

HEALTH AND SAFETY EXECUTIVE

RESEARCH AND LABORATORY SERVICES DIVISION

Broad Lane, Sheffield S3 7HQ

An estimation of the maximum allowable
capacities of Pens 3 and 4

by

A L Collins

and

D Waterhouse BSc(Eng) CEng MIMechE FIMEMME

IR/L/ME/89/35

Issue authorised by: Dr A Jones

Date: 31 January 1990

Distribution

The Court of Inquiry (5 copies)

ACC J Mervyn Jones West Midlands Police

Mr D C T Eves

Mr A Barrell TD

Mr P G Jones TD

Mr M S Nattrass FAID Area 14

Mr J P Giltrow HFS (N)

Mr M R Stephenson NE FCG

Mr M Fountain TD3

Mr M James TD3

Mr C J Pertee NE FCG

Mr J B Hibbs NE FCG

Dr J McQuaid

Dr A Jones

Dr J H Foley

Dr C E Nicholson

Mr P F Heyes

Mr I R Price

Mr G A C Games

Mr G Norton

Authors

RPS

Library (2)

Registry File

TO RLSD/DIAS STAFF ONLY

NOT TO BE COMMUNICATED OUTSIDE
RLSD WITHOUT THE APPROVAL OF
THE AUTHORISING OFFICER

SMR/343/235/01

S80.02.OTH.814

CONTENTS

1 INTRODUCTION

2 ESTIMATIONS OF THE CAPACITIES OF PENS 3 AND 4

3 METHOD OF CALCULATING THE REVISED MAXIMUM CAPACITIES OF PENS 3 AND 4

4 ASSESSMENT OF REVISED CAPACITIES

5 SUMMARY AND CONCLUSIONS

APPENDIX 1 Tabulated calculations of the maximum allowable number of persons
in Pens 3 and 4

1 INTRODUCTION

As part of the investigation by the Health and Safety Executive (HSE) into the incident at Sheffield Wednesday Football Club's Hillsborough stadium on 15 April 1989, Mr A L Collins, a Scientific Officer, and Mr D Waterhouse, a Principal Scientific Officer, of HSE's Research and Laboratory Services Division (RLSD) calculated the maximum number of persons (the capacity) that was appropriate for Pens 3 and 4. The calculations were based on their interpretation of recommendations contained within the Home Office/Scottish Office publication "Guide to Safety at Sports Grounds" (H M Stationery Office: 1986).

2 ESTIMATIONS OF THE CAPACITIES OF PENS 3 AND 4

Dr Nicholson, a Deputy Director of RLSD's Safety Engineering Laboratory (SEL) provided us with a drawing that he had received from Eastwood and Partners on 24 April 1989. The drawing was labelled Eastwood and Partners, was numbered 8945/1A, had the title "Sheffield Wednesday F.C. PLC Hillsborough Ground Layout 1987" and was dated 16/4/87 with Revision A dated 21/10/87. This drawing showed the capacity of one of the two central 'pens' of the West terraces of the stadium to be 1,200 persons and that of the other to be 1,000 persons, i.e. the capacity of the combined area was 2,200 persons.

The interim report IR/L/ME/MM/89/1 prepared by RLSD for the Court of Inquiry states that, "if 54 people per 10 sq m is assumed as the allowable packing density for the West Terrace then the capacity of Pen 3 is 1015 and Pen 4 is 1036 making a total of 2051 for the combined area".

However, Paragraph 221 of the 1986 edition of the Home Office/Scottish Office publication "Guide to Safety at Sports Grounds" (H M Stationary Office) states "Where crush barriers meet the strength and spacing guidelines of Chapter 9 the capacity of a terrace or viewing slope should be assessed from the area available for standing by allowing a packing density of between 54 and 27 persons per 10 square metres depending upon the condition of the terrace or slope".

We knew that RLSD's calculation had been made as a preliminary check of the capacity assigned by Eastwood & Partners to the two central 'pens'. We therefore examined two drawings that had been prepared for HSE by Ralph Brade & Associates, Consulting Engineers, Midland Bank Chambers, 3 Sharrow Lane, Sheffield. Drawing No 1340/02 Rev A, dated 3/5/89, showed a plan view of Pens 3 and 4 on the West terraces and Drawing No 1340/03A Rev A, also dated 3/5/89, showed a section through part of the West terraces. These drawings are reproduced, to a smaller scale, in Figs 1 and 2 respectively.

Our examination of these drawings caused us conclude that RLSD's nominal maximum capacity 2051 persons for the central 'pens' might have to be reduced to compensate for some departures from the recommendations of Chapter 9 of the Guide. We therefore calculated capacities for Pens 3 and 4 on the basis of the areas behind crush barriers and perimeter fences in which a crowd packing density of 5.4 persons/sq m would be permissible, provided all other aspects of the terraces conformed with the Guide's recommendations.

3 METHOD OF CALCULATING THE REVISED MAXIMUM CAPACITIES OF PENS 3 AND 4

The calculation of the revised maximum capacity of Pens 3 and 4 was based on our interpretation of Paragraph 113, Paragraph 225, and Table 1 of the Guide.

Paragraph 113 states: "Ideally, crush barriers should be provided along the full width of a terrace, with gaps only at radial gangways".

Paragraph 225 states "The capacity of the terrace is calculated by multiplying the area available for standing by the appropriate packing density. The following following formula may be used:

$$\text{Capacity (Number of persons)} = \frac{A}{10} \times (27 \text{ to } 54)$$

where 'A' is the area available for standing in square metres.

Table 1 recommends the maximum horizontal distance that should exist between barriers conforming to the "greater" and the "lesser" strength requirements when they are installed on "peak viewing areas" and on "other areas". We classified Pens 3 and 4 as being 'peak viewing' areas because they were behind a goal, and the barriers as conforming to the "greater strength requirement" because this permitted greater horizontal distances.

Pens 3 and 4 did not have radial gangways, nor did their crush barriers extend the full width of the terraces, gaps being present along the rows. We therefore calculated the plan area of terrace behind each barrier (or perimeter fence) by multiplying the length of the barrier by a 'permissible depth' behind it. This 'permissible depth' was either the maximum horizontal distance between barriers that was recommended for "peak viewing" in Column A of Table 1 of the Guide, or the existing distance between the barrier and the next barrier (or wall) behind it, whichever was the least.

Brade's Drawing No 1340/03A showed the slope of Pens 3 and 4 to be 13 degrees 40 minutes. The recommended maximum horizontal distance between crush barriers that corresponded to this slope was interpolated from Table 1 of the Guide as being 3.9 m. Brade's Drawing No 1340/02 Rev A showed that the horizontal distance between the rows of crush barriers in Pens 3 and 4 was usually 3.5 m, i.e. the existing distance between the rows of crush barriers was usually within the recommended maximum value.

The heights of the barriers were generally less than the values of 1.02 m to 1.12 m recommended in the Guide. However, we did not discount any of the crush barriers in our calculations; no barrier had a height less than 81% of the minimum recommended value, and our intention was to calculate a 'base' capacity that could be further reduced because of other departures from the Guide's recommendations.

We multiplied each plan area behind a barrier (sq m) by 5.4 persons/sq m and truncated the product to obtain the number of persons appropriate to each area. Fig 3 is a pictorial representation of the method of calculation, the details of which are shown in Appendix 1. The total capacities of Pens 3 and 4 were then obtained by summing the numbers of persons appropriate to each area behind a barrier. Our calculations showed the capacity of Pen 3 to be 822 persons and that of Pen 4 to be 871 persons, i.e. the combined capacity of the central 'pens' was 1,693 persons.

4 ASSESSMENT OF REVISED CAPACITIES

The white areas of Fig 3 represent those parts of the terrace where, ideally, persons should not stand, otherwise the thrust exerted on part of a crush barrier by a crowd of 5.4 persons/sq m might exceed the force intended by the Guide.

Our calculations did not include any reduction in capacity of the central 'pens' to compensate for departures from other recommendations contained in the Guide. Brade's drawings indicated that departures from Paragraphs in the Guide, other than those associated with the continuity (Paragraph 113) and spacing (Table 1) of crush barriers, existed in the central 'pens', i.e.

Paragraph 92 - "A terrace step should not be less than 280 mm or more than 380 mm wide. The preferred dimension is between 355 mm and 380 mm". Pens 3 and 4 had 33 terrace steps, of which 28 (85%) were slightly wider, (not more than 10 mm), than the maximum recommended width.

Paragraph 96 - "The aim should be to ensure that every spectator on the terraces is within 12 metres of a gangway or exit so that spectators can move quickly on to exit routes at the end of an event or in the event of an emergency. This may be achieved by a pattern of gangways (not less than 1.1 metres wide) linked to the exit system". There were no gangways in Pens 3 and 4 and if the perimeter gates are not considered as exits, then approximately 40% of the persons in these 'pens' were not within 12 m of an exit.

Paragraph 110 - "In order to locate the top rail against that part of the body most able to tolerate pressure the heights of crush barriers should be 1.02 m to 1.12 m above the nosing of the step immediately behind the barrier, with a preferred height of 1.1m". Four of the five barriers in Pen 3 and six of the nine barriers in Pen 4 did not conform with this recommendation.

Paragraph 114 - "Where barriers are not continuous between radial gangways, the alignment of gaps in successive rows of barriers on a terrace should form an angle of less than 60 degrees to the line of the barriers. There should be no more than 2 consecutive gaps in any line of gaps". Two of the four 'paths of gaps' in Pen 3 and one of the eleven 'paths of gaps' in Pen 4 did not conform with the recommendation on alignment.

Paragraph 115 - "Where there are gaps in the line of crush barriers these should be at least 1.1 m and not more than 1.4 m in width". Four of five gaps in Pen 3 did not conform and nine of ten gaps in Pen 4 did not conform to a literal interpretation of this recommendation. A more liberal interpretation, relating the acceptability of the width of a gap to the resulting depth of crowd that could form between two rows of barriers, resulted in four of five gaps in Pen 3 and three of six gaps in Pen 4 not conforming, as shown in the schematic plan of Fig 4.

Paragraph 215 - "For most major stadia, whether used for association football or other sports, the pitch perimeter fence will be required either to prevent access to parts of the pitch as mentioned above (Paragraph 214), or at least to discourage attempts by spectators to enter the playing area. Gates or other access points (minimum width of 1.1 m) should nevertheless be provided for use in an emergency and, at those grounds where a perimeter track is used as part of the exit system, for the departure of spectators at the end of an event.

Provision of such gates or access points is particularly important to allow for access to the playing area (or track) where it is likely to be used as a place of safety in an emergency. Such gates or access points should be properly stewarded and clearly marked so that immediate access to the playing area or perimeter track can be ensuredⁿ. The gate to Pen 3 had a clearance width of 0.81 m to 0.82 m and the gate to Pen 4 had a clearance width of 0.77 m to 0.79 m. The two gates in the perimeter fence of the central 'pens' therefore did not conform with this recommendation.

It is our opinion that it might be advisable to reduce the 'base' capacities of 822 persons for Pen 3 and 871 persons for Pen 4, because of these six departures from the Guide's recommendations.

5 SUMMARY AND CONCLUSIONS

5.1 We used recommendations contained within the 1986 edition of the Home Office/Scottish Office publication "Guide to Safety at Sports Grounds" (the Guide) to calculate revised maximum allowable capacities for Pens 3 and 4 of the West terraces of Sheffield Wednesday Football Club's Hillsborough stadium. We calculated the maximum allowable capacity of Pen 3 to be 822 persons, and that of Pen 4 to be 871 persons. It is therefore our opinion that the combined maximum allowable capacity of the two-central 'pens' should not exceed 1,693 persons, provided that all other aspects of the terraces conformed with the Guide's recommendations.

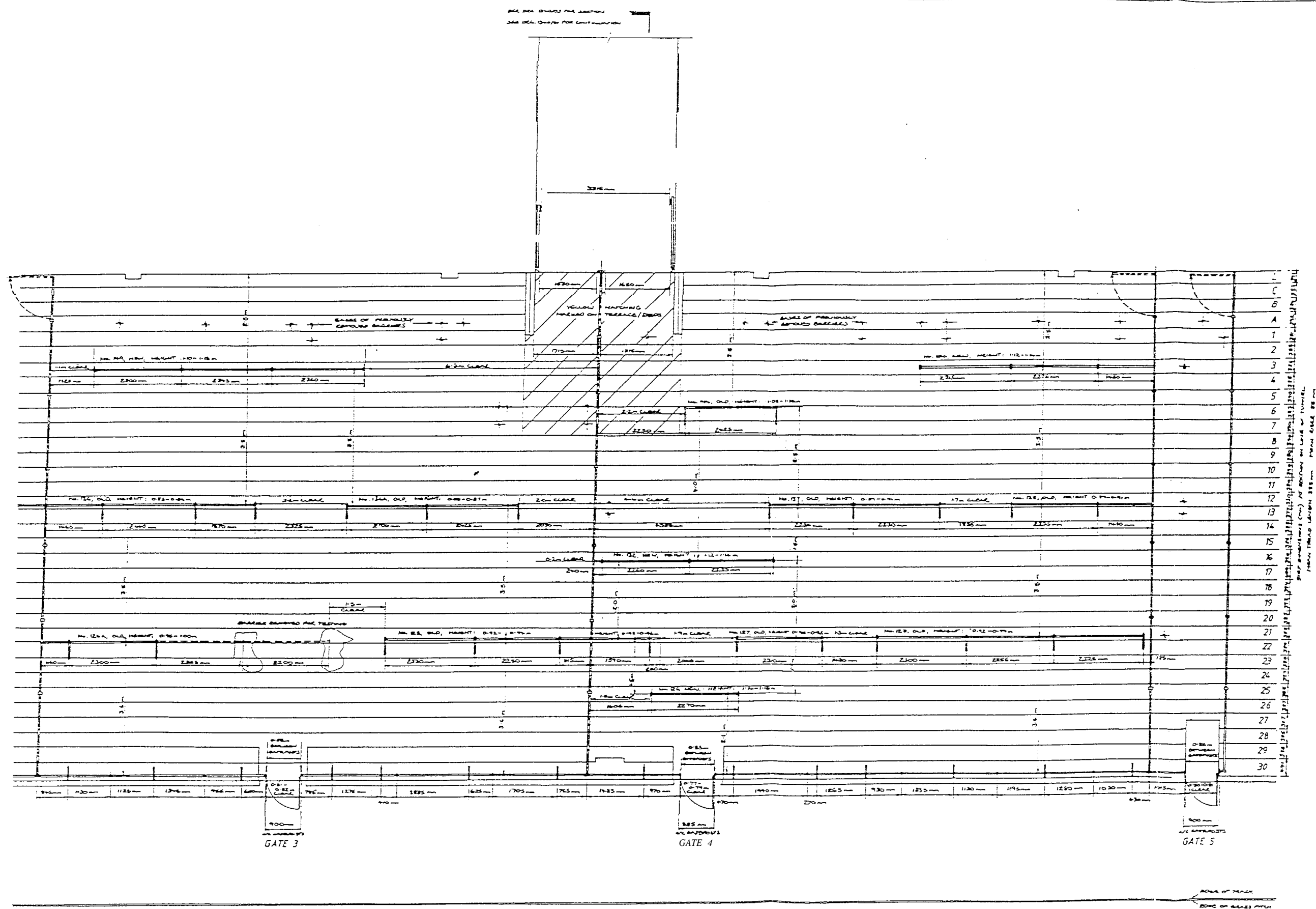
5.2 Our calculations showed the capacity of Pen 3 to be less than that of Pen 4. Eastwood & Partners Drawing No 8945/1A dated 16/4/87 showed The capacity of Pen 3 to be greater than that of Pen 4.

5.3 Our revised maximum allowable combined capacity of 1,693 persons for the two central 'pens' was 83% of that initially calculated by RLSD, solely on the basis of the area of Pens 3 and 4, and was 77% of that shown on Eastwood & Partners Drawing No 8945/1A, dated 16/4/87.

5.4 Our calculation of the revised capacities of Pens 3 and 4 did not include any reduction that might be needed to compensate for some departures from the Guide's recommendations in these 'pens'. These departures were associated with:

- (i) the width of the terrace steps.
- (ii) the distance of persons from gangways or exits;
- (iii) the heights of crush barriers;
- (iv) the alignment of gaps in the rows of crush barriers;
- (v) the width of gaps in the rows of crush barriers;
- (vi) the width of the gates in the perimeter fence;

It is our opinion that the revised number of 1,693 persons for the maximum combined capacity of Pens 3 and 4 should be reduced further because of these six departures from the Guide's recommendations.



- NOTES
1. THE SECTION SHOWN IS A CROSS SECTION.
 2. FOR CLARIFICATION THE CENTRAL TUNNEL IS SHOWN TO BE 1200mm.
 3. SHOWN DIMENSIONS INDICATED THIS IS THE OLD TYPE - VERTICAL DIMENSIONS - 31-31 FOR BARRIERS - 31-31 FOR NEW TYPE - STRUCTURE 1000mm HIGH, 1200mm WIDE.
 4. DIMENSIONS ARE INDICATED FROM THE TOP OF THE TUNNEL UP TO THE TOP OF THE - CLARE TO BARRIERS - DIMENSIONS 1200mm AND 1200mm.
 5. DIMENSIONS OF OLD, PREVIOUSLY EXISTING BARRIERS (CUT OFF APPROXIMATELY 1200mm) SHOWN THIS IS -

Ralph Brade & Associates
Consulting Engineers

Sheffield S11 8AE
Tel: 0742 562256

HEALTH & SAFETY EXECUTIVE

SHEFFIELD WEDNESDAY FOOTBALL CLUB
HILLSBOROUGH

WEST TERRACE
PLAN DETAILS OF
CENTRAL PENS

Scale: 1:100
Date: 3-5-89
Job No: 1340
Drawing No: 1340/02A

Fig 1 PLAN VIEW OF PENS 3 AND 4 OF WEST TERRACES

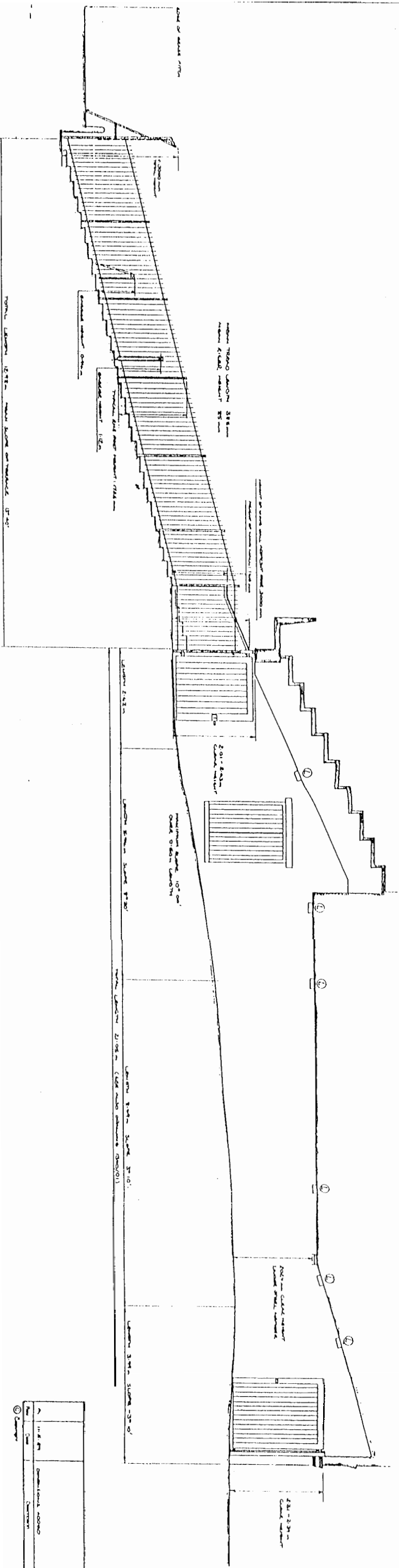


Fig 2 SECTION THROUGH PART OF WEST TERRACES

Ref	Dim	Description
1	11.8m	OPERATIONAL ROOM
2	11.8m	OPERATIONAL ROOM
3	11.8m	OPERATIONAL ROOM
4	11.8m	OPERATIONAL ROOM
5	11.8m	OPERATIONAL ROOM
6	11.8m	OPERATIONAL ROOM
7	11.8m	OPERATIONAL ROOM
8	11.8m	OPERATIONAL ROOM
9	11.8m	OPERATIONAL ROOM
10	11.8m	OPERATIONAL ROOM
11	11.8m	OPERATIONAL ROOM
12	11.8m	OPERATIONAL ROOM
13	11.8m	OPERATIONAL ROOM
14	11.8m	OPERATIONAL ROOM
15	11.8m	OPERATIONAL ROOM
16	11.8m	OPERATIONAL ROOM
17	11.8m	OPERATIONAL ROOM
18	11.8m	OPERATIONAL ROOM
19	11.8m	OPERATIONAL ROOM
20	11.8m	OPERATIONAL ROOM
21	11.8m	OPERATIONAL ROOM
22	11.8m	OPERATIONAL ROOM
23	11.8m	OPERATIONAL ROOM
24	11.8m	OPERATIONAL ROOM
25	11.8m	OPERATIONAL ROOM
26	11.8m	OPERATIONAL ROOM
27	11.8m	OPERATIONAL ROOM
28	11.8m	OPERATIONAL ROOM
29	11.8m	OPERATIONAL ROOM
30	11.8m	OPERATIONAL ROOM
31	11.8m	OPERATIONAL ROOM
32	11.8m	OPERATIONAL ROOM
33	11.8m	OPERATIONAL ROOM
34	11.8m	OPERATIONAL ROOM
35	11.8m	OPERATIONAL ROOM
36	11.8m	OPERATIONAL ROOM
37	11.8m	OPERATIONAL ROOM
38	11.8m	OPERATIONAL ROOM
39	11.8m	OPERATIONAL ROOM
40	11.8m	OPERATIONAL ROOM
41	11.8m	OPERATIONAL ROOM
42	11.8m	OPERATIONAL ROOM
43	11.8m	OPERATIONAL ROOM
44	11.8m	OPERATIONAL ROOM
45	11.8m	OPERATIONAL ROOM
46	11.8m	OPERATIONAL ROOM
47	11.8m	OPERATIONAL ROOM
48	11.8m	OPERATIONAL ROOM
49	11.8m	OPERATIONAL ROOM
50	11.8m	OPERATIONAL ROOM
51	11.8m	OPERATIONAL ROOM
52	11.8m	OPERATIONAL ROOM
53	11.8m	OPERATIONAL ROOM
54	11.8m	OPERATIONAL ROOM
55	11.8m	OPERATIONAL ROOM
56	11.8m	OPERATIONAL ROOM
57	11.8m	OPERATIONAL ROOM
58	11.8m	OPERATIONAL ROOM
59	11.8m	OPERATIONAL ROOM
60	11.8m	OPERATIONAL ROOM
61	11.8m	OPERATIONAL ROOM
62	11.8m	OPERATIONAL ROOM
63	11.8m	OPERATIONAL ROOM
64	11.8m	OPERATIONAL ROOM
65	11.8m	OPERATIONAL ROOM
66	11.8m	OPERATIONAL ROOM
67	11.8m	OPERATIONAL ROOM
68	11.8m	OPERATIONAL ROOM
69	11.8m	OPERATIONAL ROOM
70	11.8m	OPERATIONAL ROOM
71	11.8m	OPERATIONAL ROOM
72	11.8m	OPERATIONAL ROOM
73	11.8m	OPERATIONAL ROOM
74	11.8m	OPERATIONAL ROOM
75	11.8m	OPERATIONAL ROOM
76	11.8m	OPERATIONAL ROOM
77	11.8m	OPERATIONAL ROOM
78	11.8m	OPERATIONAL ROOM
79	11.8m	OPERATIONAL ROOM
80	11.8m	OPERATIONAL ROOM
81	11.8m	OPERATIONAL ROOM
82	11.8m	OPERATIONAL ROOM
83	11.8m	OPERATIONAL ROOM
84	11.8m	OPERATIONAL ROOM
85	11.8m	OPERATIONAL ROOM
86	11.8m	OPERATIONAL ROOM
87	11.8m	OPERATIONAL ROOM
88	11.8m	OPERATIONAL ROOM
89	11.8m	OPERATIONAL ROOM
90	11.8m	OPERATIONAL ROOM
91	11.8m	OPERATIONAL ROOM
92	11.8m	OPERATIONAL ROOM
93	11.8m	OPERATIONAL ROOM
94	11.8m	OPERATIONAL ROOM
95	11.8m	OPERATIONAL ROOM
96	11.8m	OPERATIONAL ROOM
97	11.8m	OPERATIONAL ROOM
98	11.8m	OPERATIONAL ROOM
99	11.8m	OPERATIONAL ROOM
100	11.8m	OPERATIONAL ROOM

Ralph Brade & Associate
Consulting Engineers
Hillside Lane, Overton
35, Overton Lane
Sheffield S11 8AE
Tel: 0114 252255



HEALTH & SAFETY EXECUTIVE

SHEFFIELD WEDNESDAY
FOOTBALL CLUB
HILLSBOROUGH

CENTRAL TUNNEL
& WEST TERRACE
LONGITUDINAL SECTION

Scale: 1:100
Date: 3-5-89
Drawn by: D.R./R.B.
Job No: 1340
Drawn by: 1340/03A/A

PEN 3

TOTAL 822

PEN 4

TOTAL 871

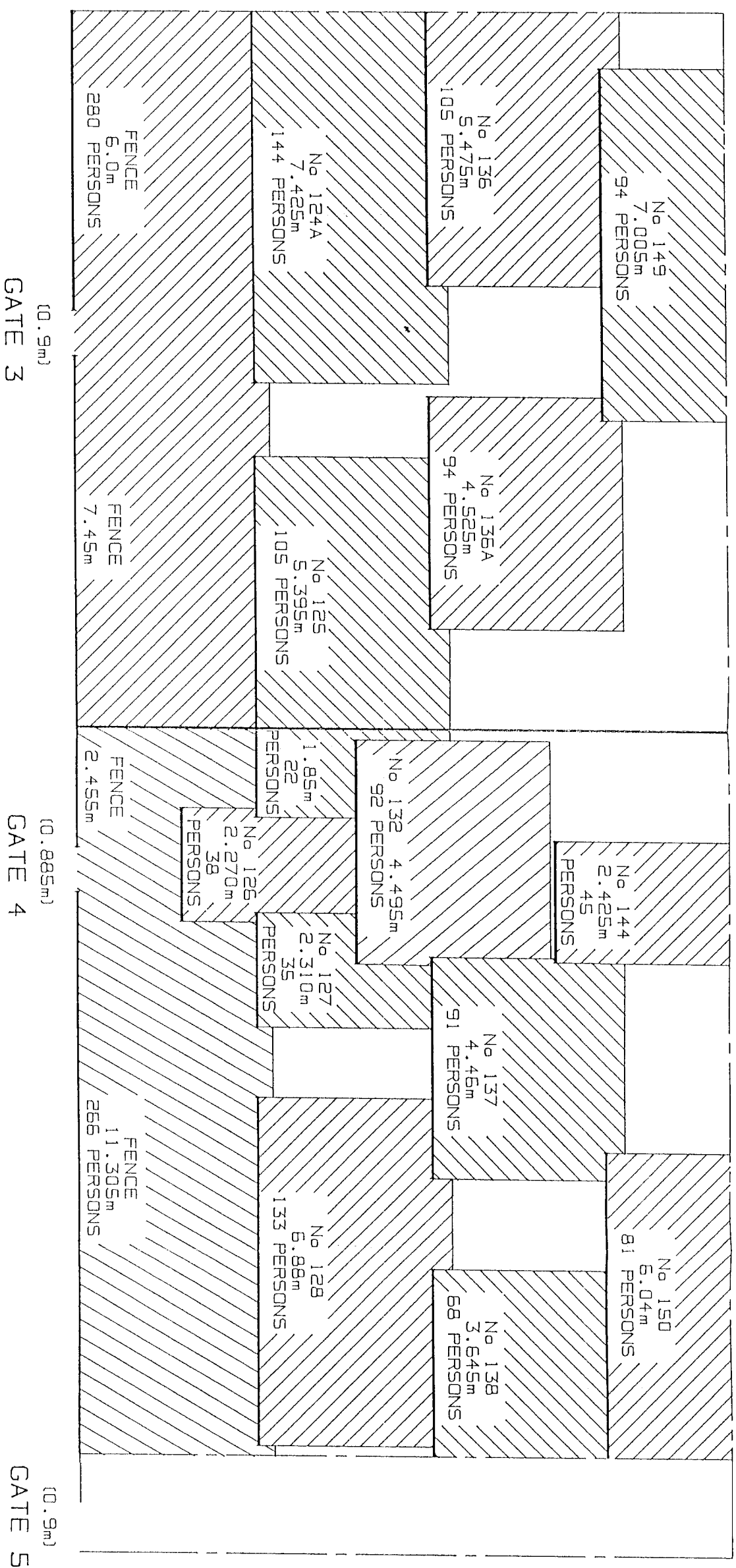
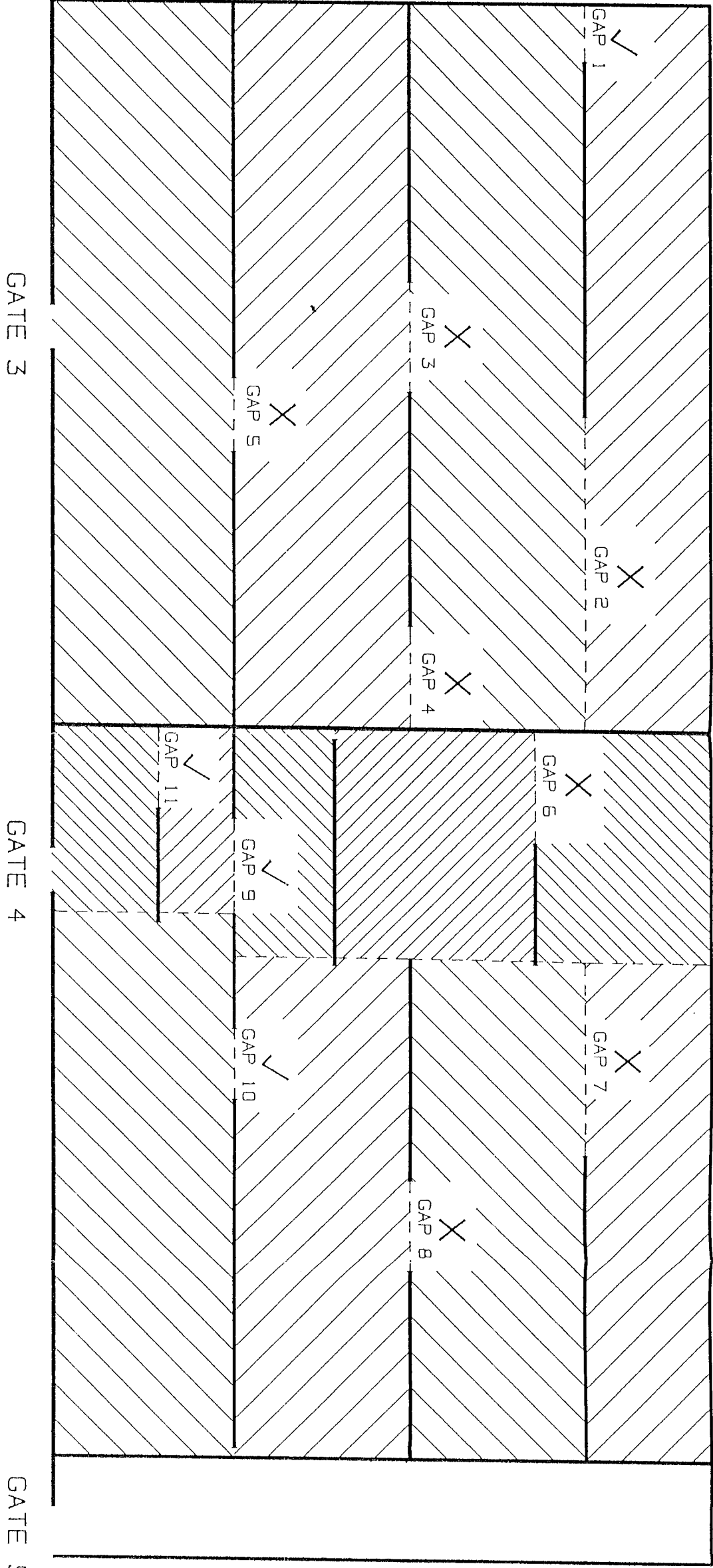


Fig 3 WEST TERRACE - IDEAL DISTRIBUTION OF PERSONS IN CENTRAL PENS

PEN 3

PEN 4



X GAP DOES NOT CONFORM TO GUIDE TO SAFETY AT SPORTS GROUNDS

✓ GAP CONFORMS TO GUIDE TO SAFETY AT SPORTS GROUNDS

Fig 4 CONFORMITY OF WIDTH OF GAPS BETWEEN BARRIERS IN PENS 3 AND 4

APPENDIX 1

Table 1 Calculations of maximum allowable number of persons in Pen 3

PEN 3 Barrier number	Available spectator area sq m			Number of spectators at a density of 5.4 persons/sq m	
				Calculated	Truncated
149	7.005 x 2.5	=	17.513	94.570	94
136	1.125 x 3.9	=	4.388	23.695	23
136	4.350 x 3.5	=	15.225	82.215	82
136A	0.330 x 3.5	=	1.155	6.237	6
136A	4.195 x 3.9	=	16.361	88.349	88
124A	5.475 x 3.5	=	19.163	103.480	103
124A	1.950 x 3.9	=	7.605	41.067	41
125	3.365 x 3.5	=	11.778	63.601	63
125	2.030 x 3.9	=	7.917	42.752	42
Fence	7.425 x 3.6	=	26.730	144.342	144
Fence	1.530 x 3.9	=	5.967	32.222	32
Fence	5.395 x 3.6	=	19.422	104.879	104
Total				827.409	822

APPENDIX 1 (cont)

Table 2 Calculations of maximum allowable number of persons in Pen 4

PEN 4 Barrier number	Available spectator area sq m			Number of spectators at a density of 5.4 persons/sq m	
				Calculated	Truncated
150	6.040 x 2.5	=	15.100	81.540	81
144	2.425 x 3.5	=	8.488	45.835	45
137	0.095 x 2.5	=	0.238	1.285	1
137	3.825 x 3.9	=	14.918	80.557	80
137	0.540 x 3.5	=	1.890	10.206	10
138	3.645 x 3.5	=	12.758	68.893	68
132	4.340 x 3.9	=	16.926	91.400	91
132	0.155 x 1.5	=	0.233	1.258	1
125	1.610 x 2.0	=	3.220	17.388	17
125	0.240 x 3.9	=	0.936	5.054	5
127	0.885 x 2.0	=	1.770	9.558	9
127	1.425 x 3.5	=	4.988	26.935	26
128	1.565 x 3.5	=	5.478	29.581	29
128	1.855 x 3.9	=	7.235	39.069	39
128	3.460 x 3.5	=	12.110	65.394	65
126	0.245 x 1.5	=	0.368	1.987	1
126	2.000 x 3.5	=	7.000	37.800	37
126	0.025 x 1.5	=	0.038	0.205	0
Fence	1.605 x 3.6	=	5.778	31.201	31
Fence	2.270 x 2.1	=	4.767	25.742	25
Fence	2.275 x 3.6	=	8.190	44.226	44
Fence	1.430 x 3.9	=	5.577	30.116	30
Fence	6.880 x 3.6	=	24.768	133.747	133
Fence	0.185 x 3.9	=	0.722	3.899	3
Total				882.876	871