ABSTRACT

Deep beams are structural elements which frequently occur in practice as transfer girders, pile caps, tanks, folded plates and foundation walls, often receiving many concentrated loads and transferring them to a small number of reaction points. In the present work, comprehensive experimental studies were performed to study the response of reinforced concrete continuous deep beams (RCCDB's) till failure with different shear span-to-depth (*a/d*) ratios, concrete compressive strength (f_{cu}), tension steel ratios, shear reinforcement ratios, and bond condition. The obtained experimental results are compared with design code predictions in flexure and shear. Also, the testing results are compared with the predictions of nonlinear finite element (FE) analysis using the well established program; ANSYS 10. Finally, a modified strut-and-tie model (STM) was developed as analysis and design tool for RCCDB's.

In the experimental program, eighteen RCCDB's were tested. The test specimens were divided into two main groups as flexural beams and shear beams. Each group contains nine equal-span beams. Different values of (*a/d*) ratios were used as 1.25, 1.0, and 0.8. Tested beams were made by (f_{cu}) ranged from 25 MPa to 35 MPa. Ratio between top and bottom longitudinal tension reinforcement (A_{s-ve}/A_{s+ve}) ranged from 1.0 to 1.35. For two flexural specimens, two steel layers were used as tension top reinforcement. Anchorage length for all specimens was 800 mm except for one specimen was 300 mm. Vertical and horizontal shear reinforcement ratios are ranged from 0.0% to 0.6%. The research objectives were to study effect of the test variables on the structural response characteristics of RCCDB's which include load-carrying capacity, stiffness, load-deflection curves, strain distribution for flexural and shear reinforcement, cracking patterns, and failure modes. The testing results indicated that the strength and stiffness reduction was prominent in case of lower f_{cu} and higher *a/d* and that the variation of strains along the main longitudinal top and bottom bars was found to be dependent on the *a/d*. For tested beams having small *a/d*, horizontal shear reinforcement was always more effective than vertical shear reinforcement. For the vertical web reinforcement, a major redistribution of strains occurred for beams with $a/d > 1$ only. For the horizontal web reinforcement, major strain redistribution occurred for beams with $a/d < 1$. Increasing (*a/d*) ratio from 1.0 to 1.25 resulted in a decrease in the first flexural cracking, first diagonal cracking, and ultimate loads by about 20.0%, 18.0%, and 12.0%, respectively. The comparison between test results and current design codes indicated that American (ACI) and Egyptian (ECP) codes underestimate the shear capacity of RCCDB's. The obtained experimental field moments are higher than that obtained from the theoretical predictions for both ECP and ACI codes.

The predictions of load-deflection response as well as the cracking patterns using the nonlinear FE analysis show a good agreement with the testing results. The FE predicted successfully the ultimate loads, displacement ductility, stiffness changes and failure mechanisms for deep beams with different variables. The proposed STM accounts for the effects of concrete compression softening, longitudinal flexural top and bottom steel, web reinforcement and bearing elements. Comparison of the results of the proposed STM with 60 test results indicates that the model generally performs well in predicting the ultimate load carrying capacities for RCCDB's. The overall average value of the ratio between the experimental strength to the predicted strength is of value 1.09 and a standard deviation of 0.12. The STM of the current design codes underestimate the strength of continuous RC deep beams. The predictions are consistent and accurate for RCCDB's with different geometrical properties, concrete compressive strengths and total reinforcement ratios. The proposed STM predicts well the reaction at the internal support compared to the experimental results. The overall average value of the ratio between the experimental reaction to the predicted reaction is of value 1.04 and a standard deviation of 0.14.