



Dr C E Nicholson

HILLSBOROUGH INQUIRY - CROWD DENSITIES AND PRESSURES

1 Further to my note of the 1 May. I have been able to make some progress with my enquiries and discuss these below.

**A The capacity of the terraces**

2 In correspondence obtained from Dr Eastwood it appears from his report to the directors of Sheffield Wednesday Football Club Ltd and from the application he made on their behalf for a safety certificate dated 12/1/79 and 17/1/79, he proposed that the numbers of persons using the Leppings Lane terraces should be restricted to 7,200. This is 10% less than the maximum that could be allowed in the area using the Green Guide figure of 54 persons to 10 sq m. The 10% being deduced because there were no gangways within the terrace area.

3 The rough figures used to calculate the area of the terraces to obtain the crowd capacity are also on the file and from these it is possible to plot on drawing 1610/64E the area that was considered in making these proposals. This is the drawing I have been given as showing the current position of the terrace capacity. This drawing indicates that the total capacity of the same areas of terraces referred to in the January 1979 correspondence is still 7,200.

4 From drawing 1610/64E the areas of the pens and the numbers of persons who could use them at 54 persons per 10 sq m less 10%, are shown in the table below together with the capacities given on drawing 1610/64E.

				Numbers given on drwg 1610/64E
S.W. corner pen	532.6 sq m	x 5.4 x 0.9 =	2588	2600
Central pen	198.8 sq m(190.8)	"	966(927)	)total 2200 )
Central pen	201.6 sq m(192.4)	"	979(935)	
N.W. end pen	322 sq m	"	1564	1600
N.W. (lower) corner pen	206.7 sq m	"	1004	800
Total	1461.7		7101(7018)	7200

- 5 The difference in the area from that given in the correspondence and that worked out from the drawing in the above table is partly accounted for by the corridor now in place between the central pens and the NW pen. From drawing 1610/64E this has an area of 26.6 sq m.
- 6 It should also be noted that the calculated areas of the central pens have not been reduced to deduct the areas at the mouth of the tunnel hatched on site in yellow. Presumably this area is so marked to keep it clear of spectators. Therefore the figures in brackets in the table would be the areas if this hatched section of terrace was ignored.
- 7 From the table it can be seen that the capacities of the two central pens has been overestimated by nearly 12% on the basis of Dr Eastwood's original figures (or 18% if the hatched area is deducted). However the basis of these original figures, particularly the 10% arbitrary reduction, is questionable.
- 8 Advice given in the Green Guide and also apparently reinforced at a seminar given by the Home Office when the Guide was launched in 1972, is that those barriers which do not meet the Guide standard should be ignored when calculating the area available for viewing. Although the Green Guide only mentions spacing and strength in this respect, Mr Stickley says he included references to height in his seminar.
- 9 **On** terraces which slope at around  $15^{\circ}$ , as at the Leppings Lane end terraces, and where the barriers have been tested to the 6 KN/m proof load, then an area extending 3.8 m max behind the barrier should be used in the calculation.
- 10 Working from the Ralph Brade and Associates drawing 1340/02, the drawing of their survey of the central terraces, this shows many barriers are far below the Green Guides recommended height of 1.02 - 1.1 m. If those barriers which are lower than 0.92 m high are ignored i.e. allowing barriers up to 100 **mm** low by Green Guide standard, the usable terrace area is 119.51 sq m and 135.14 sq m which at the full 54 persons/10 sq m would only allow 645 and 729 persons respectively to use the terraces.
- 11 Therefore by generously applied criteria, using the Green Guide as a basis, the designated numbers were 60% more than those which could be regarded as

acceptable even when considerable latitude had been given. For instance if only those barriers which meet the Green Guide recommendations were used in this calculation, the allowable numbers of persons able to use the central terraces would drop to **389** and 540.

- 12 A search through the correspondence may throw more light on how the designated numbers were chosen and accepted, and on why other barriers were installed at later dates as shown in the revision notes on drawing 1610/64E.
- 13 It is probable that a member of the Safety Committee attended the Home Office Seminar in 1972 referred to in para **16** and should therefore have been quite clear how the Green Guide was to be applied even though the Guide itself is a little ambiguous. I hope to obtain the delegate list of those who attended the Seminar.
- 14 It is clear that some barriers have been removed from the central pens over the last 10 years when Dr Eastwood made his original proposals. If left in place some of these could have increased the area calculated in paras 9, 10 and 11, which could be designated for spectators. Further searches will have to be made to find out their detail and the history of their removal.
- 15 All which I have said above assumes that the barriers are perfectly adequate to carry their loads, and ignores the effect of connecting a downward sloping tunnel, of the length noted at Hillsborough, directly into the terraces.
- 16 From conversations we have had so far with Dr Eastwood I query whether the test procedures used, could categorically guarantee the reliability of the barriers. That is whether the tests would pick up all the weaknesses in the barrier.
- 17 It appears that the test procedure was only nominally as required by the Green Guide i.e. in loading the barriers three times. I do not believe at the moment this would be very significant, as the required procedure seems a little excessive. However as an indication of the state of affairs, it seems that Dr Eastwood and his staff thought they were implicitly following the Guide.

18 The procedure as I presently understand it, could have resulted in the end frame in bay 1, not being measured for permanent deflection. (See the notes of my telephone conversation with Dr Eastwood, 5/6/89 in reply to question 3).

**B The recommendations of the Green Guide in respect of the barriers and crowd densities**

19 I have had discussions with Brian Stickley of the Home Office Prison Service. He is the structural Engineer who worked out the structural provisions in the Green Guide and is probably the most informed person about what was intended to be in it and what research or other information was available as a basis for those provisions.

20 Mr Stickley clearly believed that both the provisions of the Green Guide were exceeded and had they been complied with, then the number of injuries could have been greatly reduced, if not avoided altogether. The basis of this comment was not just that the designated crowd densities were too high because of the position, number and height of the barriers, but also that the Guide's recommendations on stewarding were not followed. Clearly a huge influx of fans down the tunnel, whatever the level of occupancy of the terraces, was potentially hazardous.

21 However there are certain inconsistencies with his comments. Mr Stickley has agreed that many of the provisions of the Guide are vague, almost ambiguous. (This is further discussed in Appendix 'A' giving abstracts from the Guide with comments). He stated that this was deliberate because there are so many grounds with widely different characteristics that it would be impossible to give definitive clauses without either unnecessarily penalising some and being too lenient with others. However it was expected in the Guide that the engineer working for the club would use the background philosophies from the Guide and relate these to any particular ground. Hence when the Guide was launched in 1972 a seminar was organised by the Home Office for members of the safety committees, in which Mr Stickley explained how the engineering provisions of the Guide should be applied, in particular how to work out the safe number of persons who should use the terraces.

22 While this may seem reasonable, a problem could have been caused because the Green Guide does not clearly describe the difference between its general

philosophy and practical provisions (so much so that those dealing with the spacing & height of barriers are not stated as being the absolute minimum). It is therefore difficult to see how competent engineers like Dr Eastwood, can be criticised too much for not strictly following the Guide or because they were too liberal in interpreting its recommendations.

- 23 In addition, Mr Stickley is now giving support to the Institution of Structural Engineers working party which is writing guidance called the 'Appraisal of Sports Grounds', expressly to give less ambiguous guidance to engineers. This suggests some degree of recognition of the Green Guide's shortcomings.
- 24 The references in the Guide to restraining crowd surges suggests that its authors considered its recommendations would prevent these. Although the heights of barriers must have a big influence on this, heights are only mentioned in para 110. However the paragraph only proposes its the recommended height to enable the body to tolerate the crowd pressure. There are other opportunities to refer to height when discussing crowd safety but only position and strength are mentioned e.g. paras 118, 221, 226, 227 and the preliminary to Chapter 9.
- 25 From the video pictures it is quite clear that there was a considerable amount of sway or surge in the crowd. This seemed to be related to the crowd density, layout of the barriers and presumably barrier height.
- 26 It is also quite clear that at Hillsborough the barriers failed to break up the crowd pressure as recommended in para 21. However the use of barriers to control the exit from an area as recommended in the Guide could allow surges in the crowd as the two recommendations may not be compatible. This contradiction also appears in paras 113, and 114, leaving considerable discretion to the licensing authorities.
- 27 In a similar way the design of a layout to help a crowd to disperse when an event finishes may result in increasing crowd pressures where there is a sudden ingress of people. The fanning out philosophy for persons moving in one direction can easily form a steadily restricting funnel when they move in the opposite way. In general, ingress will normally be at a trickle so that

the funnelling effect is of little consequence, while egress will nearly always be in mass when the fanning out effect is highly desirable.

- 28 The guide is reasonably firm about the height of the barriers although the stress on the idea that it is a "voluntary code" and "should be interpreted" at the beginning of the Guide could weaken the importance of having barriers at the correct height. The Wheatley Report, from which the Guide was drawn, expresses the height recommendations much more strongly e.g. the height of crush barriers should preferably be 3'-6" above the ground". In all cases they should be between 3'-4" and 3'-8"'. Clause 23.5 'Report of the Inquiry into Crowd Safety at Sports Grounds' by the Rt Hon Lord Wheatley.
- 29 The recommendations concerning height appear to have been determined "In order to locate the top rail against that part of the body most able to tolerate pressure" (para 110). There seems some evidence that depending on the density of the crowd, a low barrier allows a body to bend over the barrier, passing the force it is subjected to, to those in front. This action could make low barriers largely ineffective.
- 30 The testing of barriers described in Annex "C" fails to make a recommendation about the maximum deflection. Strict interpretation could result in barriers that move 1 mm yet fail to recover 0.5 mm being failed, while those that move 100 mm and recover 75 mm being passed. Although the examples given are extreme they do illustrate that without skilled examination and interpretation of the results, the tests could encourage the acceptance of weakened barriers, while rejecting others that were satisfactory. Paragraph 6 of the Annex does point out that barriers should be examined if any doubt exists about their strength, but the lack of more positive advice could easily lead to a vice variety in the quality of barriers across the country.
- 31 Paragraph 6 of Annex "C" says that detailed investigations should be carried out where there was doubt about the safety of the barrier, such as might be indicated by the distortion of connections. Quite a few of the barriers now show distortion and I question when this occurred.
- 32 When referring to the packing density on terraces in para 221, little or no guidance is given on the criteria which should be used to govern the variation between 27 and 54 persons per 10 sq metres.

- 33 In the 1946 Hughes Report on the disaster at Bolton Wanderers Football ground a maximum packing density of 6.5 persons per metre was recommended. This was reduced to 5.4 in the Wheatley Report. Dr Eastwood has suggested that average densities of around 8.5 were achieved immediately post war, which is similar to that which must have occurred on the terraces at Hillsborough.
- 34 Examination of the videos appear to show an increasing variation in density from the back to the front, while those at the centre of the terrace do not appear to be unduly worried by their situation. Initial estimates from the video suggest the density varied from about 6 to 10 or 11 persons per sq metre, so that those in the centre were at around 8 persons per sq metre.
- 35 This raises the question of what are suitable densities? If 6.4 was acceptable in 1946 and 5.4 in 1972, should the Green Guide's criteria be revised again? It might be that people today are generally larger and more restless, requiring more space, apart from any trend towards the public expecting more comfortable conditions.

#### Further work

- 36 The maximum crowd densities for various situations should be more adequately researched. Some work might be possible from the photographs and videos of Hillsborough, counting the number of persons in the situations where they are obviously a) contented, b) overcrowded and c) in distress. This work could be reinforced by packing people into given areas and counting the number of teenagers, women and mature men that will accept various densities.
- 37 Work should be undertaken to check out suitable heights and construction of barriers, in particular measuring the most effective height that will stop or suitably reduce a crowd surge.
- 38 Finally, research should be undertaken into modelling the pressures and densities in the crowd at Hillsborough so that alternative layouts can be tried out and the most suitable layout of barriers and exits can be discovered. I originally considered that a hydraulic model might be suitable

but having seen the videos, which appear to show a variation in density across the terrace, I am now not so sure. I will try to obtain further advice on this.

**M JAMES**

**6 June 1989**

APPENDIX A

REVIEW OF THE CLAUSES RELEVANT TO CONTROLLING THE DENSITY OF SPECTATORS ON TERRACES FROM THE "GUIDE TO SAFETY AT SPORTS GROUNDS" (THE GREEN GUIDE)

<p>1 This booklet provides guidance to ground management, local authorities and technical specialists such as engineers on measures for improving spectator safety at existing sports grounds. It is a <u>voluntary code</u> and has no legal force.</p>	<p>The guide continually stresses its voluntary nature and that a considerable amount of interpretation is permissible or even desirable.</p>
<p>4 The problem of crowd safety at sports grounds is complex and cannot be solved simply by ensuring that each component of a ground, such as stairways, passages or sections of terracing, is satisfactory in itself. <u>The inter-relation of these and other components is essential</u>: none of them can be considered in isolation without consideration of its effects on the others, and they should all <u>be compatible and combine to form a balanced unit</u>.</p>	<p>Once again great stress is laid on the need for intelligent assessment of the guide's provisions.</p>
<p>6 <u>Deviations from individual guidelines are possible</u> without necessarily detracting from the overall safety of the ground. The variety of type, function and layout of sports grounds and the inter-relationship of the different parts of them means <u>that a flexible approach</u> should be maintained to take account of the particular circumstances at individual grounds. for these reasons the Guide does <u>not</u> attempt to set a <u>minimum standard</u> which would be acceptable for a well-attended stadium but excessive for a smaller, sparsely-attended ground; or which would be an appropriate standard for the latter but insufficient for the former.</p>	<p>As above.</p>
<p>8 It should be borne in mind that, when using the Guide to assess whether existing circumstances provide adequately for the safety of spectators, the criterion to be aimed for is that <u>of a reasonable degree</u> of safety. It would be <u>unreasonable</u>, even if it were practical, to seek the <u>absolute safety</u> of everyone attending a ground.</p>	<p>Such terms are meaningless, how many injuries are acceptable?</p>
<p><u>11</u> ..... the guide is an <u>aid</u> to, not a substitute form, <u>professional judgement</u> and common sense.</p>	
<p><u>13</u> It follows <del>that</del> in general in a ground where it is proposed to retain a high speccator capacity, the measures needed to be taken to accommodate safely such large crowds <u>are potentially more</u> extensive.</p>	

16 The second type is far more important and involves crowd pressures. When large crowds are present and densities are high, pressures build up within the crowd either through motion or swaying which make it difficult, or even impossible for individuals to control their ~~own~~ movements. Under these conditions crowd pressures can escalate to a dangerous level and if a person stumbles or falls the crowd cannot adapt to avoid him or to stop to help. Since this type of danger arises from crowd pressures its remedy lies in their removal or restraint within safe limits.

These dangers arise in particular on terraces and exit routes, and so careful attention must be paid to restraining surges and similar pressures on the terraces and to ensuring free movement throughout the exit systems. Such free movement is dependent upon the capacity of all the various sections of the exit systems and interactions between them.

21 ..... Barriers not only serve to break up crowd pressures but also assist in controlling movement off the terraces by regulating the rate of arrival at exits to suit their capacity, and encouraging the formation of queues so that spectators arrive at exits in an orderly fashion.

#### Prelim. to Ch. 8 - Terraces and Viewing Slopes

Arrangements should be made to encourage the even distribution of the crowd on the terraces to provide ease of access and egress: to control and facilitate movement, particularly if a local emergency should arise during the event; and to contain pressures before they reach dangerous proportions. The provisions set out here will assist in achieving these conditions (i.e. paras 89-109).

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 emergency. ...

99 Where sinking gangways, lateral or radial, is not thought to be practical, their boundaries should be highlighted with paint and spectators advised by signs not to stand there.

To some extent there is a conflict of interests in "restraining surges" but "ensuring free movement" through the exit systems. Comments about the height of barriers would have been particularly useful here.

Gaps in barriers which will allow filtered approach to the exits can allow crowd surges to develop.

It seems quite clear that the layout at the Leppings Lane terraces discouraged an even distribution of people. encourage is a rather weak requirement, this provision is essential. If the provisions will only assist then additional engineering input is required IN ADDITION TO THE GUIDES RECOMMENDATIONS.

"advised" by signs is rather a weak piece of advice.

102 Each of the major sections should be subdivided by such means as gangways and crush barriers, arranged so as to minimise the sway and surge of spectators.

To minimise sway etc., the barriers must be of a suitable height.

Prelim. to Ch. 9 - Crush barriers and handrails

Many of the hazards arising from crowd pressure on terraces can be eliminated by provision of well constructed, correctly positioned and properly mounted crush barriers (paras 110-119).

110 In order to locate the top rail against that part of the body most able to tolerate pressure, the height of crush barriers should be between 1.02 metres and 1.12 metres above the nosing of the step immediately behind the barrier, with a preferred height of 1.1 metres.

If this is so then there is no excuse for allowing barriers of other heights.

111 ..... Although a barrier with a top rail of 50 mm internal diameter tube has been favoured at many sports grounds, research has shown that there would be advantage in the use of a flat rail of 100 mm vertical depth.

Again if this is so then a programme of modification should be advocated.

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

If full length barriers are ideally the best they should be forcefully recommended.

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  $60^{\circ}$  to the barriers. There should be no more than 2 consecutive gaps in any line of gaps.

115 Where there are gaps in the line of crush barriers these should be at least 1.1 metres and not more than 1.4 metres in width.

117 ..... The peak viewing areas are particularly associated with football grounds and are typically behind the goal areas, ....

118 Existing crush barriers and handrails should be capable of resisting the forces indicated in the existing test load columns of Table 2 overleaf when applied in a test as described in Annex C. ....

- 206 Crowd movement on terraces should be strictly controlled in order to give the police the fullest opportunity for crowd control. Less problems occur when terraces are subdivided as far as possible into sections by use of both radial and lateral barriers or railings which should comply with the strength requirements set out in Ch. 9. ....
- 209 Access to the pitch must be made as difficult as possible in normal circumstances .....
- 215 ..... Gates or other access points (minimum width 1.1 metres) should nonetheless be provided for use in an emergency ....
- 217 ..... This section suggests a method of calculating the number of people that can be safely accommodated when taking into account interactions between these individual features and where there are deviations from the guidelines. The following paragraphs contain as of necessity generalised guideline in view of the wide variety of types, sizes, configurations of sports grounds, their use and condition.
- 221 Where crush barriers meet the strength and spacing guidelines of Ch. 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 sq metres depending upon the condition of the terrace or slope. ....
- 222(b) 27 persons per 10 sq metres when it materially deviates from the recommended guidelines, so as to constitute a possible hazard to individuals closely packed.
- 223 ..... When the positioning and length of gangways do not meet with the recommendations of Ch. 8, paras 96-100, an appropriate reduction should be made to the area available for standing.
- 224 Even distribution of spectators on the terrace may be difficult to overcome notwithstanding the measures in this guide, because spectators may prefer to gather in certain parts or parts of a terrace. Ground management should therefore take such factors into account when assessing safe capacity levels.

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When the strength of crush barriers conforms with the guidelines but the spacing of such barriers does not, the capacity is calculated from the provision of crush barriers in the area available for standing (as defined in para 221) as follows:

- (a) Where a terrace contains either "peak viewing areas" only or "other viewing areas", by multiplying the total length of the crush barriers by an appropriate distance between barriers (as given in Ch. 9, paras 116-117) or the existing distance, whichever is the less, and multiplying by the appropriate packing density.

227 Crush barriers which do not meet the guidelines on the strength set out in Ch. 9 should ~~in general~~, be discounted for calculation purposes, although where crush barriers are well constructed, consideration may be given to allowing a lower packing density figure for the purpose of the calculation.

No reference to the height of the barriers.