SOME SEISMIC ASPECTS OF COUPLED SHEAR WALLS

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SYNOPSIS

Two features of the behaviour of coupled shear walls, studied in a continuing research project at the University of Canterbury, are briefly presented. The ductility, hence the elasto-plastic performance, of deep coupling beams, in which shear is often the cause of failure, can be greatly improved if the principal reinforcement is placed diagonally. Another potential weakness in shear walls, a non-ductile failure along horizontal construction joints, can be eliminated using the concept of shear friction. It is shown that adequate vertical reinforcement across coarse textured joints can assure that even under alternating cyclic loading such joints will not become the weakest link of the resisting mechanism in shear walls.

INTRODUCTION

In many multistorey buildings the earthquake imposed lateral forces are resisted by shear walls which contain one or more rows of openings. Short and often relatively deep beams between adjacent cantilever walls constitute the coupling between these walls. The performance of such beams strongly affects the efficiency of the load resistance in coupled shear walls. Previous studies[1] of the elasto-plastic response to seismic type of static lateral loading indicated large ductility demands for the coupling beams. These beams, because of their short span, are subjected to large shearing forces when they develop their full flexural capacity.

Deterministic seismic oriented design approaches to coupled shear walls rest on the premise that the gravity load carrying walls should be the last ones to be damaged. This implies that all coupling beams over the full height of the structure should develop their strength before yielding could occur in any of the walls. During the process of developing the full strength of the whole structure some of the coupling beams may have to undergo large plastic distortions[1]. Conventionally reinforced beams, with a span to depth ratio of less than 1.5 , were found to be unable to supply these theoretically required ductilities[2]. After a few cycles of alternating loading a vertical sliding shear failure, parallel to the stirrups, occurs[3]. Stirrups provided even in excess of the maximum possible shear demand can not prevent this failure. The observation led to a search for alternative solutions.

DIAGONALLY REINFORCED COUPLING BEAMS

Experiments showed that the ductility of coupling beams can be considerably increased if, instead of the conventional arrangement, the principal reinforcement is placed diagonally as suggested in Fig. 1. The design can be based on the premise that the shearing force, to be transferred from one wall to the other, resolves itself

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into diagonal compression and tension forces, intersecting each other at midspan where no moment is to be resisted. Initially the compression component is transmitted mainly by the concrete. However, after the first excursion of the tension bars into the yield range large cracks form and upon load reversal the reinforcement across these diagonal cracks will have to carry the compression at yield strength level. As an equal amount of steel is to be provided along each diagonal the loss of the contribution of the concrete is without consequence, as long as the diagonal bars do not become unstable. It is therefore necessary to provide ample ties, perhaps in the form of spiral winding as suggested in Fig. 1, so as to retain the concrete within the reinforcing cage. This concrete is required to provide flexural rigidity against lateral buckling of the compression cage. Fig. 2 shows the load rotation relationship for such a typical coupling beam. The hysteresis loops for 13 load cycles bear the characteristics of a steel member. Strength degradation, when it occurred,was found to commence with the buckling of the compression bars. However, upon load reversal these bars take up tension and straighten themselves. Repetition of this process leads eventually to the complete disintegration of the concrete around and within the compression bars. The superior response of diagonally reinforced coupling beams to high intensity alternating cyclic loading is compared in Fig. 3 with that of conventional beams. It is expressed in terms of the cumulative ductilities imposed during the tests. The load is shown as a percentage of the theoretical strength capacity of each beam. The span to depth ratio of these beams varied between 1.03 and 1.29. These findings are currently being re-examined in one quarter full size seven storey reinforced concrete coupled test shear walls.

HORIZONTAL CONSTRUCTION JOINTS ACROSS SHEAR WALLS

Earthquakes have been the cause of sliding movements along horizontal construction joints. The type of damage or worse, non-ductile failure, should be avoided. Therefore the following design criteria are suggested:

(a) A construction joint should not form the weakest link in the chain of structural resistance. As shear is the governing mode of load transfer it is necessary to ensure that the shear strength of a joint is equal but preferably larger than the shear (diagonal tension) strength of the shear wall itself.

(b) Under moderate loading shear displacements and crack widths should be small enough so as not to interfere with functional requirements or require repair.

(c) The desired surface preparation should be afforded by the simplest possible means.

A well prepared construction joint will produce a rough surface and hence it could transfer shearing forces by means of aggregate interlock. The mechanism is also referred to as "shear friction" or "interface shear transfer". As soon as the sliding movement commences a crack, formed along the construction joint, will tend to widen. Means which will prevent or delay the opening of such a crack will necessarily boost the interface shear capacity. Any clamping force acting across the joint, either applied externally as a load or generated internally by means of vertical reinforcement, can be utilised for this purpose. Its load carrying effect is made use of in the traditional sense of the friction concept. For well prepared construction joints a friction factor of 1.0 appears to be adequate.

In an experimental project the respose of horizontal construction joints to monotonic and alternating cyclic shear loads was studied. In particular the effects of various surface preparations, the bond between old and new concrete and the amount of reinforcement passing through a joint was examined[4]. In some specimens the interface shear transfer from concrete to concrete was completely eliminated so as to enable the contribution of the dowel action of the reinforcement alone to be determined. This was found to be significant only after large shear displacements, which are likely to cause other forms of distress in a shear wall. Fig. 4 shows typical shear stress-shear slip relationships along a construction joint for a constant concrete cyclinder strength, $f'_c = 4000$ psi, and constant steel content of $\rho_v = 0.69\%$. The bottom curve shows the contribution of dowel action only. The other curves show the concrete interface shear transfer with dowel action excluded. The top four curves show the results for rough, coarse textured surfaces upon which the fresh concrete was placed directly without any other treatment. When bond along the surface was eliminated the slip along the joint was approximately doubled. The inferior performance of a smooth (trowelled) surfaced joint with bond is also evident. Fig. 4 also shows three significant design shear stress levels. One is based on a friction coefficient of $\mu = 1.0$ and the second on $\mu = 1.4$. The third ($v = 10\sqrt{f'_c}$ psi) represents the absolute maximum average shear stress to which a shear wall section would ever be subjected to according to current American practice. The curves show that a design based on a friction factor of 1.0 should provide ample safeguard against distress along a construction joint. Tests with alternating cyclic loading indicated that this shear stress level can be maintained for many cycles. When the vertical wall reinforcement provided a yield force of over 250 lbs per in^2 of construction joint area the failure plane was formed below the construction joint in a layer of inferior concrete.

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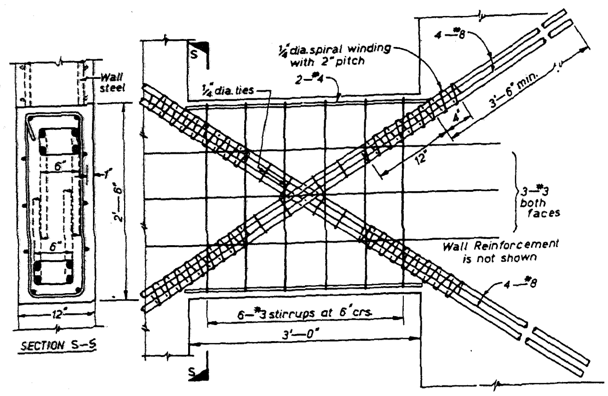

Fig. 1. Prototype of a diagonally reinforced coupling beam.

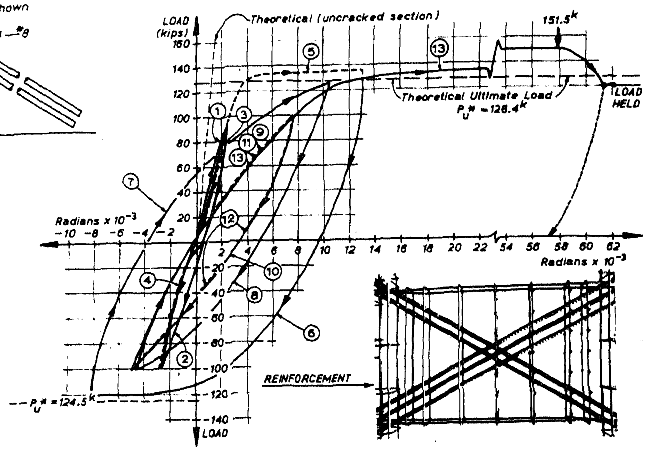

Fig. 2. Typical load rotation relationship for diagonally reinforced coupling beams.

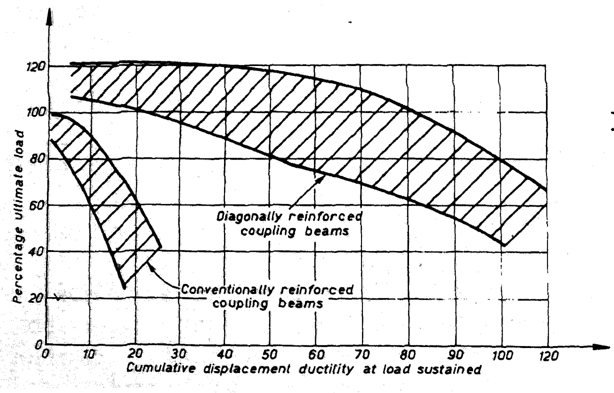

Fig. 3. The range of cumulative ductilities sustained at observed load levels in deep coupling beams.

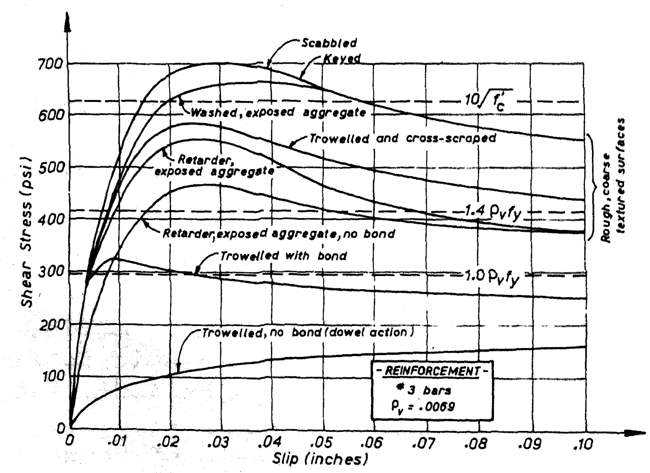

Fig. 4. Nominal shear stress-slip relationships for various surface preparations of construction joints.