Building Egress Flow Rates:
Research, Application & Limitation

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ABSTRACT

A fundamental part of building fire safety design across the world is the adequate provision and location of exits and stairways. Over provision can simply lead to inefficiency. Areas of a building taken up by stairs and exit routes add little monetary value. An under provision of exits is not acceptable, resulting in emergency egress (and ingress) times being either uncomfortable or hazardous. As such, exit width forms a fundamental part of design.

This paper seeks to provide a further level of understanding for current building design, identifying where building design is strong and weak in this field. The application of current approaches and their limitations, both at present and going forward, are highlighted.

This research includes state-of-the-art technology, provided by Axiomatic, to automatically count people queuing through exits. The automatic nature of this approach, applied in this research context, sheds new light on egress flow rates which can help inform building design in the future. This work is on-going with preliminary findings highlighted.

INTRODUCTION

This paper reviews the current application of flow based egress models and egress from buildings. It summarises previous literature studies, tests the application of current approaches and their influence on design and provides supporting evidence for the assessment of flow rates from buildings.

In this regard, Architects, Engineers and Approval Authorities can use this work (and future work) to provide the best practicable solution for egress from buildings during normal conditions, fire or other emergencies. To determine the requirements for evacuation, Fire Engineers and Designers are using evacuation mathematical models to predict occupant behaviour and movements. These models vary in degree of complexity, underlying mathematical assumptions and resolution. They range from hand calculations & hydraulic models, to 3D behavioural & discrete occupant modelling tools. They also vary, surprisingly, in accuracy, i.e. how precisely do they predict occupant behaviour and movement.

As a result, this fundamental aspect of building fire safety design is unexpectedly less understood when compared to other areas of fire engineering. There is also a limited amount of occupant behaviour and evacuation modelling available in the public domain. Furthermore, recent publications[2] have removed their references to occupant flow rates while others provide a range of predictions for occupant flow.

To underpin fire engineering design and development in this field, this paper provides initial research into egress from buildings including experimental evidence of occupant flow rate in a rail station.

This paper includes:

- Literature review of egress methods, guides and simulations (such as the UK Green Guide, Guide to Safety At Sports Grounds, SFPE Handbook of Fire Protection Engineering);
- Practical research into egress from buildings including occupant behaviour and evacuation modelling; and,
- The application of this research and current limitations.

The occupant behaviour and evacuation modelling in this paper involves the use of automated egress counters in real buildings. This new area of technology (normally used to count people walking in to buildings) has been adapted to study egress and occupant densities from buildings. These cameras include egress from a rail station. The work gives an insight into occupant flow rates for varying crowd densities and dynamics. A fundamental objective of the study is to review many events and provide a distribution of results.

RESEARCH

The flow rate through the exits has been studied by a number of authors. This paper does not seek to summarise all these studies, but provides a fire engineer's perspective of the available literature this additional study.

Literature Review

Approved Documents B provides the primary fire safety design reference for the UK. The derived flow rate from ADB is 1.33p/m/s. This equates to the recommended available exit width of 5mm per person exiting in 150 seconds. For comparative purposes 'boundary layers' are relevant and for a 2m wide exit, the available exit width is 2-(0.15*2) = 1.7m. Assuming the same exit rate (5mm per person exiting in 150 seconds) results in an effective flow rate of 1.57p/m/s. This 'Boundary Free' flow rate of course reduces towards 1.33p/m/s, as the exit increases in width, but it worth noting that the effective flow rate through an ADB assumed design is actually relatively high.

BS 7974 Part 6[6] provides guidance, and a brief summary, for exit flow rates. A range of exit flow rates are presented:

Table 1 Summary Exit Flow Rate

Reference	Flow Rate (p/m/s)	Boundary Free Flow Rate [2x150mm] (p/m/s)	Density modified
ABD	1.33	1.57, for a 2m wide exit.	✗
BS7974	n/a	1.3	✗
SFPE 3rd Edition	n/a	1.425	✓
Green Guide	1.37	1.61, for a 2m wide exit	✗
NFPA 130 2007	1.488	1.75, for a 2m wide exit	✗

Of note:

1. The literature does not explicitly differentiate between different purpose groups. Office workers are assumed to exit at the same rate as commuters using a rail station. However, a slightly higher exit flow is provided for stadia designed to the Green Guide;

2. It is unclear if the flow rates are the 'average' or a percentile of the slowest to fastest exit rates. It is also unclear if there are natural variances in exit rates from buildings. For example, for a

given building with a fixed population and pre-movement time, will the egress time always be the same or would it be expected to vary ±10% for example;

3. The Green Guide provides separate flow rates for horizontal exits and stairs. The other codes are comparatively vague in this area and flow rate down and up stairs requires further investigation; and,

4. The 3rd Edition of the SFPE Handbook[3] provided guidance on exit flow rates which has been removed from the current edition. The 4th Edition of SFPE Handbook[2] provides a range of speeds with a standard deviation. However, the exit flow rates are no longer explicitly stated and could be derived from knowing the speed of occupants approaching an exit and their local density.

In summary, there are robust references for egress flow rate albeit there is variance and the important items noted in points 1 and 2 above are not explicitly investigated.

Huddersfield Station – Research Case

Huddersfield Station is a neo-classical style major rail station serving the commuter belt between Manchester, Sheffield and Leeds. The station has an annual rail patronage in the order of 3.5million users. It has been chosen as an ideal case study for assessment as the existing listed nature of the building results in two exits from the main platforms through the main ticket hall. During the PM peak periods a predictable short queue occurs, allowing assessment of crowd density and flow rates through the doors.

The assessment caveats the following:

- Users in this study are generally commuters and as such they are familiar with the station. This would be the case for most commuter rail hubs.
- Users would generally be expecting the queue. This may influence flow rate.
- Ticket checks occur in the ticket hall, and this may influence a queue – however the data shown is after the ticket check is removed.
- Alternative means of escape is provided from the platform and as such the existing configuration in no way affects safety.

The following provides an illustration of the station.

Figure 1 - Huddersfield Station

Figure 2 – Platform Configuration

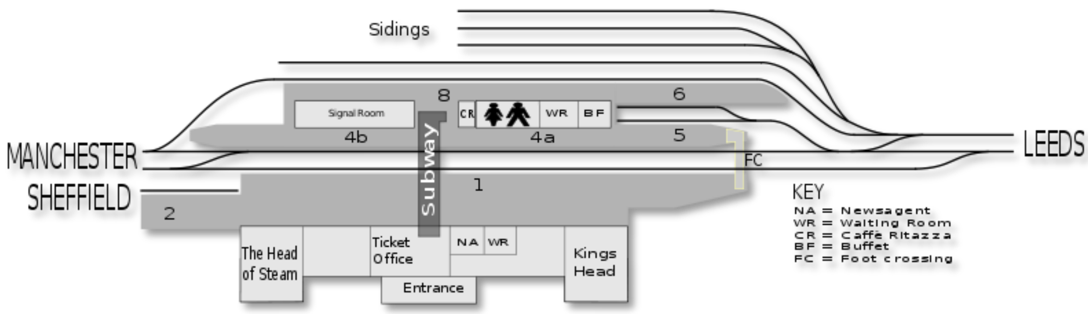


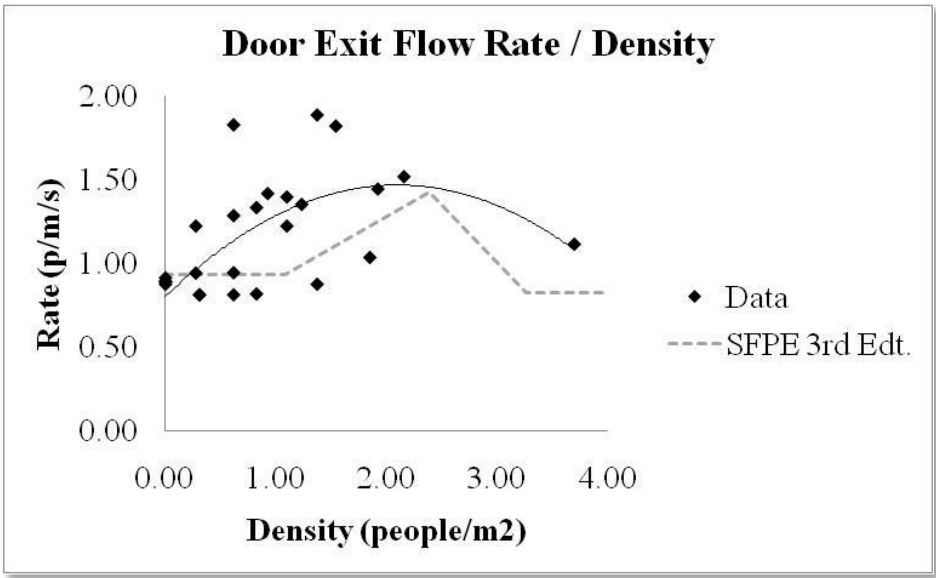
Figure 2 shows the plan of the station. The PM peak trains arriving from Leeds detrain onto Platform 1 and exit above the area marked 'Subway'. A 1.12m exit and a 1.2m wide exit are provided, which generate a queue condition for busy periods.

The data was gathered using Advanced Clarity Stereoscopic Video Counters (figure 3) with the ability to monitor both flow rates and queue density simultaneously.

Figure 3 - Brickstream Clarity Video Counter

The results of the study are present below. These are initial findings and subject to further assessment.

Figure 4 - Flow Rate/Density



The cases above show a general peak around 1.5p/m^2. (The above cases show an effective rate, taking into account a boundary layer for comparative purposes with the SFPE Handbook).

APPLICATION

A number of models are available for assessment of egress in buildings. Evacmod.net provides a thorough list of over 50 models. Each model ranges in assessment type from network 'ball bearing' models to discrete evacuation models. NIST[1] have provided a comprehensive summary of models in 2005. They note that each model is unique due to the various modelling techniques inherent within them. Indeed some models do not use an empirical flow rate at all and calculate flow from first principles, including individual size and physical interactions as people flow through doors. However, popular models such as STEPS[1] and buildingEXODUS[1] use flow rate, as do simpler models using spreadsheets.

It is clear from the results above and other work[4] that density affects egress, although the initial results illustrate significant natural variance. Importantly this work demonstrates that local density at the door, rather than averaged out within a room, drives flow rate. Models which use a fixed flow rate irrespective of density at the door may well be conservative in this regard assuming that they use the lowest figures. An assumed higher flow in the optimum region may not be representative of higher local densities at the doors.

In financial terms 'over provision' of exit width, i.e. larger exits without improving safety, will affect a building's economic performance. For example a ten storey, 2000m^2 office building would typically be provided with four lobby approached stairs. The size of the stairs could vary depending on the egress flow rates used. An 'optimum' SFPE Handbook design, compared to an ADB flow rate (with the same egress time) could result in a 5% reduction in core area. This, although small, over a 25 year period could improve a single building's lettable value in the order of £0.5m, taking an average £60/sq ft per year rental. Therefore there is a robust case for justifying exit flow rates as the financial impact can affect a building throughout its life. Use of the NFPA standard for flow rate would yield even smaller exits, simply as the effective flow rate is higher.

LIMITATION

Egress modelling cannot be simplified to an 'exit flow' calculation for all cases. There are a number of key drivers for egress from buildings including social forces, groupings such as family members, crowd movement and travel distance. More complex models including 3D discrete evacuation models can be set up to take these factors in to account. Nonetheless flow rates are still very important for egress at busy exits.

In this regard the author questions the following key points of flow rates:

- Is the use of a fixed flow rate representative of real buildings which appear to have variability?
- Are flow rates limited to certain purpose groups?

CONCLUSIONS

The key findings of this work are:

1. Are egress flow rates linked to occupant densities?

   The results indicate that flow rate through doors is linked to density. This correlates with the SFPE handbook data, however in this case the results showing higher density do not result in a sharp reduction in flow rate and that peak flow rates can also occur at lower densities.

2. How egress flow rates differ between the different types of occupancy?

   The results above show relatively high exit flow rates in some cases. Commuters are familiar with the exit and move through relatively quickly. Further research in this area, reviewing flow rate variance for different occupancies is recommended.

3. Are the current egress rates in established references and guides (such as the SFPE Handbook and Green Guide mentioned above) applicable?

   The egress flow rates (based on this study) show that in most cases commuters familiar with the route would flow through the doors more quickly than the SFPE and ADB guides' state –but not in all cases. A flow rate more akin to the NFPA 130 rates is applicable. However the NFPA 130 rate would be seen as a maximum flow rate and the data shows a nature variance in flow.

4. Is a distribution of egress rates a real phenomenon, i.e. will there always be a natural range of egress times from a building and how large is the range likely to be? Furthermore should designers use a distribution of results, i.e. the average, a reasonably high percentile or the 100th percentile?

   The research above shows that it is difficult to predict exactly how quickly people exit through doors. In any given case the flows range by ±10%. Further investigation is required to provide the percentile values which can then be tallied against the established flow rates given in the references above.

5. Given Point 4 above, should the egress times be assessed in a risk context with multiple cases assessed? For example the use of Monte Carlo type analysis to model many scenarios.

   In many cases it is not necessary to undertake Monte Carlo type analysis where a reasonably conservative fire scenario is modelled. However, where a safety factor is marginal and results could be sensitive to reduced flow rate, it is important to understand the impact this may have on fire safety. A real life fire scenario would rarely have already been assessed at design stage, albeit the most conservative scenario would hopefully have been modelled, i.e. up to the 80th or 90th percentile of possible outcomes. In a risk context we should start to understand design up to 99th percentile of possible outcomes, which would include scenarios such as reduced flow rates at doors, which may be rare but predictable.

As fire engineers and designers balance the challenging requirements for safety, function, aesthetic needs and cost it is fundamental that our understanding and application of egress models is based on sound engineering principles and research.

The application of this new technology in this field is developing and this research will continue over the coming months. The data points provided are only indicative, capturing only a few busy periods. We expect to provide further data on this study and also different purpose groups in the future to help support research in this important part of building design.

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