Case Studies in Fire Safety 3 (2015) 44–50

Contents lists available at ScienceDirect

Case Studies in Fire Safety

journal homepage: www.elsevier.com/locate/csfs

Fire load energy densities for risk-based design of car parking buildings

M.J. Spearpoint *, M.Z.M. Tohir [1], A.K. Abu, P. Xie

Department of Civil and Natural Resources Engineering, University of Canterbury, New Zealand

ARTICLE INFO

Article history:
Received 17 February 2015
Received in revised form 1 April 2015
Accepted 1 April 2015
Available online 29 April 2015

Keywords:
Car parking
Fire load
Risk

ABSTRACT

The time-equivalence method is one way to determine the appropriate fire severity in buildings. One of the input parameters required is the fire load energy density (FLED) and in a deterministic design this is taken to be a fixed value. This paper illustrates the use of a simple Monte Carlo tool that accounts for statistical variations in car energy content as a function of vehicle size to determine probabilistic FLED values for a risk-based calculation approach to the design of car parking buildings. The paper briefly discusses FLED values for car parking buildings that can be found in the literature and results from the Monte Carlo tool suggest that 260 MJ/m^2 could be used as an appropriate design value in lieu of using a probabilistic approach.

Introduction

Background

Currently there is debate in New Zealand regarding the design of steel structure car parks and the use of the time-equivalence calculations to determine appropriate severity for these buildings. Equations for calculating time-equivalence can be found in the New Zealand verification method C/VM2 [1]. These are based on equations from the Eurocode [2], but with an expanded set of factors to allow for adequate consideration of the contributions of different room lining materials [3].

In order to calculate fire severity using a time-equivalence method one of the parameters needed is the fire load energy density (FLED) which is the sum of all the energy available for release when the combustible materials are burned, divided by the total floor area of the compartment. The available energy content can be distinguished into permanent, variable, protected and unprotected loads [4]. Typically an 80th percentile variable fire load is used as a design value when using data from fire load surveys [4,5]. For a car parking building the variable load is essentially the vehicles and the calculation of FLED incorporates any floor areas used for vehicle lanes and ramps, pedestrian walkways, etc.

Typically time-equivalence calculations are carried out deterministically with fixed values assigned for FLED, compartment geometry, ventilation conditions, lining materials and the structural material being used for the design. The process considers that the compartment is uniformly heated throughout the fire exposure and for a car park fire scenario this effectively assumes the building is densely populated with vehicles and that they are on fire simultaneously. However in a densely populated car park it is possible that the fire will travel from vehicle to vehicle rather than assuming all are burning

* Corresponding author. Tel.: +64 (03) 364 2237.
E-mail address: michael.spearpoint@canterbury.ac.nz (M.J. Spearpoint).

[1] Permanent address: Department of Chemical and Environmental Engineering, Universiti Putra Malaysia, Serdang, Selangor Darul Ehsan, Malaysia.

http://dx.doi.org/10.1016/j.csfs.2015.04.001
2214-398X/

simultaneously. Recent work on travelling fires by Stern-Gottfried et al. [6] has introduced a new methodology using travelling fires to produce more realistic fire scenarios in large, open-plan compartments for structural fire design. Stern-Gottfried et al. examined the impact of FLED on their estimation of the peak structural member temperature. Their results show that local concentrations of dense fuel loads produce long-duration fires and have a significant effect on structural resistance. Alternatively in a sparsely populated car park, fires could be localised, may involve only a small number of cars and, depending on the location of the fire, they could be detrimental to the structure. Thus advanced calculation methods for the design of car parking buildings investigate localised fires of different sizes at different locations in the building and their resulting building structural response [7].

In order to provide adequate fire resistance there needs to be a realistic assessment of the response of the structure as a whole as deformations in one part of the building need to be resisted by other parts. As discussed by Moss et al. [8] a statistical approach to fire behaviour could be used in fire safety and structural engineering applications instead of using a deterministic methodology. As part of a statistical approach to find appropriate fire resistance ratings for car parking buildings the structural fire severity assessment needs to incorporate the variable fire load. This requires an investigation on how the FLED can vary depending on the energy content of cars, the occupancy of car parks, the area of parking spaces etc. and this paper illustrates an approach to this subject.

Static efficiency of car parks

As well as the space for each vehicle, a car parking area will also include lanes, ramps, pedestrian walkways, etc. Every parking layout has its own advantages and disadvantages depending on the functional design of the parking building. The spaces within a parking layout can be angled with 90°, 60°, 45° or 30° being typical. Large capacity parking areas give a better efficiency than smaller capacity areas since there has to be proportionally less room for ramps and accessways.

Chrest et al. [9] has a set of recommended values for designing a parking area. The recommendation considers the classification of the vehicles and the level of service (LOS). LOS is method developed by traffic engineers to classify the degree of congestion of traffic where the higher the degree of congestion, the lower the LOS. The highest LOS is Category A, which is considered as free flow and no delay, while the lowest LOS is Category F which is popularly called ‘gridlock’. From the set of recommendations, the static efficiency of a parking area could be as low as 16 m^2/space for a LOS D category while it could be as high as 40 m^2/space for a LOS A category. Chrest et al. note that efficiencies as low as 16 m^2/space are car park designs for 100% ‘small’ cars.

Hill [10] suggests that a ‘good’ parking efficiency ranges from 20 m^2/space for 300 parking spaces at 90° up to 35 m^2/space for 30 spaces at 45° while Butcher et al. [11] cited parking areas per vehicle in the range of 18.5–26.8 m^2. A survey of open top floors of 41 New Zealand multi-storey car parking buildings using Google Earth found typical static efficiencies are 28.9 ± 5.1 m^2/space. Assuming the top floor is representative, then a lower 80th percentile design value for calculating FLED of 25 m^2/space appears to be reasonable for New Zealand car parking buildings. If anything it is possible that there could be slightly more spaces on an open top floor than lower floors since there are no columns, etc. to take up some of the footprint and so the static efficiency might be slightly higher on lower floors.

Available FLED values

Research as far back as the late 1960s by Butcher et al. [11] found that the wood equivalent fire load density for a car park could be taken to be 17 kg/m^2 using an area per vehicle of 18.5 m^2. Using a heat of combustion for wood as 17–20 MJ/kg [4] gives a FLED of 290–340 MJ/m^2. Alternatively Gewain [12] suggested that the wood equivalent fire load density for a car park would generally be below 9.75 kg/m^2, equivalent to 166–195 MJ/m^2. A survey of fire loads cited by Thomas [4] suggests an average variable fire load density ($\bar{F}$) of 190 MJ/m^2 with a standard deviation of 105 MJ/m^2 for ‘Garaging, maintenance and exploitation of vehicles’. The survey gave 80%, 90% and 95% fractile values of 270, 340 and 420 MJ/m^2, respectively for this category. Thomas [4] also quotes Swiss data which gives an average FLED of 200 MJ/m^2 for ‘Parking buildings’. Thomas suggests that 80%-fractile and 90%-fractile values for well-defined occupancies can be found from $(1.45–1.75) \times \bar{F}$ and $(1.65–2.0) \times \bar{F}$ respectively, giving 250–300 and 270–330 MJ/m^2. A more recent study on the design of a car parking building as part of the rebuild of L’Aquila, Italy [7] used a FLED value of 268 MJ/m^2.

Clearly there are a range of suggested values for the FLED of a car park that start around 166 MJ/m^2 and reach an upper value of 420 MJ/m^2. Many of the results are based on data that is now several decades old and it might be argued does not account for any changes in the energy content of modern vehicles and the layout of modern car parks.

In terms of design guidance Eurocode 1 [2] contains a table of recommended FLED values but not for car parking occupancies. C/VM2 on the other hand gives a value of 400 MJ/m^2 for regular car parking buildings and a value of 400 MJ/m^2 per tier of car storage for car stacking systems. The C/VM2 FLED value of 400 MJ/m^2 is comparable to the work by Collier [13] which suggested that a FLED of 400 MJ/m^2 was reasonable. Collier’s value was obtained by using an upper value of 12,000 MJ for the energy content of a car from the range of values cited by Schleich et al. [14] and using a typical parking space area of 29 m^2/space as used by Li and Spearpoint [15] to give 414 MJ/m^2, comparable to the 95% fractile value given by Thomas [4]. Prior to the introduction of C/VM2 the earlier New Zealand compliance document for fire design (C/AS1 [5])