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Retrofitting & Repairing with Composite Materials

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Abstract - Many expansive methods are available for retrofitting structures and choice of suitable method/material is a challenge to a structural engineer. The term retrofit is used if the damaged structure performance was satisfying than before with some additional resistance then the term retrofit will be representative. A new method of strengthening and upgrading various types of concrete structures is presented. The advantages of the present method, over conventional retrofitting methods, are discussed. A literature review of existing retrofitted structures along with experimental works and various analytical and design approaches for strengthened structural member are introduced. The feasibility and the effectiveness of the method is discussed.

Keywords: retrofitting, composite material

1. Introduction

Retrofitting is strengthening of existing structures or structural elements to enhance their performance with new technology, features, and components. Generally retrofitting can be classified in two categories:

1. Global retrofitting
2. Local retrofitting

A. Global retrofitting: The global retrofitting technique targets the seismic resistance of the structures. It includes adding of shear structure, adding of steel bracings, adding of infill structure and base isolation. Shear structures can be introduced in a building with flat slabs or flat plates. These can be provided in the exterior frames with least disruption of the buildings use.

B. Local retrofitting: Local retrofitting technique targets the seismic resistance of a member. The local retrofit technique includes the concrete, steel or fibre reinforced polymer jacketing to the structural members, like beams, columns, foundation, and beam column joint. Concrete jacketing involves adding a new layer of concrete with longitudinal reinforcement and closely spaced ties. The jacket increases both the flexural strength and the shear strength of the beam or the column.

There are several factors that control the choice of the retrofitting technique for RC structures, some of these factors are:

• The deficiency in the existing structure and its expected mode of failure.

• The goal of intervention (e.g. increased stiffness, strength, ductility, etc).
• Consequences of structure rehabilitation (e.g. increased demand on foundation, etc).
• The allocated budget for retrofit.
• Physical constraints (e.g. architectural requirements, accessibility of the building during the retrofitting process, etc).

2. Retrofitting of Structure by Composite Materials

Fibre-reinforced polymer (FRP) composite materials have received an increasing attention in the past few decades as a potential material for retrofitting of existing structures due to their high strength, light weight, ease of application, Figure 6 Retrofitted RC structure using steel bracings at 1.0 % drift and their high resistance to corrosion. FRP laminates, sheets or rods can be used, and the fibres might be pre-stressed to increase the efficiency of retrofit. The use of FRP composites offers also a faster and easier retrofit alternative, especially when the evacuation of the entire building during the retrofit is not possible, in that case FRP will provide the required strength without interrupting the use of the building.

ADVANTAGES – All structural problems have more than one technical solution, and the choice of solutions will ultimately rest upon economic evaluation of the alternatives. Enlightened clients will ensure that this evaluation includes the total cost that will be incurred during with a minimum initial cost.

The potential advantages of FRP composites plate bonding are as follows:

- Strength of Plates: FRP composites plates may be designed with components to meet a particular purpose and may comprise varying proportions to different fibres. The ultimate strength of the plates can be varied, but for strengthening schemes the ultimate strength of the plates is likely to be at least three times the ultimate strength of steel for the same cross-sectional area.
- Weight of Plates: The density of FRP composite plates is only 20% of the density of steel. Thus, composite plates may be less than 10% of the steel weight with same ultimate strength. Apart from transport costs, biggest saving arising from this is during installation. Composite plates do not require extensive jacking and support system to move and hold in place. The adhesive alone will support the plate until curing has taken place. In contrast, fixing of steel plates constitutes a significant proportion of the works costs.
- Versatile Design of systems: Composite plates are unlimited length, may be fixed in layers to suit two directions may be accommodated by varying the adhesive thickness.
- Reduced Mechanical Fixing: Composite plates are much thinner than steel plates of equivalent capacity. This reduces peeling effects at the ends of the plates and thus reduces the likelihood of a need for end fixing. The overall depth of the strengthening scheme is reduced, increasing head-room and improving appearance.
- Durability of Strengthening System: There is the possibility of corrosion on the bonded face of steel plates, particularly if the concrete to which they are fixed is cracked or chloride contaminated. This could reduce the long-term bond. Composite plates do not suffer from such deterioration.
- Improve Fire Resistance: Composite plates are a low conductor of heat when compared to steel, thus reducing the effect fire has on the underlying adhesives. The itself chars rather than burns and the system thus remain effective for a much longer period than steel plate bonding.
- Maintenance of Strengthening System: Steel plates require maintenance and painting and access costs as well as the works costs. Composites plates

will not require such maintenance, reducing the whole life cost of this system.

- Ability to Pre-Stress: The ability to pre-stress composites opens up a whole new range of applications for plate bonding. The plate bonding may be used to replace lost pre-stress and shear capacity of the section be increased by the longitudinal stresses induced. Formation of cracks be inhibited and the serviceability of the structure enhanced. Strengthening of materials such as cast iron also becomes more practicable.

Strengthening ID elements (Beams and Columns) - Tests of reinforced concrete beams, strengthened with epoxy bonded steel plates. Results of these tests showed, on one hand, a significant increase in the flexural stiffness and in the load capacity with thin cracks well distributed, but on the other hand failure mode had changed from a ductile yielding mode to a brittle one, i.e., separation of the strengthening plate from the concrete. Full scale loading tests on the strengthened M5 motorway bridge in Quinton, U. K. reveal an increase of about 11% of the flexural stiffness and a reduction of existing crack width by 35%-40%. Light-weight FRP laminates, developed for high performance military aircrafts, can offer major advantages for retrofitting of existing structures and replace steel plates with overall saving in the order of 25%. A comparison of the behavior members strengthened by FRP with conventional steel plates, reveal that FRP plated beams are superior in terms of failure loads and ductility. The plate separation failure mode is common to the two retrofitting methods. Various anchorage methods of the retrofitted strip were used in an attempt to prevent the brittle plate separation. Such methods were partially successful when the strip edges were wrapped around the concrete beam thus creating a combined shear and flexural strengthened beam. Seismic strengthening RC columns is achieved by wrapping the FRP sheets or straps around the column thus improving the confinement of the concrete, and thereby the strength and ductility of the column.

Strengthening 2D elements (Walls, Slabs) - Another important application of the method is strengthening of two-dimensional structural elements, like concrete and masonry walls, slabs and even natural stone plates. The experiments of such application pointed out the effectiveness of the strengthening process to an extent that non-structural masonry walls were capable of resisting out-of-plane seismic inertial forces and became structural load carrying members with sufficient ductility.

3. Conclusion and Discussion

From the short review the following conclusions can be drawn:

1. Comprehensive experimental work, carried out in the last two decades, demonstrates the efficiency of the method in strengthening different kinds of structures members such as beams, plates, masonry walls and others, along with the brittle failure modes. Satisfactory prediction of these failure modes are in scarce.
2. The plate separation failure mode is the main obstacle of such structures. A full picture of the stresses involved and prevent of this mode of failure is a necessity. Anchoring methods that consist of bolts, externally links and wrapping of the beams edges have been considered to some success.
3. The conventional RC theory should be used very carefully for design of such members since in most cases the failure mode consist of breakage of the concrete under the ordinary reinforcement and not necessarily at the cross-

section subjected to the maximum bending moment. Hence, an additional or alternative design approach should be used.

4. Various approaches where used for analyzing the behavior of strengthened members. Numerical analyses using F.E. solutions have been used successfully for the general global behavior of the retrofitted member but failed to predict the behavior in the vicinity of the edges, as a result of the singularities involved. Another approach replaces the glue layer with an equivalent elastic foundation, represented by normal and shear springs. Although it provides satisfactory predictions of the overall behavior, it violates equilibrium equations and boundary conditions and yield inaccurate results in the vicinity of the singular conditions. Failure predictions based on this approach compared bad with experimental failure loads and modes.

5. The survey reveals that there are no proper analytical solutions for the different kinds of retrofitted RC elements, which fulfill equilibrium and boundary conditions accurately.

6. A different new analytical approach, that fulfils equilibrium and boundary conditions, is being developed with the ability to handle the singularities involved when using the FRP strengthening methods such as plate separation, end anchorage in beams or slabs, local behavior in the vicinity of debonded zones and cracks in the concrete and the global behavior of the strengthened member.

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