

Methods for flexural strengthening of reinforced concrete elements using steel plates

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Abstract. When reinforced concrete elements are incapable of safely sustaining the anticipated load, flexural strengthening may be necessary. Two major construction methods have been reported in literature for strengthening reinforced concrete (RC) elements in bending. These methods include Externally Bonded Reinforcement (EBR) and Near Surface Mounting (NSM). The aim of this paper is review these methods, including the extensive surface preparation that must be performed on bonded elements. Previous investigations have shown that these techniques are effective in salvaging old and distressed reinforced concrete structures. This paper identifies the problems associated with the utilisation of steel plates as strengthening material for RC elements in EBR and NSM techniques.

Keywords. Reinforced concrete, flexural strengthening, externally bonded reinforcement, near surface mounting, scabbling, epoxy bonding, steel plates

Introduction

The most common structural elements that resist loads in bending only are beams and slabs. If these elements are not properly designed and constructed, some problems, such as excessive deflection, flexural and shear failure as well as materials degradation (for example, spalling of concrete and corrosion of steel) may occur. To prevent total collapse, the elements may require flexural strengthening. Flexural strengthening may also be required if there is a change in the use of a structure, and this change results in an increase in the applied loadings. Primarily, strengthening is a means of enhancing the structural performance of an existing structure beyond its current level. When the strength of a concrete structure is enhanced and its design life extended, several economic and environmental problems can be avoided since concrete is bulky and rarely recycled [1].

A steel plate is one of the materials used in the flexural strengthening of RC elements. This is usually carried out by gluing the plate to the concrete element's tension face, using epoxy glue. Essentially, two methods are available in which this task can be achieved, and these include Near Surface Mounting (NSM) and Externally Bonded Reinforcement (EBR) [2, 3]. A number of investigations on these methods have been reported in the literature, and these range from experimental, analytical to

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field application of the technique [4-6]. From these studies it has been found that when adequate bond exist between the concrete elements and the epoxy-bonded steel plates, the ductility of the concrete element increases significantly [7]. Additional advantages of using steel plates for strengthening RC elements include enhanced ultimate strength capacity and flexural stiffness, tensile strain reduction resulting from composite action as well as improved serviceability performance through reduced deflection and crack control [8-9]. Strengthened RC beams with thin plates have been found to reach their full flexural capacity before failure and devoid of shear peeling [6-7]. Although some work on the influence of the plate parameters has been investigated this work is not comprehensive enough, and needs further investigations. This will assist to standardize the design and construction specifications.

Other strengthening materials include carbon fibre reinforced polymers (CFRP), glass fibre reinforced polymer (GFRP) and aramid fibre reinforced polymer (AFRP) [10, 11]. According to Jumaat *et al* [10], these advanced materials are used in special applications where other benefits of low maintenance, corrosion resistance, fire resistance, lightweight and long span, override any cost disadvantage. It should be noted that, fibre reinforced polymers (FRP) are very expensive and not readily available in Africa, as they have to be imported from advanced countries where they are being produced. The cost of FRP can be ten times as much as that of steel plates, and they are brittle at failure [6, 11]. Although the problem of corrosion of steel has been stated as one of the disadvantages of steel plating, grades of steel which are corrosion resistant are now available at much cheaper cost than FRP. Durability of steel can also be increased by using protective long-life coatings, such as hot-galvanizing or other coatings. The American Galvanizers Association [12] projected that hot-dipped galvanized (HDG) items will last 75 to 100 years in an aggressive marine environment. For steel plates that require painting it should be noted that today's paints are now expected to last for about 30 years before a major touch-up of a modern three coat paint system [13].

Strengthening with externally bonded (EB) plates has been practiced for more than 50 years, and today this method is still popular worldwide. The popularity of steel plates is due to the easiness of its application on site, little addition to the concrete element size and enhanced internal lever arm, which translates to increased moment capacity [11, 14]. It is observed that most of the investigations in this area have been carried out under static loading, but very few studies are available on investigations with dynamic loading. Analysis for dynamic loading is very important in the design and rehabilitation of bridge, stadium, dance hall and gallery structures. This paper reviews the various investigations on the use of externally bonded (EB) steel plates in strengthen RC elements in bending. This is done with a view to update information on the technique, identify some problems associated with the technique as well as identifying some missing gaps for further studies, in order to standardise this technique.

1. Overview of the flexural strengthening using plates

The structural behaviour of beams and slabs is similar in most respects, however, slabs have their own unique structural properties in that their thicknesses are considerably smaller than their other dimensions, shear reinforcement is not normally required due to higher shear span/depth ratio [15] and their flexural reinforcement spacing differs from that of beams. Due to these factors, the results of beams strengthening studies

cannot be just extrapolated to slabs. Researchers [4, 10, 14] have credited the pioneering work in the post-construction strengthening of RC elements to L'Hermite and Bresson [16] who first reported on the use of epoxy to glue steel plates onto the concrete surface to improve its load carrying capacity. Research thereafter continued in this area until the 1990s, and during this period many RC structural members were successfully strengthened with steel plates in the Netherlands and United Kingdom [11, 14]. According to DOT BA 30/94 [17] the bridges that were successfully strengthened with steel plates in UK include (i) Quinton Bridge (M5) near Birmingham in 1975; (ii) Swanley Interchange (M25) in 1977; (iii) Brinsworth Road Bridge (M1) in 1982; (iv) Stainsby-Teversal Road bridge in 1986 and (v) Brandon Creek Bridge (A10) in 1985. Also, Fleming and King [18] used steel plates as externally bonded shear and flexural reinforcements in South African and reported an increase of both shear and bending strengths of the steel plated beams. Since then several buildings and bridges have been successfully strengthened in South Africa using steel plates. Two major construction methods have been reported in literature for strengthening reinforced concrete (RC) elements in bending. These methods include Externally Bonded Reinforcement (EBR) and Near Surface Mounting (NSM) [2, 19]. The use of either of these two methods does not have any adverse effect on the headroom.

1.1. Externally bonded (EB) steel plates

This method involves mounting the strengthening steel plates at the tension surface of the concrete using adhesive of adequate properties. Most of the failure modes in plate strengthening are associated with the externally bonded (EB) or surface mounting technique. It is noted that most of the early investigations [4, 14, 20] have adopted EB technique for plate strengthening of RC elements due to the simplicity of its installation.

1.2. Near surface mounted (NSM) steel plates

In this method, the strengthening steel plate is usually installed in pre-made groove on the tension face of RC element with the aid of an appropriate adhesive. This method has been adopted in recent studies to overcome some of the failure modes in the externally bonded (EB) reinforcement [20, 21]. The method gives a better aesthetic appearance to the structural element being strengthened as the steel plate could be fixed to completely level with the surface of the concrete. Another advantage is that the steel plate could be covered with thin layer of mortar to protect it from corrosion and/or fire effects. However, the effectiveness of this method depends on the provision of adequate cover to the original reinforcement bars; otherwise it would be difficult to develop a groove of adequate depth.

The NSM strengthening technique is an effective method, and epoxy grout or cement grout can be used for its surface finishing. It increases the stiffness and load carrying capacity of the strengthened beams as well as reduces debonding and other premature failures of the elements in bending [22].

2. Surface preparation (SP) of the materials

The technique of bonding steel plates to concrete slabs surface requires high quality control and good workmanship. For composite action to exist between the concrete and

steel surfaces, both concrete and steel must be properly prepared. However, few authors [2, 6, 23] have given details in this regard. Chajes et al. [2] and Aykac et al. [6] used grinding wheel to prepare the concrete surface while Bruwer and Dundu [23] used scabbling machine for the same purpose. Zhang et al. [9] used chiseling method to roughen the concrete surface and electric grinder to roughen the steel plate surface. The use of scabbling machine for surface preparation of the concrete is considered better for effective exposure of the aggregates and for situation in which only certain portion is to be exposed, such as for slabs. Generally, the preparation of the bonded surfaces involves scabbling of the concrete and gritblasting of the steel plate surfaces, before gluing both materials together with an appropriate epoxy [14, 20, 22]. Wire-brushing and high pressure air must be applied to remove the dust and grid remnants from the concrete surface before the application of the primer and epoxy. Gritblasting of the steel plate surface to a white metal finish is done to remove any surface mill scales, grease or oil that may interfere with the gluing process. In the surface mounting (SM) or externally bonded (EB) reinforcement method, the scabbling of concrete surface is performed to remove the weak mortar laitance and expose the well bonded aggregates in order to increase the surface frictional grip between the RC element and epoxy laden plate [14, 23]. As for the near surface mounting (NSM) method, the groove is prepared to an appropriate depth within the concrete cover, to create space for the steel plates. Figure 1 shows the beams with the grooves and plates, installed into the grooves. It can be observed that the plates are levelled with the soffit of the beam and can be covered with a thin layer of adhesive or cement grout to achieve smoothness and better aesthetic finishing.

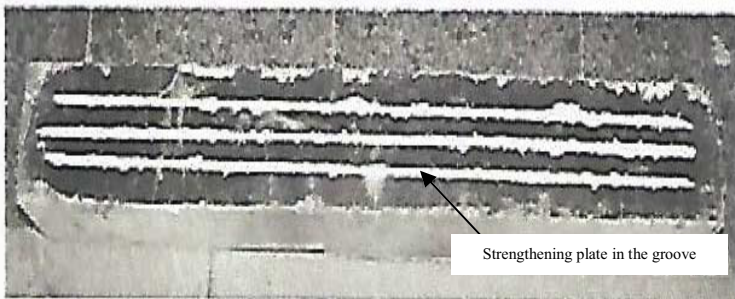


Figure 1. Near surface mounted strengthened reinforced concrete beams [22].

The epoxy consists of two coats; a primer adhesive and a two-part (resin and hardener) epoxy adhesive. The primer adhesive is mixed first and applied onto the prepared concrete surface. This gives it time to penetrate deep into the hairline cracks of the concrete and provide a surface ready for the application of the epoxy adhesive. The two-part epoxy adhesive is mixed thoroughly with low speed mechanical mixer to prevent entrained air that can adversely affect bonding and an appropriate thickness is applied on the grit-blasted steel plate. The resin and the hardener are usually of different colour, and the uniform colour of their mixture is an indication of adequate mixing [17]. Finally, the steel plate is pressed onto the soffit of the RC concrete slab and the two parts are allowed to bond for about 5 days. It should be noted that the thickness of the epoxy influences the composite action of the strengthened element. Thicker adhesive layer leads to stress lag [24, 25].

Figure 2 shows scabbled surfaces from the current investigation. The scabbled surfaces were achieved using the pneumatic machine. About 3 mm depth of scabbling was conveniently achieved, and it can be observed that this is adequate as the aggregates have been well exposed before the steel plate is bonded to the concrete surface. It should be noted that it may be necessary to putty fill any void or bug holes that might have been created by the removal of some loose aggregates during scabbling. This is done to prevent the formation of air bubbles at the concrete-epoxy interface that may adversely affect bonding between the steel plate and the concrete.



(a) Scabbling process



(b) Completed scabbled surface

Figure 2. Scabbled concrete slabs

3. Conclusions

This paper has shown that a lot of investigations have been carried out on the use of steel plates in strengthening and increasing the flexural strength of reinforced concrete elements, using Externally Bonded Reinforcement (EBR) and Near Surface Mounting (NSM) techniques. The techniques have been found to be very effective. The use of near surface mounting (NSM) of plates is a recent development but its effective usage may be jeopardized by inadequate concrete cover. Since the strengthening techniques are generally applied to old structures the information about the concrete cover and reinforcement arrangement may not be available. Even when the concrete cover is available it might not be adequate enough to accommodate the grooves required in near surface mounting method. NSM could also damage the reinforcing bars during the preparation of the grooves. Based on these shortcomings, the externally bonded (EB) strengthening technique has better practical application than the near surface mounting (NSM) technique.

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