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STRENGTHENING OF BRIDGE DECKS BY ADDING NEW CONCRETE LAYERS

Ourania T. Tsioulou[1], **Andreas P. Lampropoulos**[2], **Eftychia C. Apostolidi**[1],

Nikoleta P. Karela[1] **and Stephanos E. Dritsos**[1]

[1] Department of Civil Engineering
University of Patras, 26500-Patras, Greece
e-mail: tsioulou@upatras.gr
eapostolidi@upatras.gr
nkarela@upatras.gr
dritsos@upatras.gr

[2] School of Environment and Technology
University of Brighton, Lewes Road, BN24GJ Brighton, UK
e-mail: A.Lampropoulos@brighton.ac.uk

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Abstract. *Deterioration or need to increase the load bearing capacity of bridge decks requires the strengthening of the decks by the addition of new elements. Placing reinforced concrete layers to strengthen or repair and strengthen concrete bridge decks on the compression or the tension side of the element is a normal construction practice. However, there are many unresolved issues regarding the capacity and the interface behaviour between the existing deck and the new layer of the strengthened elements especially under seismic actions. The new deck created is a reinforced concrete composite member. In the present study an analytical model has been developed for the estimation of the ultimate strength of such a composite deck. The shear stress at the interface of the function results from experimental data and depends on the connecting means. The influence of cyclic loading on the behaviour of the interface between the new concrete layer and the existing deck is considered. The model is complemented by a computer program in order to facilitate the relative calculations. Finally, an analytical procedure for the structural design and detailing of strengthened or repaired and strengthened bridge decks by the addition of new concrete is proposed. Moreover the induced shear stresses and forces at the interface can be assessed to design the necessary connection means, in order that there will be no failure of the contact interface, before the retrofitted deck reaches its flexural capacity.*

1 INTRODUCTION

Retrofitting and strengthening of concrete bridge decks after material degradation due to environmental conditions (e.g. icing, humidity, etc) and functional damages (e.g. accidents, application of salt, etc) is a real practical need. Moreover strengthening is necessary when the bridge must sustain additional loads than those it was designed for. In the cases mentioned above, the technique of placing reinforced concrete layers to strengthen or repair and strengthen reinforced concrete elements on the compression or the tension side of the element seems to be a good solution in the case of strengthening existing bridge decks. The subject may be of great interest in concrete bridges in earthquake prone areas, where the application of this technique is part of the total retrofitting solution applied to the whole structure. Obviously in that case, depending on the whole structural system, cycling loading is a very important parameter affecting the connection between the existing structure and the new additional elements, and consequently the behaviour of the contact interface of the new concrete layer and the existing deck.

The retrofitted deck can be considered as a composite element which performs differently from a monolithic one. The behavior of this composite element depends on the interface interaction between the existing deck and the new layer since interface longitudinal slip displacements cannot be restricted. In the present paper, a procedure is proposed for the assessment of the flexural capacity of such retrofitted decks, taking into account possible cycling loading at the interface of the new added layer and the existing deck. Through this procedure the induced shear stresses and forces can also be defined, in order to design the necessary connection means that secure the load transfer between the two members of the composite element. In this way, it can be ensured that there will be no failure of the interface before the composite element reaches its flexural capacity.

2 ANALYTICAL PROCEDURE

In the following, a simple computer model is developed for the evaluation of the ultimate flexural strength of concrete structural elements, such as RC beams and RC bridge decks, strengthened with new R.C. layers at the tensile side of the member. In Figure 1 the distribution of strains, stresses and internal forces of the case to be examined is presented. The discontinuity of the strain profile equal to ε_L depends on the specific behaviour of the connecting means used at the interface. Depending on the interface behaviour different strain profiles can be observed as it has been discussed in detail in previous papers [1], [2]. However, the whole procedure and the analytical expressions presented in the following can be considered valid for all strain profile cases when only the tensile reinforcement of the existing and the new element is considered.

The analytical method presented in this paper is an ultimate strength method for the flexural design of concrete bridge decks strengthened by new concrete layers under pure bending. Apart from the specific assumptions considered at the interface (as will be mentioned in the following) the rest of the assumptions adopted are the same as in the design of monolithic R.C. elements. In general, the necessary relationship between the interface shear stress τ and the respective slip strain ε_L is assumed according to available experimental results obtained from pure shear test data or from proposed analytical formulas available in reliable literature. In the present paper that later option is chosen.

As shown in Figure 1, the composite element examined consists of the existing concrete deck of height h and the new additional concrete element, resulting to a total element height of h_t. A_{so} and A_{su} are the tensile reinforcement on the tensile side of the existing and the new member of the composite element.

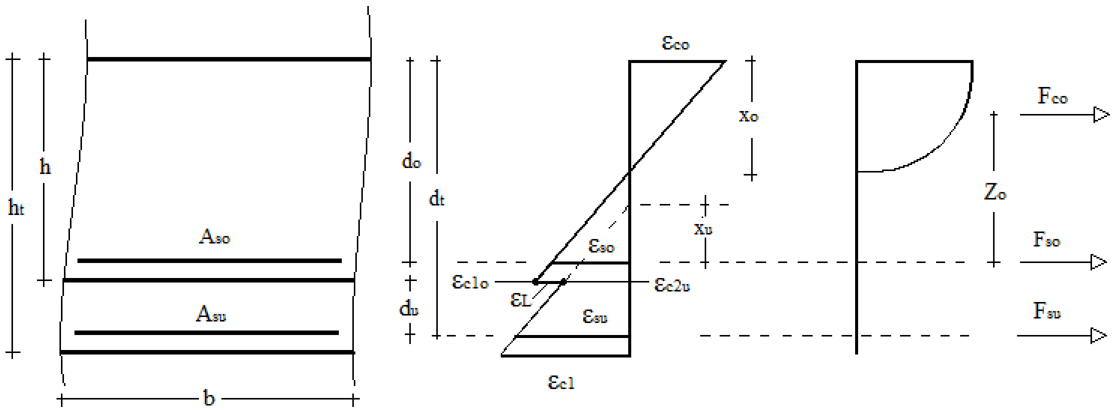

Figure 1: Distribution of strain, stress and internal forces

By considering the equivalence between the applied moment M_s and the internal forces F_i acting in the cross section of the composite element the following equations are obtained:

$$\Sigma F_i = 0 \Rightarrow F_{co} + F_{so} + F_{su} = 0 \tag{1}$$

$$\Sigma M_i = M_s \Rightarrow F_{co} \cdot Z_o + F_{so}\left(d_t - d_o\right) = M_s \tag{2}$$

where F_{so} and F_{su} are the forces of the steel reinforcement of the upper and lower element, respectively, F_{co} is the concrete force of the existing deck, M_i are the corresponding internal moments and Z_o is the distance of the concrete force F_{co} from the level of the old-existing steel reinforcement and d_t and d_o are the effective depths to the level of the existing and the additional tensile reinforcement, respectively.

As already mentioned the interface strain ε_L represents the strain discontinuity of the strain distribution and by definition this strain difference at the interface is equal to:

$$\varepsilon_L = \varepsilon_{c1o} - \varepsilon_{c2u} \tag{3}$$

In addition, the shear force F_T that acts at the interface level can be expressed as follows:

$$F_T = \int_0^{lx} b\tau(\varepsilon_L)dx \tag{4}$$

where l_x is the distance between the considered cross-section and the section with zero moment. By considering the equilibrium between the internal forces F_c, F_{so}, F_{su} and F_T for each of the two elements one can obtain:

$$F_T = F_{su} = -F_{co} - F_{so} \tag{5}$$

The shear stress at the interface level is a function of the slip strain ε_L:

$$\tau = \tau(\varepsilon_L) \tag{6}$$

The above relationship should be considered as general and on the basis of the experimental data it is related to the connecting means of the two elements.

In case the load bearing structure induces cyclic loading to the interface of the strengthened deck, due to earthquake actions, the Greek Code for Structural Interventions proposes the following analytical expression that describes the interface shear strength ($\tau_n(\varepsilon_L)$) after n cycles of loading, when the friction resistance is considered for roughened interfaces [3]:

$$\tau_n(\varepsilon_L) = \tau_1(\varepsilon_L)\left(0.05\left(\frac{f_c}{\sigma_o}\right)^{\frac{1}{2}}(n-1)^{\frac{1}{2}}\left(\frac{\varepsilon_L}{\varepsilon_{Lu}}\right)^{\frac{1}{3}}\right) \tag{7}$$

where $\tau_1(\varepsilon_L)$ is the shear resistance of the first circle for slip strain ε_L, f_c is the concrete compressive strength, σ_o is the compressive stress perpendicular to the interface, which is a result of the sum of the externally induced compression plus the compression stress induced by the clamping action of the reinforcement that crosses the interface. ε_{Lu} is the strain that corresponds to the maximum slippage at the interface, which is related to the acceptable level of damage, i.e. to the respective performance level chosen for the design of the bridge deck. According to the Greek Code for Structural Interventions the maximum values of the acceptable interface slippage are 0.2 mm, 0.4 mm and 1.0 mm for the A, B and C performance levels, respectively [3]. Worth noticing that the above performance levels are equivalent to the “Damage Limitation”, “Significant Damage” and “Near Collapse” limit states defined in Eurocode 8-Part 3 [4].

Moreover it is adopted that only longitudinal slip is allowed at the interface of the old and new concrete element. Therefore, since there is no vertical separation between the two elements, their curvature is considered the same.

$$k_o = k_u \tag{8}$$

where k_o and k_u are the curvatures of the upper and lower element of the composite element during bending, respectively. According to the Navier-Bernoulli’s assumption one obtains:

$$k_o = \frac{\varepsilon_{co}}{x_o} = \frac{\varepsilon_{so}}{d_o - x_o} = \frac{\varepsilon_{c1o}}{h - x_o} \tag{9}$$

$$k_u = \frac{\varepsilon_{c2u}}{x_u} = \frac{\varepsilon_{su}}{d_u + x_u} \tag{10}$$

ε_{co} is the steel strain of the upper element, ε_{c1o} is the bottom fiber concrete strain of the upper element, ε_{c2u} is the top fiber concrete strain of the lower element, ε_{su} is the steel strain of the lower element, x_o and x_u are the neutral axis depths of the upper and lower element, respectively and d_u is the section height of the additional layer from the level of the interface to the level of the new reinforcement, as shown in Figure 1.

Expressing the internal forces F_{co}, F_{so}, F_{su} and the leverarm Z_o as functions of the cross-section strains and the geometrical dimensions of the deck and the new concrete layer, the relationships (1) and (2) can be written in terms of strains.

Therefore, for given action effects of the deck, predetermined characteristics of the side elements (existing deck and new layer) and connecting means used, the strain distribution, the magnitude of the internal section forces and the interface shear stress can be obtained following an analytical procedure involving the system of basic equations (1)-(10). Equivalently, using the above procedure one could determine the mechanical characteristics of the connection means required to avoid premature failure at the interface before the strengthened deck reaches its ultimate flexural capacity.

To facilitate the relative calculations a simple computer program is developed.

3 CONCLUSIONS

An analytical procedure to evaluate the flexural capacity under pure bending of strengthened or repaired and strengthened bridge decks by the addition of new concrete is proposed. Cycling loading, due to seismic actions, induced at the interface between the existing deck and the new concrete is considered. Following the aforementioned procedure, the strain distribution and the interface shear stresses and forces of the strengthened section can be obtained.

The necessary connection means at the interface between the existing concrete deck and the new additional layer can be designed, in order to avoid the failure of the interface before the composite element exceeds its flexural capacity.

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