Timber Engineering:

Design of an environmentally friendly multi-storey car park

B. Torrance: supervisor Dr. D. Symons

Introduction

High rates of structural new build coupled with a worldwide supply shortage are causing a steep rise in steel price. At the same time, global warming has become a reality, and there is increasing interest in alternative, low embodied energy building materials.

Brief

Design an environmentally sustainable 500-space multi-storey car park. Conduct a comparison of costs and environmental impact with a typical steel solution.

Material choice

Timber is a widely available, flexible building material that has been in use for thousands of years, and, in the form of Glued Laminated (Glulam) timber, is a highly engineered material with good homogeneity of properties.

A timber – concrete composite main span beam makes full use of the compressive strength and stiffness of concrete, and the low density and strength in tension of timber.

Conceptual design

The car park follows the common split-level design which is compact, maintains clean external lines with ramps on the inside, and has an efficient search path with separate up and down flows.

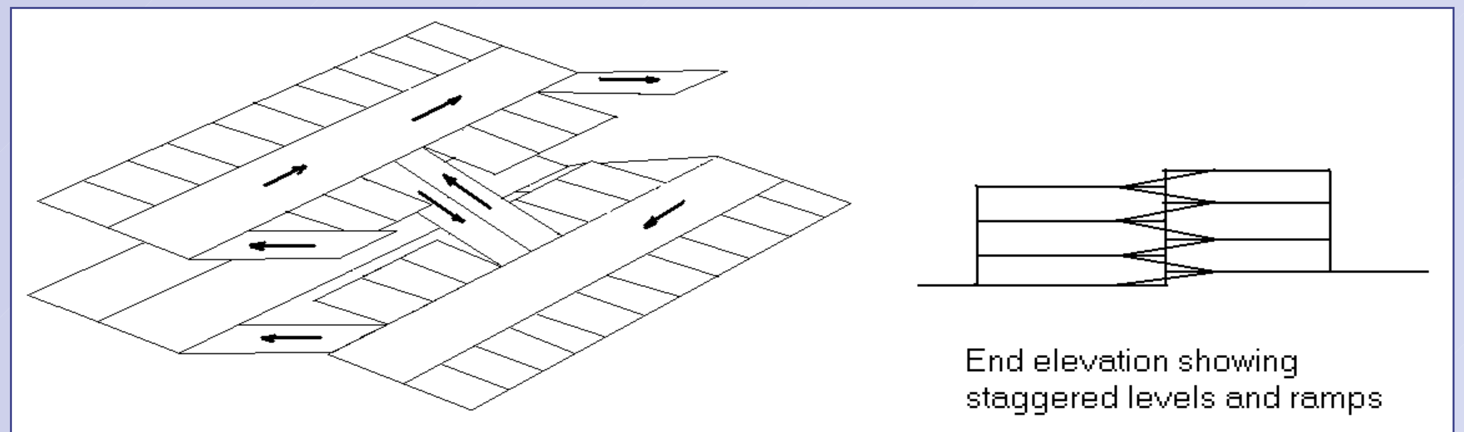

Fig. 1: Sketches of the split level concept

Basing the design around a 3 storey structural bay of span 15.5 m and length 4.8 m ensure a high degree of modularity, enabling capacities to range from 192 to 512 spaces in different length car parks using the same bay design.

Primary Beam design

The primary span of 15.5 m uses a concrete slab acting compositely with Glulam beams at 2.4 m centres (see fig.1). The shear connection is coachscrews, inserted at an angle of 30^0 to the vertical, increasing the strength and stiffness of the shear connection by 40% [1].

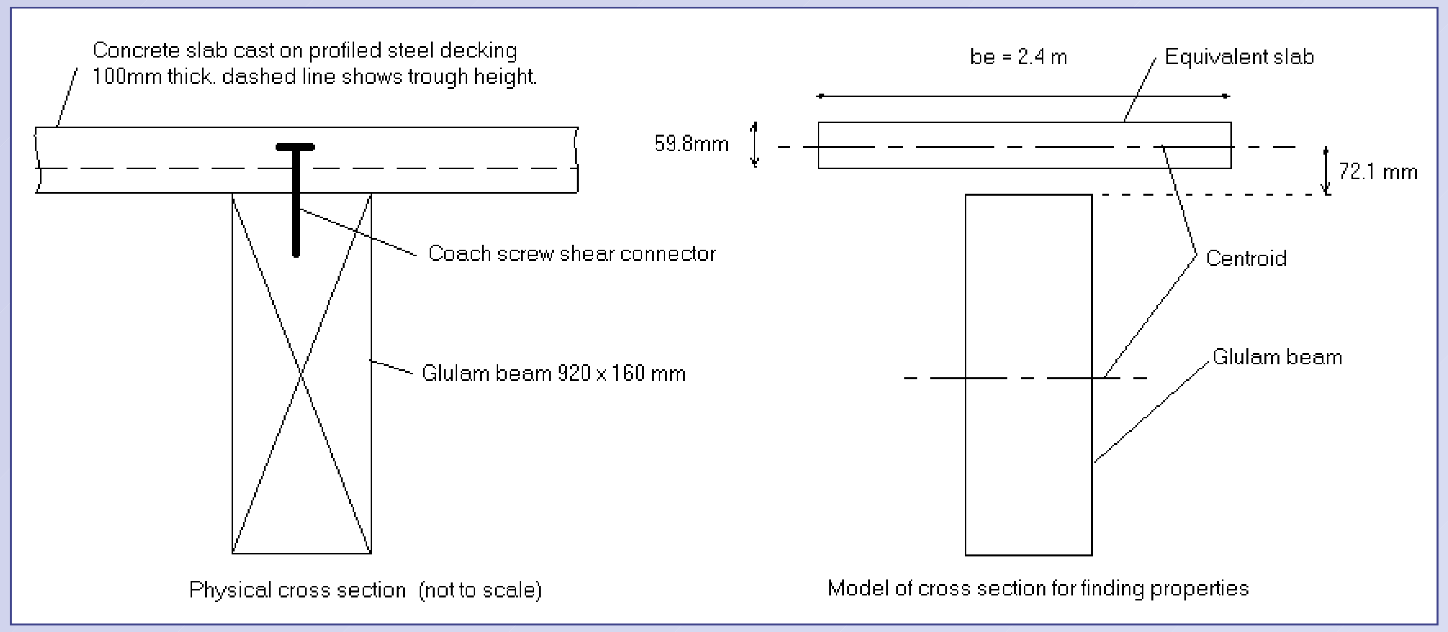

Fig. 2: Primary Beam physical cross section (left) and equivalent model (right)

Partially composite action of the primary beam

The gamma method used in Eurocode 5 [2] assumes linear shear connectors, with a reduced slip modulus K_u used to approximate plasticity at the ultimate limit state. The elasto-plastic method as described by Fontana & Frangi [3] assumes plastic capacity of the shear connection in the ultimate section capacity.

Abaqus is used to calculate the behaviour of a finite element model of half of the primary span (see fig. 3). Non-linear spring elements reflect the plasticity in the shear system at collapse, and this model is capable of taking into account thermal expansions.

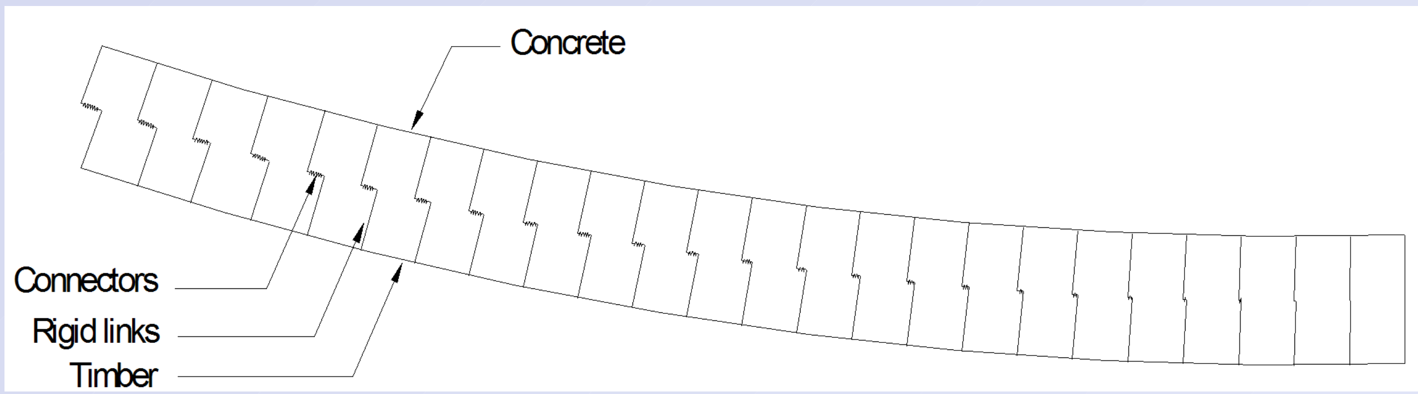

Fig. 3: Finite element half-beam model (deformed state) [1]

Comparison of Methods

It can be seen in table 1 that composite action increases the moment capacity of the beam almost twofold, and calculations show that the stiffness increases by a factor of 3. The gamma method is more conservative than the elasto-plastic method, applying a linear approximation to a case of plastic failure (in the shear connectors).

Design Method	Ultimate moment capacity (kNm)
Gamma method (BS EN1995)	538
Elasto-plastic	604
Timber beam only	329

Table 1: Composite beam moment capacity according to different methods

Comparison of cost and environmental impact

Preliminary costing of the timber frame and a steel equivalent (table 3), indicate that the timber solution comes at a relatively small £30,000 premium, which is 5% of the total project cost. Furthermore, 704 tonnes of CO_2 are saved by using timber. If steel material costs rise as expected, or governments introduce carbon taxes, timber could be financially advantageous. The equivalent timber beam for non-composite action would be 920 x 278 mm in section, so composite action saves a total of 380 m^3 timber, lowering the cost by £270,000.

Frame material	Quantity in frame	Frame cost (£)	Embodied CO_2 (tonnes/tonne material)
Steel	500 tonnes	700,000	900
Timber	850 m^3	730,000	204

Table 3: Cost and embodied CO_2 comparison for steel and timber frames

Conclusions

- Using composite beam theory enables the design of a composite beam which is 3 times stiffer and almost twice the strength of a timber beam alone, saving £270,000 in timber.
- The timber-composite frame car park design is £30,000 more expensive than a steel solution, but saves 704 tonnes CO_2.
- This design improves understanding and confidence in the use of timber in structures.

Acknowledgements:

This project has been undertaken with generous guidance and input from Whitbybird Structural Engineers and Bourne Parking.

Thanks are due to Richard Persaud, whose PhD and MPhil work this project builds on, and to my supervisor Dr. Digby Symons.

References:

[1] Persaud, R., The structural behaviour of a composite timber and concrete floor system incorporating steel decking as permanent formwork. *PhD thesis*, Cambridge University, 2004

[2] BS EN 1995-1-1, Eurocode 5: *Design of timber structures.* British Standards Institute, 2004

[3] Fontana, M., Frangi, A., 'Elasto-plastic model for timber-concrete composite beams with ductile connection'. *Structural Engineering Int.,* 2003, **13**/1, p47-57