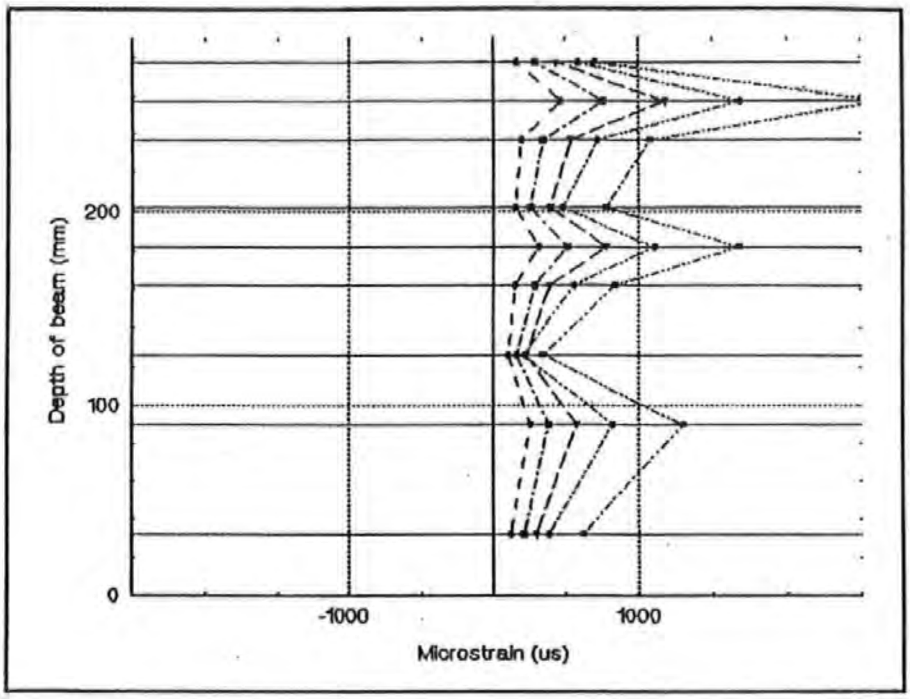
Demec plot 2/221

Graph 23



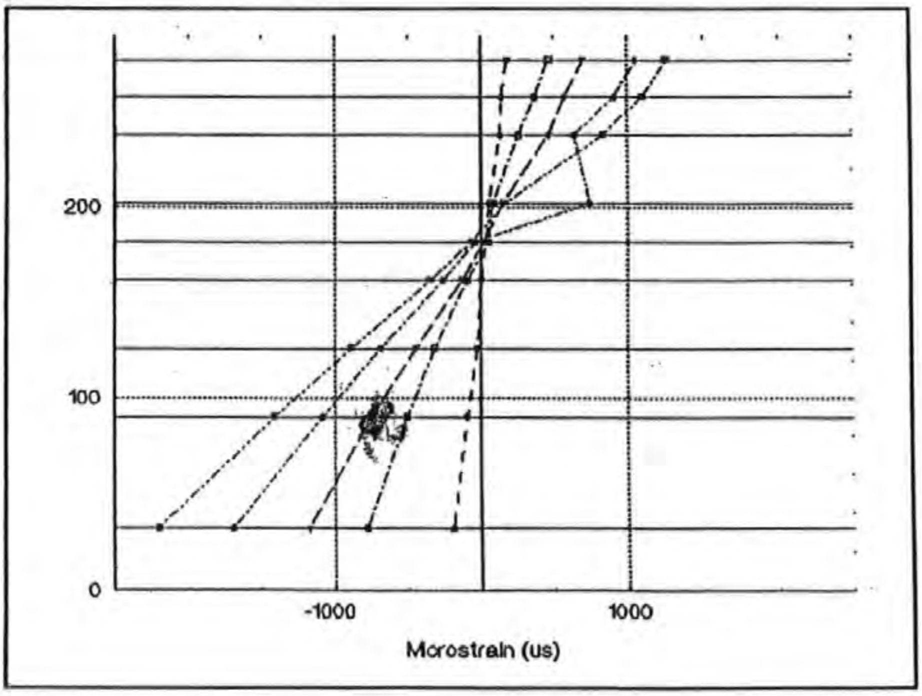
Demec plot 3/221

Graph 24



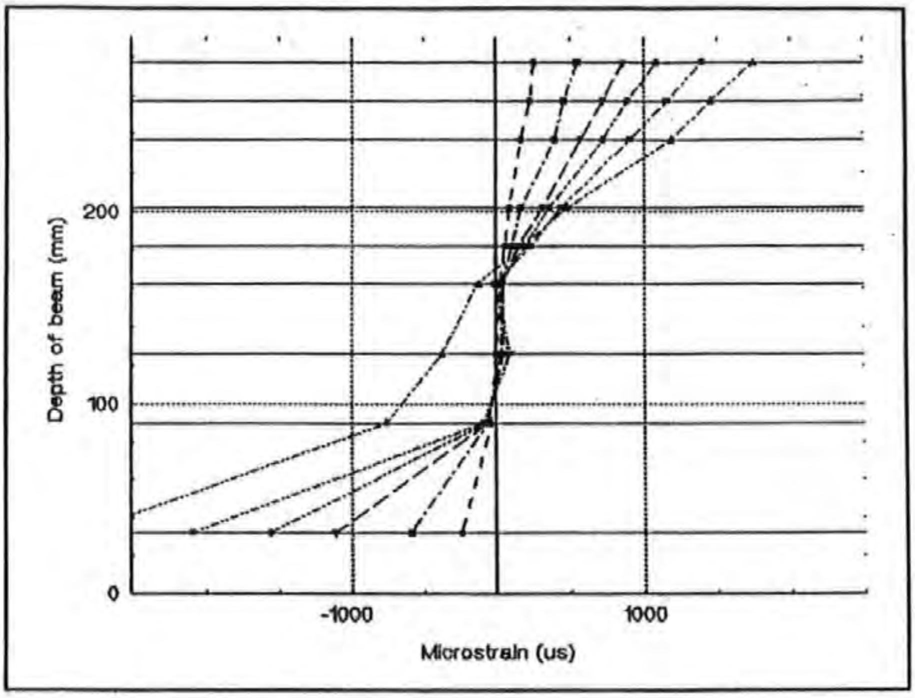
Demec plot 1/230

Graph 25



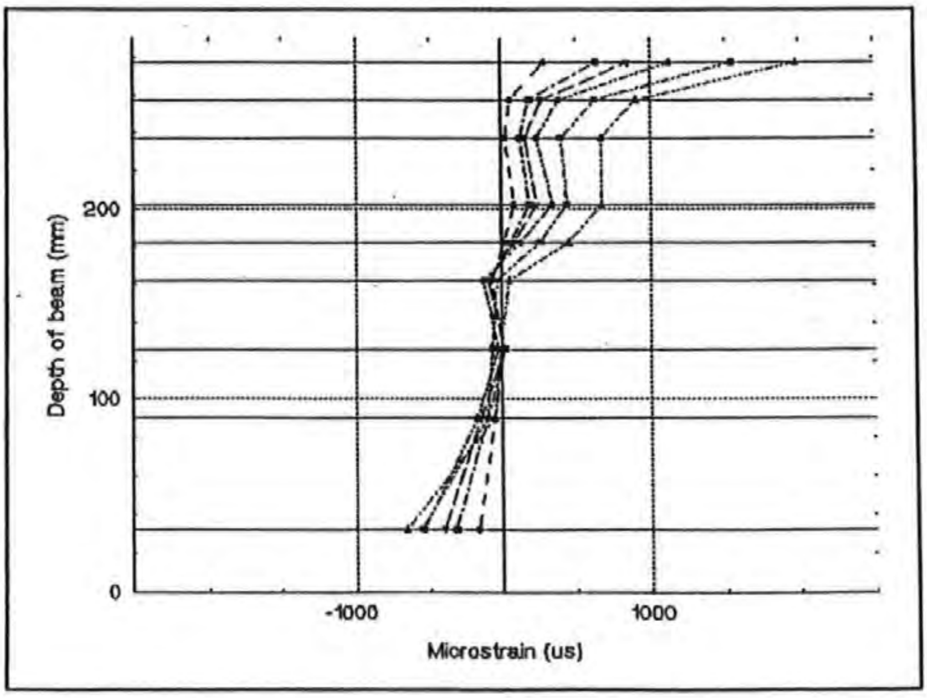
Demec plot 2/230

Graph 26



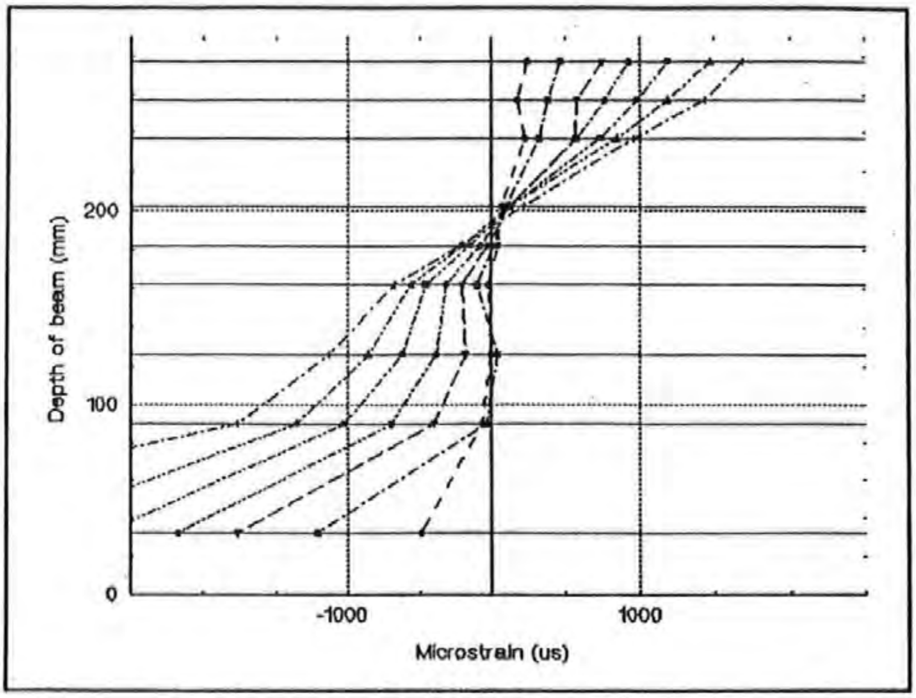
Demec plot 3/230

Graph 27



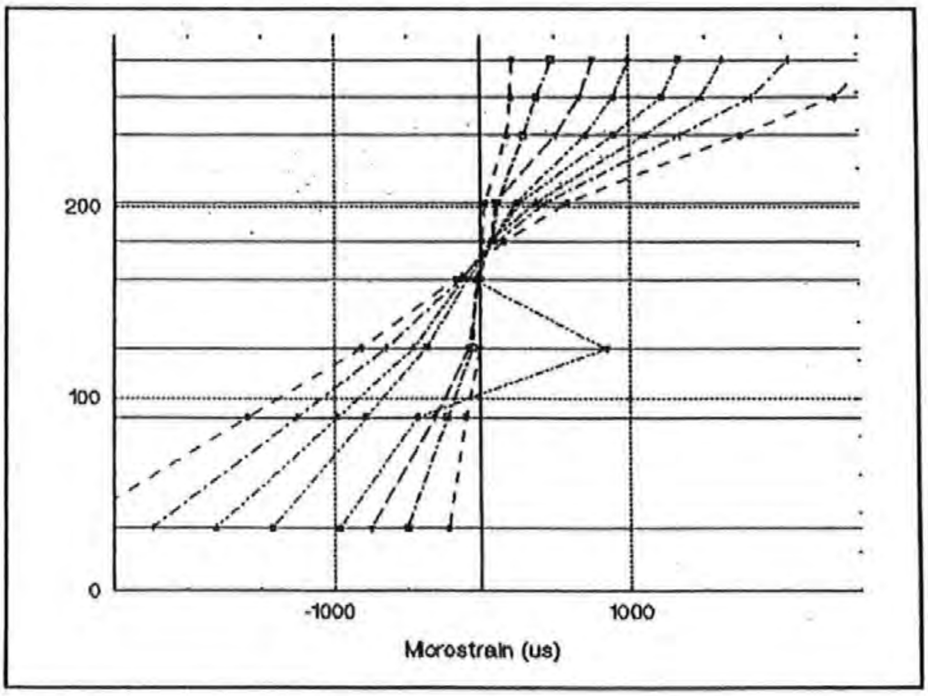
Demec plot 1/231

Graph 28



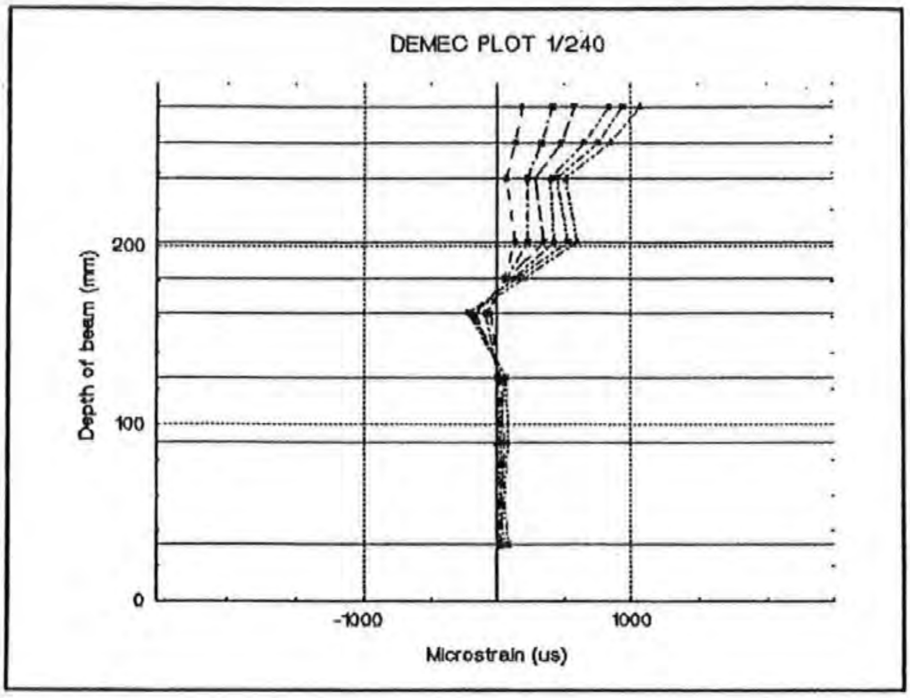
Demec plot 2/231

Graph 29



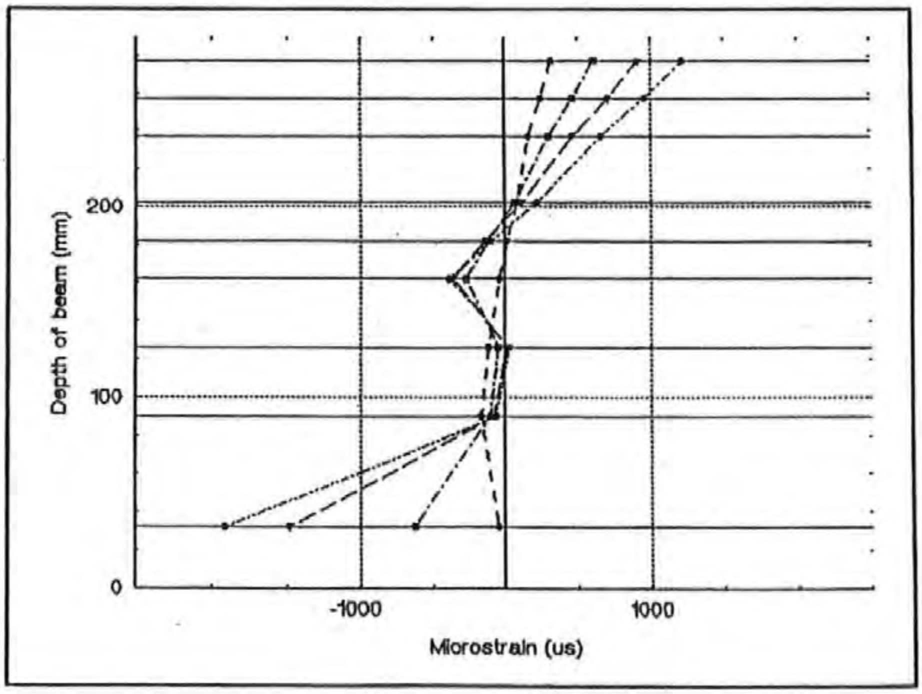
Demec plot 3/231

Graph 30



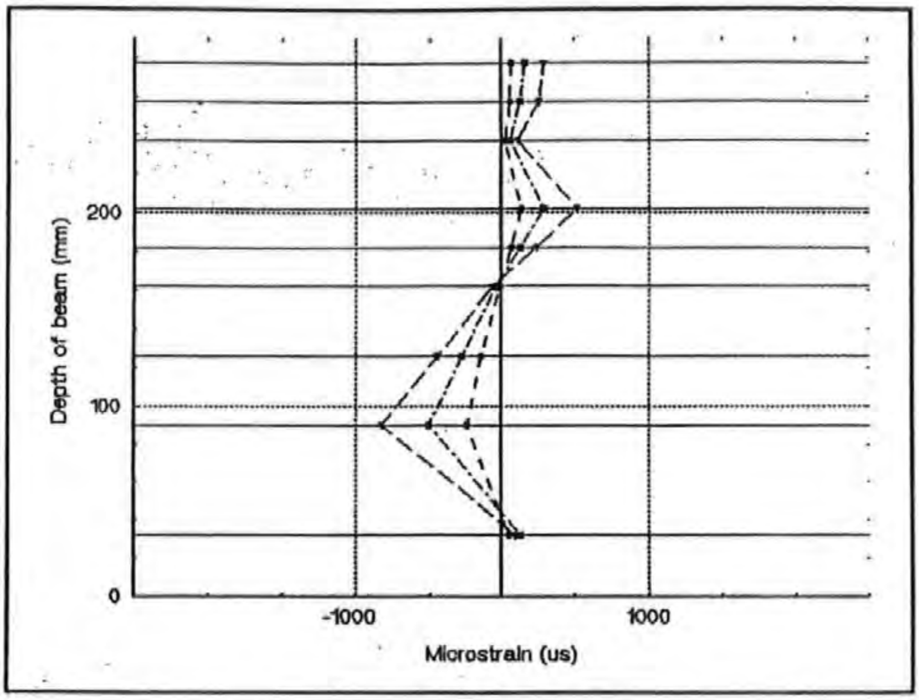
Demec plot 1/240

Graph 31



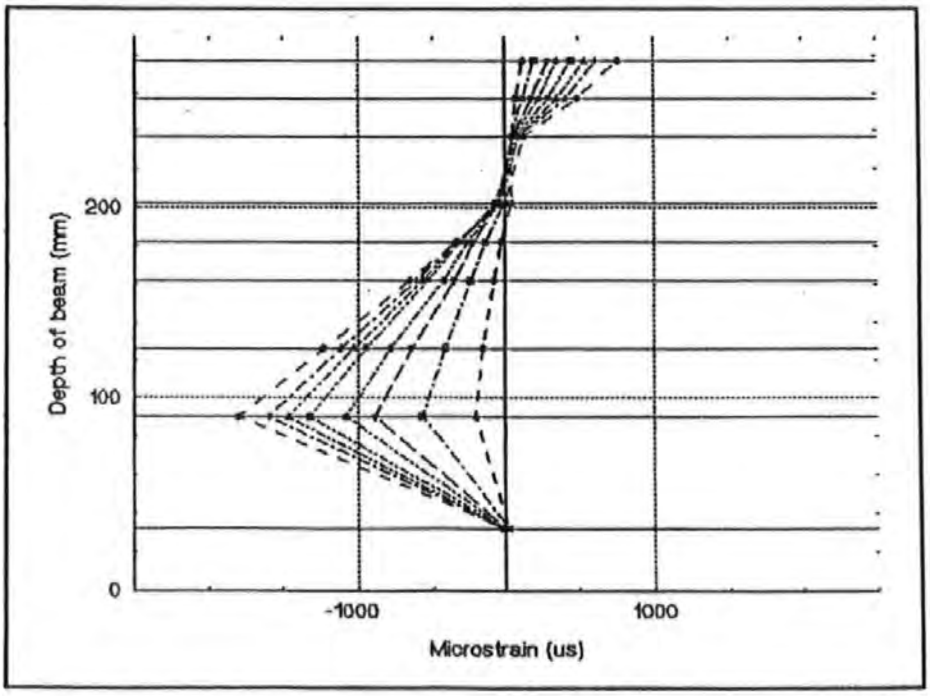
Demec plot 2/240

Graph 32



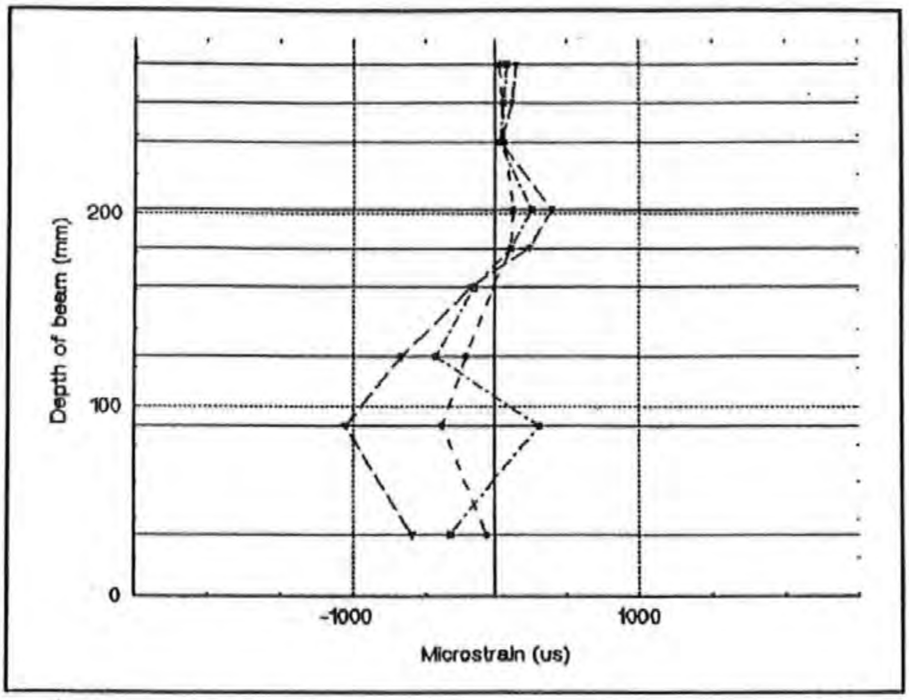
Demec plot 3/240

Graph 33



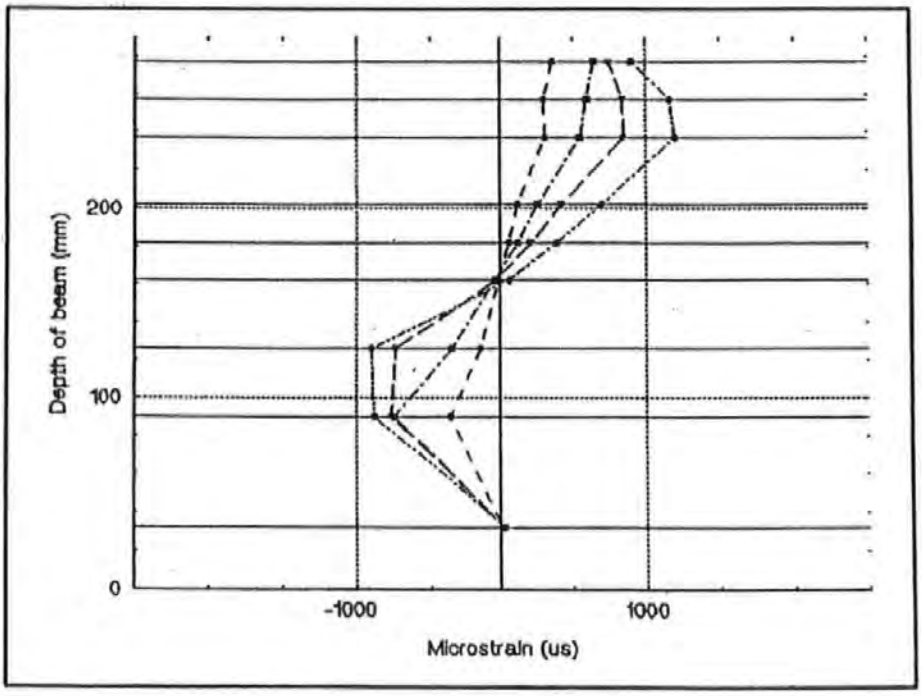
Demec plot 1/241

Graph 34



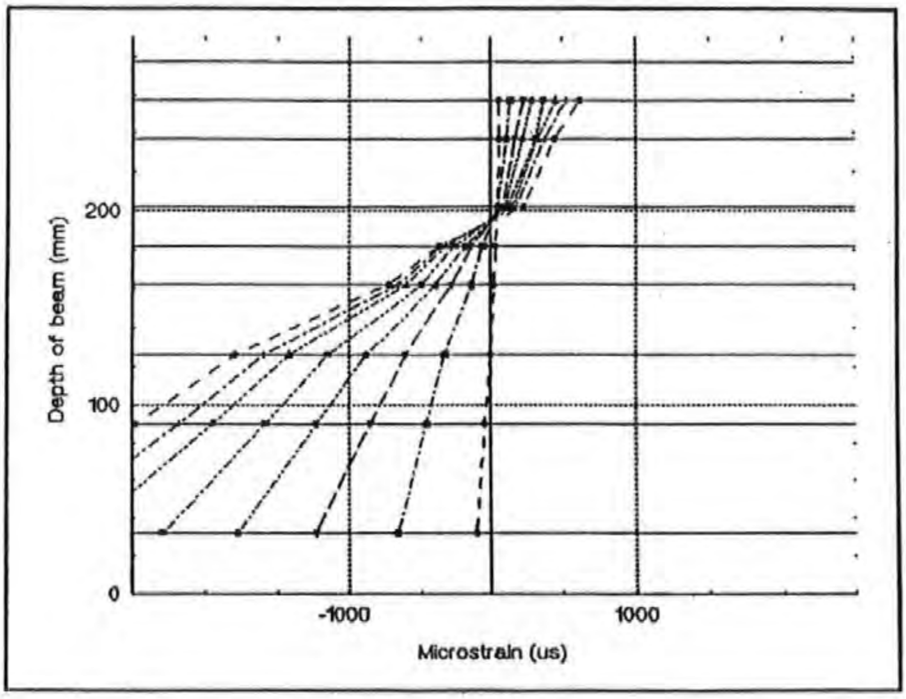
Demec plot 2/241

Graph 35



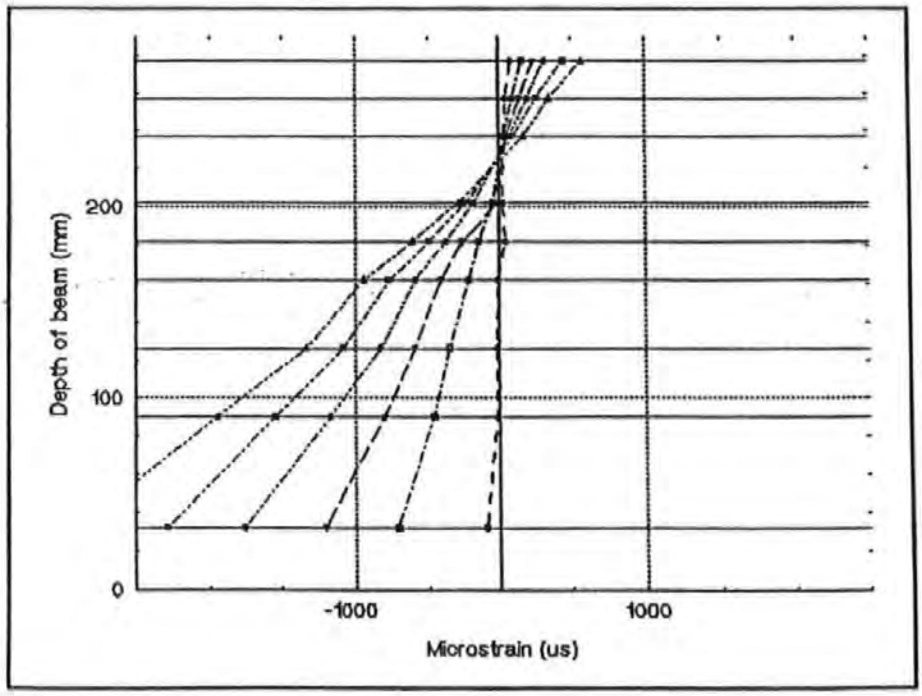
Demec plot 3/241

Graph 36



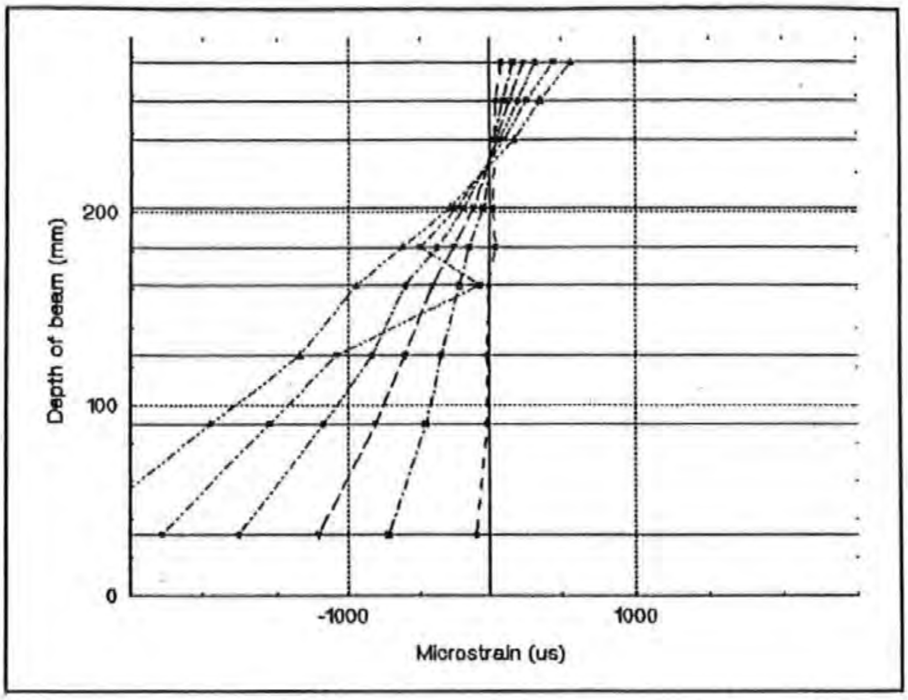
Demec plot 1/320

Graph 37



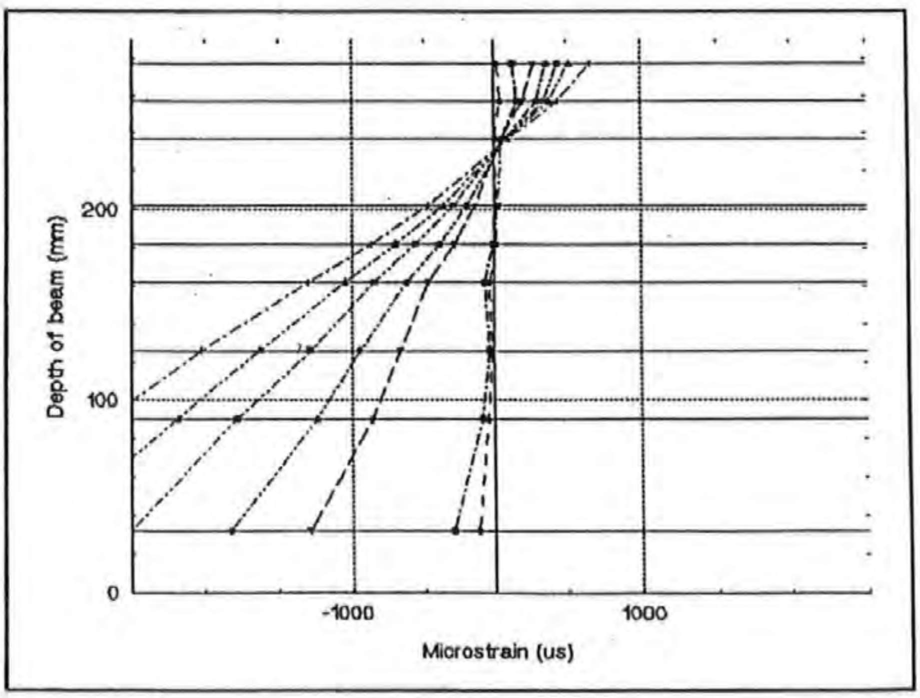
Demec plot 2/320

Graph 38



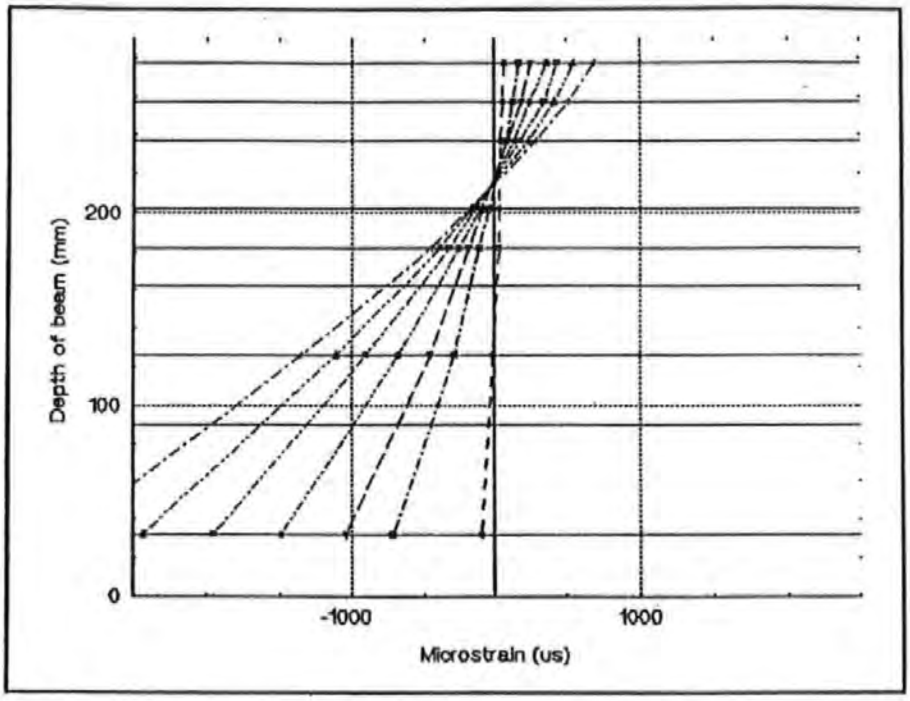
Demec plot 3/320

Graph 39



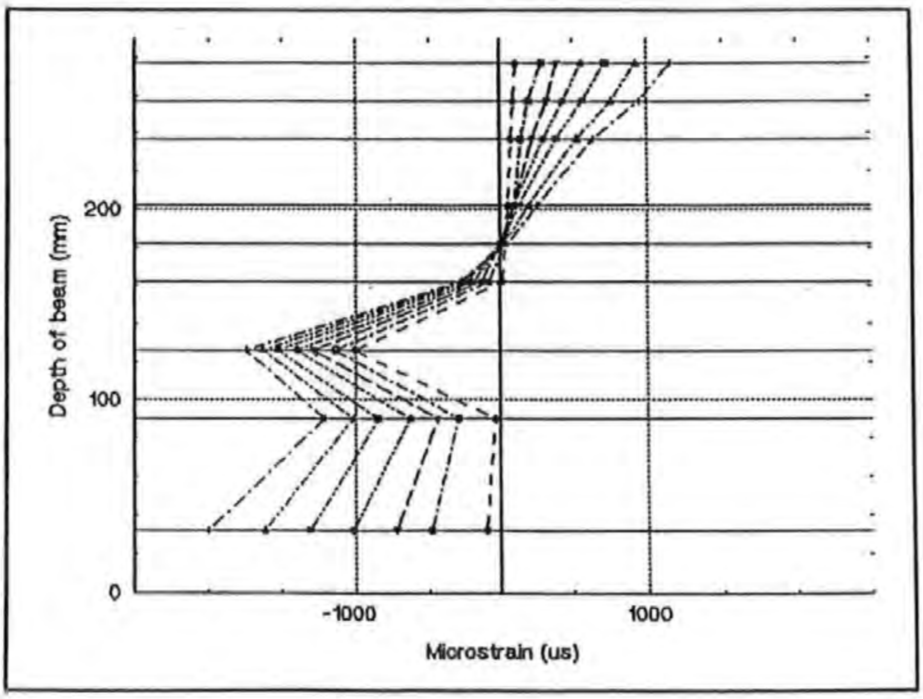
Demec plot 1/321

Graph 40



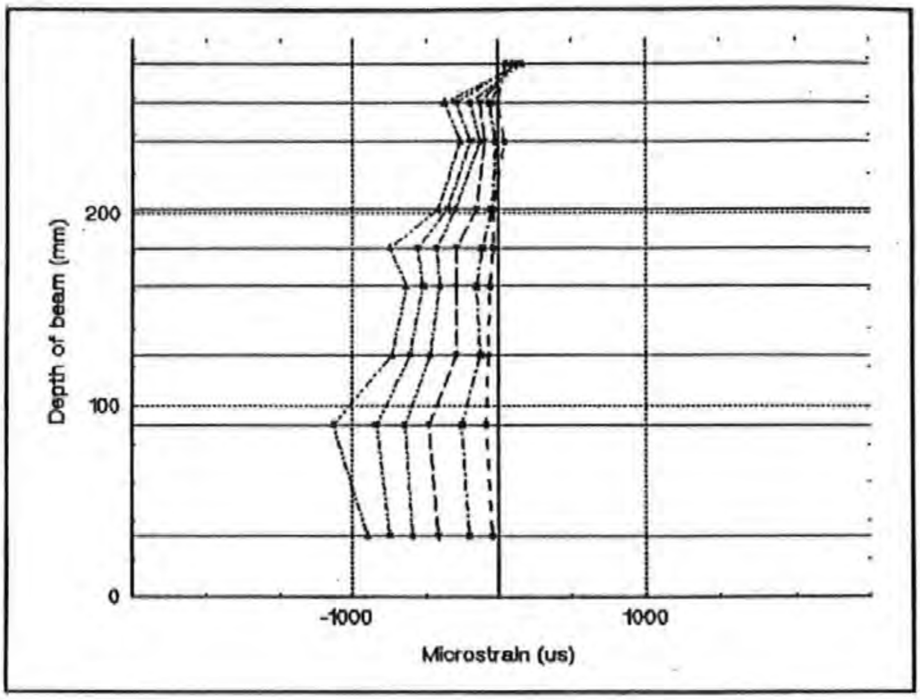
Demec plot 2/321

Graph 41



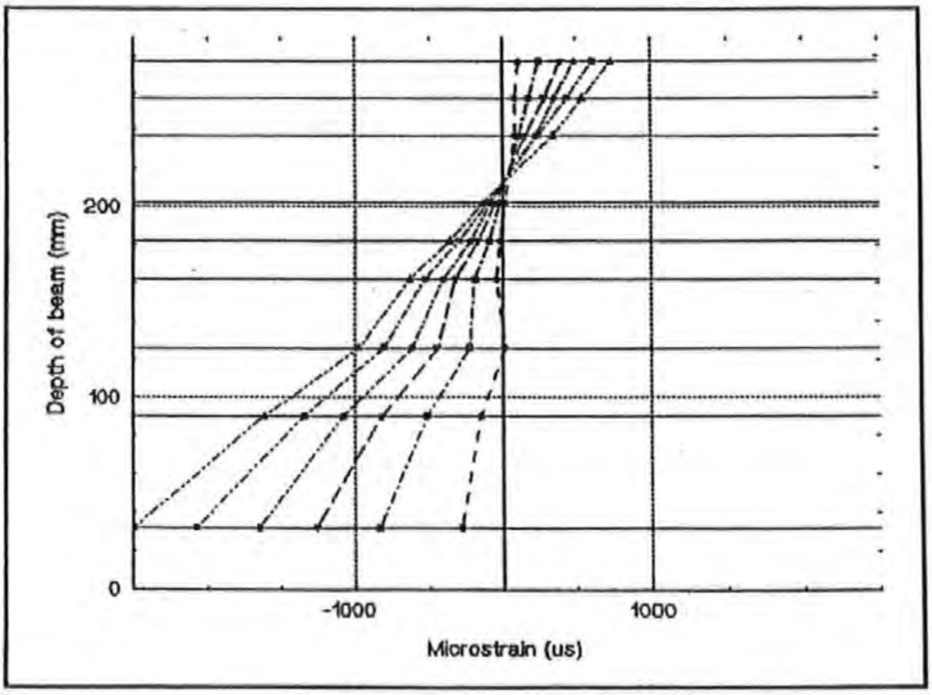
Demec plot 3/321

Graph 42



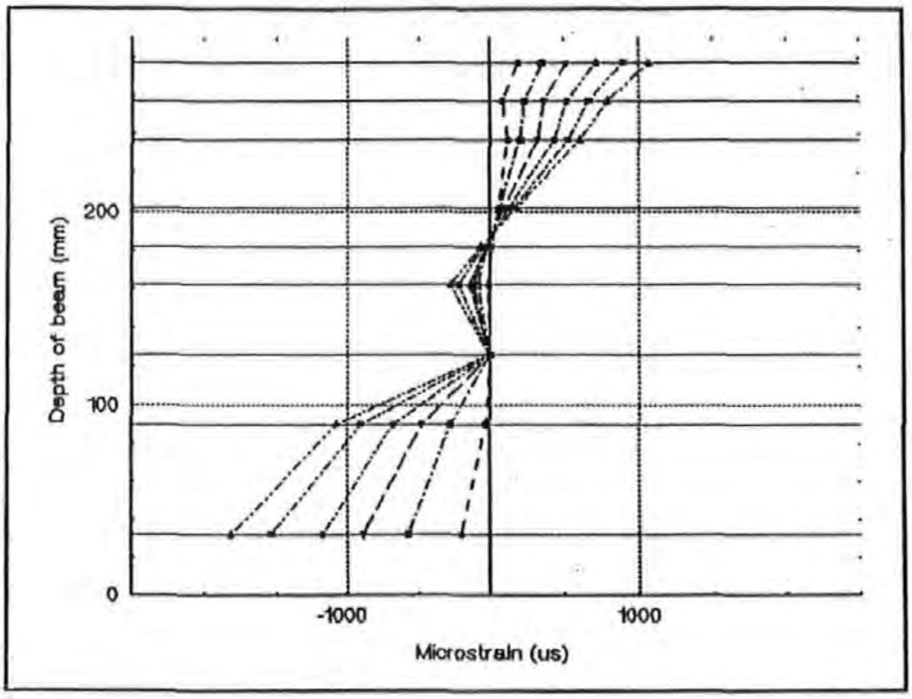
Demec plot 1/330

Graph 43



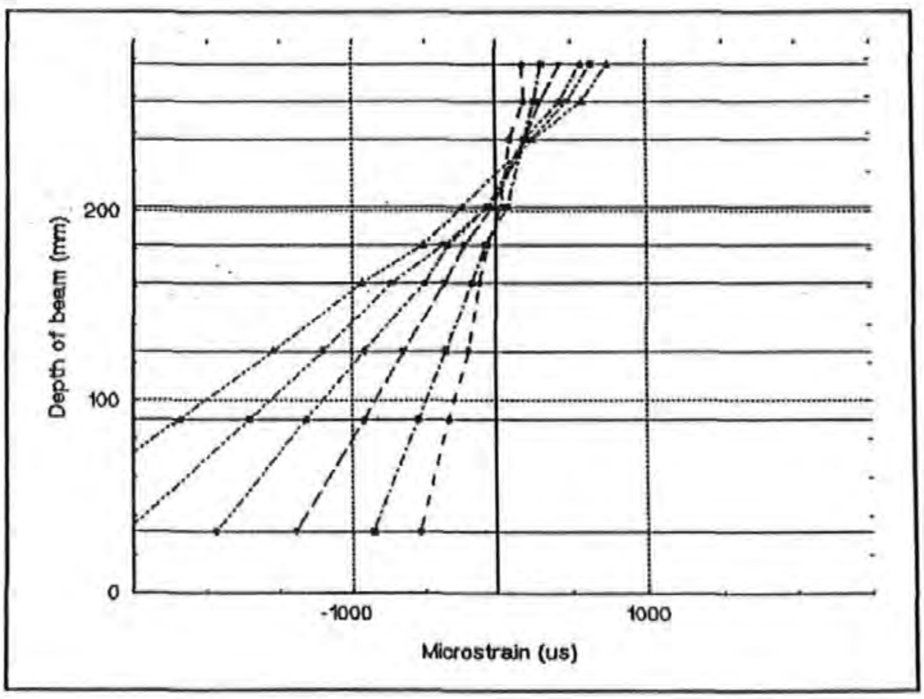
Demec plot 2/330

Graph 44



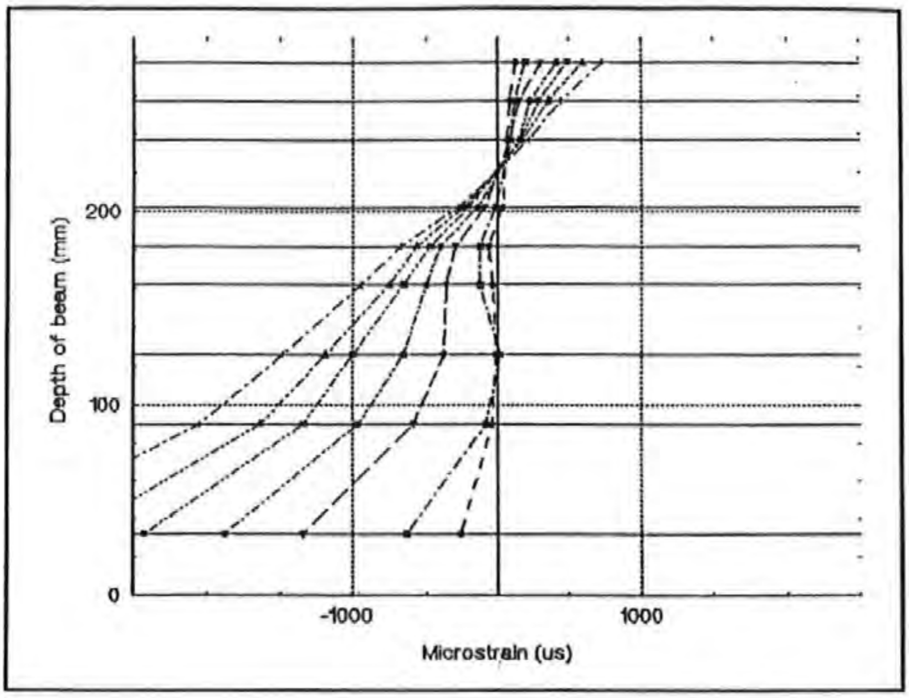
Demec plot 3/330

Graph 45



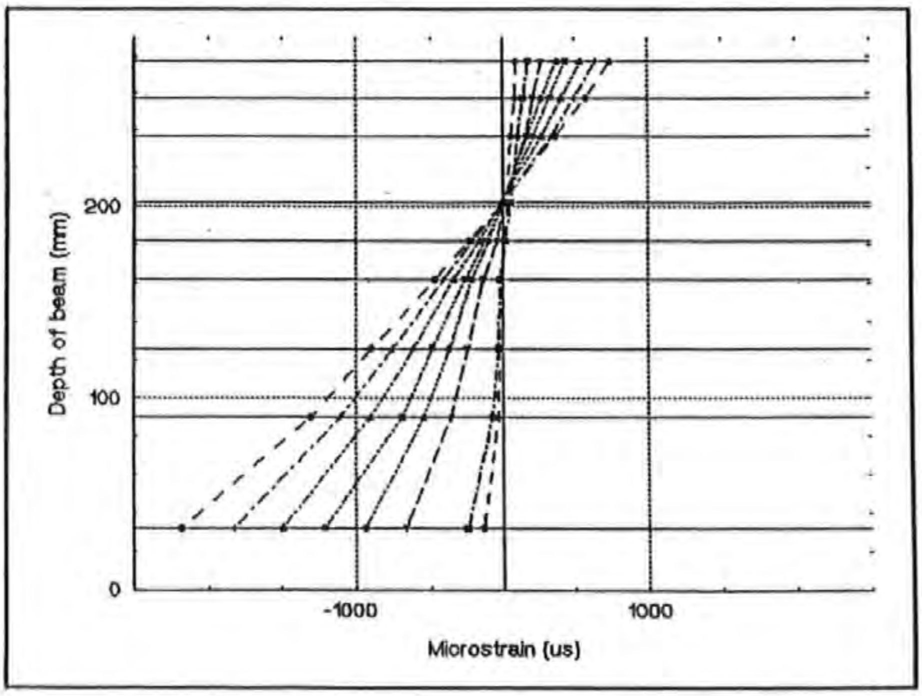
Demec plot 1/331

Graph 46



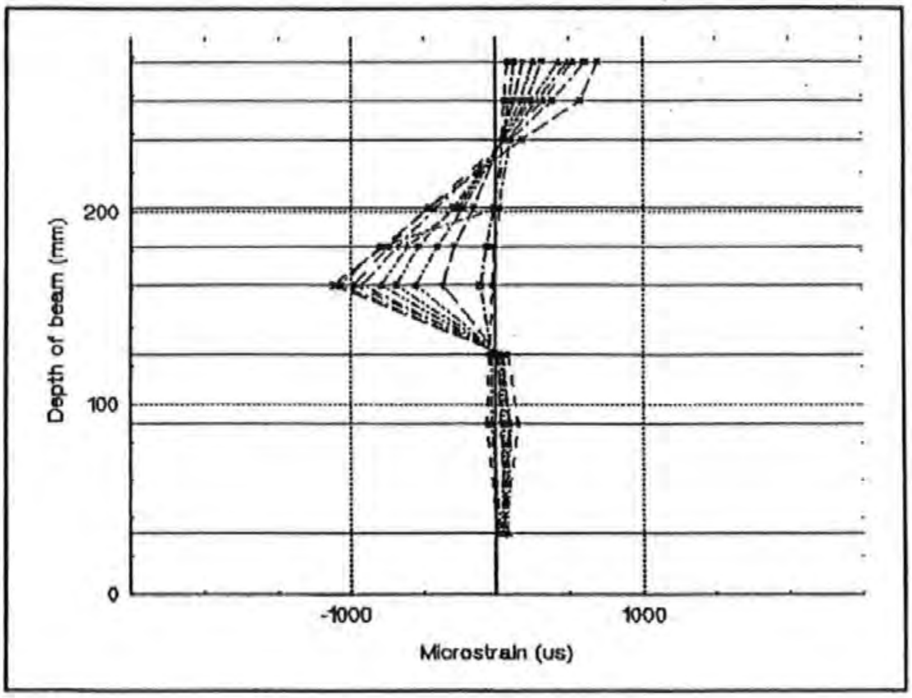
Demec plot 2/331

Graph 47



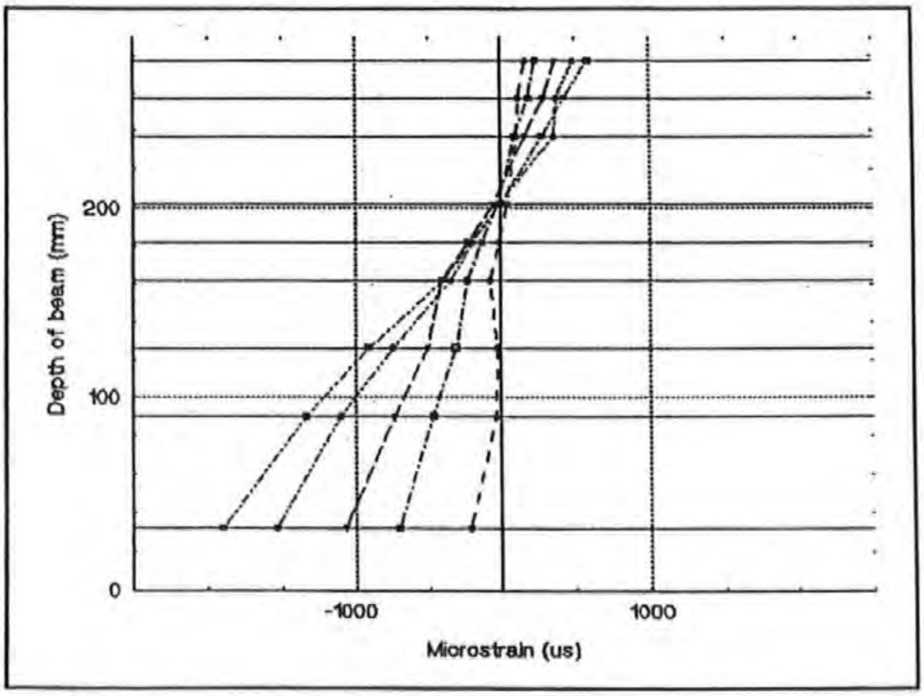
Demec plot 3/331

Graph 48



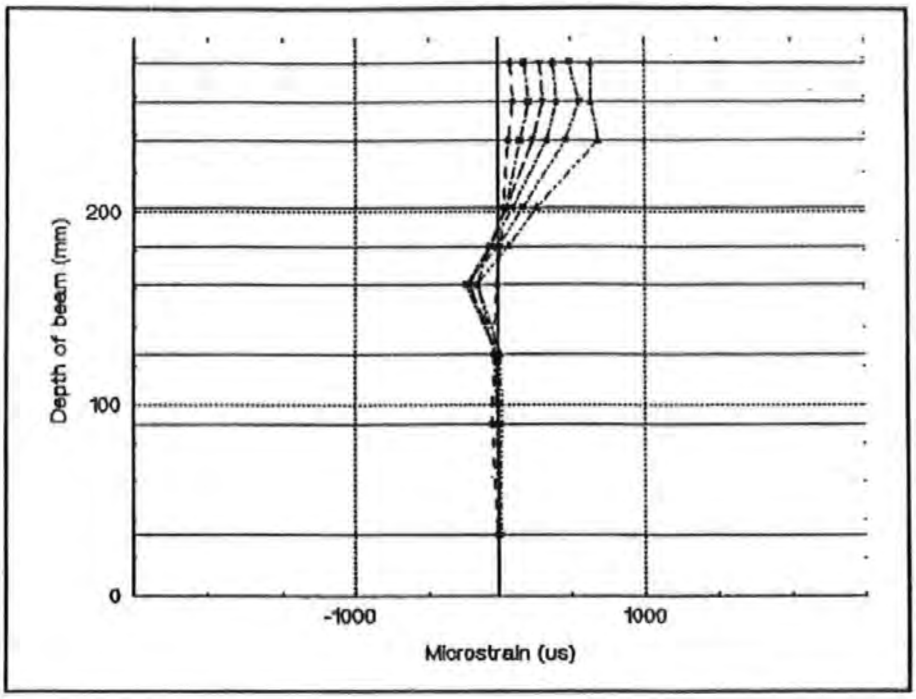
Demec plot 1/340

Graph 49



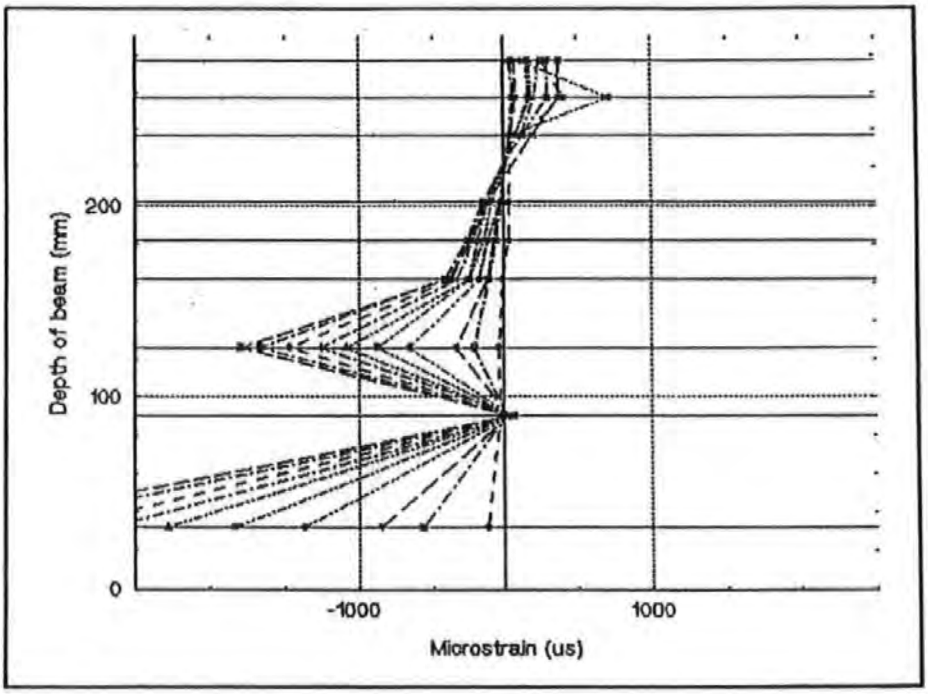
Demec plot 2/340

Graph 50



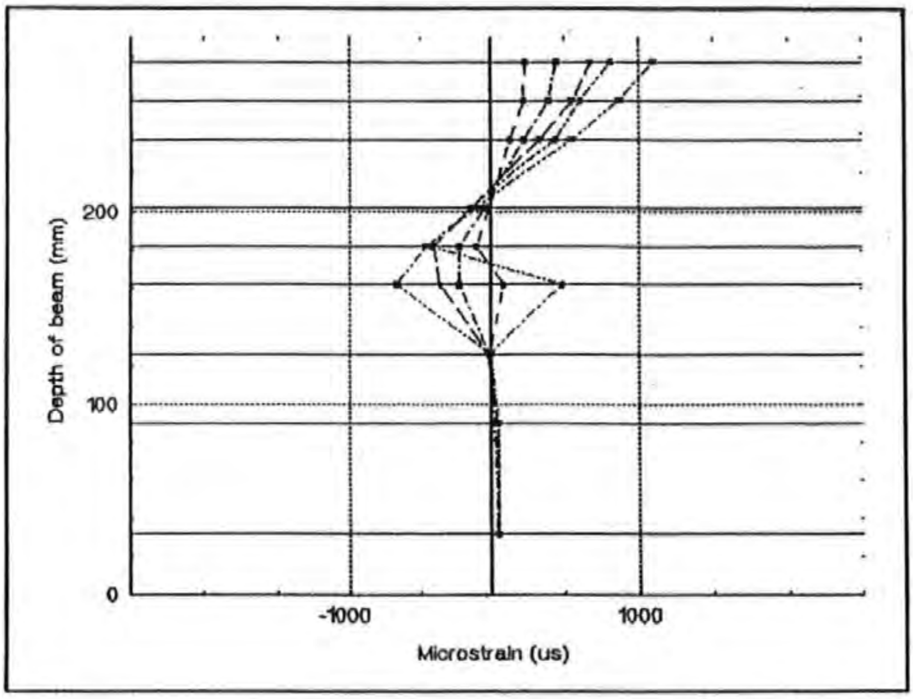
Demec plot 3/340

Graph 51



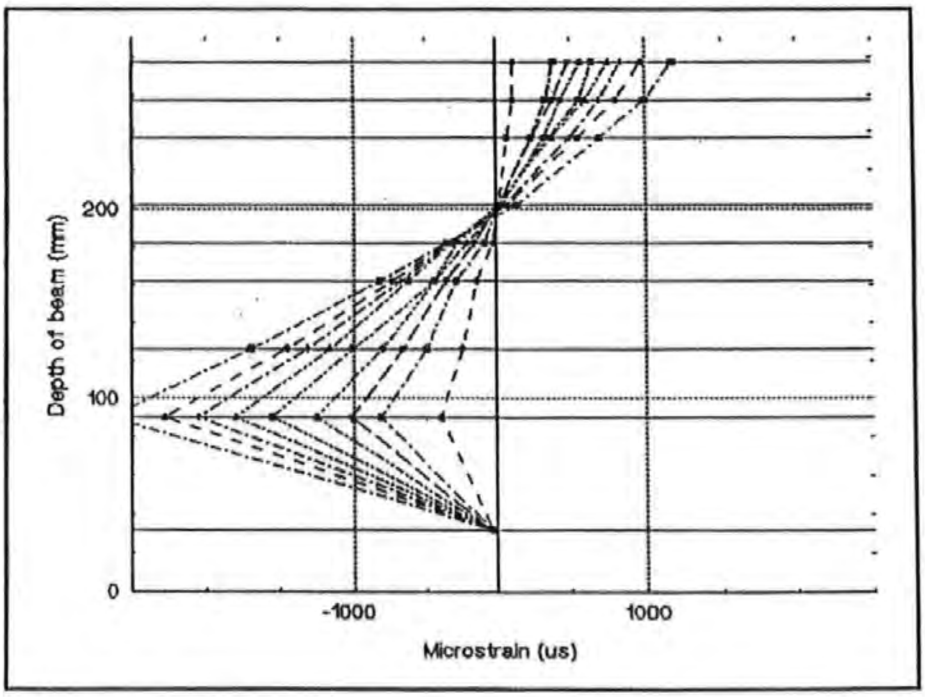
Demec plot 1/341

Graph 52



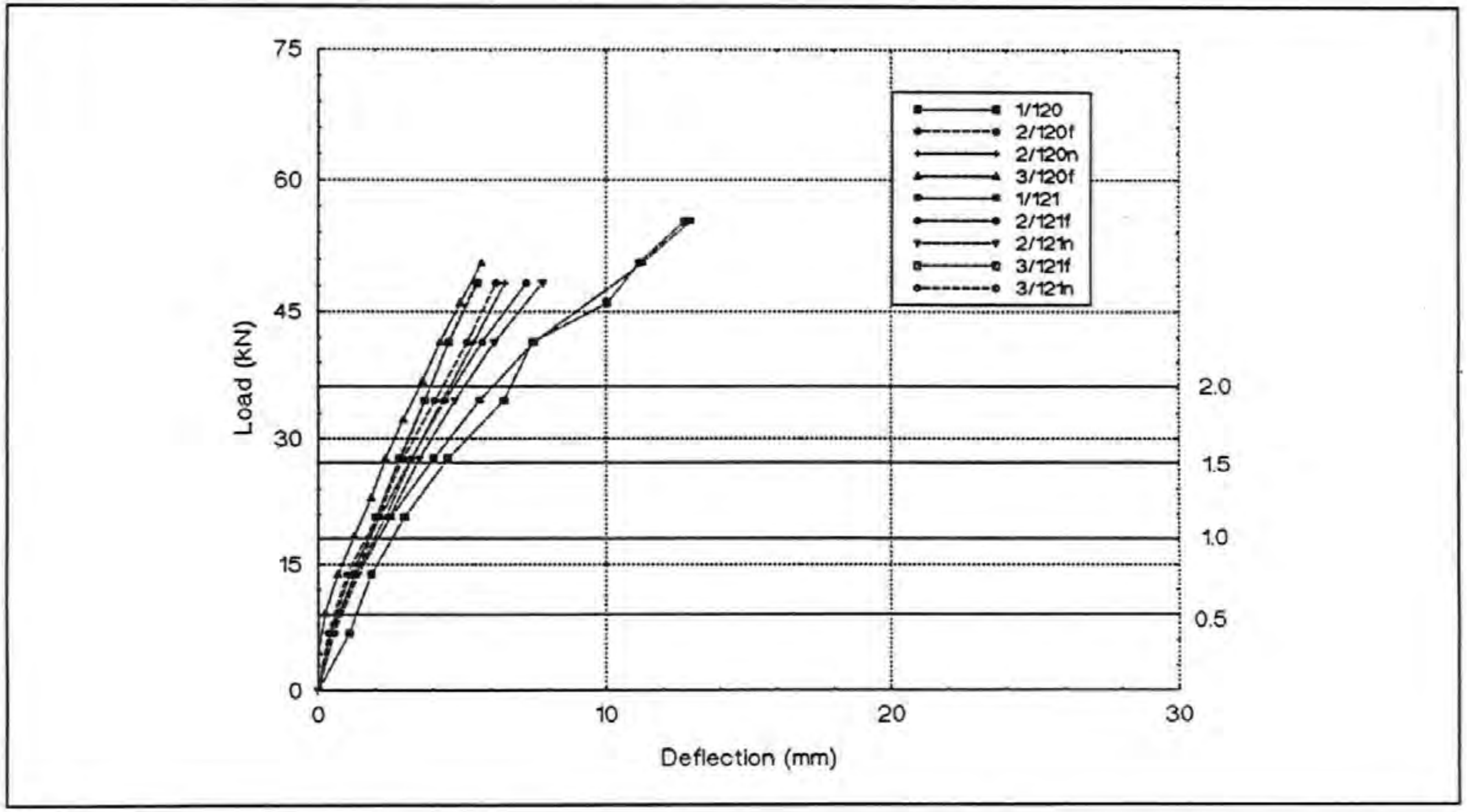
Demec plot 2/341

Graph 53



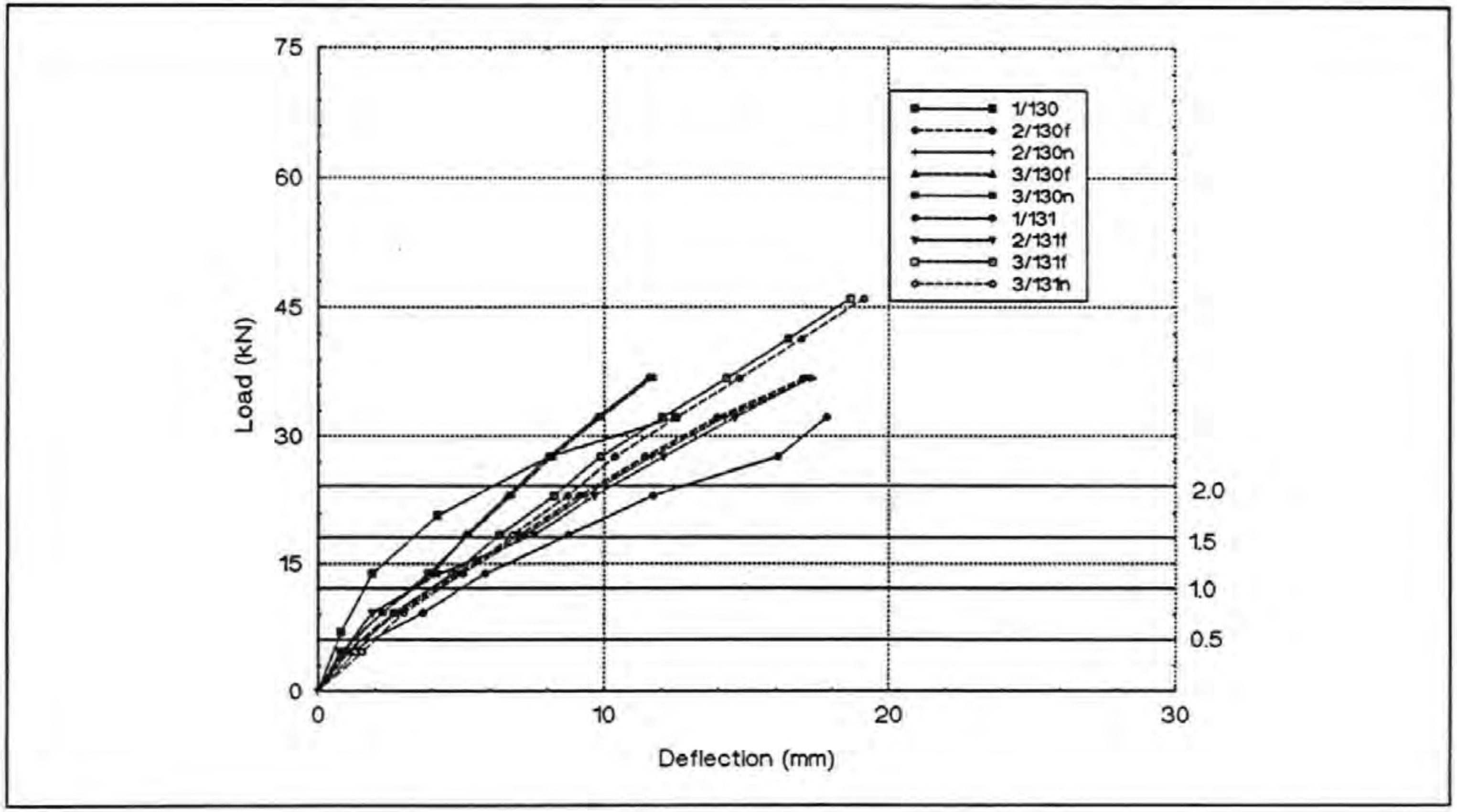
Demec plot 3/341

Graph 54



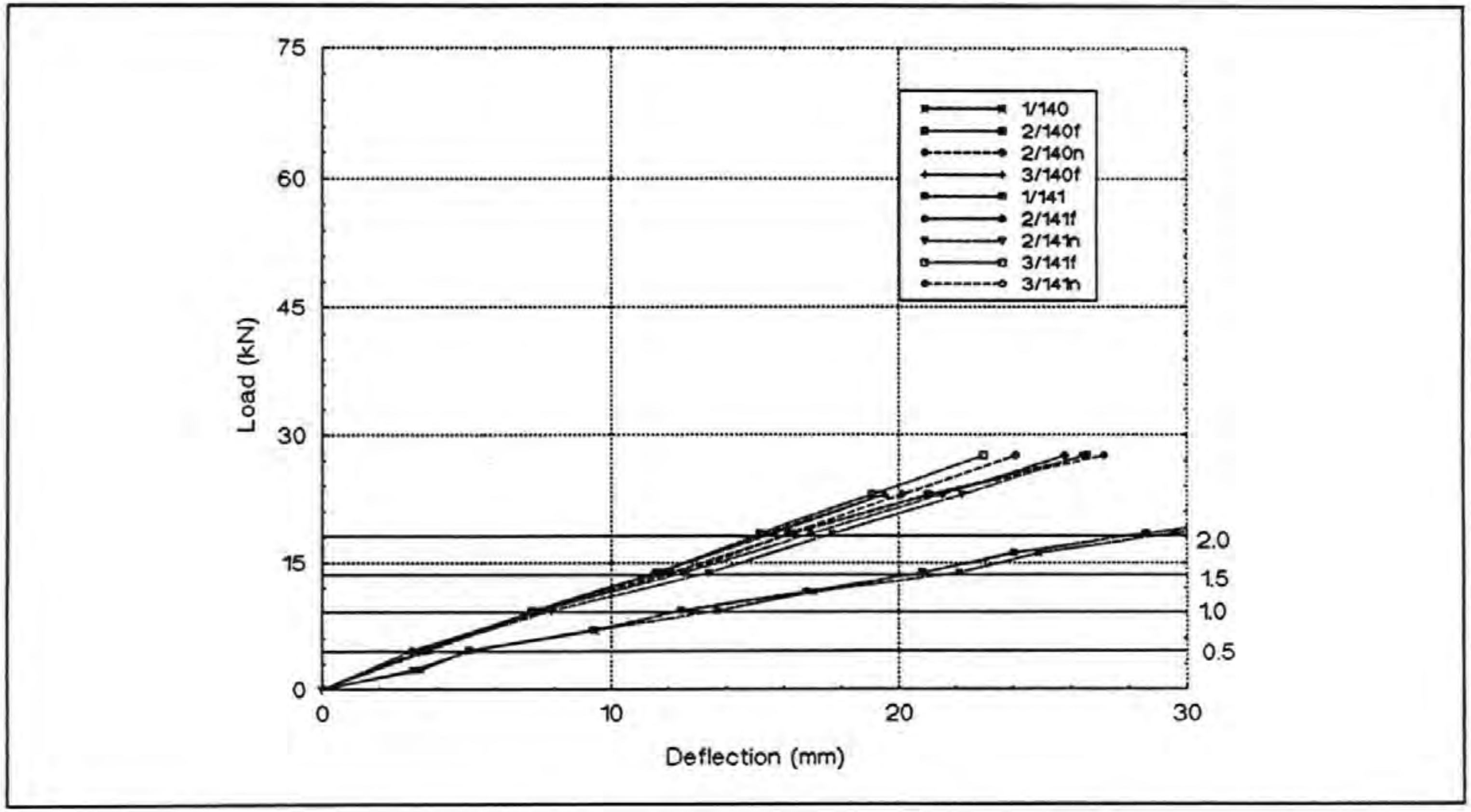
Load versus deflection - beams 120 & 121

Graph 55



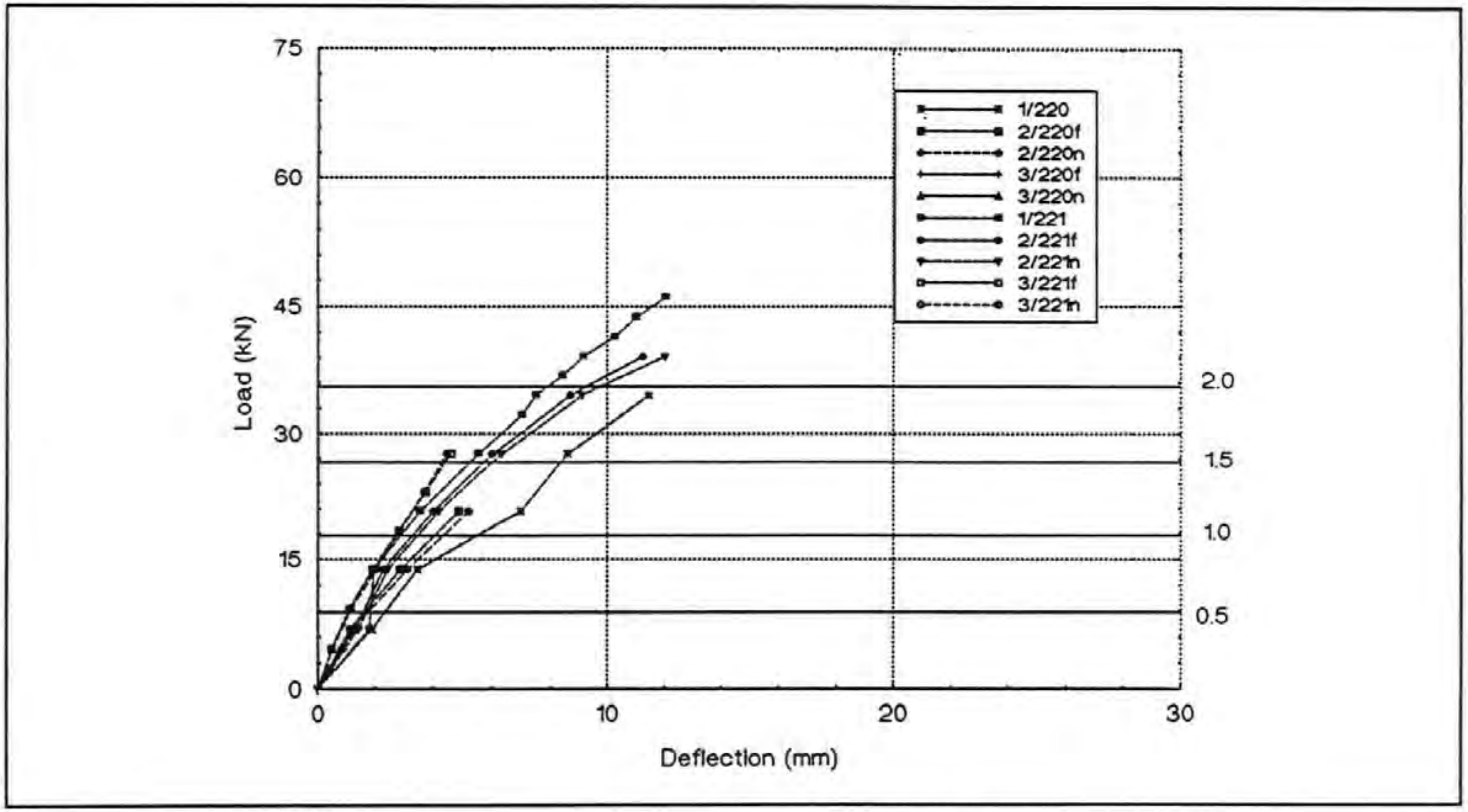
Load versus deflection - beams 130 & 131

Graph 56



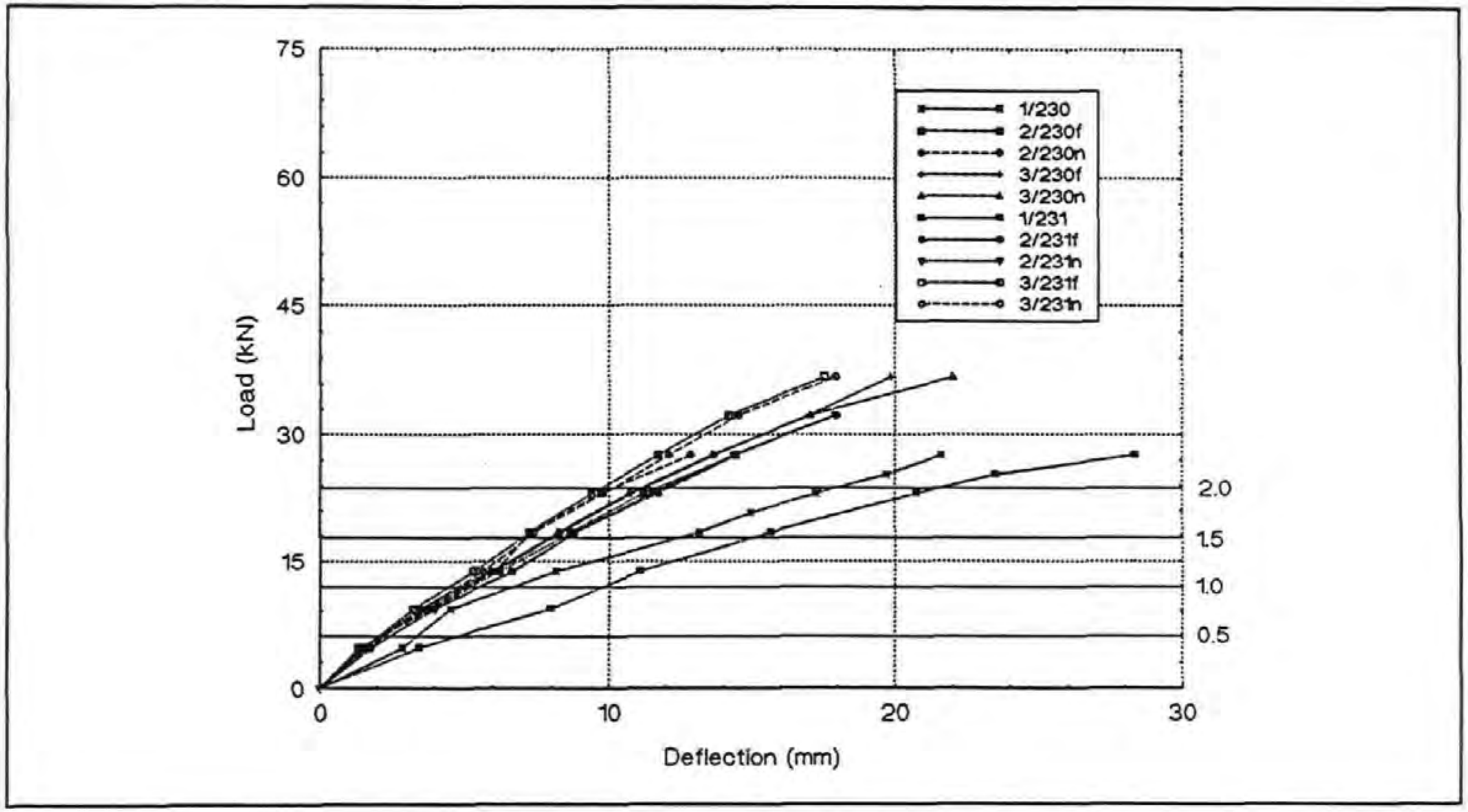
Load versus deflection - beams 140 & 141

Graph 57



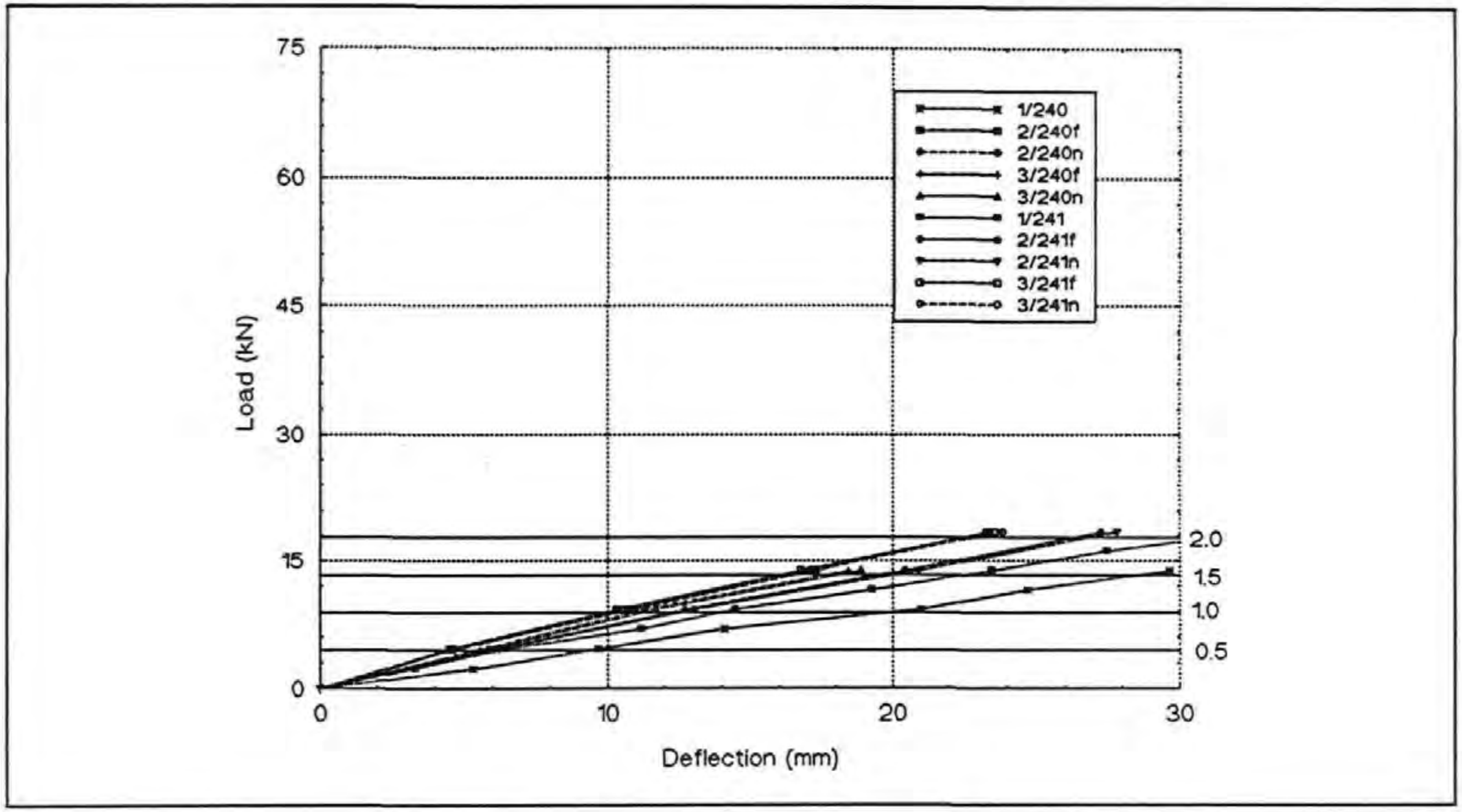
Load versus deflection - beams 220 & 221

Graph 58



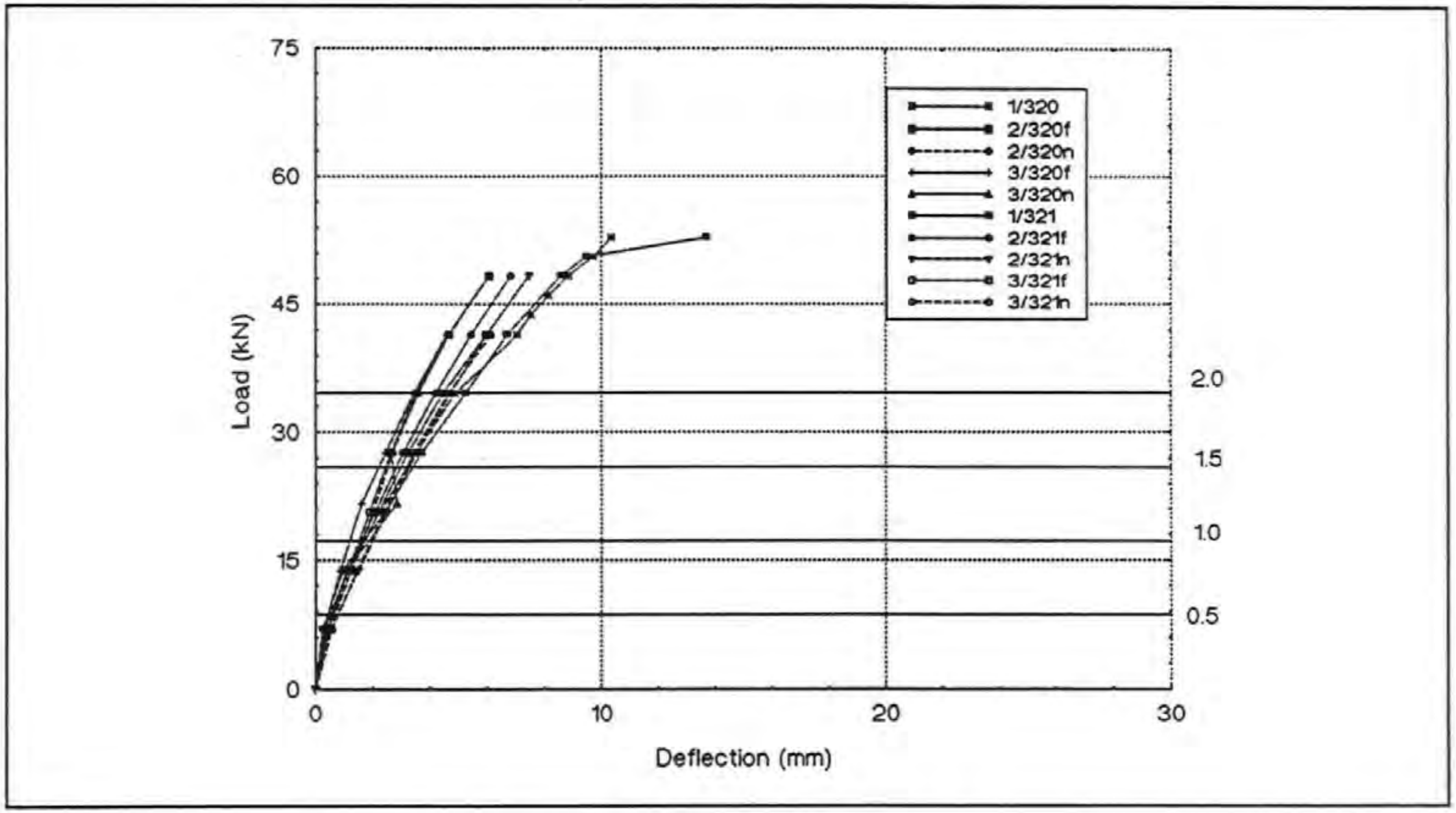
Load versus deflection - beams 230 & 231

Graph 59



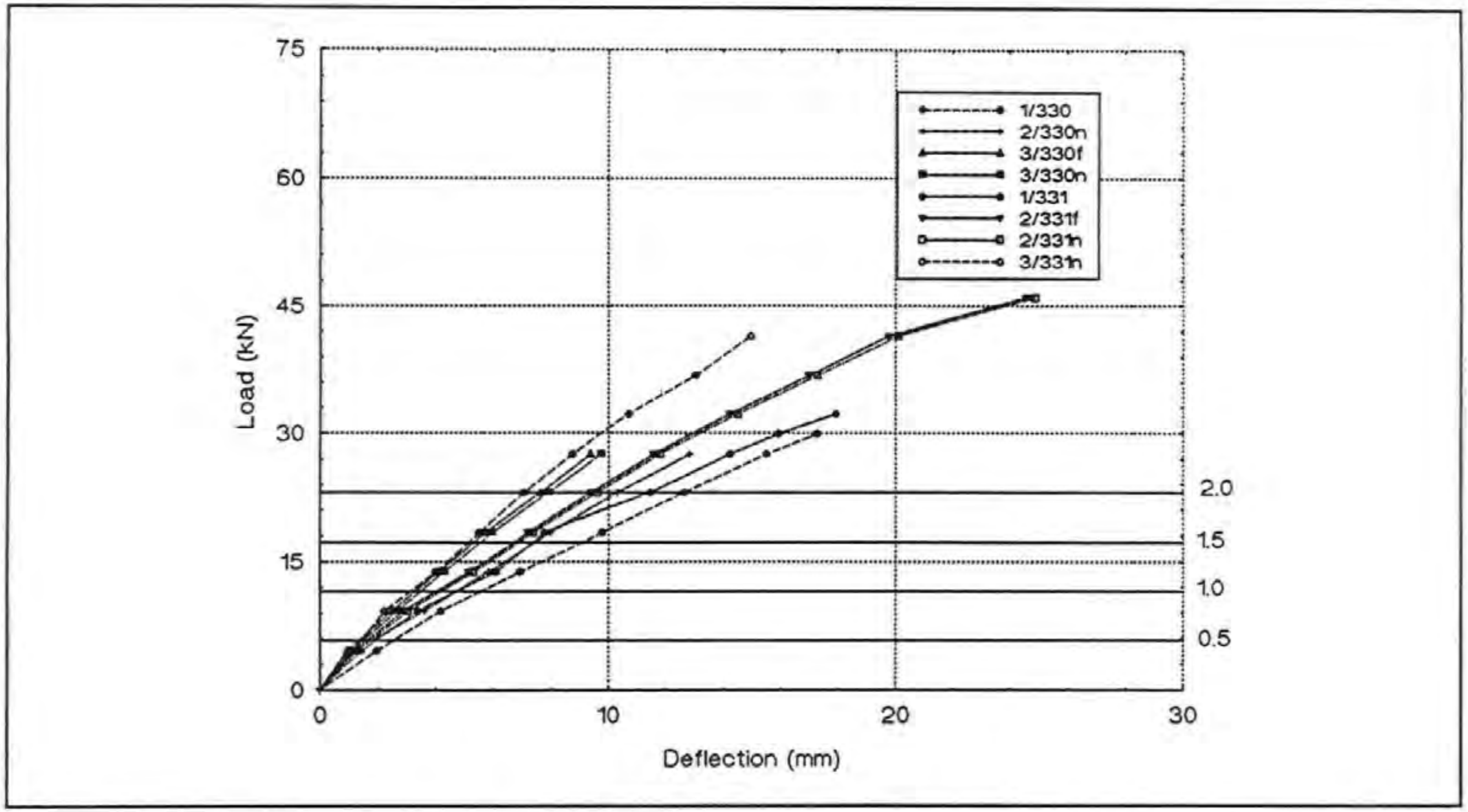
Load versus deflection - beams 240 & 241

Graph 60



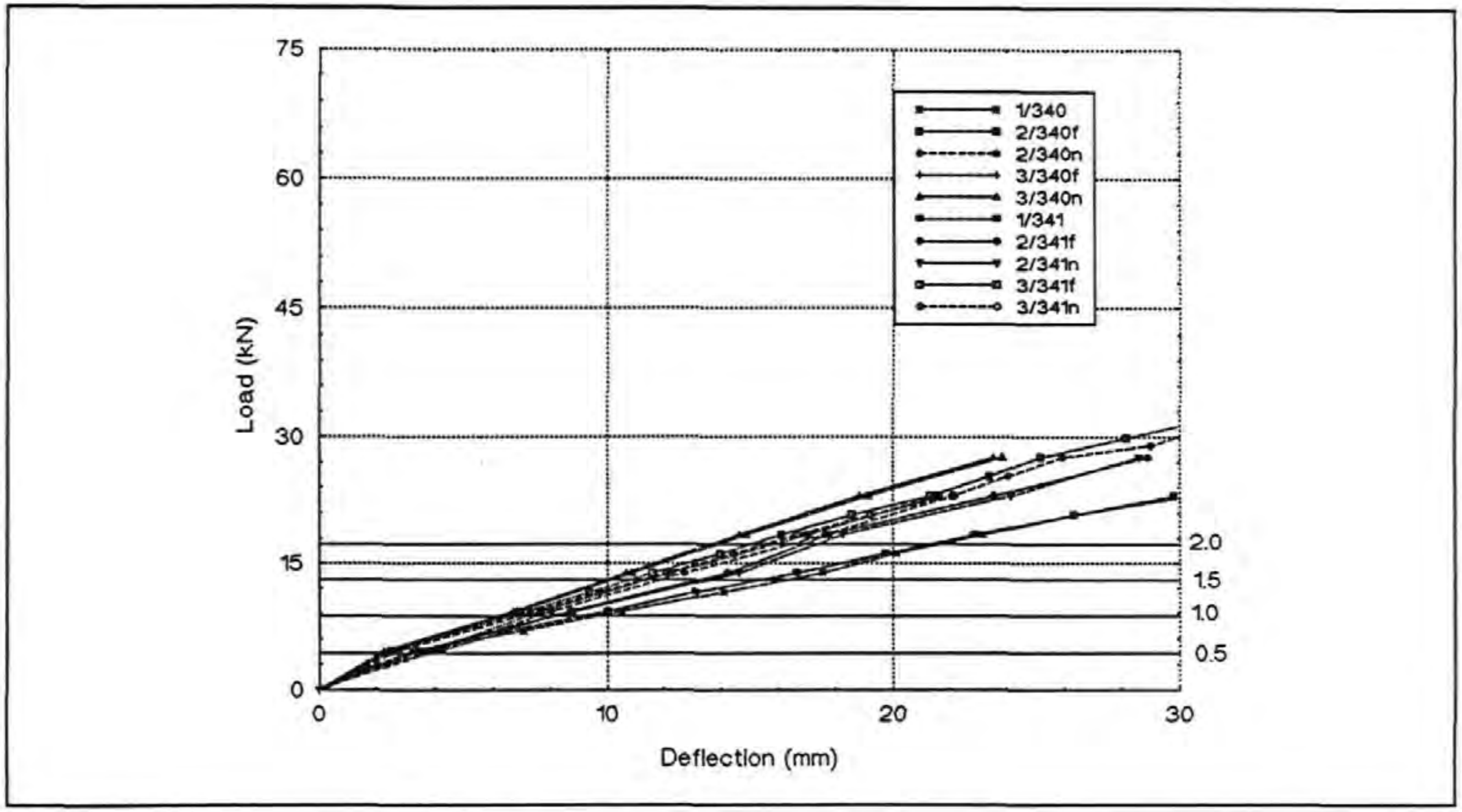
Load versus deflection - beams 320 & 321

Graph 61



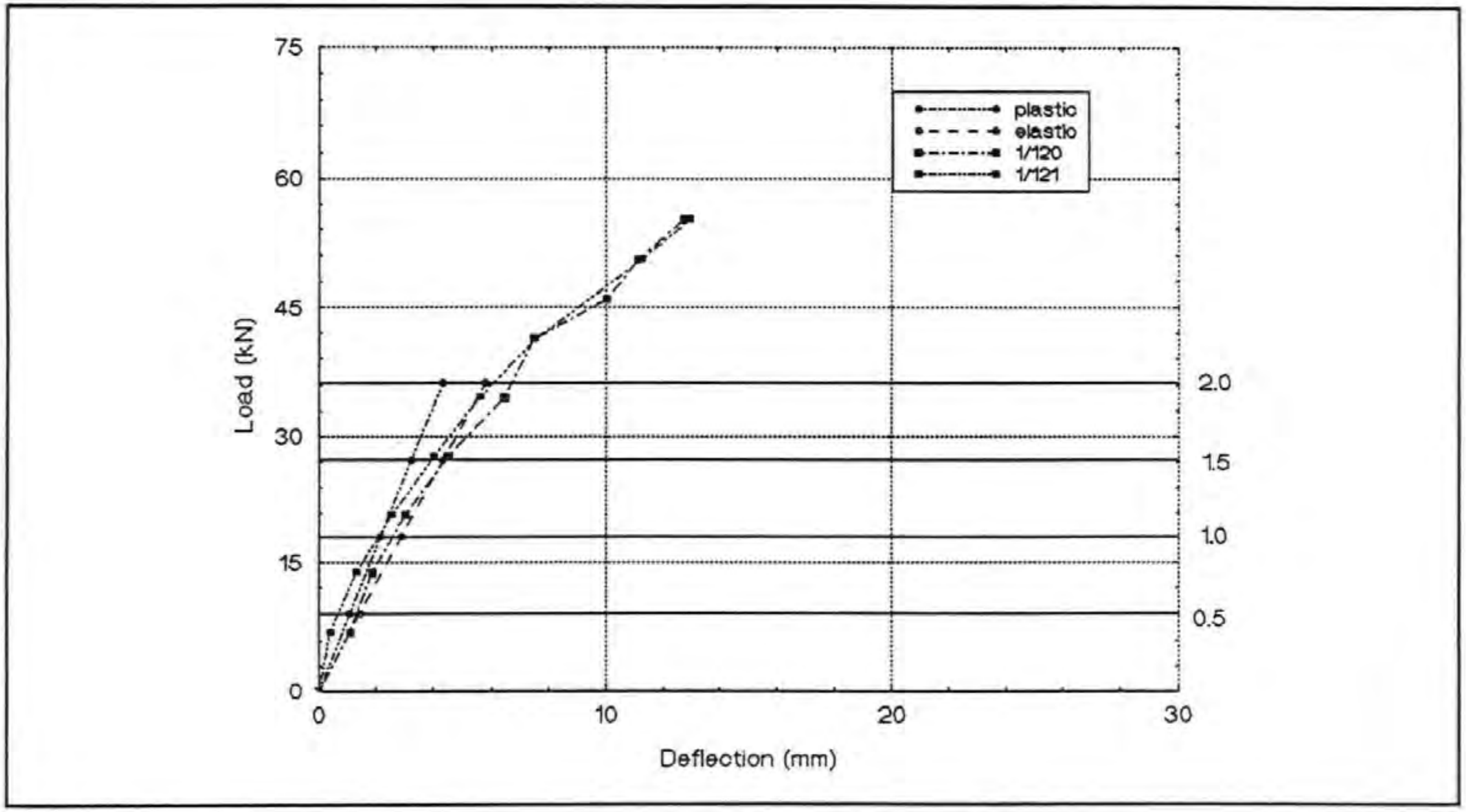
Load versus deflection - beams 330 & 331

Graph 62



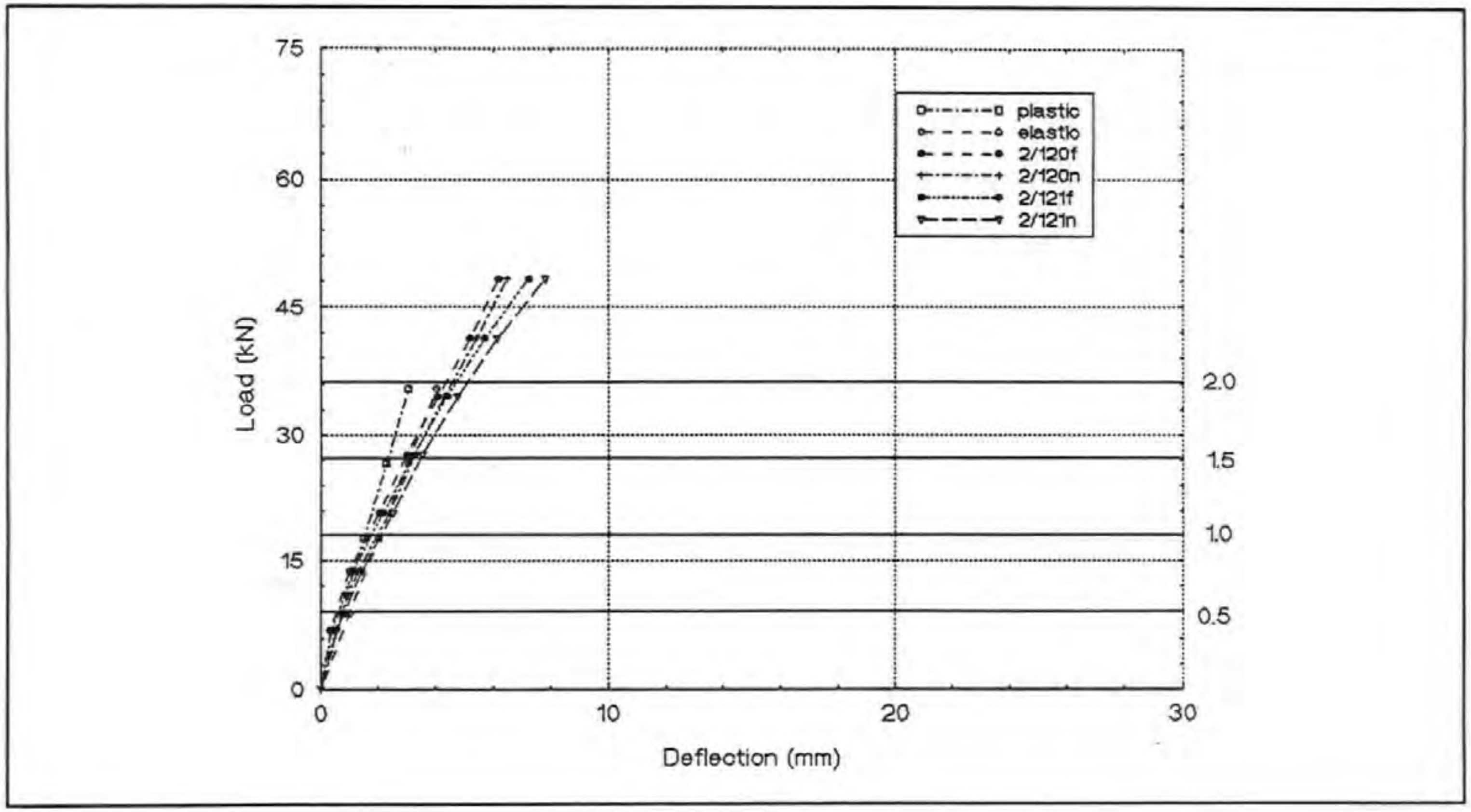
Load versus deflection - beams 340 & 341

Graph 63



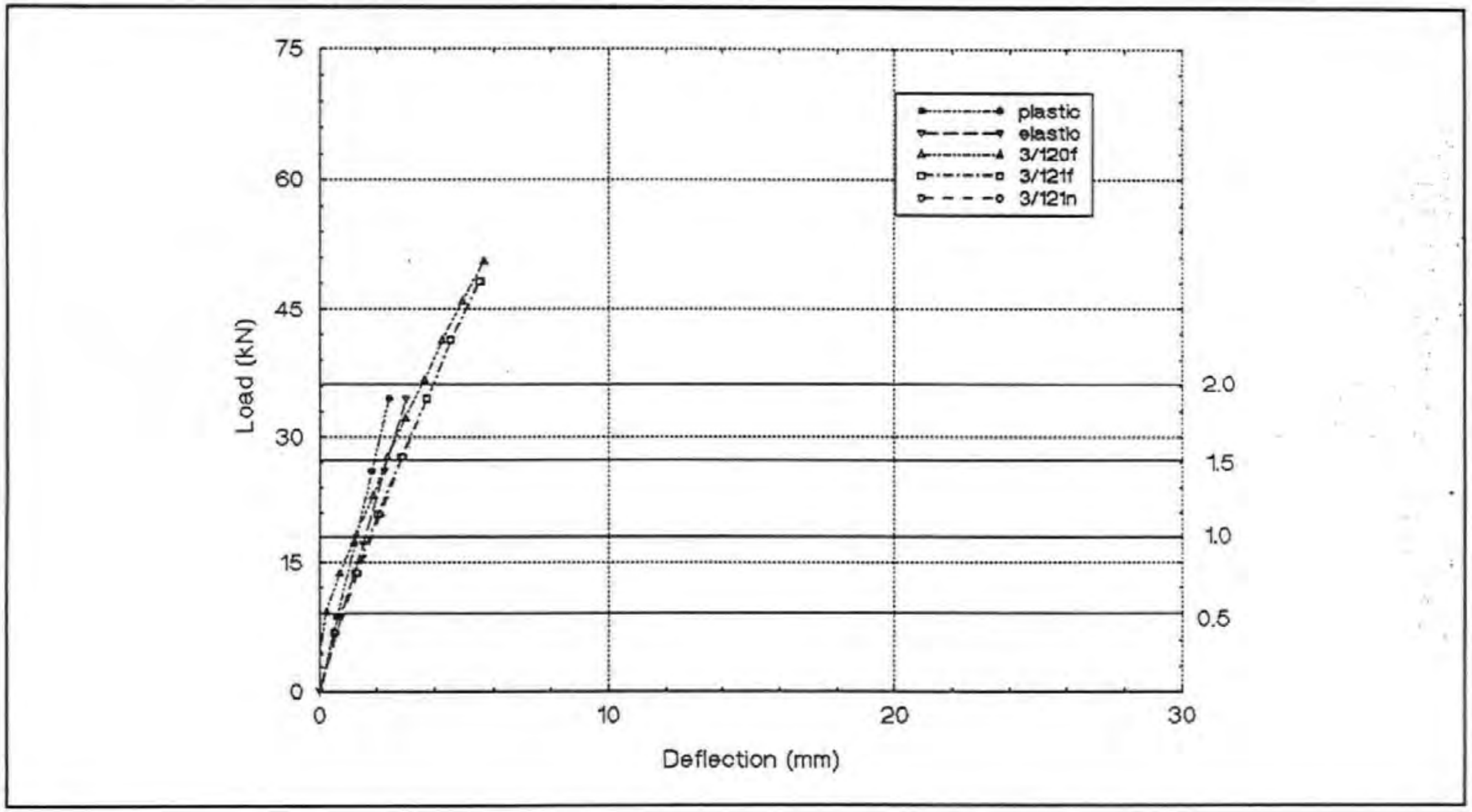
Predicted and experimental deflections - beams 1/120 & 1/121

Graph 64



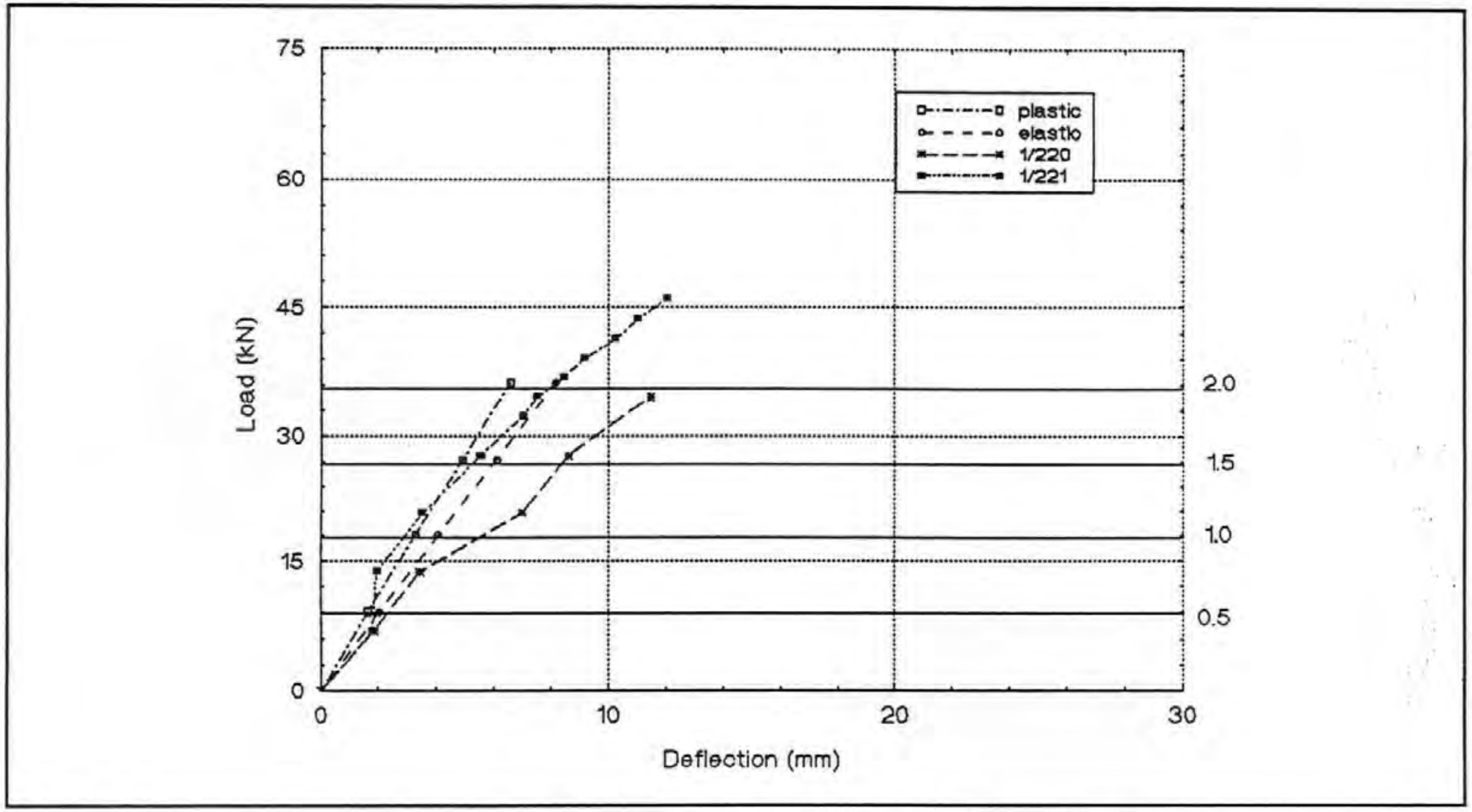
Predicted and experimental deflections - beams 2/120 & 2/121

Graph 65



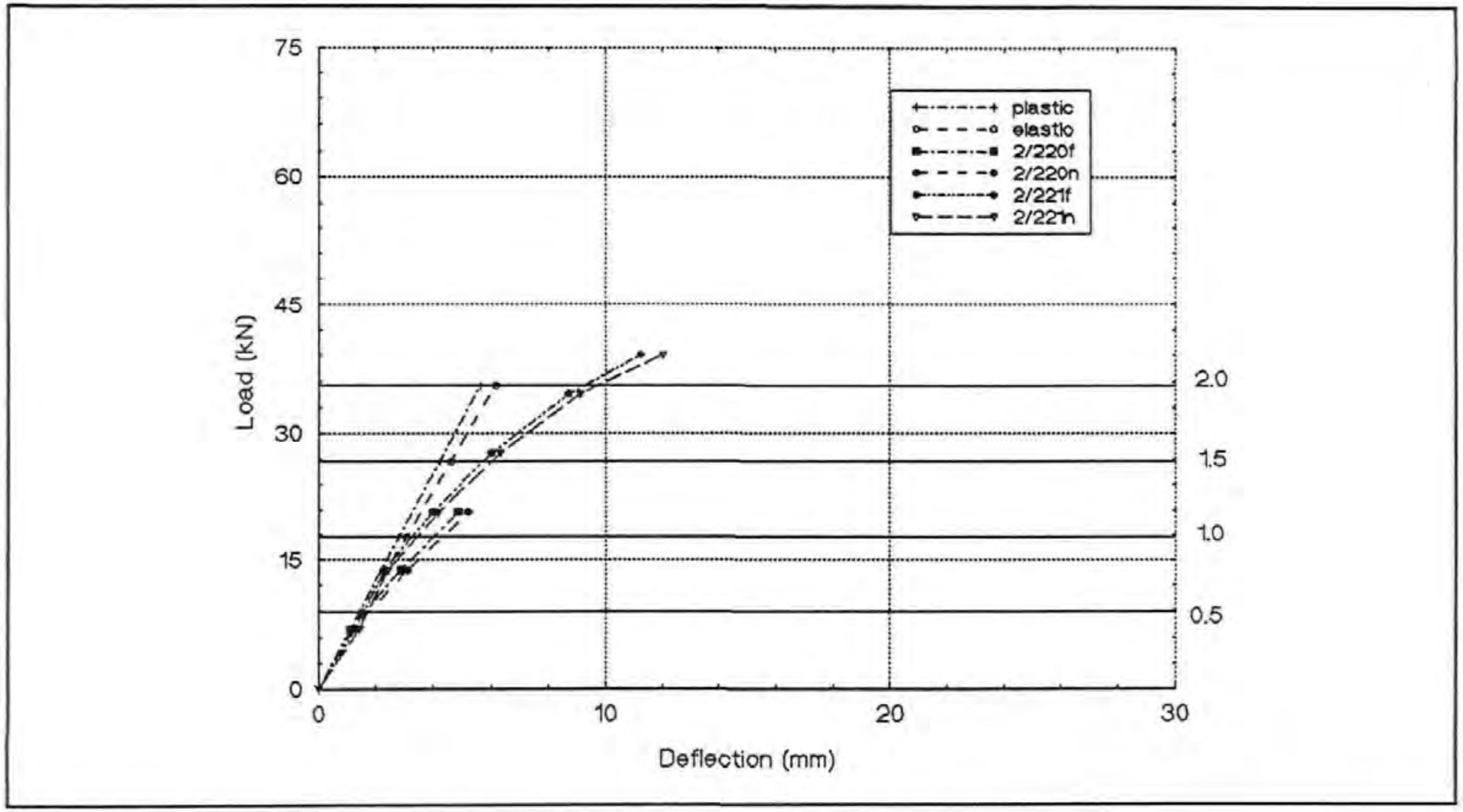
Predicted and experimental deflections - beams 3/120 & 3/121

Graph 66



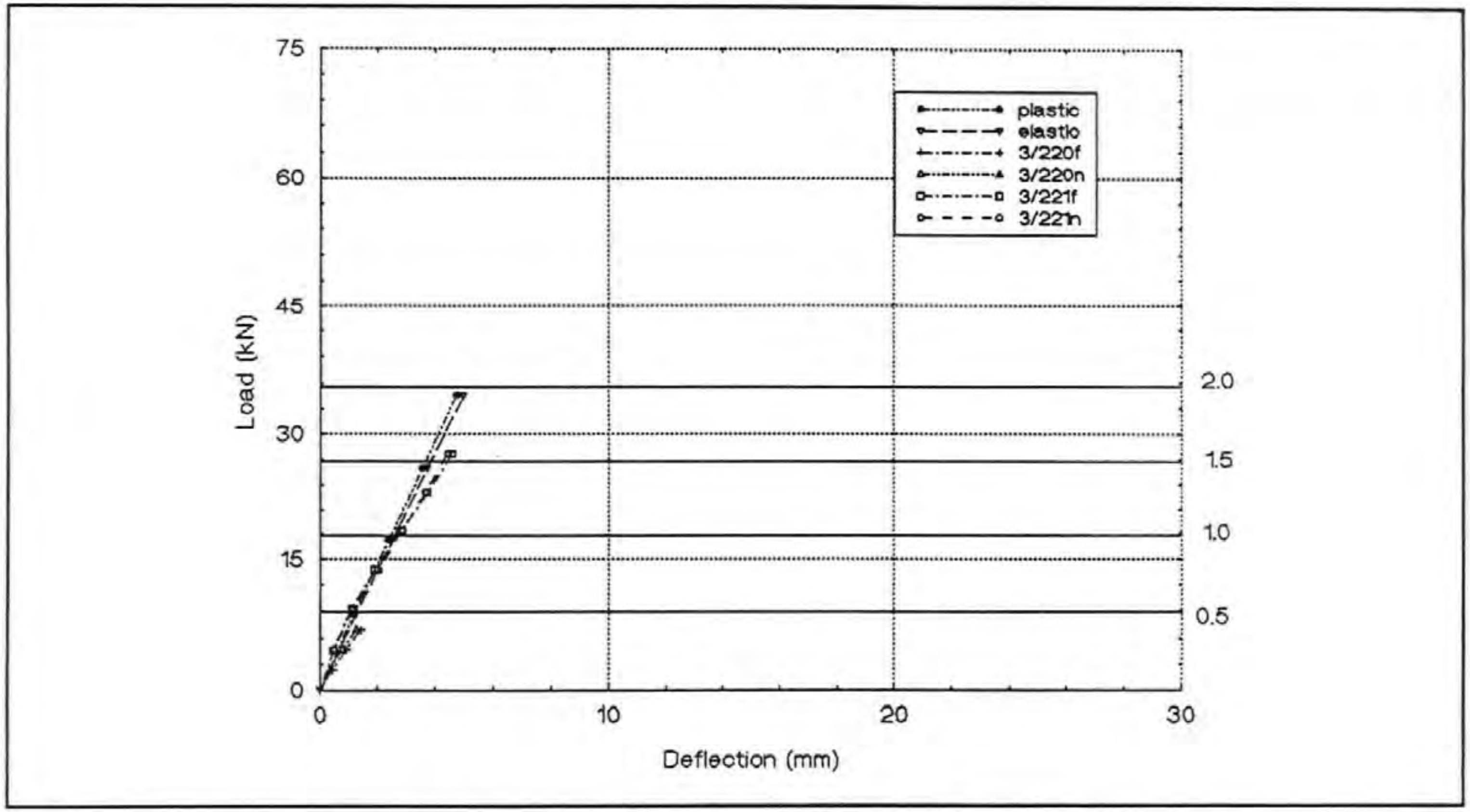
Predicted and experimental deflections - beams 1/220 & 1/221

Graph 67



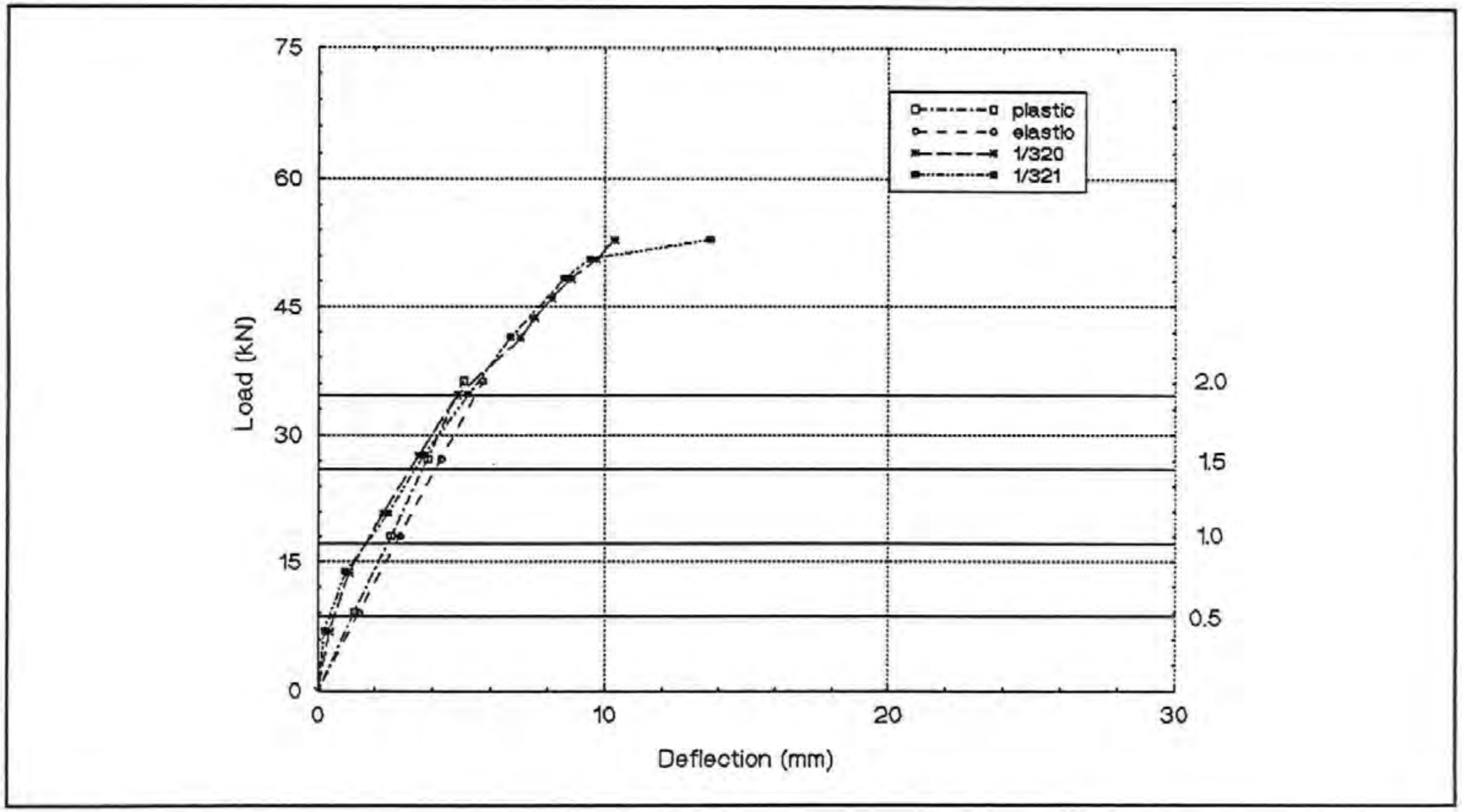
Predicted and experimental deflections - beams 2/220 & 2/221

Graph 68



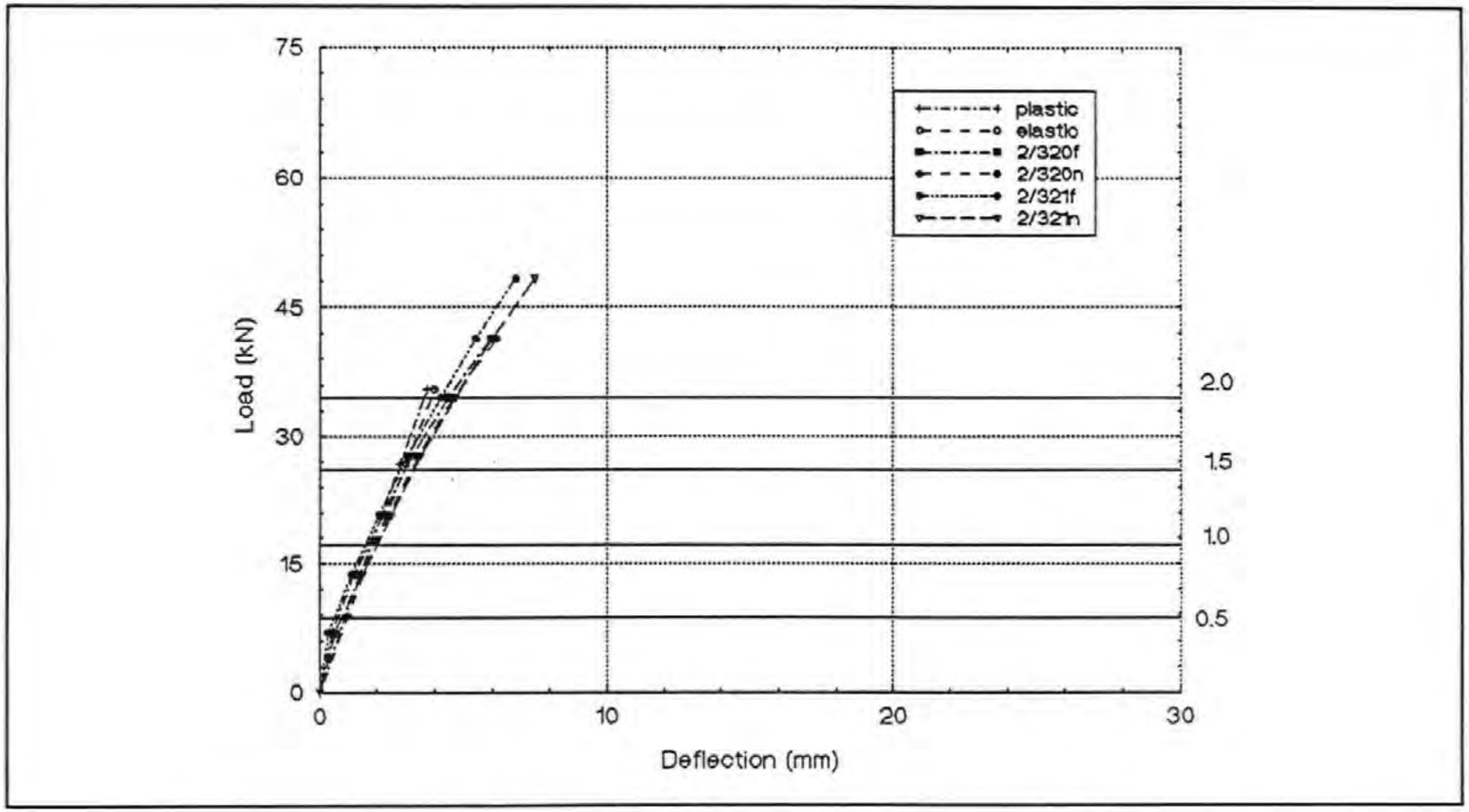
Predicted and experimental deflections - beams 3/220 & 3/221

Graph 69



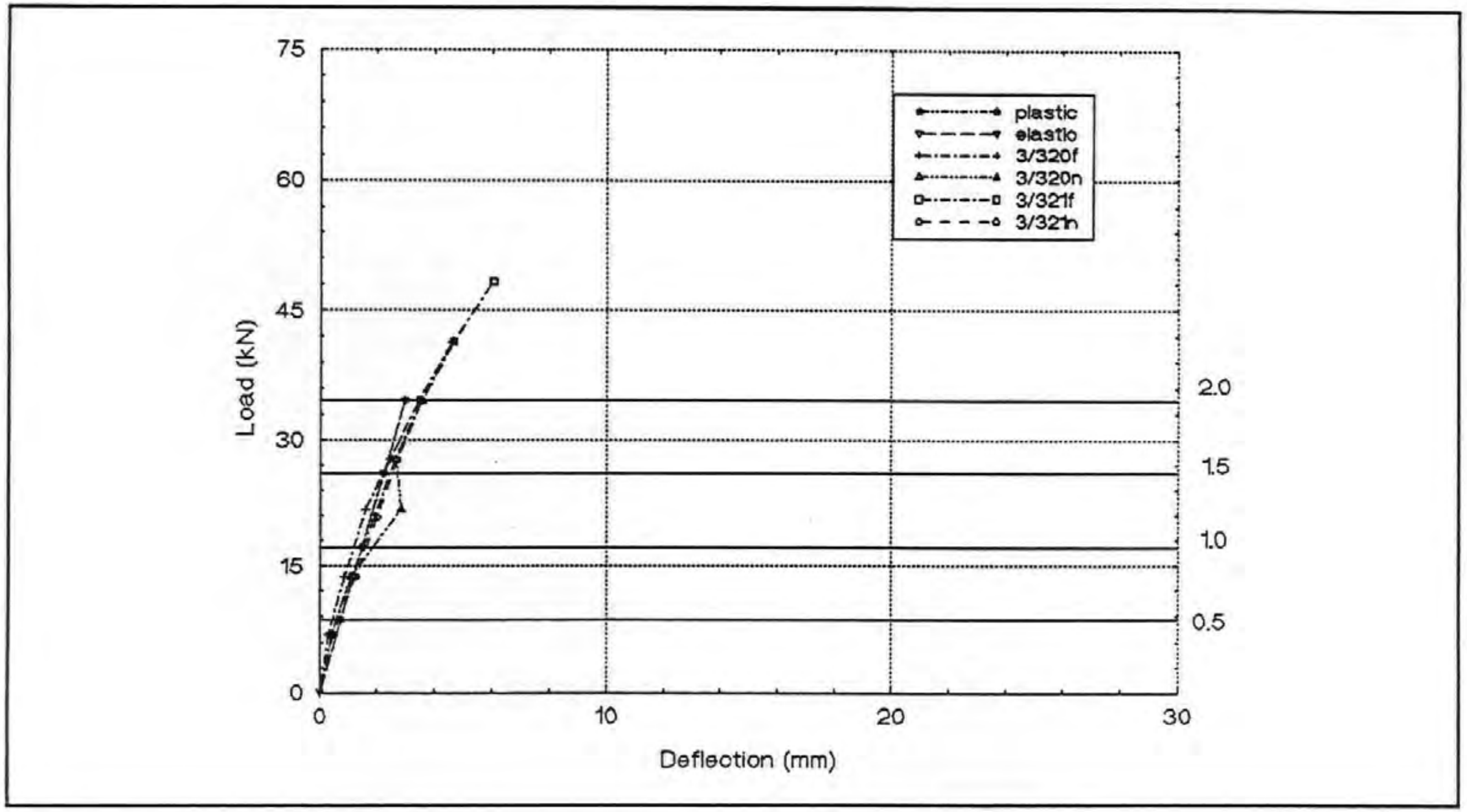
Predicted and experimental deflections - beams 1/320 & 1/321

Graph 70



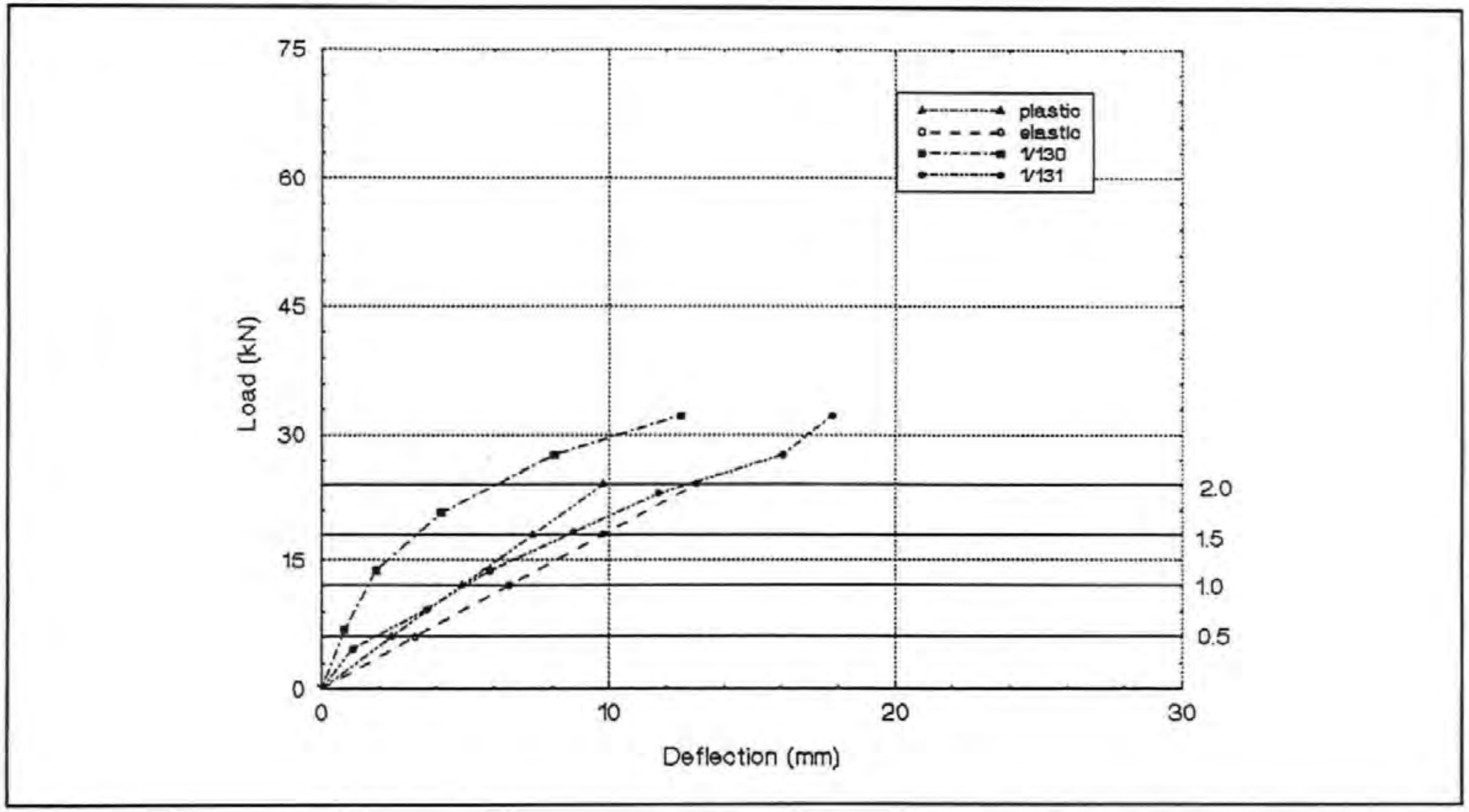
Predicted and experimental deflections - beams 2/320 & 2/321

Graph 71



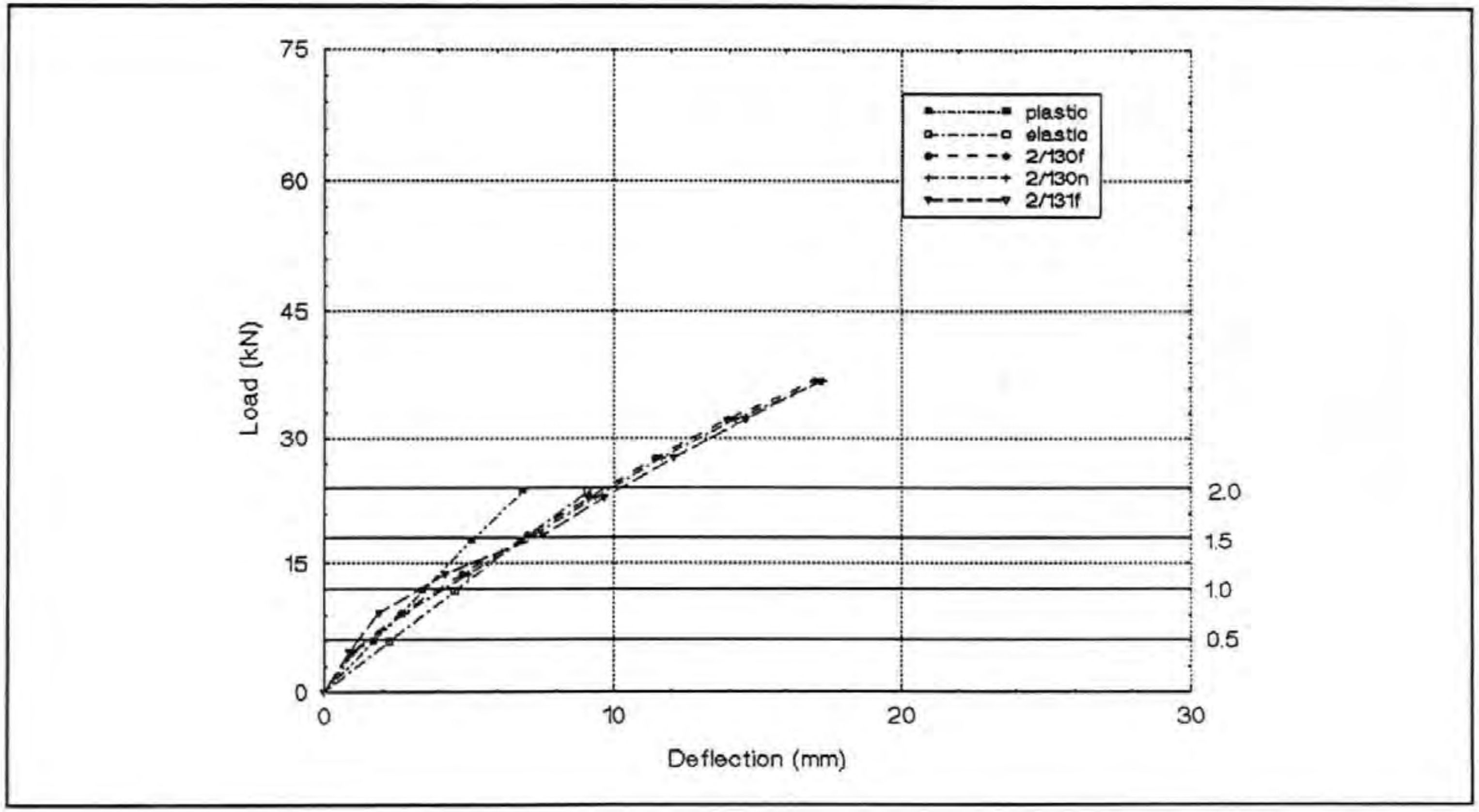
Predicted and experimental deflections - beams 3/320 & 3/321

Graph 72



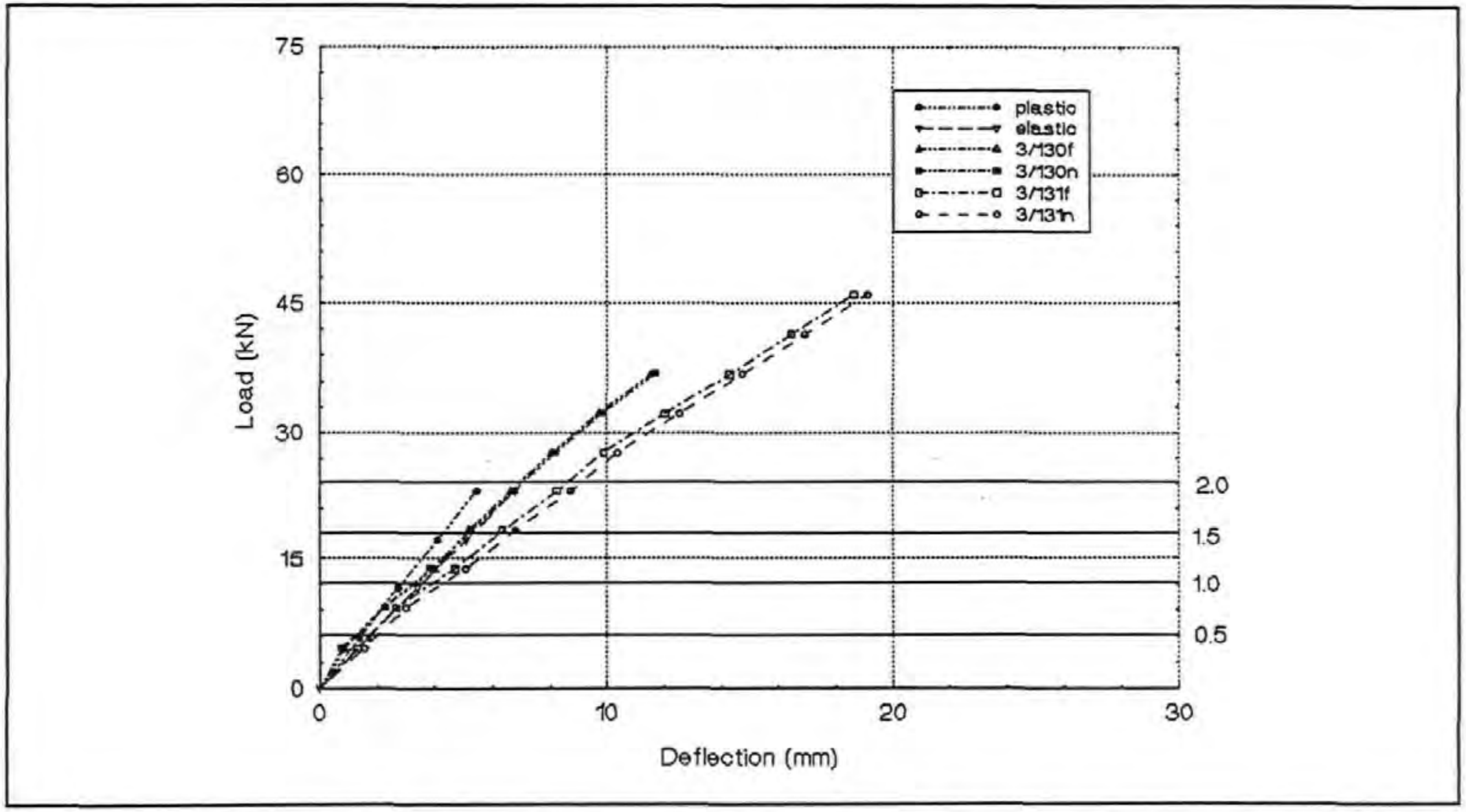
Predicted and experimental deflections - beams 1/130 & 1/131

Graph 73



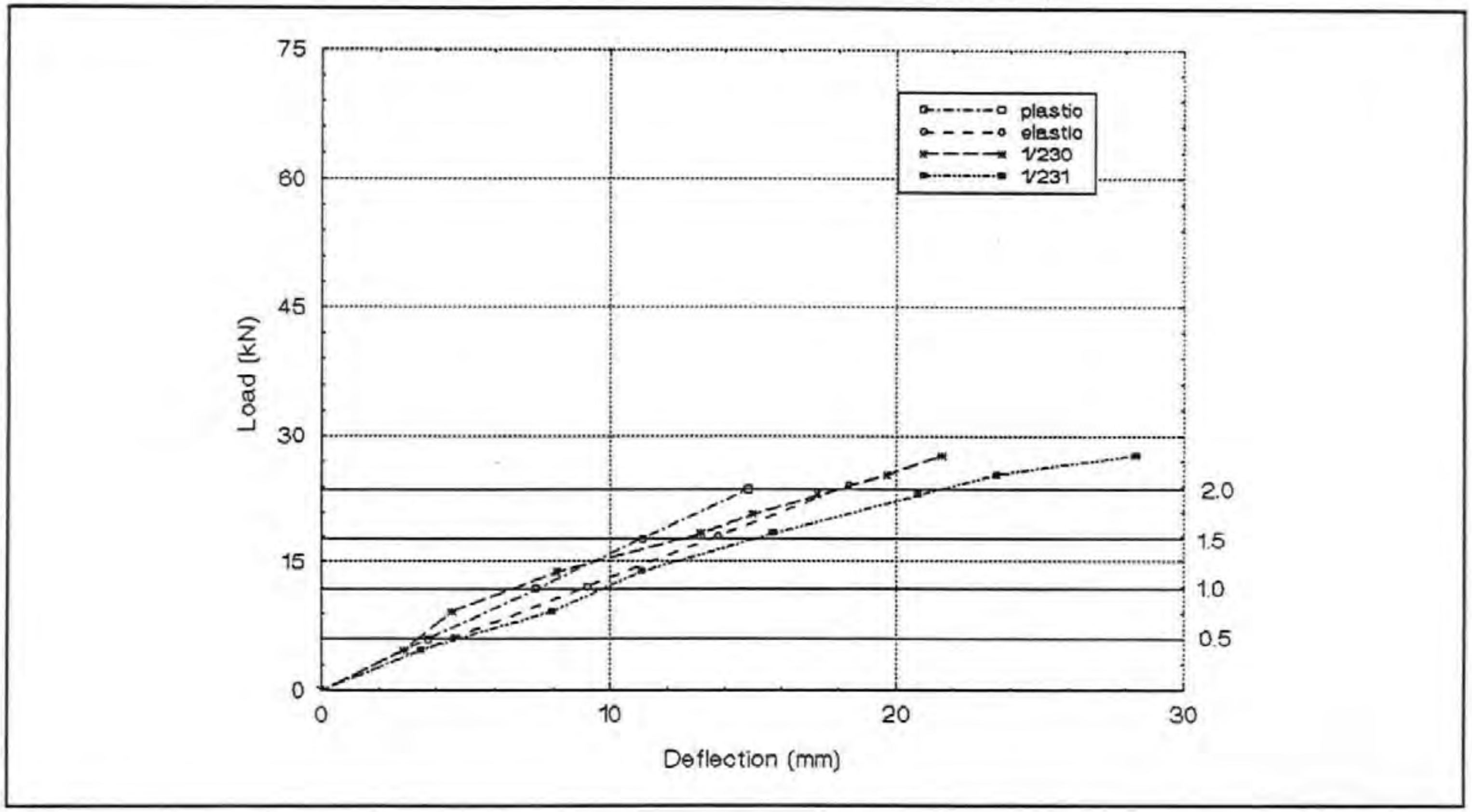
Predicted and experimental deflections - beams 2/130 & 2/131

Graph 74



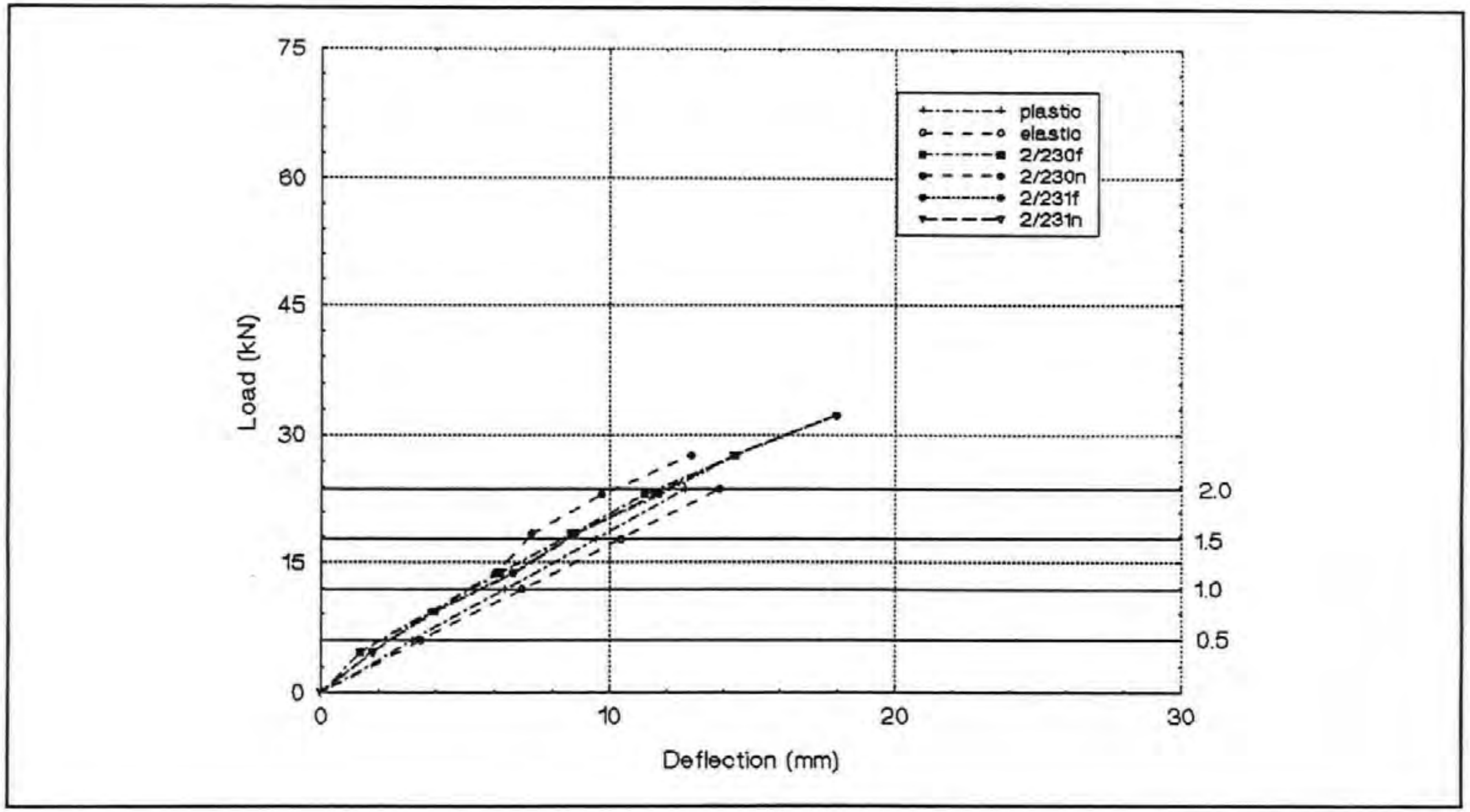
Predicted and experimental deflections - beams 3/130 & 3/131

Graph 75



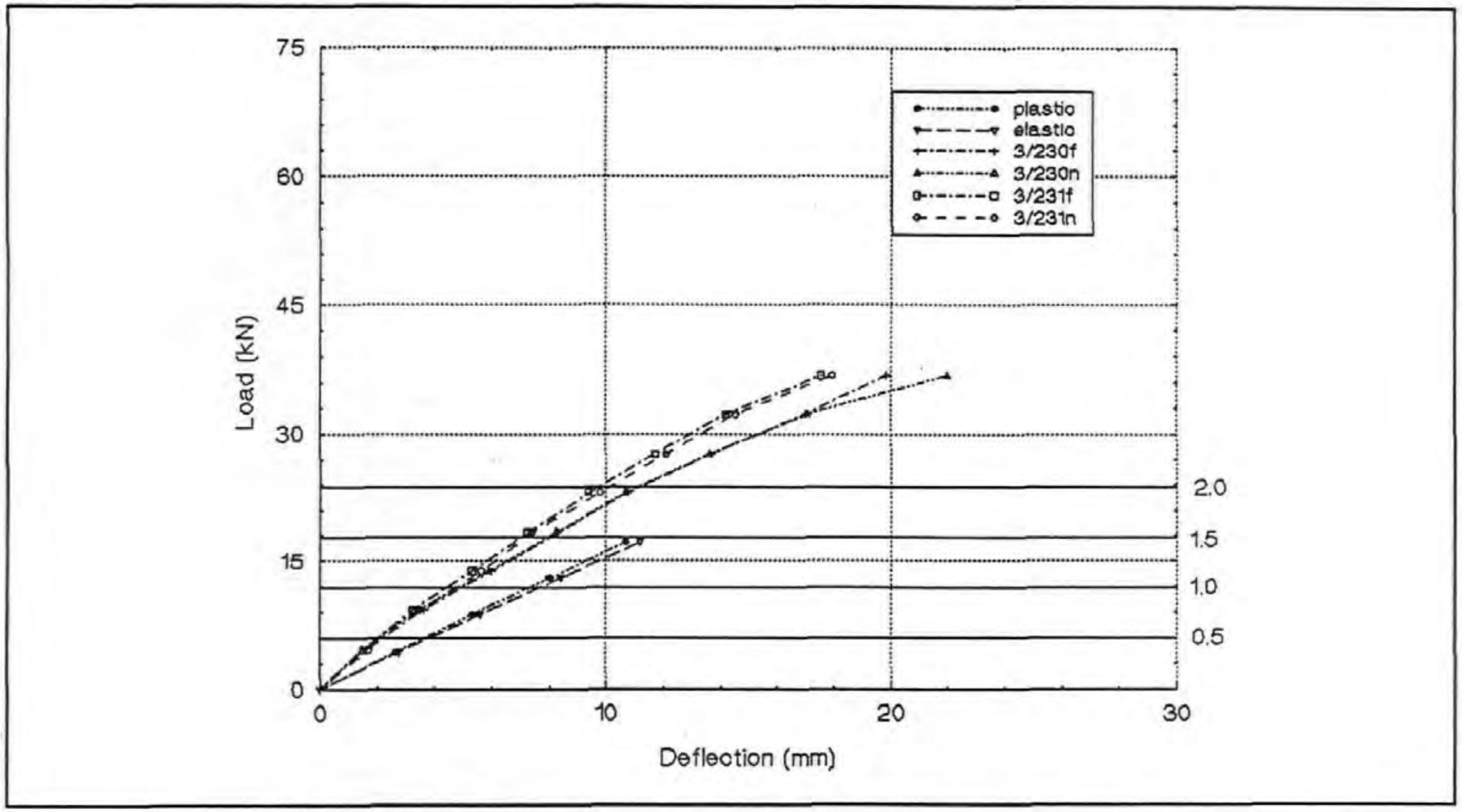
Predicted and experimental deflections - beams 1/230 & 1/231

Graph 76



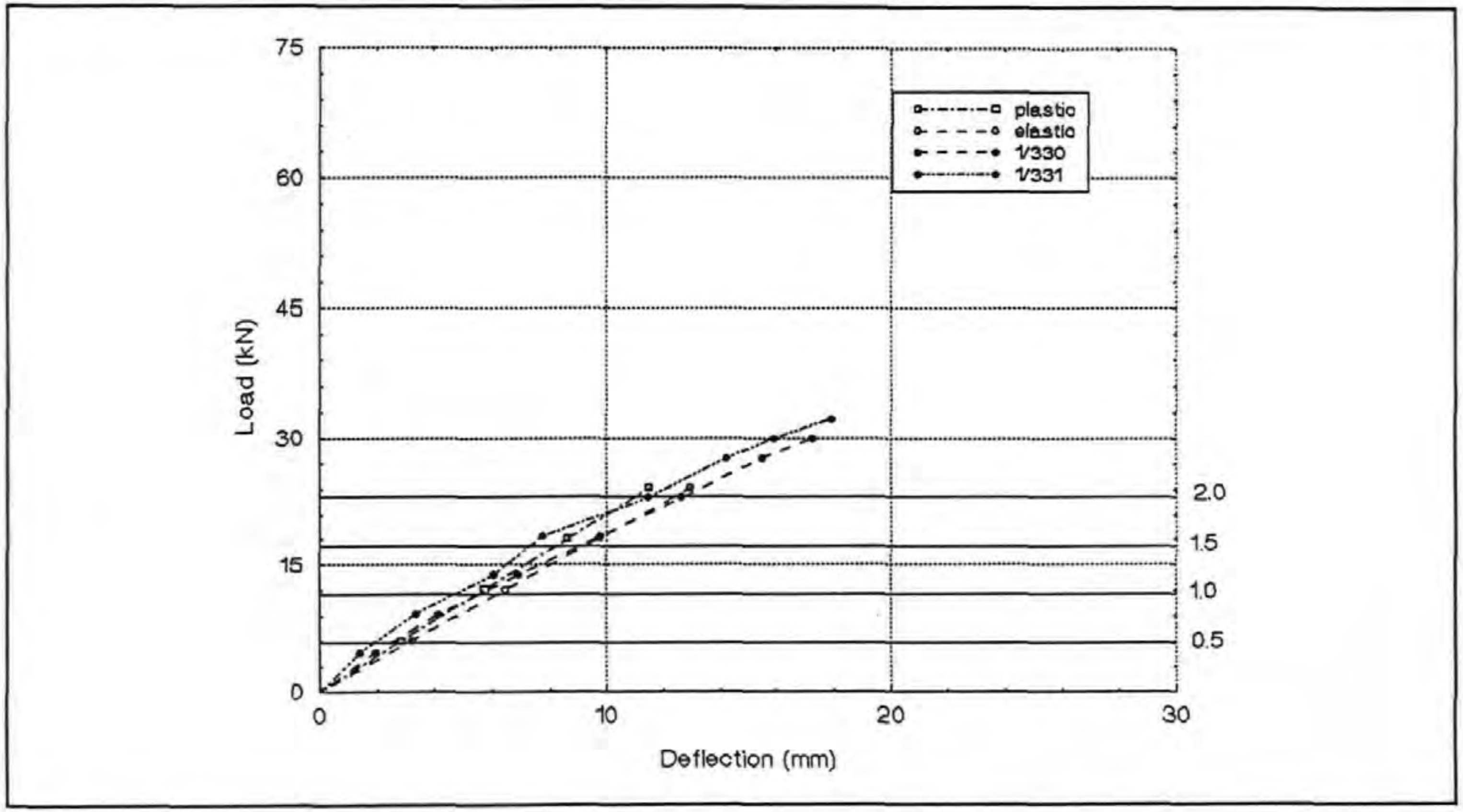
Predicted and experimental deflections - beams 2/230 & 2/231

Graph 77



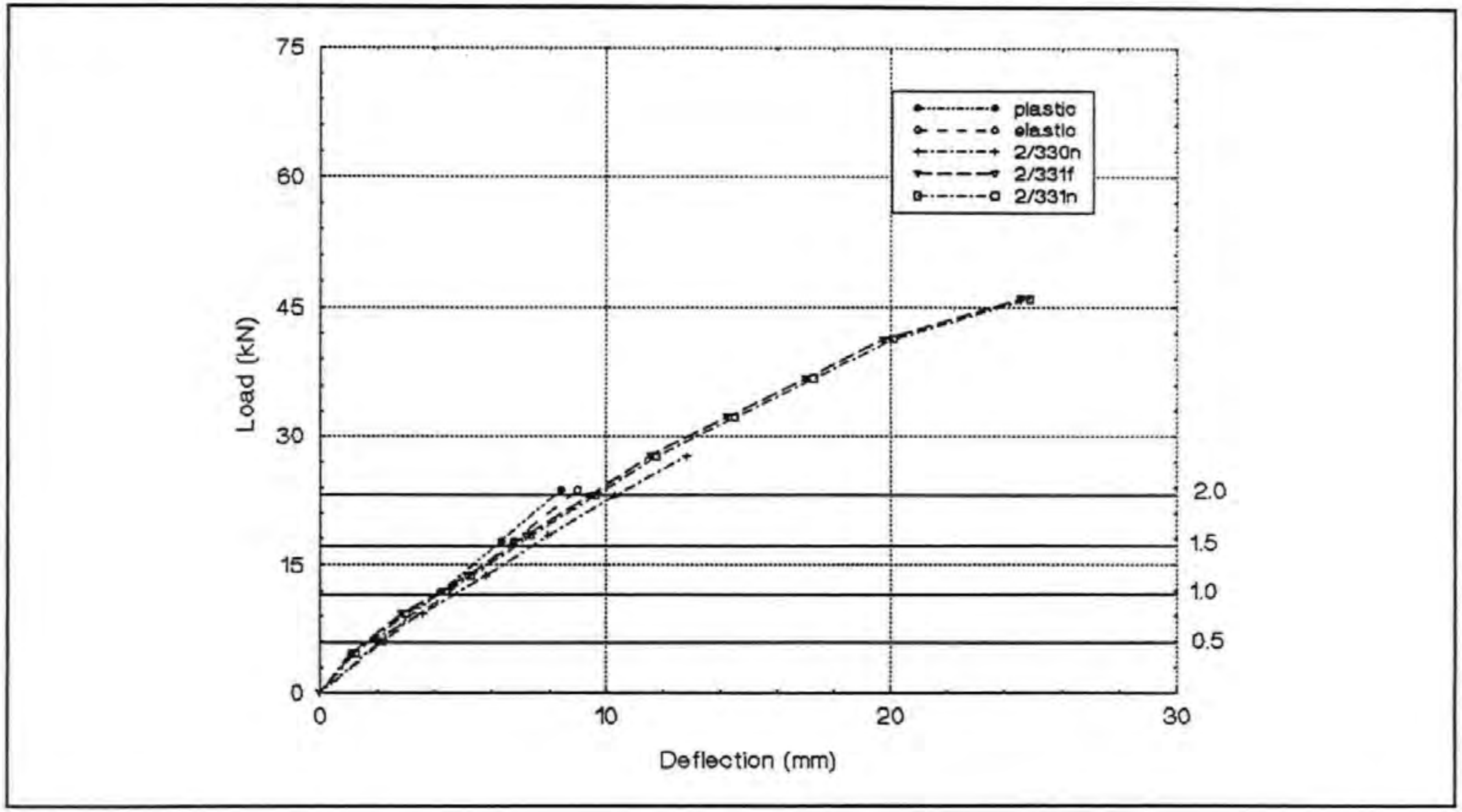
Predicted and experimental deflections - beams 3/230 & 3/231

Graph 78



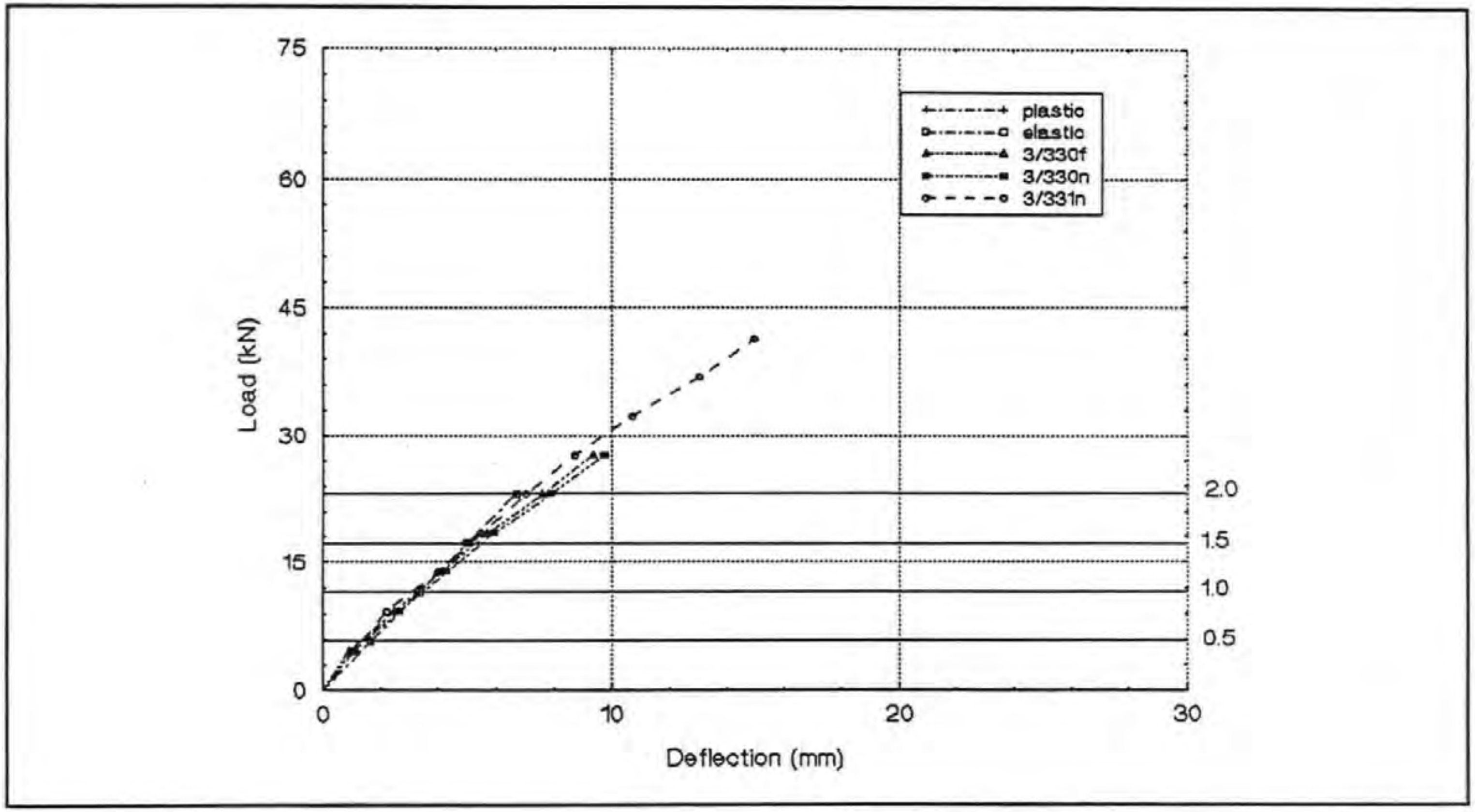
Predicted and experimental deflections - beams 1/330 & 1/331

Graph 79



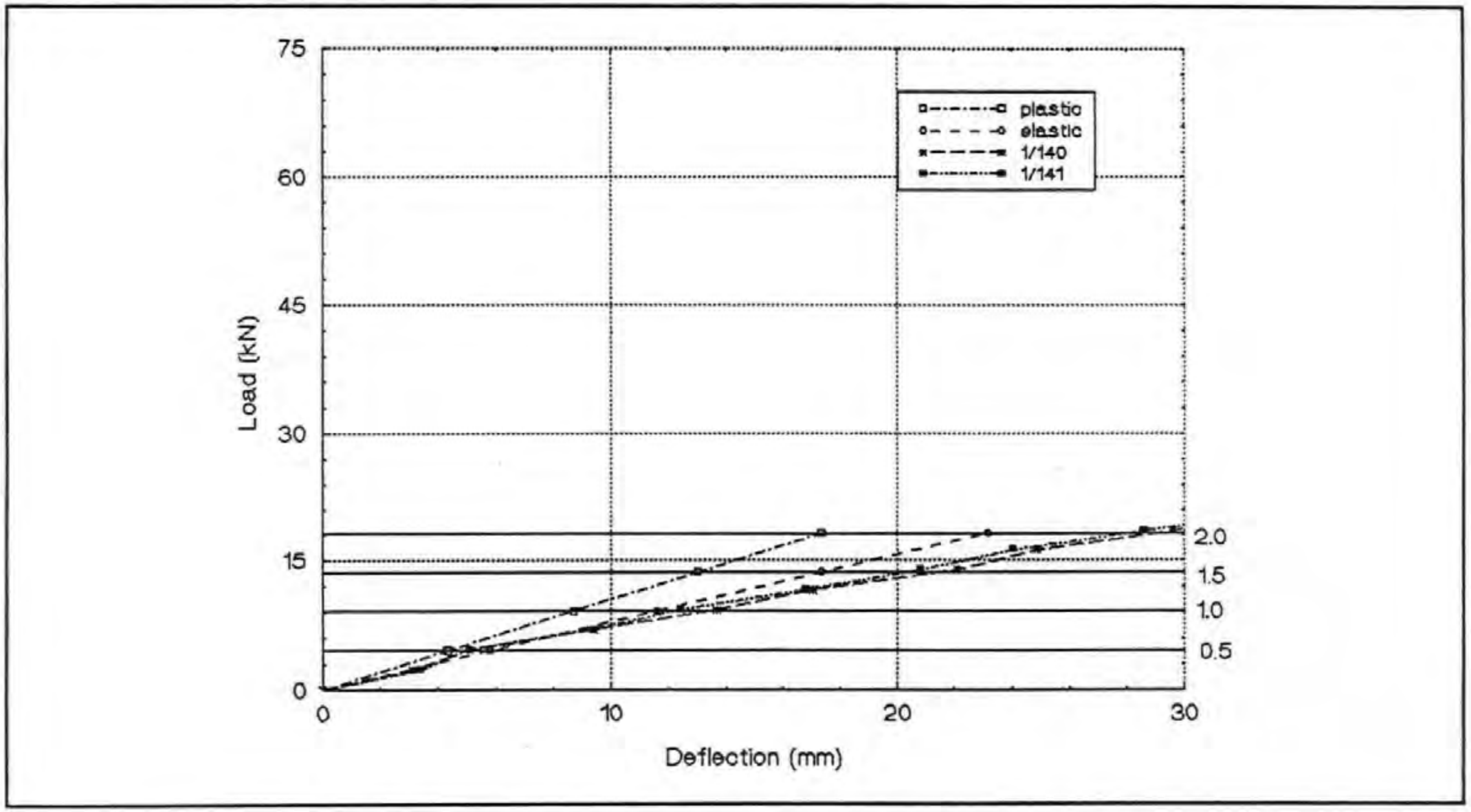
Predicted and experimental deflections - beams 2/330 & 2/331

Graph 80



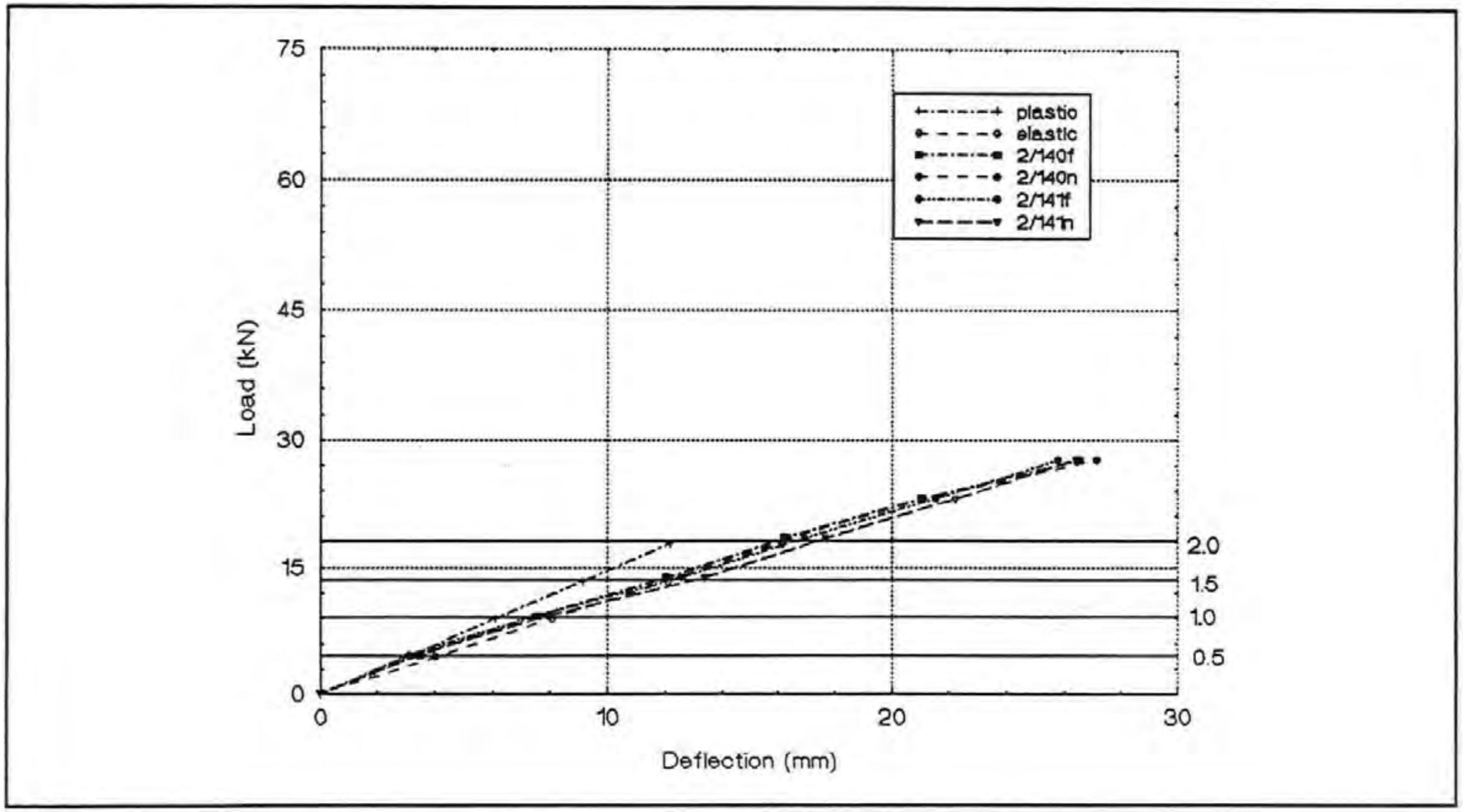
Predicted and experimental deflections - beams 3/330 & 3/331

Graph 81



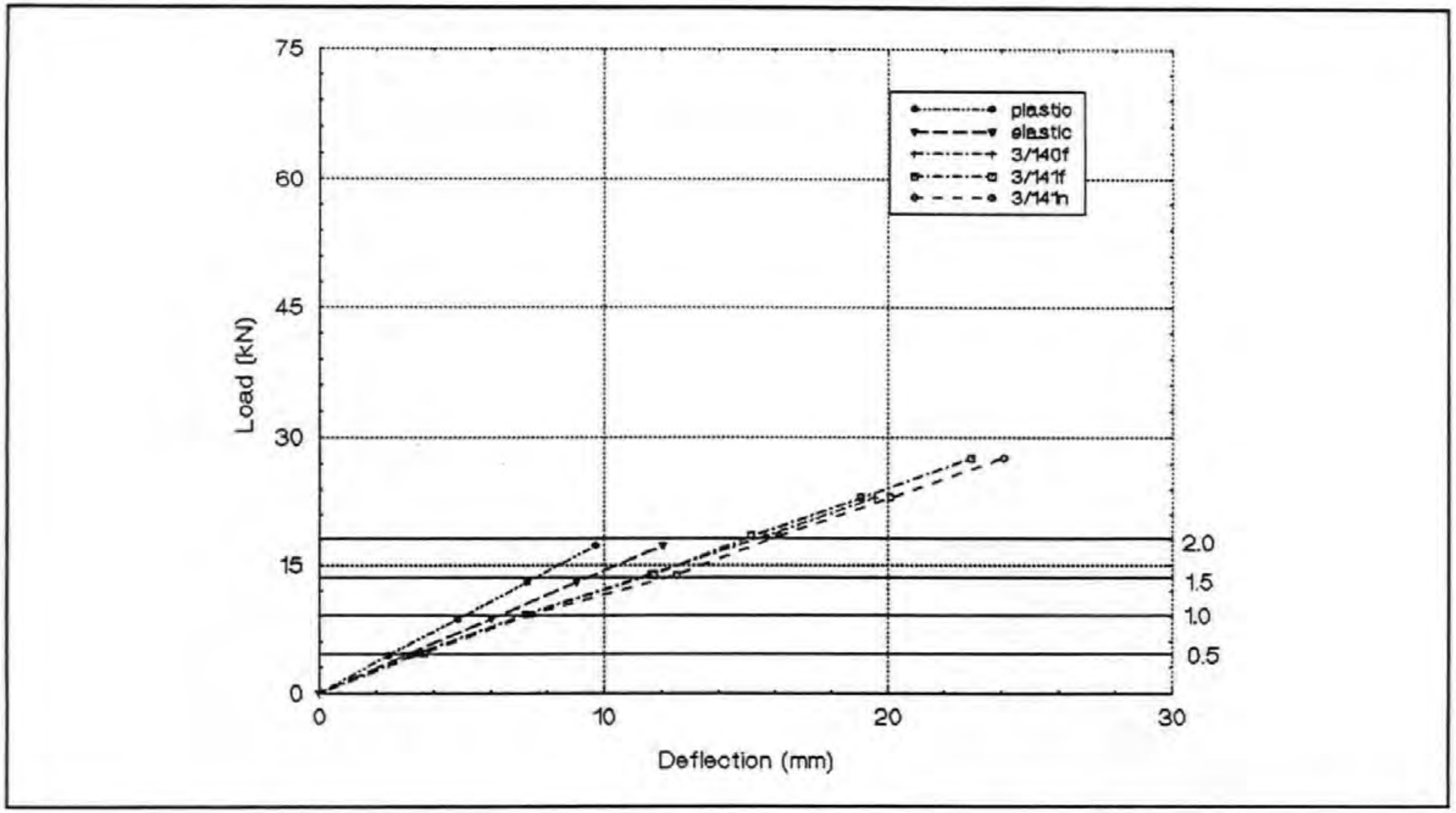
Predicted and experimental deflections - beams 1/140 & 1/141

Graph 82



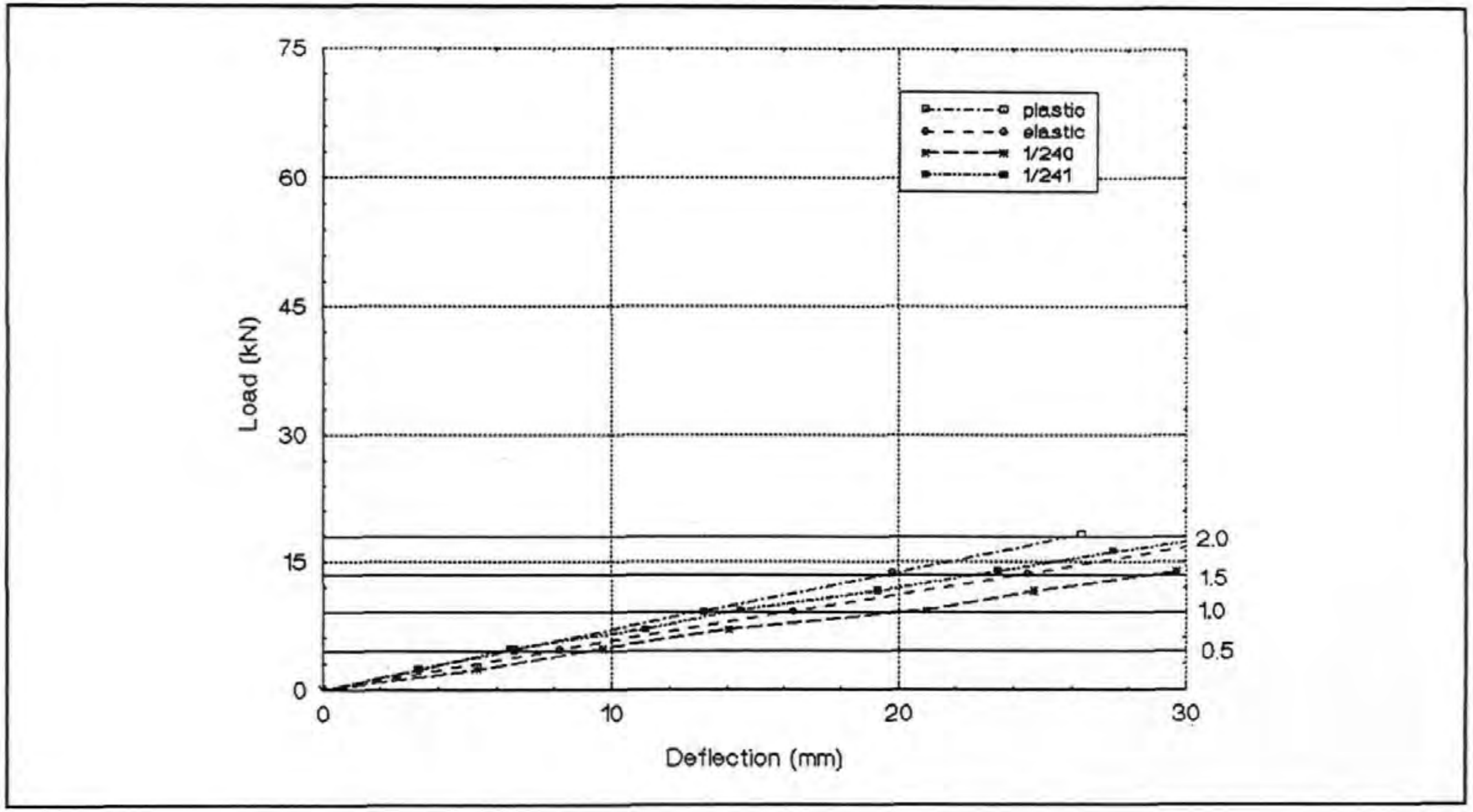
Predicted and experimental deflections - beams 2/140 & 2/141

Graph 83



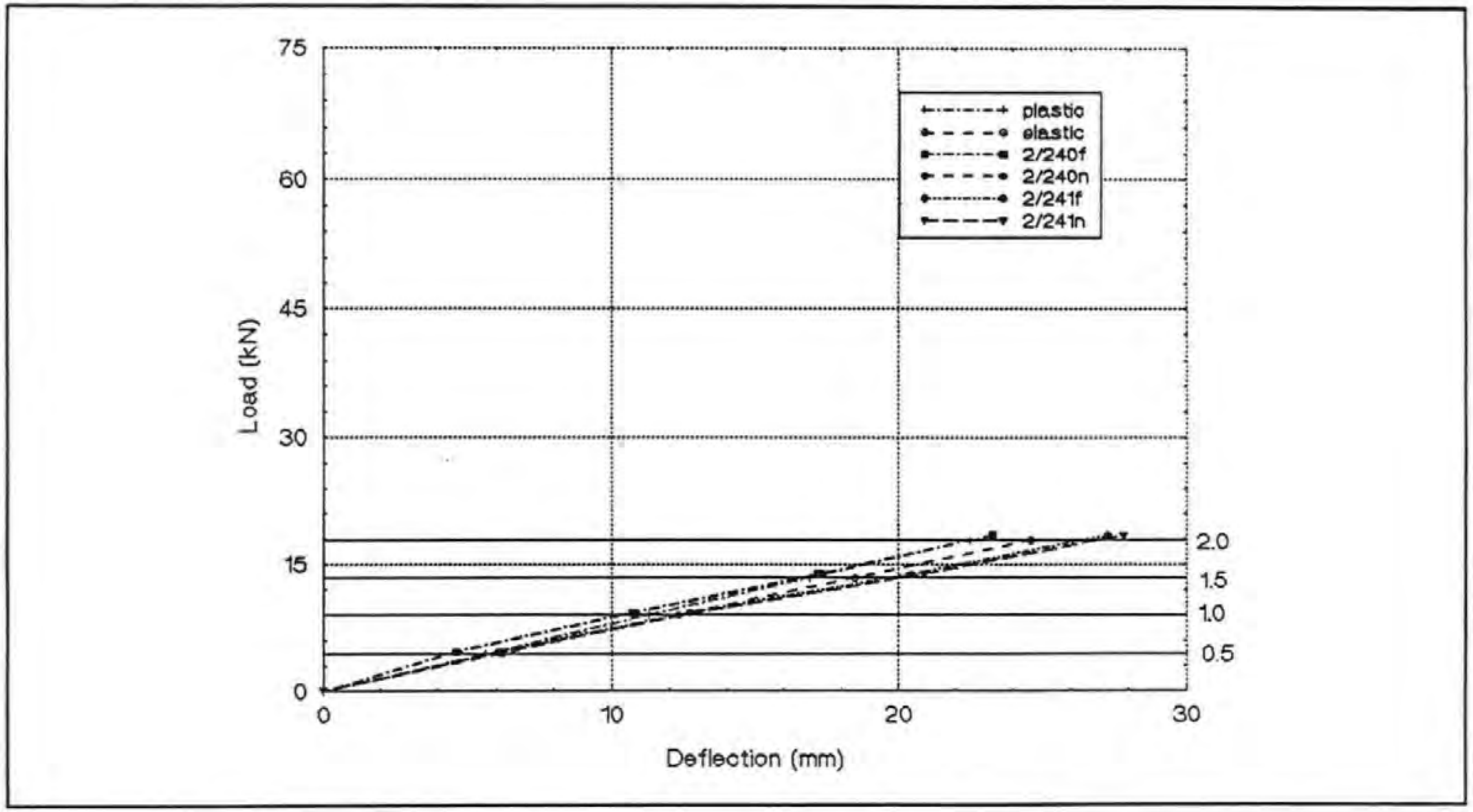
Predicted and experimental deflections - beams 3/140 & 3/141

Graph 84



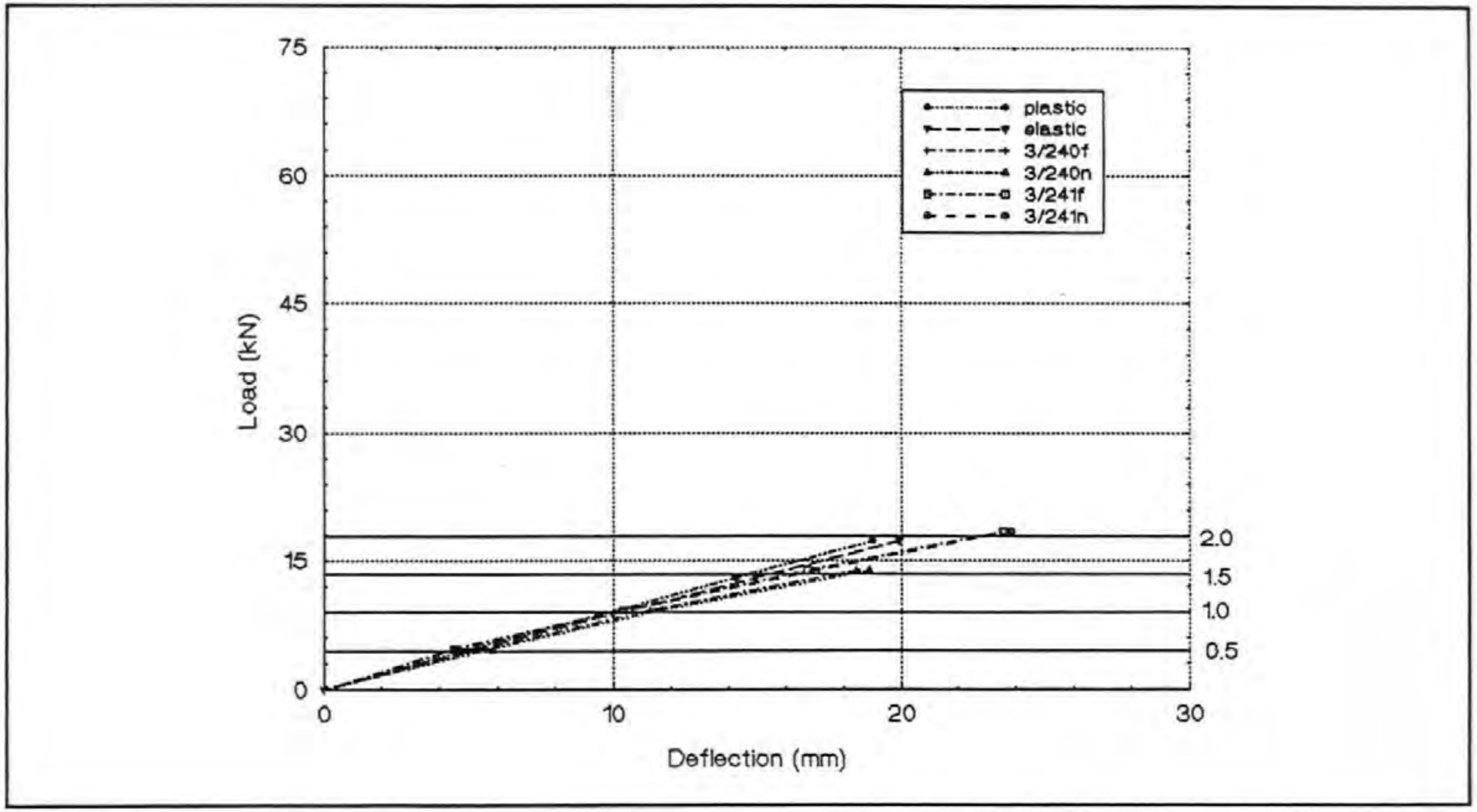
Predicted and experimental deflections - beams 1/240 & 1/241

Graph 85



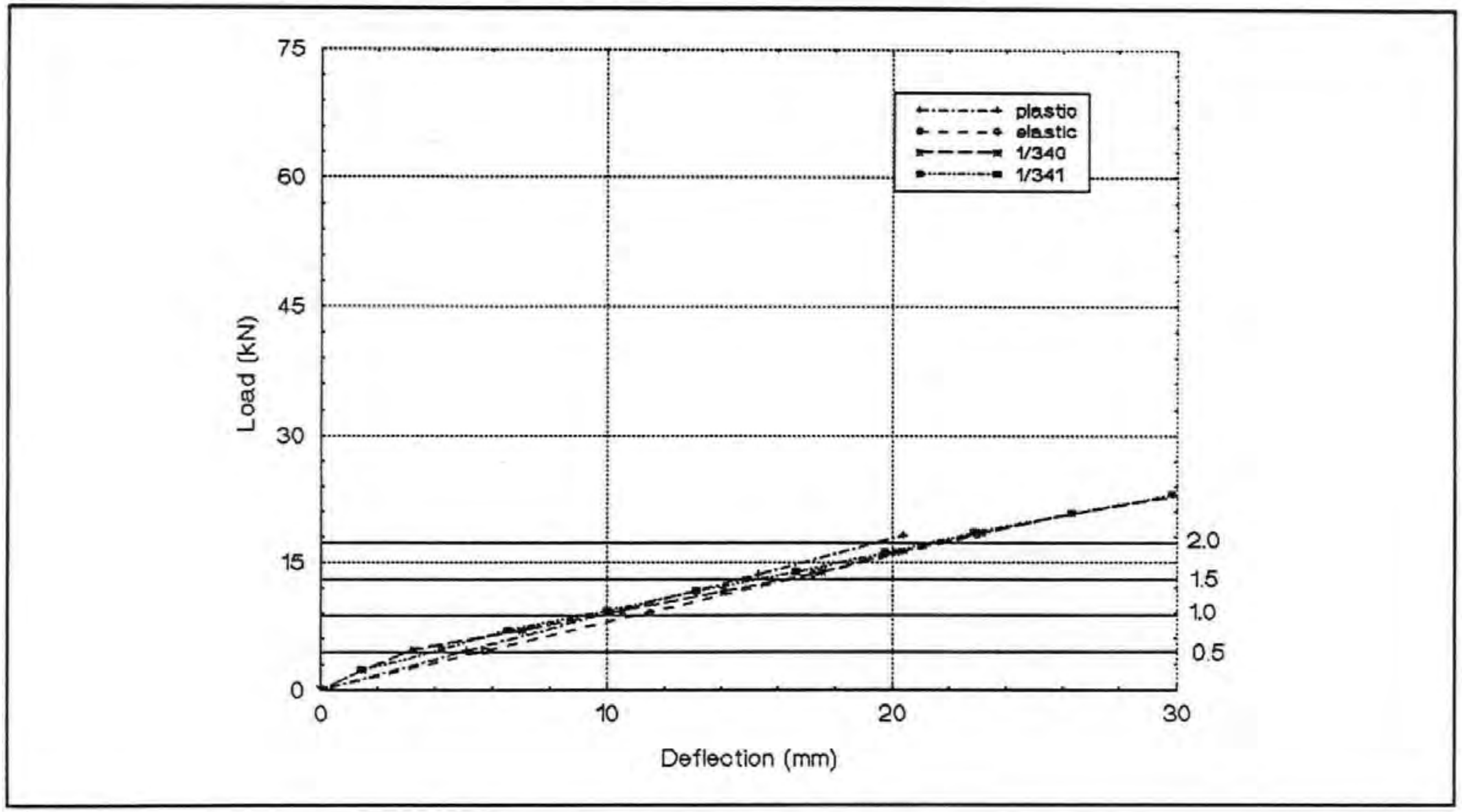
Predicted and experimental deflections - beams 2/240 & 2/241

Graph 86



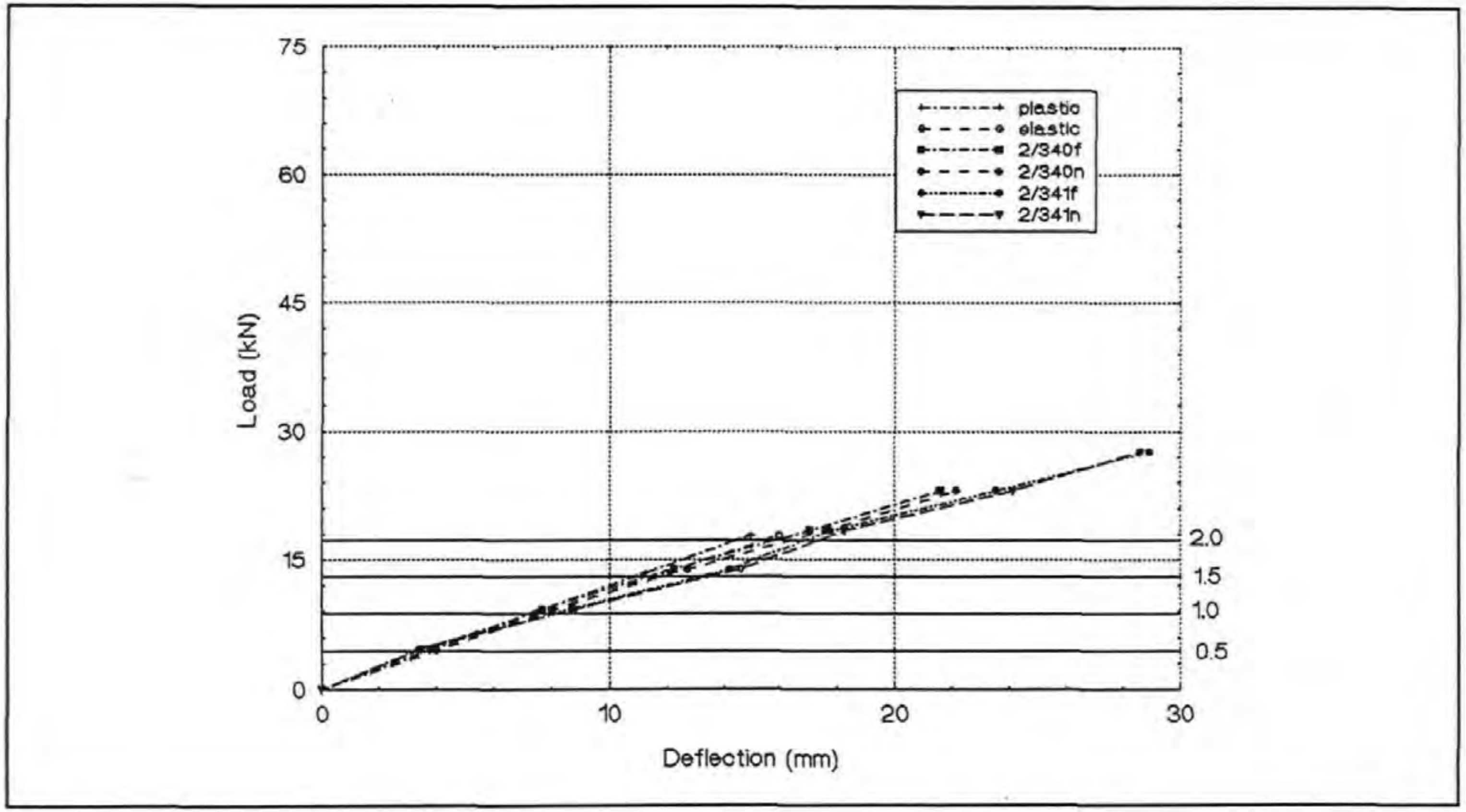
Predicted and experimental deflections - beams 3/240 & 3/241

Graph 87



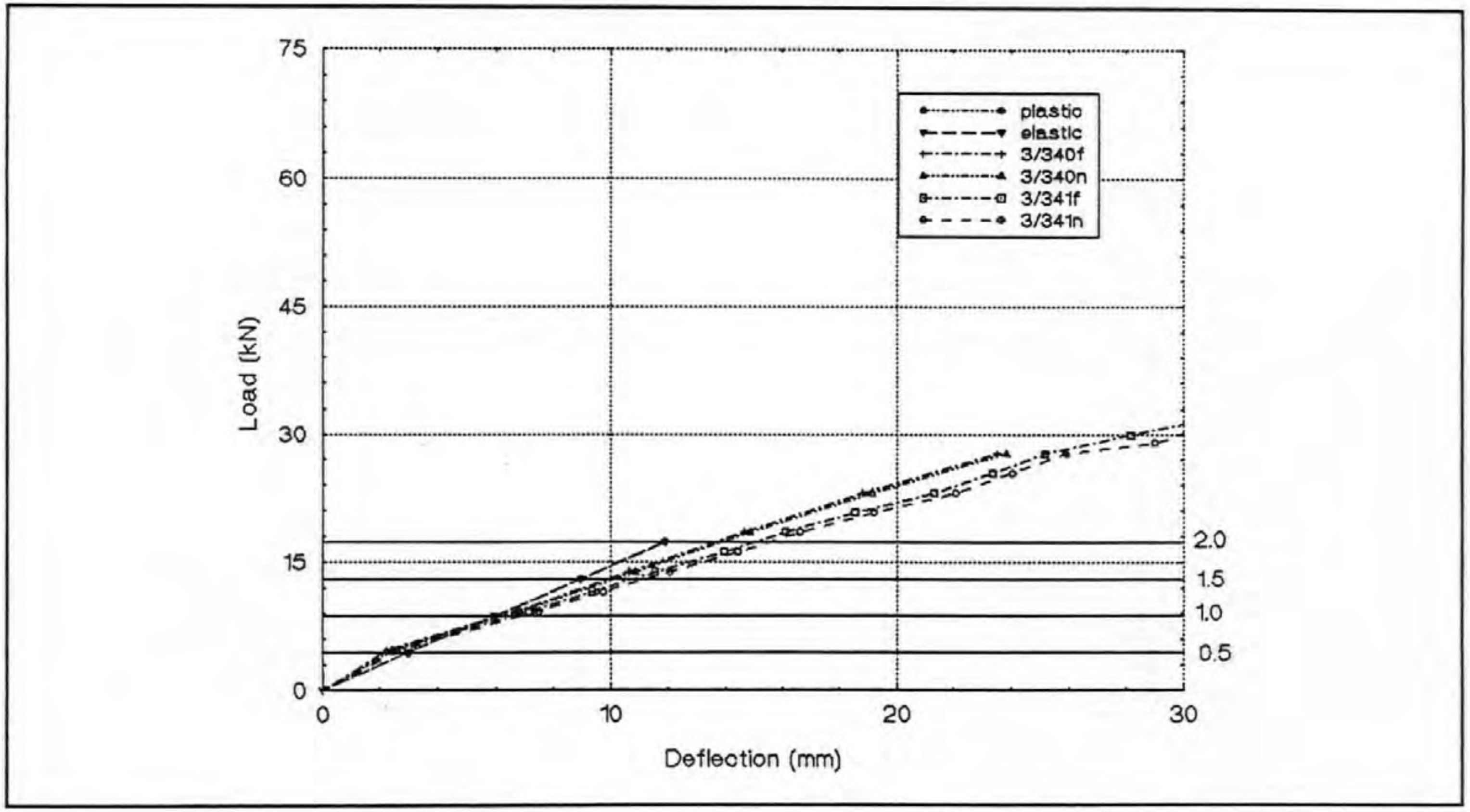
Predicted and experimental deflections - beams 1/340 & 1/341

Graph 88



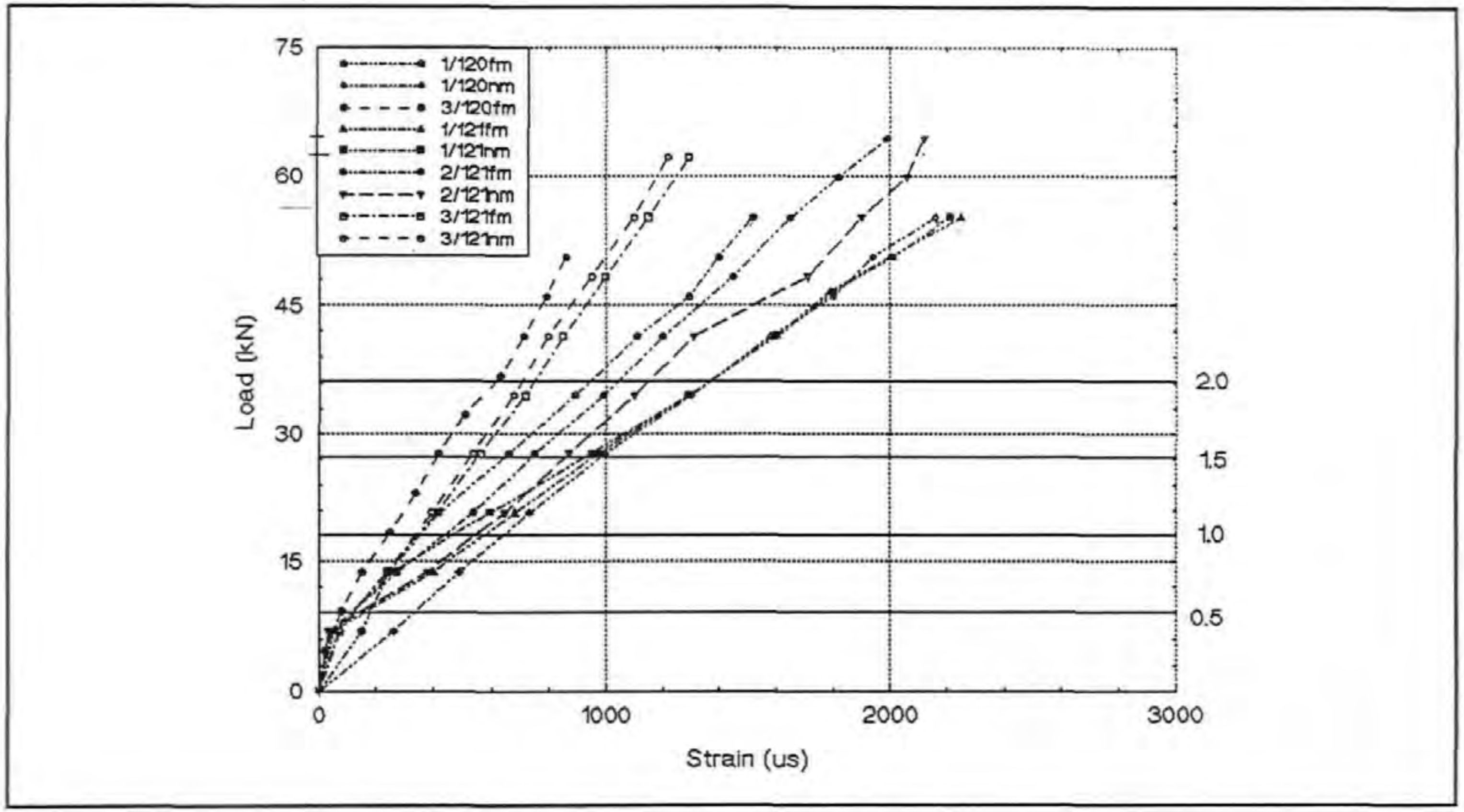
Predicted and experimental deflections - beams 2/340 & 2/341

Graph 89



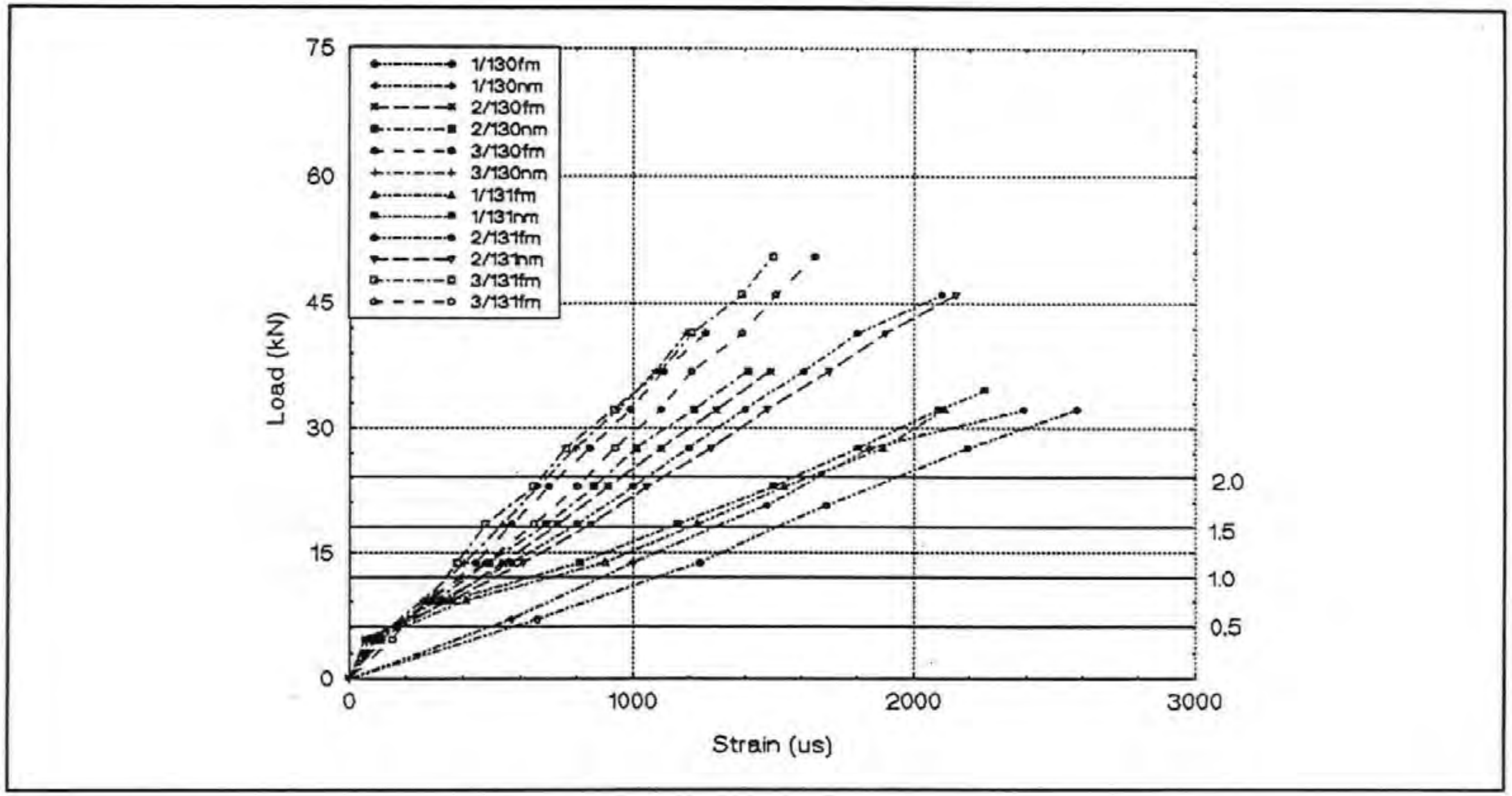
Predicted and experimental deflections - beams 3/340 & 3/341

Graph 90



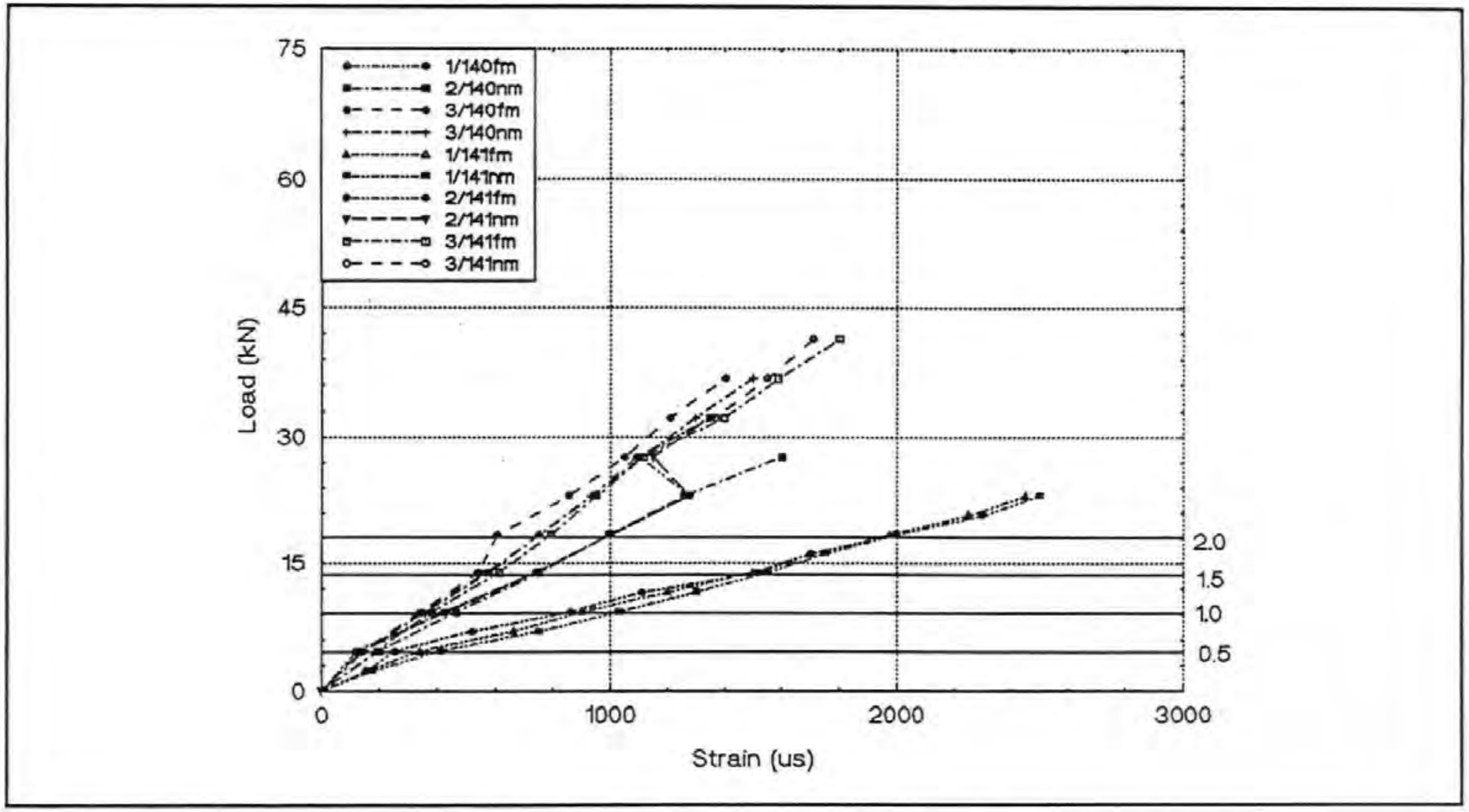
Load versus strain - beams 120 & 121

Graph 91



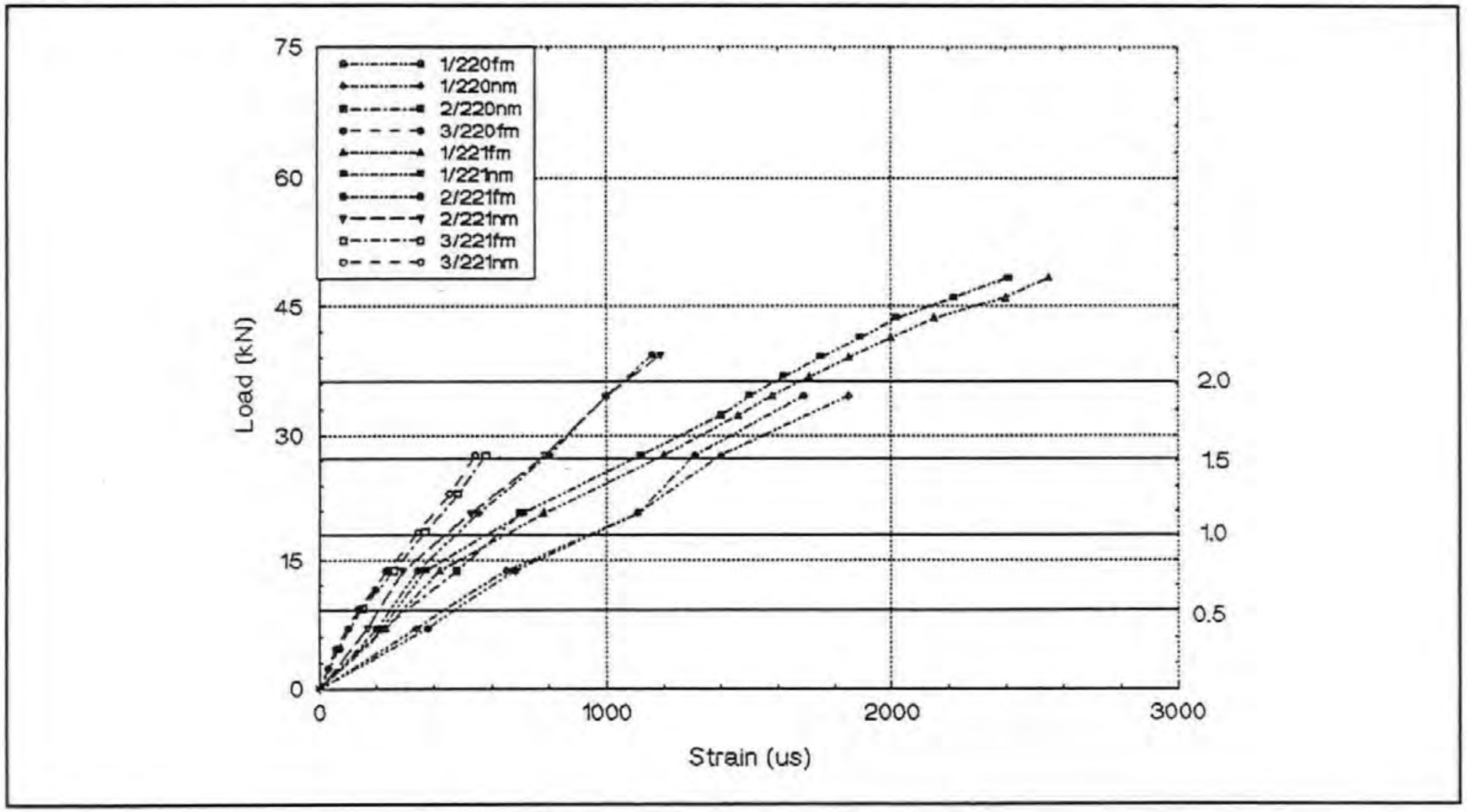
Load versus strain - beams 130 & 131

Graph 92



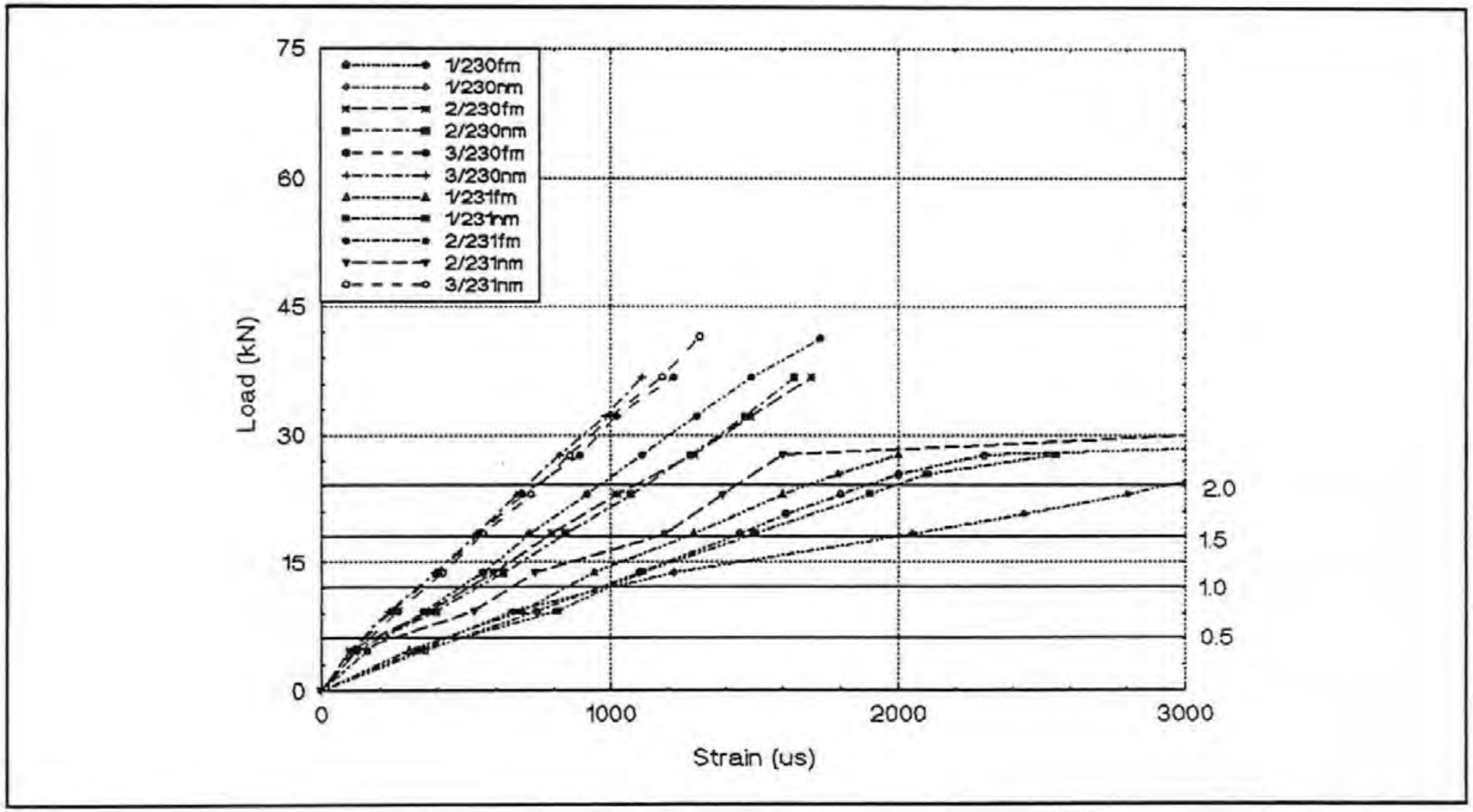
Load versus strain - beams 140 & 141

Graph 93



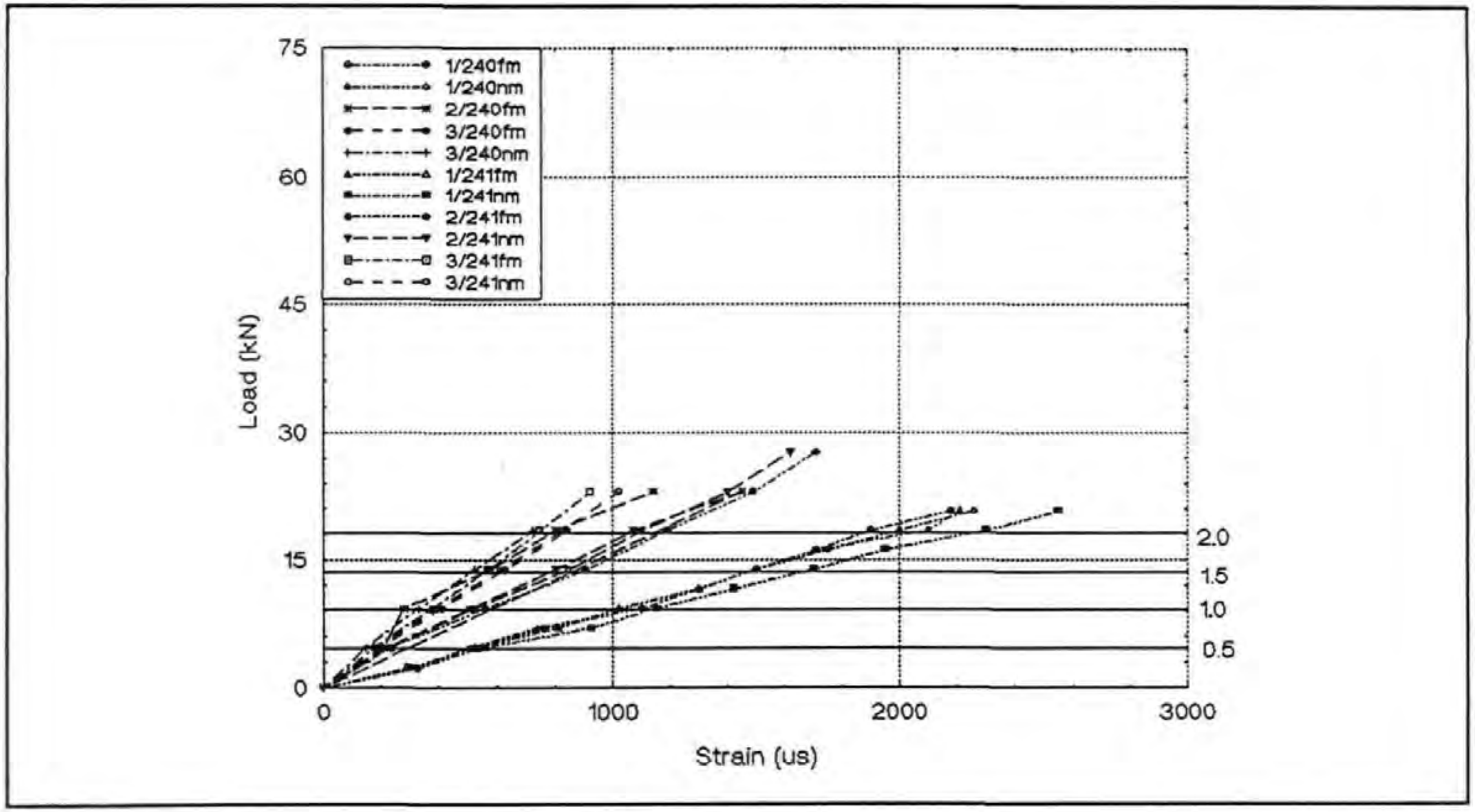
Load versus strain - beams 220 & 221

Graph 94



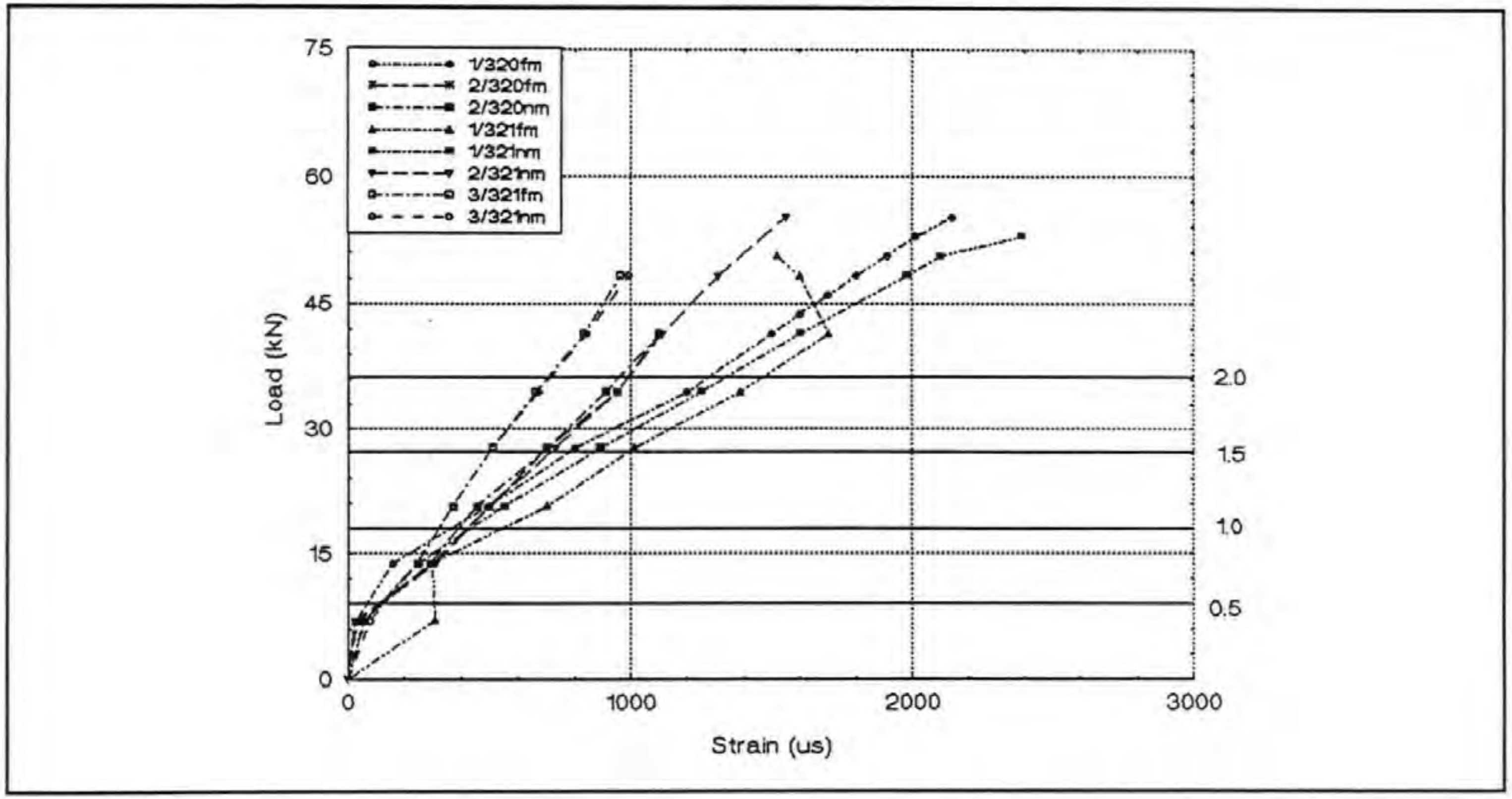
Load versus strain - beams 230 & 231

Graph 95



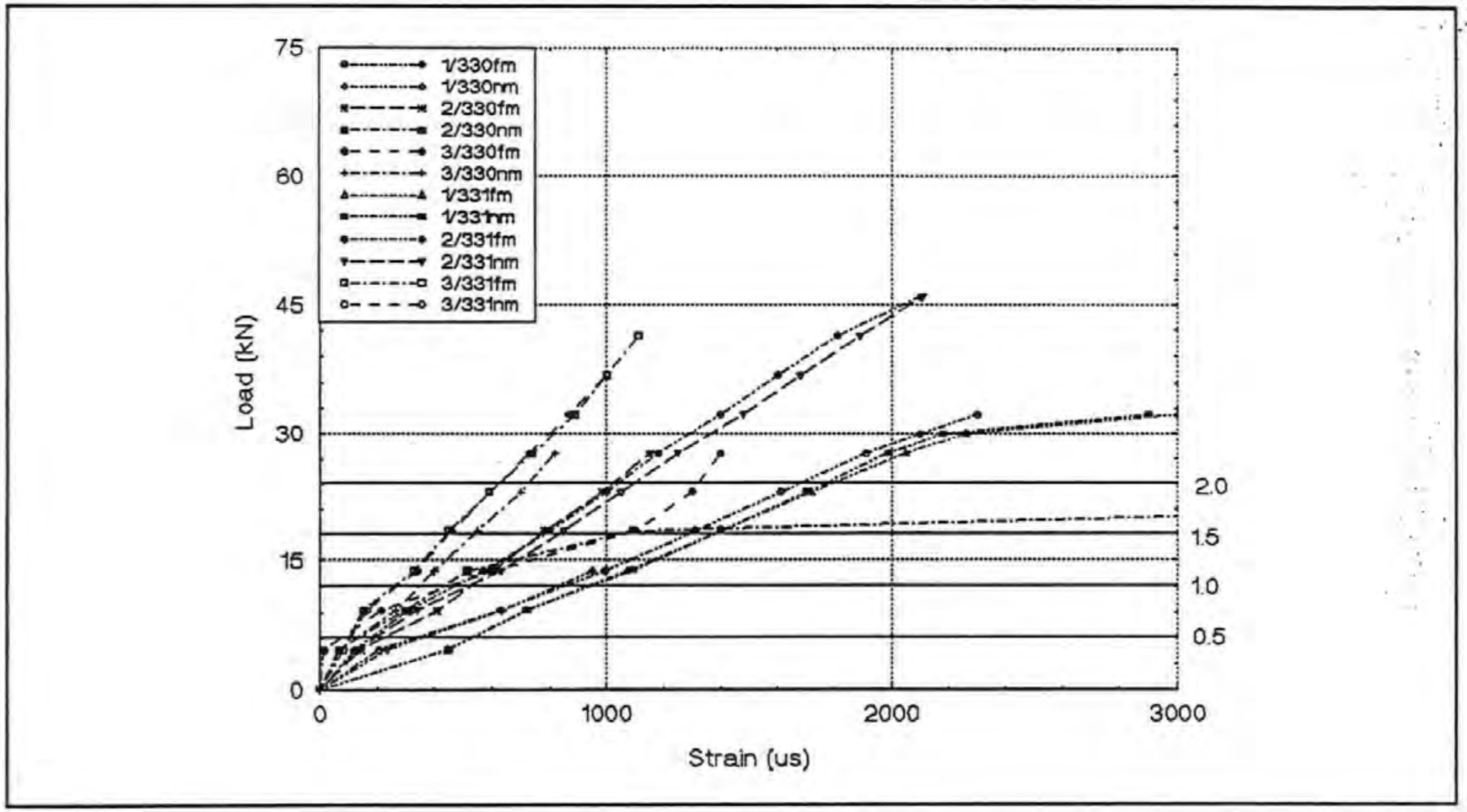
Load versus strain - beams 240 & 241

Graph 96



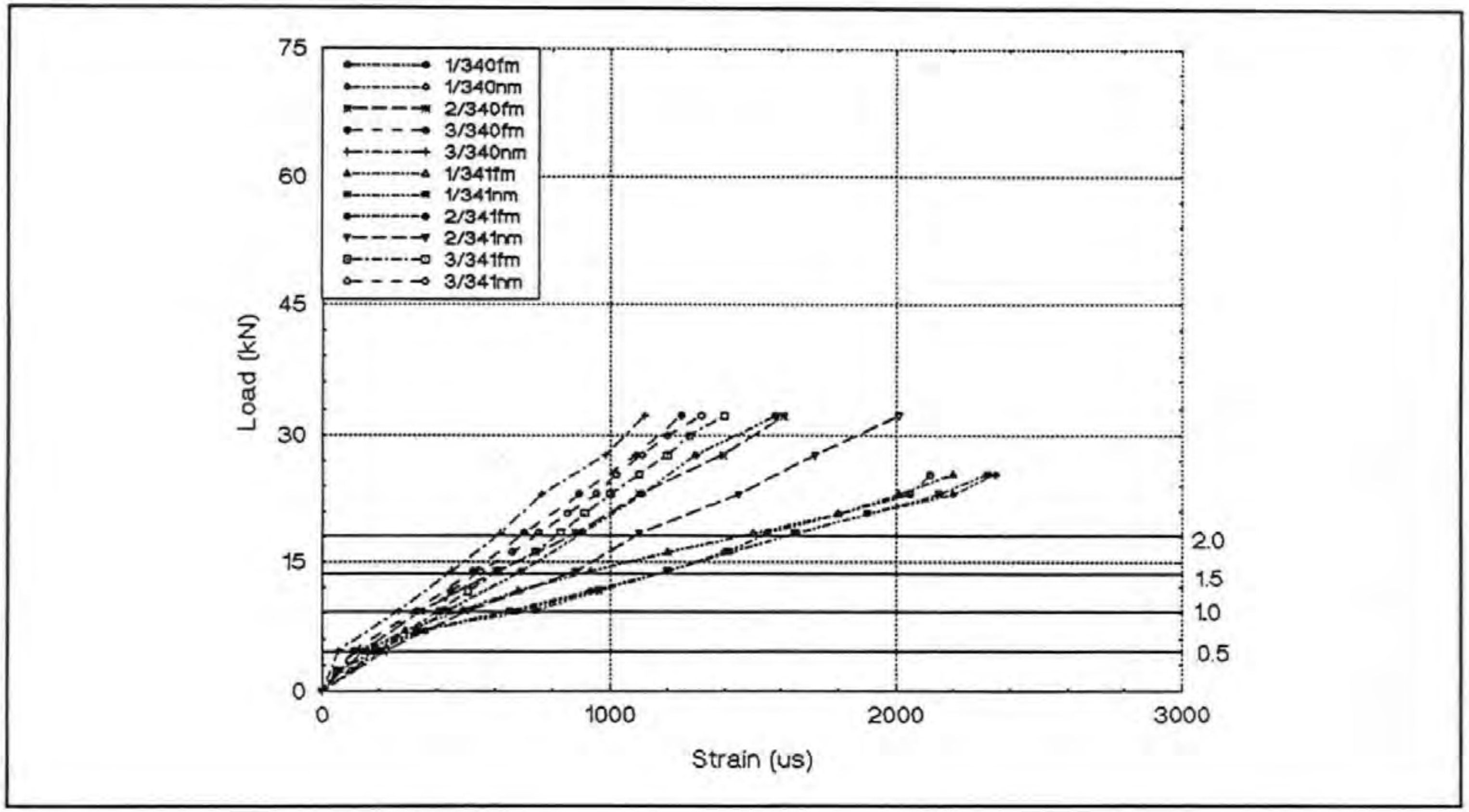
Load versus strain - beams 320 & 321

Graph 97



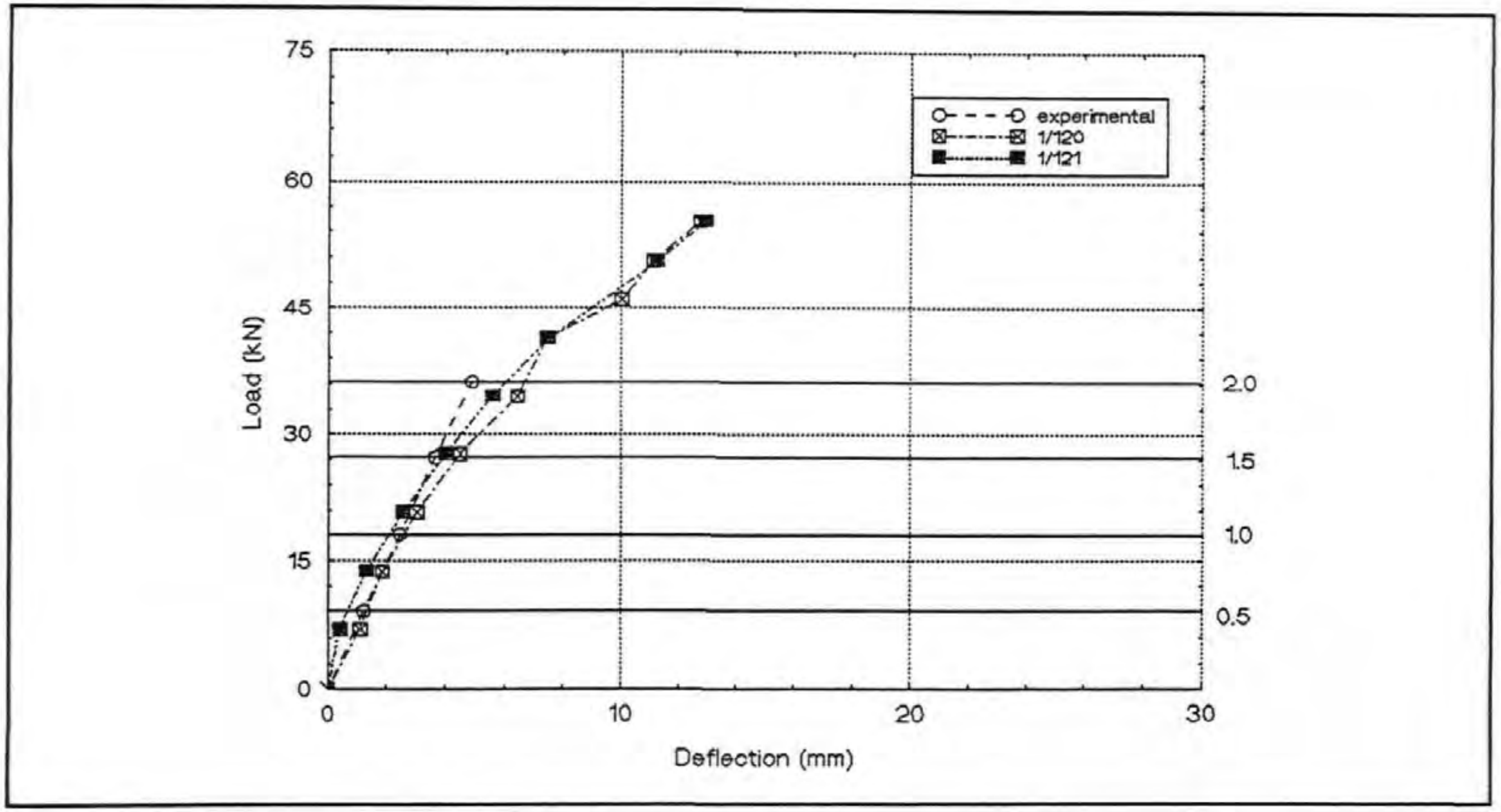
Load versus strain - beams 330 & 331

Graph 98



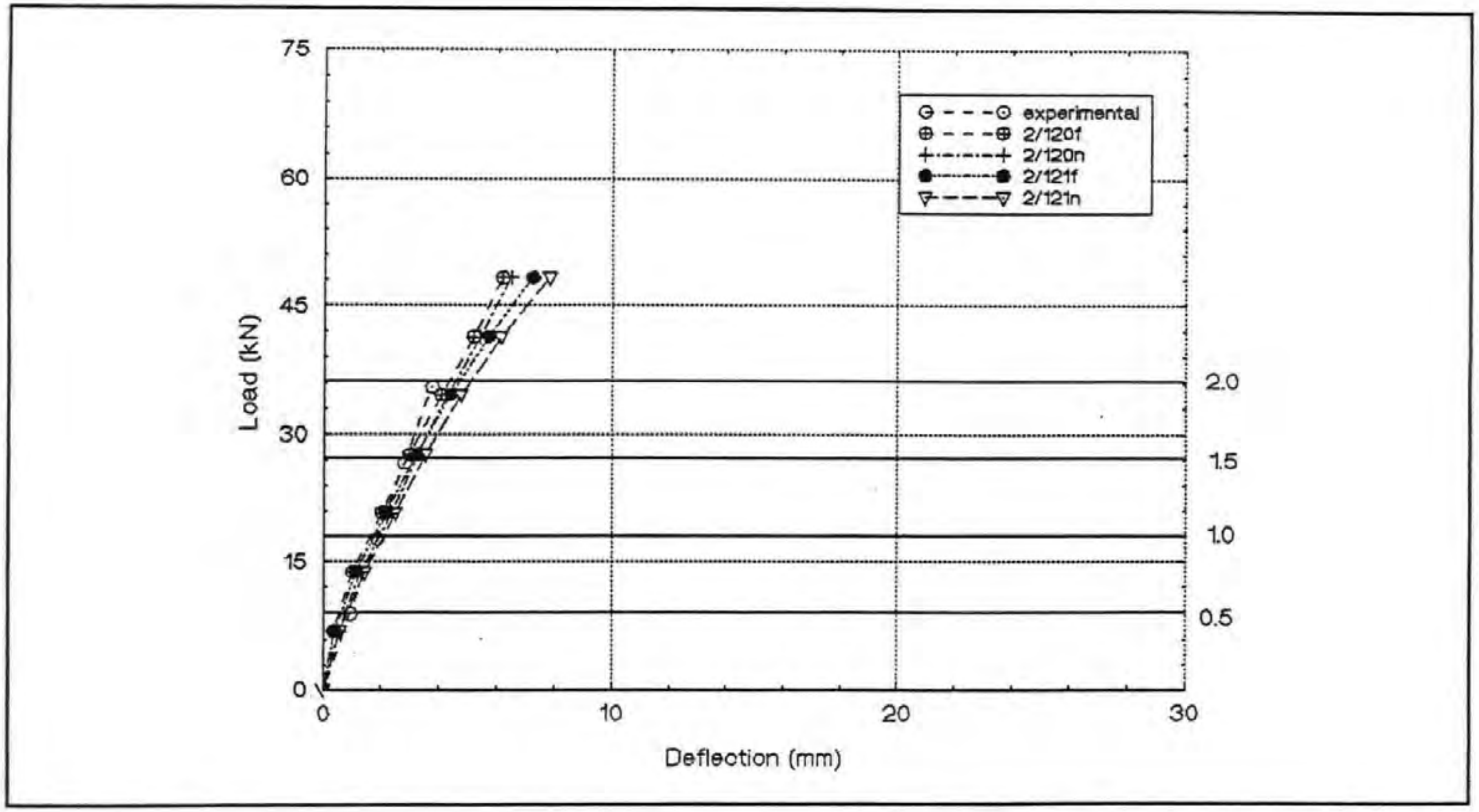
Load versus strain - beams 340 & 341

Graph 99



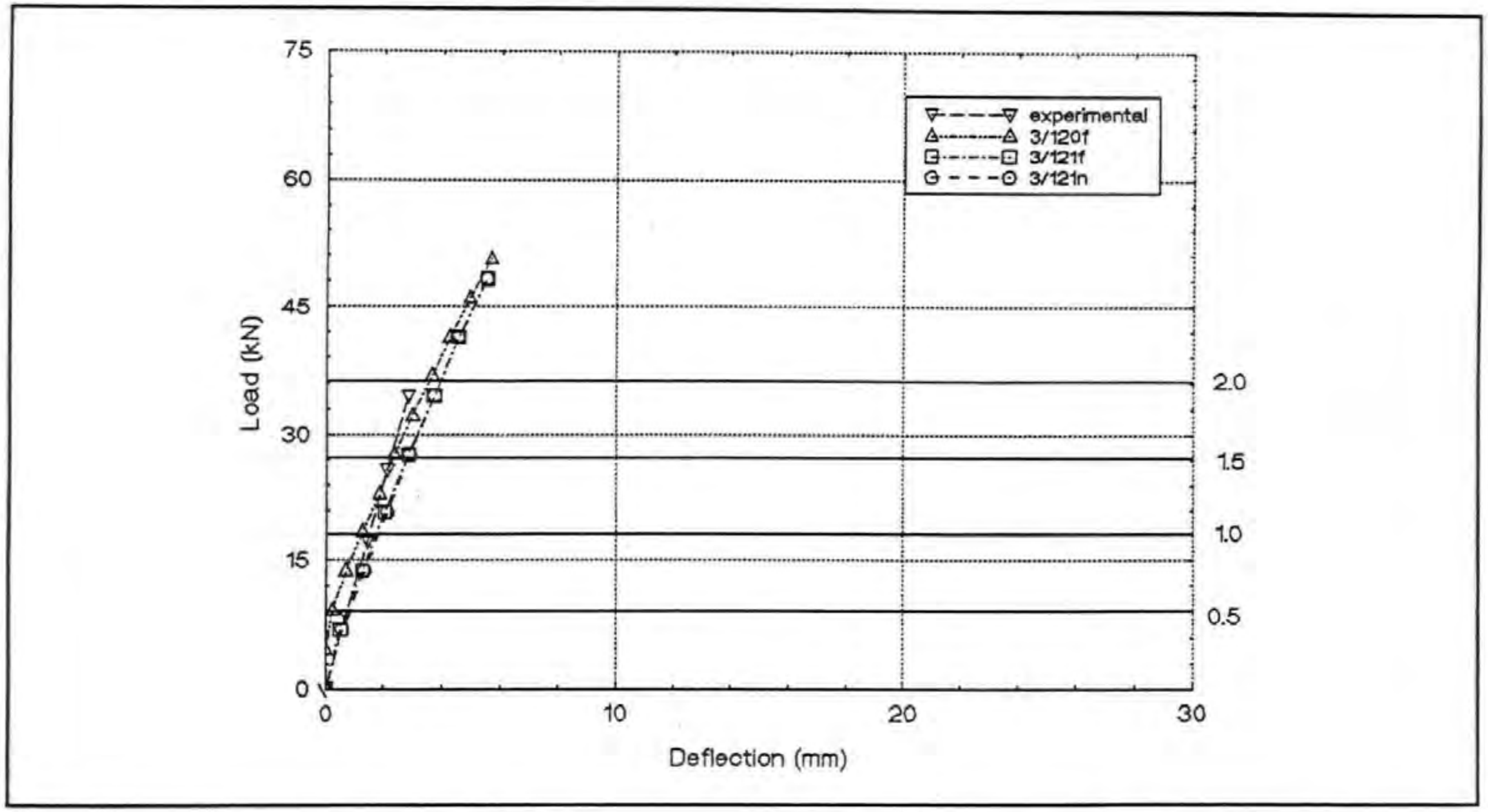
Deflections predicted using experimental neutral axis - beams 1/120 & 1/121

Graph 127



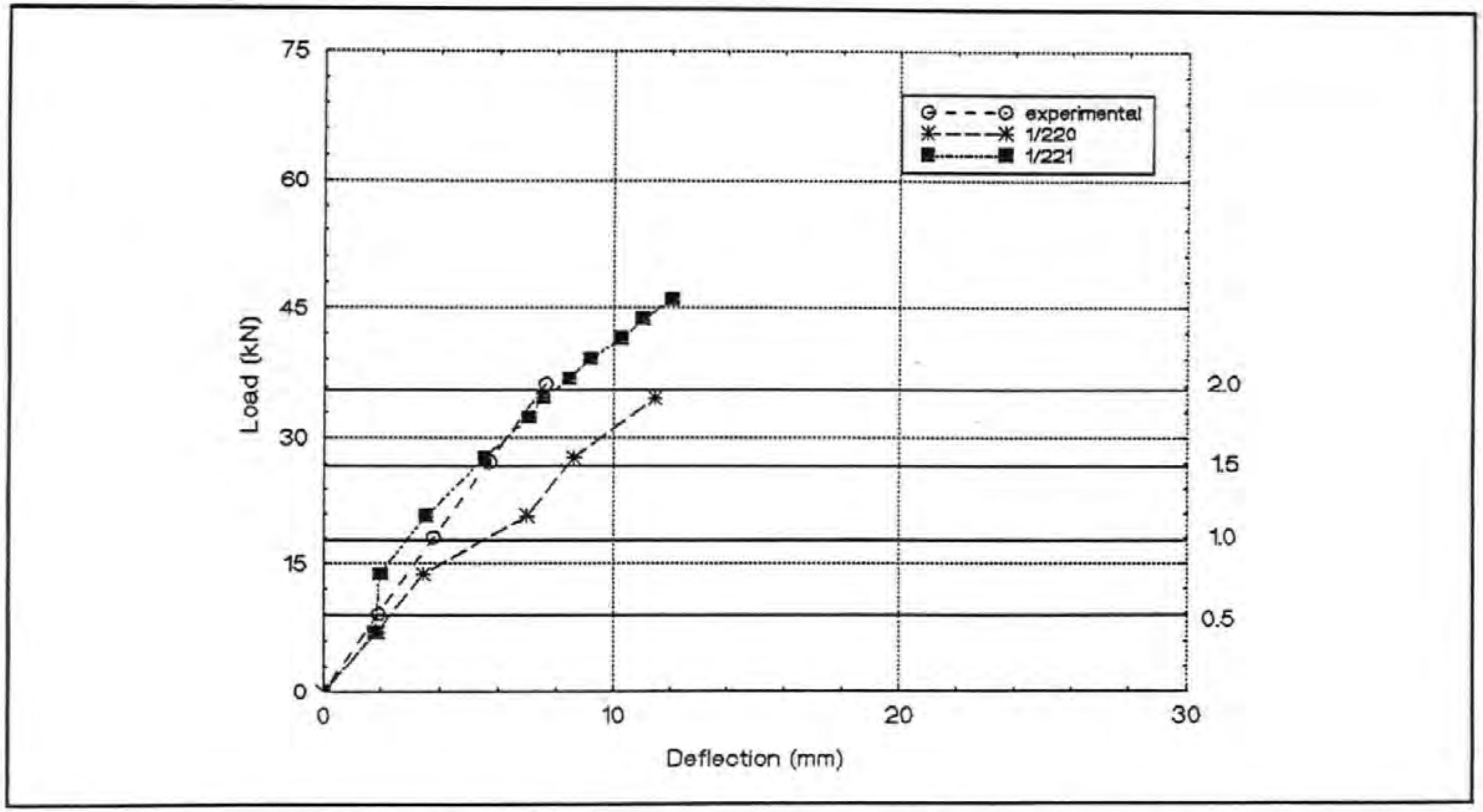
Deflections predicted using experimental neutral axis - beams 2/120 & 2/121

Graph 128



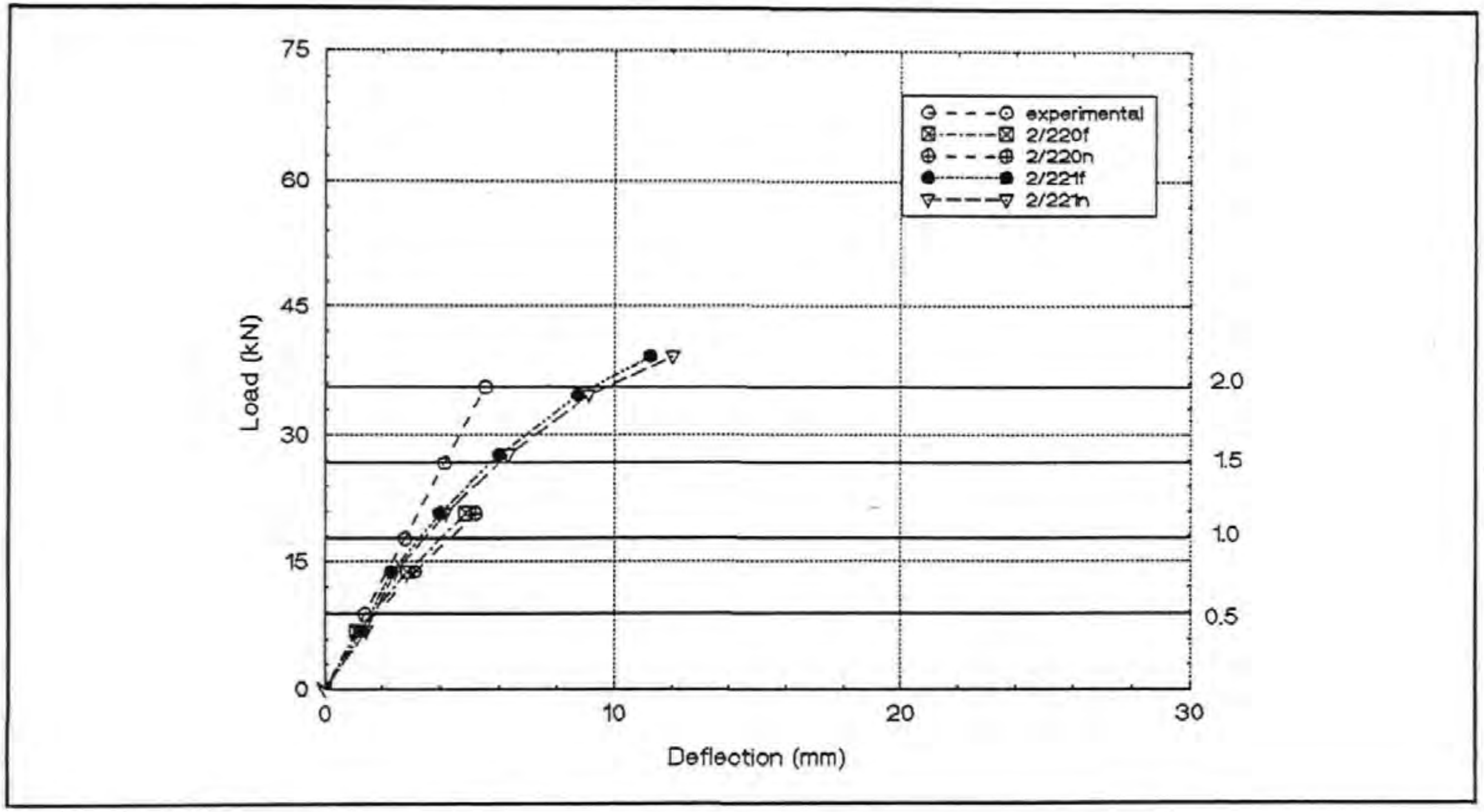
Deflections predicted using experimental neutral axis - beams 3/120 & 3/121

Graph 129



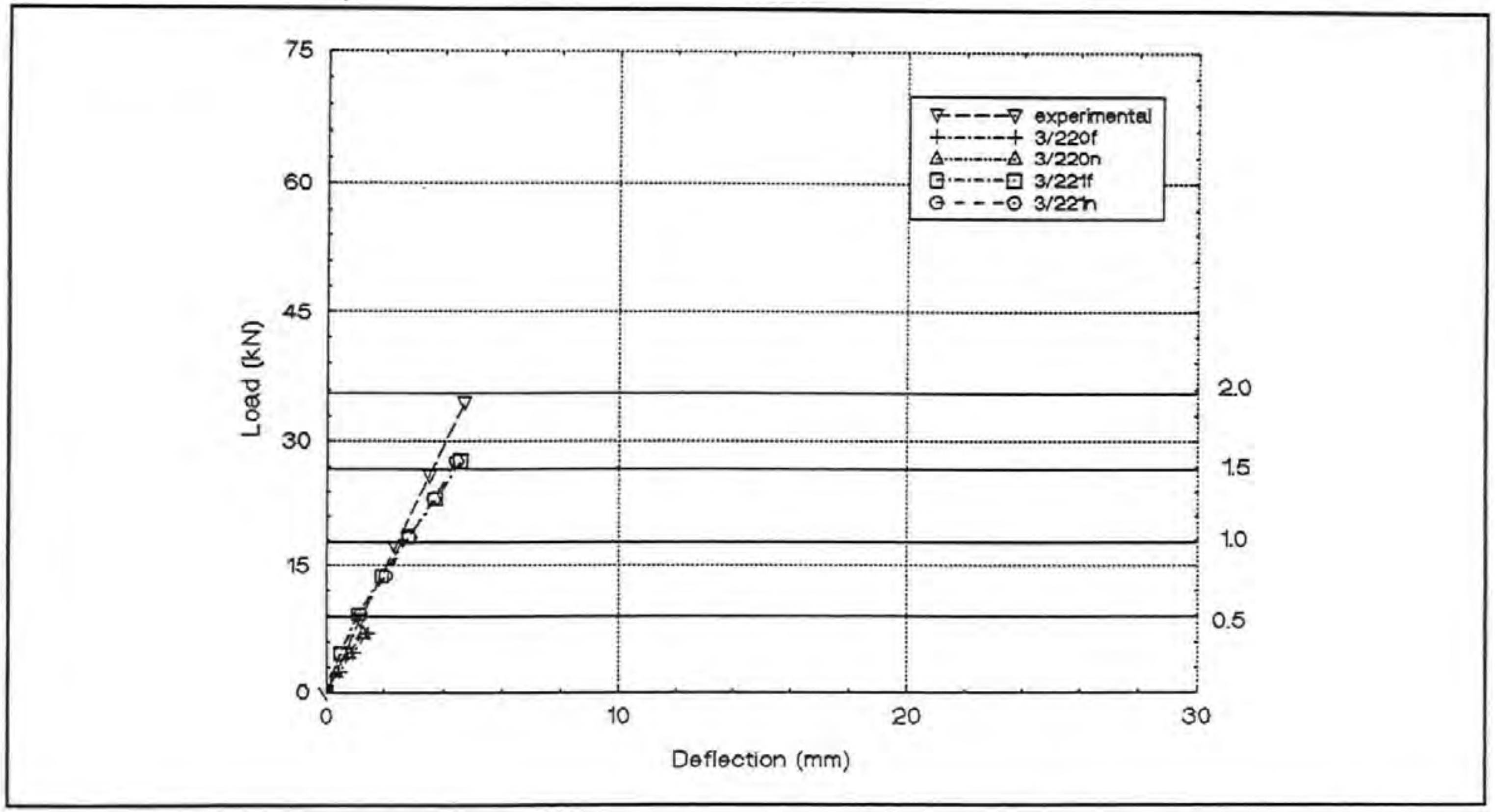
Deflections predicted using experimental neutral axis - beams 1/220 & 1/221

Graph 130



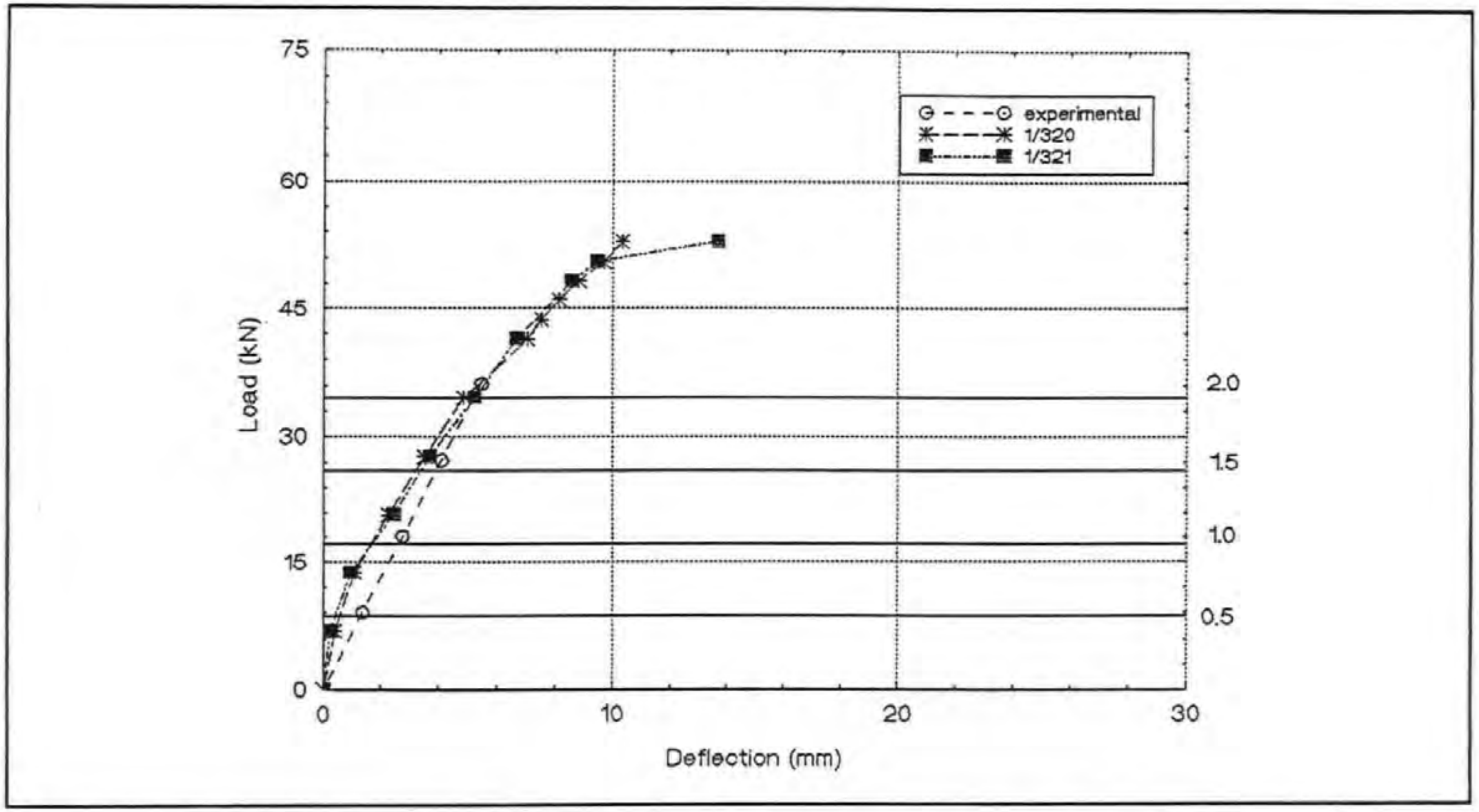
Deflections predicted using experimental neutral axis - beams 2/220 & 2/221

Graph 131



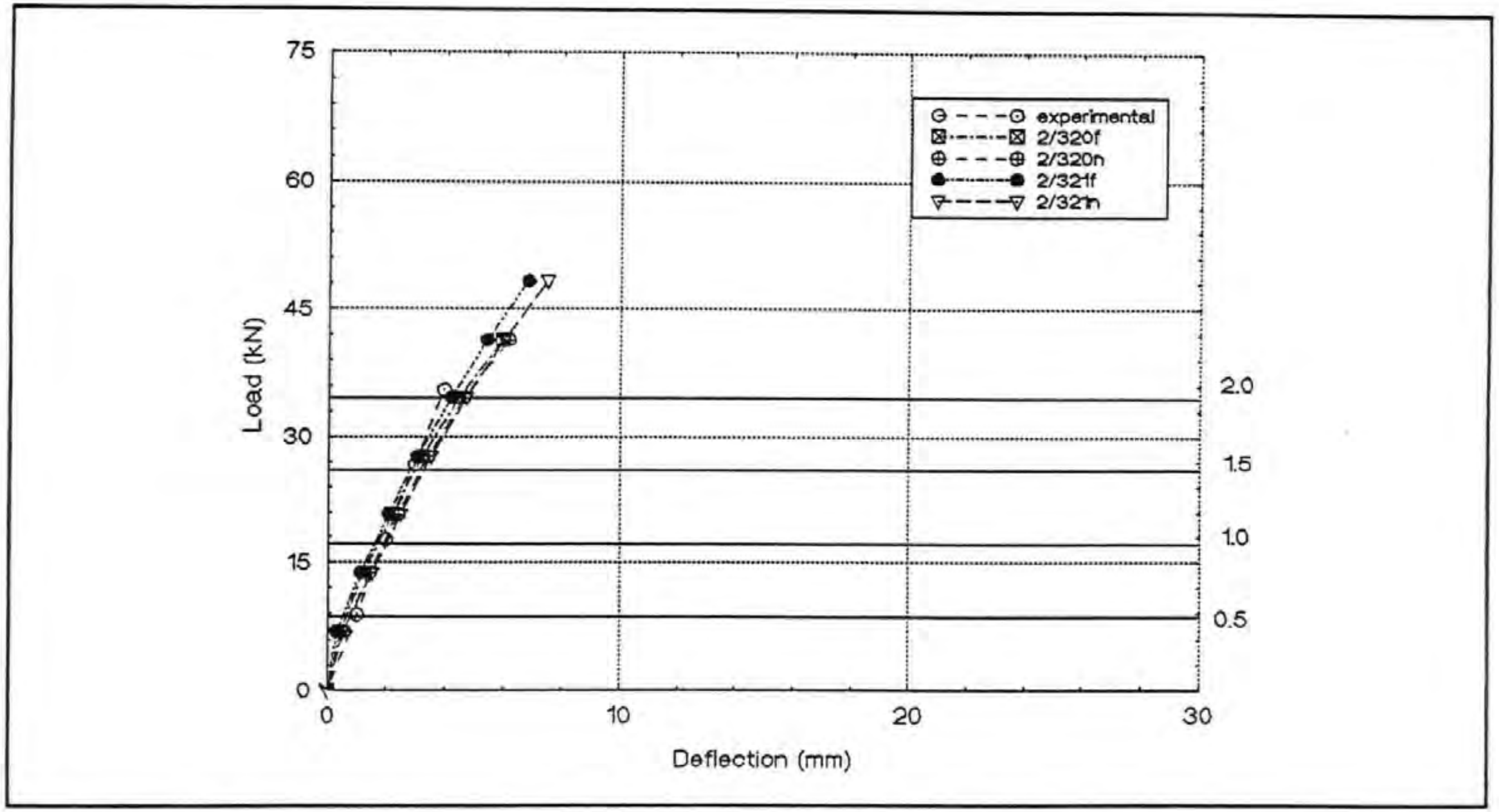
Deflections predicted using experimental neutral axis - beams 3/220 & 3/221

Graph 132



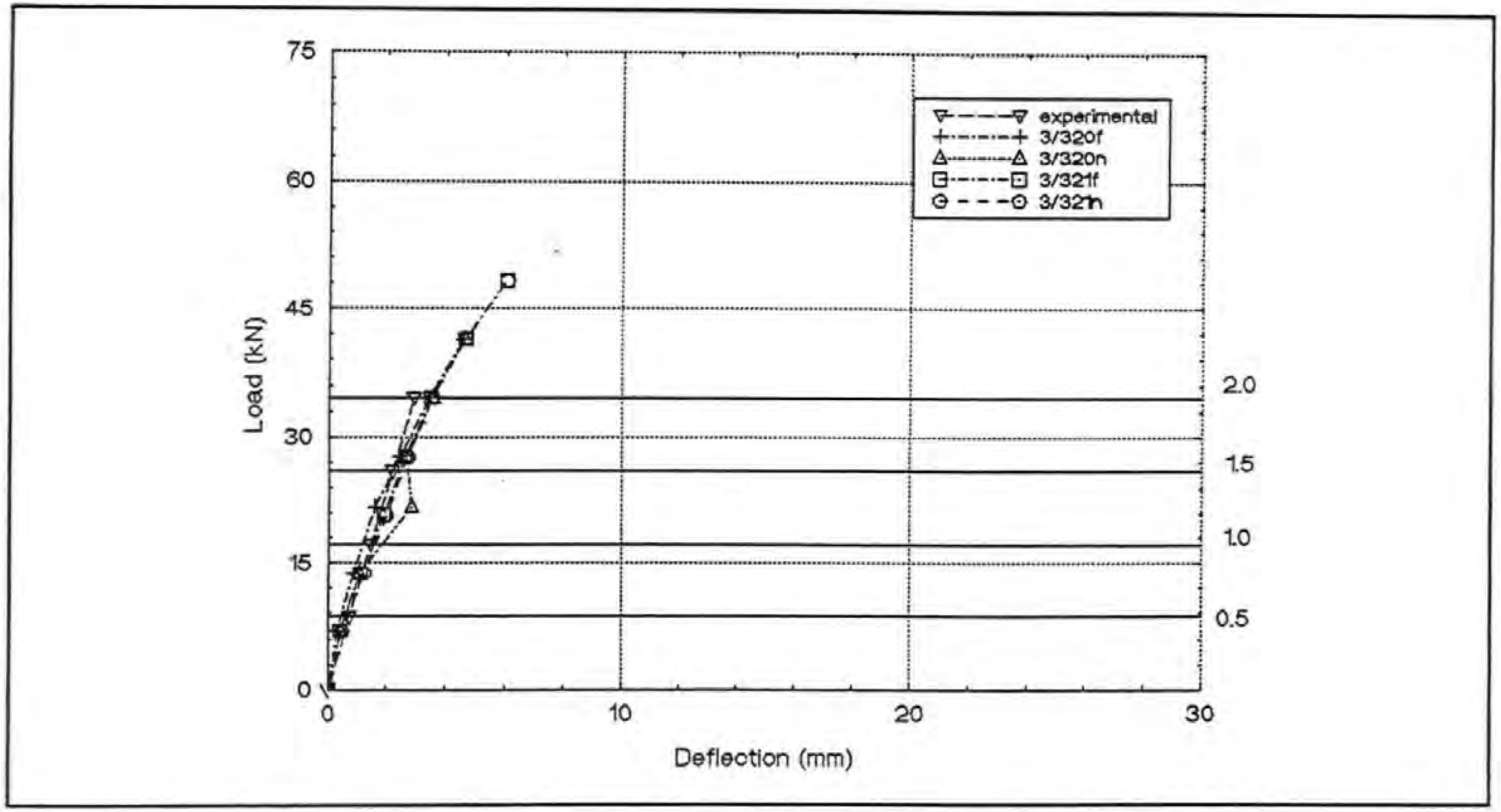
Deflections predicted using experimental neutral axis - beams 1/320 & 1/321

Graph 133



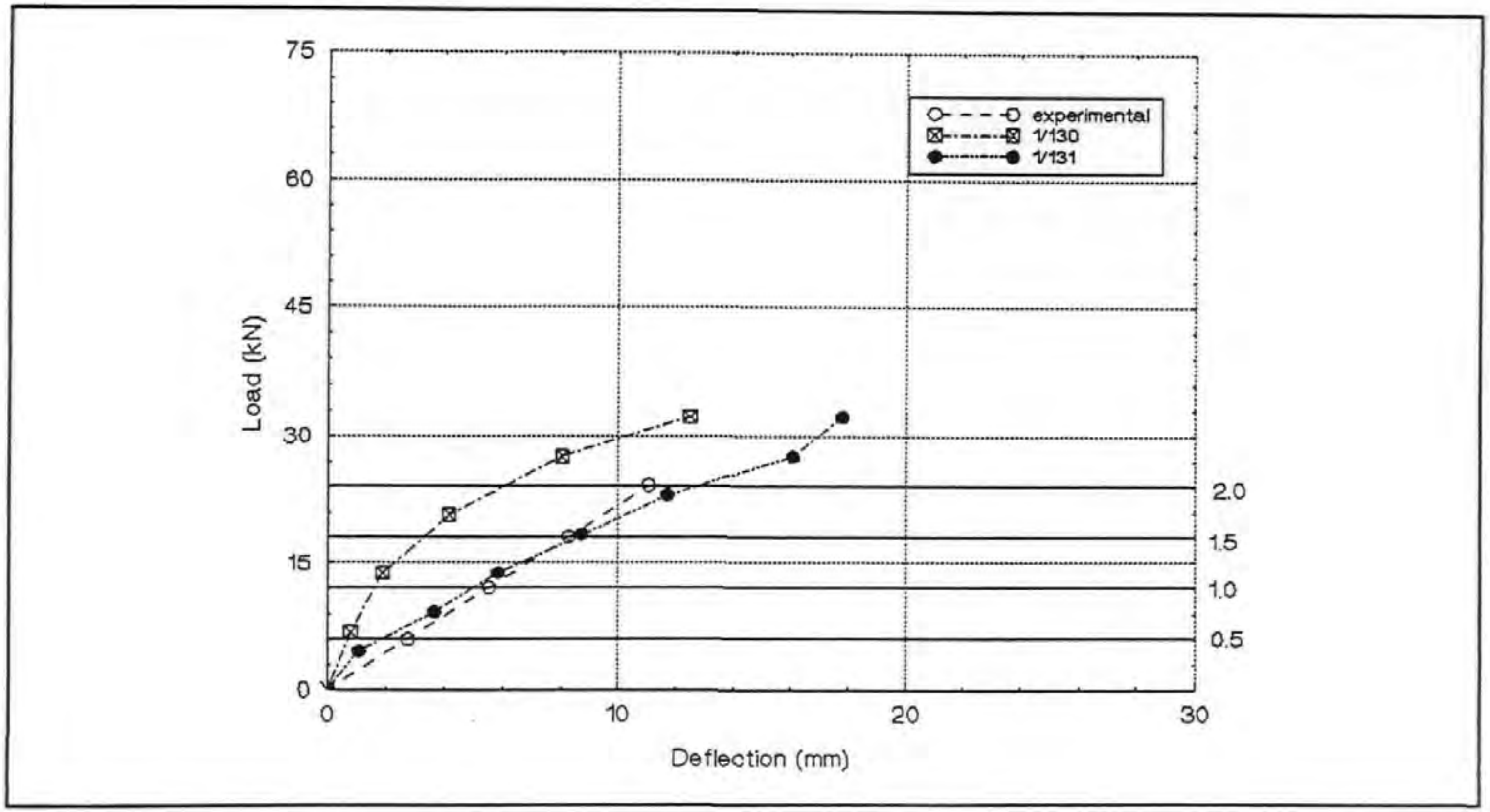
Deflections predicted using experimental neutral axis - beams 2/320 & 2/321

Graph 134



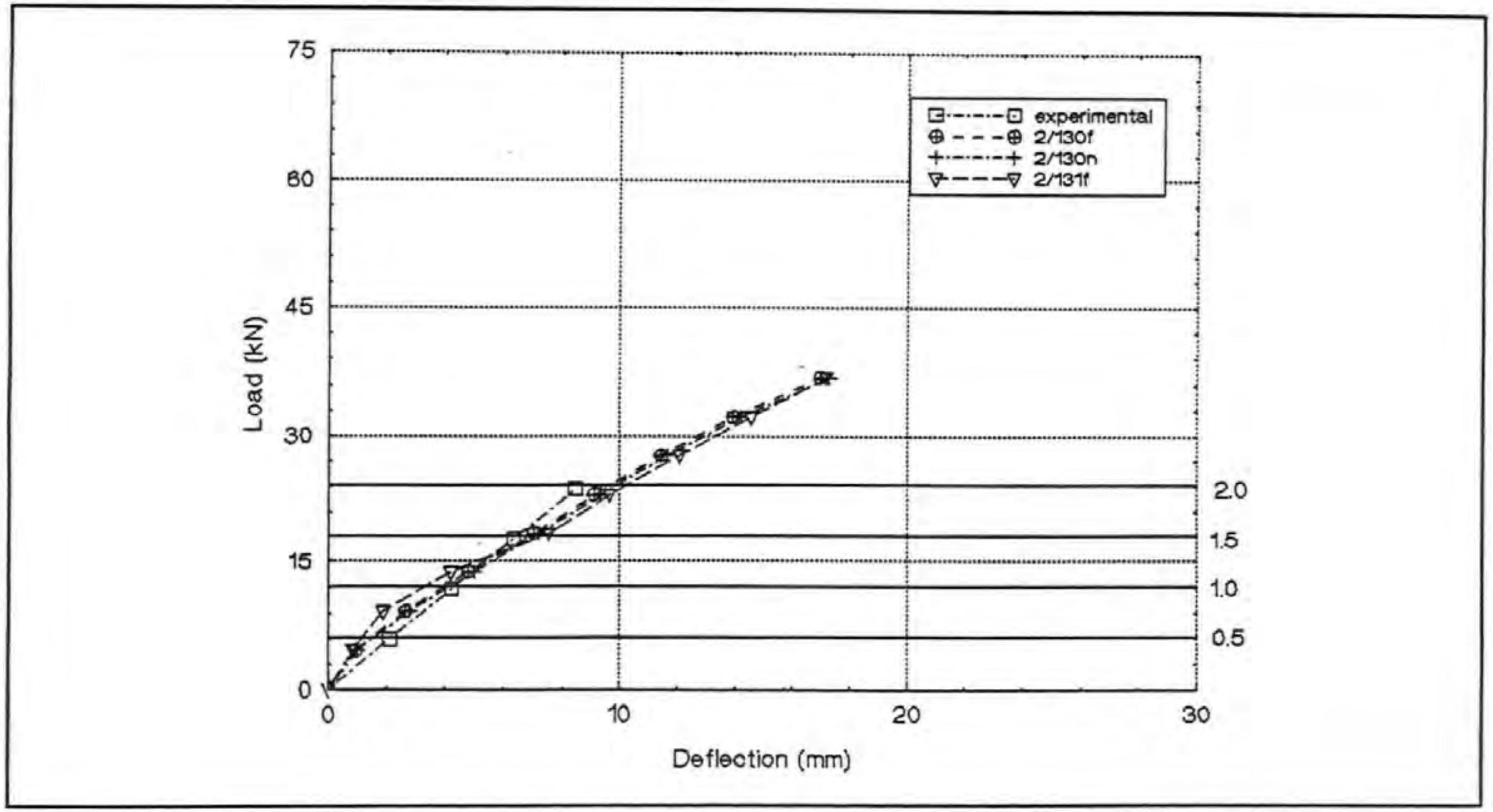
Deflections predicted using experimental neutral axis - beams 3/320 & 3/321

Graph 135



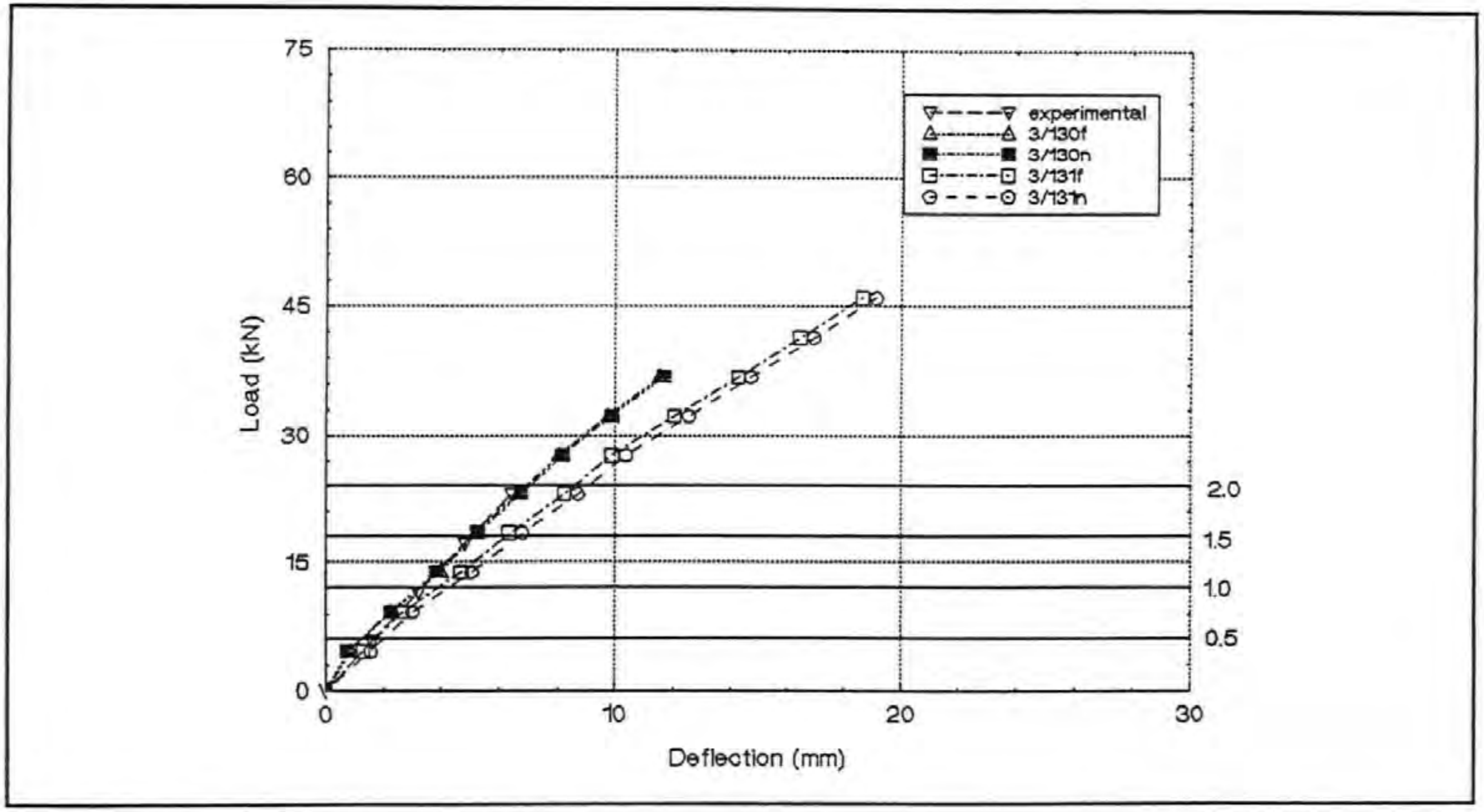
Deflections predicted using experimental neutral axis - beams 1/130 & 1/131

Graph 136



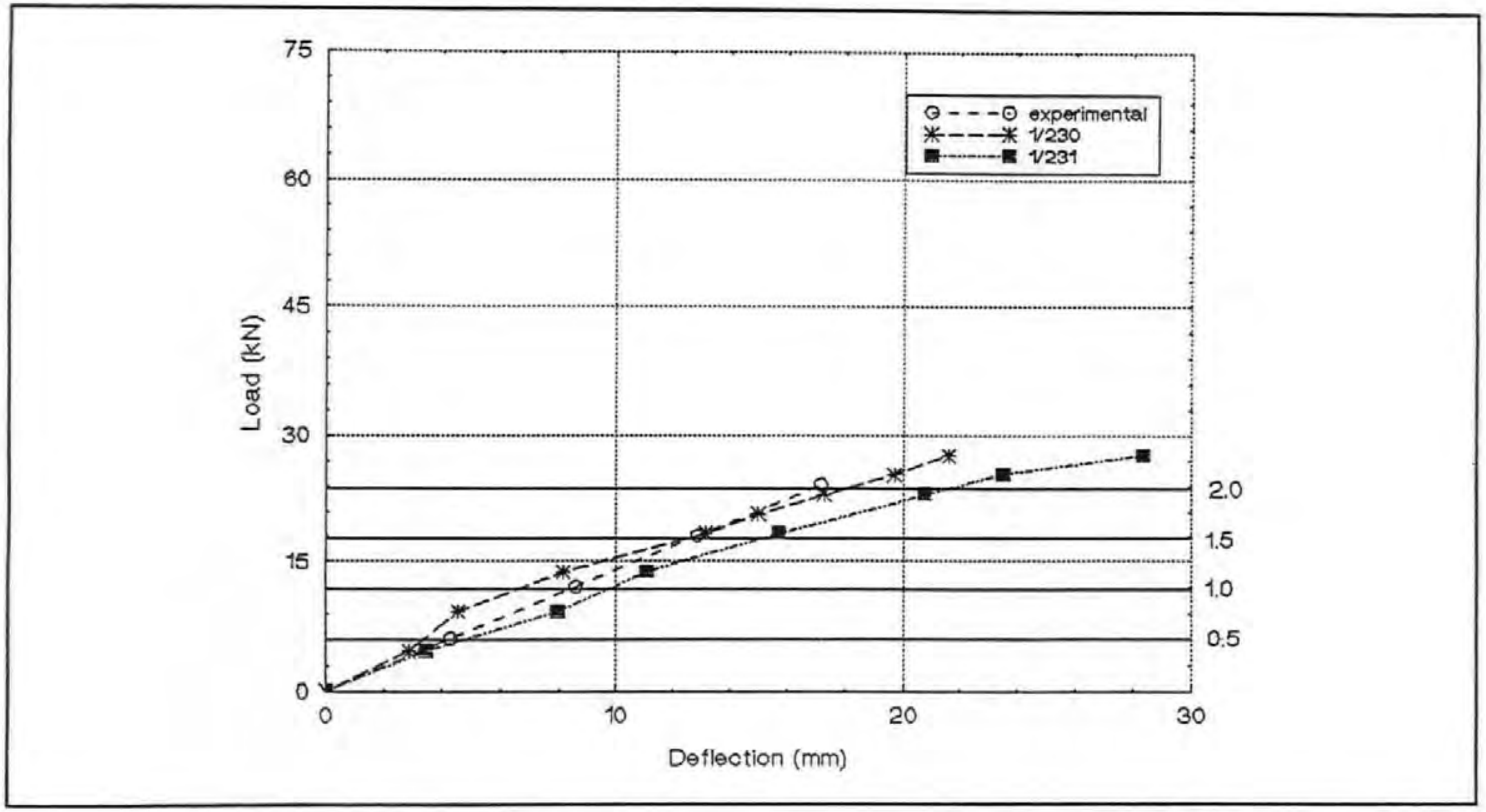
Deflections predicted using experimental neutral axis - beams 2/130 & 2/131

Graph 137



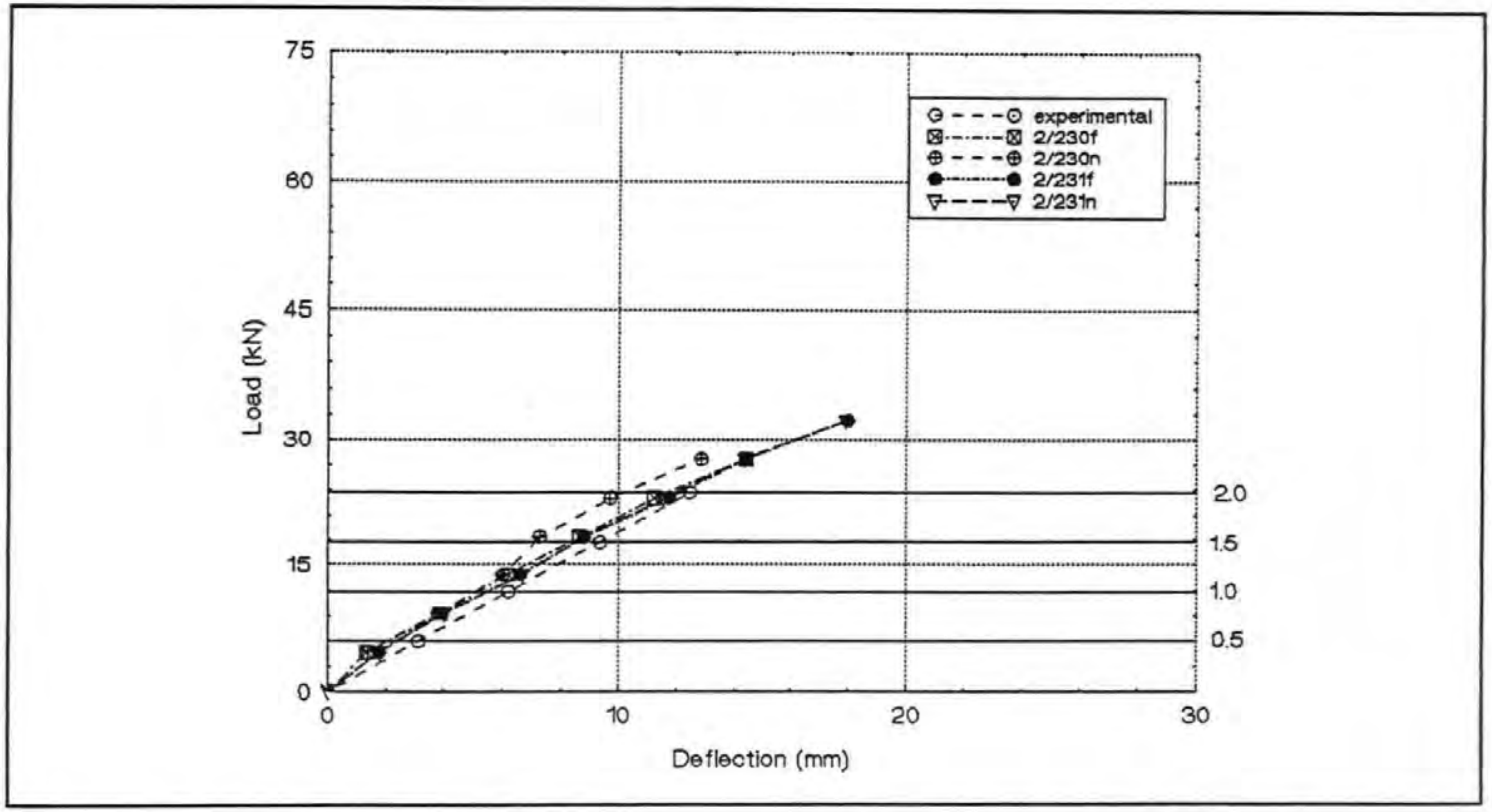
Deflections predicted using experimental neutral axis - beams 3/130 & 3/131

Graph 138



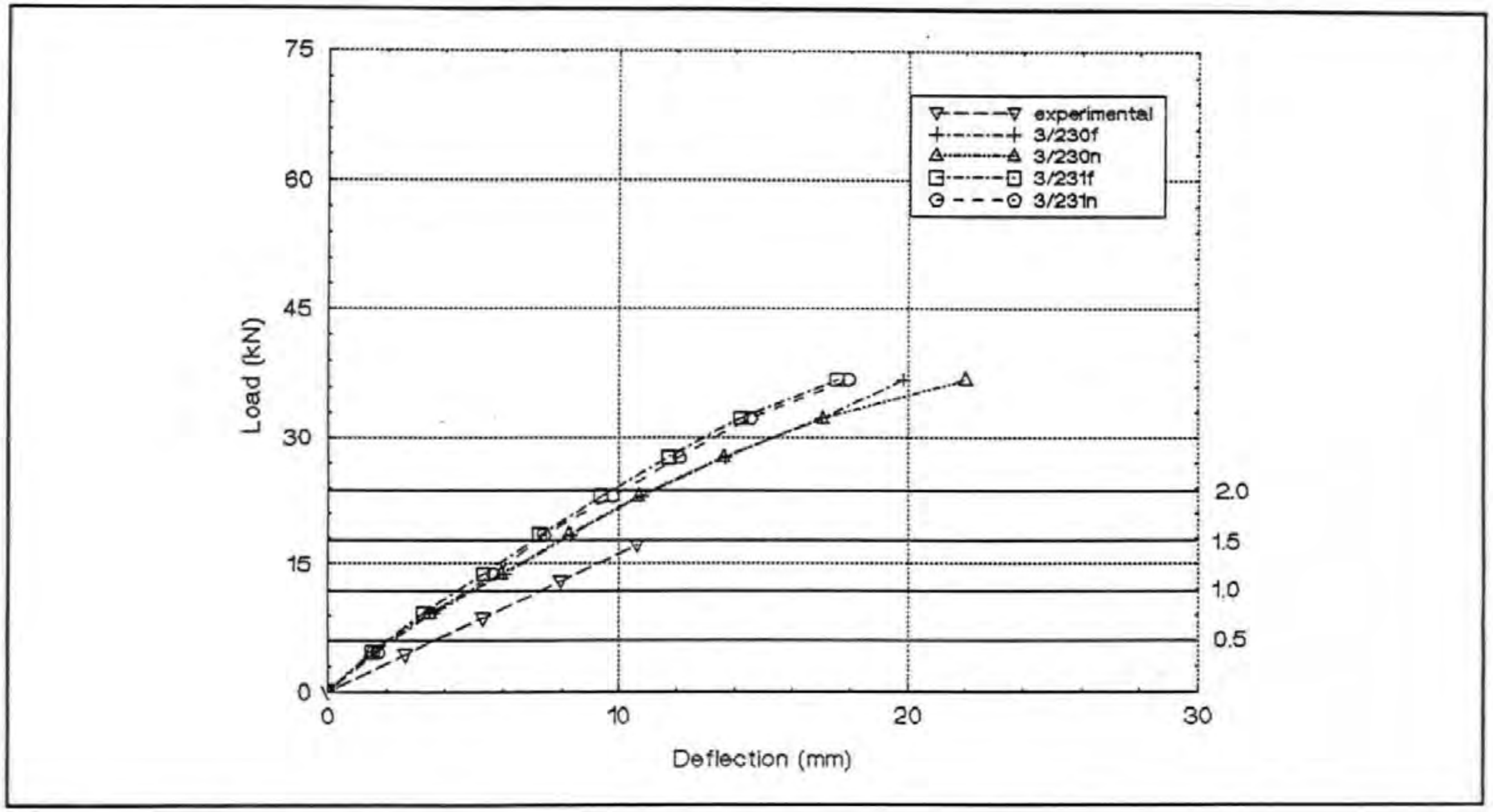
Deflections predicted using experimental neutral axis - beams 1/230 & 1/231

Graph 139



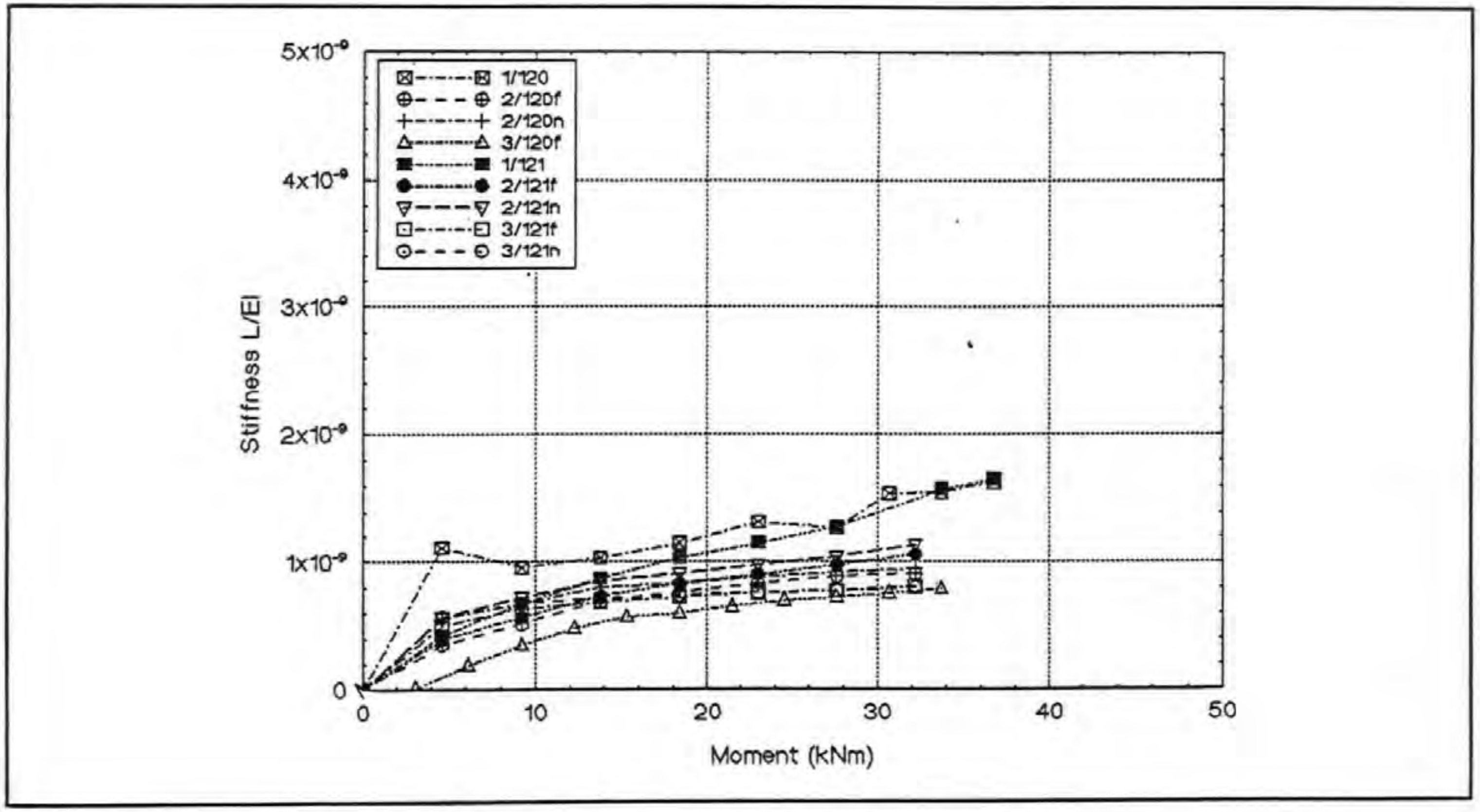
Deflections predicted using experimental neutral axis - beams 2/230 & 2/231

Graph 140



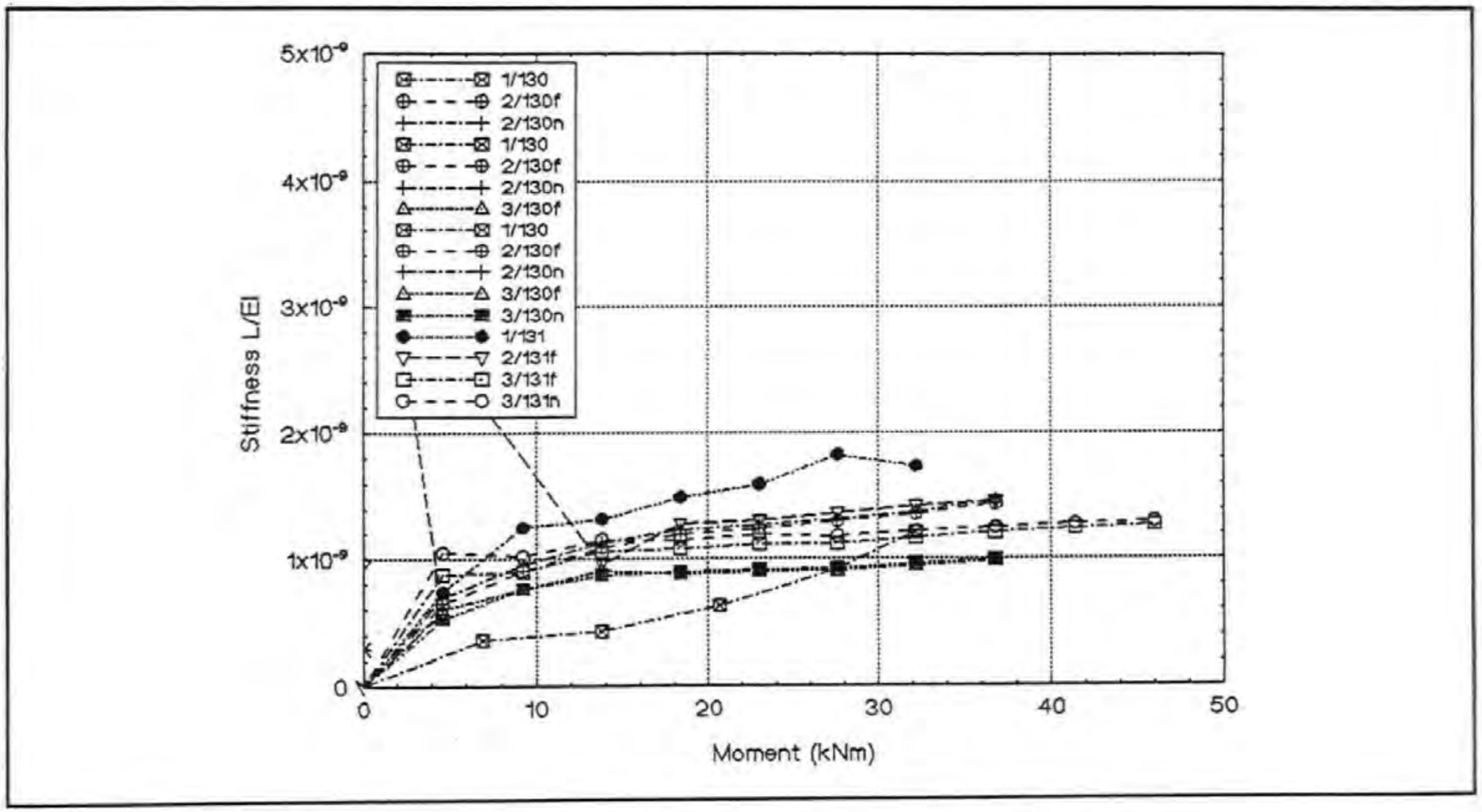
Deflections predicted using experimental neutral axis - beams 3/230 & 3/231

Graph 141



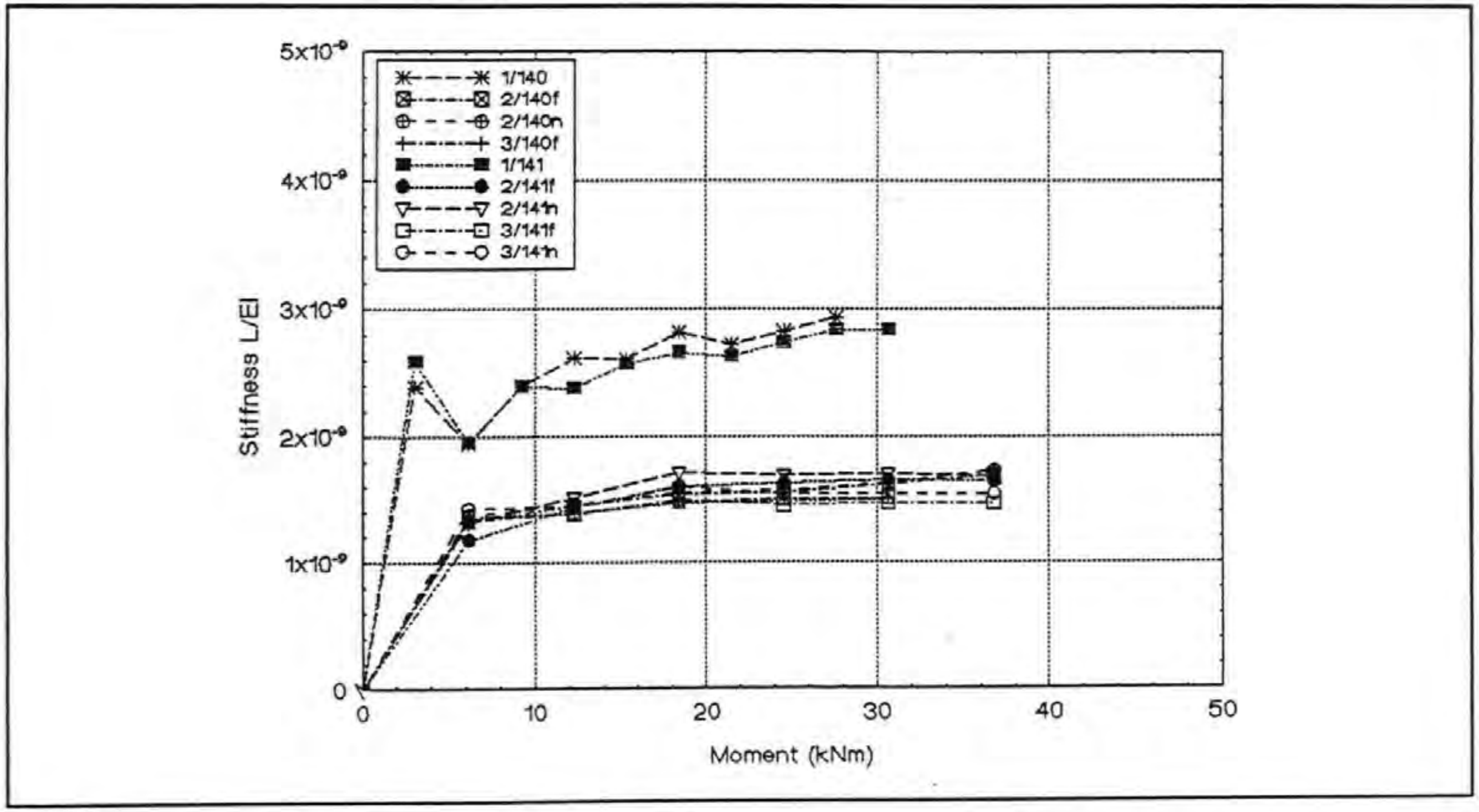
Moment versus beam stiffness - beams 120 & 121

Graph 154



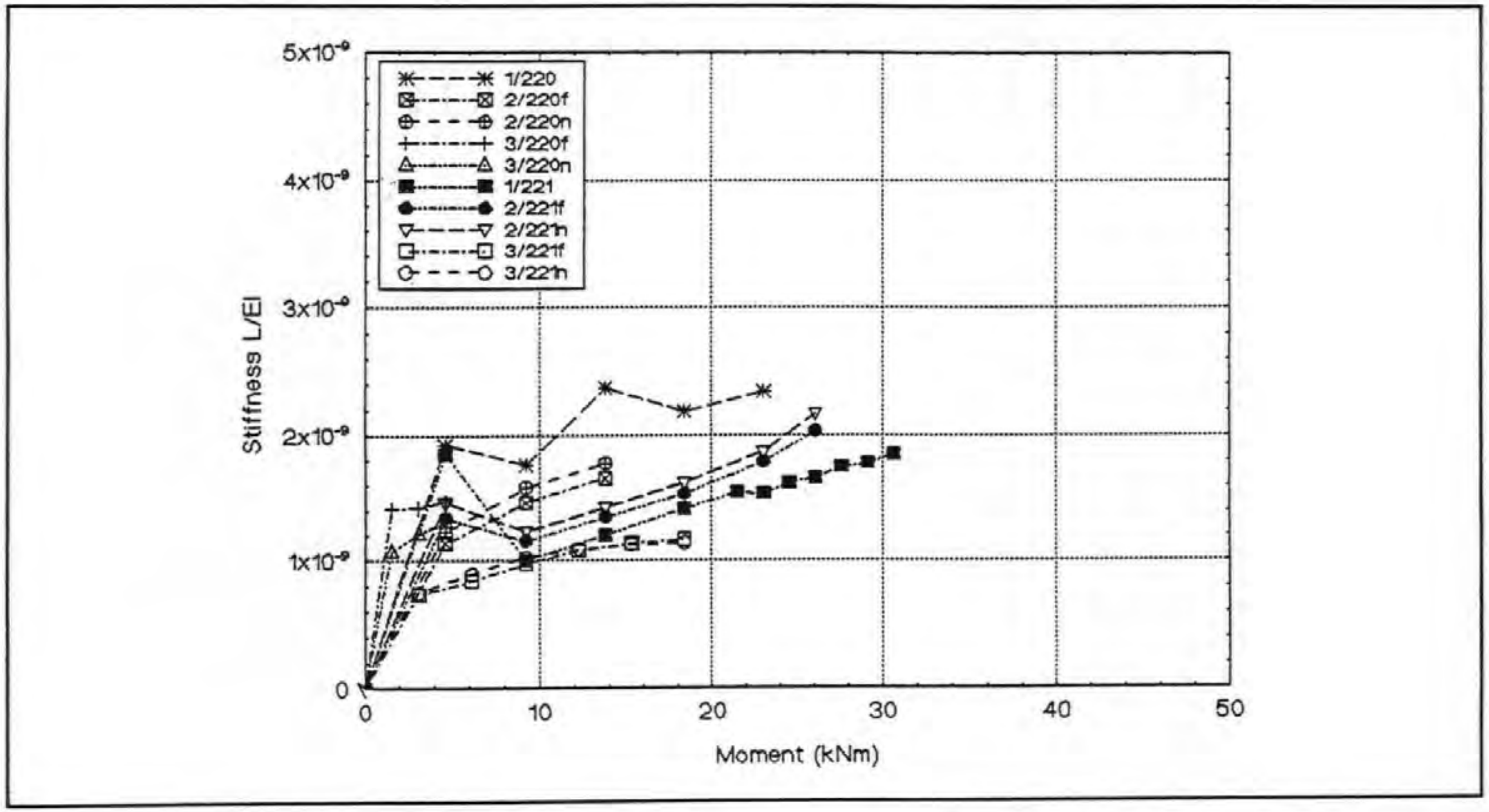
Moment versus beam stiffness - beams 130 & 131

Graph 155



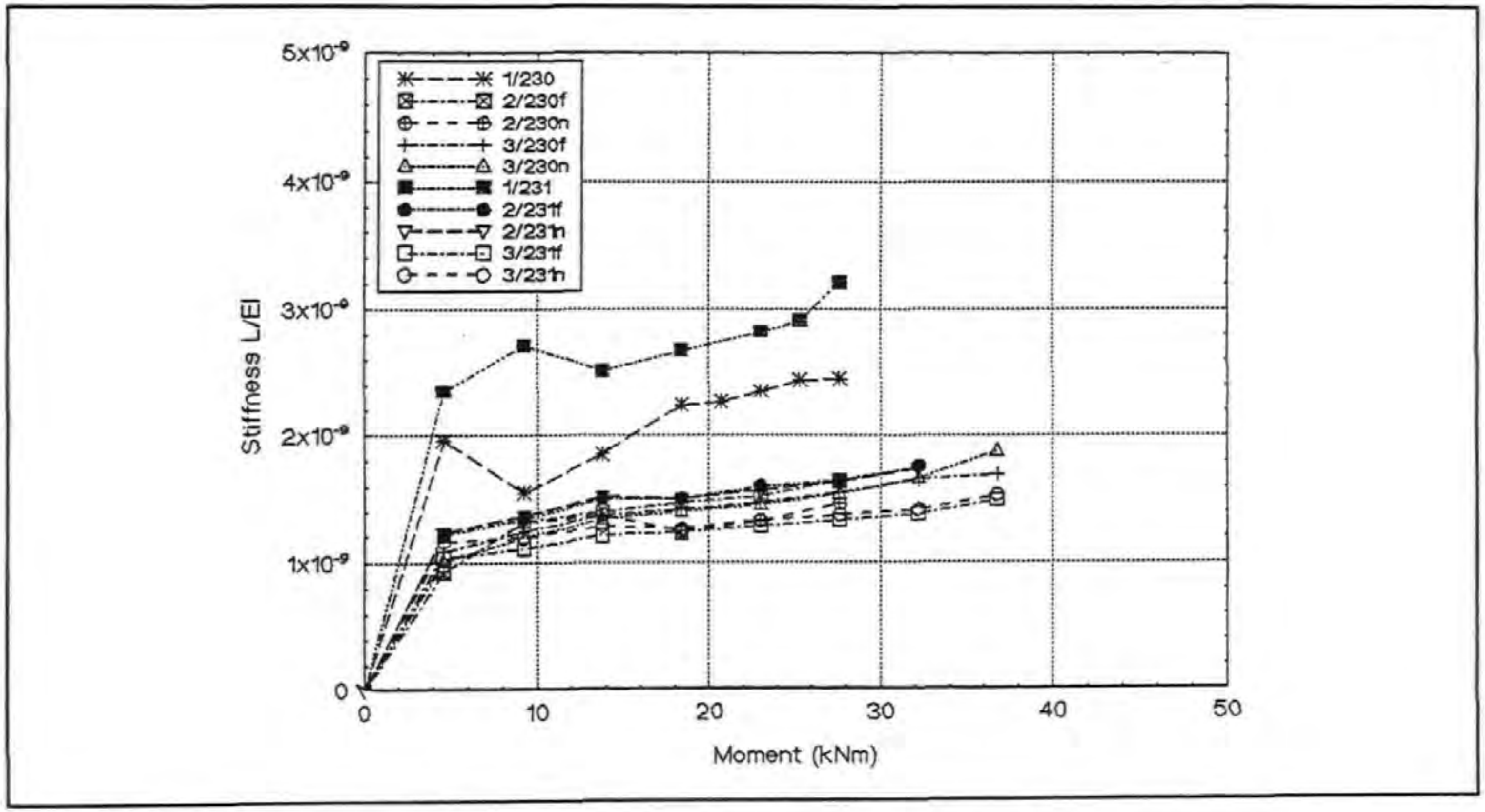
Moment versus beam stiffness - beams 140 & 141

Graph 156



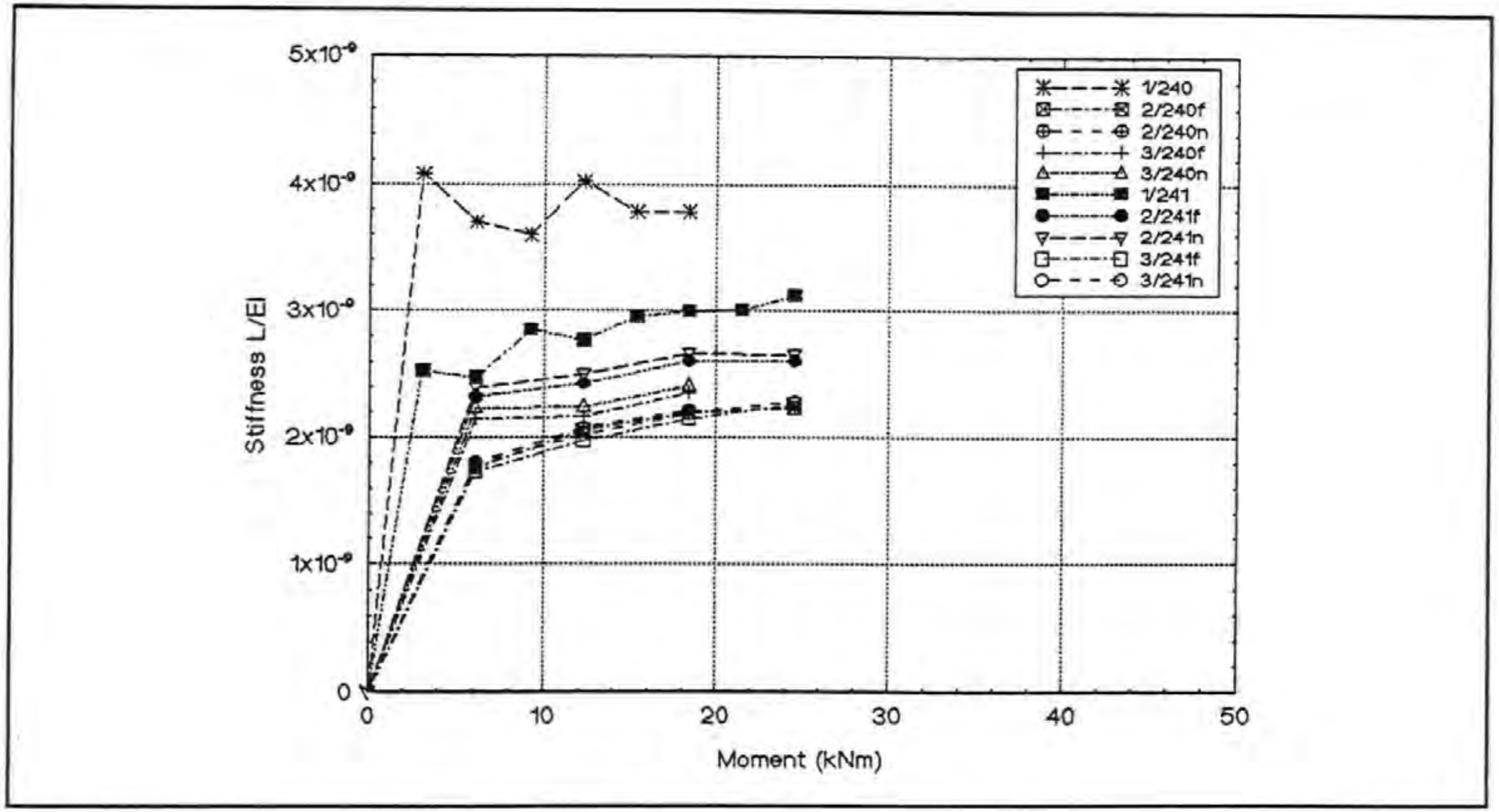
Moment versus beam stiffness - beams 220 & 221

Graph 157



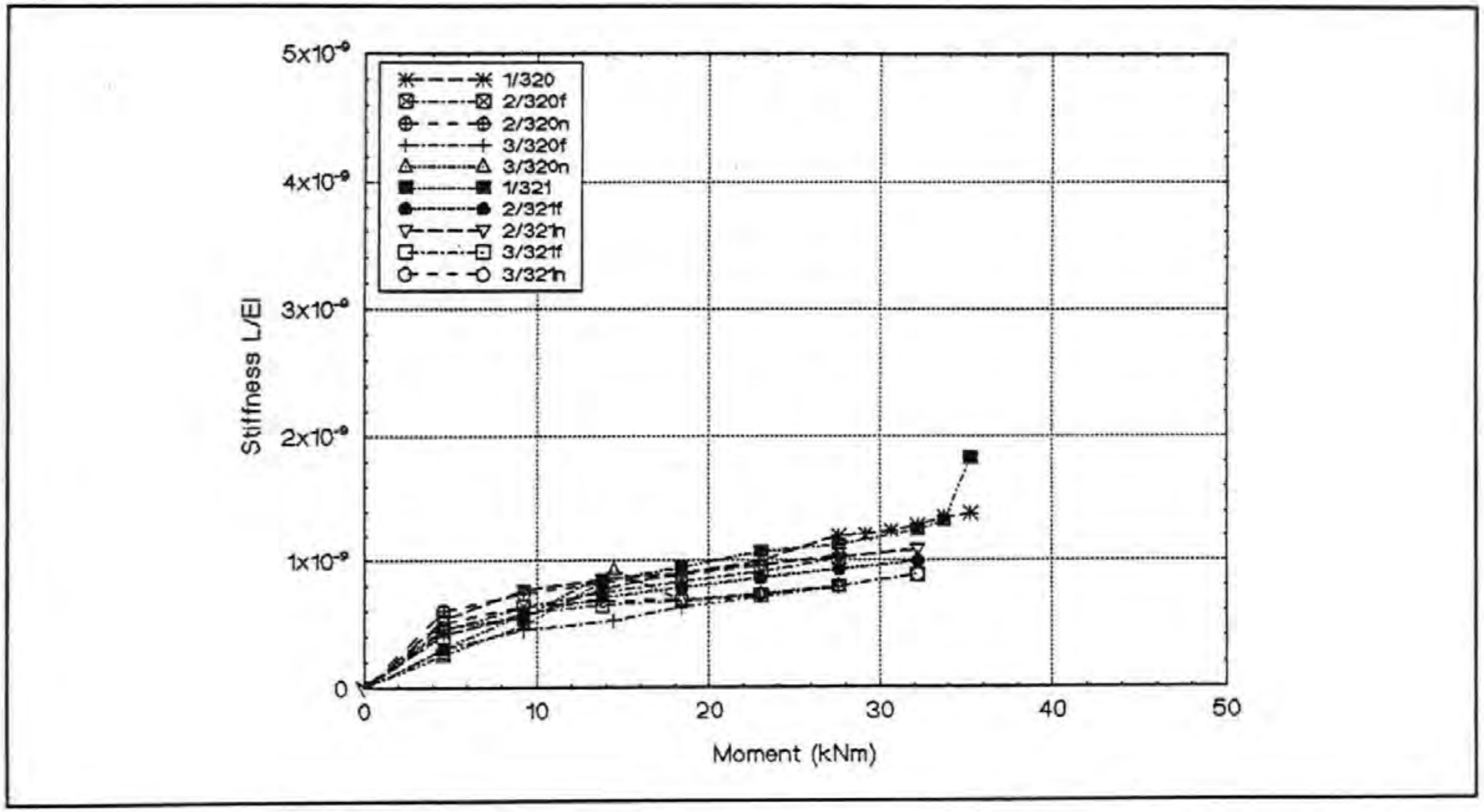
Moment versus beam stiffness - beams 230 & 231

Graph 158



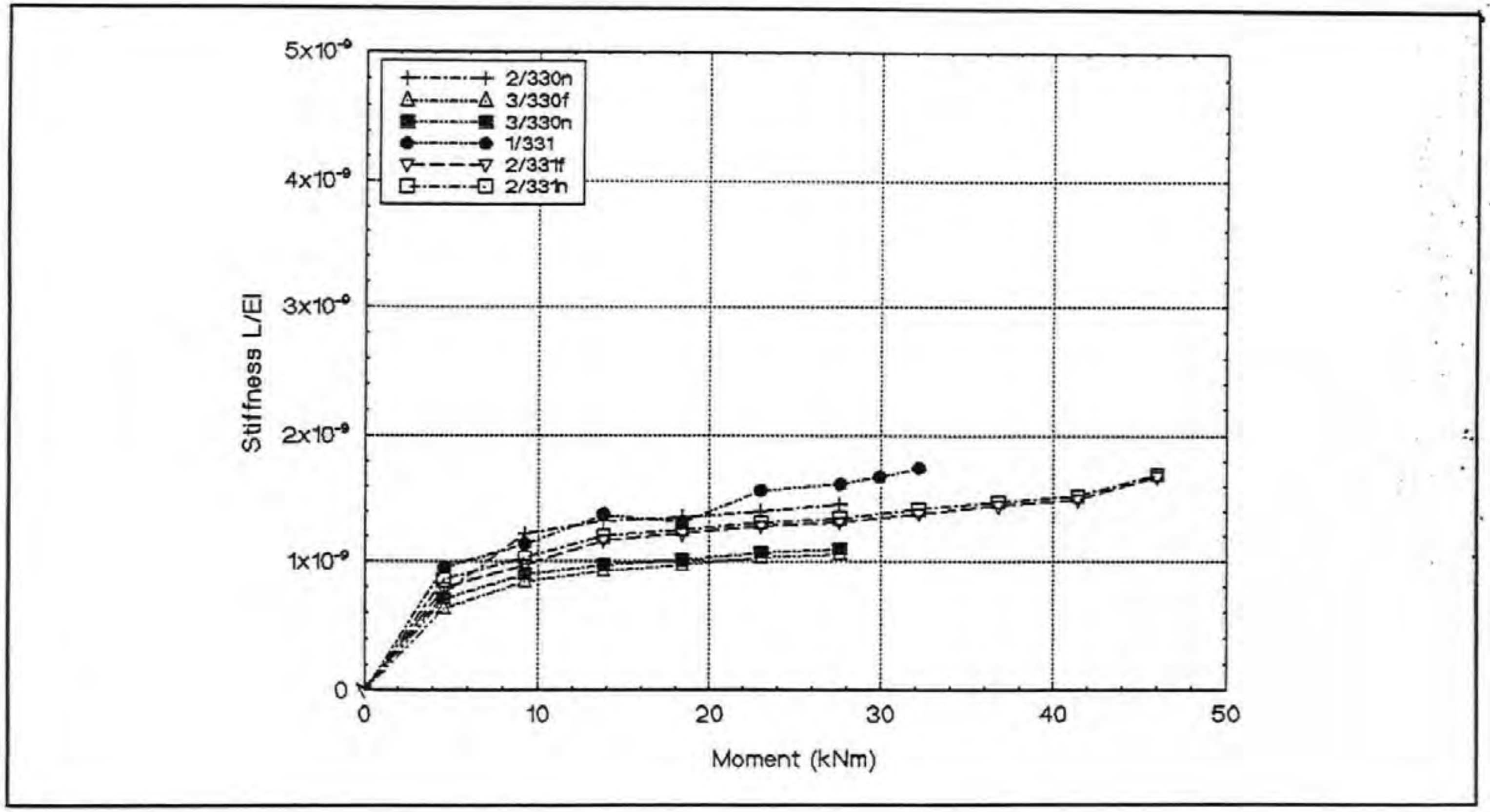
Moment versus beam stiffness - beams 240 & 241

Graph 159



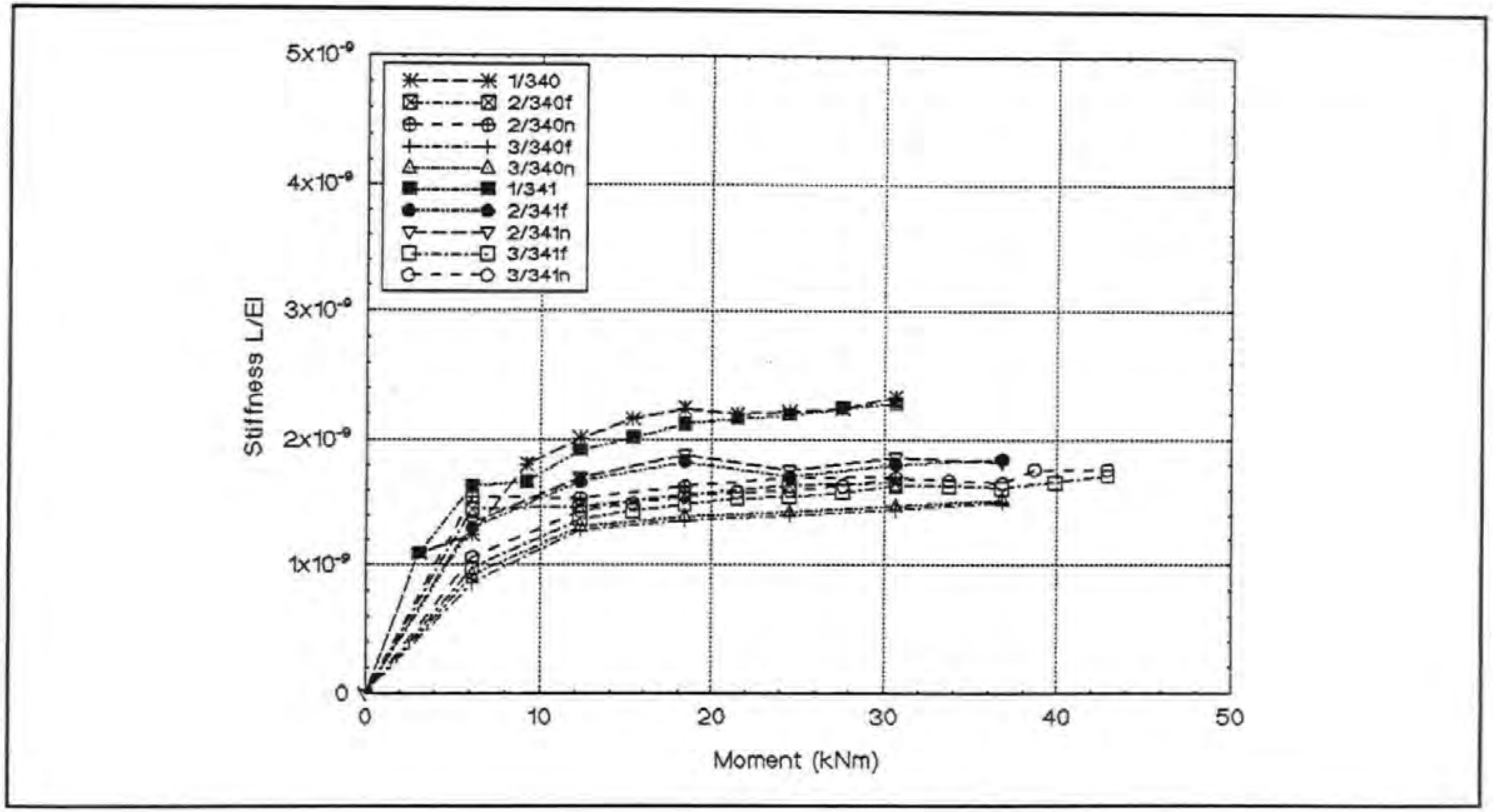
Moment versus beam stiffness - beams 320 & 321

Graph 160



Moment versus beam stiffness - beams 330 & 331

Graph 161



Moment versus beam stiffness - beams 340 & 341

Graph 162

APPENDIX 3

**Figures, Tables
and photographic plates**

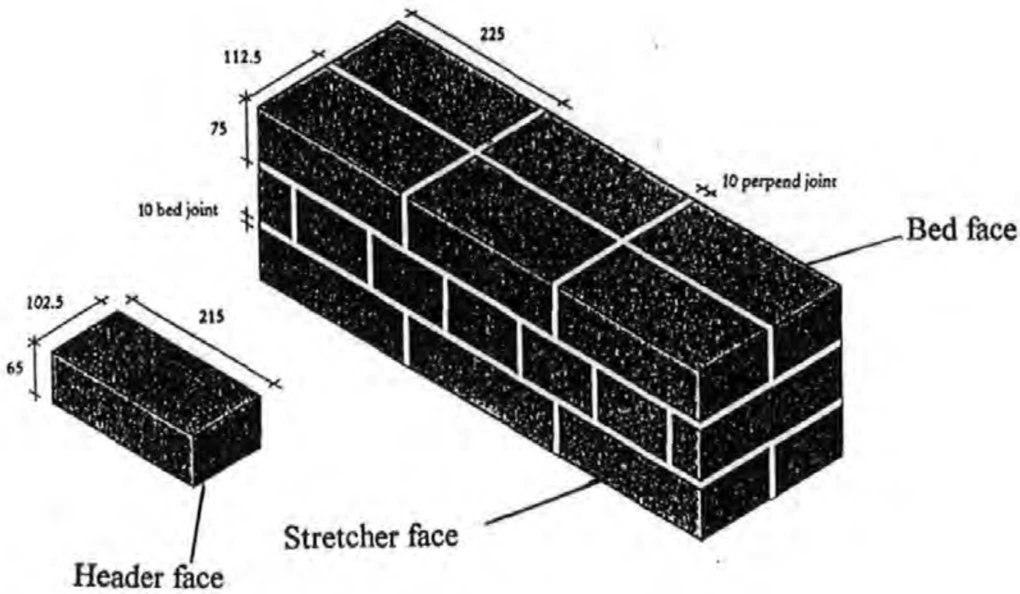
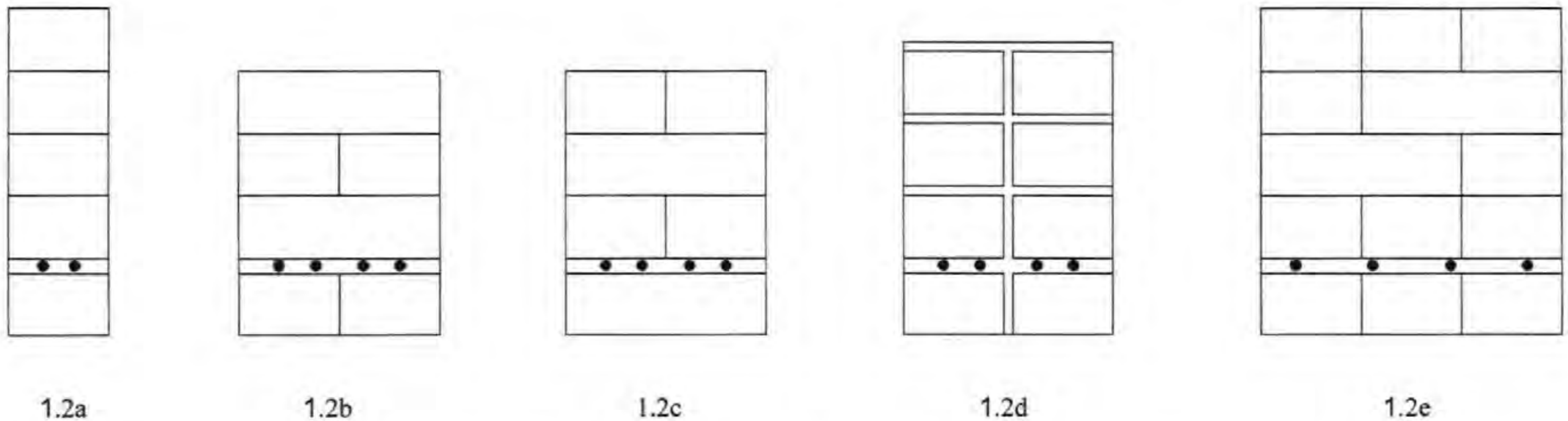


Figure 1.1 – Brick and Brickwork Dimensions and Notations



Figures 1.2a to 1.2e – Cross section of Beams with Bed Joint Reinforcement

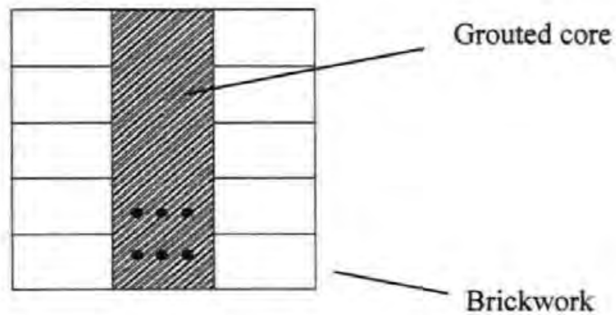


Figure 1.2f Cross section of a Grouted Cavity Beam

Figure 1.2 – Cross sections of various Reinforced Brickwork Beams

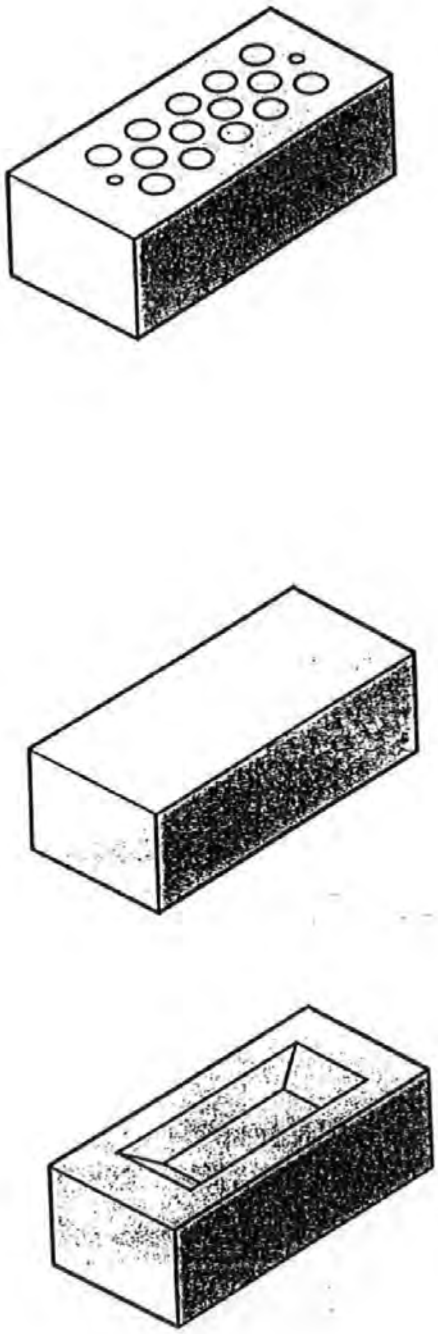


Figure 1.3 – Brick Types
Perforated, Solid and Frog

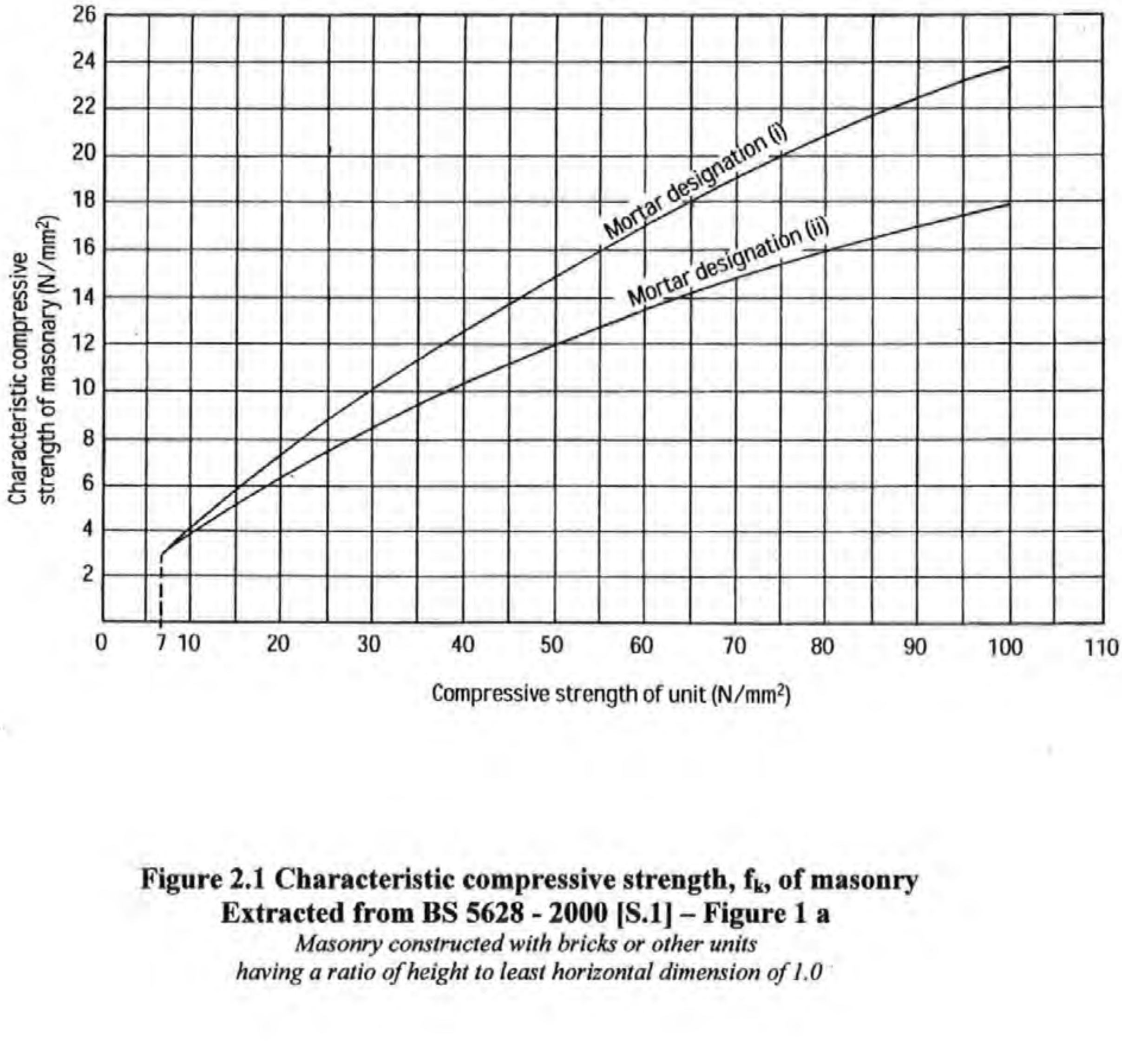
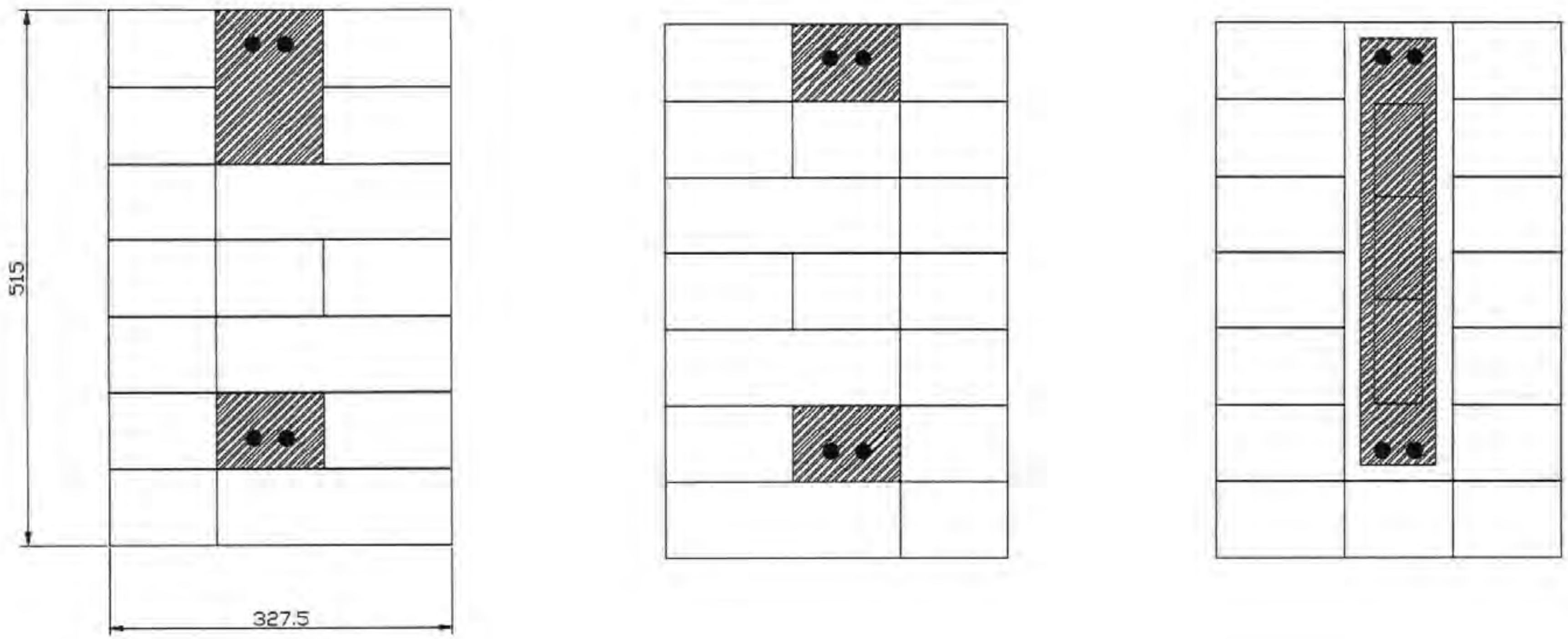


Figure 2.1 Characteristic compressive strength, f_k, of masonry
Extracted from BS 5628 - 2000 [S.1] – Figure 1 a

Masonry constructed with bricks or other units
having a ratio of height to least horizontal dimension of 1.0



Cross sections along the length of a Garwood and Tomlinson Beam.

Figure 2.4 – Three cross sections from a Garwood and Tomlinson Test Beam

Note: Steel ties were used to join the outer brickwork and central core of brick/grout. Of note is the significant use of snap headers.

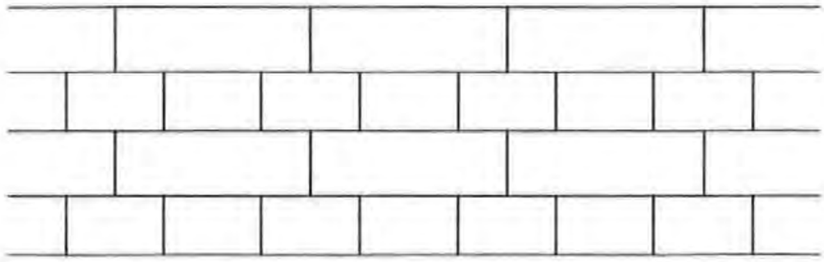


Figure 3.1a – English Bond

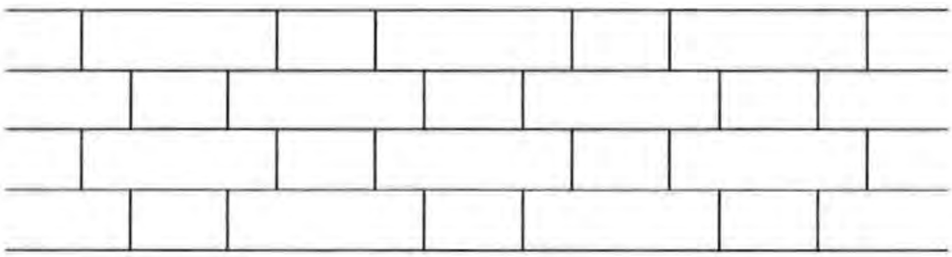


Figure 3.1b – Flemish Bond

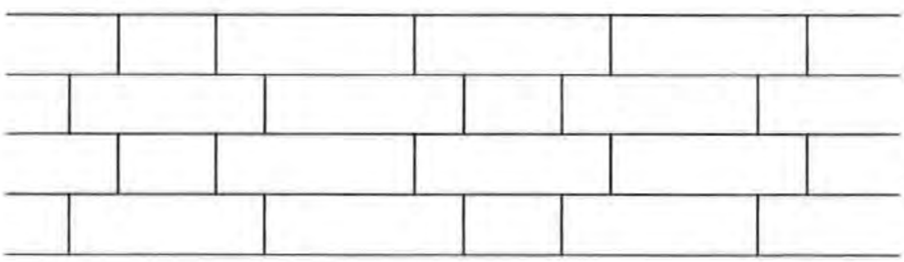


Figure 3.1c – Sussex or Garden Wall Bond

Figure 3.1 – Elevations of Brickwork Bonding Formats

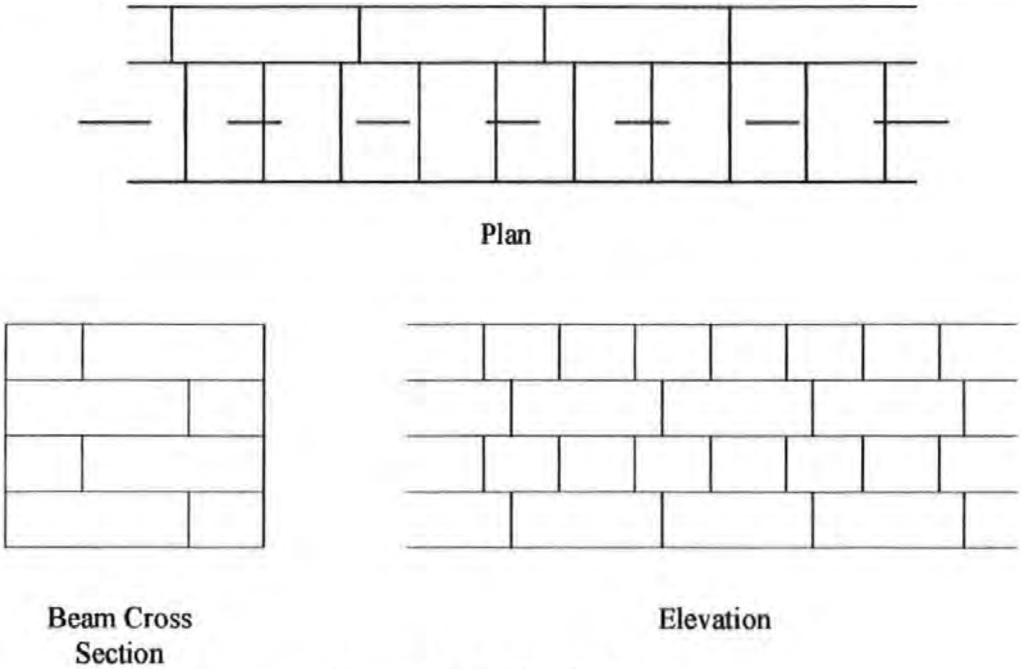


Figure 3.2a – English Bond

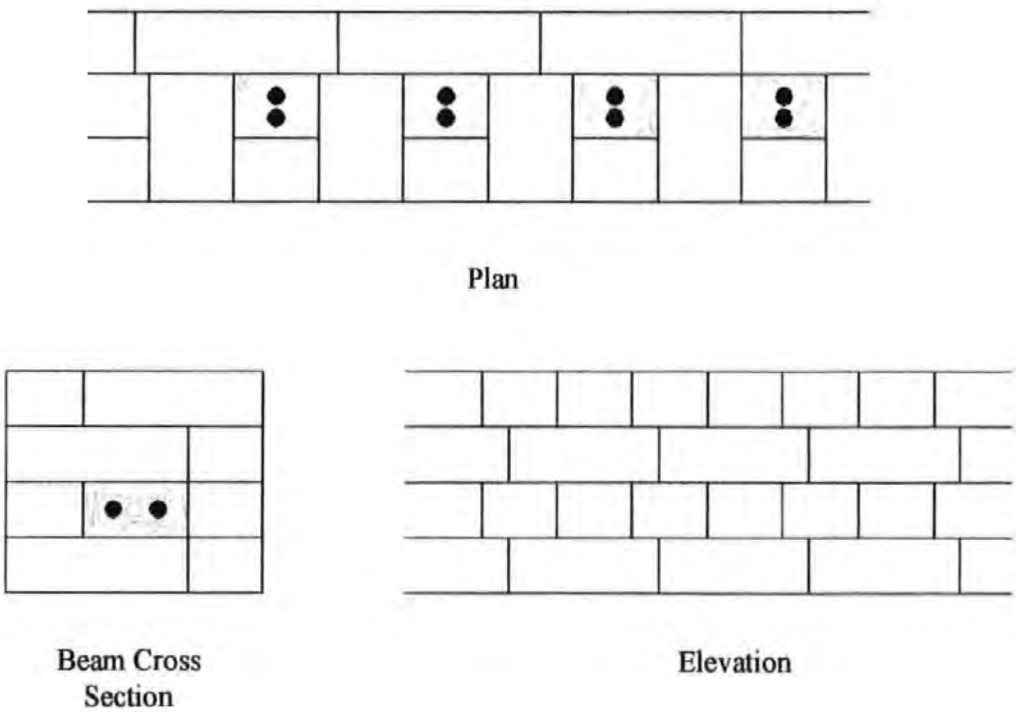


Figure 3.2b – Modified English Bond

Figure 3.2 – English Bond and Modified English Bond

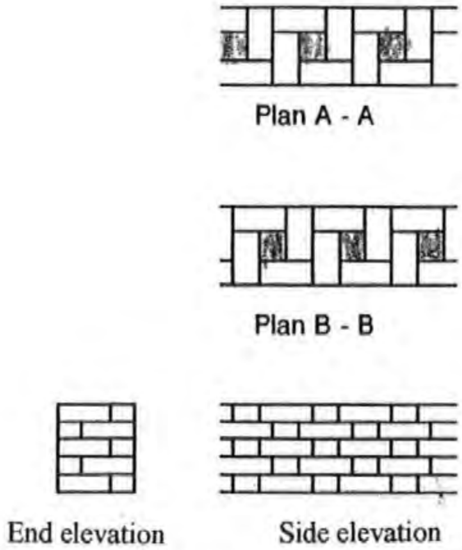


Figure 3a - Flemish Bond

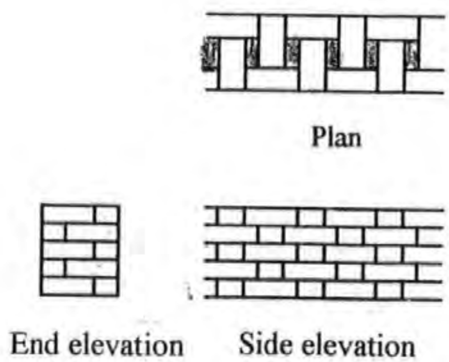


Figure 3.b – Modified Flemish Bond

Figure 3.3- Flemish Bond

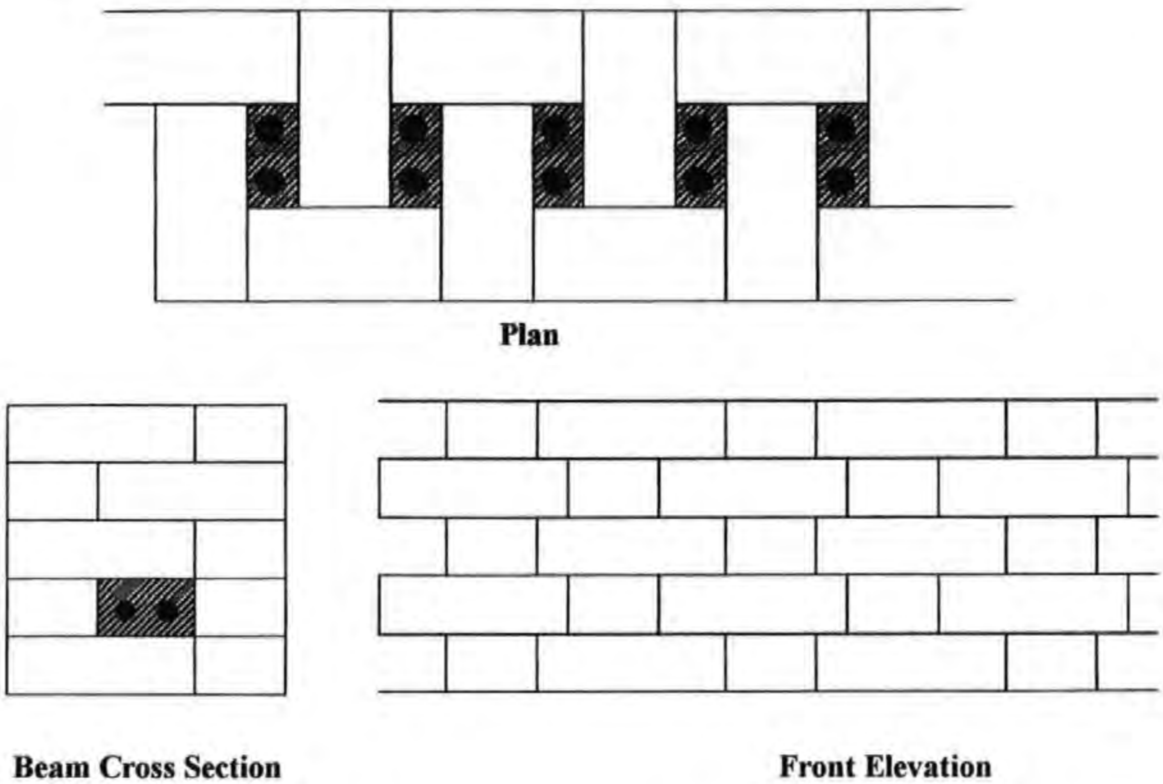


Figure 3.4a – Quetta Bond

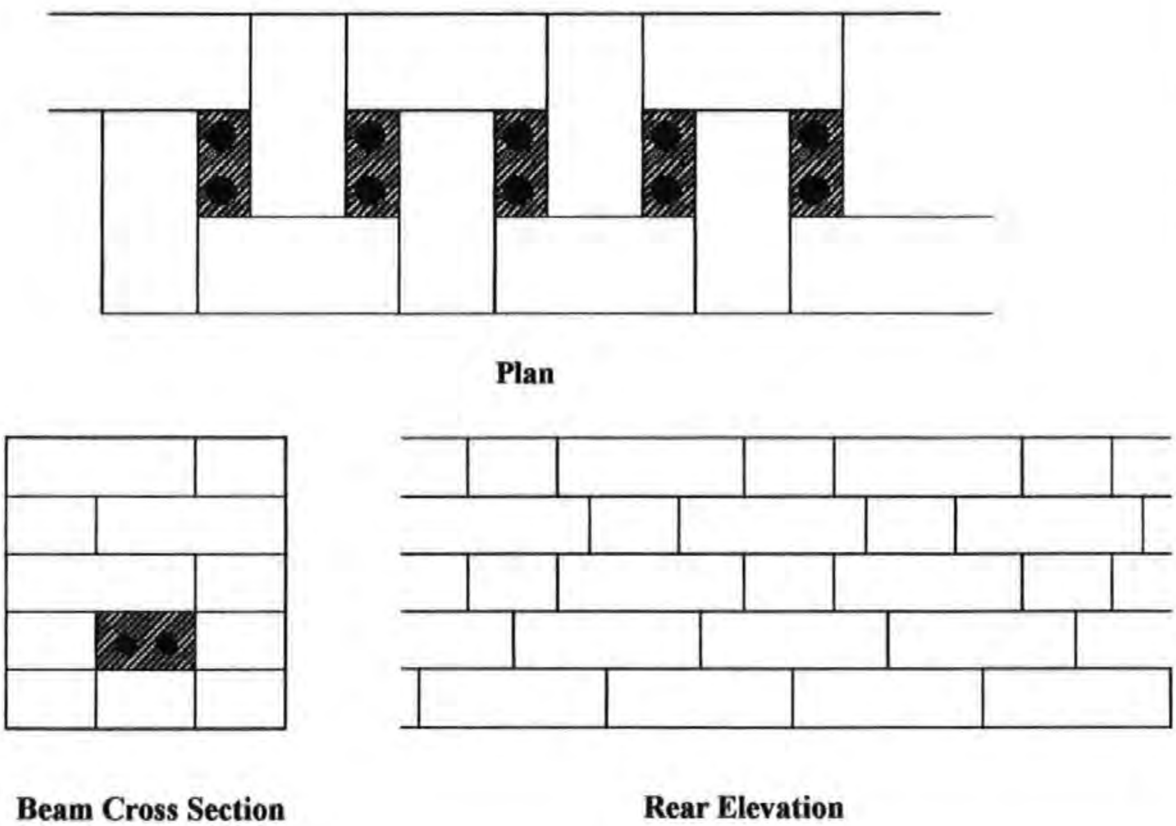


Figure 3.4 b– Quetta Style Bond

Figure 3.4 – University of Plymouth Quetta Style Bond

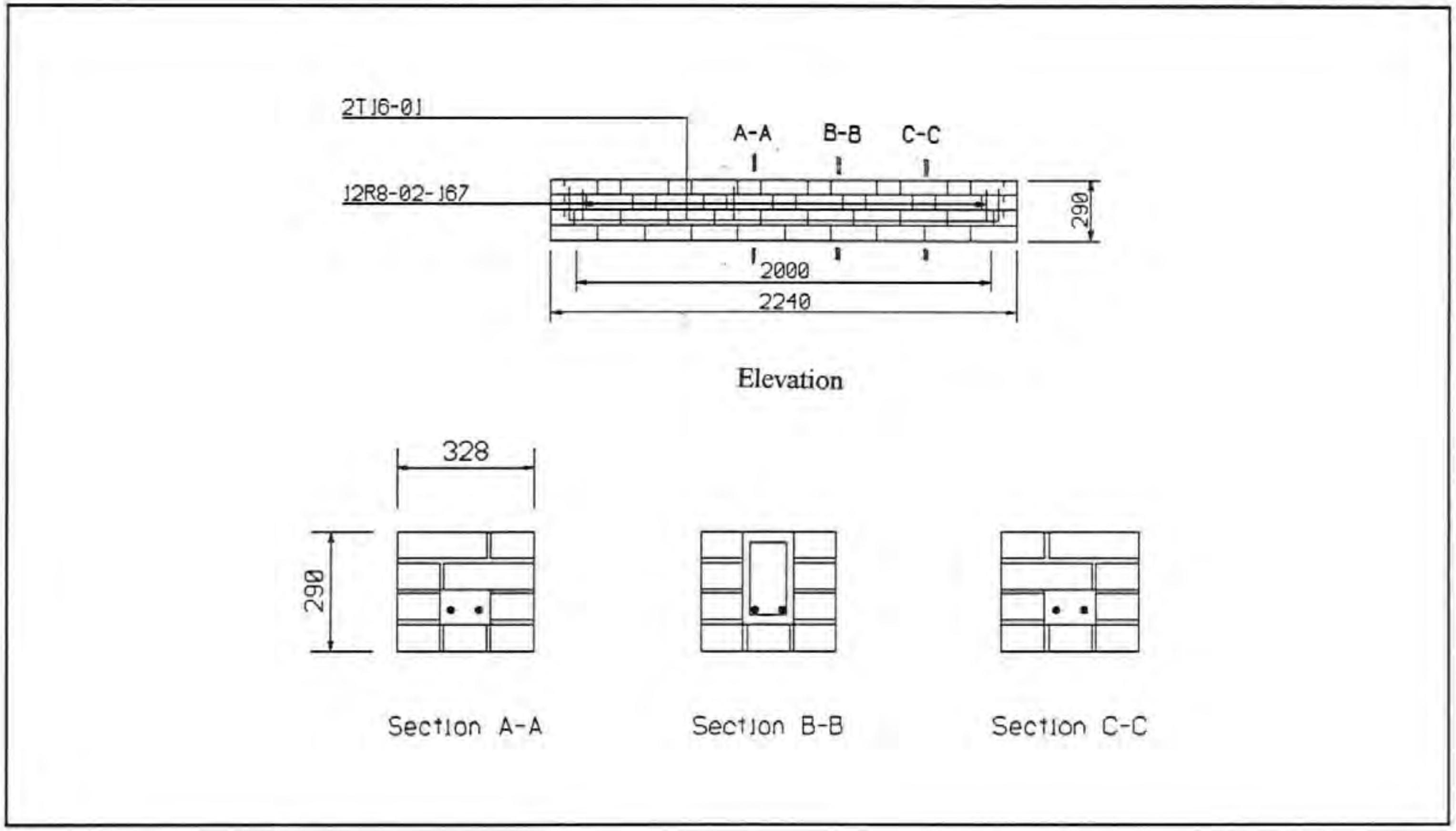


Figure 3.5 - Details of 2m Span UOP Quetta Style Test Beam

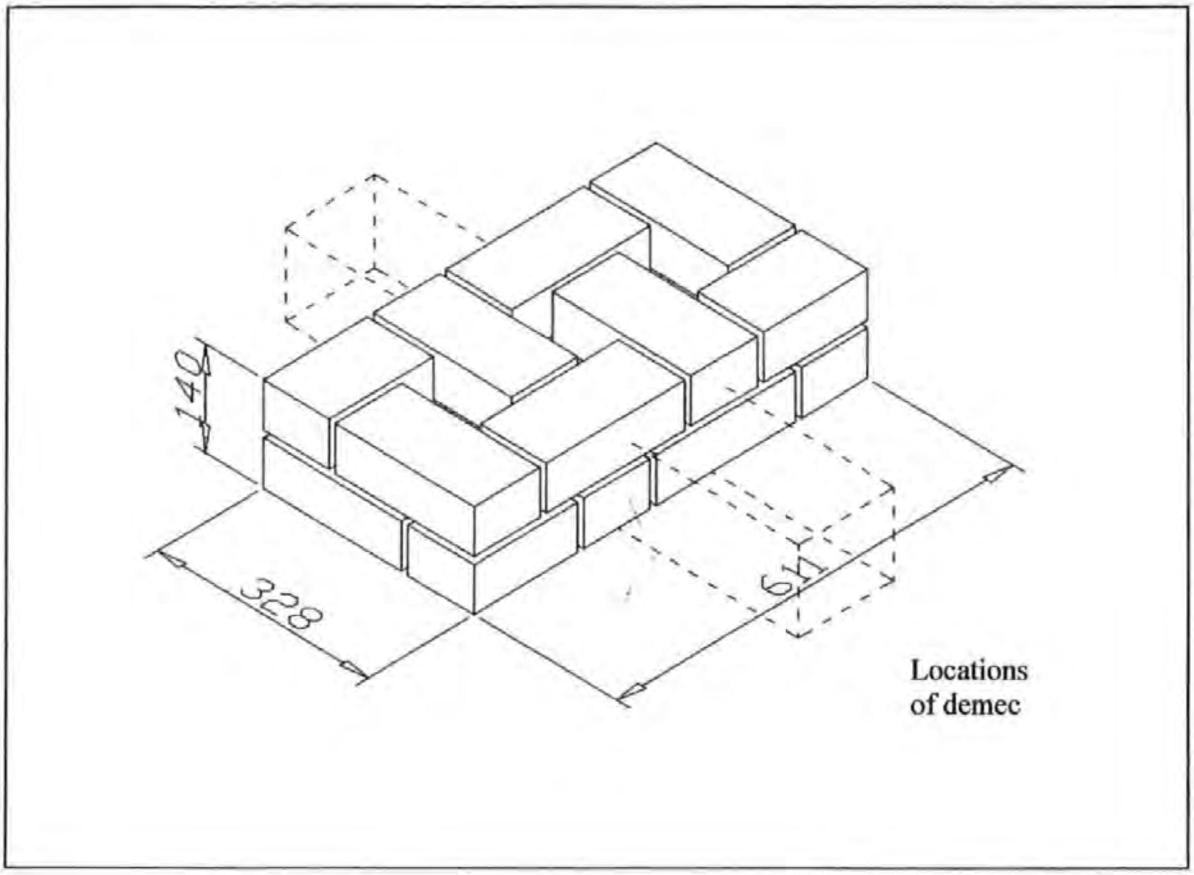


Figure 4.1 – Typical UOP Quetta Style Beam prism specimen

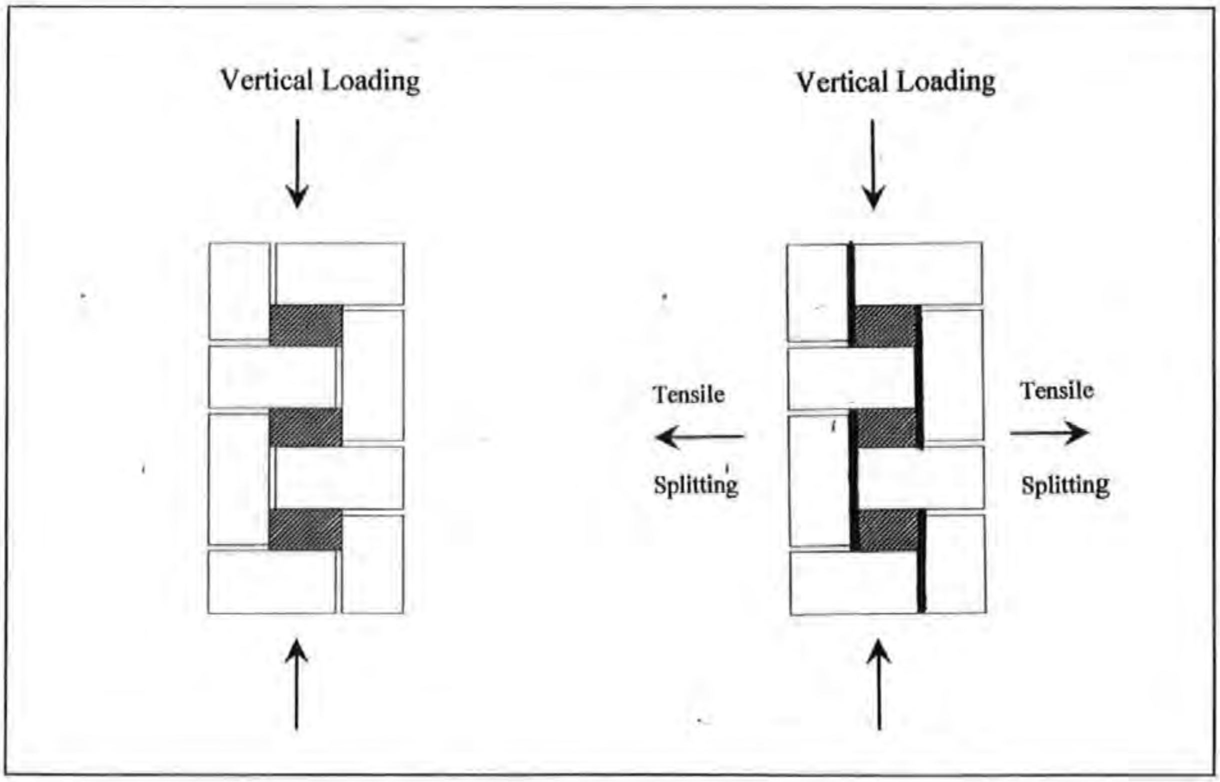


Figure 4.2 – Typical UOP Quetta Style Beam prism
Behaviour under load

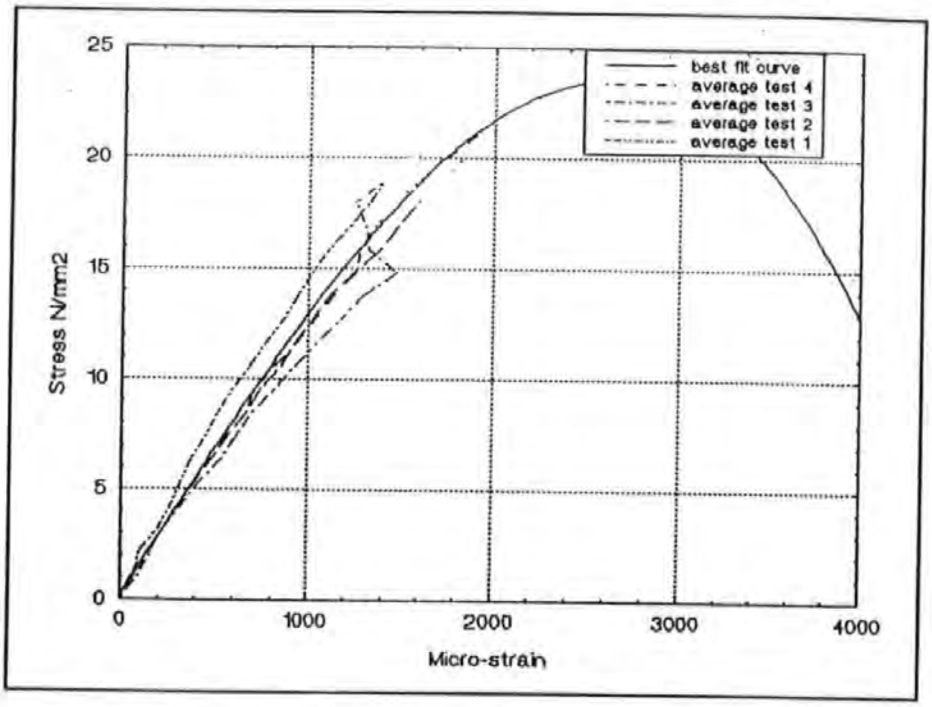


Figure 4.3a – Brick Prism Tests, Stress/Strain Plots, Brick Type 1

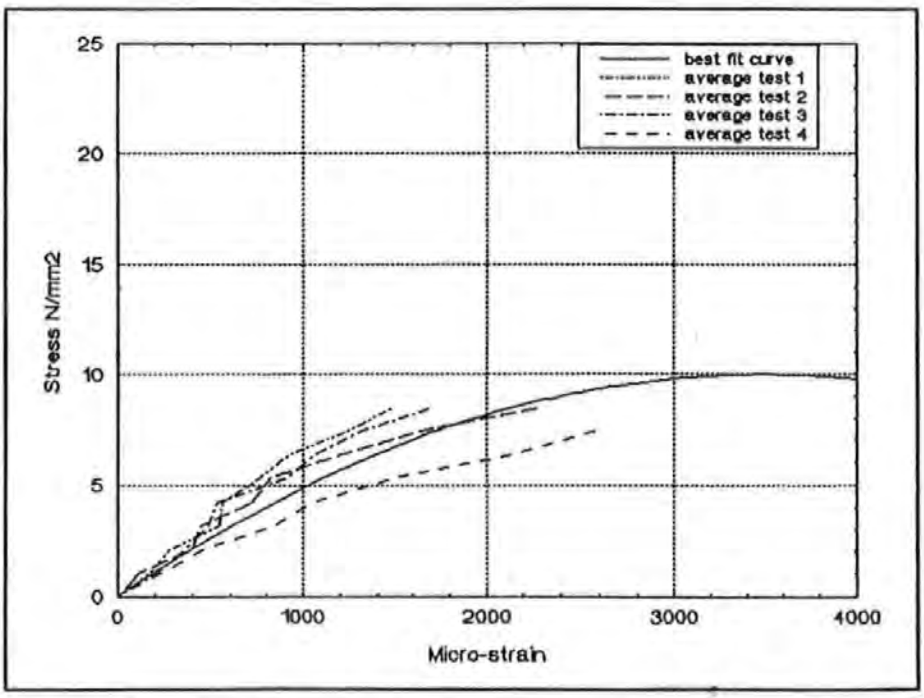


Figure 4.3b – Brick Prism Tests, Stress/Strain Plots, Brick Type 2

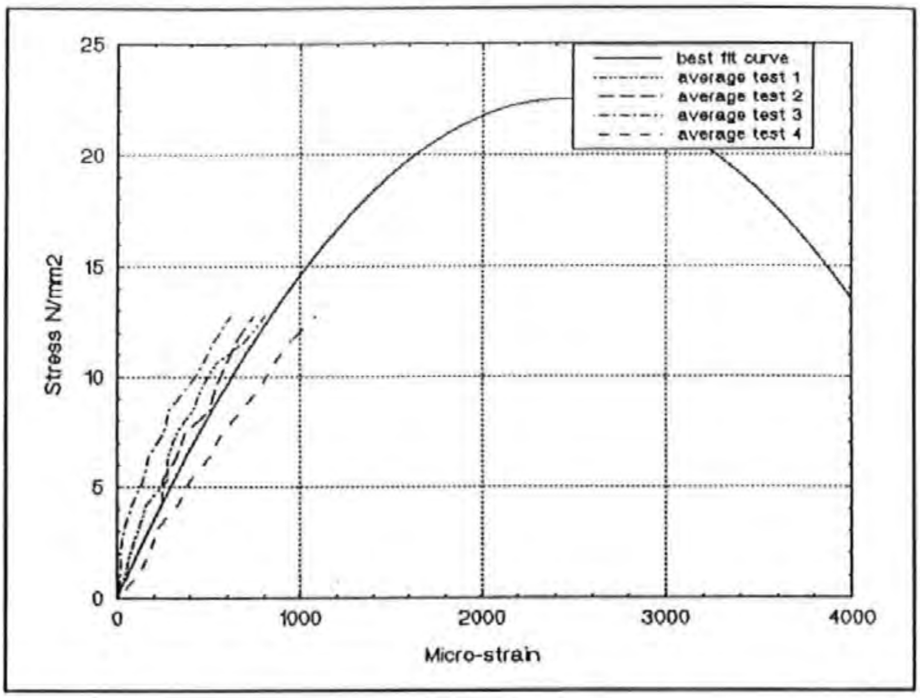


Figure 4.3c – Brick Prism Tests, Stress/Strain Plots, Brick Type 3

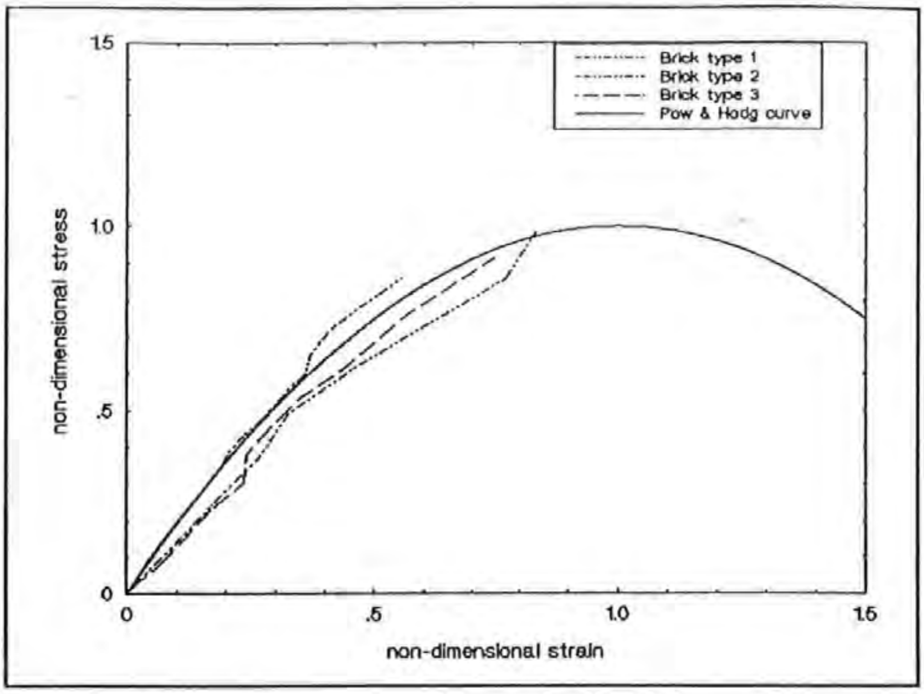


Figure 4.4 – Brick Prism Tests, Mean Non-dimensional Plot Of Stress/Strain

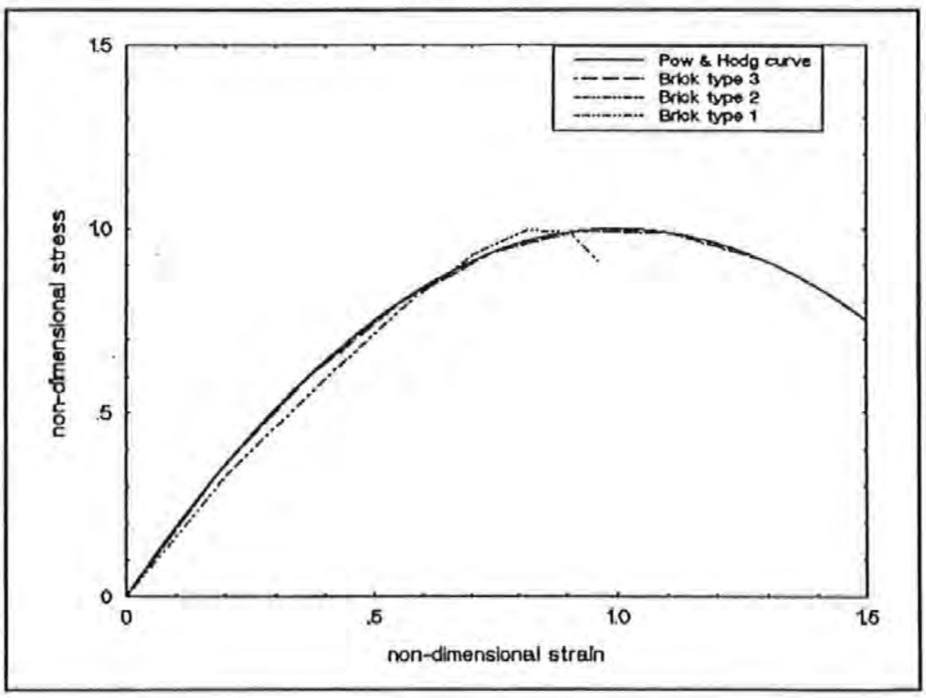


Figure 4.5 – Brick Prism Tests, Idealised Non-dimensional Plot Of Stress/Strain

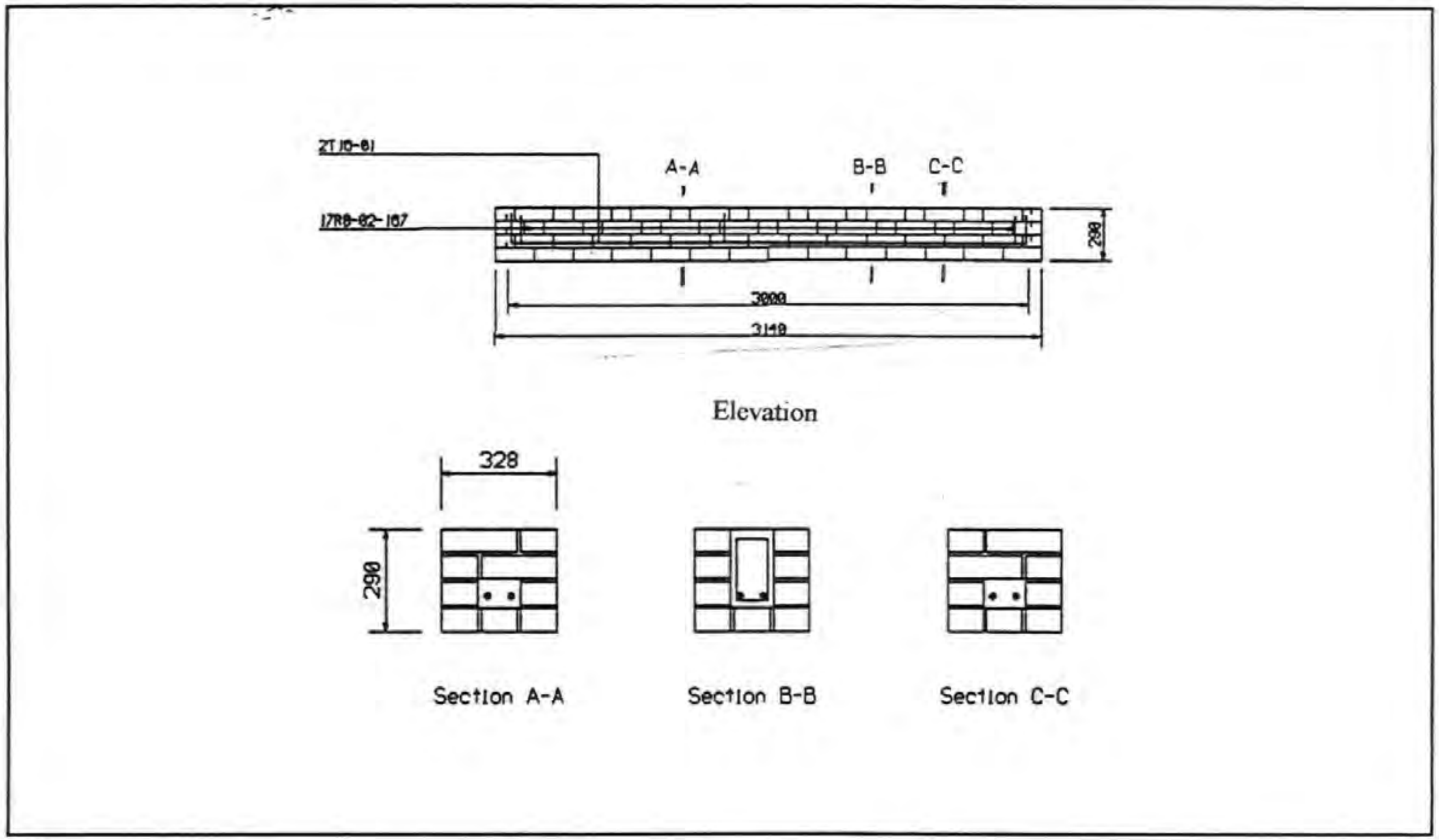


Figure 4.6 – UOP Quetta Style Test Beam, 3m span

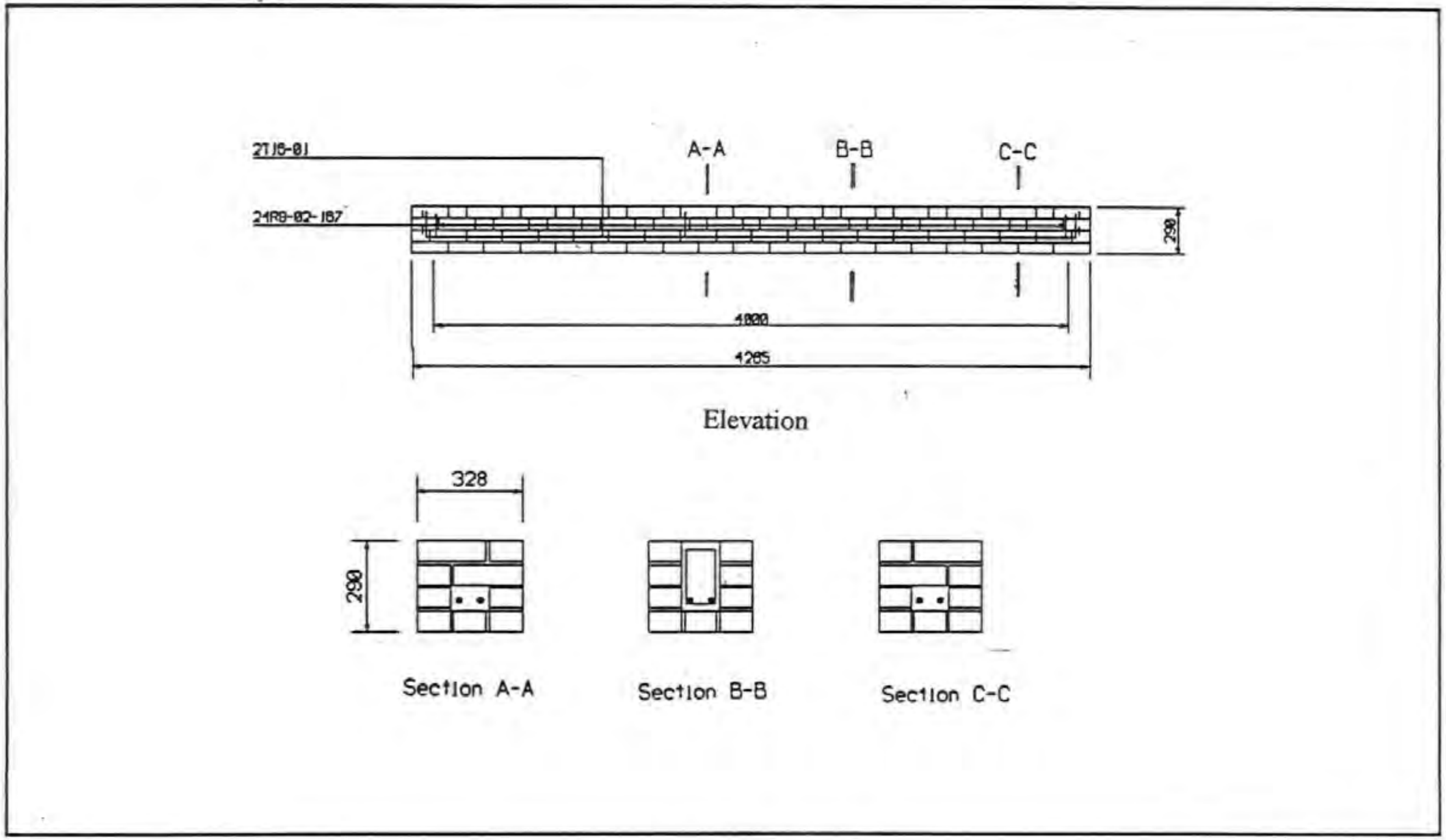


Figure 4.7 – UOP Quetta Style Test Beam, 4m span

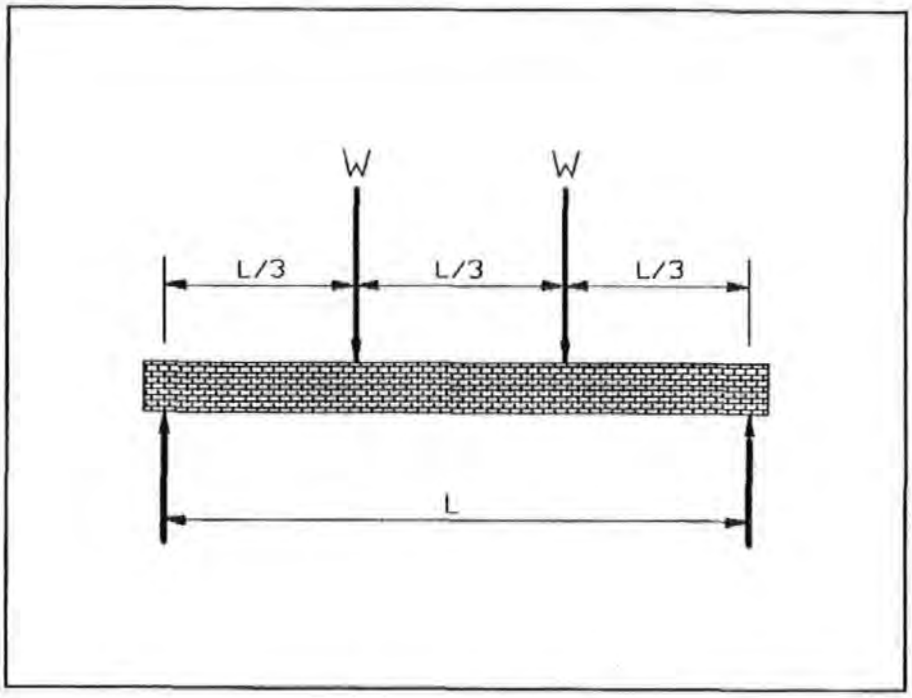


Figure 4.8 UOP Quetta Style Test Beam. Loading Arrangement

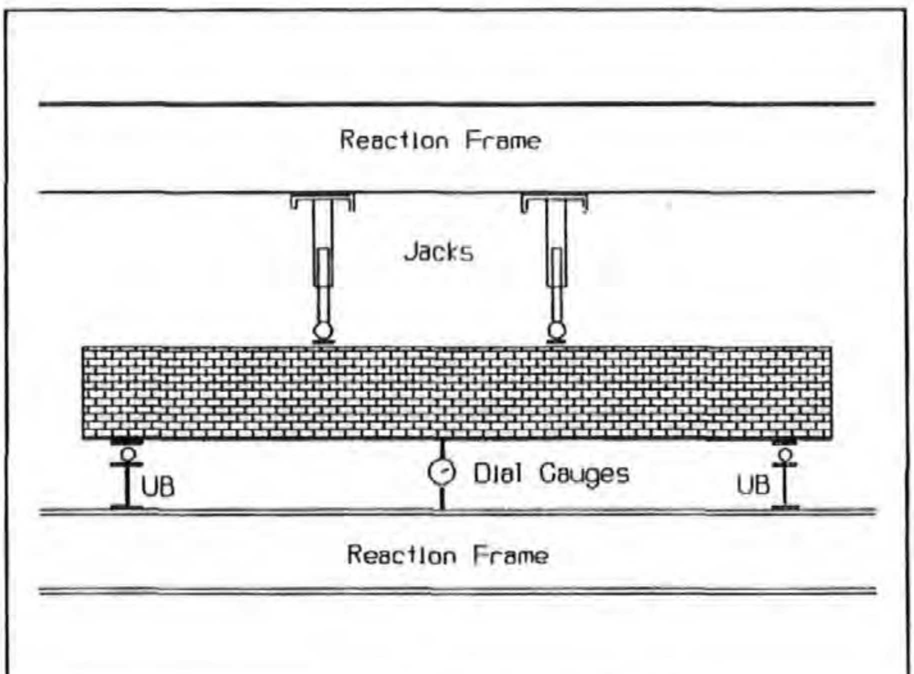


Figure 4.9 UOP Quetta Style Test Beam. Loading Apparatus

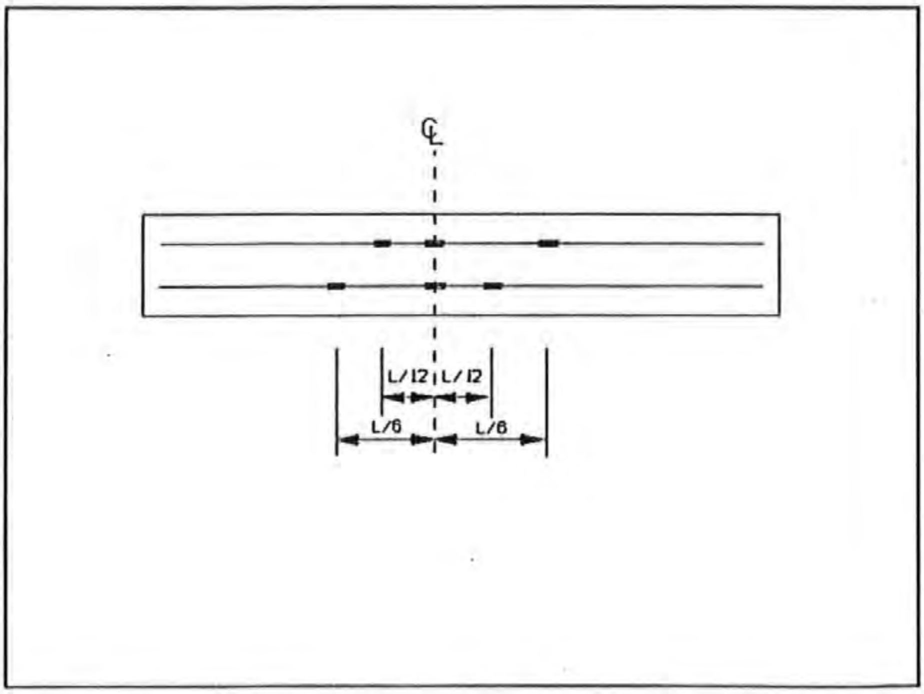


Figure 4.10 - UOP Quetta Style Test Beam
Plan of Beam Showing Locations of Active Electrical Resistance Strain Gauges
In Tensile Reinforcing Bars

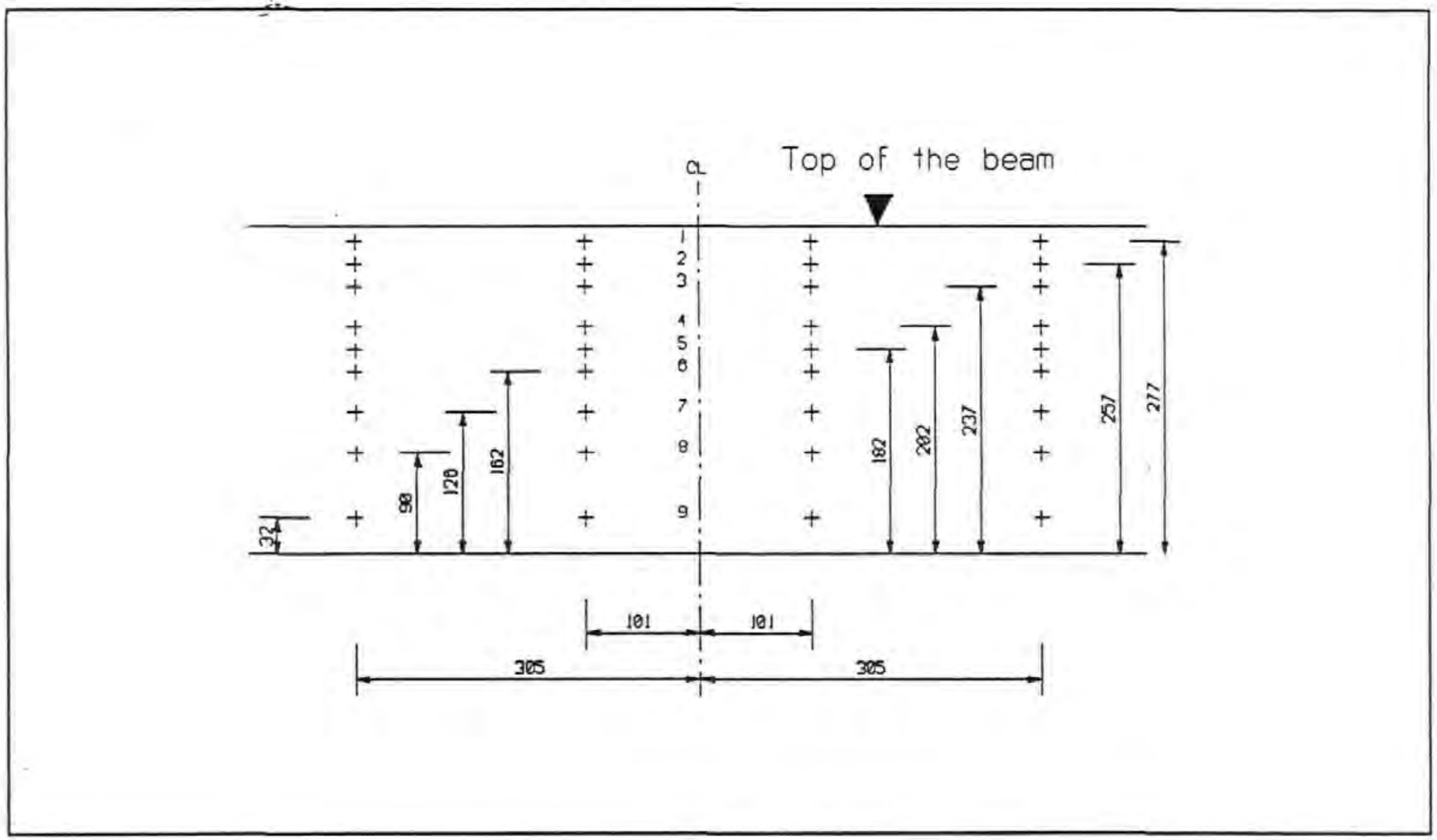


Figure 4.11 - UOP Quetta Style Test Beam
Elevation of Beam Showing Locations of Demec Studs

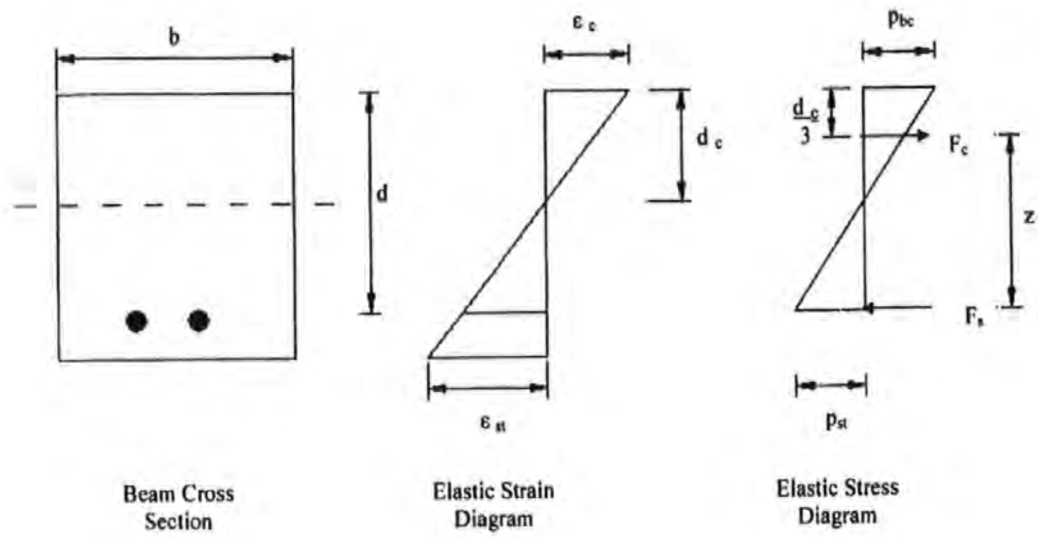


Figure 5.3 Theoretical linear elastic stress and strain diagrams

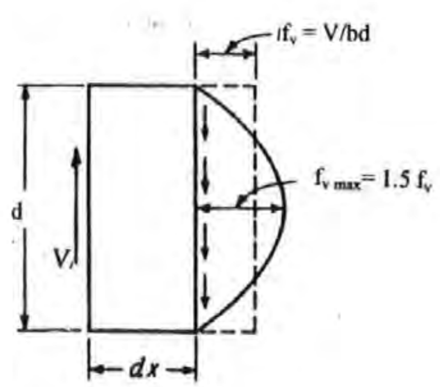


Figure 5.4 Shear stress distribution diagram

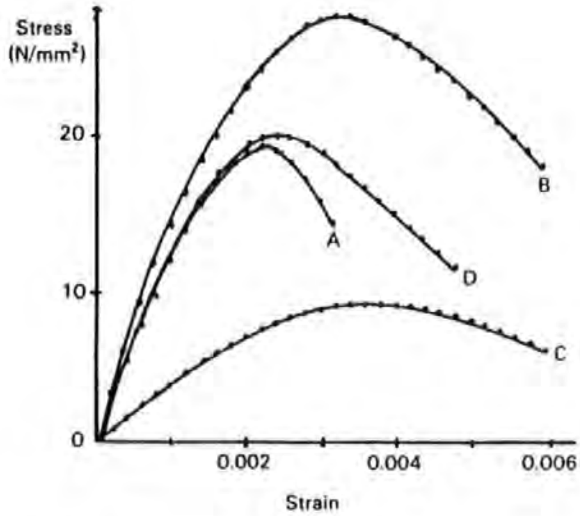


Figure 5.5 Stress-strain curves for four different bricks in compression (Powell and Hodgkinson [37])

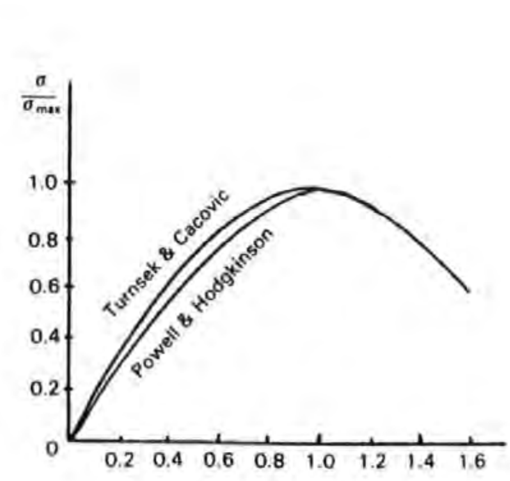


Figure 5.6a Idealised dimensionless stress-strain curves for brickwork (Hendry[80])

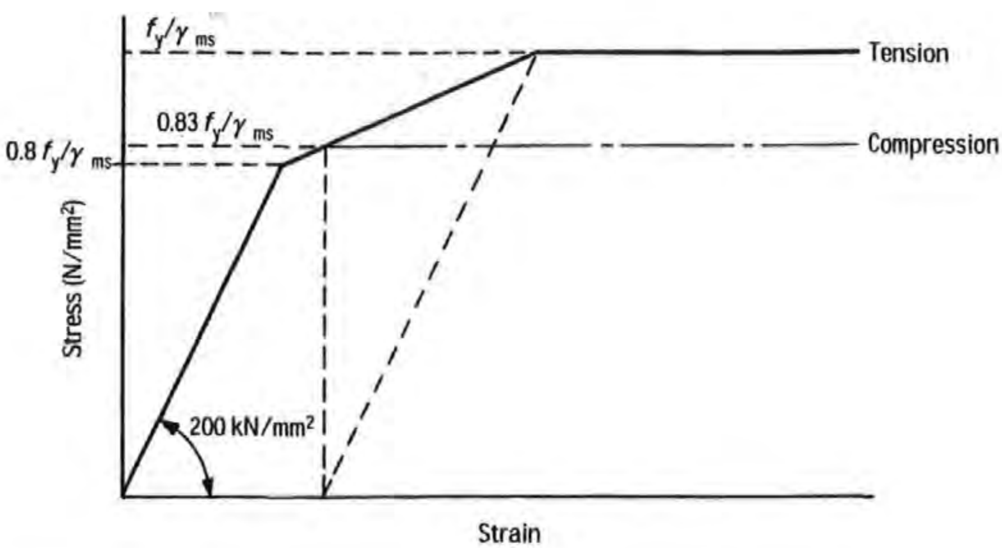


Figure 5.6b Idealised short term design stress-strain curve for reinforcement (BS 5628 Part 2, Figure2 [S.1])

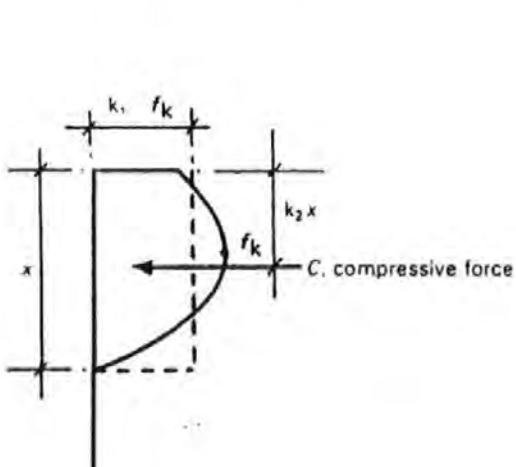
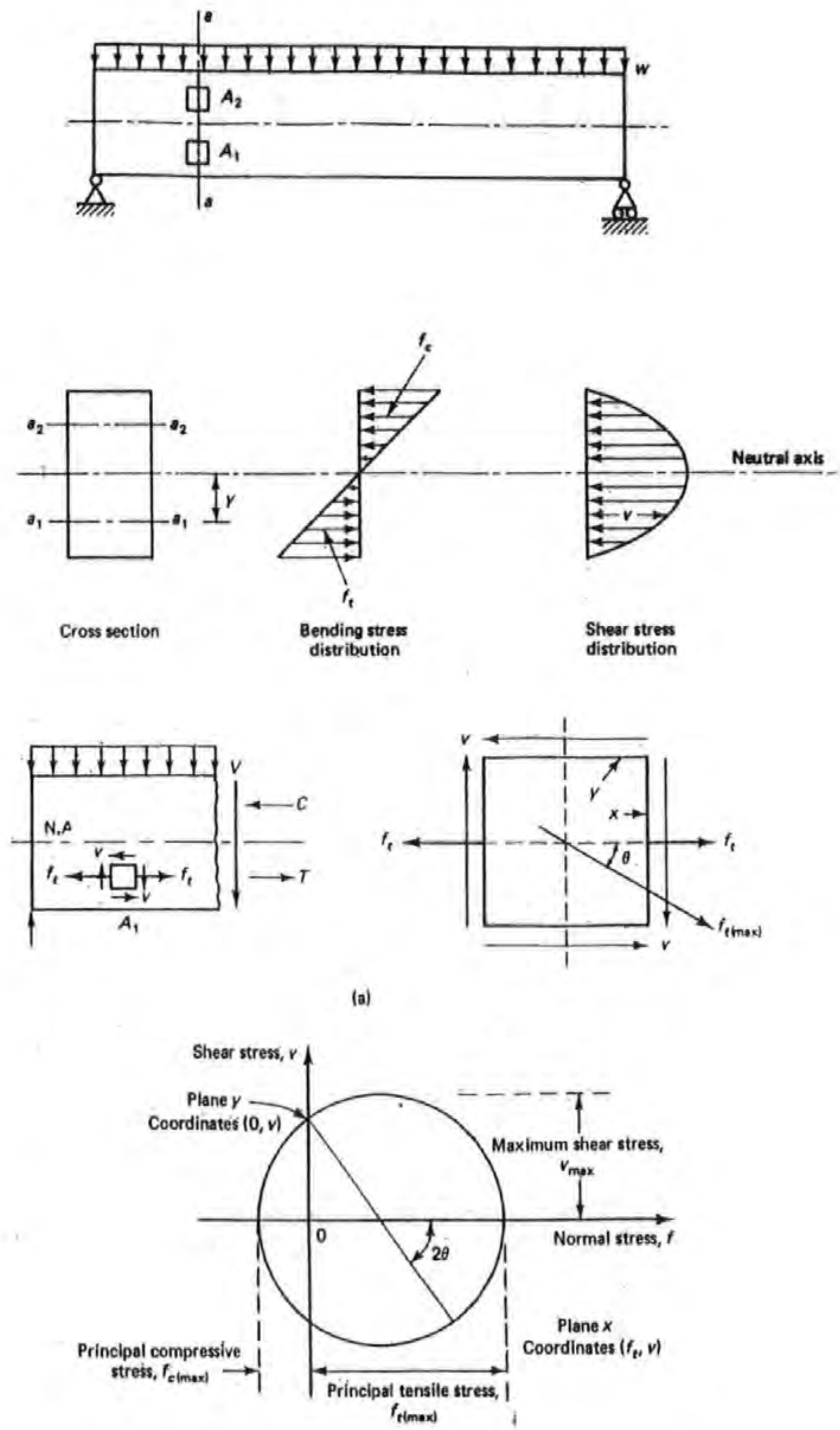


Figure 5.7 Rectangular-parabolic stress diagram for singly reinforced brickwork beam (Hendry[80])



(b)

Figure 5.8 Typical Mohr's circle representation of stress in an element A_1 (Nawy [80])

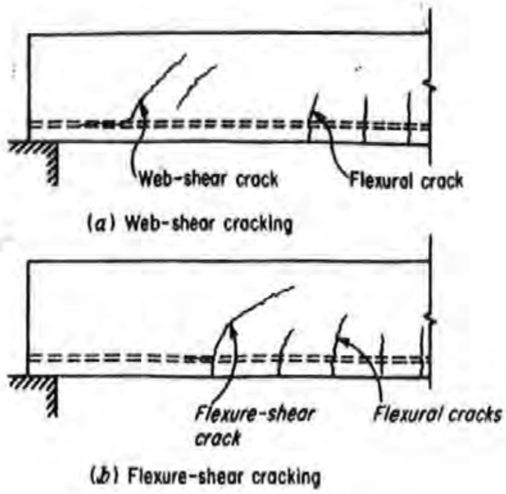


Figure 5.9 Web-shear, flexure-shear and flexure cracks

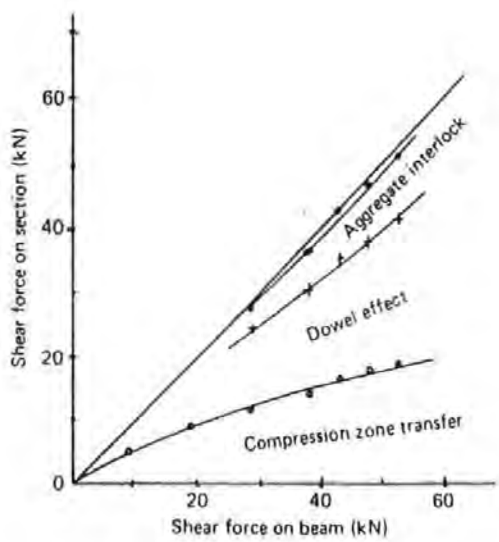


Figure 5.10 Shear transmission by different mechanisms in a grouted cavity beam (Osman and Hendry[68])

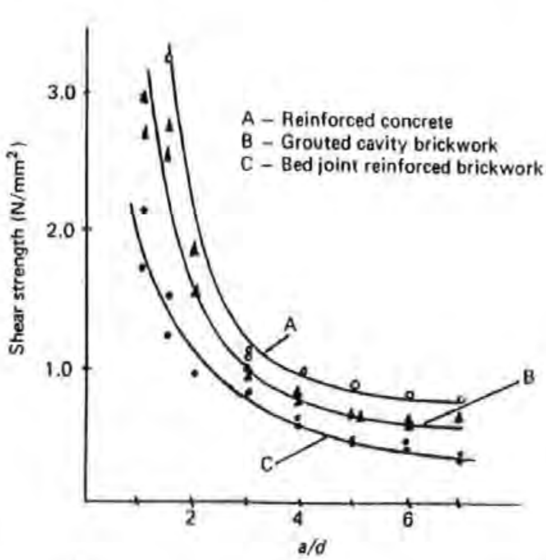
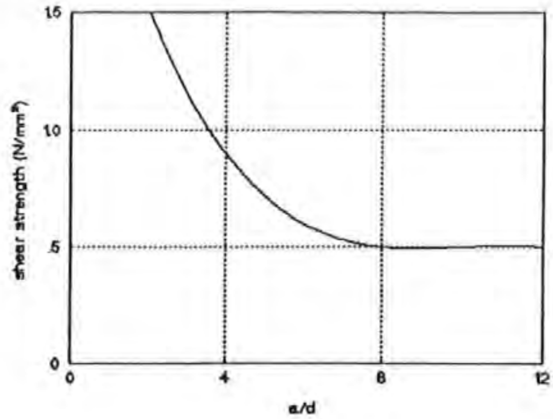


Figure 5.11 Shear strength of grouted cavity brickwork against shear span ratio (Suter and Keller[80])



(after Sinha and deVekey[76])

Figure 5.12 Shear span versus shear span/depth ratio

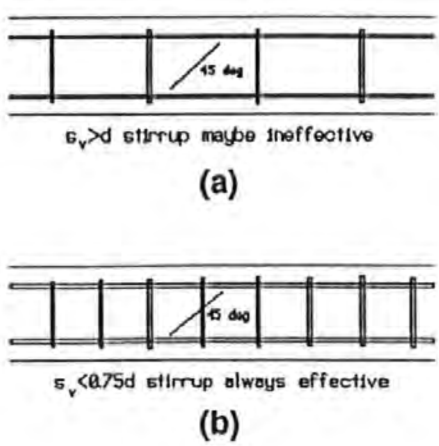
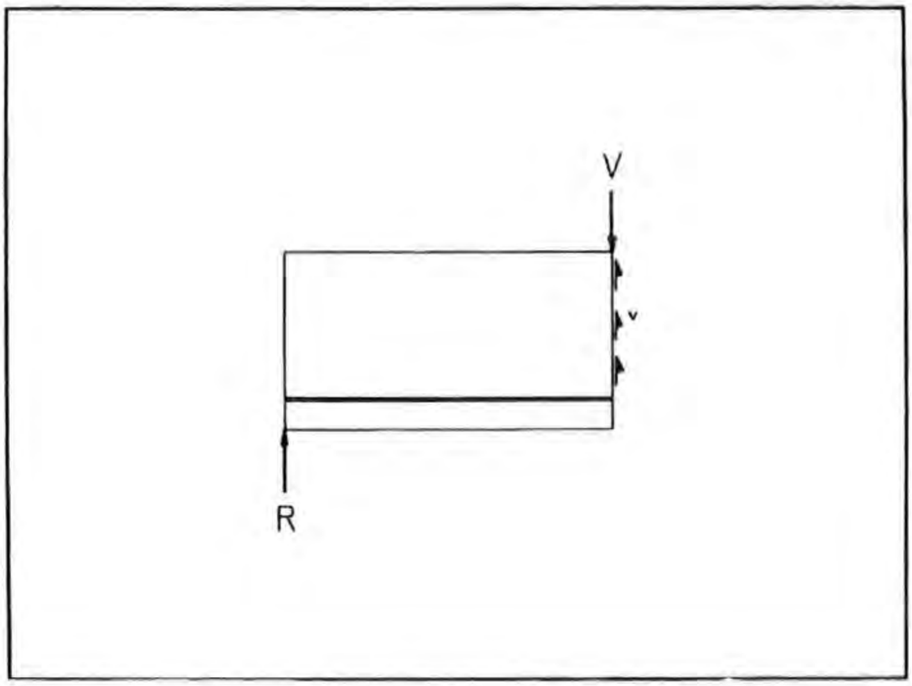
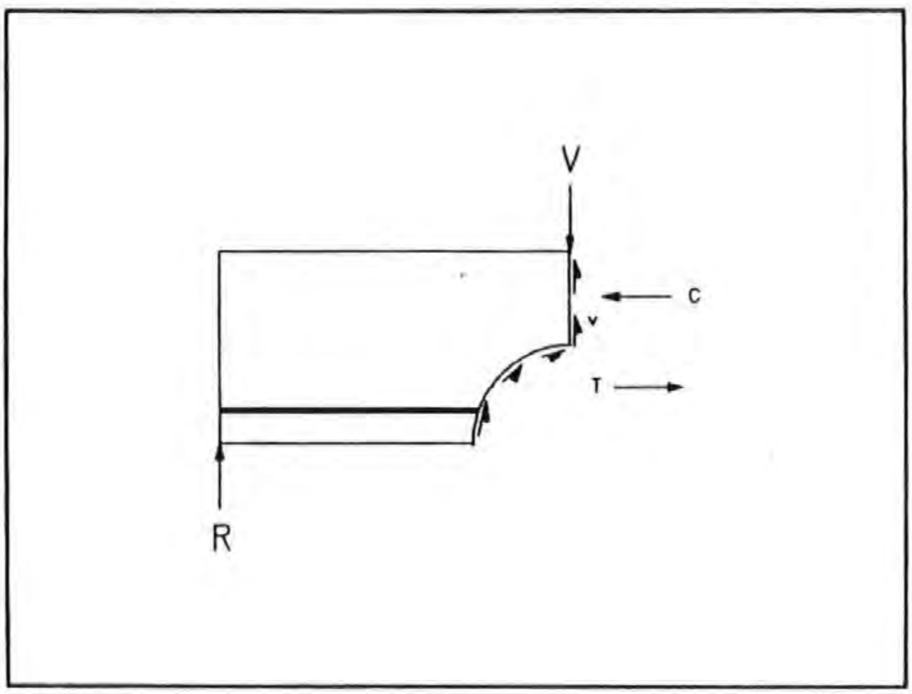


Figure 5.13 Stirrup spacing rule



Idealised uniform distribution of shear stress
Figure 5.14a



Idealised components of shear resistance of section
Figure 5.14b

Shear across a section
Figure 5.14

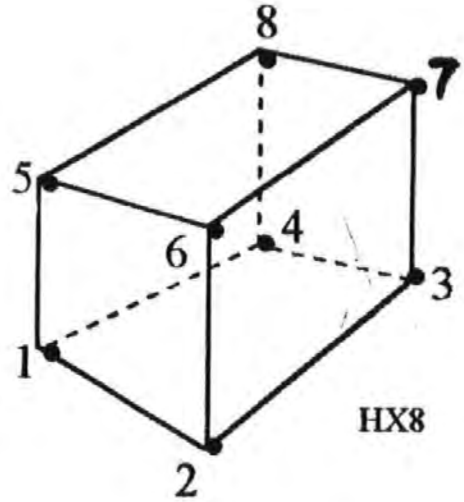


Figure 6.1 Nodal Configuration for Hexagonal Solid Element

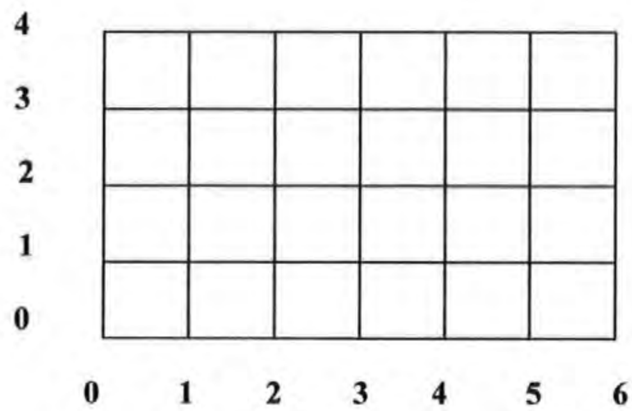


Figure 6.12 - Numbering of LUSAS Analysis nodes for bending stress diagrams. Diagrams plotted in Figures 6.13 a -g

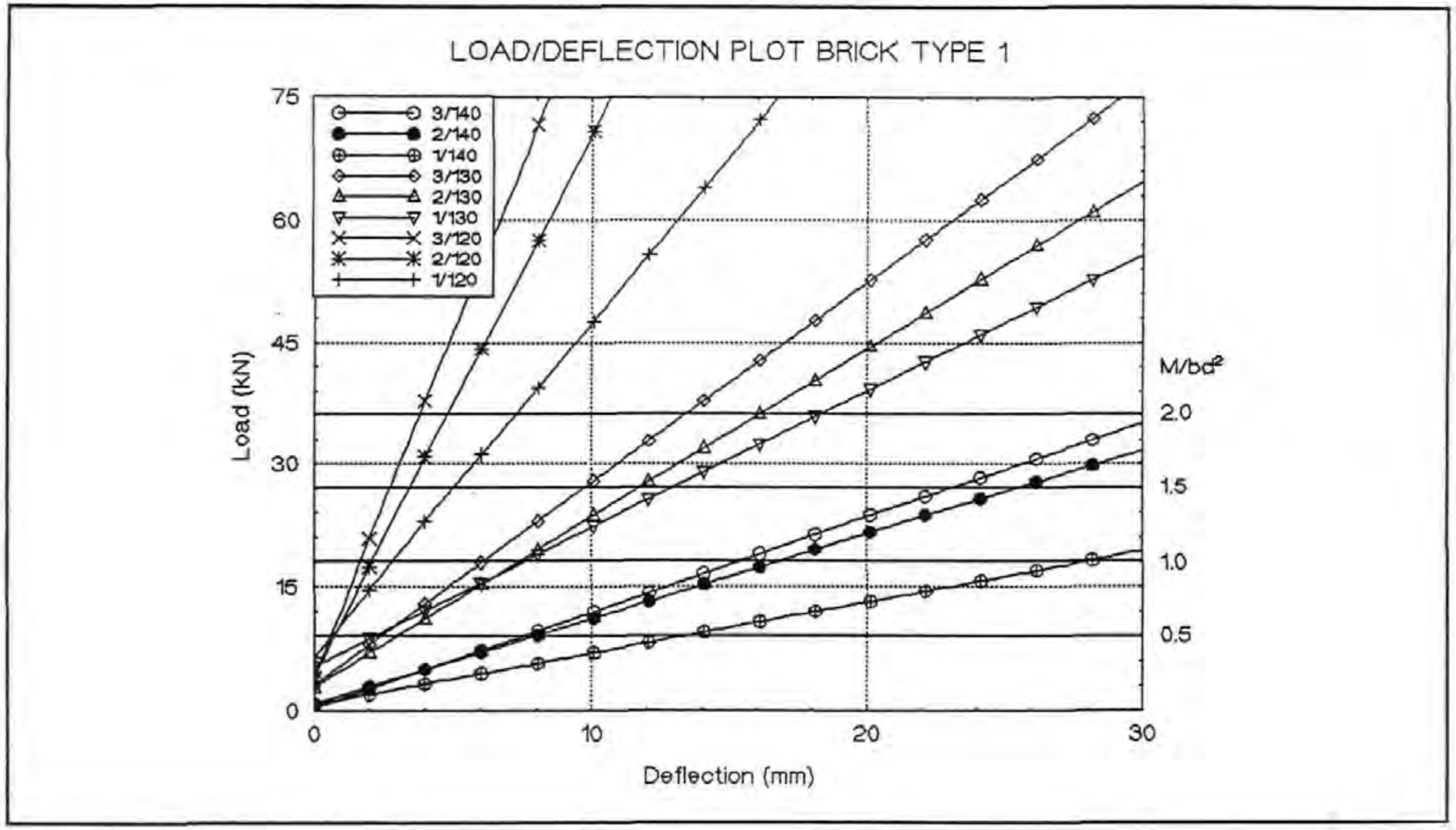


Figure 7.1a --Load versus deflection plot – brick type 1

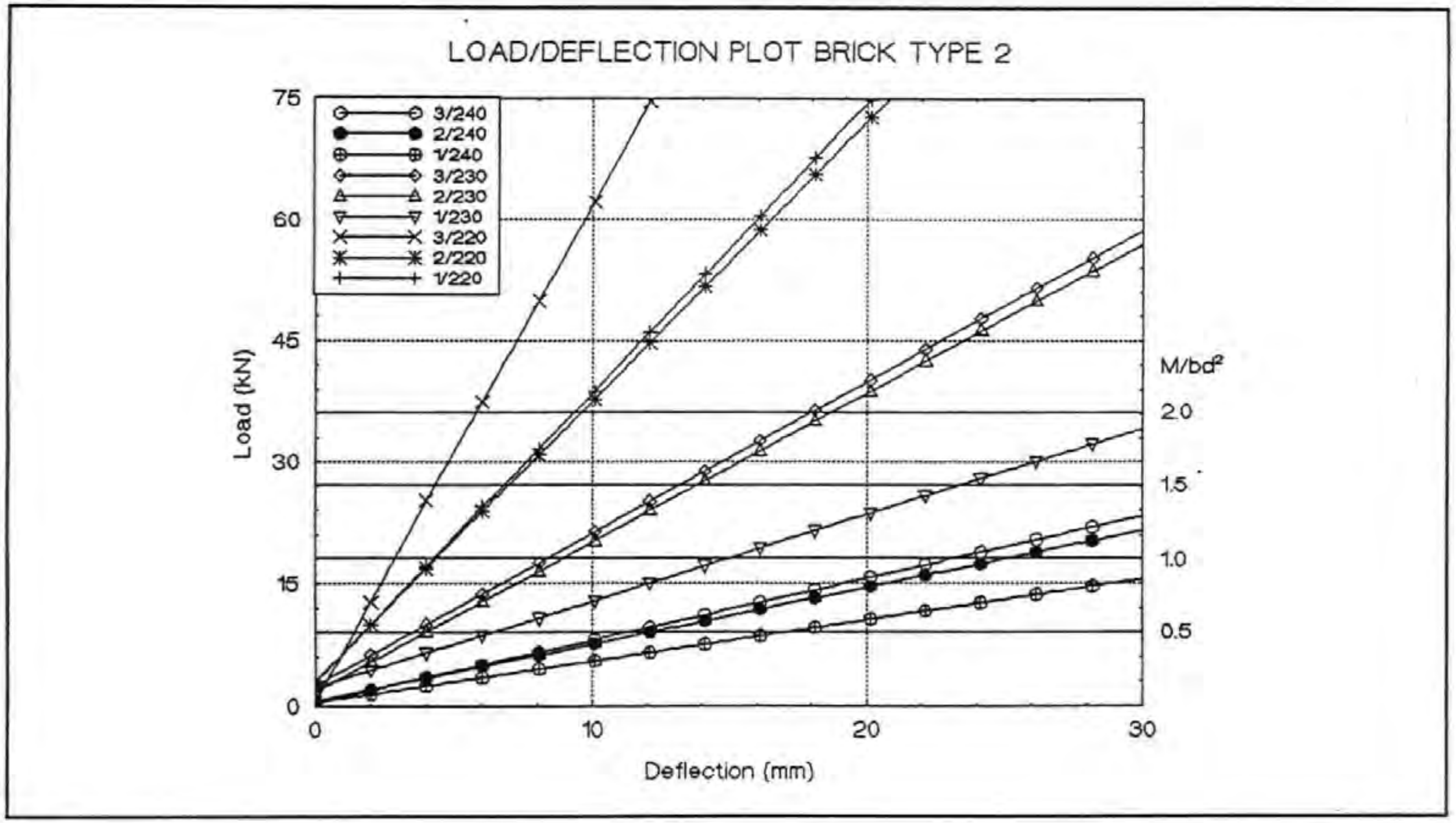


Figure 7.1b – Load versus deflection plot –brick type 2

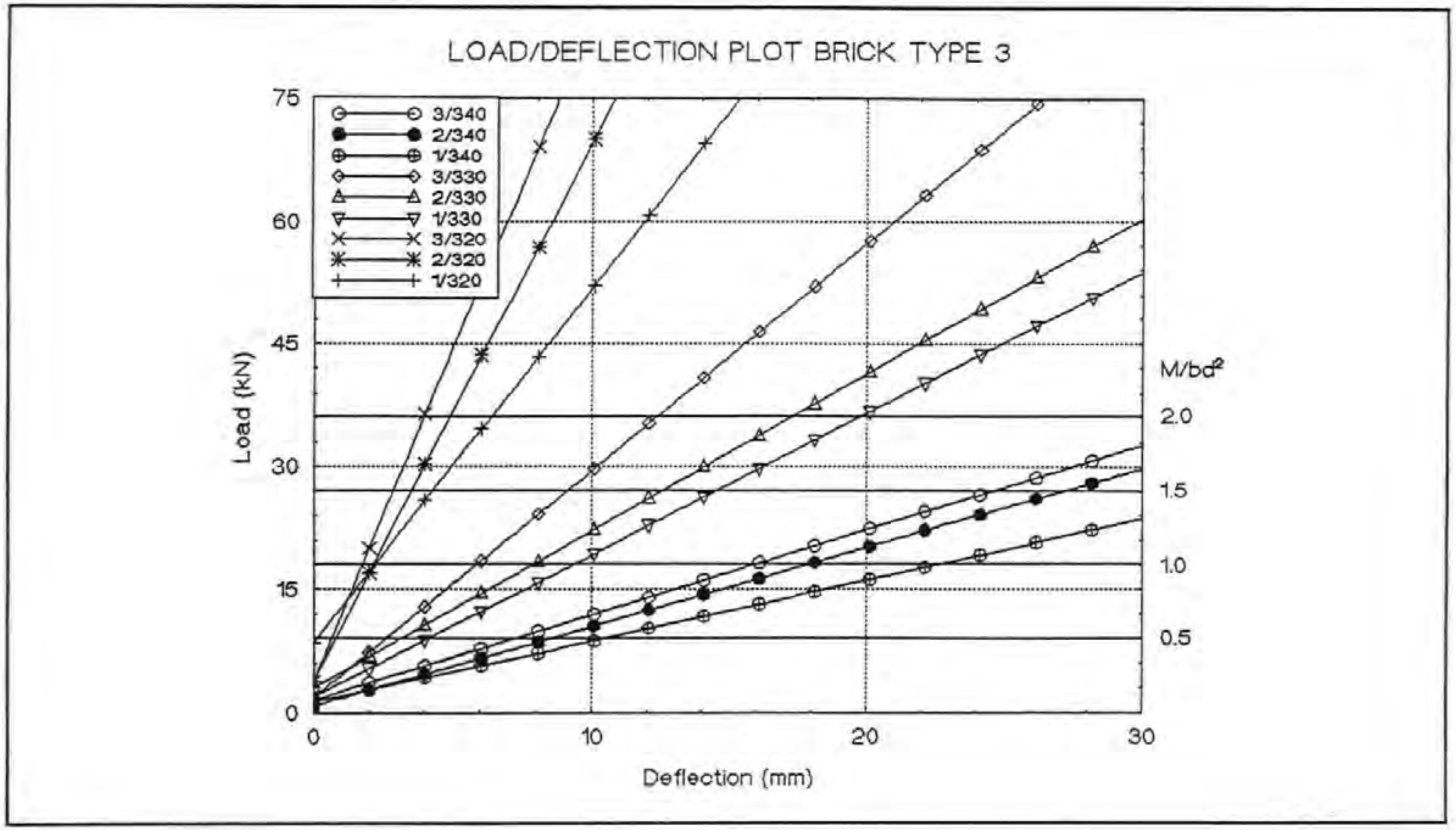


Figure 7.1c - Load versus deflection plot – brick type 3

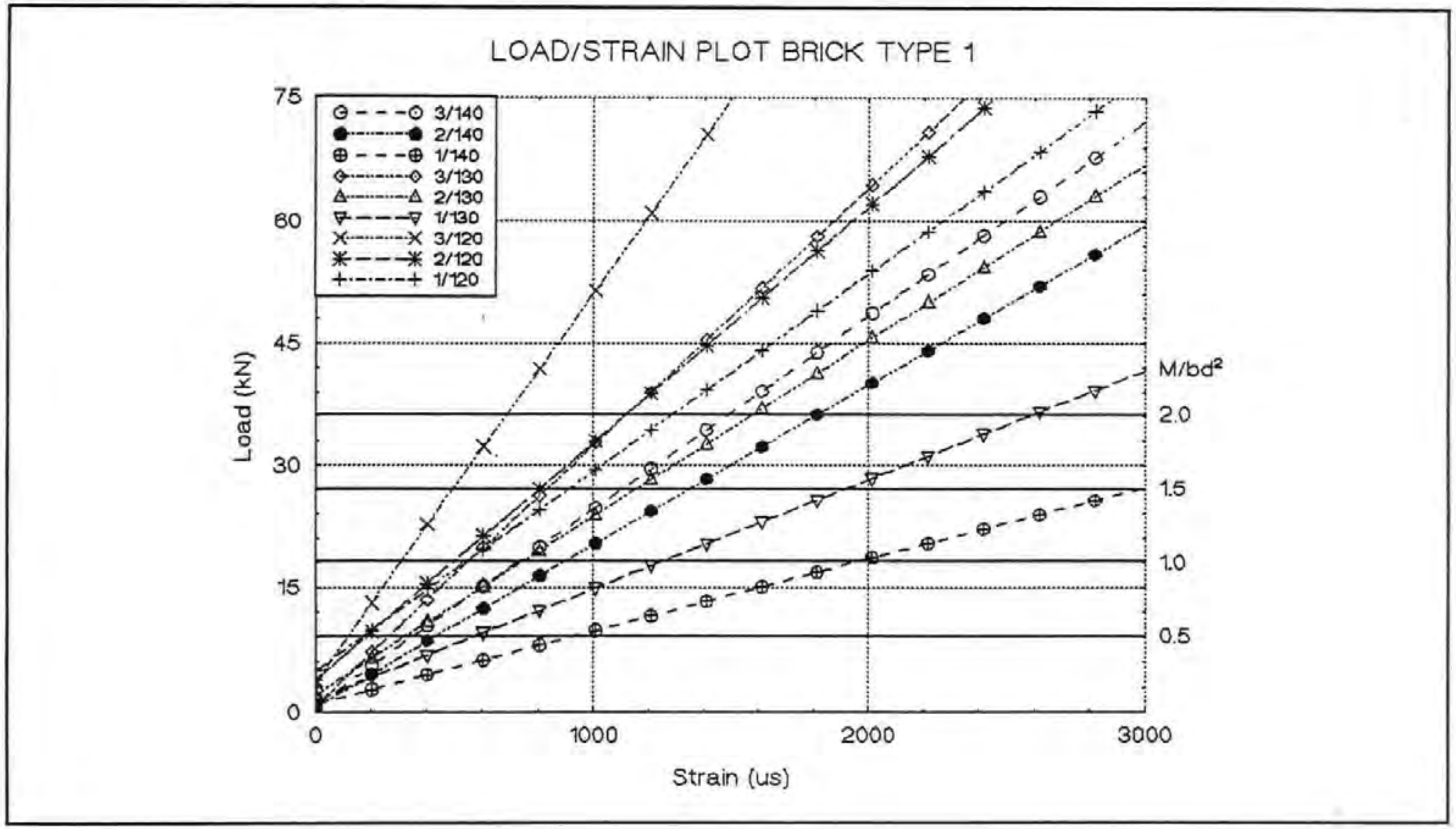


Figure 7.2a -Load versus steel strain plot – brick type 1

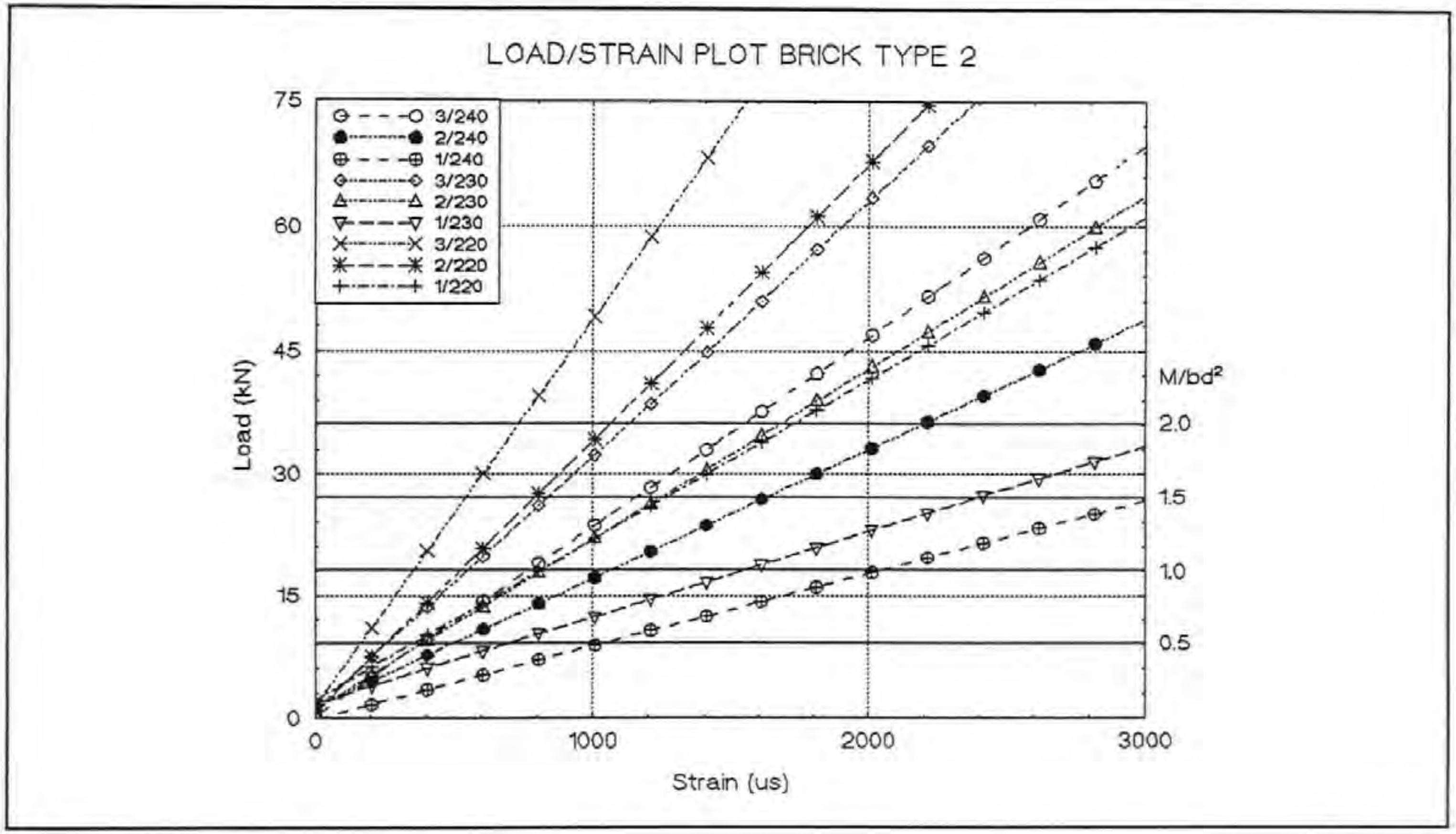


Figure 7.2b -Load versus steel strain plot – brick type 2

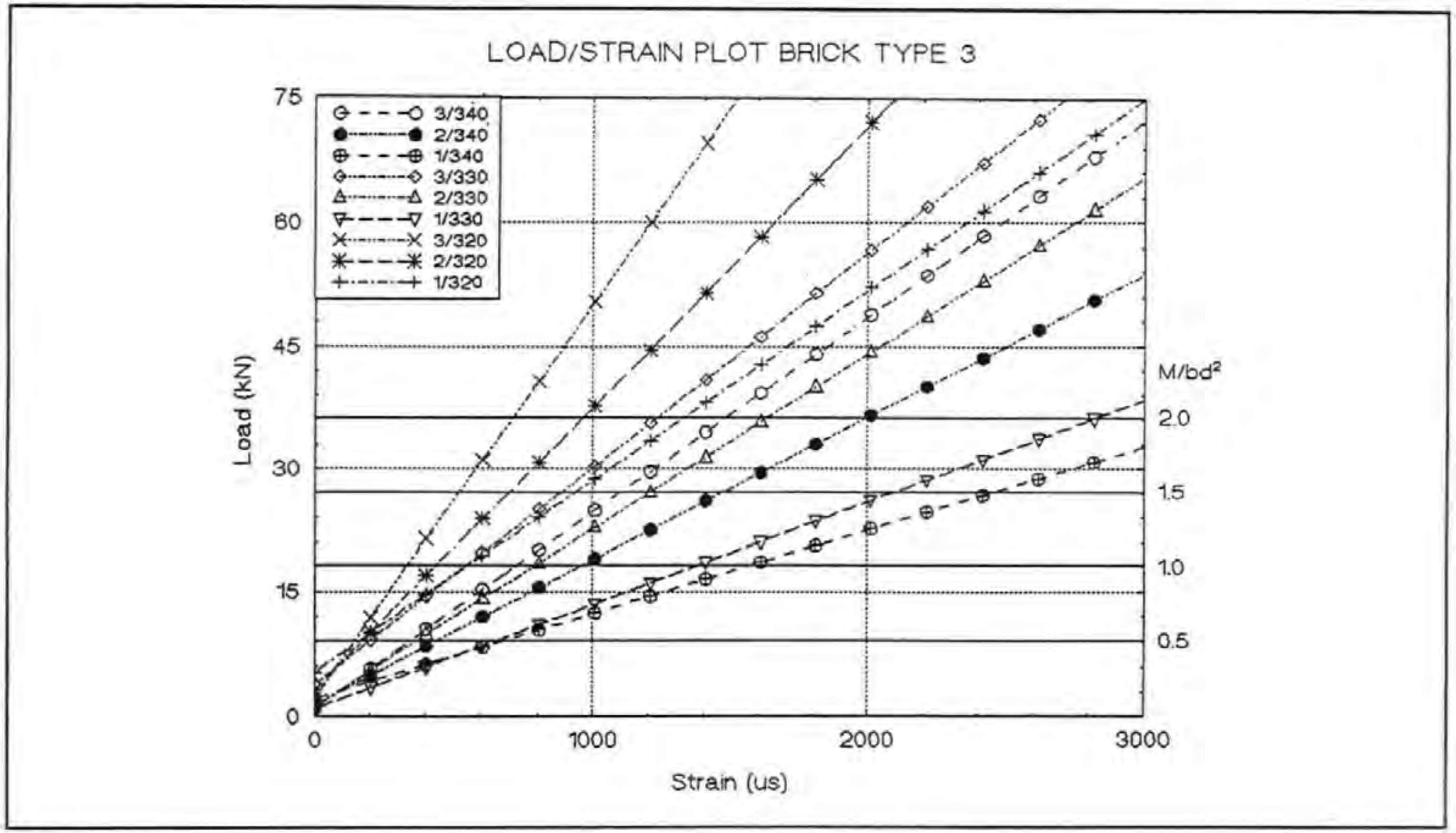


Figure 7.2c -Load versus steel strain plot – brick type 3

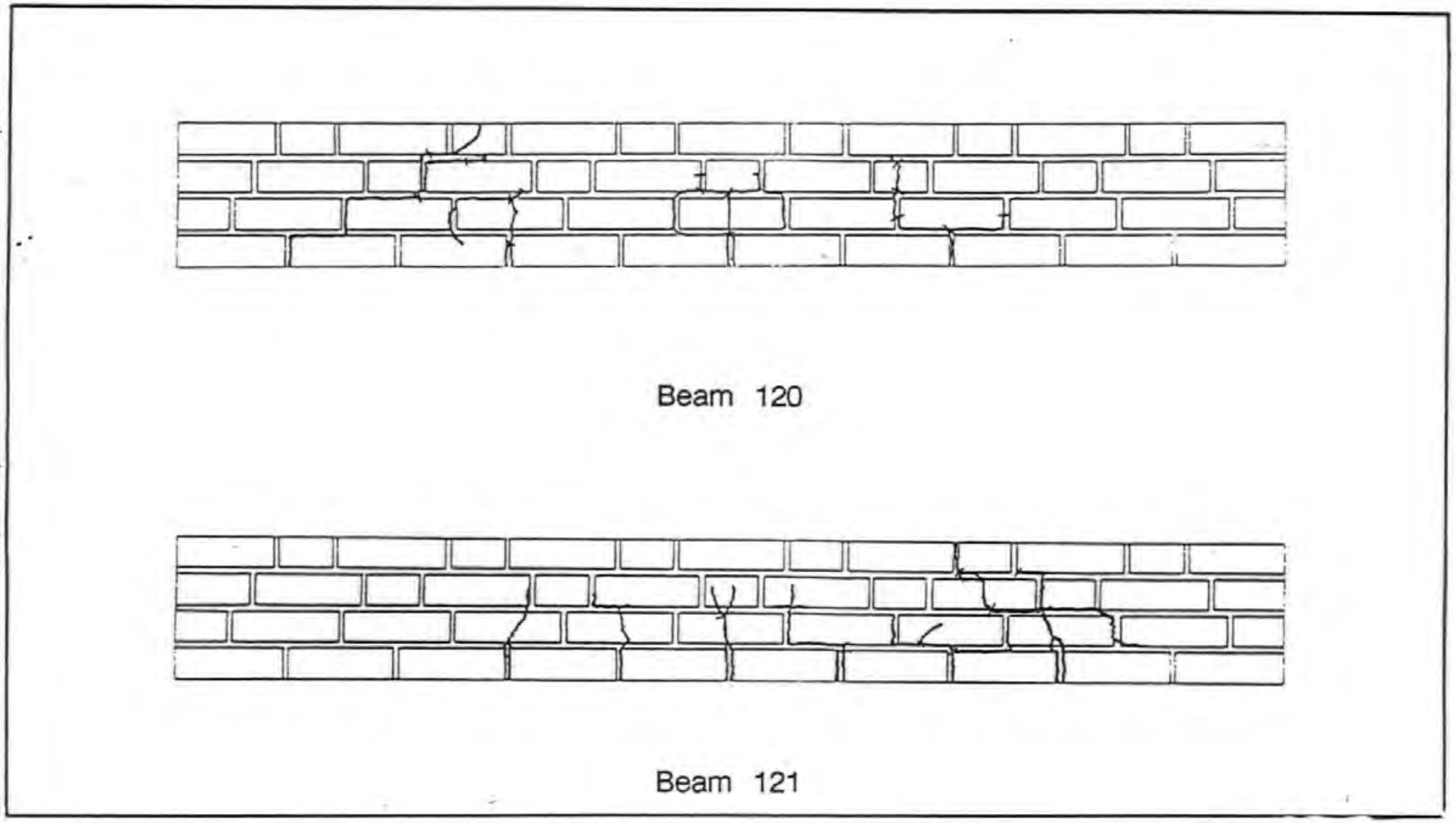


Figure 7.3a – Crack patterns, beams 120 and 121

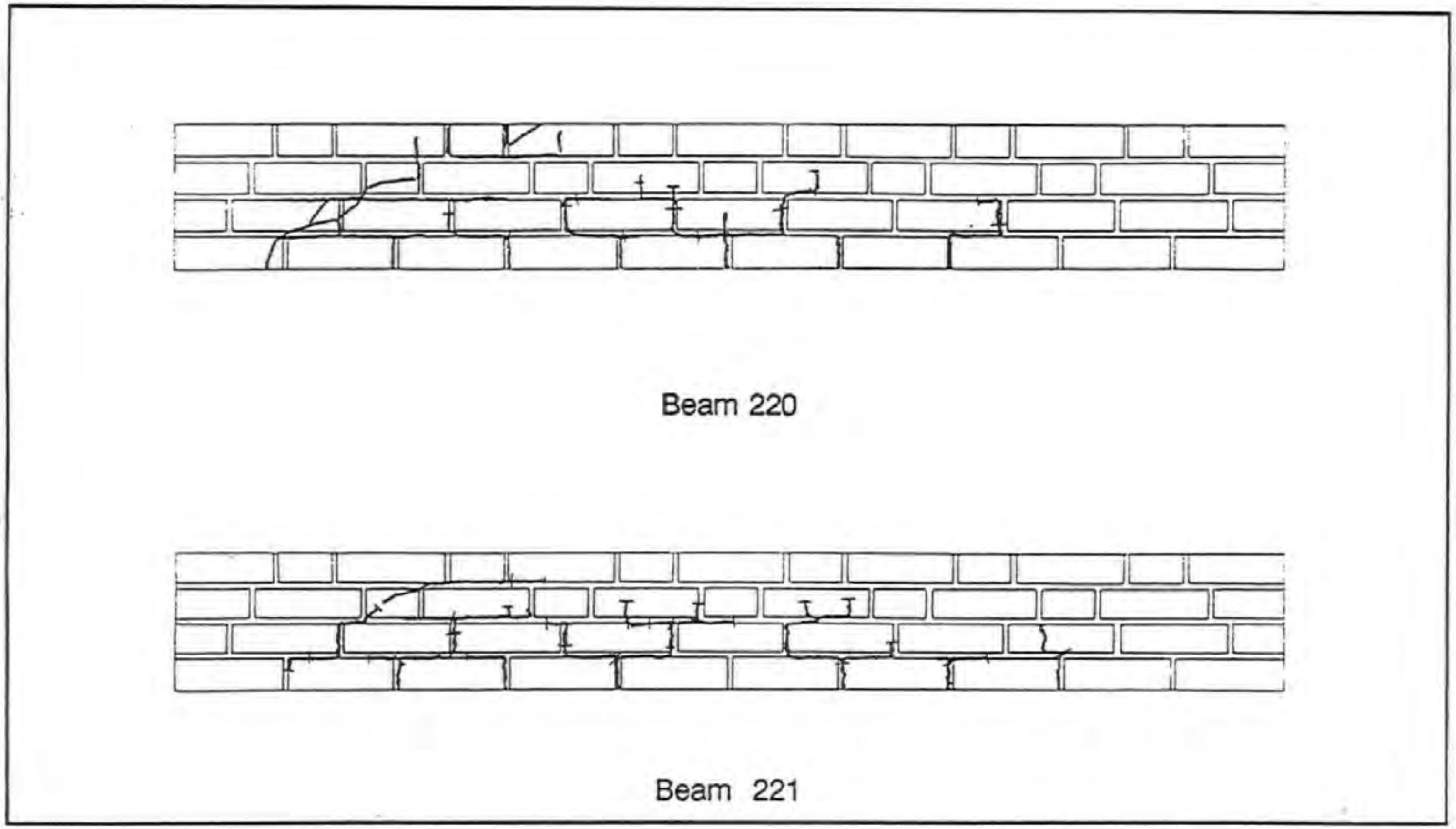


Figure 7.3b – Crack patterns, beams 220 and 221

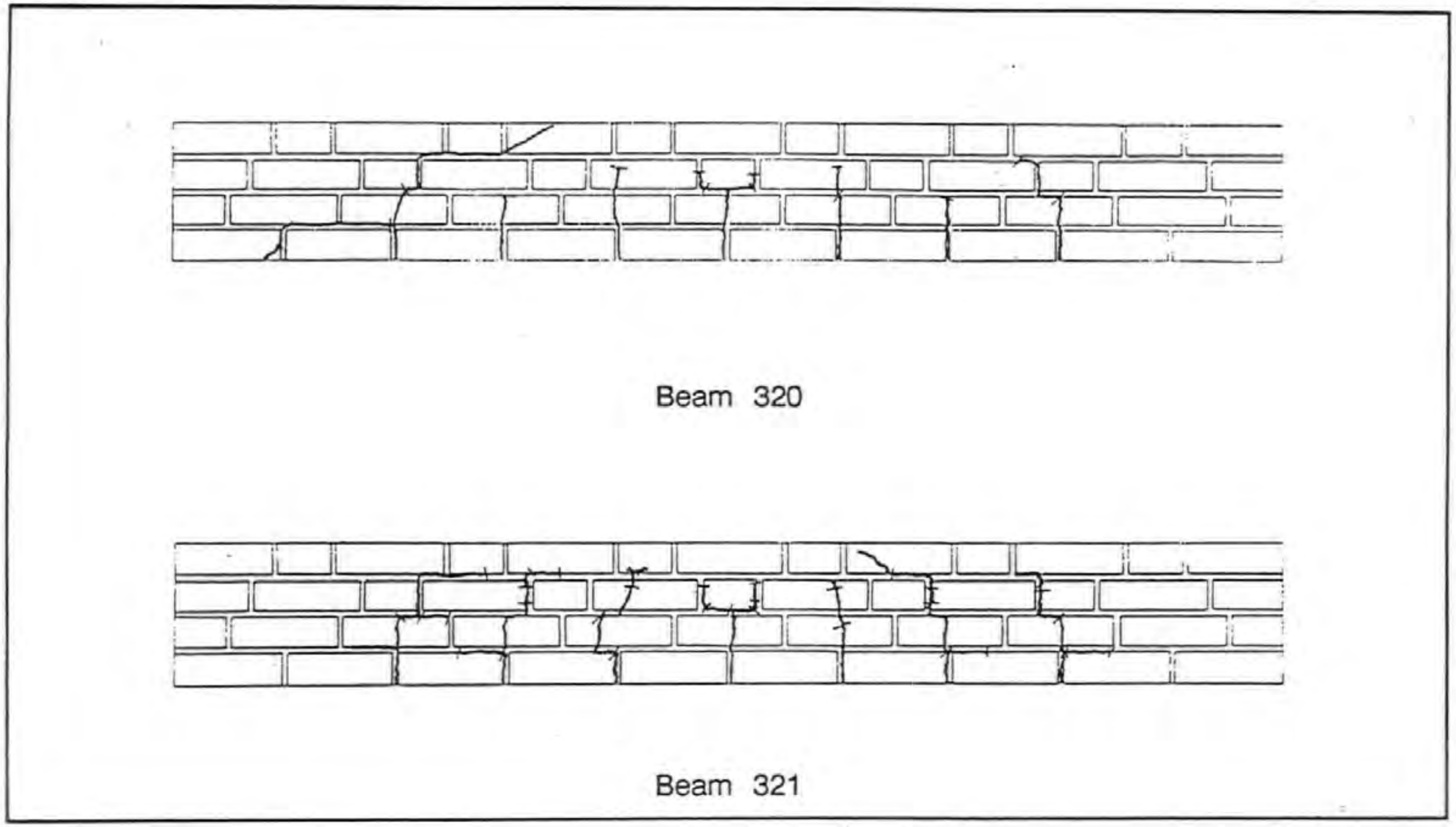


Figure 7.3c – Crack patterns, beams 320 and 321

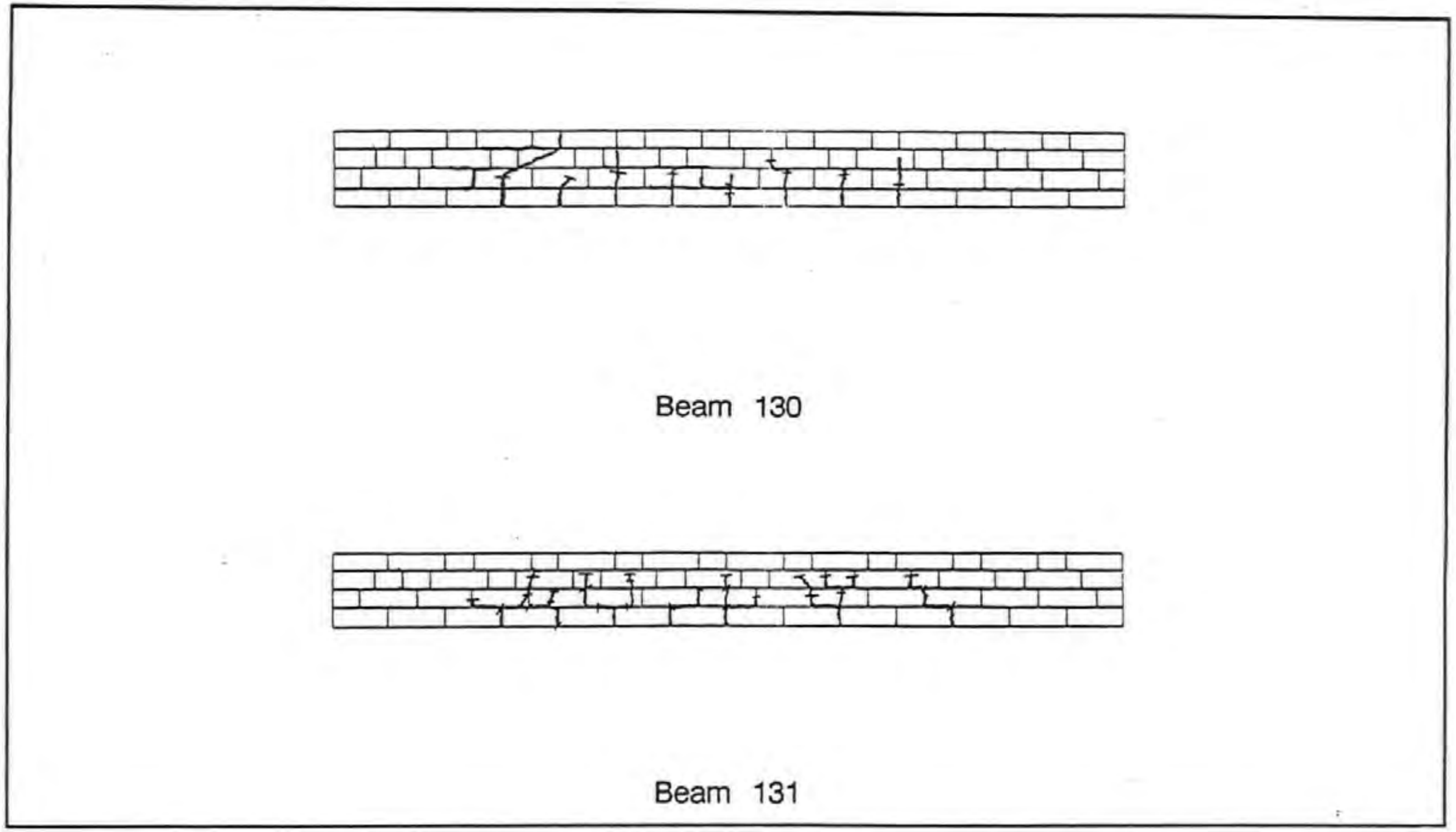


Figure 7.3d – Crack patterns, beams 130 and 131

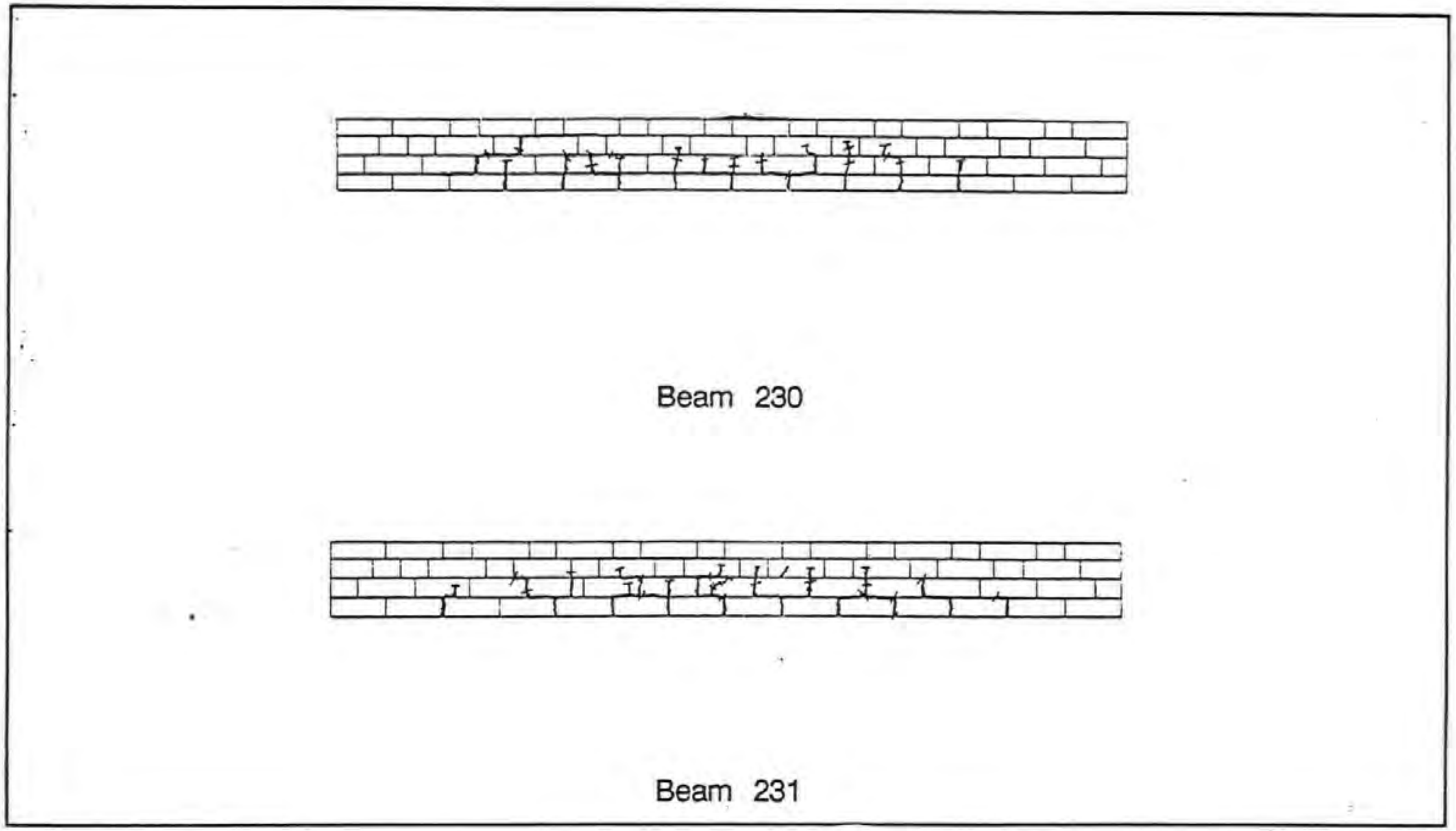


Figure 7.3e – Crack patterns, beams 230 and 231

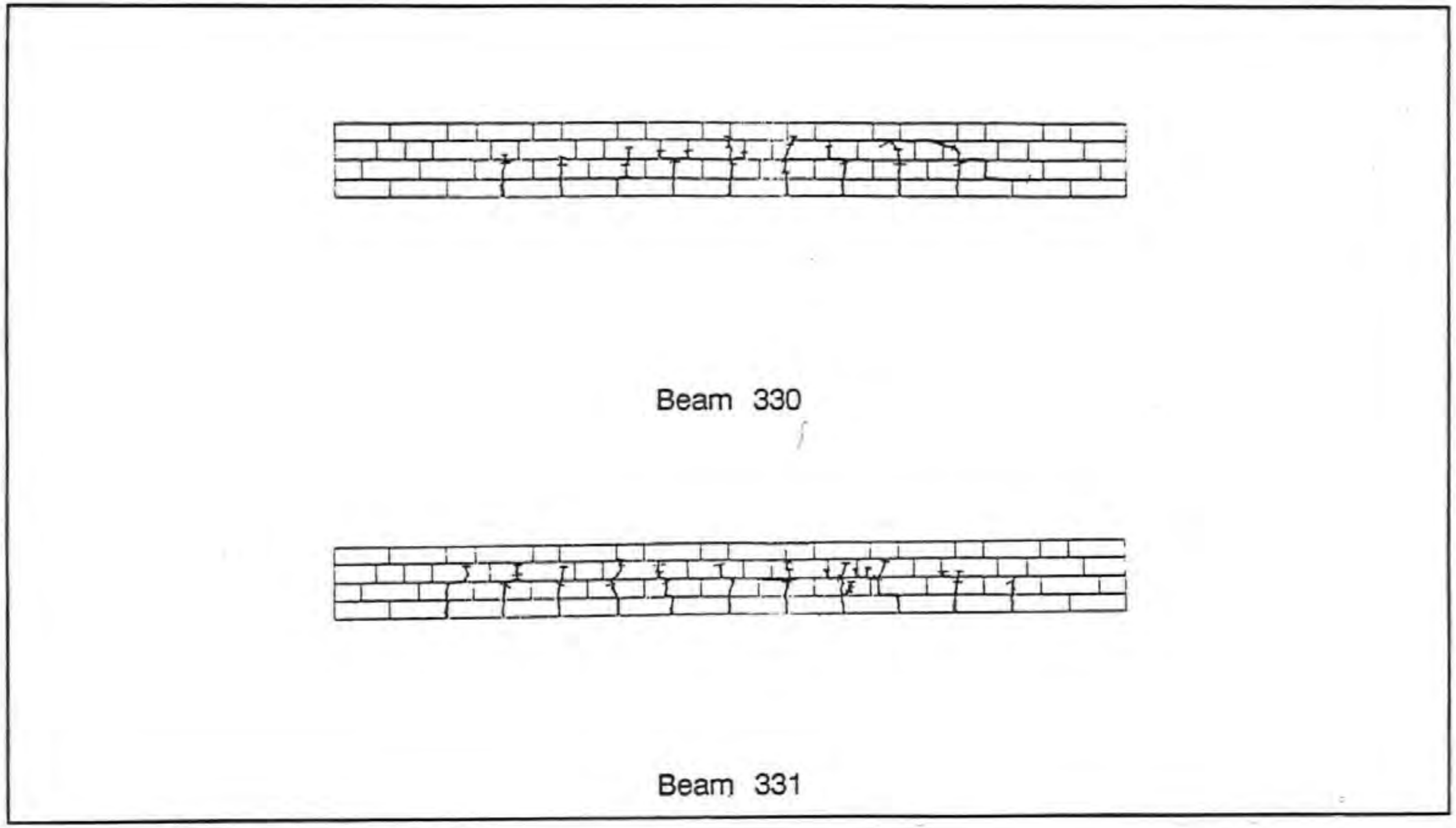


Figure 7.3f – Crack patterns, beams 330 and 331

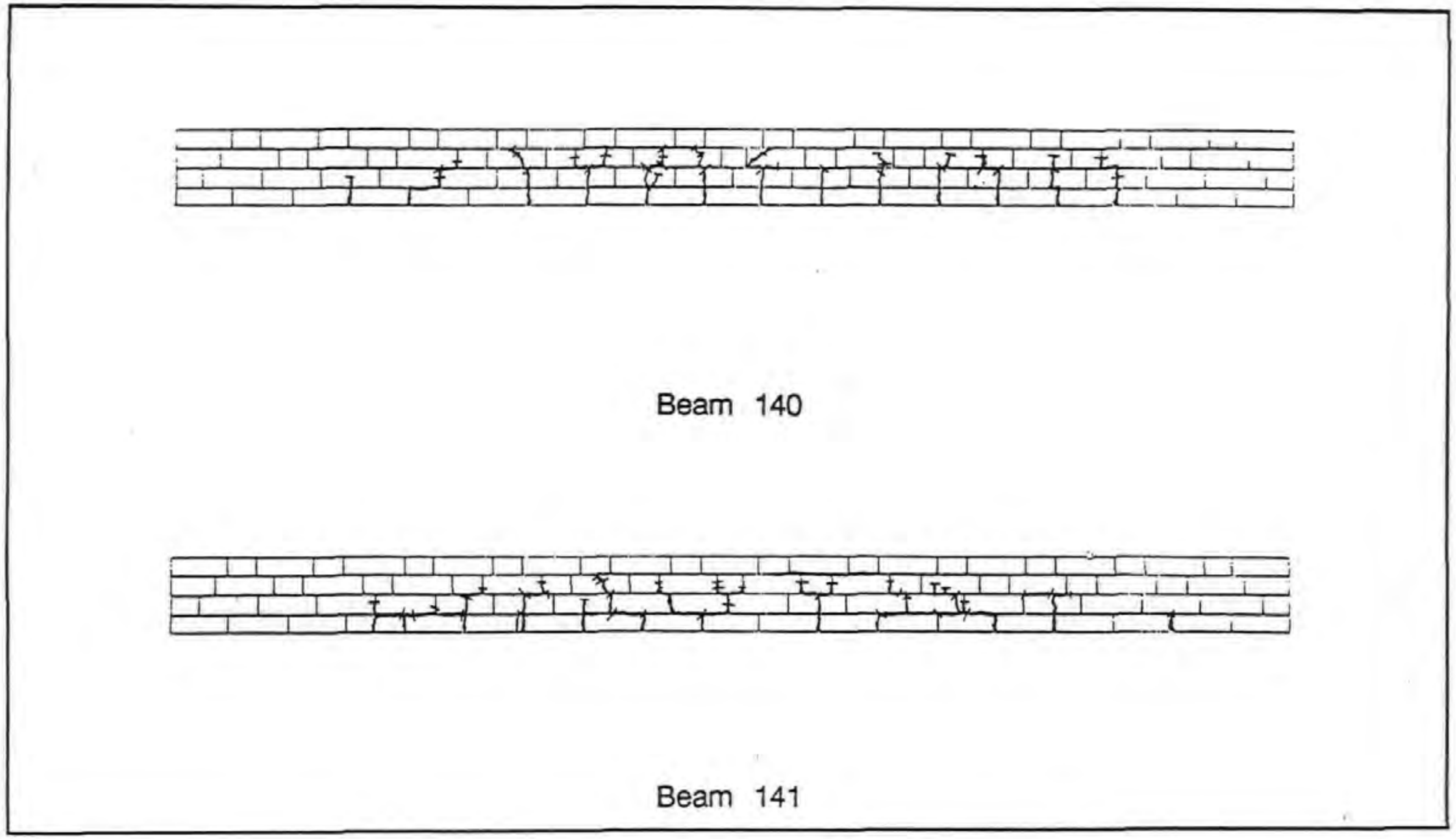


Figure 7.3g – Crack patterns, beams 140 and 141

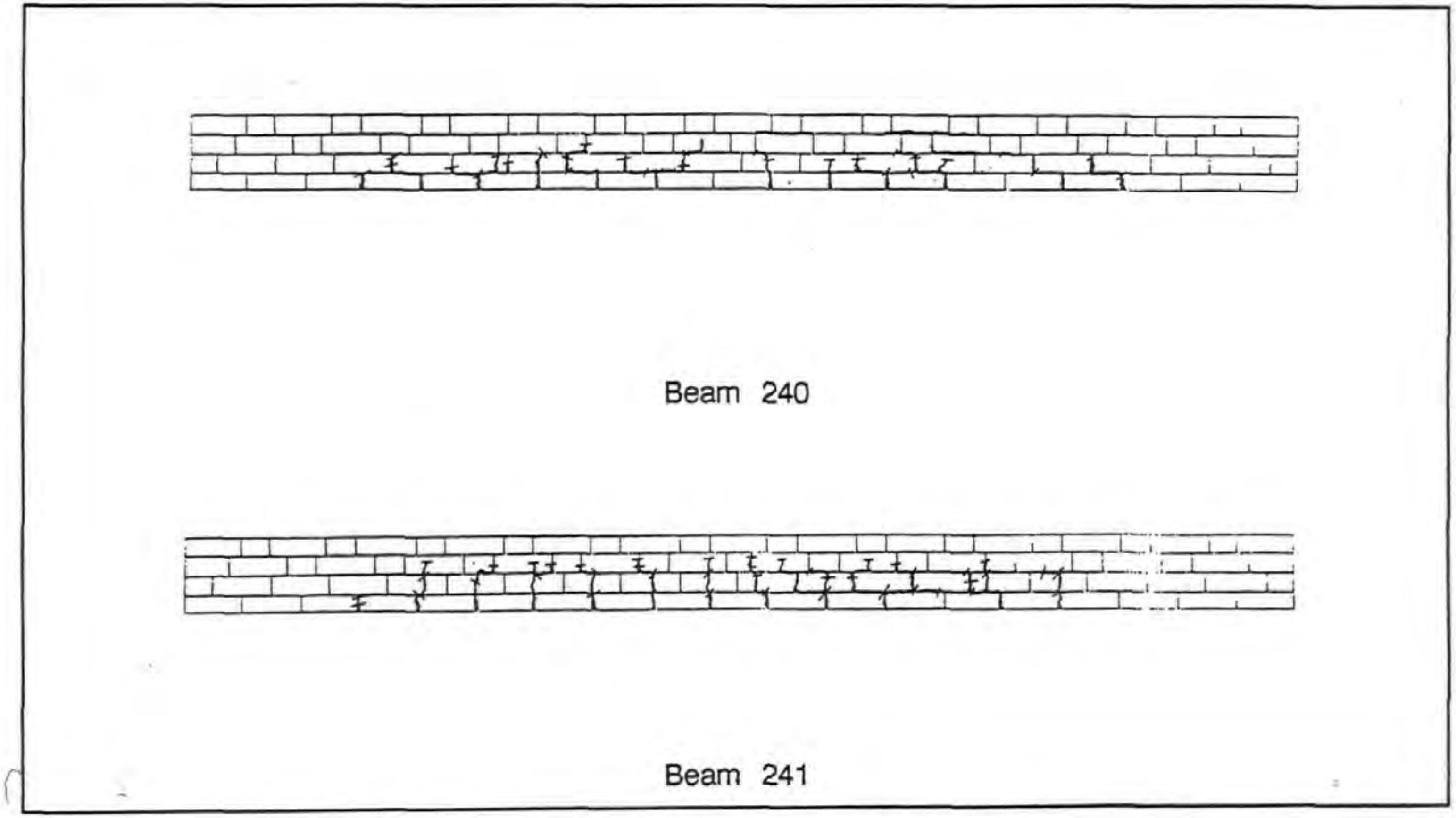


Figure 7.3h – Crack patterns, beams 240 and 241

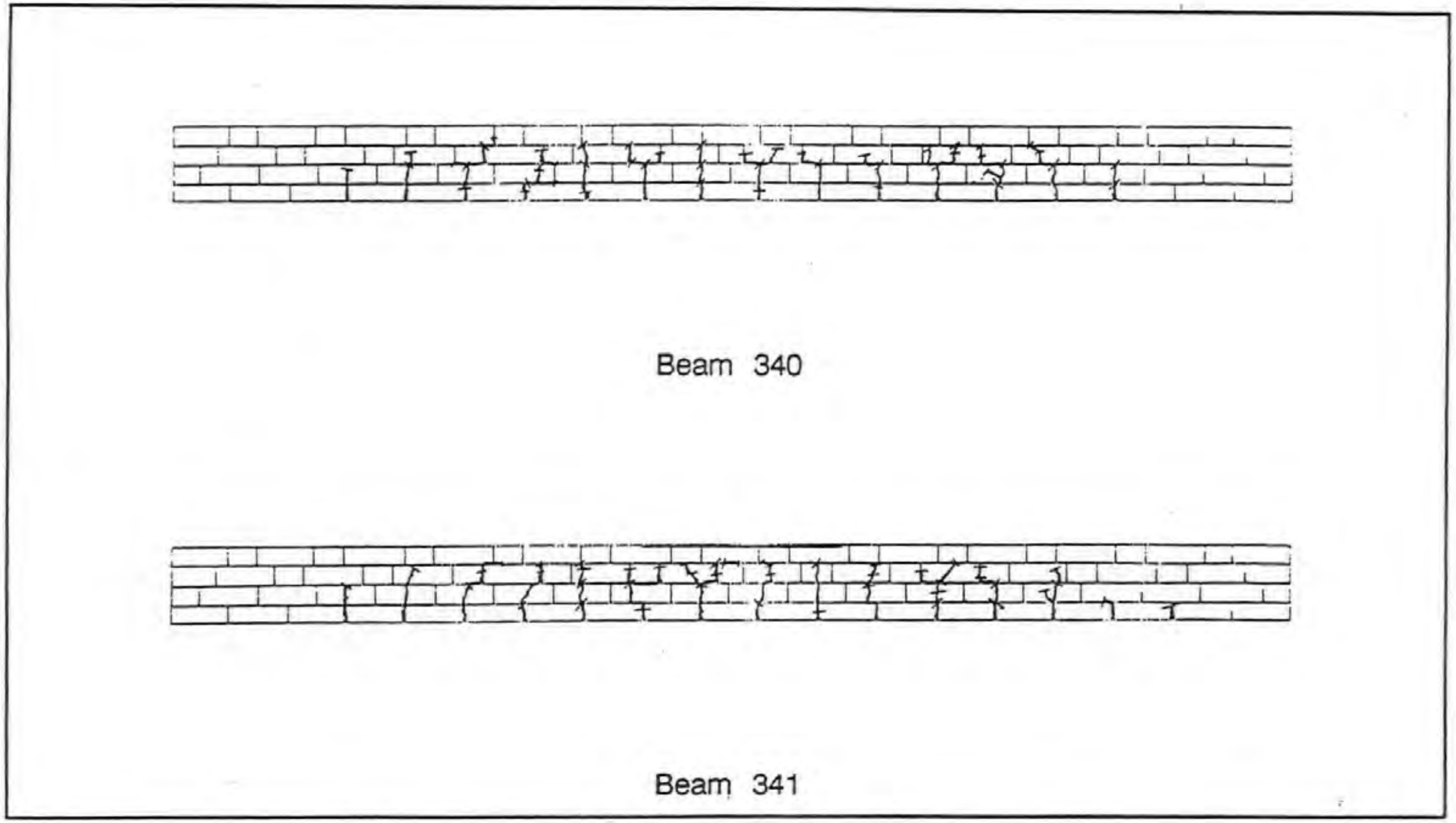
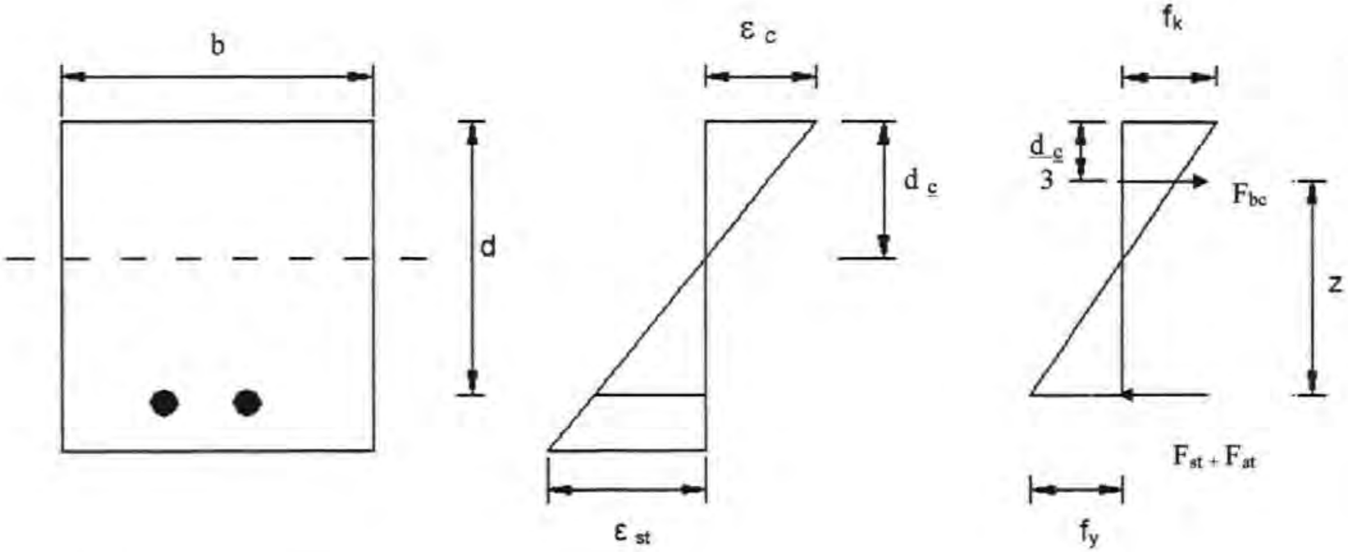


Figure 7.3i – Crack patterns, beams 340 and 341



Beam Cross Section
Steel area A_{st}

Strain
Diagram

Stress
Diagram

Figure 8.7
Theoretical Stress and Strain Diagram
Including Excess Tensile Force

Brick type	Brick strength N/mm^2			
	Loaded on Bed	Loaded on Stretcher	Loaded on Header	
3 hole	90.4	50.7	28.8	Garwood
3 hole	82.0	53.2	40.2	Pedreschi
14 hole	74.3	26.2	10.4	Pedreschi
10 hole	70.2	29.5	21.7	Pedreschi
10 hole	64.7	20.2	8.6	Powell
5 slots	64.1	51.8	13.8	Pedreschi
3 hole	58.0	19.4	16.0	Robson
23 hole	49.4	11.0	10.5	Powell
8 hole	49.1	17.8	13.4	Powell
Solid	43.5	29.0	28.1	Powell
3 hole	42.6	21.7	35.2	Rad
3 hole	35.7	21.0	17.1	Rad
Frog	33.7	16.6	17.1	Powell
Frog	31.7	29.1	15.9	Powell
3 hole	26.4	14.3	10.4	Powell
Frog	25.4	10.5	9.1	Powell
3 hole	22.7	9.2	6.0	Powell

REFERENCES:

1. Pedreschi and Sinha[73]
2. Robson [33]
3. Rad [34]
4. Garwood36]
5. Powell 37]

Table 2.1 Compressive Strengths of Clay Bricks when Compressed on Different Faces

Brick type	Loaded on Bed	Loaded on Stretcher	Loaded on Header	
3 hole	90.4	50.7	28.8	Garwood
3 hole	82.0	53.2	40.2	Pedreschi
3 hole	58.0	19.4	16.0	Robson
3 hole	42.6	21.7	35.2	Rad
3 hole	35.7	21.0	17.1	Rad
3 hole	26.4	14.3	104.	Powell
3 hole	22.7	9.2	6	Powell

REFERENCES:

1. *Pedreschi and Sinha[73]*
2. *Robson [33]*
3. *Rad [34]*
4. *Garwood[36]*
5. *Powell [37]*

Table 2.2 Compressive Strengths of 3 Hole Clay Bricks when Compressed on Different Faces

Materials		Brick			Prism		Mortar		Reinforcement	
Researcher	Date	Dimensions (mm)	Water Absorption (%)	Comp Strength (N/mm^2)	Comp Strength (N/mm^2)	Youngs Modulus (kN/mm^2)	Comp Strength (N/mm^2)	Tensile Strength (N/mm^2)	0.2% Proof Stress (N/mm^2)	Ultimate Strength (N/mm^2)
Sinha & Foster	1978		4.2	71.32	33.9	20.5	28.38		476.0	525.0
Garwood & Tomlinson		215x102.5x65			25.0		26.0 20.0 20.0		475.0 355.0	536.20
Osman & Hendry		215x101x67.3		23.86 88.28	12.24 22.63	11.97 18.50	21.4 21.4		562.0 572.0 580.0	575.0 636.7 649.3

Table 2.3a Summary of Material Properties for Previous Research Work

Materials		Brick			Prism		Mortar		Reinforcement	
Researcher	Date	Dimensions (mm)	Water Absorption (%)	Comp Strength (N/mm^2)	Comp Strength (N/mm^2)	Youngs Modulus (kN/mm^2)	Comp Strength (N/mm^2)	Tensile Strength (N/mm^2)	0.2% Proof Stress (N/mm^2)	Ultimate Strength (N/mm^2)
Withey	1932	204.6x92.3x58.0		17.80	18.60	16.56	19.90			
		195.2x89.0x55.4		86.30	19.80	24.15	19.90			
		204.1x93.5x55.9		63.50	14.40	14.49	19.90			
Hamman & Burridge	1937		3.40	65.90	37.80	16.49	23.80		445.10	536.20
					42.90	16.15	23.80			
			14.10	11.90	4.30	2.07	23.80			
					3.80	2.35	23.80			
Thomas & Simms	1938		15.70	27.90	14.75	10.63	24.15	1.93		

Table 2.3b Summary of Material Properties for Previous Research Work

Beam Type	Beam Ref	ρ (%)	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	M_{max}/bd^2 (N/mm²)	v_{av} (N/mm²)	Failure Mode	Stirrup Ratio (%)	Mortar Strength (N/mm²)	Pier Strength (N/mm²)
RM	C1	0.57	211.0	233.9	56.5	22.28	1.93	0.66	Bt	194	19.9	18.6
RM	C2	0.56	199.5	249.9	58.5	23.10	1.85	0.66	Bt	100	19.9	18.6
RM	C4	0.61	208.4	222.4	53.5	21.10	2.05	0.66	Bt	0	19.9	18.6
RM	C5	0.98	208.4	225.7	80.3	31.94	3.01	1.02	Bc	381	19.9	18.6
RM	C6	0.93	205.9	238.9	80.3	31.93	2.72	0.97	Bt	386	19.9	18.6
RM	C9	1.23	201.3	252.7	119.9	48.33	3.76	1.44	Bt+Sdt	455	19.9	18.6
RM	C3	0.62	203.4	221.1	49.1	19.30	1.93	0.63	Sdt	0	19.9	18.6
RM	C7	1.33	204.6	228.8	74.0	29.38	2.74	0.97	Sdt	336	19.9	18.6
RM	C8	1.24	214.8	233.9	76.3	30.21	2.57	0.92	Sdt	428	19.9	18.6
RM	W3	0.62	195.7	229.5	53.5	21.85	2.12	0.67	Bt	102	19.9	19.8
RM	W4	1.00	191.4	239.7	78.0	31.09	2.83	0.99	Bt	208	19.9	19.8
RM	W5	1.04	195.7	225.0	74.6	29.71	3.00	0.99	Bt	305	19.9	19.8
RM	W6	1.02	192.2	233.9	78.9	31.45	2.99	1.02	Bt	310	19.9	19.8
RM	W7	1.41	189.4	233.1	107.8	43.90	4.27	1.46	Bc	485	19.9	19.8
RM	W8	2.31	197.0	226.2	145.4	58.39	5.79	2.03	Bc	467	19.9	19.8
RM	W1	0.66	194.7	216.8	51.3	21.11	2.31	0.69	Bt+Sdt	0	19.9	19.8
RM	W2	0.70	187.1	213.5	52.8	20.83	2.44	0.75	Sdt	0	19.9	19.8

Table 2.4a Summary of Test Results, Withey 1933

Beam Type	Beam Ref	ρ (%)	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	M_{max}/bd^2 (N/mm^2)	v_{av} (N/mm^2)	Failure Mode	Stirrup Ratio (%)	Mortar Strength (N/mm^2)	Pier Strength (N/mm^2)
RM	S1	0.66	202.3	210.5	49.5	19.38	2.16	0.68	Bt	0	19.9	14.4
RM	S2	0.66	200.6	212.8	58.0	23.00	2.53	0.79	Bt	0	19.9	14.4
RM	S3	1.15	202.1	214.3	71.3	28.37	3.06	1.01	Bt	0	19.9	14.4
RM	S4	1.29	205.9	234.9	109.7	43.98	3.87	1.40	Bt	446	19.9	14.4
RM	S5	1.06	203.4	230.6	75.8	30.18	2.79	0.98	Bt	293	19.9	14.4
RM	S6	1.03	205.1	235.4	81.2	32.35	2.85	1.02	Bt	194	19.9	14.4
RM	S8	1.30	202.1	236.4	117.3	47.07	4.17	1.51	Bt	295	19.9	14.4
RM	S7	2.22	199.0	233.1	120.4	48.32	4.47	1.68	Sdt	462	19.9	14.4

Table 2.4b Summary of Test Results, Withey 1933

Beam Type	Beam ref	ρ (%)	a/d	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	M_{max}/bd^2 (N/mm^2)	v_{av} (N/mm^2)	Span (mm)
RM	B1	0.52	2.45	228.8	249.1	40.4	25.1	1.77	0.76	1830
RM	B2	0.52	2.53	228.8	241.5	41.4	25.4	1.9	0.83	1830
RM	B3	0.23	1.63	228.8	249.1	31.5	13.0	0.92	0.62	1220
RM	B4	0.23	1.60	228.8	254.2	34.0	14.0	0.95	0.69	1220
RM	B6	0.52	2.53	228.8	241.5	34.5	21.5	1.61	0.69	1830
RM	B8	0.52	2.45	228.8	249.1	34.0	21.3	1.50	0.69	1830
RM	B5	0.23	1.68	228.8	241.5	18.5	7.7	0.58	0.41	1220
RM	B7	0.23	1.68	228.8	241.5	30.5	12.0	0.94	0.62	1220
RM	B9	0.27	1.87	330.5	325.4	55.4	34.0	0.99	0.55	1830
RM	B10	0.27	1.87	330.5	325.4	54.4	34.0	0.98	0.55	1830
RM	B11	0.12	1.29	330.5	315.2	43.9	18.0	0.56	0.41	1220
RM	B12	0.12	1.27	330.5	320.3	44.9	18.0	0.55	0.41	1220

Table 2.5a Summary of Test Results, BRS 1938, Series 1

Beam Type	Beam ref	ρ (%)	a/d	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	M_{max}/bd^2 (N/mm^2)	v_{av} (N/mm^2)	Span (mm)
RM	2C3	0.92	2.50	228.8	246.0	40.5	25.3	1.83	0.83	1830
RM	2C4	0.92	2.50	228.8	246.0	42.9	26.7	1.93	0.9	1830
RM	2C1	0.92	1.65	228.8	246.0	52.9	21.7	1.57	1.10	1220
RM	2C2	0.92	1.65	228.8	246.0	62.9	25.8	1.86	1.31	1220
RM	2B3	0.92	2.50	228.8	246.0	35	21.8	1.57	0.76	1830
RM	2B4	0.92	2.50	228.8	246.0	36	22.4	1.62	0.76	1830
RM	2B1	0.92	1.65	228.8	246.0	52.9	21.7	1.57	1.10	1220
RM	2B2	0.92	1.65	228.8	246.0	51.9	21.4	1.55	1.10	1220
RM	2A3	0.92	1.90	330.5	321.5	95.4	59.1	1.73	1.04	1830
RM	2A4	0.92	1.90	330.5	321.5	99.9	61.8	1.81	1.10	1830
RM	2A1	0.92	1.26	330.5	321.5	122.4	50.2	1.47	1.31	1220
RM	2A1	0.92	1.26	330.5	321.5	145.3	59.3	1.74	1.59	1220
RM	4C1	0.92	3.10	228.8	246.0	78.9	30.9	2.23	0.84	1525
RM	4C2	0.92	3.10	228.8	246.0	84.9	32.9	2.38	0.90	1525

Table 2.5b Summary of Test Results, BRS 193, Series 2A

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	$M_{max}/bd2$ (N/mm^2)	v_{av} (N/mm^2)	Span (mm)
RM	3C3	1.04	2.50	228.8	246.0	67.9	42.1	3.04	1.45	1830
RM	3C4	1.04	2.50	228.8	246.0	75.4	46.6	3.37	1.59	1830
RM	3C1	1.04	1.65	228.8	246.0	99.9	40.8	2.95	2.14	1220
RM	3C2	1.04	1.65	228.8	246.0	89.9	36.8	2.66	1.93	1220
RM	3B3	0.92	2.50	228.8	246.0	65.4	40.5	2.93	1.38	1830
RM	3B4	0.92	2.50	228.8	246.0	67.4	41.7	3.01	1.45	1830
RM	3B1	0.92	1.65	228.8	246.0	89.9	36.8	2.66	1.93	1220
RM	3B2	0.92	1.65	228.8	246.0	98.9	36.9	2.67	2.14	1220
RM	3A1	0.92	1.90	330.5	321.5	137.3	84.9	2.49	1.45	1830
RM	3A2	0.92	1.90	330.5	321.5	164.3	101.1	2.96	1.79	1830
RM	3A3	0.92	1.26	330.5	321.5	219.7	89.9	2.63	2.35	1220
RM	3A4	0.92	1.26	330.5	321.5	237.7	97.1	2.84	2.55	1220

Table 2.5c Summary of Test Results, BRS 1938, Series 2B

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	M_{max}/bd^2 (N/mm^2)	v_{av} (N/mm^2)	Failure Mode
RM	3	1.50	2.67	343.2	228.8	219.7	134.0	7.46	1.65	S
RM	4	1.50	2.67	343.2	228.8	232.2	141.7	7.89	1.75	S
RM	7	0.18	2.67	228.8	228.8	93.9	57.3	4.78	1.18	S
RM	8	0.18	2.67	228.8	228.8	107.0	65.8	5.49	1.36	Bc

S = Shear; Bc = Bending compression

Table 2.6 Summary of Test Results, Hamman and Burridge 1939

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	v_1 (N/mm^2)	v_2 (N/mm^2)	v_d (N/mm^2)	v_{u1} (N/mm^2)	v_{u2} (N/mm^2)	Failure Mode 1	Failure Mode 2	Mortar Strength (N/mm^2)	Pier Strength (N/mm^2)
RM	1	0.24	1.0	215	300	1.04	>1.1	0.01	1.06	>1.11	Ssl	S	12.10	7.94
RM	2	0.24	1.5	215	300	0.54	0.84	0.02	0.56	0.86	Ssl	B	11.65	
RM	3	0.24	2.0	215	300	0.39	0.63	0.02	0.40	0.65	Ssl	Stl/B	12.07	7.72
RM	4	0.24	2.5	215	300	0.46	–	0.02	0.48	–	B	–	10.68	
RM	5	0.24	3.0	215	300	0.35	0.35	0.02	0.36	0.36	Ssl	Ssl	10.43	
RM	6	1.46	1.0	215	300	1.50	>1.5	0.01	1.51	>1.51	Ssl	Ssl	11.33	11.00
RM	7	1.46	1.5	215	300	0.77	0.93	0.02	0.79	0.94	Ssl	Ssl	9.27	
RM	8	1.46	2.0	215	300	0.58	0.67	0.02	0.60	0.68	Ssl	Ssl	12.10	
RM	9	1.46	2.5	215	300	0.42	0.54	0.02	0.44	0.56	Ssu	Ssl	11.10	10.98
RM	10	1.46	3.0	215	300	0.47	0.47	0.02	0.49	0.49	Ssu	Ssl	13.80	
RM	11	1.46	4.0	215	300	0.39	>0.40	0.02	0.41	0.43	Ssu	Ssu	12.94	
RM	12	1.46	5.0	215	300	0.31	0.39	0.02	0.33	0.42	Ssu	Ssu	13.06	

Table 2.7 Summary of Test Results, Suter and Hendry, 1975

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	v_{u1} (N/mm²)	v_{u2} (N/mm²)	Failure Mode 1	Failure Mode 2	Mortar Strength (N/mm²)	Grout Strength (N/mm²)	Pier Strength (N/mm²)	Span (mm)
RM	1	1.49	1.0	95	273	1.70	2.13	Ssl	Ssl	18.58		28.77	1156
RM	2	1.49	1.5	95	273	1.19	1.49	Ssl	Ssl	18.58		28.77	1429
RM	3	1.49	2.0	95	273	0.93	0.97	Ssl	Ssl	18.05		36.31	1702
RM	4	1.49	3.0	95	273	0.80	1.03	Ssu	Ssl	11.74		34.15	2248
RM	5	1.49	4.0	95	273	0.56	0.61	Ssu	Ssu	13.91		33.37	2794
RM	6	1.49	5.0	95	273	0.44	0.47	Ssu	Ssu	14.29		31.97	3340
RM	13	1.49	6.0	95	273	0.41	0.46	Ssu	Ssu	9.17		34.54	3886
RM	15	1.49	7.0	95	273	0.32	0.37	Ssu	Ssu	13.53		32.49	4432
GRM	7	1.41	1.0	305	273	2.68	>2.95	Ssl	-	18.58	28.82	28.77	1156
GRM	8	1.41	1.5	305	273	2.51	2.75	Ssl	Ssl	18.58	28.82	28.77	1429
GRM	9	1.41	2.0	305	273	1.54	1.85	Ssl	Ssl	18.05	26.22	36.31	1702
GRM	10	1.41	3.0	305	273	0.86	0.91	Ssl	Ssl	11.74	17.46	34.15	2248
GRM	11	1.41	4.0	305	273	0.71	0.78	Ssu	Ssu	13.91	24.37	33.97	2794
GRM	12	1.41	5.0	305	273	0.65	>0.65	Ssu	-	14.29	28.56	31.97	3340
GRM	14	1.41	6.0	305	273	0.57	0.62	Ssu	Ssu	9.17	31.54	34.54	3886
GRM	16	1.41	7.0	305	273	0.65	0.69	Ssu	Ssu	13.53	34.22	32.49	4432

Table 2.8a Summary of Test Results, Suter and Keller 1976

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	v_{u1} (N/mm²)	v_{u2} (N/mm²)	Failure Mode 1	Failure Mode 2	Mortar strength (N/mm²)	Grout Strength (N/mm²)	Pier Strength (N/mm²)	Span (mm)
RC		1.41	1.0			4.93		Ssl			25.03		
RC		1.41	1.5			3.26		Ssl			26.32		
RC		1.41	2.0			1.83		Ssl			25.61		
RC		1.41	3.0			1.09		Ssu			27.93		
RC		1.41	4.0			0.97		Ssu			25.86		
RC		1.41	5.0			0.89		Ssu			26.99		
RC		1.41	6.0			0.81		Ssu			24.17		
RC		1.41	7.0			0.79		Ssu					

Table 2.8b Summary of Test Results, Suter and Keller 1976

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	v_1 (N/mm^2)	v_d (N/mm^2)	v_{av} (N/mm^2)	Failure Mode	Mortar Strength (N/mm^2)	Grout Strength (N/mm^2)	Pier Strength (N/mm^2)
GRM	1	0.88	2	660	138	1.45			Ssu	23.0	15.2	33.90
GRM	2	0.88	2	660	138	1.94	0.03	1.79	Ssu/B	29.7	27.0	
GRM	3	0.88	2	660	138	1.90			Ssu/B	26.7	19.8	
GRM	4	0.88	3	660	138	1.23			Ssu/B	29.7	23.0	
GRM	5	0.88	3	660	138	0.91	0.04	1.18	Ssu	31.0	18.0	
GRM	6	0.88	3	660	138	1.28			Ssu/B	31.8	16.6	
GRM	7	0.88	4	660	138	0.86			Ssu	27.9	22.4	
GRM	8	0.88	4	660	138	0.73	0.04	0.82	Ssu	27.3	23.5	
GRM	9	0.88	4	660	138	0.74			Ssu	28.4	28.2	
GRM	10	0.88	5	660	138	0.38			Ssu	32.9	22.3	
GRM	11	0.88	5	660	138	0.56	0.05	0.46	Ssu	28.9	19.2	
GRM	12	0.88	5	660.	138	0.29			Ssu	29.2	14.0	

Table 2.9 Summary of Test Results, Sinha and Foster 1978

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	M_{max}/bd^2	Failure Mode	Mortar Strength (N/mm^2)	Grout Strength (N/mm^2)	Pier Strength (N/mm^2)	Span (mm)
GRM	1	0.33	2.94	328	422	104	129	2.21	Sdt	26	35	25.0	3680
GRM	2	0.33	2.94	328	422	60	74.4	1.27	Ssu	20	27	25.0	3680
GRM	3	0.50	2.94	328	422	134	166.2	2.29	Sdt	20	27	25.0	3680

Table 2.10 Summary of Test Results, Garwood and Tomlinson 1980

Beam Type	Beam Ref	ρ (%)	a/d	b (mm)	d (mm)	V_{max} (kN)	M_{max} (kNm)	$\frac{M_{max}}{bd^2}$ (N/mm²)	Failure Mode	Mortar strength (N/mm²)	Grout strength (N/mm²)	Pier strength (N/mm²)
GRM	1.1.1	0.91	5.9	295	387	62.51	143.1	3.24	Sdt	21.4	17.4	10.6
GRM	1.1.2	0.91	5.9	295	387	62.98	144.2	3.26	Sdt	21.4	18.3	11.9
GRM	1.2.1	1.47	5.9	295	384	73.86	169.1	3.83	Sdt	22.9	18.5	14.3
GRM	1.2.2	1.47	5.9	295	384	78.82	180.5	4.09	Sdt	22.9	19.1	14.3
GRM	2.1.1	0.91	5.9	295	387	60.07	137.6	3.11	Sdt	19.2	21.1	22.4
GRM	2.1.2	0.91	5.9	295	387	63.39	145.2	3.29	Sdt	22.2	18.9	22.5
GRM	2.2.1	1.47	5.9	295	384	66.39	152.0	3.44	Sdt	19.5	18.5	24.3
GRM	2.2.2	1.47	5.9	295	384	62.72	143.6	3.25	Sdt	21.5	16.9	22.5

Table 2.11 Summary of Test Results, Osman and Hendry 1982

	ENGLISH BOND	FLEMISH BOND	UOP QUETTA STYLE BOND
Ceramic/Grout Ratio Plan	3.91:1	2.57:1	1.67:1
Number of Snap Headers per 900mm	4	0	0
Spacing of Shear Voids mm	225	163 or 167	169

Table 3.1 – Ceramic/grout Ratios of Different Brickwork Bonds

Brick Beam Type and Specification Value	Bed Joint Reinforcement	Grouted Cavity Beam	*UOP Quetta Style Beam*
Aesthetically pleasing elevation	3	3	3
Aesthetically pleasing soffit	3	1	3
Wide range of bonds	3	3	1
Homogeneous interaction through cross section	0	1	3
Blend into adjacent brickwork	3	3	3
Easy soffit construction	3	1	3
Easily adapted for wall widths	2	3	2
Maximum use of brickwork	3	1	2
Minimum grout required	N/A	2	3
Accommodate shear reinforcement	0	3	3
Optimise shear capacity	0	3	3
High flexural strength (Relative)	1	3	3
Accept wide range of bar size	1	3	3
Resistance to corrosion of mild steel reinforcement	1	3	3
TOTAL	23	31	38

Table 3.2 - Scorecard

Scoring is based on decreasing weightings of 3, 2, 1 and zero.

Brick Type	Perforations		Comp Strength	Water Absorption	Initial Suction Rate
	Number	% of brick bed face	N/mm^2	%	$kg/m^2/min$
1	10	14	38.2	10.6	1.032
2	3	10	32.0	13.5	0.758
3	14	13	107.9	5.2	0.249

Table 4.1 – Brick properties

Sieve Size mm	Mass Retained g	Percentage Passing %	BS 1200 Limits
10	0	100	100
5	31	98	100
2.36	273	80	90-100
1.18	453	51	70-100
0.600	363	27	40-80
0.300	206	14	5-40
0.150	122	6	0-10
pan	94	0	

Table 4.2 - Sand grading

Brick Type	1	2	3
f_{mx} (N/mm^2)	38.2	32.0	107.9
f_{my} (N/mm^2)	11.5	7.3	9.3
f_m (N/mm^2)	25.2	8.8	14.2
$E_{initial}$ (kN/mm^2)	18.04	5.7	18.66
E_{secant} (kN/mm^2)	12.65	4.48	14.66

Table 4.3 – Compressive strength and moduli of elasticity of UOP Quetta Style Beam prisms

Steel Type	Bar Diameter mm	Load at Yield kN	Load at Failure* kN	Yield Stress N/mm^2	Ultimate Stress N/mm^2	Modulus of Elasticity kN/mm^2
HT	25	230.3	300.76	469.2	612.7	197.7
HT	20	146.2	183.7	465.4	584.7	201.2
HT	16	95.7	118.08	476.2	587.3	195.4
MS	8	14.6	20.4	290.5	405.8	242.4
MS	6	10.9	14.4	385.5	509.3	227.4

* Based on nominal bar area, no allowance has been made for necking

Table 4.4 – Mean Reinforcement Properties

Brick Type*	Brick Bed	Bwk bed fk	Prism Stretcher	Prism Header	Prsm Hdr** + Str**	Design = fk/6	Series/ref
20.1/16h	64.7	18.1	5.2	7.5	9.7	3	1-6A
14.4/23h	49.4	14.9	12.2	14.5	13.3	2.5	2-6I
12.2/8h	49.1	14.8	17.6	19.7	12.5	2.5	3-6H
Solid	43.5	13.4	11.7	10.2	11.7	2.2	4-6E
6.2/frog	33.7	11	14.4	13.2	11.5	1.8	5-6C
8.6/frog	31.7	10.4	17.8	16.6	17	1.7	6-6D
18.1/frog	25.4	8.7	5.3	5.3	6	1.4	7-6B
9.7/3h	22.7	8	5.4	8.2	7.6	1.3	8-6F

*Notes * Brick type - perorations % and number of holes*

Reference

6A -6I Davies and Hodgkinson,Ed [92]

Table 5.1a

Compressive strengths N/mm^2

Brick units on bed, brickwork f_k on bed, prism tests and prism design strengths

Refer Figure 5.1

Ref	Brick type	Code fk	Prism	Prism/2	fk/6	Ref
1	14 hole	24	22.5	11.25	4	9Arm
2	20.1 (16 hole)	18.1	9.7	4.85	3	6A
3	14.4 (23 hole)	14.9	13.3	6.65	2.5	6I
4	12.2 (8 hole)	14.8	12.5	6.25	2.5	6H
5	(10 hole)	12.2	21.2	10.6	2	9Wb
6t	(3 hole)	10.5	8	4	1.7	9Cot
7	9.7 (3hole)	8.7	7.6	3.8	1.3	6F

Reference

6 Davies and Hodgkinson,Ed [92]

9 UOP internal report

Table 5.1b Compressive strengths N/mm^2

Brickwork f_k on bed,

prism tests and prism design strengths

Refer Figure 5.2

Mortar	Statistic	Flexural tensile strength N/mm2		
		Normal to bed joint Stack prism	Parallel to bed joint	
			3 course specimen	4 course specimen
1:2:9	Mean (Cof V %)	0.39(23.3)	2.08(20.6)	1.78(26.1)
1:1:6	Mean (Cof V %)	0.594(22.9)	2.40(15.5)	2.03(18.5)
1:1/4:3	Mean (Cof V %)	0.984(25.5)	2.74(18.0)	2.29(16.5)

Reference : James [79]

Table 5.2 Flexural tensile strengths of prisms

Test	Brick type		
	A **Solid**	**B** **23 Hole**	**D** **Solid**
Compression Strength f_b N/mm^2	96.9**	61.1	18.3
E kN/mm^2	25.4	35.7	10.1
Relative E value N/mm^2	262f_b	584f_b	552f_b

REFERENCE: Riddington and Jukes [82] ***Half brick samples*

Table 5.3 Brick properties

Researcher	Brick type	Brick compressive strength f_b N/mm^2	Relative E value N/mm^2
Riddington and Jukes [82]	23 hole	61.1	262 f_b
Powell and Hodgkinson [37]	16 hole	69.6	262 f_b

Table 5.4 Comparison of brick properties

Modulus Measured	Non-dimensional Modulus of Elasticity	Non-dimensional Poissons Ratio
Between bedding planes (compression)	1.0	1.0
Between stretcher planes (tension)	0.82	0.68
Between header planes (tension)	0.63	0.54

Reference Shrive and Jessop [85]

Table 5.5 Relative brick properties

Beam category	**Failure mode**	**Shear span/depth ratio as a measure of slenderness**
Slender (greater than 60b or 250b, whichever is the lesser)	Flexure	Exceeds 5.5
Intermediate	Diagonal Tension	2.5-5.5
Deep (Span/d $\leq$5)	Shear compression	1-2.5

Reference Nawy[89]

Table 5.6 Shear failure modes

Element	Property	Value
Brick loaded on header	Elastic Modulus kN/mm^2	4.7
	Poisson's Ratio	0.3
Brick loaded on stretcher	Elastic Modulus kN/mm^2	2.9
	Poisson's Ratio	0.3
Grouted core	Elastic Modulus kN/mm^2	25.6
	Poisson's Ratio	0.3
Reinforced concrete beam	Elastic Modulus kN/mm^2	25.6
	Poisson's Ratio	0.3

Table 6.1 Analytical half-model UOP Quetta Style Beam material properties for Lusas analysis

Bending stresses N/mm^2							
Nodes X and Y	0	1	2	3	4	5	6
4	6.10	4.45	10.14	13.94	11.31	3.99	6.39
3	3.70	2.62	6.08	7.53	5.48	2.55	3.19
2	0.22	0.02	0.66	1.84	0.78	0.39	0.29
1	-2.61	-1.93	-6.31	-10.51	-6.43	-1.97	-2.58
0	-4.69	-4.23	-4.27	-4.34	-4.24	-4.22	-4.70

Legend: Compressive stresses are shown as positive values
Tensile stresses are shown as negative values
Refer Figures 6.13a – g for plots of stress diagrams

Table 6.2 Bending stresses at the nodes shown in Figure 6.12

Brick	Type 1			Type 2			Type 3		
Span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
b mm	327.50	327.50	327.50	327.50	327.50	327.50	327.50	327.50	327.50
d mm	192	190	187.50	192	190	187.50	192	190	187.50
Φ mm^2	16	20	25	16	20	25	16	20	25
n	2	2	2	2	2	2	2	2	2
A_{st} mm^2	402	628	982	402	628	982	402	628	982
ρ	0.006	0.010	0.016	0.006	0.010	0.016	0.006	0.010	0.016
p_{cb} N/mm^2	25.20	25.20	25.20	8.80	8.80	8.80	14.20	14.20	14.20
f_y N/mm^2	476.2	465.4	469.2	476.2	465.4	469.2	476.2	465.4	469.2
E_{bi} kN/mm^2	18.04	18.04	18.04	5.70	5.70	5.70	18.66	18.66	18.66
E_s kN/mm^2	195.4	201.20	197.7	195.4	201.20	197.7	195.4	201.20	197.7
m	10.83	11.2	11.0	34.3	35.3	34.7	10.5	10.8	10.6

Table 7.1a Basic data for predictions using elastic analysis
(Brickwork prism strength and initial modulus)

Brick	Type 1			Type 2			Type 3		
Beam span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
d_c mm	59.1	71.3	83.0	91.4	106	119	58.2	70.4	82.0
z mm	172	166	160	162	155	148	173	167	160
I_{brick} x 10^6 mm^4	22.5	40.0	62.3	83.3	132	185	21.6	38.0	60.1
I_{steel} x 10^6 mm^4	76.0	99.0	118	138	156	160	74.4	97.2	117
I_{beam} x 10^6 mm^4	98.5	138	181	221	287	345	95.9	135	177
M_{st} kNm	32.8	48.5	73.8	30.7	44.8	68.2	32.9	48.8	73.8
M_{bc} kNm	42.0	49	54.9	21.3	23.7	25.4	23.4	27.2	30.5
W_{st} kN	49.3	48.5	55.4	46.1	44.8	51.2	49.4	48.8	55.4
W_{bc} kN	63.0	49	41.6	32	23.7	19.0	35.1	27.3	22.9

Table 7.1b Predictions using elastic analysis

Brick	Type 1			Type 2			Type 3		
Span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
b mm	327.50	327.50	327.50	327.50	327.50	327.50	327.50	327.50	327.50
d mm	192	190	187.50	192	190	187.50	192	190	187.50
Φ mm^2	16	20	25	16	20	25	16	20	25
n	2	2	2	2	2	2	2	2	2
A_{st} mm^2	402	628	982	402	628	982	402	628	982
f_k N/mm^2	25.20	25.20	25.20	8.80	8.80	8.80	14.20	14.20	14.20
f_y N/mm^2	476.2	465.4	469.2	476.2	465.4	469.2	476.2	465.4	469.2
E_{bs} kN/mm^2	12.65	12.65	12.65	4.48	4.48	4.48	14.66	14.66	14.66
E_s kN/mm^2	195.4	201.2	197.7	195.4	201.2	197.7	195.4	201.2	197.7
m	15.4	15.9	15.6	43.3	44.9	44.1	13.1	13.7	13.5

Table 7.2a Basic data for predictions using limit state analysis
(Brickwork prism strength and secant modulus)

Brick	Type 1			Type 2			Type 3		
Beam span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
d_c mm	24	36	55	66	101	159	41	63	100
z mm	180	172	160	159	130	108	171.5	159	137
I_{beam} x 10^6 mm^4	177	242	290	243	338	476	100	166	212
M_{st} kNm	34.4	50.2	73.8	30.4	40.6	49.8	32.8	46.3	64
M_{bc} kNm	35.7	51.1	72.6	30.2	40.5	49.5	32.7	46.6	63.7
W_{st} kN	51.6	50.2	55.4	45.6	40.6	37.4	49.2	46.3	48
W_{bc} kN	53.6	51.1	54.5	40.5	40.5	37.1	49.1	46.6	47.8

Table 7.2b Predictions using modified BS 5628 Part 2 equations
(Material factors γ_{mb} = γ_{ms} = 1.0)

Brick	Type 1			Type 2			Type 3		
Beam span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
d_c mm	30.9	47.1	74.5	88.4	115	127	54.7	85.6	112
z mm	179	170	156	155	142	135	169	154	132
$I_{beam} \times 10^6$ mm^4	202	218	241	263	333	385	117	165	228
M_s kNm	34.2	49.7	72.1	29.6	39.0	*	32.3	45.1	61.0
M_b kNm	69.3	78.7	86.2	32.5	35.3	36.9	46.5	51.5	55
W_s kN	51.3	49.7	54.1	44.4	39.0	*	48.5	45.1	45.8
W_b kN	104	78.7	64.8	48.7	35.3	36.9	69.7	51.5	41.3

Table 7.2c Predictions using limit state analysis considering ductile/brittle failure
(Material factors $\gamma_{mb} = \gamma_{ms} = 1.0$)
** Feasible solution not possible due to high value of d_c*

Brick	Type 1			Type 2			Type 3		
Beam span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
d_c mm	40	62	97	116	*N/A*	*N/A*	145	144	101
z mm	172	159	139	134	*N/A*	*N/A*	94	118	173
$M_s = M_b$ kNm	28.5	40.5	55.6	22.3	*N/A*	*N/A*	26.0	34.4	40.5
$W_s = W_b$ kN	42.8	40.5	43	33.6	*N/A*	*N/A*	39	34.4	30.3

Table 7.2d Predictions using the design equations from BS 5628 Part 2
(Prism brickwork strengths and material factors γ_{mb} =2.0 γ_{ms} = 1.15)

N/A – values for the depth of the neutral axis obtained from the calculations were not acceptable.

Method of analysis (Table No.)	Brick Type 1			Brick Type 2			Brick Type 3		
Beam span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
Elastic (7.1b)	59.3	71.4	83.1	91.8	106	119	58.6	70	82
Modified BS 5628 $\gamma_{ms} = \gamma_{mm} = 1.0$ (7.2b)	24	36	55	66	101	159	41	63	100
Ductile/brittle (7.2c)	31	47	75	88	115	127	55	86	112
BS 5628 Factored (7.2d)	40	62	97	116	176	279	145	144	101
Experimental values16c Grade 1	90	87	85	-	106	-	75	82	90
Experimental values Grade 2 - 4	-	-	80 *3 No Rejected*	6 No *Rejected*	119 *2 No Rejected*	94 *4 No Rejected*	111	105 *1 No rejected*	78 *2 No Rejected*

Table 7.3 Comparisons of predicted and experimental neutral axis depths

Brick	Type 1			Type 2			Type 3			Type 1	Type 2	Type 3
Beam series	1	2	3	1	2	3	1	2	3	All	All	All
Span mm	Reinforced in shear											
2000	77.5	99.4	91.4	R (-)	R (133)	R (141)	59.6	93.4	111	78.8	93.4	101.2
3000	90	95.3	97.3	R (162)	97.3	119	71.5	65.5	90	80.8	88	102.1
4000	85.4	R (92.0)	93.4	85.4	R (119	R (135)	R (71.5)	79.5	95.3	85.4	79.5	94.4
	Unreinforced in shear											
2000	101.5	92.3	90.8	R (90)	R (187	R (32/127)	93.4	65.5	63.6	97.5	78.9	77.2
3000	75.4	75.4	115.2	R (-)	103.3	119	R (20)	99.3	105	88.6	92.7	99.8
4000	67.5	R (71.5)	R (105.2)	R (107)	103.3	R (111)	59.6	90	R (20)	63.6	90	(-)R

Table 7.4 Comparison of neutral axis positions

(Depth in mm from top of the beam)

R ( )- Strain diagrams contain irregularities in the shape of the curves

Brick	Type 1,2 and 3		
Span mm	2000	3000	4000
b mm	327.5	327.5	327.5
dbmm	192	190	187.5
A_{st} mm^2	402	628	982
ρ	0.0064	0.00101	0.016
A_{sv} mm^2	56.55	56.55	56.55
f_{yv} N/mm^2	385.5	385.5	385.5
S_v mm	168.8	168.8	168.8
γ_{mv}	2.0	2.0	2.0
γ_{ms}	1.0	1.0	1.0
a mm	667	1000	1333
a/d	3.47	5.26	7.1
n_i	1.63	1.19	19.3
f_{vu} N/mm^2	0.753	0.63	0.63
V_{UE} kN	17.6	17.4	17.2
V_{RE} kN	42.4	41.9	41.4
V_{UL} kN	23.7	19.6	19.3
V_{RL} kN	48.5	44.1	43.5

Table 7.5 Predictions of Elastic and Ultimate Shear Strengths for Unreinforced and Reinforced beams

Series	Brick Type 1						Brick Type 2						Brick Type 3					
Beam span mm	2000		3000		4000		2000		3000		4000		2000		3000		4000	
1/0	40.9	S	38.9	B_t/S	**		*		*		*		39.9	S	*	S	**	
1/1	40.9	S	38.9	B_t	37.5	B_t	*		*		**		37.7	S	36.6	S	*	
2//0	36.8	S	41.4	S	*	S	*		39.1	S	**		37.7	S	32.2	S	46	S
2/1	44.5	S	50.6	B_c	*		*		43.7	S	*		40.6	S	47.2	S	**	
3/0	36.8	S	44.8	S	*		*		**		*		39.9	?	**		*	
3/1	46	S	59.8	S	61.3	B_c	*		46	B_c	*		**		46	S	**	
Ave	41		46.7		49.4		-		42.9		-		39.2		40.5		46	

Table 7.6a Comparison of Experimental BMs (kNm) - Grade 1 Beams

1/0 Series 1 unreinforced *1/1 Series 1 reinforced*

* *Strain readings rejected* *S Shear failure*

** *Beams Grade 2-4* *B_t Tensile bending failure*

B_c Compression bending failure

Series	Brick Type 1						Brick Type 2						Brick Type 3					
Beam span mm	2000		3000		4000		2000		3000		4000		2000		3000		4000	
1/0	*	*	*	*	39.1	B_t	*	*	*	*	*	*	*	*	*	*	40.6	B_t
1/1	*	*	*	*	*	*	*	*	*	*	*	B_t	*	*	*	*	*	*
2//0	*	*	*	*	*	*	*	*	*	*	39.9	B_c	*	*	*	*	*	*
2/1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	47.6	B_c
3/0	*	*	*	*	*	*	*	*	40.3	B_c	*	*	*	*	32.2	S	*	*
3/1	*	*	*	*	*	*	*	*	*	*	*	*	36.8	S	*	*	49.1	?
Ave	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 7.6b Comparison of Experimental BMs (kNm)- Grade 2-4 Beams

1/0 Series 1 unreinforced *1/1 Series 1 reinforced*

* *Strain readings rejected*

Table No.	Method of beam analysis	Brick Type 1 Beam span mm			Brick Type 2 Beam span mm			Brick Type 3 Beam span mm		
		2000	3000	4000	2000	3000	4000	2000	3000	4000
7.1b	Elastic M_s	32.8	48.5	73.8	30.7	44.8	68.2	32.9	48.8	73.8
7.1b	Elastic M_b	42.0	49	54.9	21.3	23.7	25.4	23.4	27.2	30.5
7.2b	Limit state M_s $\gamma_{mb} = \gamma_{ms} = 1.0$	34.4	50.2	73.8	30.4	40.6	49.8	32.8	46.3	64.0
7.2b	Limit state M_b $\gamma_{mb} = \gamma_{ms} = 1.0$	35.7	51.1	72.6	30.2	40.5	44.5	32.7	46.3	63.7
7.2e	Factored BS 5628 M $\gamma_{mb} = 2.0$ $\gamma_{ms} = 1.15$	28.5	40.3	35.7	23.4	25.9	*	25.9	34.3	40.5
7.2c	Ductile M_s $\gamma_{mb} = \gamma_{ms} = 1.0$	34.2	49.7	51.3	29.6	-	*	32.3	45.1	-
7.2c	Brittle M_b $\gamma_{mb} = \gamma_{ms} = 1.0$	-	-	-	-	35.3	36.9	-	-	55
7.6a	Experimental G1	41	46.7	49.4	36	42.9	-	39.2	40.5	46
7.6b	Experimental G2 – G4	-	-	39.1	-	40.3	36.7	36.8	32.2	49.1
	Factored BS 5628 M_s using $f_k/3$ $\gamma_{mb} = 2.0$ $\gamma_{ms} = 1.15$	9.9	9.7	9.4	8.5	8.3	8.0	19.3	18.9	18.4

Table 7.7 Comparison of all bending moments (kNm) –elastic, ultimate and experimental

**Calculation showed neutral axis depth to be greater than 'd'.*

Refer Figures 7.13a -c

Brick Type	1			2			3		
Brick Span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
Unit Weight kN/m^3	23.7	23.7	23.7	22.3	22.3	22.3	25.4	25.4	25.4
E_i kN/mm^2	18..04	18.04	18.04	5.7	5.7	5.7	18.66	18.66	18.66
M_{max} kNm	1.125	2.53	4.5	1.06	2.38	4.23	1.21	2.71	4.82
v N/mm^2	0.024	0.036	0.048	0.23	0.34	0.045	0.026	0.039	0.051
$f_{bc} = f_{bt}$ N/mm^2	0.25	0.56	1.00	0.24	0.53	0.94	0.27	0.60	1.07
$\varepsilon_{bc} = \varepsilon_{bt}$ $x\ 10^{-6}$	14	32	56	41	92	165	15	32	57
T = C kN	5.9	13	24	5.6	12	22.6	6.3	13.9	25.7

Table 7.8 Calculation of self weight effects

Method of beam analysis of MOR	Brick Type 1			Brick Type 2			Brick Type 3		
	Beam span mm			Beam span mm			Beam span mm		
	2000	3000	4000	2000	3000	4000	2000	3000	4000
Elastic	99.5	139	180	224	319	345	79.2	136	177
Limit state	177	242	290	243	338	476	100	166	212
Factored BS 5628	150	185	226	244	*	*	99	200	*
Ductile -tension	164	218	241	263	–	–	117	165	–
Brittle-compression	–	–	–	–	333	385	–	–	228

Table 7.9 Comparison of second moments of area I $cm^4 \times 10^6$

Elastic calculations based on initial modulus and other analyes based on secant modulus

1 Graph No	2 Beam Ref	4 Expt BM kNm	5 Mode of failure	6 d mm	7 dc From Strain graph mm	9 Expt beam Tex at failure kN	14 pcb / fk N/mm2	15 f b from expt Tex Triangle N/mm2	16 f b from expt Tex Rectangle N/mm2	17 Brick strain from Tex E initial x 10 - 6	18 Brick strain from Tex E secant x 10 - 6	19 Brick strain from expt graphs x 10 - 6
Grade 2												
34	1/241	28.1	Bt	187.5	85.4	247	8.8	16.9*	10.6		2366	950
27	3/230	40.3	Bc	190	119	287	8.8	23.8*	8.8		1964	1900
42	3/321	55.2	S	192	111	237	14.2	13		697		1300
45	3/330	32.2	S	190	105	208	14.2	12.1		648		1250
54	3/341	36.8	S	187.5	95.3	382	14.2	20.2*	12.8		873	1300
Grade 3												
13	1/140	29.3	Bt	187.5	67.5	237	25.2	21.4		1186		1300
18	3/141	46	Bc	187.5	93.4	392	25.2	25.6		1419		1600
Grade 4												
49	1/340	40.6	Bt	187.5	59.6	250	14.2	26.3*	15.4		1050	750
32	2/240	39.9	Bc	187.5	103.3	270	8.8	17.4*	9.8		2188	1400
53	2/341	47.6	Bc	187.5	79.5	308	14.2	24.7*	17.5		1194	1200

Table 7.10d – Analyses of Tensile and Compressive Behaviour of Beams using the Experimental Results – Beams Grade 2 to 4 (Contd)

1 Graph No	2 Beam Ref	3 Expt Load kN	4 Expt BM kNm	5 Mode of failure
Grade 2				
14	2/140	Reject		S
15	3/140	Reject		S
Grade 3				
17	2/141	Reject		Bc
35	2/241	Reject		Bc
36	3/241	Reject		Bc
51	3/340	Reject		S
Grade 4	**Grade 4**			
28	1/231	Reject		Bt
31	1/240	Reject		Bt
52	1/341	Reject		Bt
33	3/240	Reject		Bc
19	1/220	Reject		S
20	2/220	Reject		S
21	3/220	Reject		S
22	1/221	Reject		S
23	2/221	Reject		S
24	3/221	Reject		S
25	1/230	Reject		S
43	1/330	Reject		S

Table 7.10e – Analyses of Compressive and Tensile Behaviour of Beams using the Experimental Results — Beams Grade 2 to 4

Graph	Beam	Mode	p cb/fk Prism N/mm^2	f b Experimental N/mm^2	Tex - Tey kN
1	1/120	S	25.2	15.6	68
4	1/121	S	25.2	19.4	55
7	1/130	Bt +S	25.2	19.1	-56
10	1/131	Bt	25.2	16.5	-49
16	1/141	Bt	25.2	16.9	-230
2	2/120	S	25.2	15.1	37
5	2/121	S	25.2	17.2	89
8	2/130	S	25.2	20.3	-41
11	2/131	Bt + Bc	25.2	20.5	28
3	3/120	S	25.2	15.3	37
6	3/121	S	25.2	16.5	56
9	3/130	S	25.2	21.7	77
12	3/131	S	25.2	23.8	88
				Ave 18.3	
26	2/230	S	8.8	9.4	-26
29	2/231	Bc	8.8	11.0	0
30	3/231	Bc	8.8	10.1	36
				Ave10.2	
37	1/320	S	14.2	10.2	70
40	1/321	Bt	14.2	13.9	35
46	1/331	Bt	14.2	11.7	-64
38	2/320	S	14.2	12.8	38
41	2/321	S	14.2	10.4	74
44	2/330	S	14.2	12.6	-87
47	2/331	S	14.2	16.2	-2
50	2/340	S	14.2	12.5	-159
39	3/320	S	14.2	13.9	50
48	3/331	S	14.2	12.3	10
				Ave12.7	

Table 7.10f – Analysis of Compressive Stress relationship between calculated stresses from BM and prism tests. Comparison also with mode of failure and reserve force in tension zone Beams Grade 1

Method of Beam Analysis	Brick Type 1			Brick Type ` 2			Brick Type 3			Row No.
	Beam Span mm			Beam Span mm			Beam Span mm			
	2000	3000	4000	2000	3000	4000	2000	3000	4000	
$I_{cr\ initial}$ x 10^6 mm^4	99.5	139.2	180	224	319	345	79.2	136	177	1
$I_{cr\ secant}$ x 10^6 mm^4	177	242	290	243	338	476	100	166	212	2
W selected from Load/Deflection Graph	48	32	18	21	28	14	48	28	23	3
y_i calculated from W on Load/Deflection Graph	7.6	12.2	12.6	4.7	14.8	16.2	9.2	10.6	15.8	3
$y_{s\ calculated}$ from W on Load/Deflection Graph	10.8	17.4	18.0	5.9	18.8	20.6	11.7	13.5	20.1	5
y_{mean} from all Load/Deflection Graphs	7.3	12.8	19	4.6	15.9	20.7	7.2	11.6	23.2	6
W_{max} from beam tests	69.0	59.8	46.0	52.0	46.0	29.9	60.9	47.2	36.8	7
Calculated y_{max} from tests	8.8	18.7	28.5	13.6	29.1	31.9	11.8	18.6	26.9	8
W_{max} from Table 7.7 calcs	63.0	50.2	55.4	46.0	44.8	51.2	49.4	48.8	55.4	9
Calculated y_{max} using Table 7.7 tests	8.0	15.7	34.4	12.0	28.4	54.5	9.6	18.0	40.5	10
y_{max} from Load/Deflection Graphs	12.8	19.0	30.0	12.0	28.0	29.5	13.5	24.5	28.8	11

Table 7.11a Deflection calculations and comparisons

y_i based on initial modulus
y_s based on secant modulus
Graphs refer to Experimental Load/deflection Plots
Units: W kN y mm
Refer Figure 8.9

Method Of Beam Analysis	Brick Type 1 Beam Span mm			Brick Type ` 2 Beam Span mm			Brick Type 3 Beam Span mm			
	2000	3000	4000	2000	3000	4000	2000	3000	4000	Row No
y_i calculated from W on Load/Deflection Graph	7.6	12.2	12.6	4.7	14.7	16.2	9.2	10.6	15.8	1
y_s calculated from W on Load/Deflection Graph	10.8	17.4	18.0	5.9	18.8	20.6	11.7	13.5	20.1	2
y_{mean} from all Load/Deflection Graphs	7.3	12.8	19.0	4.6	15.9	20.7	7.2	11.6	23.2	3
y_{max} from all Load/Deflection Graphs	12.8	19.0	30.0	12.0	28.0	29.5	13.5	24.5	28.8	3
y_{max} calculated from W_{max} experimental load	8.8	18.7	28.5	13.6	29.1	31.9	11.8	18.6	26.9	5
y_{max} calculated using $W_{max\ from}$ Table 7.7 calcs	8.0	15.7	34.3	15.4	15.4	18.6	9.6	18.0	40.5	6
y_{max} calculated from BS 5628 Part 2	5.4	15.7	34.4	4.7	14.0	21.6	2.4	6.3	11.6	7
y_{max} calculated from BS 5628 Part 2, using f_k /3	1.8	5.2	11.5	1.6	4.7	7.2	0.8	2.1	3.5	8

Table 7.11b Summary of Deflection calculations and comparisons

y_i based on initial modulus

y_s based on secant modulus

Graphs refer to Experimental Load/deflection Plots

Units: W kN y mm

Refer Figure 8.10

	Elastic analysis					Ultimate limit state analysis				
Beam Ref.	W_s kN	W_b kN	V kN	Failure Load	Failure Mode	W_s kN	W_b kN	V kN	Failure Load	Failure Mode
120	49.3	63.0	17.6	17.6	S	51.3	104.0	23.7	23.7	S
130	48.5	49.0	17.4	17.4	S	49.7	78.7	19.6	19.6	S
140	55.4	41.6	17.2	17.2	S	54.1	64.8	19.3	19.3	S
121	49.3	63.0	42.4	42.4	S	51.3	104.0	48.5	48.5	S
131	48.5	49.0	41.9	41.9	S	49.7	78.7	44.1	41.1	S
141	55.4	41.6	41.4	41.4	S	54.1	64.8	43.5	43.5	S
220	46.1	32.0	17.6	17.6	S	44.4	48.7	23.7	23.7	S
230	44.8	23.7	17.4	17.4	S	39.0	35.3	19.6	19.6	S
240	51.2	19.0	17.2	17.2	S	*	56.9	19.3	19.3	S
221	46.1	32.0	42.4	32.0	Bc	44.4	48.7	48.5	44.4	Bt
231	44.8	23.7	41.9	23.7	Bc	39.0	35.3	44.1	35.3	Bc
241	5.2	19.0	41.4	19.0	Bc	*	36.9	43.5	36.9	Bc
320	49.4	35.1	17.6	17.6	S	48.5	69.7	23.7	23.7	S
330	48.8	27.3	17.4	17.4	S	45.1	51.5	19.6	19.6	S
340	55.4	22.9	17.2	17.2	S	45.8	41.3	19.3	19.3	S
321	49.4	35.1	42.4	35.1	Bc	48.5	69.7	48.5	48.5	Bt+S
331	48.8	27.3	41.9	27.3	Bc	45.1	51.5	44.1	44.1	S
341	55.4	22.9	41.4	22.9	Bc	45.8	41.3	43.5	41.3	Bc

Table 7.12 Predicted failure loads and failure modes – Series 1, 2 and 3 Beams

S = Shear   Bt = Bending tension   Bc = Bending compression

** Feasible solution not possible due to high value of d_e*

Method	Elastic		Ultimate Limit State		Experimental			
Beam Ref.	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Factor of safety	
							Elastic	Ultimate
1/120	17.6	S	23.7	S	61.3	S	3.48	2.59
1/130	17.4	S	19.6	S	38.9	Bt+S	2.24	1.98
1/140	17.2	S	19.3	S	29.3	Bt	1.70	1.52
1/121	42.4	S	48.5	S	61.3	S	1.45	1.26
1/131	41.9	S	41.1	S	38.9	Bt	0.93	0.80
1/141	41.4	S	43.5	S	28.1	Bt	0.68	0.65
1/220	17.6	S	23.7	S	42.8	S	2.43	1.81
1/230	17.4	S	19.6	S	32.0	S	1.84	1.63
1/240	17.2	S	19.3	S	24.7	Bt	1.44	1.28
1/221	32.0	Bc	44.4	Bt	52.0	S	1.63	1.17
1/231	23.7	Bc	35.3	Bc	34.3	Bt	1.45	0.97
1/241	19.0	Bc	36.9	Bc	28.1	Bt	1.48	0.76
1/320	17.6	S	23.7	S	56.6	S	3.22	2.39
1/330	17.4	S	19.6	S	36.6	S	2.10	1.87
1/340	17.2	S	19.3	S	30.5	Bt	1.77	1.58
1/321	35.1	Bc	48.5	Bt+S	56.6	Bt	1.61	1.17
1/331	27.3	Bc	44.1	S	36.6	Bt	1.34	0.83
1/341	22.9	Bc	41.3	Bc	29.3	Bt	1.28	0.71

Table 7.13a Predicted and experimental failure loads and failure modes – Series 1 Beams

S = Shear Bt = Bending tension Bc = Bending compression
Based on code value for γ_{mv} unit values for γ_{mm} and γ_{ms}

Method	Elastic		Ultimate Limit State		Experimental			
Beam Ref.	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Factor of safety	
							Elastic	Ultimate
2/120	17.6	S	23.7	S	55.2	S	3.14	2.33
2/130	17.4	S	19.6	S	41.4	S	2.38	2.11
2/140	17.2	S	19.3	S	32.2	S	1.87	1.67
2/121	42.4	S	48.5	S	66.7	S	1.57	1.38
2/131	41.9	S	41.1	S	50.6	Bt+Bc	1.21	1.23
2/141	41.4	S	43.5	S	39.1	Bc	0.94	0.90
2/220	17.6	S	23.7	S	20.7	S	1.18	0.87
2/230	17.4	S	19.6	S	39.1	S	2.25	1.99
2/240	17.2	S	19.3	S	29.9	Bc	1.74	1.55
2/221	32.0	Bc	44.4	Bt	43.7	S	1.37	0.98
2/231	23.7	Bc	35.3	Bc	43.7	Bc	1.84	1.24
2/241	19.0	Bc	36.9	Bc	27.6	Bc	1.45	0.75
2/320	17.6	S	23.7	S	48.3	S	2.74	1.16
2/330	17.4	S	19.6	S	32.2	S	1.85	1.64
2/340	17.2	S	19.3	S	34.5	S	2.01	1.79
2/321	35.1	Bc	48.5	Bt+S	60.9	S	1.74	1.26
2/331	27.3	Bc	44.1	S	47.2	S	1.73	1.07
2/341	22.9	Bc	41.3	Bc	35.7	Bc	1.56	0.86

Table 13b Predicted and experimental failure loads and failure modes – Series 2 Beams

S = Shear Bt = Bending tension Bc = Bending compression
Based on code value for γ_{mv} and unit values for γ_{mm} and γ_{ms}

Method	Elastic		Ultimate Limit State		Experimental			
Beam Ref.	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Factor of safety	
							Elastic	Ultimate
3/120	17.6	S	23.7	S	55.2	S	3.14	2.33
3/130	17.4	S	19.6	S	44.8	S	2.57	2.29
3/140	17.2	S	19.3	S	36.8	S	2.14	1.91
3/121	42.4	S	48.5	S	69.0	S	1.63	1.43
3/131	41.9	S	41.1	S	59.8	S	1.43	1.45
3/141	41.4	S	43.5	S	46.0	Bc	1.11	1.06
3/220	17.6	S	23.7	S	29.9	S	1.70	1.26
3/230	17.4	S	19.6	S	40.3	Bc	2.32	2.06
3/240	17.2	S	19.3	S	23.6	Bc	1.37	1.22
3/221	32.0	Bc	44.4	Bt	32.2	S	1.01	0.73
3/231	23.7	Bc	35.3	Bc	46.0	Bc	1.94	1.33
3/241	19.0	Bc	36.9	Bc	29.9	Bc	1.57	0.75
3/320	17.6	S	23.7	S	55.2	-	3.14	2.33
3/330	17.4	S	19.6	S	32.2	S	1.85	1.64
3/340	17.2	S	19.3	S	34.5	S	2.01	1.79
3/321	35.1	Bc	48.5	Bt+S	55.2	S	1.57	1.14
3/331	27.3	Bc	44.1	S	46.0	S	1.68	1.04
3/341	22.9	Bc	41.3	Bc	36.8	-	1.61	0.89

Table 7.13c Predicted and experimental failure loads and failure modes – Series 3 Beams

S = Shear Bt = Bending tension Bc = Bending compression
Based on code value for γ_{mv} and unit values for γ_{mm} and γ_{ms}

Beam Ref.	Failure Mode	Factor of safety	
		Elastic	Ultimate
1/120	S	3.48	2.59
1/130	Bt+S	2.24	1.98
1/140	Bt	1.70	1.52
1/220	S	2.43	1.81
1/230	S	1.84	1.63
1/240	Bt	1.44	1.28
1/320	S	3.22	2.39
1/330	S	2.10	1.87
1/340	Bt	1.77	1.58
2/120	S	3.14	2.33
2/130	S	2.38	2.11
2/140	S	1,87	1.67
2/220	S	1.18	0.87
2/230	S	2.25	1.99
2/240	Bc	1.74	1.55
2/320	S	2.74	1.16
2/330	S	1.85	1.64
2/340	S	2.01	1.79
3/120	S	3.14	2.33
3/130	S	2.57	2.29
3/140	S	2.14	1.91
3/220	S	1.70	1.26
3/230	Bc	2.32	2.06
3/240	Bc	1.37	1.22
3/320	-	3.14	2.33
3/330	S	1.85	1.63
3/340	S	2.01	1.79
	Ave	2.29	1.80

Table 13d Experimental/Prediction Factors of Safety
Beams unreinforced in shear

Beam Ref.	Failure Mode	Factor of safety	
		Elastic	Ultimate
1/121	S	1.45	1.26
1/131	Bt	0.93	0.80
1/141	Bt	0.68	0.65
1/221	S	1.63	1.17
1/231	Bt	1.45	0.97
1/241	Bt	1.48	0.76
1/321	Bt	1.61	1.17
1/331	Bt	1.34	0.83
1/341	Bt	1.28	0.71
2/121	S	1.57	1.38
2/131	Bt+Bc	1.21	1.23
2/141	Bc	0.94	0.90
2/221	S	1.37	0.98
2/231	Bc	1.84	1.24
2/241	Bc	1.45	0.75
2/321	S	1.74	1.26
2/331	S	1.73	1.07
2/341	Bc	1.56	0.86
3/121	S	1.63	1.43
3/131	S	1.43	1.45
3/141	Bc	1.11	1.06
3/221	S	1.01	0.73
3/231	Bc	1.94	1.33
3/241	Bc	1.57	0.75
3/321	S	1.57	1.14
3/331	S	1.68	1.04
3/341	-	1.61	0.89
	Average	1.44	1.03

Table 13e Experimental/Prediction Factors of Safety
Beams reinforced in shear

Beam Ref.	Factor of safety	
	Elastic	Ultimate
1/120	3.48	2.59
2/120	3.14	2.33
3/120	3.14	2.33
1/130	2.24	1.98
2/130	2.38	2.11
3/130	2.57	2.29
1/140	1.70	1.52
2/140	1.87	1.67
3/140	2.14	1.91
1/220	2.43	1.81
2/220	1.18	0.87
3/220	1.70	1.26
1/230	1.84	1.63
2/230	2.25	1.99
3/230	2.32	2.06
1/240	1.44	1.28
2/240	1.74	1.55
3/240	1.37	1.22
1/320	3.22	2.39
2/320	2.74	1.16
3/320	3.14	2.33
1/330	2.10	1.87
2/330	1.85	1.64
3/330	1.85	1.64
1/340	1.77	1.58
2/340	2.01	1.79
3/340	2.01	1.79

Table 7.13f Experimental/Prediction Factors of Safety
Beams unreinforced in shear
Classified according to brick type and beam span
Refer Figure 7.6

Averages of the Factors of Safety by Brick Type

Brick type	*Average FOS*
1	*2.1*
2	*1.5*
3	*1.8*

Beam Ref.	Factor of safety	
	Elastic	Ultimate
1/121	1.45	1.26
2/121	1.57	1.38
3/121	1.63	1.43
1/131	0.93	0.80
2/131	1.21	1.23
3/131	1.43	1.45
1/141	0.68	0.65
2/141	0.94	0.90
3/141	1.11	1.06
1/221	1.63	1.17
2/221	1.37	0.98
3/221	1.01	0.73
1/231	1.45	0.97
2/231	1.84	1.24
3/231	1.94	1.33
1/241	1.48	0.76
2/241	1.45	0.75
3/241	1.57	0.75
1/321	1.61	1.17
2/321	1.74	1.26
3/321	1.57	1.14
1/331	1.34	0.83
2/331	1.73	1.07
3/331	1.68	1.04
1/341	1.28	0.71
2/341	1.56	0.86
3/341	1.61	0.89

Table 13g Experimental/Prediction Factors of Safety
Beams reinforced in shear
Classified according to brick type and beam span
Refer Figure 7.7

Averages of the Factors of Safety by Brick Type

Brick type	*Average FOS*
1	*1.13*
2	*0.96*
3	*1.00*

Beam	Factor of safety	
Ref.	Elastic	Ultimate
1/120	3.48	2.59
1/220	2.43	1.81
1/320	3.22	2.39
2/120	3.14	2.33
2/220	1.18	0.87
2/320	2.74	1.16
3/120	3.14	2.33
3/220	1.70	1.26
3/320	3.14	2.33
Ave	***2.69***	***1.89***
1/130	2.24	1.98
1/230	1.84	1.63
1/330	2.10	1.87
2/130	2.38	2.11
2/230	2.25	1.99
2/330	1.85	1.64
3/130	2.57	2.29
3/230	2.32	2.06
3/330	1.85	1.64
Ave	***2.49***	***1.91***
1/140	1.70	1.52
1/240	1.44	1.28
1/340	1.77	1.58
2/140	1.87	1.67
2/240	1.74	1.55
2/340	2.01	1.79
3/140	2.14	1.91
3/240	1.37	1.22
3/340	2.01	1.79
Ave	***1.78***	***1.59***

Table 7.13h Experimental/Prediction Factors of Safety
Beams unreinforced in shear
Classified according to beam span
Refer Figure 7.8

Beam	Factor of safety	
Ref.	Elastic	Ultimate
1/121	1.45	1.26
1/221	1.63	1.17
1/321	1.61	1.17
2/121	1.57	1.38
2/221	1.37	0.98
2/321	1.74	1.26
3/121	1.63	1.43
3/221	1.01	0.73
3/321	1.57	1.14
Ave	***1.51***	***1.17***
1/131	0.93	0.80
1/231	1.45	0.97
1/331	1.34	0.83
2/131	1.21	1.23
2/231	1.84	1.24
2/331	1.73	1.07
3/131	1.43	1.45
3/231	1.94	1.33
3/331	1.68	1.04
Ave	***1.51***	***1.10***
1/141	0.68	0.65
1/241	1.48	0.76
1/341	1.28	0.71
2/141	0.94	0.90
2/241	1.45	0.75
2/341	1.56	0.86
3/141	1.11	1.06
3/241	1.57	0.75
3/341	1.61	0.89
Ave	***1.30***	***0.81***

Table 7.13j Experimental/Prediction Factors of Safety
Beams reinforced in shear
Classified according to beam span
Refer Figure 7.9

Beam Ref.	Failure Mode	Factor of safety	
		Elastic	Ultimate
1/120	S	3.48	2.59
1/121	S	1.45	1.26
1/220	S	2.43	1.81
1/230	S	1.84	1.63
1/221	S	1.63	1.17
1/320	S	3.22	2.39
1/330	S	2.10	1.87
2/120	S	3.14	2.33
2/130	S	2.38	2.11
2/140	S	1.87	1.67
2/121	S	1.57	1.38
2/220	S	1.18	0.87
2/230	S	2.25	1.99
2/221	S	1.37	0.98
2/320	S	2.74	1.16
2/330	S	1.85	1.64
2/340	S	2.01	1.79
2/321	S	1.74	1.26
2/331	S	1.73	1.07
3/120	S	3.14	2.33
3/130	S	2.57	2.29
3/140	S	2.14	1.91
3/121	S	1.63	1.43
3/131	S	1.43	1.45
3/220	S	1.70	1.26
3/221	S	1.01	0.73
3/330	S	1.85	1.64
3/340	S	2.01	1.79
3/321	S	1.57	1.14
3/331	S	1.68	1.04
	Average	2.03	1.60

Table 7.13k Experimental/Prediction of Factors of Safety
Beams failing in shear
Refer Figure 7.10

Beam Ref.	Failure Mode	Factor of safety	
		Elastic	Ultimate
1/140	Bt	1.70	1.52
1/131	Bt	0.93	0.80
1/141	Bt	0.68	0.65
1/240	Bt	1.44	1.28
1/231	Bt	1.45	0.97
1/241	Bt	1.48	0.76
1/340	Bt	1.77	1.58
1/321	Bt	1.61	1.17
1/331	Bt	1.34	0.83
1/341	Bt	1.28	0.71
	Average	1.37	1.03

Table 7.13l Experimental/Prediction of Factors of Safety
Beams failing in bending tension
Refer Figure 7.11

Beam Ref.	Failure Mode	Factor of safety	
		Elastic	Ultimate
3/141	Bc	1.11	1.06
3/230	Bc	2.32	2.06
3/240	Bc	1.37	1.22
3/231	Bc	1.94	1.33
3/241	Bc	1.57	0.75
2/141	Bc	0.94	0.90
2/240	Bc	1.74	1.55
2/231	Bc	1.84	1.24
2/241	Bc	1.45	0.75
2/341	Bc	1.56	0.86
		1.58	1.17

Table 7.13m Experimental/Prediction of Factors of Safety
Beams failing in bending compression
Refer Figure 7.12

	Series 1		Series 2		Series 3	
Beam Ref.	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode	Failure Load kN	Failure Mode
120	61.3	S	55.2	S	55.2	S
130	38.9	Bt+S	41.4	S	44.8	S
140	29.3	Bt	32.2	S	36.8	S
121	61.3	S	66.7	S	69.0	S
131	38.9	Bt	50.6	Bt+Bc	59.8	S
141	28.1	Bt	39.1	Bc	46.0	Bc
220	42.8	S	20.7	S	29.9	S
230	32.0	S	39.1	S	40.3	Bc
240	24.7	Bt	29.9	Bc	23.6	Bc
221	52.0	S	43.7	S	32.2	S
231	34.3	Bt	43.7	Bc	46.0	Bc
241	28.1	Bt	27.6	Bc	29.9	Bc
320	56.6	S	48.3	S	55.2	-
330	36.6	S	32.2	S	32.2	S
340	30.5	Bt	34.5	S	34.5	S
321	56.6	Bt	60.9	S	55.2	S
331	36.6	Bt	47.2	S	46.0	S
341	29.3	Bt	35.7	Bc	36.8	-

Table 7.14 Experimental failure loads and failure modes – Series 1, 2 and 3 Beams

S = Shear   Bt = Bending tension   Bc = Bending compression

Failure Mode / Shear Condition		Shear (S)	Bending Compression (Bc)	Bending Tension (Bt)	Other: Bc + S Bt + S Not known	Total
Unreinforced	Elastic	27	0	0	-	27
	Ultimate	27	0	0	-	27
	Experimental	19	3	3	2	27
Reinforced	Elastic	9	18	0	-	27
	Ultimate	12	9	3	3	27
	Experimental	10	6	7	4	27

Table 7.15a Summary of predicted and experimental failure modes

Table No.	Method of beam analysis	Brick Type 1			Brick Type 2			Brick Type 3		
		Beam span mm			Beam span mm			Beam span mm		
		2000	3000	4000	2000	3000	4000	2000	3000	4000
7.10b	Elastic M_s	32.8	48.5	73.8	30.7	44.8	68.2	32.9	48.8	73.8
7.10b	Elastic M_b	59.3	49	54.9	21.3	23.7	25.4	23.4	27.2	30.5
7.11b	Limit state M_s	34.4	50.2	73.8	30.4	40.6	49.8	32.8	46.3	640
7.11b	Limit state M_b	35.7	51.1	72.6	30.2	40.5	44.5	32.7	46.3	640
7.13	Factored BS 5628 M	28.6	40.3	35.7	23.4	25.9	*	25.9	34.3	40.5
7.12	Ductile M_s	34.2	49.7	51.3	29.6	-	#	32.3	45.1	-
7.12	Brittle M_b	-	-	-	-	35.3	36.9	-		55
7.13a	Experimental G1	41	46.7	49.4	-	42.9	-	39.2	40.5	46
7.13b	Experimental G2 – G4	-	-	39.1		40.3	36.7	36.8	32.2	49.1
	Factored BS 5628 M, using $f_k/3$	9.9	9.7	9.4	8.5	8.3	8.0	19.3	18.9	18.4

Table 7.15b Comparison of Bending Moments

Span mm	2000	3000	4000
Allowable serviceability deflection mm*	8	12	16
Mean experimental deflection, mm	7.3	12.8	23.2
Factored experimental deflection, mm**	4.6	8	14.5

Notes :

* *Allowable deflections based on span/250*

** *Factored experimental deflection = Mean experimental deflection/γ_m, taking $\gamma_m = 1.6$*

Table 7.16 Allowable and experimental mid-span deflections

Brick type	Brickwork fk	Prism(Hdr+Str)	(Hdr+Str)/2	fk/6	Col4/Col5	Ref
1	24.0	14.2	7.1	4.0	1.8	1 A
2	24.0	22.5	11.3	4.0	2.8	9 A
3	18.1	9.7	4.8	3.0	1.6	6A
4	14.9	13.3	6.0	2.5	2.9	6I
5	14.8	12.5	6.0	2.5	2.6	6H
6	13.4	11.8	5.9	2.2	2.5	6E
7	12.2	21.2	10.6	2.0	5.3	9B
8	12.0	25.2	12.6	2.0	6.3	1B
9	10.5	8.0	4.0	1.7	2.4	9 C
10	9.6	8.8	4.4	1.6	2.7	1 C
11	8.0	7.6	3.8	1.3	2.9	6F
				Ave	3.1	

Table 8.1 – Brickwork compressive strengths N/mm^2
See also Figure 8.1

Notes: 1. Strengths from perforated brick units tested on bed face; brickwork f_k (code value); prism (test).
2. References:
1. UOP Quetta Style Beam prism tests.
6. Davies and Hodgkinson [125]
9. Regan (internal report. UOP)

Brick type	Brickwork fk	Prism(Hdr+Str)	(Hdr+Str)/2	fk/3	(Psm Hdr + Str)/1.5	Ref
1	24	14.2	7.1	8	9.5	1A
2	24	22.5	11.3	8	15	9A
3	18.1	9.7	4.8	6	6.5	6A
4	14.9	13.3	6	5	8.9	6I
5	14.8	12.5	6	4.9	8.3	6H
6	13.4	11.8	5.9	4.5	7.9	6E
7	12.2	21.2	10.6	4	14.1	9B
8	12	25.2	12.6	4	16.8	1B
9	10.5	8	4	3.5	5.3	9C
10	9.6	8.8	4.4	3.2	5.9	1C
11	8	7.6	3.8	2.7	5.1	6F

Notes: 1. Strengths from perforated brick units tested on bed face; brickwork f_k (code value)

2. References:

1. UOP Quetta Style Beam prism tests.

6. Davies and Hodgkinson [125]

9. Regan (internal report. UOP)

Table 8.1 a Compressive strength of brickwork showing f_k /3 and (Prism Header + stretcher) strength/1.5

Refer Figure 8.4

Compressive failure stresses of UOP Quetta Style Beams (N/mm^2)			Compressive strength of UOP Quetta Style Prisms (N/mm^2)			Ratio of beam/prism results (%)			Ratio of Beam/ factored prism results (%)		
Brick type			Brick type			Brick type			Brick type		
1	2	3	1	2	3	1	2	3	1	2	3
19.0	10.4	13.2	25.2	8.8	14.2	75	118	93	150	236	186

Table 8.4a Comparison of the compressive strengths of the UOP Quetta Style Beams and Prisms

Compressive failure stresses of UOP Quetta Style Beams (N/mm^2)			Compressive strength of UOP Quetta Style Prisms (N/mm^2)			Ratio of beam/prism results (%)			Ratio of Beam/ factored prism results (%)		
Brick type			Brick type			Brick type			Brick type		
1	2	3	1	2	3	1	2	3	1	2	3
19.25	11.0	14.2	25.2	8.8	14.2	76	125	100	152	250	200

Table 8.4b Comparison of the compressive strengths of the UOP Quetta Style Beams and Prisms, *including self weight stresses*

Refer Table 8.5

Brick Type	1			2			3		
Brick Span mm	2000	3000	4000	2000	3000	4000	2000	3000	4000
Unit Weight kN/m^3	23.7	23.7	23.7	22.3	22.3	22.3	25.4	25.4	25.4
E_i kN/mm^2	18..04	18.04	18.04	5.7	5.7	5.7	18.66	18.66	18.66
M_{max} kNm	1.125	2.53	4.5	1.06	2.38	4.23	1.21	2.71	4.82
v N/mm^2	0.024	0.036	0.048	0.23	0.34	0.045	0.026	0.039	0.051
$f_{bc} = f_{bt}$ N/mm^2	0.25	0.56	1.00	0.24	0.53	0.94	0.27	0.60	1.07
$\varepsilon_{bc} = \varepsilon_{bt}$ $x 10^{-6}$	14	32	56	41	92	165	15	32	57
T = C kN	5.9	13	24	5.6	12	22.6	6.3	13.9	25.7

Table 8.5 Calculation of the effect of self weight

Shear stress, v, linear elastic bending stresses and strains, $f_{bc,}$,$f_{bt,}$ $\varepsilon_{bc\ an}$ and ε_{bt},
Tension force, T, and compression force, C.

Brick type	Brick Bed Strength	Characteristic Brickwork Strength fk	Design str fk/2	Bed/fk strengths	Bed/Design strengths	Ref
14 hole	107.9	24	12	4.5	8.99	1A
16 hole	64.7	18.1	9	3.6	7.19	6A
23 hole	49.4	14.9	7.4	3.34	6.68	6I
8 hole	49.1	14.8	7.4	3.34	6.64	6H
Solid	43.5	13.4	6.7	3.25	6.49	6E
10 hole	38.2	12.2	6.1	3.13	6.26	1B
Frog	33.7	11	5.5	3.06	6.13	6C
3 hole	32	9.9	4.9	3.26	6.53	1C
Frog	31.7	10.4	5.2	3.05	6.10	6D
Frog	25.4	8.7	4.3	2.95	5.91	6B
3 hole	22.7	8	4.0	2.84	5.68	6F

Table 8.6 Comparison of brick bed and brickwork design strengths N/mm2
See also Figure 8.4

Reference: 6 –Powell and Hodgkinson [120]
1 – Regan [UOP internal report]

Beam Ref	Mode of failure	d_c from Strain graph	T_{ex} - T_y = F_{at}	Self wt Tension T_{swt}	F_{at} + T_{swt}	Steel test strain at yield	Tensile strain e_{ex} T_{ex}	Self wt Tensile strain e_{sw}	$e_{ex} + e_{sw}/ e_y$ times 100
		mm	kN	kN	kN	x 10 - 6	x 10 - 6	x 10 - 6	Percent
2 m span beams									
1/321	Bt	59.6	35	6	41	2460	2916	15	119
1/120	S	101.5	68	6	74	2460	3342	14	135
2/120	S	92.3	37	6	43	2460	2942	14	120
3/120	S	90.8	37	6	43	2460	2942	14	120
1/121	S	77.5	55	6	61	2460	3174	14	129
2/121	S	99.4	89	6	95	2460	3613	14	147
3/121	S	91.4	56	6	62	2460	3187	14	130
1/320	S	93.4	70	6	76	2460	3367	15	137
2/320	S	65.5	38	6	44	2460	2954	15	120
3/320	S	63.6	50	6	56	2460	3110	15	126
2/321	S	93.4	74	6	80	2460	3419	15	139
					Ave 61				Ave129

Table 8.7b Tension forces Method 1
2m span beams

Beam Ref	Mode of failure	d_c from Strain graph	$T_{ex} - T_y$ = F_{at}	Self wt Tension T_{swt}	F_{at} + T_{swt}	Steel test strain at yield	Tensile strain e_{ex} T_{ex}	Self wt Tensile strain e_{sw}	$e_{ex} + e_{sw}/$ e_y times 100	$e_{ex} + e_{sw}/$ e_y
		mm	kN	kN	kN	x 10 - 6	x 10 - 6	x 10 - 6	Percent	100
			graph				at yield	T_{ex}	e_{sw}	
		mm	mm	kN	kN	kN	x 10 - 6	x 10 - 6	x 10 - 6	Percent
3m span beams										
2/131	Bt + Bc	190	95.3	28	13	41	2313	2532	32	109
2/231	Bc	190	97.3	0	12	12	2313	2310	92	100
3/231	Bc	190	119	36	12	48	2313	2595	92	112
3/130	S	192	75.4	77	13	90	2460	3457	32	141
3/131	S	190	97.3	88	13	101	2313	3006	32	130
2/331	S	190	65.5	-2	14	12	2313	2294	32	99
3/331	S	190	90	10	14	24	2313	2389	32	103
						Ave 47				Ave 112

Table 8.7c Tension forces Method 1
3 m span beams

Beam Ref	Mode of failure	d_c from Strain graph	$T_{ex} - T_{ey} = F_{at}$	Self wt Tension T_{swt}	$F_{at} + T_{swt}$	Steel test strain at yield	Tensile strain e_{ex}	Self wt Tensile strain e_{sw}	$(e_{ex} + e_{sw})/e_y$
		mm	kN	kN	kN	x10-6	x10-6	x10-6	Percentage
1/130	Bt +S	75.4	-56	13	-43	2313	1868	32	81
1/131	Bt	90	-49	13	-36	2313	1922	32	83
2/130	S	75.4	-41	13	-28	2313	1985	32	86
1/331	Bt	71.5	-64	14	-50	2313	1803	32	78
2/230	S	103.3	-26	12	-14	2313	2104	92	91
2/330	S	99.3	-87	14	-73	2313	1622	32	70
1/141	Bt	85.4	-230	26	-204	2398	1208	56	80
2/340	S	90	-159	26	-133	2398	1578	57	66

Reserve of steel strength shown as negative value

Table 8.7d Tension forces Method 1
Beams of 2,3 and 4 m span where yield strength of the steel was not exceeded

2	3	4	5	6	7	8	9	10	10aa	
Beam	Expt	Expt	Mode	d	dc	Steel	Expt	Tex-Ty	Cex	
Ref	Load	BM	of		from	test	beam			
			failure		Strain	Ty	Tex			
					graph	at yield	failure			
	kN	kNm		mm	mm	kN	kN	kN	kN	
1/130	38.9	38.9	Bt +S	190	75.4	292	236	-56	250	
1/131	38.9	38.9	Bt	190	90	292	243	-49	257	
2/131	50.6	50.6	Bt + Bc	190	95.3	292	320	28	296	
1/141	28.1	37.5	Bt	187.5	85.4	466	236	-230	203	
1/321	56.6	37.7	Bt	192	59.6	191	226*	35	118	
1/331	36.6	36.6	Bt	190	71.5	292	228*	-64	146	
2/231	43.7	43.7	Bc	190	97.3	292	299*	0	127	
3/231	46	46	Bc	190	119	292	328*	36	244	
1/120	61.3	40.9	S	192	101.5	191	259	68	391	
2/120	55.2	36.8	S	192	92.3	191	228	37	128	
3/120	55.2	36.8	S	192	90.8	191	228	37	172	
1/121	61.3	40.9	S	192	77.5	191	246	55	321	
2/121	66.7	44.5	S	192	99.4	191	280	89	372	
3/121	59.8	39.9	S	192	91.4	191	247	56	142	
2/130	41.4	41.4	S	190	75.4	292	252	-41	231	
3/130	33.8	44.8	S	192	75.4	191	268	77	191	
3/131	59.8	59.8	S	190	97.3	292	380	88	328	
2/230	39.1	39.1	S	190	103.3	292	266*	-26	102	
1/320	56.6	39.9	S	192	93.4	191	261*	70	202	
2/320	48.3	37.7	S	192	65.5	191	224*	38	110	
3/320	56.6	39.9	S	192	63.6	191	241*	50	107	
2/321	60.9	40.6	S	192	93.4	191	265*	74	179	
2/330	32.2	32.2	S	190	99.3	292	205	-87	203	
2/331	47.2	47.2	S	190	65.5	292	290*	-2	156	
3/331	46	46	S	190	90	292	302*	10	203	
2/340	34.5	46	S	187.5	90	466	307*	-159	151	
								Ave 53		

Table 8.7e Compression Forces – Method 2

2	5	8		9	10	11	12	13	14
Beam Ref	Mode of failure	Steel test T_y at yield	Steel test T_{ult} at failure	Expt beam T_{ex} failure	Tex-Ty	Compression Force $C_{ex\ secant}$	Compression Force $C_{ex\ initial}$	$C_{ex\ secant}$ - T_{ex}	$C_{ex\ initial}$ - T_{ex}
		kN	kN	kN	kN	kN	kN	kN	KN
1/130	Bt +S	292	367	236	-56	250		+14	
1/131	Bt	292	367	243	-49	257		+14	
2/131	Bt + Bc	292	367	320	28	296		-24	
1/141	Bt	466	602	236	-230	203		-33	
1/321	Bt	191	236	226*	35		150		-76
1/331	Bt	292	367	228*	-64		186		-42
2/231	Bc	292	367	299*	0		162		-137
3/231	Bc	292	367	328*	36		310		-18
1/120	S	191	236	259	68	391		+132	
2/120	S	191	236	228	37		183		-45
3/120	S	191	236	228	37		245		+17
1/121	S	191	236	246	55	321		+75	
2/121	S	191	236	280	89	372		+92	
3/121	S	191	236	247	56		203		-44
2/130	S	292	367	252	-41	231		-21	
3/130	S	292	367	268	-24		272		+4
3/131	S	292	367	380	88	328		-52	
2/230	S	292	367	266*	-26		130		-136
1/320	S	191	236	261*	70		257		-4
2/320	S	191	236	224*	38		145		-79
3/320	S	191	236	241*	50		136		-105
2/321	S	191	236	265*	74		228		-37
2/330	S	292	367	205	-87	203		-2	
2/331	S	292	367	290*	-2		199		-91
3/331	S	292	367	302*	10		258		-44
2/340	S	466		307*	-159		192		-115

Table 8.7f Tension and compression

Beam	$T_{ex} - T_{ey}$	($C_{exsecant}$ or $C_{ex\ initial}$) - C_{ex}
	kN	kN
1/120	68	132
3/120	37	17
1/121	55	75
2/121	89	92

Table 8.7 gb-Comparison of excess tensile and compressive forces

Brick type	Neutral axis depth		
	Experimental	**Equation 8..9**	**Equation 8.5.10**
1	77.5mm	78mm	68.8mm

Table 8.8 Comparative neutral axis depths

Reference	Modulus of Elasticity (N/mm^2)	% Difference from the British Standard
British Standard [S1]	$900f_k$	-
American Code [S10]	$700 f^1{}_m$	-
Eurocode [S15]	$1000f_k$	=11%
UOP Quetta Style Beam Brick Type 1	$716 f_k$	-20%
UOP Quetta Style Beam Brick Type2	$648 f_k$	-28%
UOP Quetta Style Beam Brick Type 3	$1414 f_k$	+46%
Curtin et al [71]	$700 f_k$ to $1100 f_k$	-22% to +22%

Table 8.9 Comparative modulus of elasticity

UOP Quetta Style Beam Brick Type	Experimental Prism Compressive Strength N/mm^2	Experimental Modulus of Elasticity N/mm^2
1	25.2	18.04
2	8.8	5.7
3	14.2	18.6

Table 8.10 Comparative brickwork prism strengths and initial modulus for UOP Quetta Style Beam Brickwork

Method of Beam Analysis	Brick Type 1 Beam Span mm			Brick Type 2 Beam Span mm			Brick Type 3 Beam Span mm		
	2000	**3000**	**4000**	**2000**	**3000**	**4000**	**2000**	**3000**	**4000**
I_{cr} (secant) x 10^6 mm^4	177	242	290	243	338	476	100	166	212
I_{cr} (L/EI) x 10^6 mm^4	176	194	201	298	372	375	120	160	171
Ratio I_{cr} (secant) / $I_{cr\ L/EI}$	1.01	1.25	1.44	0.82	0.91	1.27	0.83	1.04	1.24

Table 8.11 Comparison of cracked second moments of area,
I_{cr} (secant) / **I_{cr}** (L/EI)

I_{cr} (secant) *are values extracted from Table 7.11a*

I_{cr} (L/EI) *are values calculated from L/EI v moment graphs(Vol.2 154-162)*

Refer Figure 8.8

Beam Ref.	Failure Mode	Factor of safety Experimental/ Ultimate Prediction
1/121	S	1.26
2/121	S	1.38
3/121	S	1.43
3/131	S	1.45
	Ave	1.38
1/221	S	1.17
2/221	S	0.98
3/221	S	0.73
	Average	0.96
2/321	S	1.26
2/331	S	1.07
3/321	S	1.14
3/331	S	1.04
	Average	1.12

Table 8.12a Experimental/Predictions of Factors of Safety for Brick Types
Reinforced beams failing in shear
Reference Table 7.13k

Beam Ref.	Failure Mode	Factor of safety Experimental/ Ultimate Prediction
1/120	S	2.59
2/120	S	2.33
2/130	S	2.11
2/140	S	1.67
3/120	S	2.33
3/130	S	2.29
3/140	S	1.91
	Ave	2.17
1/220	S	1.81
1/230	S	1.63
2/220	S	0.87
2/230	S	1.99
3/220	S	1.26
	Average	1.51
1/320	S	2.39
1/330	S	1.87
2/320	S	1.16
2/330	S	1.64
2/340	S	1.79
3/330	S	1.64
3/340	S	1.79
	Average	1.75

Table 8.12b Experimental/Predictions of Factors of Safety for Brick Types Unreinforced beams failing in shear

Reference Table 7.13k

Shear span a/d	Failure load kN		
	Brick type 1	Brick type 2	Brick type 3
3.47	61.6	36.9	55.5
5.26	45.7	39.2	38.5
7.11	34.5	25.1	33.2

Table 8.12c
Shear span a/d
versus
Failure load for different brick types
Reference Tables 7.13a –c

Beam Span m	Shear Span a/d	Percentage area of reinforcement	Factor of Safety Failure/Ultimate Predicted Load		
			.Brick type 1	Brick type 2	Brick type 3
2	3.47	0.639	2.42	1.31	1.78
3	5.26	1.010	2.20	1.81	1.72
4	7.11	1.599	1.79	n/a	1.79

Table 8.12 d
Beam span, Shear span a/d and percentage area of reinforcement versus
Factor of safety of failure/ultimate predicted load for different brick types
Beams unreinforced in shear
Reference Table 8.12b

Brick Type	Mean M/bd^2 N/mm^2	Brickwork Strength N/mm^2	Unit Strength N/mm^2
1	3.69	25.2	38.2
2	2.77	8.8	32.0
3	3.32	14.2	107.9

Table 8.13 Comparison of brick and brickwork strengths with M/bd^2
Refer Figure 8.13a

Span	Mean M/bd^2
2m	3.22
3m	3.41
4m	3.51

Table 8.14 Comparison of span and M/bd^2

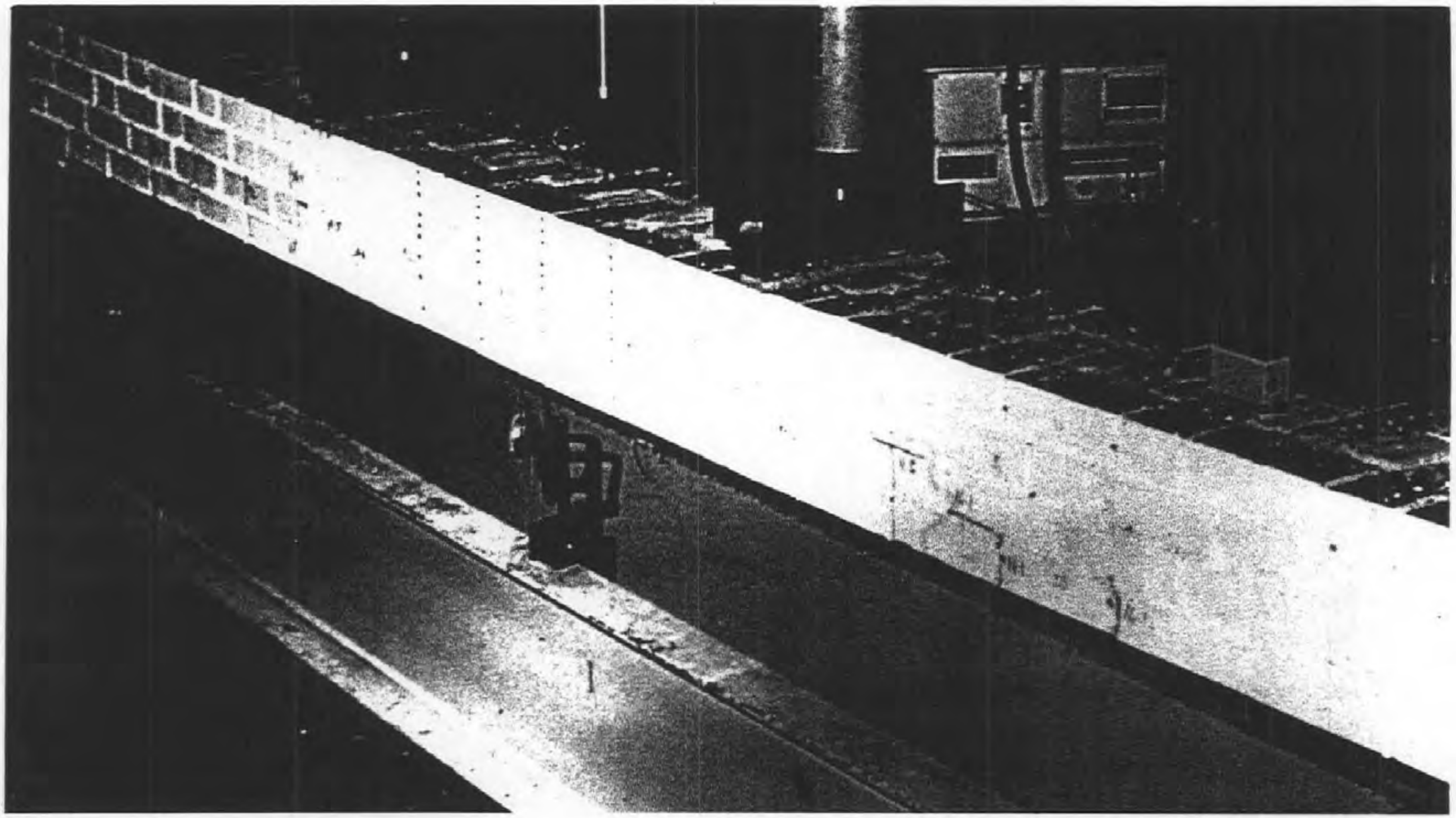
Researchers	Beam Type	Mean M/bd^2 N/mm^2	Brickwork compressive strength N/mm^2	Unit compressive strength N/mm^2	Number of beams tested
Withey	BR BR BR	2.51 3.22 3.24	18.6 19.8 14.4	17.8 86.3 63.5	9 8 8
Osman and Hendry	GRC1 GRC1	3.60 3.27	12.75 22.95	23.86 88.28	4 4
Garwood And Tomlinson	GRC2	1.92	25.0	-	3
Regan	UOP UOP UOP	3.69 2.77 3.22	25.2 8.8 14.2	38.2 32.0 107.9	18 18 18

BR — *Reinforced brickwork beam using bed joint reinforcement*
GRC1 — *Reinforced brickwork grouted cavity beam*
GRC2 — *Reinforced brickwork beam with brick ceramic in the cavity*
UOP — *UOP Quetta Style Beam*

Table 8.15
Mean M/bd^2 versus brickwork strength for different beam formats
Refer Figures 8.13b and c

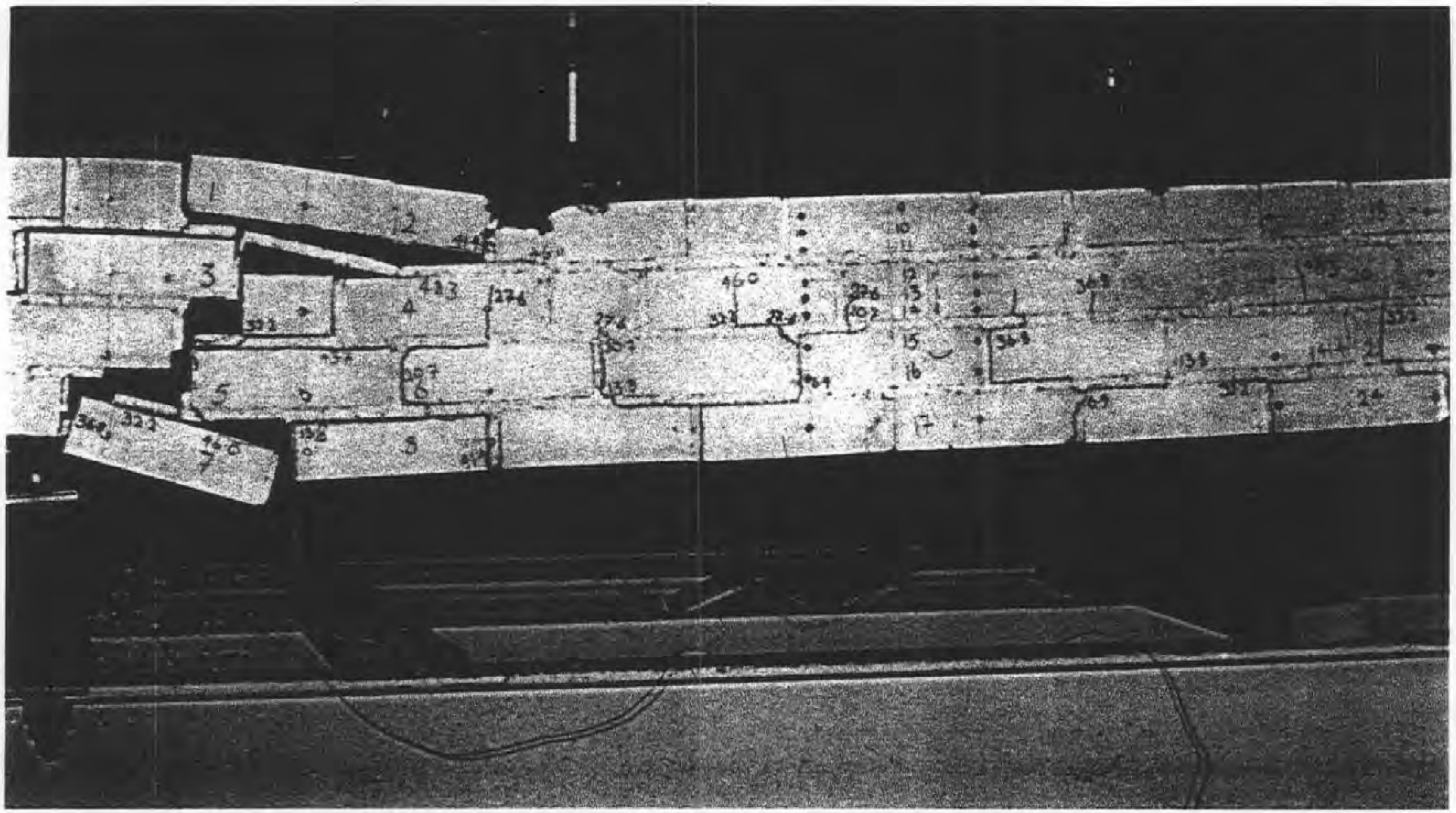
	Brickwork compressive strength		
	15 N/mm^2	20N/mm^2	25 N/mm^2
UOP prisms	3.14	3.439	3.71
Prisms by other researchers	3.26	3.089	2.92
Percentage difference (UOP – Others/ UOP	-3.8	10.2	21.3

Table 8.15a
Comparison of M/bd^2 for UOP Quetta Style Beam with tests by other researchers



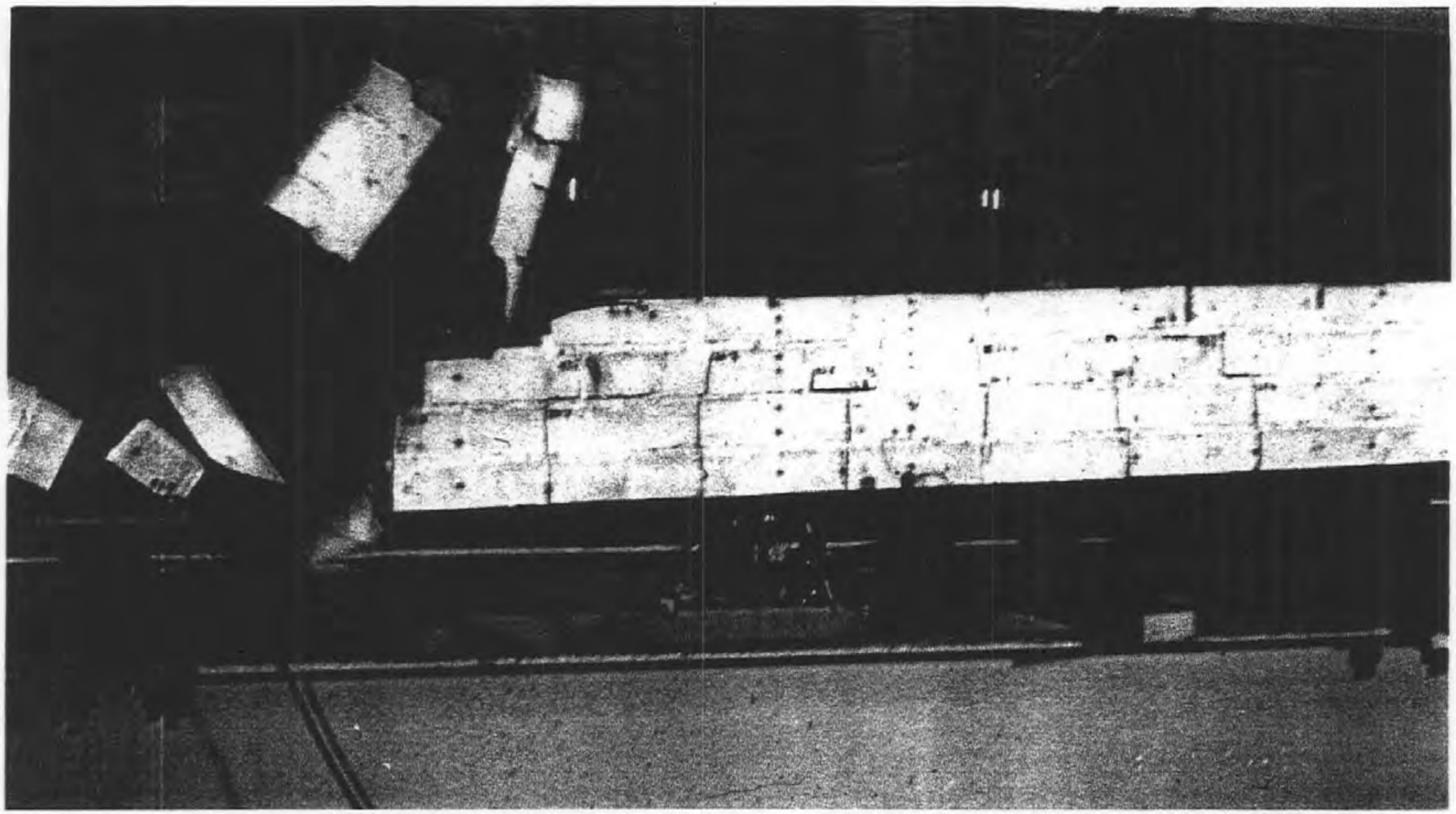
Typical 4m test beam

Plate 1



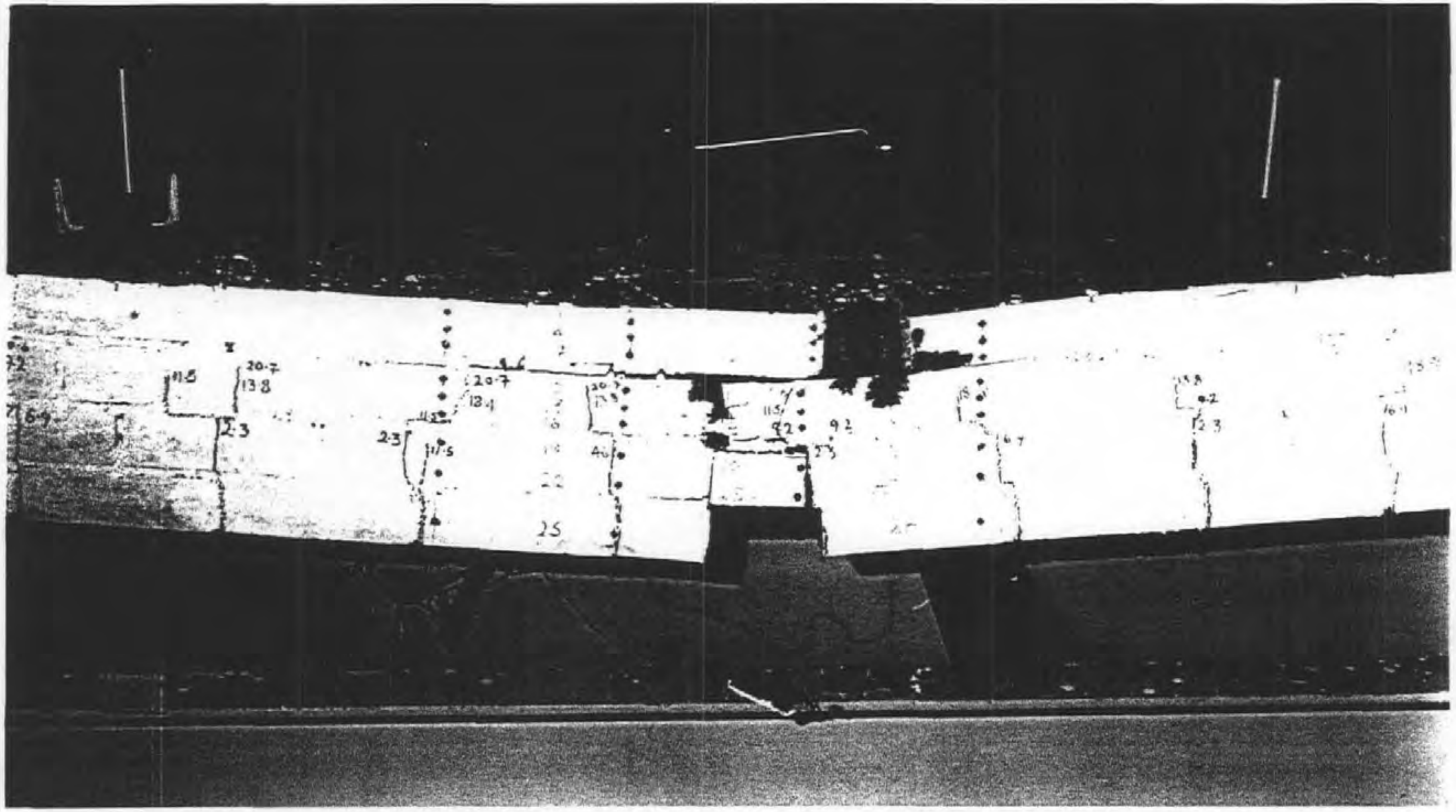
Brick type 2, progressive shear failure

Plate 2



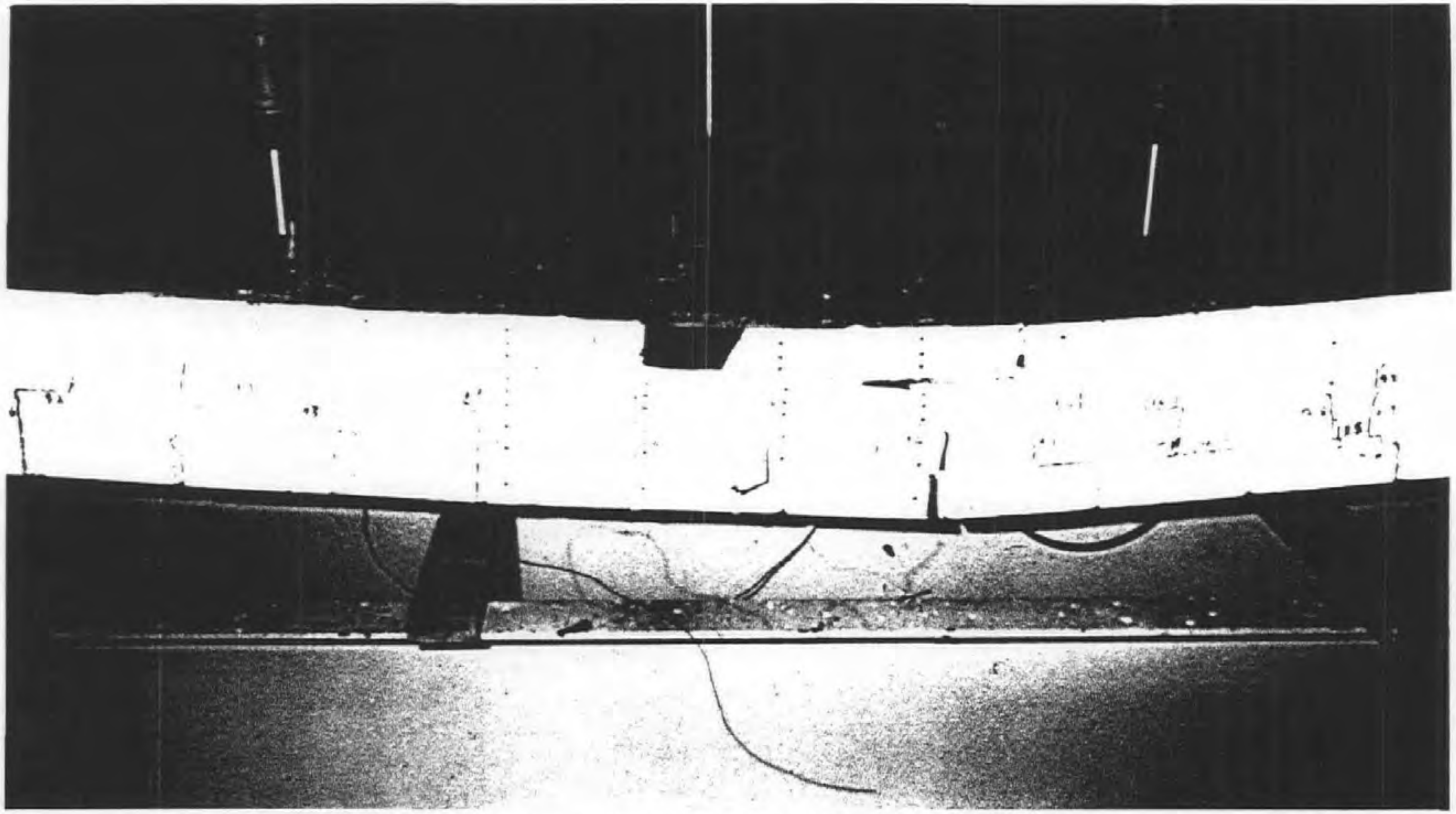
Brick type 3, explosive shear failure

Plate 3



Brick type 1, ductile to brittle flexure failure

Plate 4



Brick type 2, ductile to brittle flexure failure

Plate 5

APPENDIX 4

Annex A Example calculations

Annex B Analysis of tensile and compressive behaviour of beams from the experimental results

Annex C Limit state procedures

ANNEX A

A.0 EXAMPLE CALCULATIONS

The following calculations are a selection of solutions predicting beam behaviour.

The results are listed in Tables 7.1b, 7.1d, 7.2 b – d, 7.3, 7.5, 7.7 – 13m, 7.11a, 7.15 .

A.1 STANDARD DATA FOR 1/120 BEAM (REFER TABLE 7.1a)

$b = 327.5mm$ $d = 192mm$ $A_{st} = 402mm^2$

$\rho = 0.639 \times 10^{-2}$ $\phi = 16mm$

Brick, prism mean compressive strength = 25.2 N/mm² (p_{bc} and f_k)

$E_{bi} = 18.04$ kN/mm² $E_{bs} = 12.65$ kN/mm²

pst = 476.2 N/mm² No. of bars = n = 2

$E_s = 195.4$ kN/mm² $E_{bc} = 0.0035$

$m_i = 10.83$ $m_s = 15.6$

For elastic shear analysis:

$P_v = 0.28$ N/mm² $p_{st} = 140$ N/mm² $z = 0.85d$

A.2 PREDICTIONS USING ELASTIC ANALYSIS

A.2.1 Moments of resistance, M_{bc} and M_{st}

$b d_c^2 + 2m_i dc - 2m_i\, d\, A_{st} = 0$ (Equation A5.8)

$(327.5 \times 192^2)\, d_c^2 + (2 \times 10.83)\, d_c - 2 \times 10.83 \times 192 \times 402 = 0$

Hence $d_c = 59.3mm$

$M_{bc} = 0.5\, p_{bc}\, b\, d_c\, (d - d_c/3)$ (Equations A5.9)

$M_{bc} = 0.5 \times 25.2 \times 327.5 \times 59.3\, (192 - (59.3/3))$ $M_{bc} = 42.1$ kNm

$M_{st} = f_y\, A_{st}\, (d - d_c/3)$ (Equation A5.10)

$M_{st} = 476.2 \times 402\, (192 - (59.3/3)$ $M_{st} = 32.8$ kNm

32.8 ‹ 42.0 hence moment of resistance provided by the steel controls.

Load at collapse of 2m span beam $W_{st} = \frac{3M_{st}}{2} = 49.2$ kN

A.2.2 Elastic Shear V_{Ue} (Unreinforced) and V_{Re} (Reinforced) (Equation A5.12)

$V_{Ue} = b\ d\ p_v = 327.5 \times 192 \times 0.28 \times 10^{-3} = 17{,}6$ kN $V_{Ue} = 17.6$ kN

$V_{Re} = V_{Ue} + z\ A_{st}\ p_{st} / s_v = 17.6 + 0.85 \times 192 \times 140 / (168 \times 10^3)$

$V_{Re} = 42.4$ kN

A.2.3 Deflection

For a cracked section, using Equation 5.46

$$I_c = \frac{bd_c^{\ 3}}{3} + \frac{m\pi d^4}{64} + mA_s\,(d - d_c)^2$$

$$= \frac{327.5x59.3^3}{3} + \frac{10.83\pi x16^4}{64} + 10.83 \times 402\,(192\text{-}59.3)^2$$

$I_c = 99.5 \times 10^6 mm^4$

A.3 PREDICTIONS USING LIMIT STATE ANALYSIS

A.3.1 M_{bc} and M_{st} based on unit material factors

The analysis is based on equations A5.13 -18, A5.20. using $\gamma_{mm} = \gamma_{ms} = 1.0$, since the strength of the materials are known from the physical tests.
$f_k = 25.2\ N/mm^2$

$z = d - \frac{A_s f_y}{2bf_k}$ $z = 180mm$ Hence $d_c = 24mm$

$M_{st} = A_s\ f_y\ z$ $M_{st} = 34.4$ kNm

$M_{bc} = bf_k\ dc\ z$ $M_{bc} = 35.7$ kNm

34.4 ‹ 35.7 hence moment of resistance provided by the steel controls.

NB The code equation (BS5628)

Part 2 Clause 22.4.21) requires $M_d \geq 0.4 \dfrac{f_k b d^2}{\gamma_{mm}}$

For $\gamma_{mm} = 1.0$ $M_d = 122\ kNm$

For $\gamma_{mm} = 2.0$ $M_d = 61\ kNm$

A.3.1.1 Deflection

$$I_c = \frac{327.5x24^3}{3} + \frac{15.4x\pi x16^4}{64} + 15.4 \times 402\,(192\text{-}24)^2$$

$I_c = 177 \times 10^6\ mm^4$

A.3.2 M_{bc} and M_{st} based on material Factors set to BS5628 Part 2 Values

The analysis is based on equations A5.17-20, using $\gamma_{mm} = 2.0$ and
$\gamma_{ms} = 1.15$ $f_k = 25.2\ N/mm^2$

$z = d - \dfrac{A_s f_y \gamma_{mm}}{2 b f_k \gamma_{ms}}$ $z = 172mm$ Hence $d_c = 40mm$

$M_{st} = \dfrac{A_s f_y z}{\gamma_{ms}}$ $M_{st} = 28.6\ kNm$

$M_{bc} = \dfrac{b f_k d_c z}{\gamma_{mm}}$ $M_{bc} = 28.4\ kNm$

Moments of resistance are nominally equal as expected in a balanced design.

A.3.2.1 Deflection

Using $d_c = 40$ $I_c = 150 \times 10^6 mm^4$

A.3.3 M_{bc} and M_{st} based on ductile and brittle failure

The analysis is based on equations A5.6 – A5.9,

A.3.1.1 Ductile failure

$$d_c = \frac{A_{st} f_y}{k_1 f_k b} = \frac{402x476.2}{0.75x25.2x327.5}$$ $d_c = 30.9mm$

$M_{st} = A_{st}\, f_y\, [d - d_c] = 402 \times 327.5\, [192 - 30.9]$ $M_{st} = 34.2$ kNm

A.3.1.2 Brittle failure

$k_1\, f_k\, b\, d_c^2 + A_{st}\, E_u\, E_s\, d_c - A_{st}\, E_{bu}\, E_s\, d = 0$

$0.75 \times 25.2 \times 327.5 \times d_c^2 + 0.0035 \times 195.4\, (402 \times \times 10^3 \times d_c - 402) \times 10^2 = 0$

Solves to gives $d_c = 68.6$

$M_b = k_1\, f_k\, bd_c\, (d - k_2\, d_c) = 0.75 \times 25.2 \times 327.5 \times 68.6\, (192 - 0.417 \times 68.6)$

$M_b = 69.3$ kN

Hence $M_{st} < M_{bc}$, therefore a ductile failure would occur.

A.3.1.3 Deflection based on ductile failure

Using $d_c = 30.9$

$I_c = 202 \times 10^6 mm^4$

A.3.4 M_{bc} and M_{st} based on full application of BS 5628 Part 2

In these calculations the analysis used in 7.4 is adopted. However the brickwork compressive strength is taken as $f_k/3$ {BS 10, Clause 19.1.14). The characteristic compressive strength for Brick Type 1 with a crushing strength of 38.2 N/mm^2 aid using a mortar designation (i) is $f_k = 12.4$ N/mm^2.

$f_k = 12.4/3 = 4.1$ $\qquad \gamma_{mm} = 2.0$ $\qquad \gamma_{mm} = 1.15$

$$z = d - \frac{A_{st} f_y \gamma_{mm}}{2bf_k\gamma_{ms}} = 68\text{mm} \qquad d_c = 248 > d = 190\text{mm}$$

The value of d_c is not practical.

A.3.5 Ultimate Shear (Table 7.5) (Equations A5.21 -23)

A.3.5.1 Data for all 2m span beams

$b = 327.5$ mm $d = 192$ mm $\quad A_{st} = 402.12$ mm^2

A.3.5.2Shear Stress

$\rho = 0.0064 \qquad a = 667$ mm $\qquad \frac{a}{d} = 3.47 < 6$

$A_{sv} = 56.66$ mm^2 $\qquad s_v = 168.8$ mm $\qquad f_{ys} = 385.5$ N/mm^2

$f_{vu} = (0.35 + 17.5\rho)\, n_i$

$n_i = (2.5 - 0.25\ a/d)$ $\quad$ for $a/d \leq 6$

For 2m span $\quad n_2 = (2.5 - 0.25 \times 3.47) = 1.63$

$f_{vu} = (0.35 + 17.5 \times 0.0064)\ 1.63$

$f_{vu} = 0.753 < 1.75$ N/mm^2

A.3.5.3Shear resistance of unreinforced (V_u) and reinforced (V_R) beams.

$V_u = bdf_{vu} / \gamma_{mm}$

$V_R = bdf_{vu} / \gamma_{mm} + d \times A_{sv} \times f_{ys} / s_v \times \gamma_{ms}$

$V_R = V_u + d \times A_{sv} \times f_{ys} / s_v$

Using $\gamma_{mm} = 2.0$ $\gamma_{ms} = 1.0$

$V_u = 327.5 \times 192 \times 0.753 / 2$

$V_u = 23.7kN$

$V_R = 23.7 + 192 \times 56.55 \times 385.5 / 168.8 \times 10^3$

$V_R = 23.7 + 24.8 = 48.5$ kN

A.4 THE EFFECT OF SELF WEIGHT OF THE UNIVERSITY OF PLYMOUTH QUETTA STYLE BEAM

A.4.1 Data

Span = 2m

b = 327.5 mm D = 290 mm

Unit weight 23.7 kN/mm^2 $E_i = 18.04$ kN/mm^2

A.4.2 Calculations

Beam weight, W_d

$W_d = 327.5 \times 290 \times 23.7 \times 10^{-6}$

$W_d = 4.5$ kN

M_{max}, mid span $= \frac{WL}{8} = 1.125$ kNm

V_{max}, at support = 2.25 kN

$$V_{ave} = \frac{V}{bD} = \frac{2.25 \times 10^3}{327.5 \times 290} = 0.03 \text{ N/mm}^2$$

Elastic stresses

$$f_{bc} = f_{bt} = \frac{M}{Z} = \frac{1.125 \times 10^6 \; 6}{327.5 \; 290^2}$$

$f_{bc} = f_{bt} = 0.25$ N/mm^2

$$\varepsilon_{bc} = \varepsilon_{bt} = \frac{f_{bc}}{E_i}$$

$$= \frac{0.25}{18.04} = 14 \times 10^{-6}$$

$F_{bc} = F_{bt} = 0.5\ f_{bc}\ b\ (0.5D)$

$= 0.25 \times 0.25 \times 327.5 \times 290$

$F_{bc} = F_{bt} = 5.9$ kN

BM = $F_{bt} \times 5D/6$

= 5.9 x 5 x 290/6 x 1000

= 1.43 kNm

ANNEX B

Summary of predicted and experimental failure modes.

Analysis of Tensile and Compressive Behaviour of Beams from the Experimental Results

The following iterative procedure was adopted in order to analyse the experimental results. Tables 7.10 – 7.10e were developed with the objective of comparing the:-

- tensile behaviour. *Available tensile resistance provided by the steel, T_y kN and the actual tensile force developed by the reinforced brickwork T_{ex} kN. This is shown as $T_{ex} - T_y$.*

- compressive behaviour. *Compressive strength of the brickwork prisms, p_{bc} and f_k N/mm^2 and the compressive stress induced by the applied bending moment f_b N/mm^2.*

Relative values of the strain were also calculated.

Procedure :-

1. Collate data

1.a	Beam reference.	(Column 2)
1.b	Failure load, B M and mode.	(Columns 3,4,5)
1.c	Effective depth and depth of neutral axis from strain graphs 1-54, these are graded from 1 – 4 and described in Section 6.2.1.	Columns (6 and 7)

1.d. Steel strength, T_y, at yield. (Column 11)

1.f Initial and secant moduli for steel, as listed in Table 4.3

1.g Brickwork compressive strength p_{cb} or f_k (Column 14)

2. Assumptions

Assume triangular stress diagram, hence lever arm = $(d-d_c/3)$ with a maximum compressive fibre stress f_b.

3. Calculations

3.a Calculate tension in reinforcing bar T_{ex} where $T_{ex} = BM/(d-d_c/3)$

(Column 9)

3.b. Calculate $T_{ex} - T_y$ (Column10)

3.c Using $T_{ex} = C_{ex}$ and the appropriate A and E for the bar diameter calculate the experimental strain in steel ε_{ex} (Column 12)

3.d Determine percentage ratio of $\varepsilon_{ex}/\varepsilon_y$ (Column13)

3.e Using $T_{ex} = C_{ex}$ calculate $f_b = 2T_{ex}/bd_c$ (Column 15)

3.f *NB.*

If $f_b > p_b$ then assume that the stress block is rectangular of depth $0.834d_c$ (Hendry p 185 refers,[80]).

OR

If $f_b < p_b$ go to 3.hIf $f_b > p_b$ recalculate T_{ex} in 3.a above :-

where $T_{ex} = BM/(d- 0417d)$ (Column 9)

Then continue to 3.d.

3.g Using $T_{cx} = C_{cx}$ calculate $f_b = T_{ex}/(b(0.834d_c))$ (Column 16)

3.h *If $f_b < p_b$* calculate strain on brickwork using E_b initial, (Column 17)

OR

If f_b obtained from a rectangular stress block calculate the strain in the brickwork, using E_b secant. (Column 18)

3.i Measure maximum strains from Strain Graphs 1 – 54. (Column 19)

ANNEX C LIMIT STATE PROCEDURES.

C.0 Introduction

The basic data for the analysis is listed in Table 7.2a. The procedures produced the predictions shown in Tables 7.2b – 7.2e. The moments of resistance calculated were the the brickwork strength in compression, M_{bc}, and the tensile resistance, M_{st}.

C.1 The procedures

C.1.1 Procedure 1

Limit state analysis using Modified BS5628 Part 2 [S.3] equations, (Table 7.2), assuming a balanced design.

The basic equations are:

$$M_{st} = A_{st} f_y z / \gamma_{ms} \qquad M_{bc} = b f_k d_c z / \gamma_{mm}$$

$$z = d - 0.5 A_{st} f_y \gamma_{mm} / b f_k \gamma_{ms} \qquad d_c = 2 (d - z)$$

Both partial factors for materials, γ_{ms}, and γ_{mm}, were set to zero. The assumption that f_k was equal to the mean compressive strength of the brickwork prisms was based on the fact that the latter was derived from a set of prism test. Likewise f_y is the mean of a series of tensile tests.

The second moment of area was calculated for a transformed section, steel only. The grout and the mortar were considered to have the same material properties as the brickwork.

C.1.2 Procedure 2

Limit state analysis considering ductile and brittle failures (Table 7.2c).

The basic equations were:

Ductile failure

$Z = [d - (A_{st}\, f_y\, k_2 / f_k\, b\, k_1))]$

$Ms = A_{st}\, f_y [d - (A_{st}\, f_y\, k_2 / f_k\, b\, k_1))]$

Where $k_1 = 0.75$ and $k_2 = 0.417$ $\gamma_{mm} = \gamma_{ms} = 1.0$

From z the value of $d_c = (d - z) / k_1$

Brittle failure

$$k_1\, fk\, b\, d_c^2 \;+\; A_{st}\, \varepsilon_{bu}\, E_s\, d_c \;-\; A_{st}\, \varepsilon_{bu}\, E_s\, d \;=\; 0$$

Solve for d then

$Mbc = k_1\, fk\, bd_c\, (d - k_2\, d_c)$

c.1.3 Procedure 3

Limit state analysis using design equations from BS5628 Part 2 [S.3] (Table 7.2c).

The basic equations are:

$z = d - 0.5\, A_{st}\, f_y\, \gamma_{mm} / b\, f_k\, \gamma_{ms}$ where $\gamma_{mm} = \gamma ms = 1.0$

$d_c = 2\,(d - z)$

$M_{st} = A_{st}\, f_{y\,z} / \gamma ms$ $M_{bc} = b\, f_k\, d_c\, z / \gamma_{mm}$

The solutions provide values of M_{bc} significantly less than the code requirement,

$$M_{bc} = 0.4\, f_k\, bd^2 / \gamma_{mm}$$

C.1.4 Procedure 4

Limit state analysis using design equations from BS5628 Part 2 [S.3] with a factorised f_k (Table 7.2c).

The value of the characteristic strength was based on the code [S.3] Clause 7.4.1.1.4, where the design strength = $f_k / 3\ \gamma_{mm}$

The main effect is on the evaluation of the lever arm where::

$z = d - 1.5\ A_{st}\ f_y\ \gamma_{mm} / b\ f_k \gamma_{ms}$

$M_{bc} = b\ f_k\ d_c\ z / 3\ \gamma_{mm}$

APPENDIX 5

Correspondence

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Tel: 01752 221733

20 May 1998

Mr C Southcombe
20 The Spinney
Plympton
Plymouth
Devon

Dear Colin

Thank you for call the other day, I was pleased to hear that you are registered for a PhD, I hope your retirement provides you with the necessary time for such a project.

I realise that some of the work may well cross-over with work that I carried out towards my PhD but I wouldn't want this to cause a problem with copyright. I, therefore, authorise the use of any of my work in the completion of your thesis.

May I take this opportunity to wish you every success.

Yours sincerely

Subj: **Re: Brickwork research**
Date: 8/8/2002 12:42:42 AM GMT Daylight Time
From: Adrian.Page@newcastle.edu.au
To: ColinSouthcombe@aol.com
Sent from the Internet (Details)

Dear Colin

The Australian codes can now be accessed from the Web at www.standards.com.au. The masonry code is AS3700.2001

To my knowledge there has been virtually no work in this area in Australia recently - most of the emphasis in our research has been in unreinforced masonry.

I'm sorry I can't be more helpful!

regards

Adrian

Adrian W. Page
Pro Vice-Chancellor, Faculty of Engineering and Built Environment
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>>> <ColinSouthcombe@aol.com> 6/8/02 10:26:00 >>>
Dear Adrian

I hope this finds you well. You are no doubt very busy!

Having retired from the University of Plymouth, UK I decided to put some time to a Phd- "Reinforced Brickwork Grouted Cavity Beams". This was an area of study I successfully pursued, with researchers, in the 70s and 80s - until funding for that ran out.

I am looking to have sight of the Australian code related to reinforced brickwork. Could you let me have the relevant address please.

Also are you aware of any research into RB beams which was carried out in Australia since the 80s?

Regards

Colin Southcombe