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A quick method for emergency evacuation design in work places

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To guarantee the safety of workers in premises it is necessary to design an egress-system capable to ensure a safe evacuation during an emergency. To supplement the design tools with an analytical method that permits to assess in a fast and simple way the performance of premises egress-system, in this work the PASS (Preliminary Assessment of the egress-System Safety) method has been presented and applied. The comparison among PASS, STEPS® (a FSE evacuation model) and a real fire drill observations has shown the capabilities of the PASS method as a quick tool for emergency evacuation planning during the pre-design process. This permits a rapid preliminary definition of the main egress-system characteristics and a focused use of FSE's software, reducing thus the overall computing time necessary for the design.

1. Introduction

To achieve an emergency safety strategy to reduce losses in premises (like work places) as promoted by Fire Safety Engineering (FSE) standards, it is necessary to perform a qualitative and quantitative design analysis, and an assessment of the outcome of these analyses against the safety criteria (ISO, 1999). During this assessment process, the designer should evaluate the initiation and development of fire, the movement of fire effluents, the structural response and fire spread beyond the enclosure of origin, the detection, activation and suppression systems, and the life safety. The last can be achieved both reducing the exposure to the threatening effects of the adverse events and to adopt an egress-system that permits the movement of workers away from dangerous areas, before the achievement of untenable conditions (i.e. to guarantee that the required safe egress time, RSET, is less than the available safe egress time, ASET – SFPE, 2003).
In presence of new and complex projects, the design of a performing egress-system can not be done with prescriptive codes, because, despite the relatively easy use, are inflexible if not applied to a standard type of premises (Frantzich, 1998). In these cases performance-based approach can be used. Although this approach ensures a more flexibility, the designer is not provided with design tools, but only with the objectives to comply and the methodology to adopt. To achieve the life safety objectives prescribed, the designer can apply analytical models or the more sophisticated FSE's evacuation simulation software, that consent to calculate the RSET for each occupant, simulating

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the evacuation process in many types of premises and considering, depending on the model used, the most important people-people, people-environment and people-structure interactions. These FSE tools require that the designer have a good knowledge of evacuation process and models, and are time-requiring, especially for the modeling phase.

In the outline design tools, there are very few methods that permit to assess in a fast and simple way the performance of premises egress-system. Such types of methods could help the designer to check quickly the performances of the egress-system, prior to the use of the evacuation simulation models, permitting to find its critical points in a fast way and then to set the best egress-system design, consenting thus a more focused use of evacuation applications.

In this paper it is described the PASS method, a quick analytical method based on the vulnerability assessment that can be used to perform a preliminary check of the egress-system, prior to the use of evacuation simulation tools, and to support the decision making process during the design phase. Finally it is illustrated a comparison among the results obtained by PASS, STEPS® (a FSE's evacuation software) and a real fire drill observations.

2. The PASS method

PASS (Preliminary Assessment of the egress-System Safety) is an analytical method developed in Gri.S.U. (Grimaz and Pini, 1999) as the exodus-barriers-and-gaps method during the "Evaluation and Management of Venice Fire Safety Program". The PASS method permits to assess in a quick and simple way the egress-system vulnerability in terms of capability of the system to respond to the adverse effects of an accidental fire or explosion, i.e. to be safety covered during an emergency and to permit people to reach a safe area before the achievement of untenable conditions (RSET<ASET).

2.1 Concepts and structure

The concept adopted by PASS is the vulnerability analysis, promoted in the SFPE Handbook as the source → target concept (Barry, 2002). The assessment process in PASS is performed with a qualitative and quantitative egress-system analysis, and finally with the assessment of the outcome of the quantitative analysis. It is worth noticing that this process fulfils the requirements of the fire safety engineering assessment process (ISO, 1999).

The outcome of PASS is a judgment of the egress-system capability to be covered in emergency conditions: the flow through the exit gaps and the carrying capacity of the exit routes (horizontal and vertical) are the key elements evaluated.

All the assessment process is carried out considering the most representative and conservative scenarios that can occur in the premises-environment-people system analyzed. To set these scenarios it is hypothesized an instantaneous spread of fire into the origin enclosure and the untenable conditions are quantified in terms of CO concentrations or other toxic gases with different levels, depending on the zone of the premises analyzed.

PASS is pre-codified using tables and simple analytical equations: these are arranged to guarantee flexibility and a simple and fast use of the method. The pre-codified structure of PASS permits to guide the designer during the egress-system analysis.

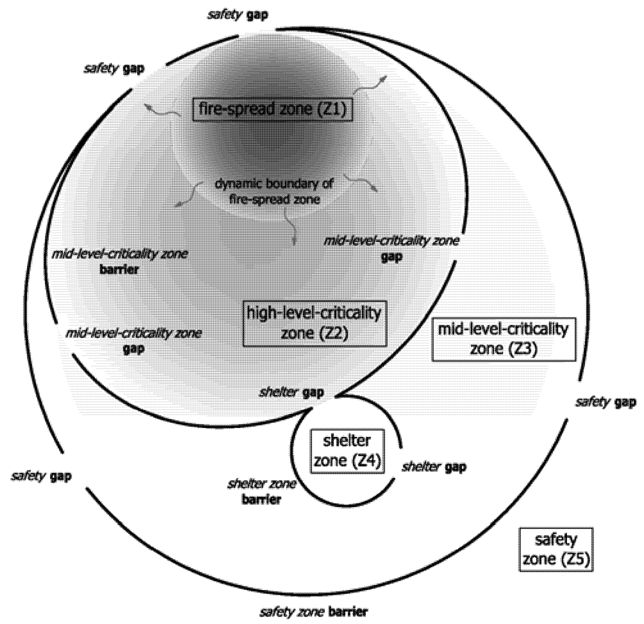

Figure 1: Zoning process in the PASS method.

2.1.1. The qualitative analysis

Referring to the different design scenarios, the qualitative analysis is carried out by the designer to classify, in terms of hazards, the different areas of the premises. During this zoning process the premises are divided in five zones considering the critical elements and safety characteristics of each enclosure (Figure 1):

- Z1. fire-spread zone (enclosures of fire origin where a CO level greater than 10000 ppm and an ASET equal to 60 s are hypothesized)
- Z2. high-level-criticality zone (enclosures adjacent to the fire-spread zone where a CO level ranging from 5000 to 10000 ppm and an ASET equal to 90 s are hypothesized)
- Z3. mid-level-criticality zone (fire insulated enclosure where a CO level ranging from 2500 to 5000 ppm and an ASET equal to 240 s are hypothesized)
- Z4. shelter zone (enclosures inside the mid-level-criticality zone that can guarantee tenability conditions for an indefinite time)
- Z5. safety zone (tenability conditions for an indefinite time)

The CO levels and the ASET values are set conservatively to avoid that people experiment health and safety detrimental effects, and in the fire-spread zone the fire is supposed instantaneous. Each zone is ideally divided from the others by barriers that can offer different degrees of fire resistance and insulation, and the passage to adjacent zones is permitted by the presence of gaps and routes. Thus, the whole egress-system is schematized with a set of zones, enclosures, gaps and routes. At the end of the qualitative analysis, the designer should have classified all the premises in the different zones and identified all the enclosures, exits and routes (paying particular attention to layout, escape guidance, untenable conditions, protection systems).

2.1.2. The quantitative analysis

The quantitative analysis is performed at the enclosures, exits and routes identified during the qualitative analysis. The whole analysis is achieved with the application of seven pre-codified analytical tests to the system. In this phase, the designer evaluates the maximum performance that the schematized egress-system can reach with respect to the design scenario analyzed. The performance is evaluated in terms of flows at the exits, carrying capacity of the routes, presence of alternative safe exits and routes. Depending on the part of the egress-system, these tests evaluate:

a. enclosures: possibility to reach the exits; presence of alternative exits; maximum flow achievable at the exits;
b. exit routes: possibility to reach exits to mid-level-criticality, shelter or safe zones; maximum flow achievable at the gaps; presence of alternative safe routes;
c. whole egress-system: possibility to leave safely the premises and to reach the shelter or safe zone.

The outcomes of the tests are assessed against reference values (maximum reachable distance and maximum flow at the exits) that vary in the different zones, and so depend on the critical conditions of each zone. These reference values can be calculated in each scenario analyzed in a flexible and pre-codified way, thus ensuring the flexibility of PASS. Therefore, these tests consent to find the critical elements of the egress-system that could improve the REST, and hence to set the main characteristics of the egress-system to guarantee the maximum performance.

2.2 Validation

PASS has been validated (Tosolini, 2008) against STEPS® (MacDonald, 2008), an evacuation software widely used in FSE. During the validation study the main coefficients and equations used by PASS have been checked. Finally a real evacuation drill has been performed, which observations and data collected have been used to a further validation study of PASS.

3. Application of PASS

The application of PASS has been performed in three steps: 1) analysis of an egress-system with PASS; 2) simulation of the evacuation in the egress-system with STEPS®; 3) real fire drill. The fire drill has been recorded and evacuation data (exit times and flows) have been collected. These observations have been compared with PASS and STEPS® outcomes.

3.1 The fire drill

The fire drill has been performed in a secondary school and involved 600 evacuees. The evacuation study developed initially into an unannounced evacuation of the entire school with a blocked emergency exit, and then into three announced micro-evacuation of a side of the school. In this paper a micro-evacuation and the study's outcomes are presented.

3.1.1. The egress-system

The egress-system analyzed is formed by three classrooms, one corridor, one emergency exit, one emergency stairway. All the classrooms are located in the same corridor on the first floor of the building. 60 students, with an age range of 16-19, have been evacuated. The fire drill has been started by vocal advise and recorded simultaneously with 4 cameras. Data have been collected by 5 operators.

3.2 STEPS®

STEPS® is a commercial microsimulation tool for the prediction of pedestrian movement in various types of premises under both normal and emergency conditions. It is a movement/partial behaviour individual model with a fine network system to model the space. The movement is modeled using a potential grid. STEPS® has been verified and validated by comparison with analytical solutions, internationally-accepted design codes and full-scale testing (MacDonald, 2008).

3.3 Results and discussions

The results obtained from the PASS application, the simulation with STEPS® and the micro-evacuation observations are presented in Figure 2. The Figure shows the classrooms' evacuation times, the evacuation time at the emergency exit, the evacuation time at the entrance of the stairway, and the total evacuation time.

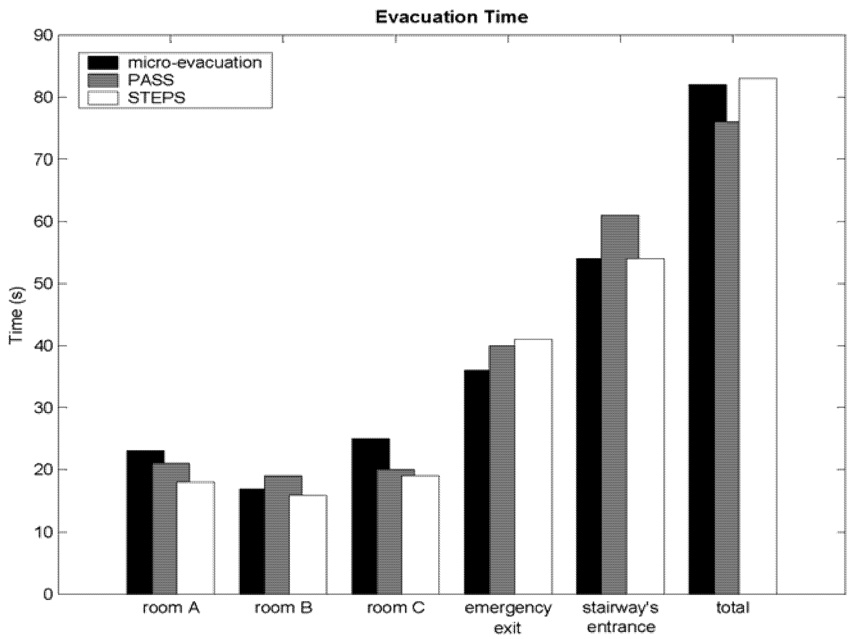

Figure 2: Comparison between the real observations, PASS and STEPS®.

The evacuation from classrooms A and C has been influenced by reentry behaviour, and thus the evacuation times are greater than those calculated by PASS and STEPS®. As emerged from video analysis, the evacuation from classroom B has not been influenced by nonadaptive behaviour, and the estimate of PASS and STEPS® is like the real values. The evacuation times at the emergency exit and at the stairway's entrance are estimated correctly (from video analysis emerged that the flow in these points has been regular), like the total evacuation time. The order of magnitude of PASS and STEPS® overall operative times is of hours and days respectively. It is worth noticing that in its quantitative analysis, PASS uses safety factors to include human behaviour factors (nonadaptive behavior, way-finding, etc.) that difficultly can be simulated and forecast. This safety factors range from 1.4 to 2, depending on the scenario analyzed. In the analysis presented before, all the results have been calculated without these factors. Using the safety factors, the whole PASS analysis would be conservative.

4. Conclusions

In this paper an application of the PASS method is presented and described. PASS is an analytical method based on the vulnerability analysis and its methodology fulfils the FSE's standards requirements. In this application a comparison among the results obtained by the method, STEPS® (a FSE's evacuation software) and a real fire drill observations has been done.
The use of PASS method prior the required application of simulation evacuation software, as emerged form the application study, permits a focused use of the FSE's software reducing the overall computing time necessary for the design. The real fire drill study has shown that both PASS judgment and STEPS® results are correct in the case that the evacuation is ideal. In order to take into account the uncertainties that arise from the human factors in emergency, it is necessary to use safety factors. The PASS method uses safety factors ranging from 1.4 to 2 depending on the scenario analyzed.
The comparison has shown that the PASS method can be used to assess and define in a rapid and simple way the main characteristics of the egress-system and to plan the emergency evacuation during the design, supporting the decision-making process.
The Authors want to emphasize that this method does not want to substitute the necessary use of evacuation models, but to support their users during the preliminary phase of definition of the main egress-system characteristics reducing the overall time of design.

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