Summary

Following changes to the UK Building Regulations in 1991, the potential market for timber frame construction increased to include medium-rise buildings. To ensure that building to this height could be conducted in a safe and economic manner the Timber Frame 2000 project (TF2000) was created to investigate technical issues for multi-storey timber frame buildings using platform frame construction. The series of impressive tests and supporting research on the TF2000 building have resulted in harmonisation of the fire regulations across the UK on many issues, including the maximum build height of 18m, and design guidance for other key issues such as structural stability, differential movement and construction tolerance. This paper discusses the key issues for multi-storey timber frame construction and introduces the design guidance provided for buildings in the UK.

Keywords: TF2000, platform frame, timber frame, design guidance, whole building tests, fire safety, robustness, disproportionate collapse, differential movement, multi-storey.

1. Introduction

The well documented Timber Frame 2000 (TF2000) project provided a six-storey experimental timber frame building (Fig.1&2), the first of its kind in the world, for the sole purpose of investigating the performance and economic prospects of medium-rise timber frame buildings in the UK. A wide range of research projects have been conducted on this building and presented on an international forum covering the following performance aspects:

- Structural stability and robustness and the structural ability to withstand disproportionate collapse when subject to accidental loading
- Benchmarking the TF2000 construction against the timber frame industry and the steel and concrete framing industry. Performance indicators included productivity rate, erection value structural frame value and design lead time.
- Fire tests demonstrating compartmentation and the performance of timber stairs
- Differential movement that can be expected in-service between the timber frame, cladding and other structures such as lift shafts.
- Racking stiffness of the TF2000 building during different phases of construction
- Building tolerances for plumbness and level.
- Acoustic performance of compartment walls and floors

Areas of this research which have specific implication for medium-rise structures in the UK (defined as 5 to 7 storeys) have lead to the design guidance offered in the publication BR454[1]. This guidance is discussed further under subsequent sections of this paper.
2. Structural stability and robustness

Connections between building elements should be sufficiently robust to ensure the overall stability of the building if a wall panel or other structural element is accidentally removed. This in essence is the basis of the ‘disproportionate collapse’ requirements in the UK for buildings of 5 or more storeys, ensuring that any structural collapse is not disproportionate to the cause. To achieve this performance criteria each structural element must be checked in isolation to ensure that there is safe redistribution of the loads when that structural element is ‘notionally removed’. Tests conducted on the TF2000 building [4] to check the ‘notional removal’ of both internal wall panels and external wall panels have identified the alternative load paths depicted in Figs. 3 and 4 below.

Fig. 3: Redistribution of loads above accidentally removed internal wall panels

Fig. 4: Redistribution of loads above accidentally removed external wall panels

Loads applied during these tests and the level of loads to consider for design checks are:

- Full dead load
- 1/3 imposed loads without reduction for the number of storeys
- 1/3 wind load

Member resistances can be modified using a factor of 2.00 for duration of load when considering both the member strength and connection strength. Any structural element that, if notionally removed, does not have sufficient alternative load paths throughout the remaining structure, must be designed as a protected element and as such should be designed to withstand an applied load of
34kN/m² in any direction. The criteria for failure of the remaining structure after notional removal of a structural element are:

- Deflection of walls or floors greater than L/30 is defined as failure of that element
- Structural elements that have been overstressed after consideration of the duration of load factor of 2.00 are defined as failed.
- Failure of the building for the ‘disproportionate collapse’ design check is defined as structural collapse of 15% or more of the immediate supported floor area or more than 70% collapse of the overall structure.

To achieve a practical design for robustness the overall structure of the building need not change that much from current common practice for low-rise structures. The main considerations are in detailing connection such that alternative load paths are ensured. One such detail is the provision of a rim beam around the perimeter of each floor level that helps to span over notionally removed wall panels. Rim beams should be continuous or jointed to ensure transfer of the accidental loads to alternative supports.

3. Fire safety

One of the most impressive tests conducted on the TF2000 building was the full-scale compartment fire test designed to investigate the structural integrity and compartmentation of a multi-storey timber frame building subject to severe natural fire exposure. The results of this test, previously documented [2], demonstrated the ability of the building to withstand and compartmentalise a natural fire 10% more severe than a standard 60-minute fire resistance test. Based on the results and subsequent analysis of this test, Building Regulations across the UK have now been harmonised on two key aspects related to multi-storey timber frame buildings:

- The use of combustible materials in separating walls is now permitted up to 18m rather than 11m previously adopted as the limit in some countries,
- The use of combustible materials in external walls within 1m of boundary is now permitted up to 18m rather than 11m previously adopted as the limit in some countries.

The test demonstrated that timber frame construction can meet the functional requirements of Building Regulations in the UK and although there were no specific additions to existing design guidance [3] some important aspects of the building performance were investigated and highlighted that:

- Care must be taken to ensure that plasterboard linings are attached using all of the required fixings,
- Correct location of cavity barriers and fire stopping is important to maintain the integrity of the structure whenever the cavity of a building provides a medium for fire spread.

4. Differential movement

Allowance for movement in timber frame buildings is especially important to accommodate shrinkage and compressive movement as the timber dries in service and loads are applied to the structure. For platform frame construction, this movement is cumulative with increasing height, making it much harder to accommodate for multi-storey buildings. Buildings less than four stories height can be easily designed to accommodate this movement using the guidance and standard details already provided [3]. For the case of differential movement, where movement occurs between the timber frame and another building component such as brickwork cladding, accommodating movement can become increasingly difficult for multi-storey buildings as investigated on the TF2000 building [5].

Take for instance, the case of a six storey timber frame building with brick cladding where the designer has not made any special provision for reducing the anticipated movement in-service. Using normal construction practices for low-rise buildings could result in movements of about 75mm around the top floor windows. This amount of movement would be extremely difficult to accommodate using standard details and would probably result in cosmetic damage to the building.
It is much better for designers to reduce the amount of movement that will occur in practice and thereby ensure the movement accommodating details around windows and at other junctions are practicable. Options proposed for reducing the amount of differential movement are:

- use timber joists and header rails with a low target moisture content, typically 12% or lower so that there is very little shrinkage in service.
- substitute timber joists and headers with engineered wood products with low moisture content
- reduce the amount of timber loaded perpendicular to the grain, such as multiple-sole plates and header plates
- use clay bricks with low movement characteristics for cladding
- specify alternative claddings such as timber boarding or tiles.

The effect that some of these options have on the overall movement of a typical six-storey building is shown in fig. 5 and subsequent design guidance provided in table 1.

5. Building tolerances and procedures

Errection of the TF2000 building was monitored for construction tolerances and it became clear that multi-storey timber frame buildings require different tolerances to ensure functionality of the completed building. Most important is the levelling of the supporting foundation slab or beams which impact on the accuracy of construction for the remaining structure. Since the accumulation of construction inaccuracies can lead to unacceptable differences in level and plumbness on the top floor of a multi-storey building construction tolerances are as equally important over the building height as they are between floors. This has lead to the following recommendations based on the TF2000 experience:

- Supporting structure or foundation to be levelled within ±5mm
- Upper floors to levelled to within ±5mm for10m length or less and ±10mm over 10m length
- Maximum deviation of upper floor levels from the ground floor level to be within ±20mm
- Wall panels to be plumb within ±10mm over any storey height and not more than ±10mm cumulative over the building height

Adherence to these recommendations should ensure an achievable construction process whilst avoiding conflicts with lift shaft designs and cladding cavity issues. During construction of the TF2000 building, measurement of the construction process identified a number of benefits that can
be incorporated at the design stage:

- Strutting used for bracing sawn timber joists dramatically reduces the construction productivity; floor construction rate 100m²/day
- Proprietary engineered joists ease floor construction; floor construction rate 300m²/day
- Prefabricated cassette floors increase site productivity by up to 60%
- Pre-assembly of the trussed rafter roof construction at ground level can reduce high level work by up to 80% and gave a 40% improvement in productivity on the TF2000 building.

These lessons from construction of the TF2000 building have also been captured in the design guidance document [1].

6. Conclusions

The TF2000 project has been instrumental in identifying the potential for multi-storey timber frame construction and helped to open up new markets for buildings up to 7 storeys height in the UK. Design guidance for multi-storey timber frame construction is offered in the BRE publication BR454 [1] which addresses issues such as structural stability, differential movement and construction tolerance with particular reference to multi-storey construction. These issues have been resolved and market confidence provide through a series of high profile tests such as the fire compartment test, disproportionate collapse tests and measurements of differential movement. Although much of the design guidance is an extension of good practice for timber frame construction there are many issues that could have more dramatic consequences in multi-storey construction if not fully considered. The design guidance provides a safe and uncomplicated means of ensuring that good practice is maintained for designing and building safe and economic multi-storey structures.

7. Acknowledgements

Both Government and Industry contributions have ensured the success of the TF2000 project, culminating in design guidance for future buildings. The published guidance [1] has been produced with important contributions from M Milner, M Bullock and G Pitts, all providing key roles in its production and drafting.

8. References
