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Design principles concerning the strengthening of coupling beams

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ABSTRACT: The paper presents practical solutions and design principles, concerning the repair and strengthening of coupling beams damaged by earthqakes. These solutions are the result of experimental and theoretic studies presented at the IX-th European Conference on Earthquake Engineering (Moscow 1990). One solution refers on the restoration of the bearing capacity of the damaged beams, by injecting the cracks with epoxy resin. The other solution consists of jacketing the coupling beams with reinforced concrete, in order to restore or increase their bearing capacity and postelastic features. The chosen solution depends on the damage level and the prevalent stress. The paper presents, four solutions for strengthening the damaged coupling beams by jacketing with reinforced concrete, including the appropriate technologies. The proposed solutions have been tested up to breaking: The experimental results are in agreement with the calculus, the increases of the experimental and theoretic bearing capacities being quite the same.

1 INTRODUCTION

The technical literature and the actual standards vaguely refer to solutions for strengthening the coupling beams of the reinforced concrete monolithic shear walls, damaged by a seismic action. Their assimilation to reinforced concrete beams, damaged by gravitational actions, makes no differential selection, according to the type or level of the damage and has no regard of the fact that a seismic action, after exhaustion, leaves the building elements in a remanent damage state, typical for this stress.

The experimental studies that led to these conclusions, elaborated by Mihaescu, Tudor, Ciuhandu, Ianca (1990) and Tudor, Ciuhandu, Ianca (1991), contained tests made on ten coupling beam models, using a 1:2 scale, strengthened and retested up to breaking, under a load simulating a seismic action.

The experimental researches covered two damage levels, of 75% and 90% respectively, of the breaking force.

Two strengthening types were considered for the two damage levels: epoxy resin injection and respectively reinforced concrete jacketing.

The experimental models consolidated thus were retested up to breaking, observing the remaking degree of their bearing capacities, stiffness and postelastic features.

The remedy way - repair/strengthening - is chosen according to the degree of influencing the behaviour of the coupling beams, to the possibility of reoccurence of similar stresses (that determined their damage) and to the necessity of increasing the safety degree in exploitation.

Consequently, the investigations performed by the authors allowed the adoption of certain repair measures, experimentally tested, both for damages caused by shearing or bending and for different levels of damage of the coupling beams.

The theoretical considerations regarding the repair solutions are elaborated by Mihaescu, Tudor, Ciuhandu (1990).

2 CONSIDERATIONS ON THE REPAIR SOLUTIONS

The repair of the coupling by injecting the cracks with epoxy resins is done only, when the remaking of the initial performances is intended, without the increasing of the bearing capacity of the coupling beams and their postelastic features.

The strengthening of the coupling beams by jacketing is done for the remaking or the increasing of their bearing capacity and ductility.

The results of the experimental measurements performed with regard to the occurrence and opening of the cracks in the elements tested up to a stress level of about 90% of the failure value are given in table 1. The required solutions of strengthening by cracks injection and by jacketing with reinforced concrete have been established on account of these data.

Table 1. Strengthening methods with regard to the maximum openings of cracks

Prevalent stress with a max.crack opening	Max.size the crack opening w(mm)	Strengthening method
Cracks produced by shearing forces:		
Isolated,inclined diagonal cracks with no crushes or exfoliations in the concrete	$0.3 < w$ $w \leq 1$	Epoxy resin injection of all cracks
High-density cracks,prevailing the inclined, diagonal cracks, with local crushes and exfoliations in the field of the coupling beam	$1 < w$ $w \leq 2.5$	Jacketing with reinforced concrete
Inclined,largely opened and high-density cracks, with dislocations of the concrete in the field area, buckled or broken reinforcements	$w > 2.5$	Rebuilding of the coupling beams
Cracks produced by bending moments:		
Cracks occurring at the ends of the coupling beam without crushing the concrete	$0.3 < w$ $w \leq 1.5$	Epoxy resin injection of all cracks
High-density cracks,prevailing the vertical cracks-at the ends of the beam with crushing and exfoliations of the concrete in this area	$1.5 < w$ $w \leq 5$	Jacketing with reinforced concrete
Vertical cracks with large openings at the ends of the coupling beams,concrete dislocation,buckled or broken reinforcements in this area	$w > 5$	Rebuilding of the coupling beams

The bearing capacity is considered to be the horizontal failure force of experimental elements. Analysing the way the failure of reinforced experimental elements takes place, it is noted that the character of breaking has been preserved on both types of strengthening, as compared to reference models.

Strengthening by jacketing of the coupling beams with prevalent shearing force is done, by covering the reinforced concrete with a layer of 5-6 cm thickness on the both sides of the coupling beam. The reinforcement can be done with welded wire fabric (Figure 1) or with independent bars (Figure 2).

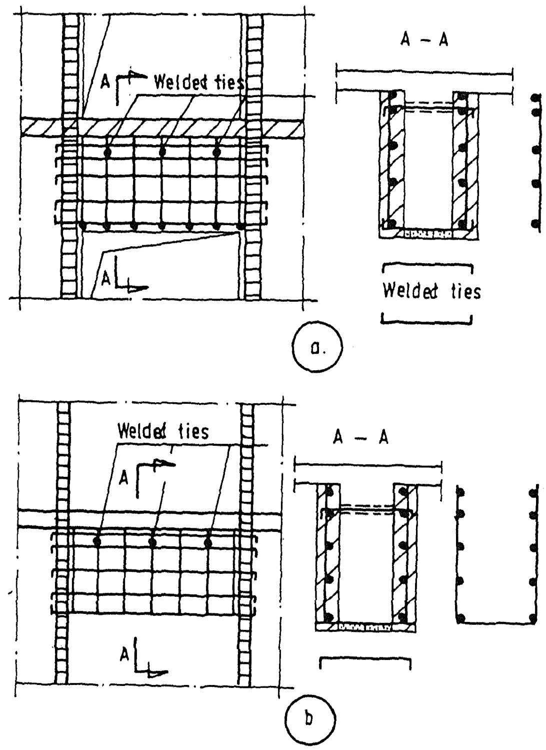

Figure 1. Strengthening by reinforced concrete jacketing with welded wire fabric.

The welded wire fabric are connected on the both sides of the beam by ties, introduced under the floor level in the holes done in the coupling beam (Figure 1a).

A second solution is similar to the first one, the difference being in using a transversal reinforcement continous at the bottom of the beam (Figure 1b). This system allows the use of different reinforcements according to the needs.

In case of the reinforcement with independent bars, the longitudinal reinforcements are to be welded to the reinforcements of the pillars (walls), that border the hole. The stirrups, either cross the floor and are fixed on its upper side (Figure 2a), or are linked to the two sides of the beam under the floor with ties (like in the welded wire fabric),or welded on steel plates, that are going to be fixed with ties. (Figure 2b).

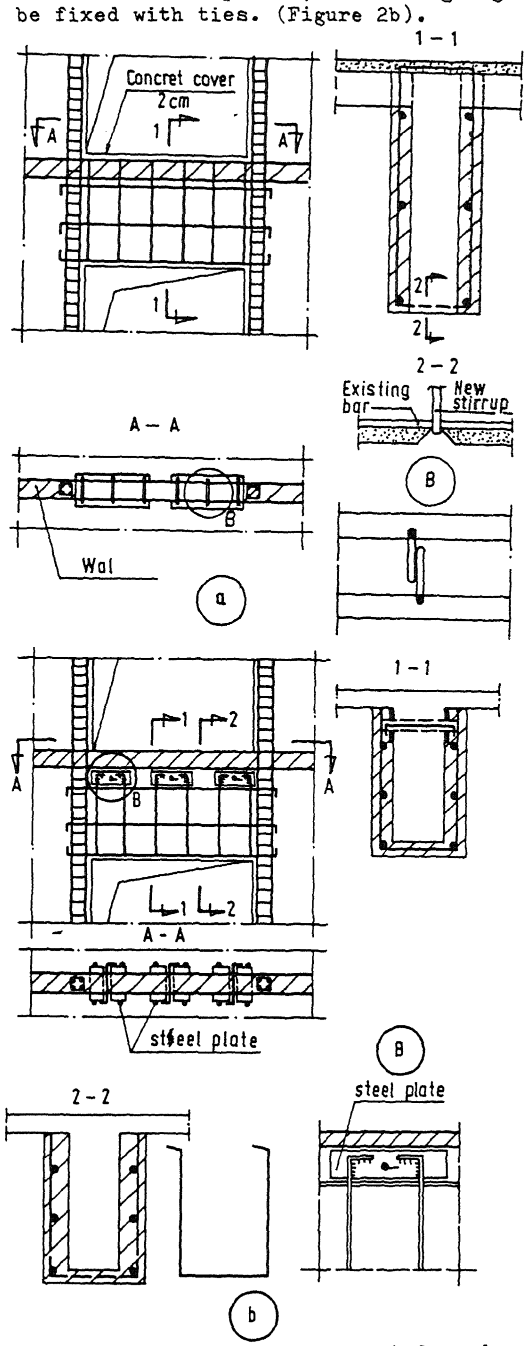

Figure 2. Strengthening by reinforced concrete jacketing with independent bars.

The strengthening by jacketing of the coupling beams, where bending is prevalent is done according to the same constructive solutions and the complying with the technologies used in the previous situation, taking into account the specifications presented in the design principles.

3 DESIGN PRINCIPLES

The repair of the coupling beams of the shear walls with openings is done according to their level of damage.

The repair of the coupling beams by injecting the cracks with epoxy resins will be done according to the usual procedure, when the reestablishement of the initial performances of the coupling beams is intended.

When the damaged building is placed according to the present-day regulations in an area with a higher safety degree against earthquakes, than that of the designing moment, the static calculation must be reconsidered according to the new loads and an appropiate strengthening of the coupling beams must be done.

The strengthening by jacketing of the coupling beams will be done, by using a reinforced concrete layer of 5-6 cm tickness on the both sides of the coupling beam (Figures 1,2).

The designing of the reinforced concrete jacketing, for the coupling beams damaged by shearing, must take into account the contribution of the whole concrete section and that of the longitudinal reinforcement of the initial beam and of the jacketing; as transversal reinforcement, only the stirrups of the coating will be considered. In addition, it is recommended to consider an unexhausted reserve of 10% of the bearing capacity at shearing of the initial beam.

The design of the reinforced concrete jacketing, for the coupling beams damaged by bending, will consider the contribution of the whole concrete section and that of the stirrups of the initial beam and of the jacketing; as longitudinal reinforcement, only the bars displaced in the jacketing will be considered. In addition, it is recommended to consider an unexhausted stock of 10% of the bearing capacity at bending of the initial beam.

The taking into account of the whole concrete section is justified by the confinement effect realised by the stirrups of the jacketing. The stock of 10%, recommended to be considered, is explained on the basis of the investigations done by the authors, as due to the fact that, the reinforcement (longitudinal and transversal) has not exhausted his resistance capacity yet, at the damage level considered for this solution.

The strengthening of the coupling beams by reinforced concrete jacketing must be restrictive, by an appropriate calculation only to the remaking, as precise as possible, of the initial beam capacity. To this purpose, the following condition must be observed, (with insuring to shearing force):

$$\frac{M_{cap.strength}}{M_{cap.initial}} = 1...1,15 \qquad (1)$$

where: $M_{cap.strength}$-capable bending moment after strengthening;

$M_{cap.initial}$-capable initial bending moment.

If relation (1) is not observed, the stiffness ratio coupling beam/wall may change after strengthening, so it is necessary to correlate the strengthening of beams with that of the walls.

The hypothesis recommended have been experimentally tested to the theoretical results, the same increase of the bearing capacity being observed.

4 CONCLUSIONS

As a consequence of the experimental researches and of the theoretical studies, two repair - strengthening variants were concluded: injection of the cracks with epoxy resins and reinforced concrete jacketing.

Coupling beams damaged as a consequence of seismic actions, presenting remanent shearing cracks - with an opening of max. 1.00 mm - and bending cracks respectively of max. 1.50 mm can be strengthened by epoxy resin injection of the cracks.

Coupling beams with 2.50 mm remanently opened shearing cracks and max. 5 mm bending cracks, extended all over the beam surface as well as concrete damage can be strengthened by reinforced concrete jacketing of laterals walls.

With coupling beams presenting higher damage levels than the previous ones, the entire rebuilding is recommended.

The steps the designer must follow in drafting the strengthening by jacketing, are as follows :

- establishement of the damage type, at bending moment or shearing force, according the typical image of the cracks;
- determination of the capable initial shearing forces and bending moments and testing the assurance of the coupling beam at shearing force;
- design of the reinforced concrete jacketing, depending on the damage type, taking into account the unexhausted resistance reserve and resulting the resistance reinforcement and,implicitly, that with constructive characteristics;
- checking of the assurance at shearing force, resulted after designing the jacketing;
- checking of the possible growth of bearing capacity in order to limit it, according to prescriptions given;
- realisation of the execution details of the strengthening according to the recommended technology.

The solutions of strengthening by jacketing in Figures 1, 2 are not restrictive, the designer having the freedom to adopt new solutions, according to the prescriptions in use.

REFERENCES

Mihaescu, A., Tudor, D., Ciuhandu,G. and Ianca,S. 1990. Research on the repair and strengthening of coupling beams in coupled shear walls damaged after earthquakes. Proc.9 th ECEE.Moscow.

Tudor, D., Ianca, S. and Ciuhandu, G. 1991. Design elements of the repair of the coupling beams damaged by earthquake. Proc. 15 th. NCC: tome 2. Timisoara.