

Institution: University of Manchester
Unit of Assessment: UoA14 Civil and Construction Engineering
Title of case study: Performance-based structural fire engineering
<p>1. Summary of the impact</p> <p>We have developed the Bailey-Method, design software FİRESOFT and a web-based information source for designers to use to produce safe and economical buildings. In buildings that have used the Bailey-Method, approximately 40% of the fire protection cost has been saved. The overall saving is about £20m in the UK over the REF period. The Bailey-Method has been presented in 2500 design guides (books), distributed to companies across Europe by ArcelorMittal, and translated into 17 languages. FİRESOFT and the associated quality assurance document enable using unprotected concrete filled tubular columns and have the British Standard status of Non Contradictory Complementary Information.</p>
<p>2. Underpinning research</p> <p>The key researchers at Manchester are: Professors Colin Bailey (from 2002) and Yong Wang (from 1997)</p> <p>The traditional “deemed-to-satisfy” method for specifying fire protection to steel-framed buildings is based on controlling the increase in temperature of the steel structure and ignoring the actual structural behaviour of the building during a fire. Our research focuses the performance-based fire engineering design methods for steel-framed structures. This was developed on the full understanding of the fundamental behaviour in fire of all the main structural components and building in its entirety, allowing the development of economical and safe design methods.</p> <p>Key insights are</p> <ol style="list-style-type: none"> 1. Development of the theory, and design method, for tensile membrane action (TMA) in composite slab steel beam floor systems at elevated temperatures [1, 2]. TMA is a load-carrying mechanism mobilised at very large deflections that enables the floor to develop a load carrying capacity much higher than the capacity that is normally used in structural design. Utilising TMA exploits the inherent reserve in strength of the floor, enabling the floor to sustain the applied loads in fire without the need for additional fire protection for up to 40% of the steel floor beams. Our research has formed the basis of the new fire engineering design method for multi-storey steel framed buildings [4] that is often referred to as the Bailey-Method in the steel and fire protection industry. 2. We have proposed and validated an alternative fire resistant design method for concrete filled steel tubular columns within buildings [5]. 3. Quantification of connection behaviour and their importance to robustness of steel-framed structures in fire [3]. Connections in steel-framed structures are critical to ensuring structural survival in fire, but connections are rarely explicitly considered in the fire resistant design of steel structures.
<p>3. References to the research</p> <p>Our research is published in the most prestigious academic and professional journals in the fields of structural engineering and fire science. Publication [3] won one of the two Henry Adams diplomas for the best research paper published in The Structural Engineer in 2010.</p> <p>Key Publications</p> <p>[1] Bailey C.G. (2004), Membrane Action of Slab/Beam Composite Floor Systems in Fire, Engineering Structures, 26, pp. 1691-1703, http://dx.doi.org/10.1016/j.engstruct.2004.06.006.</p> <p>[2] Bailey C.G., and Toh W.S. Behaviour of concrete floor slabs at ambient and elevated temperatures. Fire Safety Journal. Vol. 42. Issue 6-7. 2007 pp 425-436, http://dx.doi.org/10.1016/j.firesaf.2006.11.009.</p> <p>[3] Y. C. Wang, J. B. Davison, I. W. Burgess, R. J. Plank, H. X. Yu, X.H. Dai and C. G. Bailey</p>

(2010), The safety of common steel beam/column connections in fire, *The Structural Engineer*, 2 November 2010, pp. 26-35 [ISSN 1466-5123](#).

Other Relevant Publications

[4] Newman G.M., Robinson J.T. and Bailey C.G. (2006), *Fire Safe design: A New Approach to Multi-Storey Steel-Framed Buildings*. SCI Publication P288, second edition. The Steel Construction Institute, Ascot. 2006, [ISBN 1 85942 169 5](#) (*The design method is often referred to as the Bailey-Method in the Steel and Fire Protection industries*).

[5] Wang, Y.C. and Orton, A.H. (2008), Fire resistant design of concrete filled tubular steel columns, *The Structural Engineer*, 7 October 2008, pp. 40-45.

4. Details of the impact

Context

Fire resistance is one of the most important safety requirements in buildings and is covered by legislation. Until recently, designing for structural safety in fire was predominately based on simple “deemed-to-satisfy” prescriptive methods presented in supporting documents to the UK Regulations. Following such prescriptive rules adds 20 to 40% unnecessary fire protection cost to steel-framed buildings. Since the majority (over 70%) of multi-storey buildings in the UK are constructed using steel-framed structures the unnecessary cost in terms of materials and labour is significant within the built environment.

Our experimental and theoretical research, leading to the Bailey-Method, enabled the construction industry to finally address the use of unnecessary protection costs ensuring that protection to the structure is only applied to areas where it is needed. In addition, our research has led to a further design method for concrete filled tubular sections, where protection is safely eliminated altogether.

Pathways to Impact

Our research has been presented at leading conferences, at professional seminars, dedicated CPD courses and published in leading journals. We have developed practical design guides and software to promote the methods based on our research.

We developed the One-Stop-Shop dedicated web-site to Structural Fire Engineering (www.mace.manchester.ac.uk/project/research/structures/strucfire/) to promote performance-based methods to practical designers. This website was developed by Manchester with contributions from DTi (now TSB), TATA Steel, The Concrete Centre, Pilkington, Arup, and Buro-Happold. It offers authoritative and impartial advice together with training materials, attracting over 590,000 visitors within the REF period.

Reach and Significance of the Impact

a) Bailey-Method. The method has been implemented by a number of organisations, for example:

i) ArcelorMittal has presented the Bailey-Method in a number of design guides with 2500 copies distributed to companies in over 20 countries and incorporated it into their MACS+ design software which is available in 17 languages. The method was deployed in: the BOBST building (Switzerland, 2010); ArcelorMittal Steel Centre (Belgium, 2008); EVS Building (Belgium, 2008); Geric Commercial Centre in France (2013); and the BNP Bank Tower in France (2013) [A].

Other companies have used the Bailey-Method on projects between 2008 and 2013 including West Cheshire College Ellesmere Port (2008) saving £35k, Aquinas College Stockport (2008) saving £40k, and Derby Riverlights (2009) saving £65k [B].

Our survey of some of the UK’s over 30 specialist Structural Fire Engineering consultants indicates they use the Bailey-Method on about two projects each year. The typical saving per building is £60k [C]. This gives a total saving of over £20m over the REF period [D].

Prof Bailey has provided expert input to following iconic buildings in London (2008-2013,): The Shard; The Pinnacle; Heron Tower; Leadenhall; 8-10 Moorgate; and 35 Basinghall Street; [E] [F]

b) Design of concrete filled tubular sections using our software FIRESOFT.

Our fire resistant design method for concrete filled tubular sections has been implemented in the FIRESOFT software package that we have developed for TATA Steel. This software has been released to the general structural engineering design profession. FIRESOFT software and the associated quality assurance document have the British Standard status of Non Contradictory Complementary Information in the UK [G]. This software has recently been used by TATA Steel Tubes in the design of Broadgate Exchange in London (2012) and Bervis Marks in London (2012). [H]

International reach and significance

Bailey continues to be retained as an Expert Witness investigating the collapse of World Trade Centre building 7, a 47-storey building that collapsed on September 11th 2001 following the collapse of WTC1 and WTC2 due to impact by airplanes. [I].

Bailey was the principal author of a Concrete Centre design guide on “Performance of Concrete Structures in Fire” (Bailey, C.G. and Hourly, G.A., ISBN 9781904818830).

Wang has been invited to join the British Standards Institution Committee B/525/4 and to represent the UK in the Eurocode Fire Safety of Composite Structures Evolution Group that oversees the development of the next generation of Eurocodes [J].

5. Sources to corroborate the impact

[A] Letter from the Director of ArcelorMittal summarising the design guides, books and ArcelorMittal design software based on the Bailey-Method together with the building projects that have used the method.

[B] Report from Dr Athanasios Melandinos, Senior Engineer at Capita Symonds outlining the projects (including cost savings) where the Bailey-Method has been used.

[C] Letter from the British Constructional Steelwork Association summarising the importance and impact of the Bailey-Method to the construction industry, including the cost savings achieved.

[D] Report detailing method of estimating the savings from using the Bailey-Method over the REF period, using external sources.

[E] Published article ‘*A new icon pierces the capital skyline*’ outlining the design of The Shard in London and involvement by Bailey.

[F] Letter from the City of London (District Surveyor) outlining the projects where the Bailey-Method has been used and the projects where Bailey has acted as an expert reviewer.

[G] Copy of SCI (Steel Construction Institute) advisory desk note AD375 confirming British Standard NCCI (Non Contradictory Complementary Information) status of FIRESOFT, the program developed by Wang for the design of concrete filled tubular columns, and the associated quality assurance document.

[H] Letter from TATA steel confirming the projects where they have used FIRESOFT.

[I] Copy of title page and declaration of the Expert Report of Colin Bailey under F.R.C.P 26(e)(2) for the investigation into the collapse of World Trade Centre 7.

[J] Email from Associate Director Advanced Technology and Research, ARUP, Chair of British Standards Institute Committee BSI/525/4, confirming that Wang will represent the UK in the Eurocode Fire Safety of Composite Structures Evolution Group that oversees the development of the next generation of Eurocodes.