Polystyrene aggregate concrete subjected to hard impact

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Impact loading can be of various kinds, as follows

- (a) sufficiently frequent and predictable to require a design based on energy dissipated elastically and ensuring adequate fatigue life and energy to rupture: e.g. ships coming alongside berths, vehicles striking protective barriers on motorways
- (b) high energy impact which, although foreseeable, occurs only very rarely and for which it is enough to ensure survival of the structure even at the expense of considerable damage: e.g. collision between vessels at sea, ships berthing out of control, earthquakes. It should be noted that the collapse of certain structures is so dangerous (e.g. dams, nuclear reactors) that, however improbable, the extreme load may have to be taken into account as if it were of the first category
- (c) the extreme of impact which, although undoubtedly possible, is too rare to warrant serious consideration, e.g. a meteorite. Alternatively, the impact is not only rare but protection against it is too expensive to be justifiable. Therefore, the impact from a falling jumbo-jet is not taken into account in the design of low-rise housing even though it must be taken into account in the case of a nuclear reactor pressure vessel.

36. The subject of the Authors' paper is particularly relevant to the second category of structure—that exposed to rare but foreseeable high energy impact. The structure can be designed to function as in category (a), but under rare load, a member made of a frangible material such as that described is sacrificed and in so doing dissipates very large quantities of energy. It is not difficult to make the member both inexpensive and, more important, easy to replace so that the smallest possible delay elapses before the structure is in full use again.

37. The Authors' curve in Fig. 1 for an ideal energy absorbing material is very close to that found for 300 mm cubes of expanded polystyrene; the proportions differ with different densities, of course, but all show a remarkable recovery after compression strains approaching 90% (a typical curve is shown in Fig. 15). It is possible that this is because, as the foam consists of closed cells, the inner cells are restrained from rupture and regain their former shape.

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Much research has been undertaken at Imperial College to aid the design of offshore sub-surface oil storage tanks; in particular, the problem of protection

DISCUSSION

Fig. 15

from accidental impact caused by dropped objects. This type of loading belongs, of course, to the second category of loading outlined by Sir Alan. Indeed, any structure capable of being subjected to a loading situation, no matter how rare, which could lead to effects that cannot be tolerated, must be designed to withstand the extremity of the event, as is slowly being realized after the events in Chernobyl.¹²

39. Certainly, the recovery behaviour observed in Fig. 15 for the expanded polystyrene cubes suggests a toughness of the inner cells which could help explain the difference observed between the static and impact penetration responses for the test blocks shown in Fig. 11 (see § 22). It should be recalled that the static penetration depth was measured under an applied load during the test, while the impact penetration depth was measured after the load had been applied and then removed, allowing for 'instantaneous' recovery to take place. This is substantiated by the underestimation of crushing energy when compared with the projectile's kinetic energy given in Fig. 14 (see § 29) and, further, it explains the spongy nature of the impacted area.

40. However, some care must be taken when comparing the response of polystyrene aggregate concrete with the aggregate material itself (i.e. a cube of expanded polystyrene). To understand better the differences in behaviour, this type of concrete should be regarded as a mortar skeleton, with lightweight inclusions that exhibit little resistance. Uniaxial compression tests of polystyrene aggregate concrete cylinders exhibit a stress-strain response with a shape similar to that obtained for normal aggregate concrete.¹³ This is to be expected for a lightweight aggregate concrete, since a loaded cylinder will transfer the internal forces through the mortar matrix¹⁴ and, hence, cause failure by longitudinal cracking through the matrix before crushing can occur, whereas both the impact and static penetration test results reported in this Paper, and most likely the test described by Sir Alan, actually fail by crushing. In general, it was found that the compressive cylinder

response and penetration response were not directly comparable because of differences in their respective failure mechanisms.

41. As a postscript to this Paper, we should like to mention more recent work,¹⁵ using a simple spring-mass model (employing the static penetration resistance tests to estimate the non-linear spring stiffness in the contact zone) to calculate the contact force–time relationship during impact. This method provided very good agreement with the experimental results of this Paper and can be used to provide more accurate estimates of penetration depth (and, hence, the minimum material thickness needed to provide adequate impact protection) than the approximate method outlined in §§ 28–30.

References

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