

HEALTH AND SAFETY EXECUTIVE

RESEARCH AND LABORATORY SERVICES DIVISION

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An investigation into the number of  
people in 'pens' 3 and 4

by

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IR/L/ME/89/32

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## 1 INTRODUCTION

Following the incident at Hillsborough Stadium, Dr Nicholson provided me with several albums of photographs. He told me that these had been supplied to him by the West Midlands Police. He said that they contained some photographs of the spectators in 'pens' 3 and 4 taken at Hillsborough Stadium and that they had been taken at about the time that the game commenced. He asked me to provide him with a scientifically-based estimate of the number of persons in 'pen' 3 and in 'pen' 4, and the crowd packing density (number of persons per square metre) in these 'pens'.

I was also provided with a dimensioned drawing showing a plan view of 'pens' 3 and 4. The drawing had been prepared by Ralph Brade & Associates, Consulting Engineers, Sheffield, at the request of Dr Nicholson; it was numbered 1340/02 Rev A and was dated 3/5/89. I used this drawing to establish the locations of the crush barriers in 'pens' 3 and 4 and to calculate the areas of these 'pens'.

I was assisted in this work by Mr G A C Games, a Senior Scientific Officer of RLSD's Mechanical Engineering Section and Mrs S M Barker of RLSD's Mechanical Design Unit.

## 2 PHOTOGRAPHS USED FOR COUNTING THE NUMBER OF PERSONS

### 2.1 PHOTOGRAPHS TAKEN ON 15 APRIL 1989 SHOWING 'PENS' 2 AND 3 - PR1/7A AND PR1/8A

Two prints of the West Terrace were selected by Mr Games and myself from the albums of photographs. These prints were labelled PR1/7A and PR1/8A. West Midlands Police informed Dr Nicholson that these photographs were taken by a police photographer, Mr P Rich of the South Yorkshire Police, from a fixed position in the South Stand. The photographs were marked with a time of 15.03. The field of view on the two photographs overlapped and by identifying the same landmarks on each, it was possible to overlay the photographs to form a continuous view of the crowd. The prints from the albums were too small for further work, and I therefore requested that enlargements be provided. West Midlands Police subsequently provided enlargements of the prints and these were overlapped, as described above, and taped together.

### 2.2 PHOTOGRAPHS TAKEN ON 22 MAY 1989 SHOWING THE WEST TERRACE WHEN EMPTY - PR10/A2 TO PR10/A5

I could not identify the positions of barriers within the 'pens' from the combined photographs PR1/7A and PR1/8A. Dr Nicholson therefore requested West Midlands Police to arrange for Mr Rich, using the same equipment as used on the day of the incident, from the same position, to take a set of overlapping photographs which showed the empty West Terrace. Common landmarks were identified on these prints and a subset, marked with numbers PR10/A2 to PR10/A5, were then overlapped to form a panoramic view of the empty terrace.

### 2.3 PHOTOGRAPH TAKEN 15 APRIL 1989 SHOWING 'PENS' 2,3 AND 4 - MPLA-14

Other photographs taken on the day of the incident showed larger areas of the terrace. Photograph MPLA-14, taken from the North Stand, showed a long view of 'pens' 2,3 and 4 and was marked with a time of 14.52. Dr Nicholson requested enlargements of the photograph and these were provided by West Midlands Police.

The head of every discernible person in the crowd was digitised to produce the drawing PR178A, Fig 1 is based on this drawing.

### 3.2 DIGITISING THE CROWD FROM THE REMAINING PHOTOGRAPHS

The same digitising procedures were used with photographs MPLA-14 and 148.3, again digitising only positively discernible individuals. Figs 2 and 3 show the digitised information from MPLA-14.

### 3.3 DIGITISING THE CRUSH BARRIERS FROM PHOTOGRAPHS PR10/A2 to PR10/A5

Overlapping photographs, PR10/A2 to PR10/A5, were positioned on the digitising surface and the crush barriers, fences and wall boundaries were digitised into the CAD system as a separate drawing.

## 4 CAD MANIPULATION OF THE DIGITISED DATA

### 4.1 NUMBER OF PERSONS IN THE WHOLE AREA OF 'PEN' 3

Drawing PR178A (Fig 1) showed asterisks representing people in part of 'pen' 2 and part of 'pen' 3. The drawing did not include all of 'pen' 3, because of the limited view in the photographs, and therefore an overall count for the 'pen' could not be made using the drawing shown in Fig 1 alone.

The editing facilities of the CAD system were used on drawing PR178A to delete the asterisks representing the occupants of 'pen' 2, and produced the drawing shown in Fig 4. The CAD system was then used to overlay and position the drawing made from photographs PR10/A2 to PR10/A5, as summarized in Section 3.3, on the drawing of Fig 4 by matching common landmarks on each drawing. The resulting drawing displayed the full extent of 'pen' 3, but only contained that part of the crowd shown on the original photographs PR1/7A and PR1/8A, causing part of 'pen' 3 to appear to be empty.

I used the facilities of the CAD system to estimate the number of persons in this missing part of the crowd by creating a 'patch' of the same size and shape as the apparently empty part of 'pen' 3. This 'patch' was superimposed on the populated area of 'pen' 3 and the resulting 'crowd patch' copied to the apparently empty part of 'pen' 3. The resulting drawing is shown in Fig 5, the crush barriers having been omitted for clarity and the 'crowd patch' being shown in bold outline. I used the automatic counting facility of the CAD system to count the number of heads (asterisks) shown on this drawing.

### 4.2 NUMBER OF PERSONS IN ROWS WITHIN 'PEN' 3

I was concerned about the difficulty in discerning individual heads near the front of 'pen' 3. I also wished to have some measure of the variation of crowd density across the depth of this 'pen'. Therefore 'pen' 3 was divided into rows parallel to the front boundary fence. Using the crush barriers, digitised from photographs PR10/A2 to PR10/A5, as demarcations to divide 'pen' 3 into four parallel rows numbered from Row 1 (front row) to Row 4 (rear row).

Using the overlaying facility of the CAD system the crush barriers were superimposed on the drawing shown in Fig 5. The top rail of each barrier was then projected upwards to a common scaled height of 1.7 m, assuming this dimension to be a common height to the centre of every head. Identification of the occupants of 'pens' 3 and 4 had been undertaken by locating the position

(asterisks) within the rectangular area in each 'pen' was then obtained. This procedure was repeated at different locations until 4 sets of counts had been obtained, at the positions shown in Fig 10, taking care to ensure that obstructions e.g. persons outside the terrace, did not protrude into the rectangular areas.

## 5 RESULTS

### 5.1 NUMBER OF PERSONS IN 'PEN' 3 OBTAINED FROM PHOTOGRAPHS PR1/7A AND PR1/8A

#### 5.1.1 Number of Persons identified directly from the photographs

The number of persons counted automatically within 'pen' 3, on the basis of the number of heads directly identified with the digitising method, was 1074. To this must be added the number of persons in that part of the 'pen' not shown on the photographs but estimated by the 'crowd patch' method ie 334. This results in a total figure of 1408. It is my opinion that this total is an underestimate of the number of persons within 'pen' 3; lack of clarity in the photographs made it difficult to identify individual heads near the front boundary wall and also people outside the 'pen' obscured parts of this area.

#### 5.1.2 Number of Persons assessed by dividing the 'pen' into rows

Table 1 shows my alternative assessment of the number of persons within 'pen' 3, based on the division of the 'pen' into four rows. Persons in Rows 4, 3 and 2 were identified directly from the photographs using the digitiser and 'crowd patch' methods and counted automatically. The number of persons in the front row (Row 1) were estimated on the basis of the plan area of the row and a crowd packing density of 10 persons/sq m. This alternative and preferred assessment of the number of persons in 'pen' 3 is 1576.

Table 1 also shows the crowd packing densities for each of the four rows in 'pen' 3. The crowd packing densities for Rows 4, 3 and 2 are based on the number of persons identified with the digitiser and 'crowd patch' methods from photographs whilst that for Row 1 is a value assumed on the basis of tests made at RLSD.

### 5.2 NUMBER OF PERSONS IN 'PENS' 3 AND 4 OBTAINED FROM PHOTOGRAPH MPLA-14

Table 2 shows the number of persons in 'pens' 3 and 4 obtained by using the automatic counting facility of the CAD system, after they had been identified on photograph MPLA-14, using the digitising method.

It was extremely difficult to differentiate between individual heads on photograph MPLA-14 and only those heads that could be definitely identified were digitised. I consider this to be the reason for obtaining a count of 678 persons in 'pen' 3 from photograph MPLA-14, a number which is low compared to the 1408 persons counted from photographs PR1/7A and PR1/8A and to my preferred estimate of 1576 persons.

It is my opinion that the counts of 678 persons in 'pen' 3 and 821 persons in 'pen' 4 should be regarded as being unrealistically low. It is also my opinion that I obtained a much more reliable assessment of the number of persons in 'pen' 3 from the counts and estimate based on photographs PR1/7A and PR1/8A.

Whilst the above figures cannot be used as a total count for the 'pens' I

believe they can be used to compare crowd densities. The ground areas of 'pens' 3 and 4 are very similar (see table 1) and I consider that the counts obtained suggest that the crowd packing densities in 'pens' 3 and 4 were also similar. The larger count in 'pen' 4 can be partially attributed to the angle and position from which the photograph was taken, which enabled easier identification of individual heads in 'pen' 4 than in 'pen' 3.

### 5.3 NUMBER OF PERSONS WITHIN A SAMPLE COLUMNAR AREA OF 'PEN' 2

A total of 150 persons occupied a sample columnar area taken from the front boundary wall to the rear boundary wall of 'pen' 2. The corresponding crowd packing density was 5.0 persons/sq m.

### 5.4 COMPARISON OF THE NUMBER OF PERSONS IN 'PENS' 3 AND 4

Table 3 summarizes the number of persons identified within different areas of the same size at four locations in each 'pen'. Although the numbers of persons should not be regarded as absolute values, because of the difficulty in clear identification, it is my opinion that they do serve to compare the crowd packing densities in 'pens' 3 and 4.

Making allowance for the difficulty in identifying persons, I consider the differences between the numbers obtained in each of the four comparisons to be small. Additionally, there is no distinct bias to suggest an appreciable difference between the crowd packing densities in 'pens' 3 and 4; this is confirmed by the close agreement obtained between the average values of the four sample counts made for each 'pen'.

## SUMMARY AND CONCLUSIONS

6.1 I used photographs supplied by West Midlands Police, together with a drawing prepared by Ralph Brade & Associates, as the basis for my assessment of the number of persons in parts of the West Terrace of Sheffield Wednesday Football Club's Hillsborough Stadium. I used the facilities provided by a computer-aided draughting system to assist in identifying and counting the number of persons within 'pens' on the West Terrace.

6.2 In making my assessment I assumed that a crowd packing density in one part of 'pen' 3 was reproduced in another, adjacent part of it. Additionally, I was unable to obtain an acceptably accurate count of the persons between the front boundary wall and the nearest line of crush barriers in 'pen' 3 by the direct identification of heads on photographs. I therefore estimated the number of persons in this area of 'pen' 3 from considerations of the crowd packing densities in other areas of the 'pen', together with results from an investigation of packing densities made on RLSD's premises. It is my opinion, based on a study of photographs of 'pens' 3 and 4, that my assumption and estimation were justified.

6.3 My best assessment of the number of persons within 'pen' 3 is that 1576 persons were present at 15.03 hours on 15 April 1989. It is my opinion that 1576 persons is unlikely to be an overestimate of the true number. It represents an average crowd packing density in 'pen' 3 of 8.4 persons/sq m, which exceeds the maximum value of 5.4 persons/sq m recommended in "Guide To Safety At Sports Grounds" (ref 1) by 56%

6.4 The crowd packing density within 'pen' 3 increased between the rear boundary wall and the line of crush barriers nearest to the front boundary

wall. My lowest assessment of the crowd packing density in 'pen' 3 had an average value of 7.5 persons/sq m, this occurring in the area between the rear boundary wall and the rearmost line of crush barriers. The highest crowd packing density that I was able to assess directly had an average value of 8.1 persons/sq m, and this occurred in the area between the line of crush barriers nearest the pitch and the next line of crush barriers. These crowd packing densities exceed the maximum value recommended in "Guide To Safety At Sports Grounds" by 39% and 50% respectively.

6.5 I assessed the average crowd packing density in 'pen' 2 at 15.03 hours to be of the order of 5 persons/sq m.

6.6 I was unable to assess the number of persons in 'pen' 4 by a direct counting method and I used a technique that compared the packing densities in 'pen' 4 with those in 'pen' 3. This comparison has caused me to conclude that at approximately 15.00 hours the packing densities in 'pens' 3 and 4 were nominally the same.

Table 1 Number of persons in 'pen' 3 and their packing densities at 15.03 hours on 15 April 1989, based on photographs PR1/7A and PR1/8A

Row No	Number of persons	Crowd packing density (persons/sq m)
4 (Rear) (Fig 8)	268	7.5
3 (Fig 7)	382	7.6
2 (Fig 6)	409	8.1
1 (Front)	517 -----	10.0 (assumed)
	1576 total	8.4 mean value

Table 2 Number of persons in 'pens' 3 and 4 and their packing densities on 15 April 1989, based on photograph MPLA-14

'pen' No	Number of persons	Area (sq m)
'pen' 3 (Fig 2)	678	188
'pen' 4 (Fig 3)	821 -----	192 ---
	1499 (total)	380 (total)

Table 3 Comparison of number of persons within sample areas of the same size in 'pens' 3 and 4

	Number of persons within a sample area of the same size (see Fig 10)	
	'pen' 3	'pen' 4
First comparison	44	56
Second comparison	56	49
Third comparison	45	51
Fourth comparison	50 -----	41 -----
Mean comparison	48.75	49.25



REFERENCES

- 1 Guide to Safety at Sports Grounds (1986)  
HMSO  
ISBN 0 11 340840 4

DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A

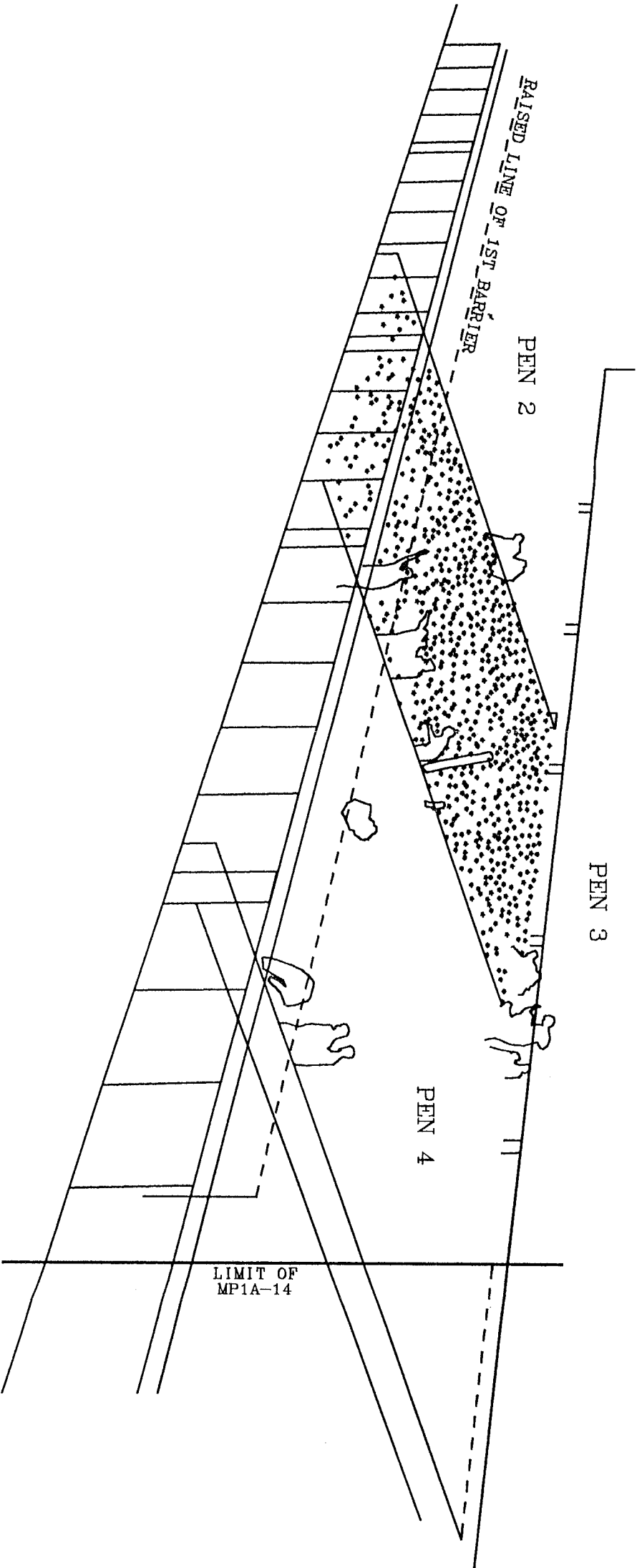


HEADCOUNT - 1419  
PHOTOGRAPHS TAKEN 15.03

FIG 1

DIGITISED DRAWING OF PHOTOGRAPH MP1A-14  
SHOWING RAISED 1ST BARRIER & PEN DIVIDING FENCES

OCCUPANTS OF PEN 3 SHOWN



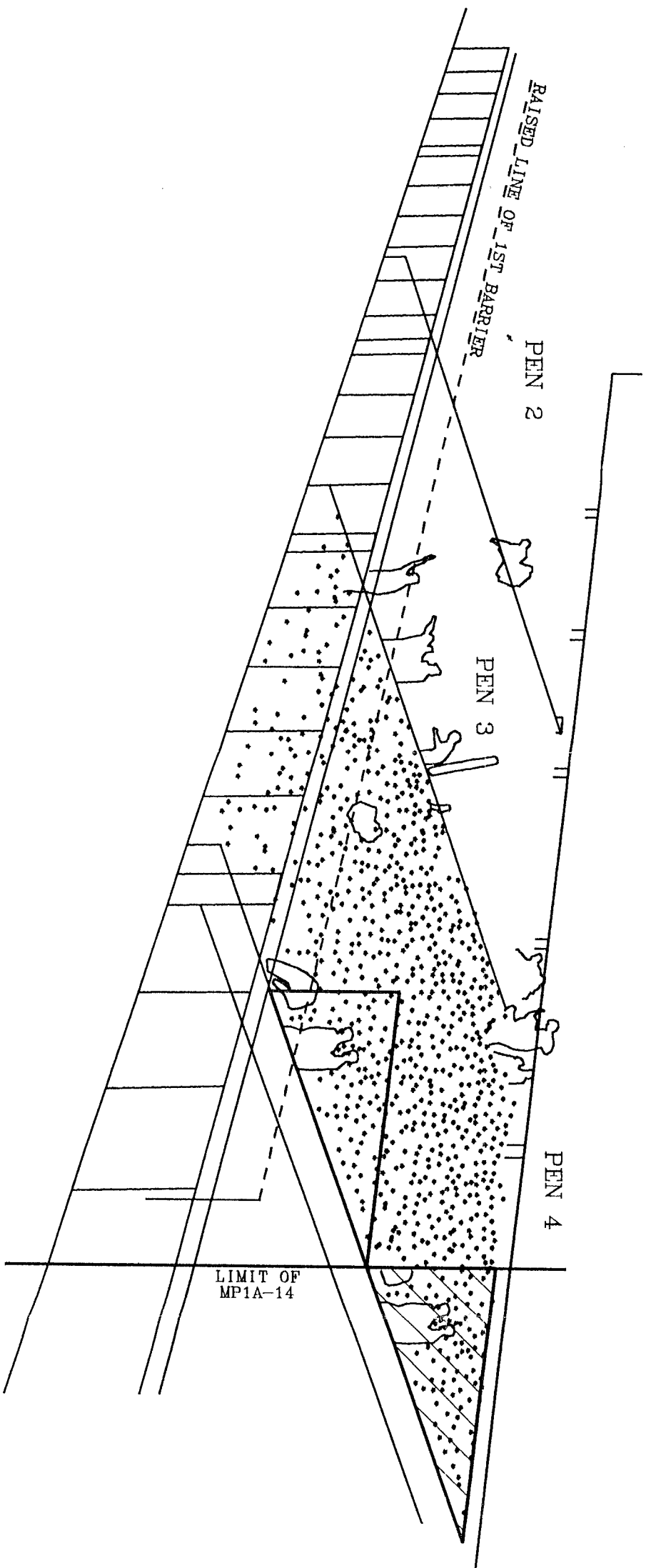
HEADCOUNT - 678

PHOTOGRAPHS TAKEN 14.52

FIG 2

DIGITISED DRAWING OF PHOTOGRAPH MP1A-14  
SHOWING RAISED 1ST BARRIER & PEN DIVIDING FENCES

OCCUPANTS OF PEN 4 SHOWN  
(NB ESTIMATED CROWD - 84 OCCUPANTS - SHOWN HATCHED)

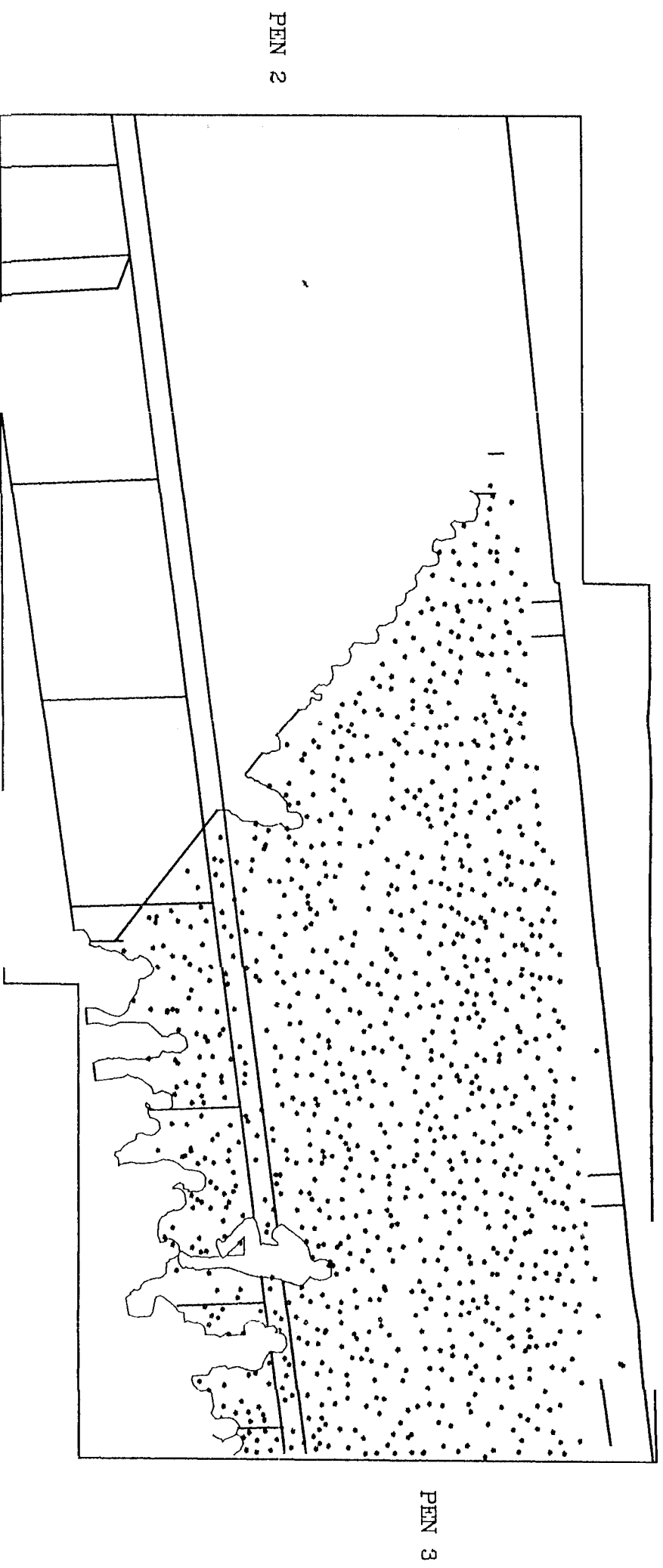


HEADCOUNT - 821

PHOTOGRAPHS TAKEN 14.52

FIG 3

DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A  
OCCUPANTS OF PEN 2 DELETED



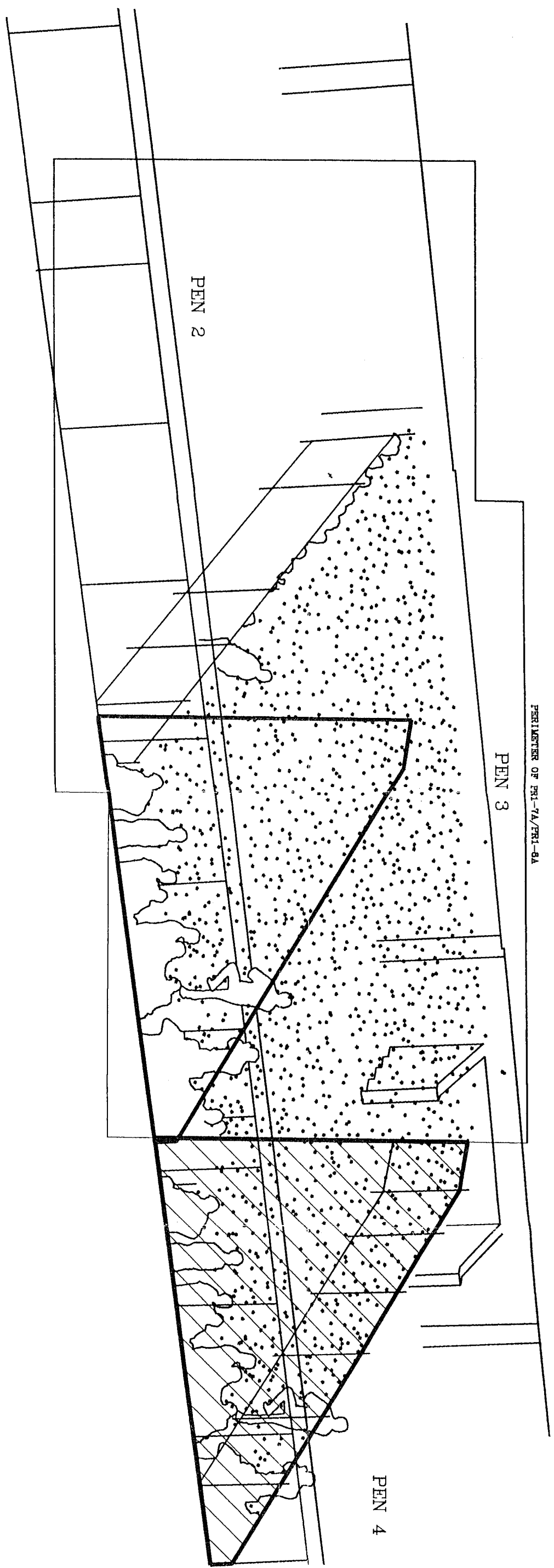
HEADCOUNT - 1074  
PHOTOGRAPHS TAKEN 15.03

FIG 4

DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A  
SUPERIMPOSED ON  
DIGITISED DRAWING OF PHOTOGRAPHS PR10A-2 TO PR10A-5, SCALED ETC TO MATCH

OCCUPANTS OF PEN 3 SHOWN  
(NB ESTIMATED CROWD - 334 OCCUPANTS - SHOWN HATCHED)

PERIMETER OF PR1-7A/PR1-8A



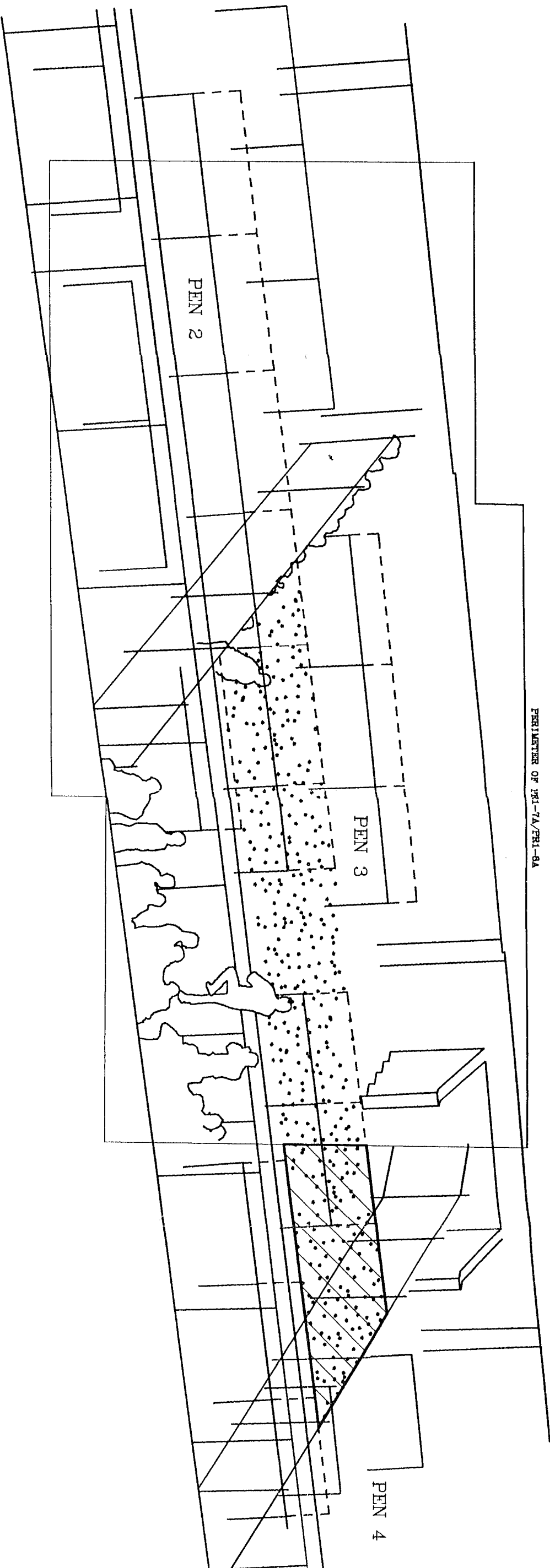
HEADCOUNT - 1408  
PHOTOGRAPHS TAKEN 15.03

FIG 5

BASED ON  
RUSD SET PEN3/PP1131

DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A  
SUPERIMPOSED ON  
DIGITISED DRAWING OF PHOTOGRAPHS PR10A-2 TO PR10A-5, SCALED ETC TO MATCH

PEN 3  
OCCUPANTS OF ROW 2 ONLY SHOWN  
(NB ESTIMATED CROWD - 118 OCCUPANTS - SHOWN HATCHED)

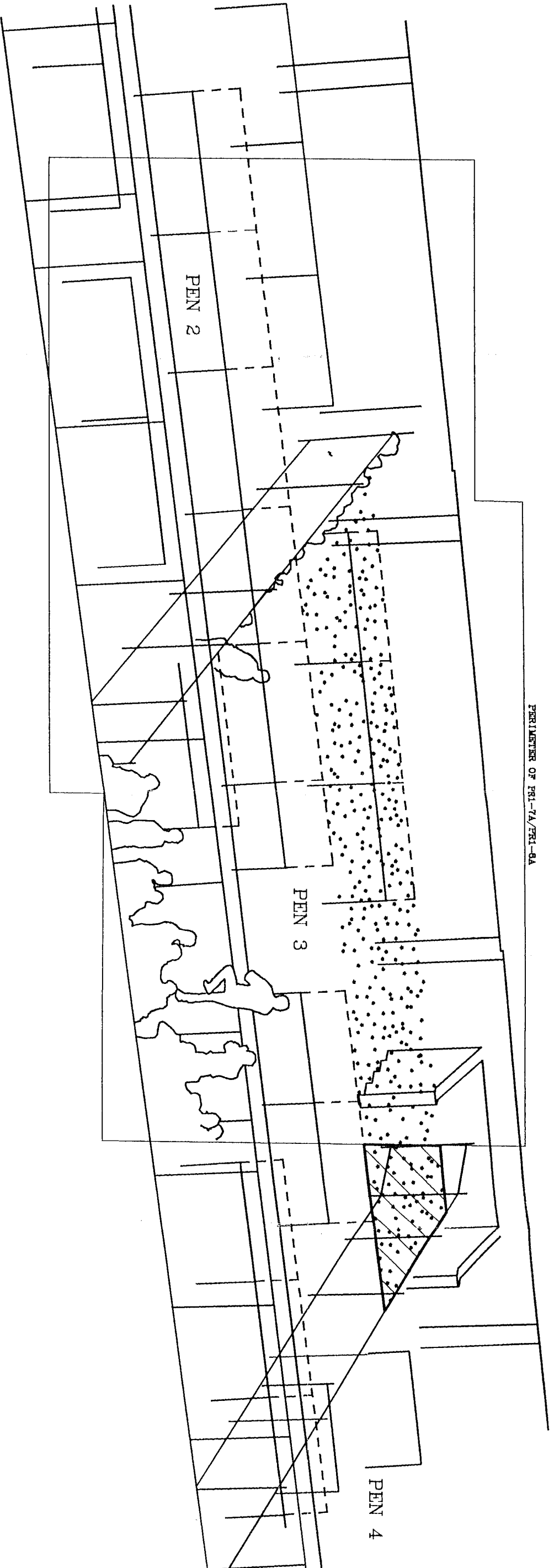


HEADCOUNT - 409  
PHOTOGRAPHS TAKEN 15.03

FIG 6

DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A  
SUPERIMPOSED ON  
DIGITISED DRAWING OF PHOTOGRAPHS PR10A-2 TO PR10A-5, SCALED ETC TO MATCH

PEN 3  
OCCUPANTS OF ROW 3 ONLY SHOWN  
(NB ESTIMATED CROWD - 60 OCCUPANTS - SHOWN HATCHED)



PERIMETER OF PR1-7A/PR1-8A

HEADCOUNT - 382

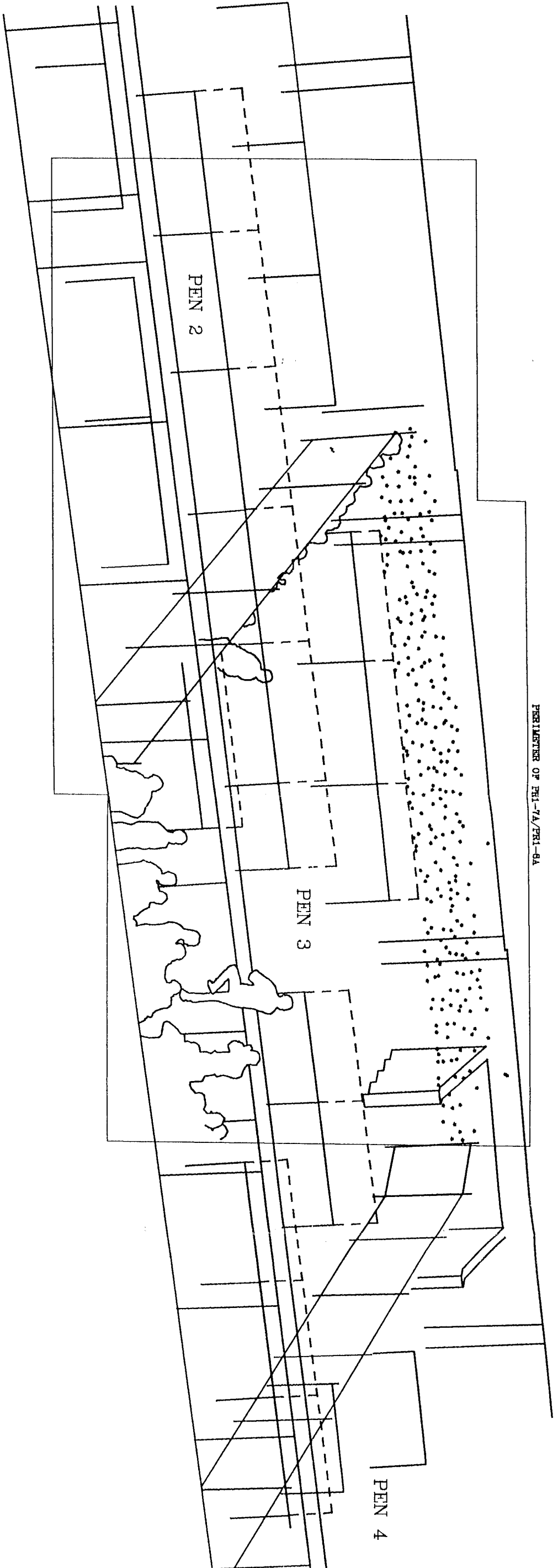
PHOTOGRAPHS TAKEN 15.03

FIG 7



DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A  
SUPERIMPOSED ON  
DIGITISED DRAWING OF PHOTOGRAPHS PR10A-2 TO PR10A-5, SCALED ETC TO MATCH

PEN 3  
OCCUPANTS OF ROW 4 ONLY SHOWN

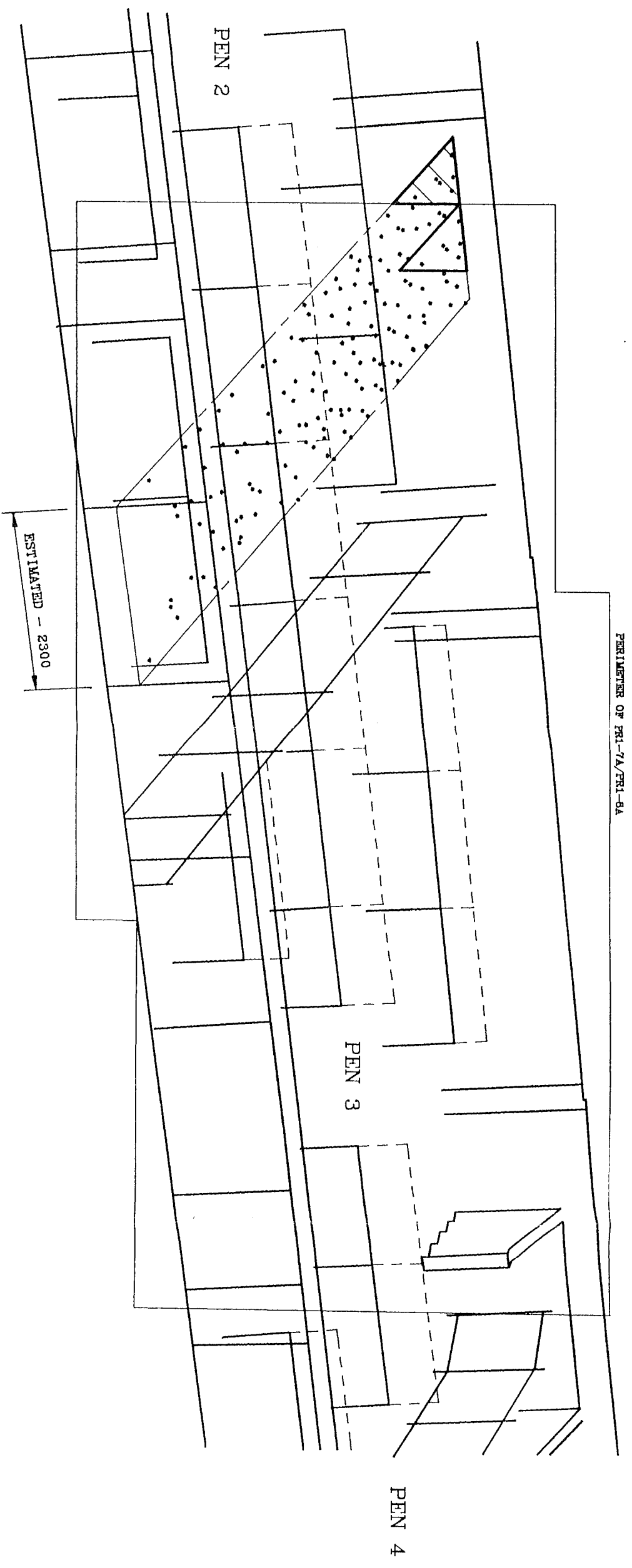


HEADCOUNT - 268  
PHOTOGRAPHS TAKEN 15.03

FIG 8

DIGITISED DRAWING OF PHOTOGRAPHS PR1-7A & PR1-8A  
SUPERIMPOSED ON  
DIGITISED DRAWING OF PHOTOGRAPHS PR10A-2 TO PR10A-5, SCALED ETC TO MATCH

OCCUPANTS OF FRONT TO BACK SLICE AS SHOWN



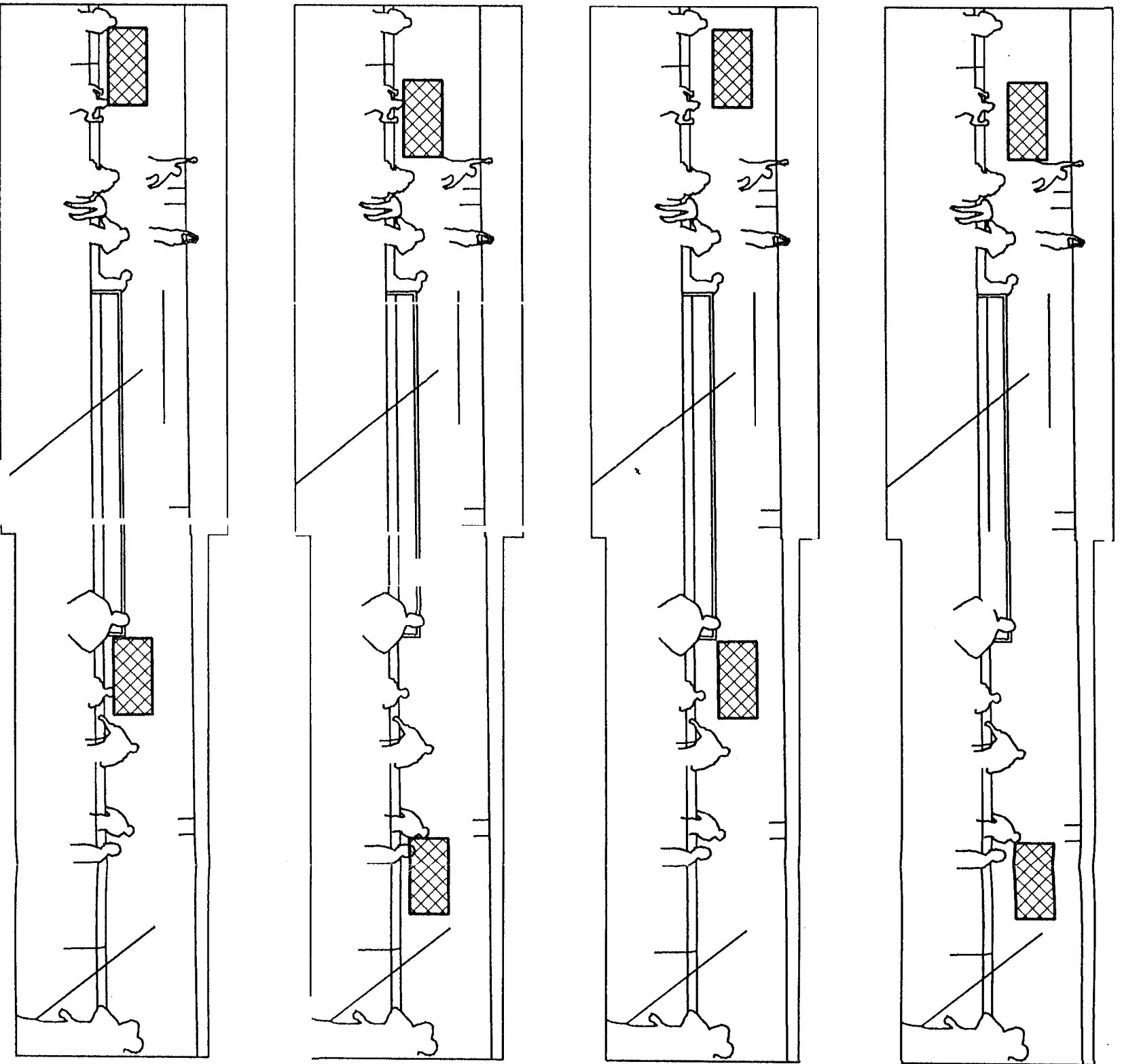
HEADCOUNT - 150

PHOTOGRAPHS TAKEN 15.03

FIG 9

BASED ON  
RUSD SET PR178F/PP1131

DIGITISED DRAWINGS OF PHOTOGRAPHS 148.3  
 COMPARING CROWD DENSITIES IN PENS 3 & 4



HATCHED AREA HEADCOUNT

PEN 3 - 44  
 PEN 4 - 56

PEN 3 - 56  
 PEN 4 - 49

PEN 3 - 45  
 PEN 4 - 51

PEN 3 - 50  
 PEN 4 - 41

AVERAGE HATCHED AREA COUNTS

PEN 3 - 48.75  
 PEN 4 - 49.25

FIG 10