Incident Report

HEALTH AND SAFETY EXECUTIVE

RESEARCH AND LABORATORY SERVICES DIVISION

Harpur Hill, Buxton, SK17 9JN

Audibility of the Public Address System
at Hillsborough Football Ground

by

I R Price, BSc MIOA MSMM

IR/I/NV/89/17

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SMR/343/235/01
NV/05/002/89
1 INTRODUCTION

As part of the investigation undertaken by the Health and Safety Executive into the incident at Sheffield Wednesday FC's Hillsborough football ground on the 15th April 1989, I was asked by Dr C E Nicholson to investigate the audibility of the Public Address system (PA system) at Hillsborough. This report sets out the results of that investigation. Information on the design of the PA system and the equipment used in it was supplied by Mr R Annible (Contracts Director) of DP Sound Systems Ltd at a meeting on the 8th June 1989 and in subsequent correspondence and telephone conversations.

This report contains details of investigations performed both on site and in the laboratory. The work was carried out by me and by other members of the Noise and Vibration Section of the Research and Laboratory Services Division (RLSD) working on my instruction and under my general supervision.

2 DESCRIPTION OF SYSTEM

I was informed by Mr Annible that the PA system at Hillsborough was designed and installed by DP Sound Systems Ltd of Sheffield. The principle components, loudspeakers and amplifiers, were made by TOA Electric Co Ltd, a Japanese company which is a specialist manufacturer of public address equipment of some 55 years standing.

Mr Annible informed me that the PA system was installed primarily as a means of communicating with the spectators for crowd control or in an emergency. The system is controlled from the police control booth located between the West and South Stands. In the booth is a control unit (TOA VR 1012) on which the microphone input to the system is located together with a button which activates the system when depressed. The control unit also has a series of buttons which enable sectors of the ground to be selected so that messages can be relayed to specific areas (see Figure 1). The PA system has been divided into eight sectors; inside and outside of each of the four stands (Figure 2). The outside sectors also include the passages leading to the upper seated accommodation in each of the stands. Any combination of the eight sectors can be selected or, using the button labelled 'ALL CALL' every sector can be selected. The sector outside the West stand also includes loudspeakers directed at the approach to the turnstiles at Leppings lane. Thus it is possible for the police to talk to those inside the ground independently of those approaching it or vice versa. It is also, for example, possible to talk to those inside and/or approaching the West stand/terracing independently of those anywhere else in or around the ground.

A second input to the PA system has been provided for use by a Disc Jockey (DJ) to play music and jingles to the spectators and to make announcements. This input uses part of the same PA system, that directed at all spectators inside the ground, i.e. the four sectors inside the stadium. The DJ's input, whether music or speech, is automatically overridden when the police control panel is used. Thus a message from the police can be relayed to one portion of the crowd whilst the rest hear the DJ. The DJ's booth is underneath the police control room.

The location of the loudspeakers in the West stand, inside and outside sectors, are shown in Figure 3. These are controlled by buttons 1 and 7 respectively. The 12 loudspeakers inside the stand are mounted under the front edge of the roof and are alternately directed into the upper stand and down to the terracing. These loudspeakers are TOA TZ 201 units. Outside
the stand TOA TC 15ML horn loudspeakers have been used. Using TOA data for
the loudspeakers calculations were made of the sound pressure level (SPL) at
various locations inside and outside the ground (see Table 1).

3 NOISE LEVELS IN FOOTBALL GROUNDS

No useful information on typical noise levels in football grounds was found
in the technical literature. Consequently limited measurements were made at
the first available opportunity which happened to be the Liverpool vs
Arsenal match at Liverpool FC's Anfield ground on the 26th of May 1989.
Tape recordings were made of the sound level at the pitch side and on the
collar of a member of RISD's Noise and Vibration Section who was a spectator
in the 'Kop'. The sound pressure level was also logged as 1 minute averages
using noise dosimeters in both cases. The pitch side microphones were
located approximately 1m from the goal line, 8m from the nearest goal post
and 4m from the spectators at the 'Kop' end of the ground. The equipment
used is detailed in Annex 1.

Plots of the 1 minute average sound pressure level (SPL) are presented in
Figure 4. The match kicked off at about 20:15 and finished about 22:00.
During this period the 1 minute average level in the Kop was always greater
than 90 dB(A) and above 100 dB(A) for much of the time. The corresponding
figures at pitch side are about 5 dB lower, viz 85 dB(A) and 95 dB(A).

Unpublished data from a football match at Bristol, and from the Rugby League
Cup Final, at Wembley, were made available to HSE. These data were obtained
as 3 minute averages and are presented in Figure 5 together with the HSE
data re-calculated as 3 minute averages. Clearly the HSE Anfield data shows
much higher levels than at Bristol and Wembley.

The logarithmic units used to measure noise as a 1 or 3 minute average can
mask much lower levels which may have occurred during the period. Thus it
is possible for the sound level to be relatively low for a significant
proportion of the time whilst the average level is high. A statistical
distribution analysis of the sound levels illustrates this effect. Table 2
presents such data for the Anfield recordings for 3 minute periods leading
up to and just beyond the start of the match. From these data it can be
seen that although the 3 minute average levels in the Kop were between 97.9
and 105.7 dB(A), the level was below 91.9 dB(A) for 10% of the total period
(as shown by L<sub>90</sub>) and below 96.9 dB(A) for 50% of the time (L<sub>50</sub>).
Figure 6 illustrates the relationship between the various statistical
measurements of fluctuating sound for a 3 minute period of the Anfield
recordings in the Kop. In this period 108.2 dB(A) was exceeded for 1% of
the time; 105.2 dB(A) for 10% and 97.2 dB(A) for 50%; whereas the average
level (L<sub>eq</sub>) was 101.1 dB(A).

In Figure 6 various crowd activities which give rise to high levels of sound
are identified.

4 TESTS ON THE HILLSBOROUGH PA SYSTEM

Recordings were made of speech relayed by the Hillsborough PA system at
locations inside and outside the West stand and terracing. The locations
are shown in Figure 7 and described in detail in Annex 2. The recordings
were made on the 7th June 1989 in an empty ground. The speech was input
using either the microphone on the control panel in the police control room
or the one in the DJ's booth and consisted of a reading of the team list
from a match programme and other lists. Recordings were made for two
different voices, one male the other female. The recordings were analysed
for their sound pressure level and amplitude fluctuation. The A-weighted
SPL at each measurement location is given in Table 1 together with the
calculated performance of the PA system. As would be expected the measured
sound levels from the PA system vary depending on how loudly the passage was
spoken, or indeed individual words in the passage. However, it is clear
that the system is capable of producing the theoretical levels calculated
from manufacturer's data inside the ground (Sector 1). Outside the West
stand (Sector 7) the levels measured are somewhat less than those
calculated.

(* The 'A' frequency weighting is applied to acoustic signals to simulate
the frequency response of the ear.)

5 INTELLIGIBILITY OF THE HILLSBOROUGH PA SYSTEM

The 'Green Guide' (Ref 1) states, in Section 12:

"There should be a communications system capable of clearly relaying
essential messages to all parts of the ground in both normal circumstances
and in an emergency."

and in paragraph 194 iii:

"Public address equipment should be installed so that broadcast messages can
be heard under reasonable conditions (including emergencies) by all persons
of normal hearing in any part of the ground to which the public has access.
The system should be capable of being controlled from a central point and
should ideally be capable of addressing messages to each major section of
the ground. The power supply to the system should be such as to enable it
to operate in an emergency such as fire or failure of the mains supply."

I understand from DP Sound Ltd that the Hillsborough PA system was designed
to fulfil this requirement.

Whether a message can be clearly understood will depend on many factors but
it was not possible to identify from the literature any criteria by which
the intelligibility of speech from public address systems could be assessed
directly. There are standards for emergency evacuation signals and guidance
for selecting warning signals but these do not address spoken warnings from
PA systems. Standards for assessing the intelligibility of speech in rooms
cannot be applied directly to sports stadia PA systems. Therefore it was
not possible to assess the performance of the Hillsborough PA system against
defined performance criteria in terms of intelligibility of messages relayed
through it.

Typically tests of speech intelligibility require panels of subjects to
listen to standard word lists against appropriate background noises. Such
tests were impracticable in this investigation. Instead an ad hoc
assessment was made using recordings of announcements made at Hillsborough
and of crowd noise made at Anfield.

In this ad hoc test twelve subjects (HSE staff of age range from 21 to 43
years) were asked to judge if they could understand the recording from
Hillsborough when replayed together with the recorded crowd noise from
Anfield. It was not possible to reproduce the exact sound field present at
Hillsborough at the time of the accident. Therefore the recordings were
replayed in an anechoic chamber through a PA system which had been set to
produce a uniform diffuse sound field at the listening position (see Figure 8). The two recordings were superimposed at known relative levels and the listeners were asked if they could hear the PA announcements and if they could understand them. The test was repeated at four relative levels of the two signals. Table 3 lists the level of the announcement relative to the crowd noise at which the listener could understand the announcement. Nearly all the listeners could understand the announcement when its average level (Leq) was 10 dB below that of the crowd noise.

6 DISCUSSION

Mr Annable informed me that in designing the PA system the installers had made the following assumptions in respect of noise levels at football matches: ambient levels 77–80 dB(A); average levels 85 dB(A); short duration levels 90–95 dB(A). The data from Bristol and Wembley would support these assumptions but the Anfield data would not. Obviously the noise level of spectators will depend on many factors such as: number of spectators; design of stadium; significance of the match; emotional state of the crowd. Each of the crowd noise measurements presented in this report were taken at important matches but with very different crowd numbers and in different stadia. This accounts for the range of noise levels reported. It should be noted that the match at Anfield was the League Championship deciding match and Liverpool FC fans are noted for their vocal (choral) support for their team. The Anfield ground is very compact with roofing covering all spectator areas. All factors which would lead to a high crowd noise level.

In general a wide range of levels will occur depending on the factors mentioned above. During any one match or even any period of a match, levels will fluctuate and although the average may be high this will be influenced by short periods of very high levels, leaving significant periods at lower levels (as illustrated in Figure 6). Messages from a PA system can be understood from information received in these periods. The simple listening test described illustrates this since messages with average sound levels 10 dB (A) below the ambient level could be understood. Thus, whilst it is impracticable to design sound systems to overcome the highest levels, a criteria based on exceeding a particular level which it is assumed crowd noise will only exceed for short periods of time is perhaps more realistic (say L10). There is, of course, a difference in the ability to hear and understand a message and actually listening to it. Spectators deeply involved in watching the game may not listen to messages they can clearly hear. At Anfield, and at a recently televised International rugby match, spectator safety messages were preceded by a chime which identified them as such. This facility seems a sensible way to attract the spectators’ attention.

In the particular case of the situation at Hillsborough leading up to the incident I have no information of crowd noise levels on the West terracing. Nor do I have such information for the areas inside and outside the turnstiles at Leppings Lane. Careful examination of a video tape, supplied by West Midlands Police, for the period 14:45 to 15:07 has not enabled noise levels at the West terracing to be determined since the ‘effects’ microphone is also picking up crowd noise from other parts of the ground. Up to 14:50 it is not possible to identify any chants clearly related to Liverpool fans. Additionally, when spectators are at their most vocal they usually wave their hands, scarves and banners in the air en masse. There is no sign of this activity on this section of the video tape. Throughout this period music is being played on the PA system and can be heard clearly above the crowd noise. At about 14:50 the teams were announced over the PA system.
From then on there were the usual chanting of the fans as their team members' names were called and as the teams entered the pitch at 14:54 and the match started. Between the announcements of the teams and the kick-off, music was being played and can be heard except during the loudest chants from the crowd.

The pattern of crowd chanting seems much the same as that observed at Anfield though visual indications from the video tape suggest that a significant percentage of the Liverpool fans were not joining in the chanting. Thus given the open nature of the West terracing and the numbers of fans there it is reasonable to conclude that crowd noise levels at the West terracing would not have been as high as those found at Anfield. In my opinion it is probable therefore that any messages relayed through the PA system would have been intelligible to the spectators. It should be noted that although the Hillsborough system is capable of having a chime, one was not fitted at the time of the incident. I understand from Mr I A Ramsay, Managing Director of DP Sounds Ltd that a chime has now been fitted following the publication of the Interim Report by Lord Justice Taylor. (Ref 2)

7 CONCLUSIONS

From this limited investigation I have made the following conclusions:

7.1 The Hillsborough PA system had been professionally installed using good quality components and meets the performance criteria to which it was designed.

7.2 It is probable that spectators in the West terracing and its approaches could have heard any messages relayed through the PA system during the period encompassing the incident.

7.3 There is limited information on crowd noise in sports stadia and the necessary performance requirements for PA systems to ensure intelligible communication.

8 REFERENCES

   ISBN 0 11 340840 4

2. The Hillsborough Stadium Disaster 15 April 1989
   Inquiry by the Rt Hon Lord Justice Taylor - Interim Report August 1989
   ISBN 0 10 1076525
TABLE 1.

Leq (dBA) measured inside and outside the West stand at the Hillsborough ground during broadcasts from the PA system.

The measurement positions quoted are shown in Figure 7 and described in full in Appendix 2.

**BROADCAST**

<table>
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**SPL AT MEASUREMENT POSITION**

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**NOTES**

1. Calculated levels assume:
   - spherical propagation from a point source;
   - non-reverberant field.

2. Measured levels are taken from a time history chart recording of a sequence of speech. The levels quoted are for the loudest passages excluding pauses.

3. Distorted output.

4. Very unclear reproduction.

5. These measurements are dominated by traffic noise from the nearby Leppings Lane.
### TABLE 2

**Statistical analysis of part of recordings at Anfield - 26 May 1989**

**BEFORE START OF MATCH**

**(A) In Kop**

<table>
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<th>START OF RECORDING PERIOD</th>
<th>$I_1$</th>
<th>$I_{10}$</th>
<th>$I_{50}$</th>
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**(B) Pitch Side**

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**AFTER START OF MATCH**

**(C) Pitch Side**

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**Notes:**

- $I_1$ is the SPL exceeded for 1% of the time
- $I_{10}$ is the SPL exceeded for 10% of the time
- $I_{50}$ is the SPL exceeded for 50% of the time
- $I_{90}$ is the SPL exceeded for 90% of the time
- $I_{99}$ is the SPL exceeded for 99% of the time
- $L_{eq}$ is equivalent steady level over the period (average level).
TABLE 3

Results of listening tests - Relative level (Leq) of announcement from the PA system to the level of the background crowd noise necessary for intelligibility.

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Figure 1  Control unit for PA system
Figure 2  PA system sectors
Figure 3 Location of loudspeakers in sectors 1 and 7
Figure 4 Plots of 1 min. average SPL at Anfield 26th May 1989
Figure 5  Plots of 3 min. average SPL
Figure 6  Time-history of noise in the crowd at Anfield 26th May 1989 (5 min. period)
Figure 8 Set-up for listening tests
ANNEX 1

Equipment used for recordings of Hillsborough public address system made on 7 June 1989

Tape recorder number 1 (Blue) - Nagra IVSJ s/n 4994

Channel 1:
B&K 4134 1/2 inch microphone s/n 736121
B&K 2619 microphone preamplifier s/n 462127
QSJP adaptor s/n 1200

Channel 2:
B&K 4134 1/2 inch microphone s/n 928525
B&K 2619 microphone preamplifier s/n 360352
QSJP adaptor s/n 340

Tape recorder number 2 (Black) - Nagra IVSJ s/n 1735

Channel 1:
B&K 4134 1/2 inch microphone s/n 666962
B&K 2619 microphone preamplifier s/n 702300
QSJP adaptor s/n 1210

Channel 2:
B&K 4134 1/2 inch microphone s/n 558290
B&K 2619 microphone preamplifier s/n 702305
QSJP adaptor s/n 149

Calibrators
B&K 4230 s/ns 542887
419695

Additional equipment used at Anfield on 26 May 1989

Sony walkman professional cassette recorder
DuPont Mk III logging dosemeters s/ns 21639
21632
21627
15997
Positions of sound recordings made at Hillsborough on 7 June 1989

The microphone positions given in this table are shown on Figure 7 and described in full below.

Position A At the front of the pen, 0.75m behind gate number 3 to the pitch, adjacent to the step before the gate. **Height above immediate ground level 1.5m.**

Position B At the back of the pen, 0.38m behind the side gate to the South West pen, under the overhang of West terrace seating, 0.59m from the rear wall above the second step from the wall. **Height above the step 1.5m.**

Position C Inside the tunnel to the centre pens, 10.5m from the end of the extended walls at the terrace end of the tunnel. **Positioned equidistant from the side walls of the tunnel. Height above ground level 1.8m.**

Position D Adjacent to the end of the extended walls from the access tunnel 0.2m across from the second upright post of the dividing barrier between the two centre pens. **Height above immediate ground level 1.5m.**

Position E In line with, and 0.5m from the end of the blue handrail between the entrance to the West terrace standing turnstiles and the access road to the South stand. **Height above ground level 1.5m.**

Position F In line with the grey sheeted fence separating the Leppings Lane entrances to the West and North stand seats from the entrances to South Stand and the West stand standing area. 10.2m from the end of the fence outside the gates by Leppings Lane. **Height above ground level 1.5m.**

Position G At the entrance to the tunnel to the centre pens equidistant from the side walls. **Height above ground level 1.5m.**

Position H In the area inside the turnstiles A-G, 4.5m from gate C and 2.9m from the wall of the turnstiles. **Height above ground 1.5m.**

Position I In the West stand seats; Row 11 next to the blue rail at seat 99. **Height 1.3m.**

Position J In the West stand seats; Row 28 next to the blue rail at seat 99. **Height 1.3m.**