

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 Natrass 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 Stationery 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:

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

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.

PEN 3

TOTAL 822

PEN 4

TOTAL 871

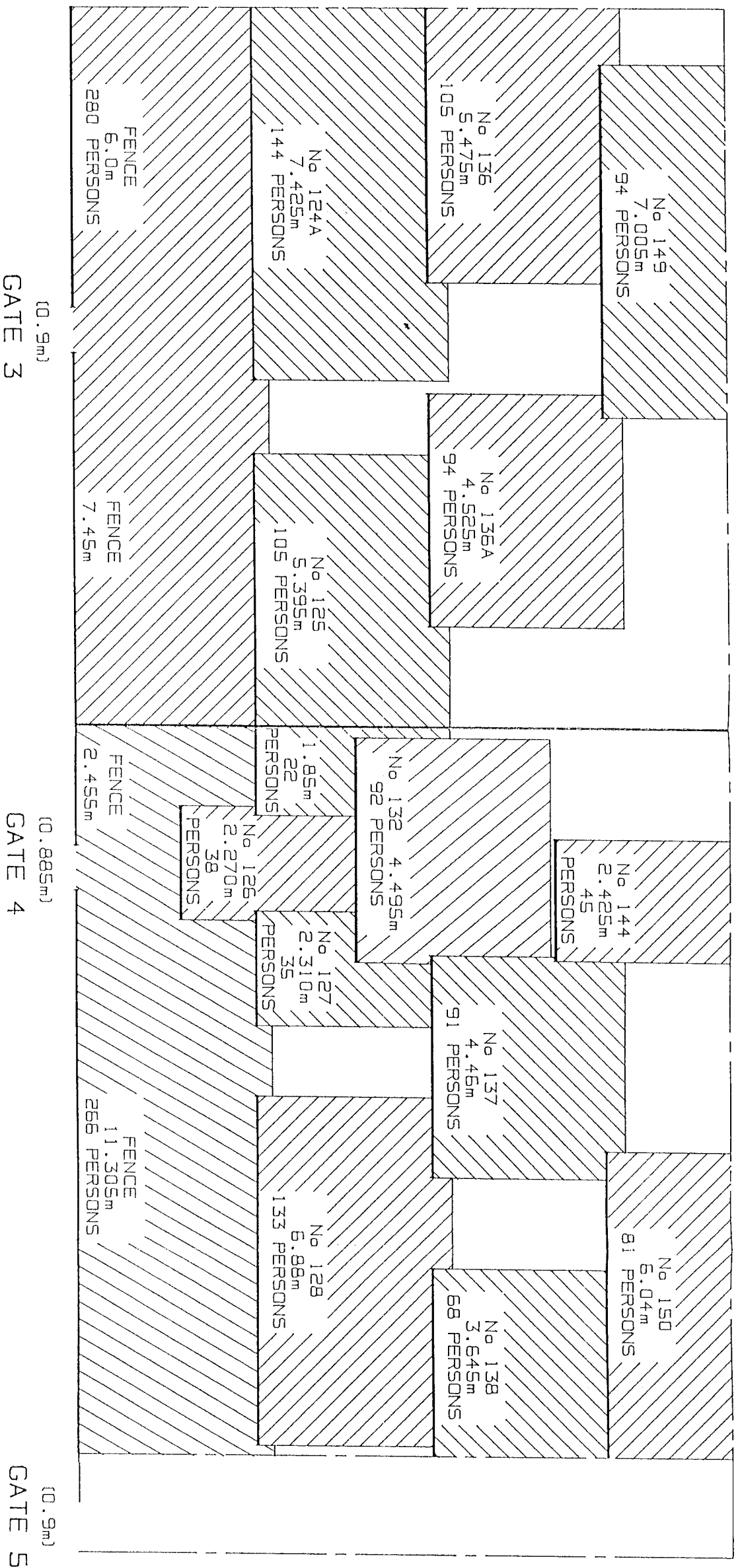
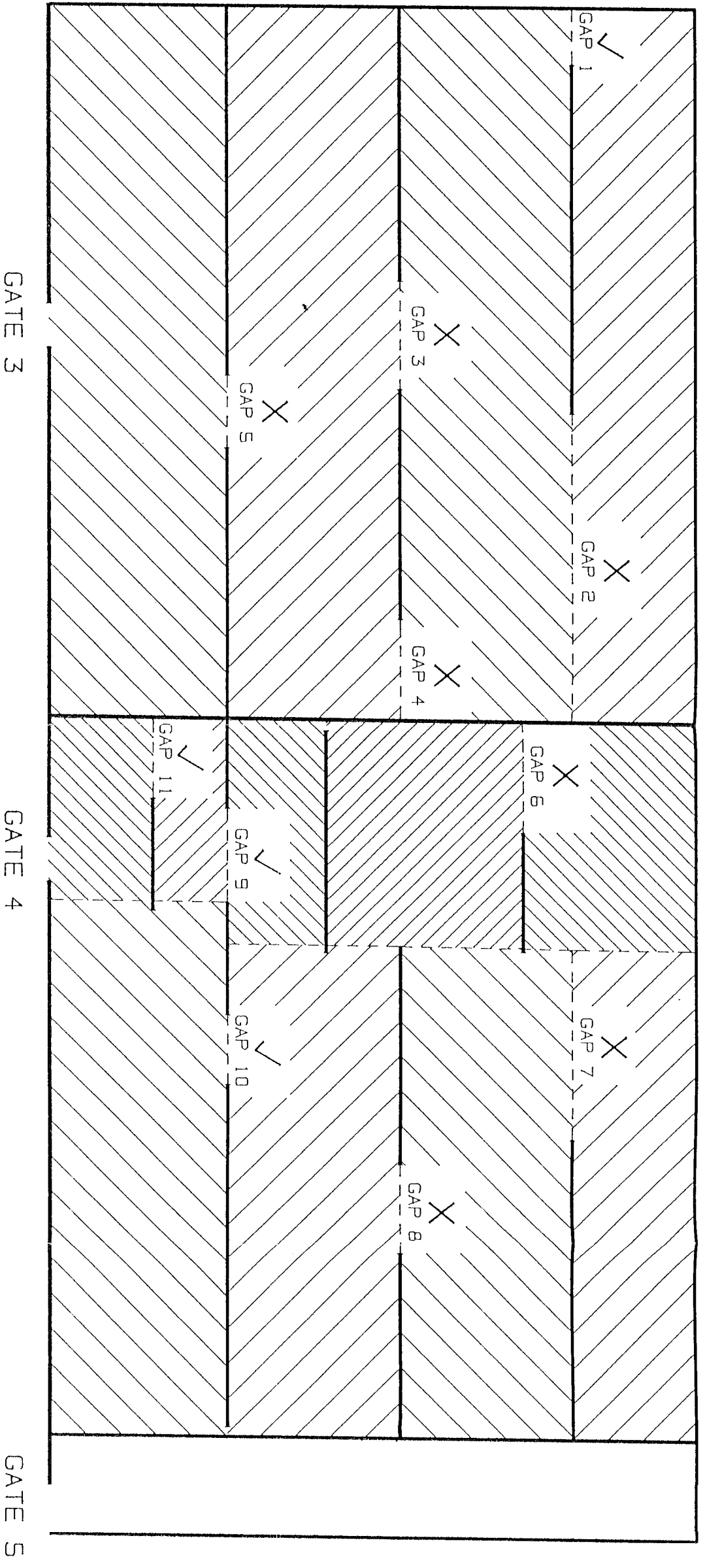


Fig 3 WEST TERRACE - IDEAL DISTRIBUTION OF PERSONS IN CENTRAL PENS

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	