

HEALTH AND SAFETY EXECUTIVE

RESEARCH AND LABORATORY SERVICES DIVISION

Broad Lane, Sheffield S3 7HQ

An investigation of the turnstiles at the
Leppings Lane entrance to the stadium

by

G A C Games BA

and

B Waterhouse BSc(Eng) CEng MIMechE FIMEMME

IR/L/ME/89/33

Issue authorised by: Dr A Jones

Date: 26 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 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 THE SCOPE OF THE INVESTIGATION
- 3 INVESTIGATION OF THE EFFECT OF A HORIZONTAL FORCE ON THE 'GATES' OF TURNSTILES SERVING THE WEST TERRACE
 - 3.1 Turnstiles in the group A to G
 - 3.2 Method of testing
- 4 INVESTIGATION OF THE ACCURACY OF THE SYSTEM FOR COUNTING AND RECORDING THE NUMBER OF ADMISSIONS THROUGH THE TURNSTILES
 - 4.1 The counting and recording system
 - 4.1.1 The counting device on the turnstiles
 - 4.1.2 The recording and display system
 - 4.2 Assessment of the accuracy of the counting and recording of admissions through the turnstiles in Leppings Lane
 - 4.2.1 Method of assessment
- 5 THE AVERAGE ADMISSION REQUIREMENTS OF THE TURNSTILES
- 6 DISCUSSION OF THE RESULTS OF THE INVESTIGATION
 - 6.1 The effect of a horizontal force on the 'gate' of a turnstile
 - 6.2 The accuracy of the system for counting and recording admissions through the turnstiles in Leppings Lane
 - 6.3 Average admission requirements of the turnstiles
- 7 SUMMARY AND CONCLUSIONS
 - 7.1 The effect of a horizontal force on the 'gates' of turnstiles serving the West Terrace
 - 7.2 The accuracy of the system for counting and recording admissions through the turnstiles in Leppings Lane
 - 7.3 Average admission requirements of the turnstiles

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 G A C Games, a Senior Scientific Officer, and Mr D Waterhouse, a Principal Scientific Officer, of HSE's Research and Laboratory Services Division (RLSD) visited Hillsborough stadium on 24 April, 25 April and 28 April 1989. They investigated aspects of the turnstiles, particularly those giving access to the terraces at the Leppings Lane end of the ground.

2 THE SCOPE OF THE INVESTIGATION

We examined a drawing labelled "Eastwood & Partners - Drawing No 8945/1AW that Dr Nicholson had received from Eastwood & Partners on 24 April 1989. This drawing had the title "Sheffield Wednesday F.C. PLC Hillsborough, Ground Layout 1987" and was dated 16/4/87. The drawing showed the number of persons (capacity) allocated to each designated zone of the stadium and showed the location and designation of turnstiles around the perimeter of the stadium. In this report the term 'West terraces' is used as the collective name for the terraced zones at the West, or Leppings Lane end, of the stadium.

The drawing showed two groups of turnstiles at the Leppings Lane end of the stadium. It appeared that group A to G could be used for admissions to the West terraces and the West Stand, and that some of group 1 to 16 could be used for admissions to the North Stand and some for admissions to the west terraces and the West Stand.

Our investigation was divided into three parts:

- i) tests to assess the difficulty experienced by an operator in releasing the rotary 'gate' of a turnstile when a horizontal force was applied to to one of its 'wings' (or 'paddles');
- ii) tests to assess the accuracy of the computerized system for counting and recording the number of persons admitted through the turnstiles in Leppings Lane;
- iii) calculation of the average number of persons to be admitted through each of the turnstiles if all zones of the stadium were filled to their designated maximum capacity, i.e. calculation of the average admission requirement of the turnstiles.

We were assisted by other staff of RLSD working under our supervision and to our instructions. Our tests to assess the effect of a horizontal force on the 'gate' of a turnstile were observed by officers of the West Midlands Police. Our investigation of the accuracy of the computerized system for counting and recording admissions through the turnstiles was supervised by Detective Chief Inspector Tope of the West Midlands Police.

INVESTIGATION OF THE EFFECT OF A HORIZONTAL FORCE ON THE 'GATES'
OF TURNSTILES SERVING THE WEST TERRACES

3.1 TURNSTILES IN THE GROUP A TO G

We examined all the turnstiles in the group A to G. Turnstiles C to G appeared to be of the same type, but turnstiles A and B were of a different pattern and were slightly different from each other. However, the principle of operation of all the turnstiles in group A to G appeared to be the same,

Fig 1 shows a view of a typical turnstile in group A to G. Each turnstile had four equally spaced 'wings' on its 'gate', which was attached to a spindle. It was apparent that a quarter-revolution of the spindle was intended to admit one person when the pedal of a pivoted locking lever, shown in Fig 2, was depressed by an operator. A counter-weight on this lever normally caused its inner end to engage with one of four teeth on the lower ratchet of a dual cam assembly attached to the base of the spindle, as shown in Fig 3. Depression of the pedal raised the inner end of the lever, allowing the spindle to rotate until the upper cam drove the inner end of the locking lever back down into engagement with the next tooth of the lower ratchet. The cam/ratchet mechanism locked the spindle after each quarter-revolution of the 'gate', the operator having to depress the pedal of the locking lever each time that he wished to admit a person. The ratchet on the upper part of the dual cam assembly prevented the 'gate' from being rotated in the reverse direction.

Our examination of the turnstiles caused us to suspect that a person pushing, or being pushed, against a 'wing' of a turnstile might cause the operator to have difficulty in depressing the pedal to release the 'gate'. It was our opinion that difficulties in releasing the 'gate' might reduce the flow through a turnstile to below the maximum notional rate of 750 persons/hour that was suggested in the Home Office/Scottish Office publication "Guide to Safety at Sports Grounds" (H M Stationery Office: 1986).

On 24 April 1989 we conducted tests on the turnstiles designated B and C to investigate the relationship between the horizontal force applied to a 'wing' of a turnstile and the force required on the pedal of the locking lever to release its 'gate'.

3.2 METHOD OF TESTING

Fig 4 shows how a horizontal force was applied to the mid-span of a 'wing' of a turnstile by means of a baulk of timber, a nylon sling, a tensile loadcell and a 'pull-lift' ratchet-hoist apparatus. The loadcell, connected between the sling and the 'pull-lift', measured the force applied to the 'wing' of the turnstile on a digital display unit. We calibrated this display unit before making the tests by suspending standard test weights from the loadcell.

We used the 'pull-lift' to apply a force to a 'wing' of the turnstile and then gently placed standard test weights on the pedal of the pivoted locking lever, as shown in Fig 5, until the 'gate' was released. This procedure was repeated with increasing forces applied to the 'wing'. The results obtained from the tests are shown in the graphs of Fig 6.

4 INVESTIGATION OF THE ACCURACY OF THE SYSTEM FOR COUNTING AND RECORDING THE NUMBER OF ADMISSIONS THROUGH THE TURNSTILES

On 25 April 1989 we visited Hillsborough stadium, accompanied by Detective Chief Inspector Tope of the West Midlands Police. We discussed the system used for counting and recording the number of persons passing through the turnstiles with Mr R J Houldsworth of Abbey Systems Ltd, whose company maintained and operated the computerized system for Sheffield Wednesday Football Club. On 28 April 1989 we conducted limited tests to assess the accuracy of the recording system on the turnstiles in Leppings Lane.

4.1 THE COUNTING AND RECORDING SYSTEM

The counting and recording system was described to us by Mr Houldsworth

4.1.1 The counting device on the turnstile

An electrical switch was attached to each of the turnstiles serving the stadium, and signal cables connected each switch to a signal conditioning unit housed in a control room beneath the South Stand. Each quarter-revolution of a turnstile was intended to cause its switch to close and re-open, transmitting an electrical pulse to the signal conditioning unit.

Mr Houldsworth said that he was in the process of modifying an earlier design that had used a roller-plunger micro-switch on each turnstile to provide the pulse signals. The intention of this system had been for the plunger of the micro-switch to be depressed as it was traversed sequentially by each of the four horizontal lugs of a cruciform cast metal boss that connected the upper tubular arms of the four 'wings' to the spindle of a turnstile. However, the micro-switch was prone to mis-counts arising from the cast surface of the lugs and the vertical 'float' of the spindle in its bearings, and the position of the micro-switches required frequent adjustment.

The reliability of the pulse generation had been improved on more modern turnstiles serving other zones of the stadium by enclosing the micro-switches within the upper mounting of the spindle, but this modification had not been possible with the older turnstiles in Leppings Lane.

The roller-plunger micro-switches on the turnstiles in Leppings Lane were being replaced by more robust switches that were operated by 'rat-tail' spring probes. The compliant probe on this type of switch was deflected horizontally by the vertical tube of each 'wing' as the 'gate' rotated, and the correct generation of pulses did not depend on a relatively precise positioning of the switch. However, the new switches had not yet been fitted on all the turnstiles in group A to G; the new switches that had been installed on this group were attached to temporary mountings, permanent installation awaiting the end of the season.

4.1.2 The recording and displaysystem

The pulse counts obtained from the switch on a turnstile were received by a storage register which was dedicated to that turnstile and formed part of the signal conditioning unit. The storage registers were scanned continuously and the counts transmitted to the central processor of a micro-computer. The programming of the micro-computer enabled its visual display unit (VDU) to

display a list identifying each turnstile and showing the number of admissions through it, i.e. the number of pulses transmitted from the turnstile. The count of the number of admissions through each turnstile was incremented continuously and the admissions through the groups of turnstiles allocated to the zones of the stadium were displayed as accumulating totals.

The system was therefore designed to count the total number of admissions through each turnstile and to provide a record of the accumulating total admissions to each zone of the stadium, i.e. Spion Kop, North Stand, West Stand, West terraces, etc. Financial information corresponding to the admission price at each turnstile was also displayed.

The rated maximum capacity of each zone of the stadium was displayed on the VDU. A warning was provided, by means of flashing inverse contrast on the display, when the capacity of each zone was within 1,000 persons of its maximum designated capacity.

The micro-computer system did not have 'backing' storage in the form of disc or magnetic tape. Long term storage was confined to obtaining a copy of the display on the VDU from a printer, although the display on the screen was retained in the memory of the computer until a command was typed from the VDU to clear this part of the memory. There were no facilities at present to undertake any further processing of the data held in the central storage of the computer.

Mr Houldsworth said that on 15 April, when he realised that a serious incident had occurred on the West terraces, he had printed three copies of the display on the VDU. Apart from the relatively few turns of the 'gates' made by HSE's staff whilst examining turnstiles A to G, the data in the computer memory and displayed on the VDU was the data that he had copied on 15 April.

4.2 ASSESSMENT OF THE ACCURACY OF THE COUNTING AND RECORDING OF ADMISSIONS THROUGH THE TURNSTILES IN LEPPINGS LANE

We assessed the accuracy of the system for counting and recording admissions through the turnstiles in Leppings Lane. We concentrated the assessment on turnstiles designated A to G because they were labelled both "Standing Only" and "Leppings Lane Standing".

However, we made some assessment of the accuracy of the counting system on the turnstiles in group 9 to 16 because, although they were labelled "West Stand", they might have provided access to the West terraces.

4.2.1 Method of assessment

Detective Chief Inspector Tope monitored turnstiles A to G whilst we observed Mr Houldsworth take a copy from the printer of the accumulated admissions displayed on the VDU. The control room was then locked and we accompanied Mr Houldsworth whilst he simulated 50 admissions through each turnstile in group A to G by rotating each 'gate' through 50 quarter-turns, at a speed corresponding to approximately 2.25 sec/admission (1600 admissions/hour). Detective Chief Inspector Tope then monitored turnstiles A to G again whilst we returned to the control room with Mr Houldsworth and observed him take another copy from the printer of the display on the VDU.

A similar procedure was used to check the accuracy of the counting and recording system of turnstiles 9 to 16, but each 'gate' in this group was rotated through only 10 quarter-turns.

We then returned to the turnstiles in group A to G and repeated the first test, rotating each 'gate' through 50 quarter-turns

Table 1 shows the results of our investigation of the accuracy of the counting and recording system on turnstiles A to G and 9 to 16.

5 THE AVERAGE ADMISSION REQUIREMENTS OF THE TURNSTILES

The number of persons (capacity) allocated to each zone of the stadium and the location and designation of the turnstiles were shown on Eastwood & Partners Drawing No 8945/1A, dated 16/4/87. The zones and their capacities are shown in Columns 1 and 2 of Table 2.

On 28 April 1989 we walked around the outside of the perimeter of the stadium and observed any labels on the entrances to the turnstiles that indicated the zones they served.

A printed record of the admissions to the stadium, made by Mr Houldsworth on the afternoon of 15 April 1989, was delivered to Dr Nicholson on 24 May 1989 by Detective Constable Phillips of the West Midlands Police. We examined a copy of this record, in conjunction with Eastwood & Partners Drawing No 8945/1A and our observations of the labels on the turnstiles, to assist us in deducing how turnstiles were allocated to zones of the stadium on 15 April 1989.

We deduced that the turnstiles were allocated to zones as shown in Column 3 of Table 2, the number of turnstiles allocated being shown in Column 4. The capacity of each zone was divided by the number of turnstiles allocated to it, giving their average admission requirements (persons/turnstile) as shown in Column 5.

6 DISCUSSION OF THE RESULTS OF THE INVESTIGATION

6.1 THE EFFECT OF A HORIZONTAL FORCE ON THE 'GATE' OF A TURNSTILE

The relationship between the force applied to the 'wing' of a turnstile and the force required to depress its release pedal showed considerable 'scatter'. Some variation between individual tests might be attributable to differences in the position at which the horizontal forces were applied to a 'wing'. Furthermore, we could not ensure that test weights were always placed on the pedal at exactly the same distance from the pivot of the locking lever, and we would have preferred to have applied smaller increments of weight to the pedal. However, a frictional force had to be overcome when depressing the pedal to release the 'gate', and it is our opinion that the 'scatter' was principally attributable to the inherent variability of the coefficient of friction between unlubricated metallic surfaces.

Fig 6 suggests that, typically, a pedal force = 0.56 x 'wing' force would be required to release turnstile B, and that a pedal force = 1.56 x 'wing' force would be required to release turnstile C, i.e. turnstile C required a force on

its pedal that typically was 2.8 times greater than that for turnstile B. We had observed that turnstiles A and B appeared to differ in detail from turnstiles C to G.

An operator weighing 750 N (169 lbf or approximately 12 stones) might have difficulty in releasing the 'gate' of turnstile B if a force exceeding 1340 N (301 lbf) was applied to a 'wing', because he might have to exert a force of more than his weight on the pedal to release the 'gate'. The same operator would probably have difficulty in releasing the 'gate' of turnstile C if a force of 480 N (108 lbf) was applied to a 'wing'. It is our opinion that turnstiles A and B would be likely to behave in a similar manner and that turnstile C was representative of those in the group C to G.

Variations about the predicted average force required on the pedal ranged between approximately plus 70% and minus 44% for turnstile B, and between approximately plus 55% and minus 36% for turnstile C. The stated relationships provide only approximate indications of the forces that might be needed to release turnstiles in the group A to G.

6.2 THE ACCURACY OF THE SYSTEM FOR COUNTING AND RECORDING ADMISSIONS THROUGH THE TURNSTILES IN LEPPINGS L A N E

Table 1 shows that the first set of 50 quarter-turns of turnstiles A to G caused turnstile E to record six more 'admissions' than we had counted, and turnstile G to record one less 'admission' than we had counted.

The second set of 50 quarter-turns of turnstiles A to G caused turnstile E to record the correct number of 'admissions' and turnstile G to record three fewer 'admissions' than we had counted. Turnstile C recorded three more 'admissions' than we had counted, but we were interrupted during the counting and it is our opinion that the discrepancy was probably attributable to this interruption.

We inspected turnstile E and concluded that the discrepancy obtained during the first 50 quarter-turns arose from vertical upward 'float' of the spindle in its bearings and the position of the roller-plunger micro-switch. The combined effect was that the micro-switch occasionally appeared to be actuated spuriously by protrusions on the cast surfaces of the lugs of the upper cruciform boss that connected the 'gate' to the spindle. The error only appeared during the first set of 50 quarter-turns and we concluded that it was likely to have occurred during the first few 'admissions' after a period of inaction. It is our opinion that the error would not persist throughout a period of continuous operation.

Turnstile G recorded fewer 'admissions' than we had counted during both sets of 50 quarter-turns. We observed that the lugs of the upper cruciform boss on turnstile G only just made contact with the roller on the plunger of its micro-switch. We concluded that this uncertain contact caused turnstile G to record less than the correct number of 'admissions'. It is our opinion that this under-recording was likely to persist throughout a period of continuous operation and that the number of admissions recorded by turnstile G was likely to be less than the correct value.

Turnstile 14 recorded one more 'admission' than we had counted whilst making the 10 quarter-turns on turnstiles 9 to 16. However, we suspected that this

discrepancy arose because the 'gate' of turnstile 14 was in a mid-travel position when the test commenced. Our tests therefore suggested that turnstiles 9 to 16 would provide an accurate record of the number of persons admitted through them.

We concluded that the computerized system would be likely to record the total number of admissions through group A to F of the turnstiles with an accuracy that was within 1%. In a test turnstile G recorded 6% less than the correct number of admissions, but we concluded that the uncertainty in the operation of its micro-switch might cause the under-recording to be more severe than this.

We concluded that the turnstiles in group 9 to 16 would record the correct number of admissions.

6.3 AVERAGE ADMISSION REQUIREMENTS OF THE TURNSTILES

Table 2 shows that the stadium's maximum capacity of 54,324 persons was served by 83 turnstiles on 15 April 1989, and that 45% (24,447 persons) of the stadium's capacity were to be admitted from Leppings Lane, where 28% (23) of the turnstiles in use were sited.

Table 2 has been arranged in descending order of the average number of admissions required from each group of turnstiles serving the different zones of the stadium. The highest admission requirement was 1,443 persons/turnstile for the West terraces, followed by 988 persons/turnstile for the North Stand Seating and by 744 persons/turnstile for the West Stand Seating. The admission requirement of the turnstiles for the West terraces was therefore almost 3.5 times greater than that for the South Stand Uncovered Seating (the lowest admission requirement) and approximately 2.9 times greater than that for Spion Kop, the other terrace zone.

Six groups of turnstiles served the stadium and the three groups with the highest admission requirements were sited in Leppings Lane. The overall average admission requirement of the 23 turnstiles in Leppings Lane was 1063 persons/turnstile.

The other overall average admission requirements were 500 persons/turnstile for the turnstiles in Penistone Road and 493 persons/turnstile for those in the Concourse behind the South Stand. The overall average admission requirement of the turnstiles in Leppings Lane was therefore approximately twice that of the turnstiles sited elsewhere around the perimeter of the stadium.

We have therefore concluded that, if a maximum capacity crowd was to be admitted, the longest delays would be likely to be experienced by persons required to enter the stadium through the turnstiles in Leppings Lane; particularly long delays would be likely to be experienced by those with tickets for the West terraces. We would therefore expect larger crowds to form outside the turnstiles in Leppings Lane than at other places of entry to the stadium.

7 SUMMARY AND CONCLUSIONS

7.1 THE EFFECT OF A HORIZONTAL FORCE ON THE 'GATES' OF TURNSTILES SERVING THE WEST TERRACES

7.1.1 Our tests suggested that, typically, the force needed on the pedal of a turnstile to release its 'gate' was 0.56 x the force on a 'wing' for turnstiles A and B, and 1.56 x the force on a 'wing' for turnstiles C to G. Variations of up to 70% were obtained in the force required to depress the pedal and these relationships should serve only as an indication of the forces that might be needed to release the turnstiles serving the West terraces.

7.1.2 A turnstile operator weighing 750 N (169 lbf or approximately 12 stones) or less might have difficulty in releasing the 'gate' of turnstiles A or B if the horizontal force applied to a 'wing' was 1340 N (301 lbf) or more, because he might have to exert a force of more than his weight on the pedal to release the 'gate'. The same operator might have difficulty in releasing the 'gate' of a turnstile in the group C to G if a horizontal force of 480 N (108 lbf) or more was applied to a 'wing'.

7.1.3 It is our opinion that the ease with which an operator could depress the pedal would affect the time taken for a person to be admitted. Therefore a thrust exceeding 480 N (108 lbf) that was imposed by a crowd on a person at the 'gate' of a turnstile would be likely decrease the flow of persons through the group of turnstiles A to G.

7.2 THE ACCURACY OF THE SYSTEM FOR COUNTING AND RECORDING ADMISSIONS THROUGH THE TURNSTILES IN LEPPINGS LANE

7.2.1 Our tests suggested that turnstiles A, B, C, D, and F would record the correct number of admissions. It is our opinion that the error obtained during the first test on turnstile E would be unlikely to persist during a period of continuous operation. In our opinion turnstiles A to F, as a group, would record the number of admissions within an accuracy of approximately 1%.

7.2.2 Our tests indicated that a persistent error was likely to occur in the counting system of turnstile G. During a period of continuous operation this turnstile could repeatedly fail to count some admissions, and the recorded admissions could be significantly less than the correct number. We concluded that the error in counting at turnstile G was probably attributable to uncertainty of contact between the roller of the micro-switch and the four lugs on the upper cruciform boss of the 'gate'.

7.2.3 Our tests suggested that turnstiles in the group 9 to 16 would record the correct number of admissions.

7.3 AVERAGE ADMISSION REQUIREMENTS OF THE TURNSTILES

7.3.1 We have concluded that on 15 April 1989 the spectators were intended to enter the stadium through 83 turnstiles, of which 23 (28%) were sited in Leppings Lane. If the stadium was to be filled to its maximum capacity of 54,324 persons then 45% (24,447 persons) of this capacity would be admitted from Leppings Lane, through 28% of the turnstiles serving the stadium.

7.3.2 The turnstiles serving the West terraces had the highest average admission requirement (1,443 persons/turnstile) of any group of turnstiles serving the stadium. It was almost 3.5 times the lowest average admission requirement of 413 persons/turnstile for the South Stand Uncovered Seating, and was approximately 2.9 times the average admission requirement of 500 persons/turnstile for Spion Kop, the other terrace zone.

7.3.3 Six groups of turnstiles served the stadium. The three groups of turnstiles with the highest average admission requirements were sited in Leppings Lane; i.e. West terraces (1,443 persons/turnstile), North Stand (988 persons/turnstile) and West Stand (744 persons/turnstile).

7.3.4 The average admission requirement of the 23 turnstiles in Leppings Lane was approximately twice that of the 42 turnstiles in Penistone Road and that of the 18 turnstiles in the Concourse behind the South Stand. It is our opinion that larger crowds would form in Leppings Lane than in the other entrance areas to the stadium when it was to be filled to its maximum capacity.

7.3.5 It is our opinion that, when the stadium was to be filled to its maximum capacity, the longest delays in admission would be experienced by persons required to enter through the turnstiles in Leppings Lane, and that those with tickets for the West terraces would experience the most severe delays.

Table 1 Results obtained from the counting and recording system
on the turnstiles at the Leppings Lane end of the stadium

'Gates' rotated at approximately 2.25 sec/quarter-turn (1600 admissions/hour)

Turnstile designation	Computer record		Quarter-turns		Comments
	Initial	Final	Counted	Recorded	
A (rat-tail)	1062	1112	50	50	
B (rat-tail)	1017	1067	50	50	
C (plunger)	1301	1351	50	50	
D (plunger)	1272	1322	50	50	
E (plunger)	976	1032	50	56	spindle 'float'; switch position
F (rat-tail)	1066	1116	50	50	
G (plunger)	612	661	50	49	
Total A to G	7306	7661	350	355	
9	634	644	10	10	
10	582	592	10	10	
11	754	764	10	10	
12	609	619	10	10	
13	784	794	10	10	
14	755	766	10	11	starting position of 'gate'
15	836	846	10	10	
16	665	675	10	10	
Total 9 to 16	5619	5700	80	81	
A (rat-tail)	1112	1162	50	50	
B (rat-tail)	1067	1117	50	50	
C (plunger)	1351	1404	50	53	counting interrupted
D (plunger)	1322	1372	50	50	
E (plunger)	1032	1082	50	50	
F (rat-tail)	1116	1166	50	50	
G (plunger)	661	708	50	47	
Total A to G	7661	8011	350	350	

Table 2 Admission requirements of the turnstiles serving the zones of the stadium

Zone	*Capacity (persons)	Turnstile designation	Number of turnstiles	Average persons per turnstile
West Terrace	10,100	A to G	7	1,443 1
North Stand Seating	9,882	1 to 8 9 and 10	10	988) Leppings) Lane)
West Stand Seating	4,465	11 to 16	6	744))
South Stand Covered Seating	5,567	23 to 32	10	557) Concourse
Spion Kop	21,000	37 to 78	42	500) Penist'n Rd
South Stand Uncovered Seating	3,310	19 to 22 33 to 36	8	414) Concourse
TOTAL	54,324		83	655

* Taken from Eastwood & Partners Drawing No 8945/1A, dated 16/4/87

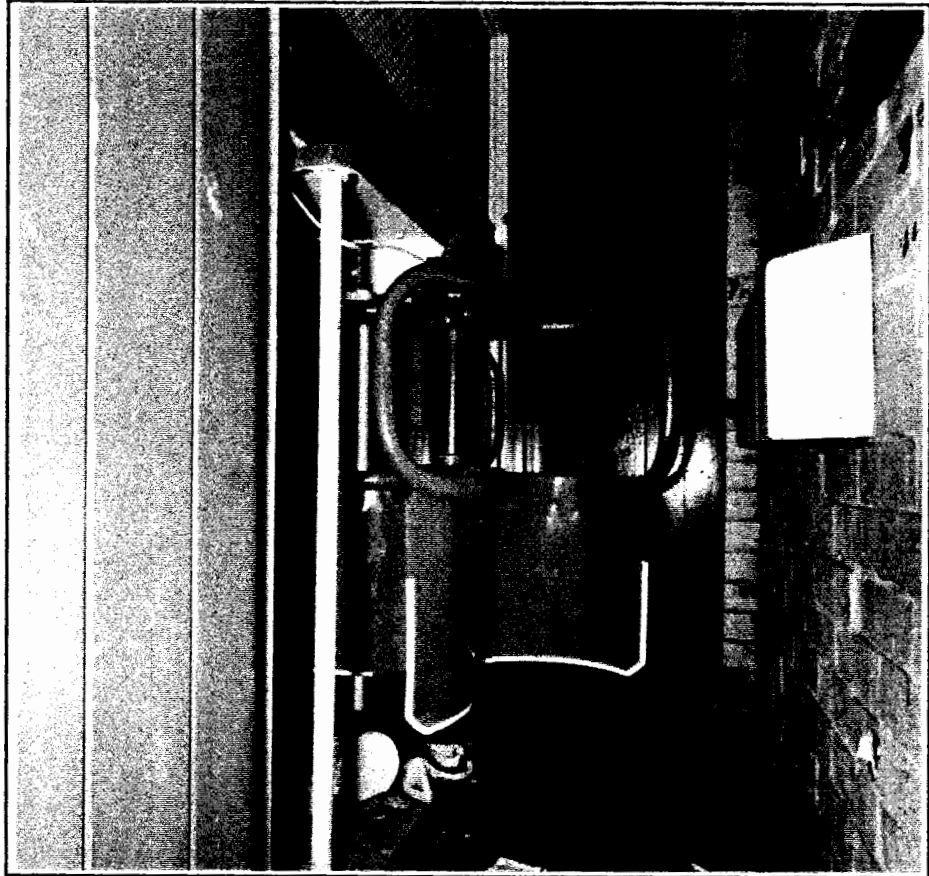
$$\frac{\text{Admissions from Leppings Lane}}{\text{Admissions to stadium}} = \frac{24,447}{54,324} \times 100 = 45\%$$

$$\frac{\text{Turnstiles in Leppings Lane}}{\text{Turnstiles serving stadium}} = \frac{23}{83} \times 100 = 28\%$$

$$\text{Leppings Lane average admission requirement} = \frac{24,447}{23} = 1063 \text{ persons/turnstile}$$

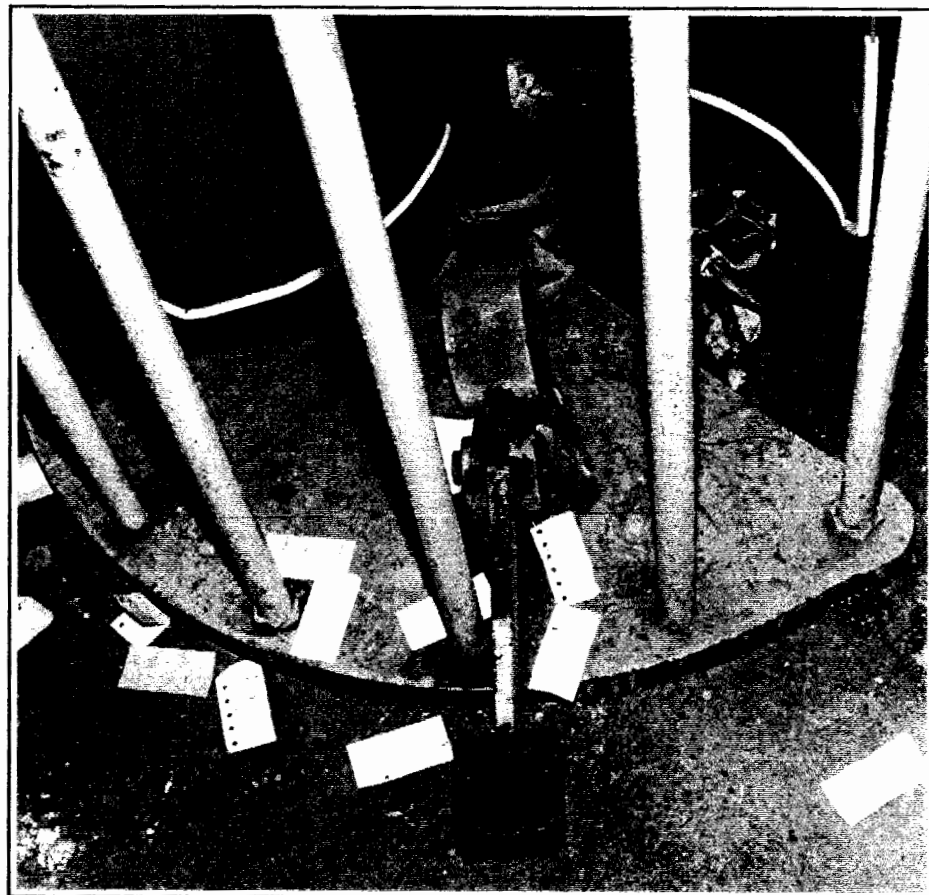
$$\text{Penistone Road average admission requirement} = \frac{21,000}{42} = 500 \text{ persons/turnstile}$$

$$\text{Concourse average admission requirement} = \frac{8,877}{18} = 493 \text{ persons/turnstile}$$



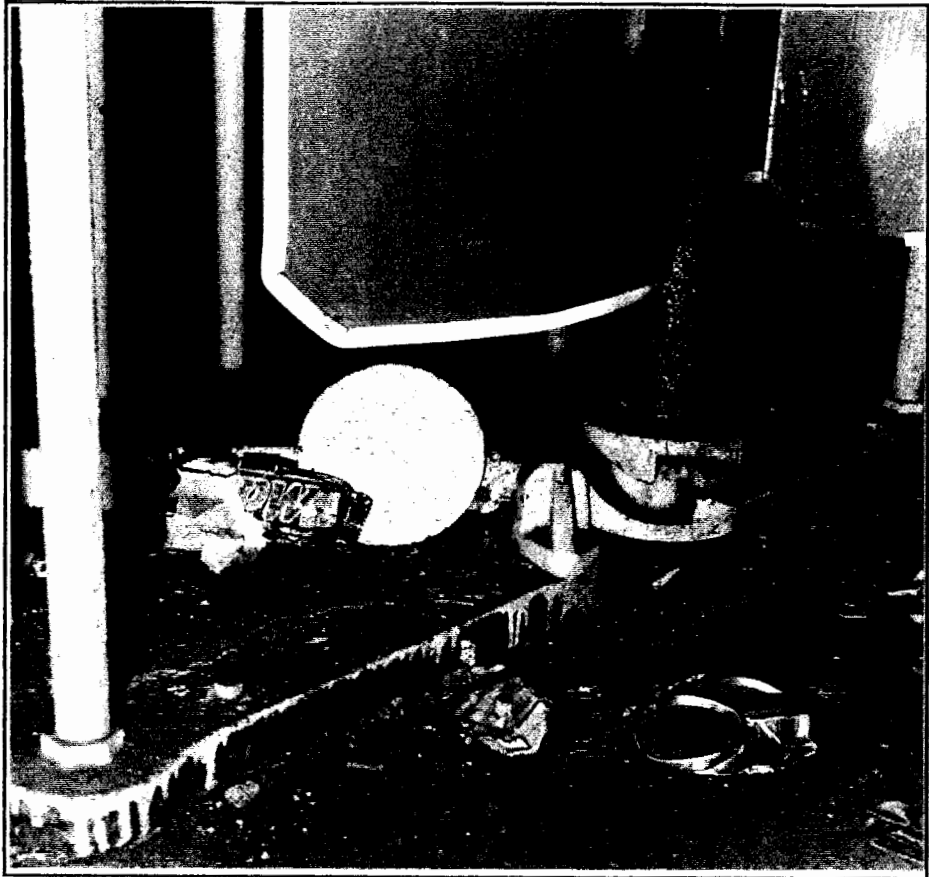
8904-097/46A

Fig.1 -A typical turnstile serving the West Terrace, viewed from the exit



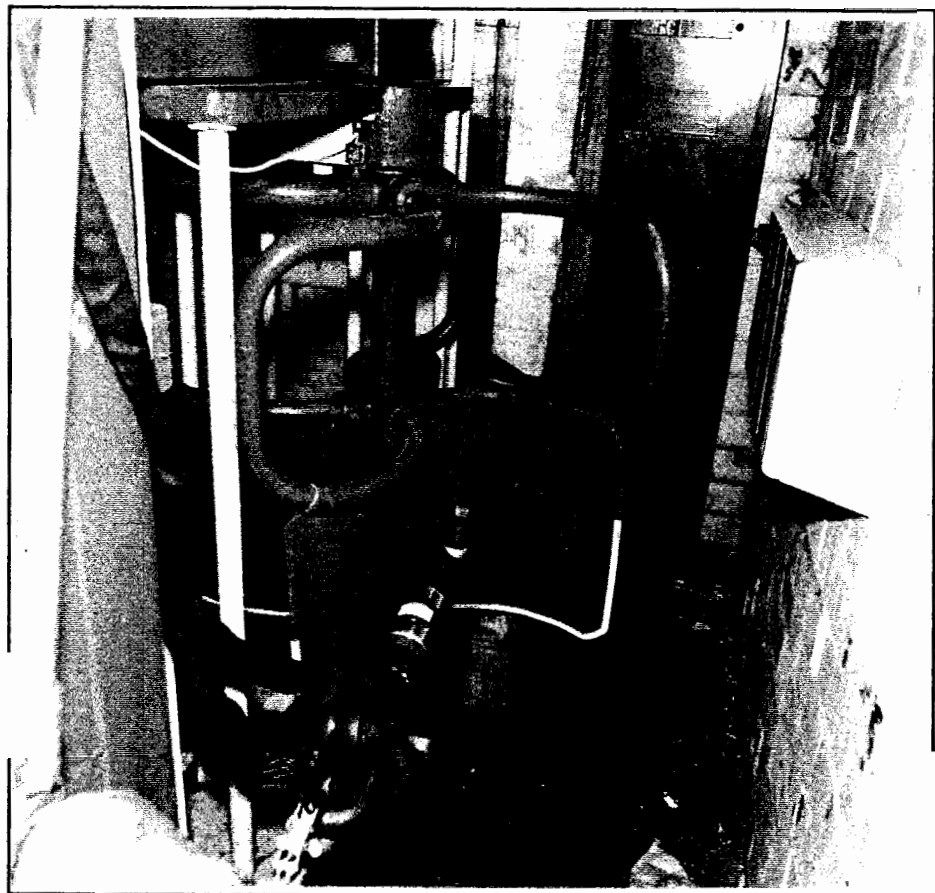
8904-097/83

Fig.2 - Pivoted locking lever; the release pedal is depressed to allow the spindle of the turnstile to rotate



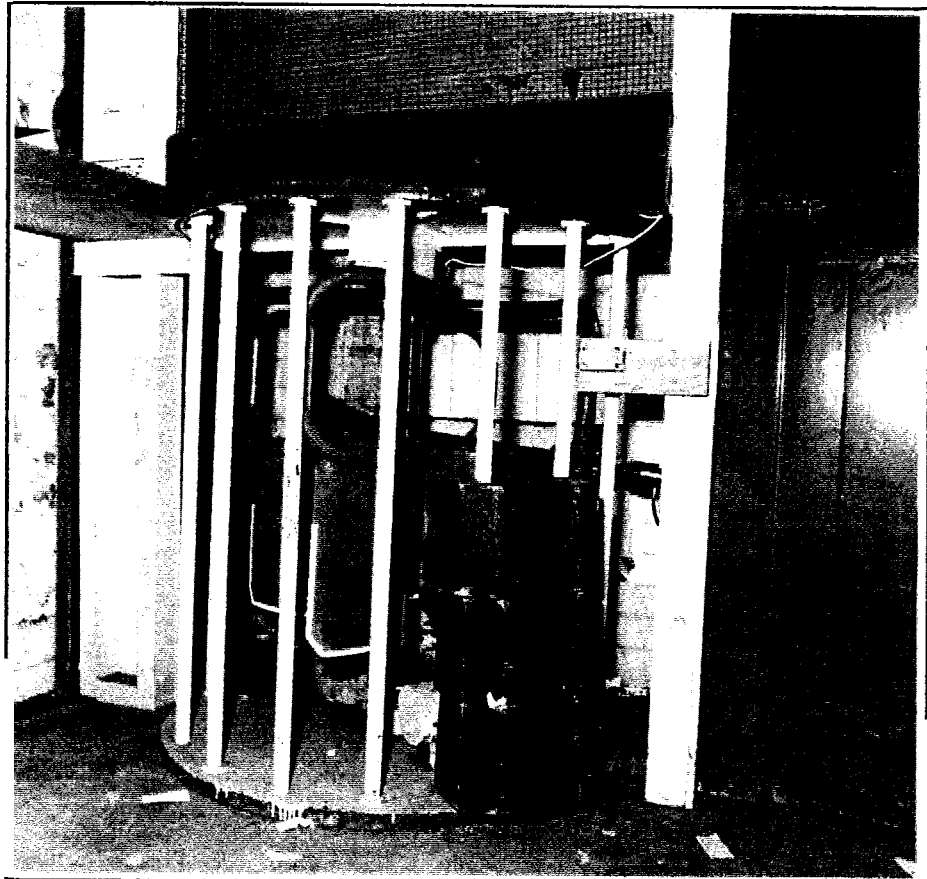
8904-097/84

Fig.3 - Dual cam assembly on the lower end of the spindle of-a turnstile



8904-106/5

Fig.4 - The equipment used to apply a horizontal, known, force to the 'wing' of a turnstile



8904-106/10

Fig.5 - Standard test weights applied to the release pedal of the pivoted locking lever of a turnstile

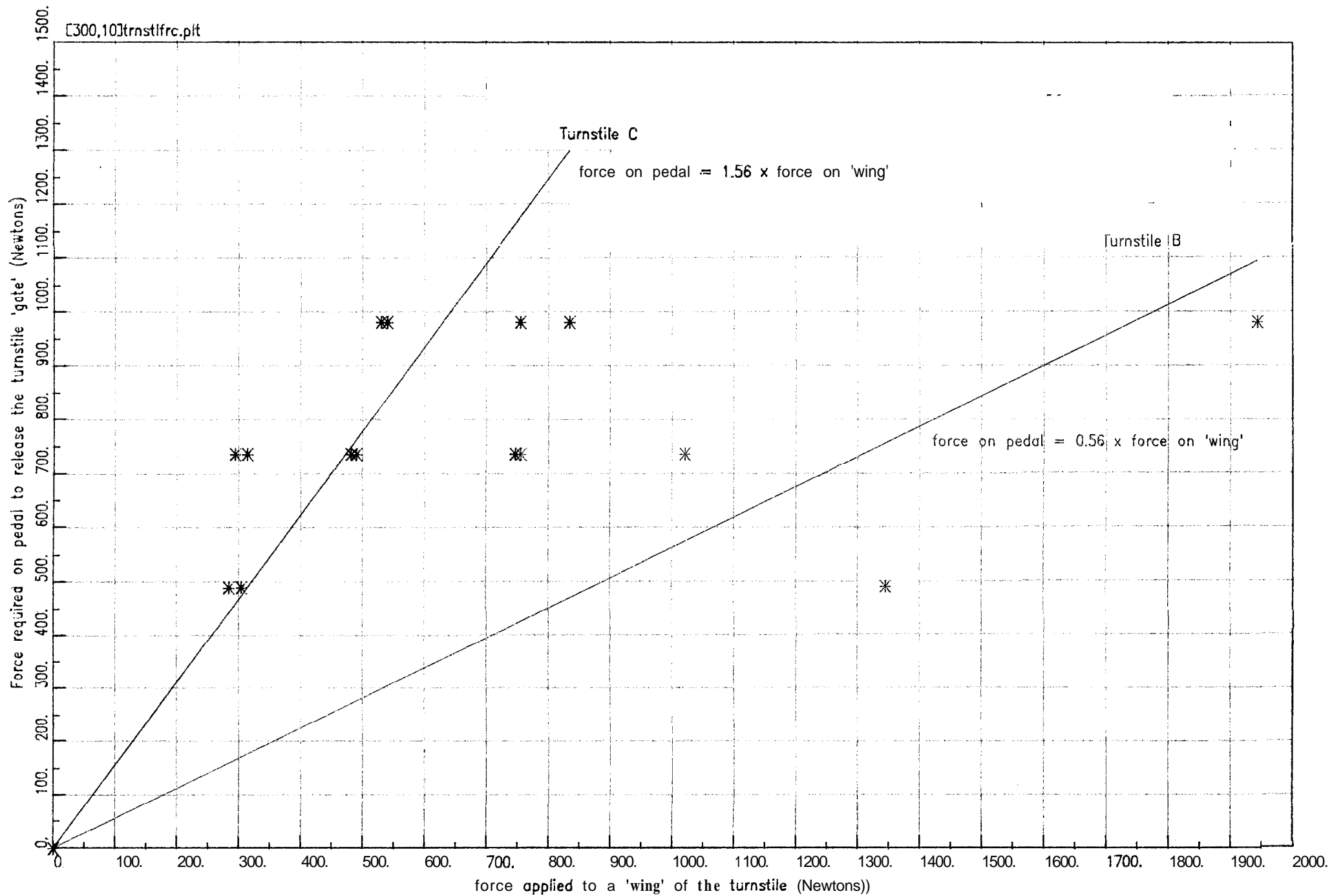


FIG. 6 RELATIONSHIP BETWEEN THE FORCE REQUIRED ON THE RELEASE PEDAL OF A TURNSTILE AND THE FORCE APPLIED TO A 'WING'