Movement of unbonded post-tensioning tendons during demolition

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Investigators who undertake research projects of direct application to design and construction deserve the encouragement and gratitude of the design and construction community. The Authors merit particular commendation for undertaking such a practical problem as the demolition of structures in which unbonded post-tensioned tendons have been used.

56. While we have no direct experience of demolition of post-tensioned structures, we have experience in the premature failure, de-tensioning, removal and replacement of unbonded tendons on account of corrosion. Our experience is at variance with the Authors' conclusions from their research.

57. The Authors have summarized their conclusions in the final paragraph as follows: 'For all combinations of tendon length and axial load at release, displacements are unlikely to exceed 100 mm'.

There is considerable hearsay evidence of cut tendons which have emerged from slab anchorages in projectile fashion and have travelled considerably greater distances than 100 mm. We have firsthand experience of a 0.5 in diameter seven-wire strand which shot out of its anchorage after the grout plug had been removed, and travelled approximately 30 ft before coming to rest. Regardless of this research, our advice is to stand well clear. Indeed, in § 10, the Authors write of the hazards of cutting tendons under high tension in the laboratory.

59. The tendons of which we write were all installed in loose-fitting sheaths, an advantage if they are to be replaced but a disadvantage from the corrosion standpoint (water can flow along the sheath and significant amounts can collect therein).

60. Engineers frequently express concern at the reluctance of their fellows to publish information on failures of structures. The reasons given, apart from embarrassment, are usually litigation or insurance. In the circumstances, a brief revelation of failures of tendons would perhaps be not only appropriate, but also welcome.

61. The stress wave theory which the Authors have developed is not dissimilar to that developed for pile driving. However, the writers view the release of a tendon in a rather more simplistic fashion. A cut end, remote from its anchorage, is snapped towards the anchorage by the unbalanced force with considerable velocity. Obviously, if the elongation between anchorage and cut is of the order of 100 mm or more, significant momentum is induced by the transformation of potential energy to kinetic energy. As the moving tendon comes up against its anchorage, it will push the anchorage out. The Authors believe that friction or viscous damping

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in the sheath dramatically retards this movement and that grouted anchorage embedments arrest anchorage displacement. While we agree with the latter belief, we doubt the former, as the experience related below forcefully demonstrates.

62. Our most recent experience is with a multi-storey, longspan floor office building, in which a post-tensioned concrete joist system was used. This system is composed of tapered ribs or beams, 5 in wide at the soffit, 18 in deep, and spaced at 36 in centres. A $2\frac{1}{2}$ in thick, monolithically placed concrete slab spanned between the ribs. Each rib contained two seven-wire strands, in addition to deformed reinforcing bars. (The two tendons were composed of a single strand, looped at one side of the building and secured in a double anchorage at the other). An initial survey of the fifteen-year old building revealed five exposed broken tendon pairs out of almost 700 pairs. In all visible failures, a loop of strand, approximately 6 ft in length, had burst through the concrete rib. The loop was always remote from the actual strand failure. In our view, this indicated that, at failure, the failed end accelerated rapidly, was resisted by a competent grouted anchorage and, in effect, buckled laterally where it was able to overcome the lateral restraint of the concrete rib.

63. Since we had no knowledge of when the tendons had failed, we concluded that water had entered the tendons during construction, and that failure ensued within a reasonable time period. However, since beginning this investigation, another tendon has failed, causing us to reconsider our conclusion. The hazard potential of this form of construction, with which we wish to acquaint our fellow engineers, is exemplified by this latest failure. A piece of the concrete rib burst through the ceiling, and landed adjacent to an office worker's desk. Fortunately, this occurred when the building was unoccupied.

64. The removal of short sections of concrete rib and sheath in a randomly selected sample of 60 tendon pairs identified two failures, which were not apparent, and free water in two other tendons.

65. In case it is concluded that these problems are unique, we hasten to point out that they are, in fact, typical of at least five structures that we have been called on to investigate. Furthermore, in response to published discussion,²¹ the second-named contributor received correspondence from engineers scattered widely on the North American continent who all had firsthand experience of the hazards of unbonded tendons.

66. In fairness to the industry, we should recognize the steps taken during recent times to prevent rapid deterioration of unbonded tendons. The promoters and users of this system have both recognized the potential for failure that arises from the following: the crude manual application of grease not specially formulated for the purpose; the few inches of bare tendon which was usual at dead end anchorages; the lack of seal between the sheath and anchorage; the vulnerability of anchorages with their inherent voids; and the difficulty of sealing anchorages exposed to the exterior environment with a material which shrinks, namely cement grout or mortar. All these problems have now been addressed. Nevertheless, the old adage, 'Once bitten, twice shy', summarizes our feelings.

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The demolition of prestressed concrete is a matter which will attract increased attention as more prestressed structures reach the end of their useful life. Therefore, any addition to the body of knowledge concerning the behaviour of such

structures is most welcome, and we should like to encourage other engineers to pass on their experiences in this field.

68. However, the unbonded system to which Springfield and Kaminker refer appears to be fundamentally different from the system which we have examined in our Paper. Their discussion refers to tendons in loose-fitting sheaths, whereas our Paper is concerned with the system widely used in flat slab construction, in which the tendons are immersed in grease and enclosed in a tight plastic casing. Our laboratory tests showed that, even in the absence of a grouted-in anchorage, the damping effect of this grease was sufficient to inhibit significant tendon motion.

69. Our conclusions regarding overall tendon movement are in good agreement with published observations from full-scale demolition exercises. Lindsell²² reports displacements at the anchorages of the order of 10 mm, although no details of tendon length or stress level are given. Barth and Aalami²³ report the cutting of over 900 tendons, with no large movements occurring in any case. In particular, Barth and Aalami monitored the cutting of 326 unbonded tendons of approximately 60 m length; the grouted-in end anchorages were dislodged in only two instances. This finding corresponds well with our conclusion that little or no movement would be expected for lengths in excess of 30 m.

70. We are surprised at the comments regarding the restraining effect of grouted anchorages. Our tests showed conclusively that the energy required to cause failure of such an anchorage represents only a small proportion of the stored strain energy in a typical tendon. Again, we can presume only that the anchorages described were substantially different from the ones studied in our research programme, which are used widely in the UK.

References

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