ARTICLE IN PRESS
Alexandria Engineering Journal (2014) xxx, xxx–xxx

HOSTED BY
ELSEVIER

Alexandria University
Alexandria Engineering Journal
www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Strengthening of RC bridge slabs using CFRP sheets

Fahmy A. Fathelbab, Mostafa S. Ramadan, Ayman Al-Tantawy *

Structural Engineering Department, Faculty of Engineering, Alexandria University, Egypt

Received 7 October 2013; revised 30 August 2014; accepted 16 September 2014

KEYWORDS
Slab;
Strengthening;
CFRP;
FEM;
ANSYS;
Modeling

Abstract Many old structures became structurally insufficient to carry the new loading conditions requirements. Moreover, they suffer from structural degradation, reinforcement steel bars corrosion, bad weather conditions...etc. Many official authorities in several countries had recognized many old bridges and buildings as structurally deficient by today's standards. Due to these reasons, structural strengthening became an essential requirement and different strengthening techniques appeared in market. Fiber Reinforced Polymer (FRP) strengthening techniques established a good position among all other techniques, giving excellent structural results, low time required and moderate cost compared with the other techniques. The main purpose of this research is to study analytically the strengthening of a reinforced concrete bridge slabs due to excessive loads, using externally bonded FRP sheets technique. A commercial finite element program ANSYS was used to perform a structural linear and non-linear analysis for strengthened slab models using several schemes of FRP sheets. A parametric study was performed to evaluate analytically the effect of changing both FRP stiffness and FRP schemes in strengthening RC slabs. Comparing the results with control slab (reinforced concrete slab without strengthening) it is obvious that attaching FRP sheets to the RC slab increases its capacity and enhances the ductility/toughness.

1. Introduction

Strengthening of structural members using Fiber-Reinforced Polymer (FRP) is one of the most powerful methods to enhance and raise the capacity of an individual members as well as the whole structure to resist the applied loads in its different levels, which are greater than the resistance capacity of the structure without strengthening. Strengthening improves the mechanical properties of an individual member along with the whole structure up to failure like ductility, toughness, cracking behavior and post-buckling behavior [1,6].

The benefits of strengthening with FRP became obvious when a large number of reinforced concrete bridges in USA and other countries are structurally deficient by today's standards [7]. The main contributing factors lead to the need of the strengthening were change in structure use, increase in load requirements, corrosion deterioration due to exposure to an aggressive environment, or the desire to enhance the structure behavior under certain load type like cyclic loads. In order to

* Corresponding author. Tel.: +20 1003368911, +965 60072918.
E-mail address: asatstr@yahoo.com (A. Al-Tantawy).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2014.09.010
1110-0168 © 2014 Production and hosting by Elsevier B.V. on behalf of Faculty of Engineering, Alexandria University.

preserve those bridges, rehabilitation considered essential to maintain their capability and to increase public safety Kachlakev et al. [5].

Many researchers have found that FRP composite strengthening is an efficient, reliable, and cost-effective means of rehabilitation [5]. American Concrete Institute committee 440 (ACI 440) established design recommendations and guidelines for FRP applications to reinforced concrete whether strengthening or design.

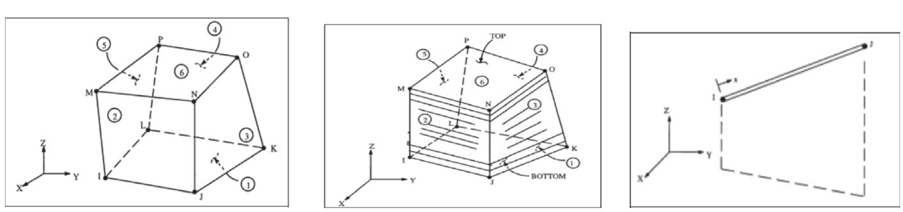
FRP typically organized in a laminate structure, such that each lamina (or flat layer) contains an arrangement of unidirectional fibers or woven fiber fabrics embedded within a thin layer of light polymer matrix material. Fibers are typically composed of carbon, aramid or glass, provide the strength and stiffness. The matrix is commonly made of polyester, epoxy, or nylon, binds to protect the fibers from damage, and to transfer the stresses between fibers. There are two additional types of FRP composite, bidirectional fibers which are used commonly for strengthening and design the two-way slab, and the FRP robs which became competitor alternative for reinforcement steel bars [8].

2. Literature review

Vasquez and Karbhari [9] studied experimentally six real scale specimens; the authors studied the failure mechanisms and post-debonding response. The first and the fourth specimens were rectangular slabs 6.0 m length, 3.20 m width and 0.18 m thickness with reinforcement mesh top and bottom, the rest of specimens were with cutout as rectangular opening measuring 1.0 m length and 1.60 m width cut in the center of each slab specimen. The specimens were divided into two groups based on the configuration of the loading. Group ''A'' consists of the first 3 specimens loaded in two points, spacing between them 2.36 m at mid line of the slabs length. Group ''B'' consists of the next 3 specimens loaded in two points spacing between them 2.30 m at mid line of the slabs width. The authors stated that, for group ''A'' after removal of the cutout region in the un-strengthened slab the first yield noticed at load 4.5 ton, the slab suffer of increasing flexure cracks in length and deflection beyond the first crack till failure which took place at load 6.7 ton. In case of the strengthened slab, failure was due to debonding of FRP strips, in load of first yield only very short and thin hairline cracks noted, the first indication of damage was noticed through cracking of adhesive at a load of 5.8 ton. The strip closest to the edge of the cutout showed the first signs of local debonding with cracking of cover concrete at a load of 16.3 ton, subsequent to which the load increased with progressive increase in peeling of the strips within the concrete cover up to a load of 16.7 ton.

Arduini et al. [2] studied experimentally 26 real scale slabs; the strengthening system consisted of CFRP laminates applied by manual lay-up, Type S with no overhang, and Type C with a cantilevered overhang. Each group was further divided into four sets (T1–T4) based on different amounts of internal steel reinforcement in tension and compression. Within each slab set, two different levels of CFRP strengthening (L1–L2) were investigated. The typical slab was 5.0 m length, 1.5 m width, and 0.24 m thickness with mesh reinforcement top and bottom. The bending tests that were carried out in the laboratory by a hydraulic jack provided the load that operated under displacement control. The authors stated that, the FRP ultimate strain for specimen (S-T2L2) that failed by concrete shear is very low while the strain in (S-T2L1) that failed by fiber rupture is approximately 0.0082. Specimens (S-T2L2) and (S-T4L2) showed extensive flexural cracking prior to failure, for specimens (S-T1L2), (S-T3L2), and (S-T4L1) the failure was by FRP laminate peeling starting at a flexural crack and progressing towards the support, and pre-cracking of the slab prior to FRP installation did not greatly influence the overall flexural performance of the member.

Ebead and Marzouk [3] studied experimentally 9 two way square slabs 1.90 m dimensions and 0.15 m thickness with different reinforcement amounts, the test specimens were simply supported along the four edges with corners free to lift and were centrally loaded through the column stub. The authors determined the reinforcement ratio depending on the failure mode, whereas the failure mode of slabs with reinforcement ratios less than or equal to 0.5% is normally a flexural mode and for reinforcement ratios of 1.0% or more are likely to fail due to a punching shear mode. The authors stated that, specimens with a reinforcement ratio of 0.35% indicated the lowest first crack loads of 7.3, 7.0, and 6.8 ton, the first crack loads of 8.4, 8.0, and 8.3 ton recorded for the specimens with reinforcement ratio of 0.5%, the first crack loads were 8.9, 10.3, and 9.6 ton for specimens with reinforcement ratio of 1.0%. The use of CFRP (Carbon Fiber Reinforced Polymer) and GFRP (Glass Fiber Reinforced Polymer) increased the equivalent reinforcement ratio slightly compared with the reference specimens. The deflection value decreased as the reinforcement ratio increased, the deflection at the ultimate load decreased from 42 to 24 mm as the reinforcement ratio increased from 0.35% to 1.0%. For the flexural strengthening specimens, the slope of the load–deflection curve was higher than that of the corresponding reference specimens, the average deflection at the ultimate load of the flexural strengthening specimens was approximately 0.6 that of the corresponding reference specimens. The flexural strengthening specimens experienced a smaller deformation compared to the corresponding refer-



(a) Solid65 (b) Solid46 (c) Link8, 3-Dlink

Figure 1 Used modeling elements.

Please cite this article in press as: F.A. Fathelbab et al., Strengthening of RC bridge slabs using CFRP sheets, Alexandria Eng. J. (2014), http://dx.doi.org/10.1016/j.aej.2014.09.010