Structural lightweight aggregate concrete

A structural engineer making an initial assessment of the above question will consider lightweight concrete (LWC) because it is lighter for the same cube crushing strength, ie, it has an improved strength to weight ratio. This is perhaps an obvious deduction for the engineer, but will he follow this through to its conclusion? In practice he will need to satisfy himself of a number of other main aspects:

- availability of the aggregates
- technical feasibility
- value for money
- suitability for use on site.

This article will address itself towards these aspects, and bring together some principal sources of data so that an informed decision can be made.

Before proceeding, it is worthwhile to pause and consider the environmental factors surrounding the supply of aggregates for concrete. In the UK natural aggregate extraction is proceeding at a rate of over 200 million tonnes/year. Now according to BS 6543: 1985[1] at least 100 million tonnes/year of industrial by-products are produced from power generation, steel making, coal extraction, etc, of which more than 70 per cent is dumped. Yet at least 25 million tonnes/year of this dumped material is suitable for lightweight aggregate in the construction industry, but current production is no more than 5 million tonnes/year. There is only one conclusion to be drawn from these facts: greater efforts should be made by government, producers and engineers to re-cycle these dumped materials. It is a major challenge and it is also eminently worthwhile.

The case is put by P M Follett, Pozzolanic Lytag Ltd

Availability

To answer the question of availability, there is enough raw material to produce a fivefold increase in lightweight aggregate production; however, some additional production facilities would also be necessary. At this time, because the use of lightweight aggregate for structural concrete is relatively low (about 5 per cent of all the manufactured lightweight aggregate produced) there is room for at least a fourfold increase in demand without additional factories. With reference to the location of suitable plants, it should be remembered that haulage costs are halved for each unit volume of lightweight aggregate, thus it can be transported twice the distance for similar cost. Deliveries to UK mainland customers can usually be made the following day. Finally, the majority of ready mix plants have spare bin capacity and are willing to supply a LWC (with natural sand fines), and in some areas of the country it is the most commonly used coarse aggregate after the local natural materials.

Technical feasibility

Structural LWC has been in use worldwide for over 50 years and has been the subject of many detailed research projects. In the UK there is over 25 years of experience and it would be true to say that there is a wealth of detailed structural knowledge about each type of lightweight aggregate, usually more than there is about any particular source of natural aggregate. A most useful reference book on the subject is the *FIP Manual of lightweight aggregate concrete*[2]. Also due to be published in early 1986 is the *Guide to structural lightweight aggregate concrete*, produced by a joint Institution of Structural Engineers and Concrete Society committee[3].

The primary benefits of using LWC in

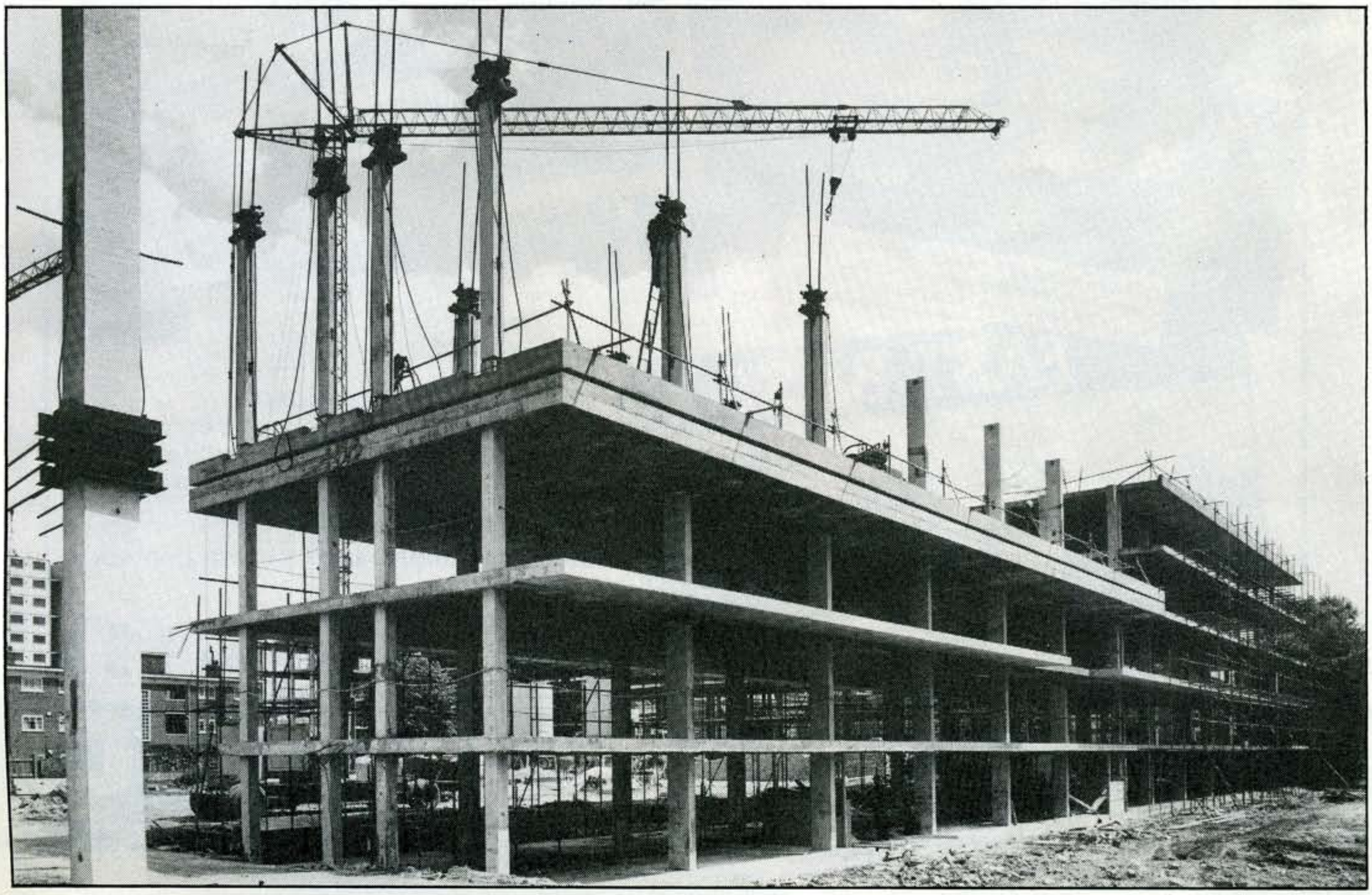

Figure 1: Lift slab floor construction using lightweight concrete at the Holly Street Housing Development, Hackney, London. Designed by Evans and Langford

Why should it be used for multi-storey structures and car parks?

multi-storey structures are in three areas:
- savings in dead load, hence reduction in reinforcement and foundations
- improvement to fire resistance
- better thermal characteristics.

Taking these benefits in turn, characteristic strengths of up to $50N/mm^2$ are available and weight savings will be about 25 per cent; thus, if a concrete element has to carry its own weight a LWC is more efficient. The overall effect of weight saving is, of course, more pronounced with lower imposed loads or awkward situations, and this is one of the keys to the successful use of LWC.
BS 6399: Part 1: 1984[4] is the code of practice for dead and imposed loads in buildings. With reference to this code, overall weight savings will be about 15 per cent for buildings other than stores and more for car parks; this ignores any additional savings due to imposed load reductions.

LWC can be used with trough or waffle void formers (nb, hollow pots are no longer available) but the option of a solid slab in LWC is always competitive and attractive from the point of view of services installation and the ability to position reinforcement most economically. Lift slab techniques (Figure 1) have been used successfully with LWC, and more recently projects using unbonded tendons (Figure 2) have been completed. The ability in both cases to save dead load in what may be a thick solid slab is useful in design.

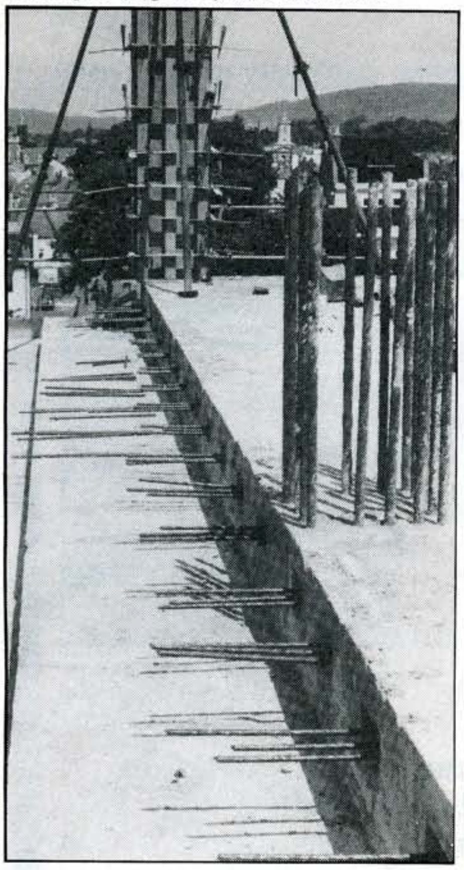

Figure 2: Flat slab flooring using lightweight concrete and unbonded tendons. Project in Cheltenham designed by Clarke, Nicholls and Marcel

An interesting practical aspect of suspended slab construction is that bay sizes can be safely increased by at least 50 per cent because: the thermal movements due to heat of hydration are reduced (lower coefficient of expansion); early drying shrinkage is reduced; the tensile strain capacity is higher[5]; plus the fact that the elastic modulus is lower.

Fire is one of the most critical limit states in a building. Although natural aggregate concrete is inherently a reasonable fire resisting material and collapse is unlikely, the damage due to spalling and deflection may be extensive. LWC is unlikely to spall and provides better thermal protection to the reinforcement. These beneficial characteristics are likely to be significant, especially where the time for remedial works should be kept to a minimum, eg, shopping centres. There is a case for economic upgrading of the fire resistance with LWC or, alternatively, investigating the possibility of reduced insurance premiums. BS 8110[6] will recognise the difference in fire performance and CIRIA Report 107[7] indicates the measured performance from recent fire tests.

Thermal performance of the concrete will not be a primary consideration for the structural engineer. However, with a thermal conductivity perhaps half that of a natural aggregate concrete, together with similar thermal mass, the energy saving benefits in use are likely to be significant over, say, a 50-year building life.

This section would not be complete without assessment of the durability and structural performance compared with normal aggregate concrete. First, here are some facts regarding durability of LWC:
- Cement contents have to be 10–15 per cent higher for LWC. This results in a lower w/c ratio and a paste of better quality
- Hydration of the cement paste is more complete because of the reservoir of moisture stored within the aggregate
- Crack paths do not exist around the surface of the aggregate
- For structural LWC rates of carbonation have been found to be the same when compared with natural aggregate concrete[8]
- Lightweight aggregates are not susceptible to alkali-aggregate reaction
- In controlled tests for permeability the figures for LWC were measured at two orders of magnitude lower[9]
- Recent work on marine structures[10] and highway bridges in the USA[11] indicates clearly that there are no long-term durability problems associated with correctly formulated LWC
- Additional cover of 10mm is required by our codes when exposure conditions are more severe than mild. There is evidence to suggest that this is not necessary but it is a useful additional safety factor for the engineer.

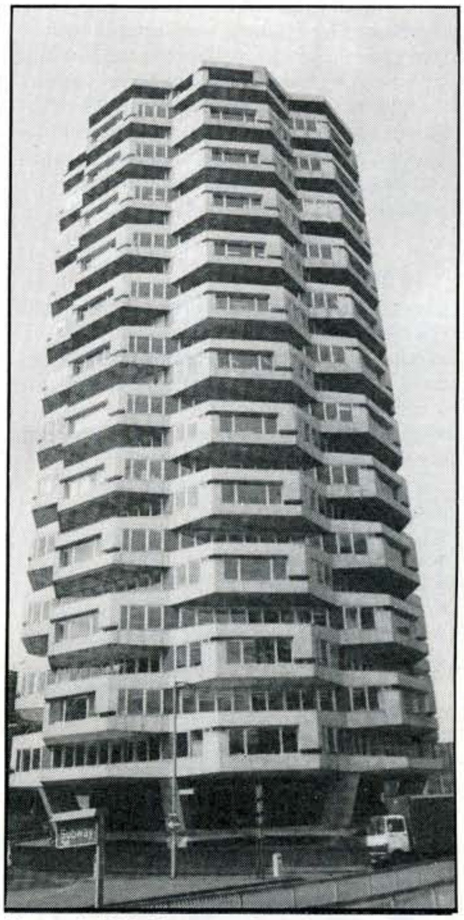

Figure 3: NLA Tower at Croydon, which uses lightweight concrete floor slabs. Designed by Ove Arup and Partners

In the area of structural performance LWC is restricted by the codes of practice for items such as shear, bond, etc. This does not mean that failure is more likely. It means that, on average, after extensive tests a reduced figure would be acceptable to cover all types of LWC. In fact, for LWC using sand fines the restrictions are too conservative for all items except elastic modulus. It is likely, therefore, that for LWC over $1750kg/m^3$ the restrictions, except for elastic modulus, will be lifted in due course.

Value for money

The unit cost of LWC is more expensive, but the reductions due to reinforcement and foundation savings, etc, are available. It is unfortunate that our system of quantity surveying is primarily concerned with the unit price of materials — it does not accommodate any consequential cost savings. This point is clearly made in a recent Concrete Society report[12] which emphasises the value for money aspects of using LWC. Two interesting projects which amplify this point are shown in Figures 3 and 4.

The NLA Tower, Croydon, gave the option for solid slab LWC or coffered slab normal concrete in the tender documents. Suffice to say the contractors, who are interested in costs not unit prices, priced the LWC alternative cheaper and quicker so the building was constructed that way[13].

Guy's Hospital Tower is another example where the use of LWC was directly beneficial, this time to the structural engineer. The building was initially too heavy, so the choice to shorten the building, increase the foundations depths or lighten the structure had to be made[14]. LWC was chosen again, representing the most suitable solution as it enabled the foundations and building height to remain as initially planned.

Figure 4: Guy's Hospital Tower near London Bridge Station, all the in situ concrete uses lightweight aggregate. Designed by R Travers Morgan and Partners

Site practice

Earlier in the article the primary benefits of LWC were identified. There are a number of what can be called secondary benefits and these contribute to the value for money:

- easy to cut, drill and fix
- cheaper temporary works and shuttering
- reduced craneage and labour requirements, for both concrete and reinforcement
- good finishes, can be directly decorated
- self-curing ability
- less shutter wear
- larger bay sizes with fewer joints
- good seismic and impact resistance
- reduced tendency to crack.

With regard to site practice all techniques are possible with LWC; the concrete has been slipformed, power floated, gunited, vacuum dewatered, pumped, and air entrained. It should be noted that pumping and vacuum dewatering are better suited to LWC with natural sand fines.

Conclusion

It is hoped that the contents of this article will promote the consideration of structural LWC at the early stages of each project.

Secondly, it is hoped that the environmental factors concerning the supply of aggregates receive greater exposure; lightweight aggregates for concrete can prevent the depletion of our natural resources.

References

1. BS 6543: 1985. Use of industrial by-products and waste materials in building and civil engineering. British Standards Institution.
2. FIP Manual of lightweight aggregate concrete. Surrey University Press, second edition.
3. Guide for structural lightweight aggregate concrete. To be published in early 1986 by the Institution of Structural Engineers.
4. BS 6399: Part 1: 1984. Design loading of buildings. Code of practice for dead and imposed loads. British Standards Institution.
5. Harrison, T A. Early age thermal crack control in concrete. CIRIA Report 91. CIRIA, London.
6. BS 8110: Parts 1 and 2: 1985. The structural use of concrete. Due to be published later this year.
7. Lawson, R M. Fire resistance of ribbed concrete floors. CIRIA Report 107. September 1985. CIRIA, London.
8. Grimer, F J. Durability of steel embedded in lightweight concrete. CONCRETE Vol 1, No 4, April 1967. pp 125–131.
9. Bamforth, P. Concrete used for storage of cryogenic liquids with special reference to temperature effects. Concrete Society symposium, Newcastle, December 1984.
10. Structural lightweight aggregate concrete for marine and offshore applications. Concrete Society Technical Report No 16. Ref no 51.078. Available from the Cement and Concrete Association.
11. Draft report on the durability of lightweight concrete in highway bridges. Federal Highways Administration, USA.
12. A case study of the comparative costs of a building constructed using lightweight aggregate and dense aggregate concrete. Concrete Society Technical Paper No 106. Ref no 53.043. Available from the Cement and Concrete Association.
13. Ryalls and Henry. Island site, Addiscombe Road, East Croydon. Arup Journal, Vol 4, December 1969.
14. Mould. Tower block development, Guy's Hospital article. The Structural Engineer, January 1971.