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Effect of using swimmer bars on the behavior of normal and high strength reinforced concrete beams

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Abstract Shear failure of RC beams is often sudden and catastrophic. The shear cracks progress rapidly without warning, and the diagonal cracks are considerably wider than the flexural cracks. In this study, two types of shear reinforcement are used, traditional stirrups and swimmer bars. Swimmer bar system is a new type of shear reinforcement defined as inclined bars welded to longitudinal top and bottom bars. High strength concrete is a more brittle material than normal strength concrete, and the cracks that form in high strength concrete will propagate more extensively than in normal strength concrete. Ten beams are tested, and the main variables investigated were two different shapes of swimmer bars in addition to traditional stirrups, number of swimmer bar planes, and compressive strength of concrete. The test results will be presented and discussed in order as deflection, ultimate loads, ultimate shear stress, cracking stress and failure modes. Moreover, shear strain is calculated.

1. Introduction

Reinforced concrete beams must have an adequate safety margin against bending and shear forces, so that it will perform effectively during its service life. At the ultimate limit state, the combined effects of bending and shear may exceed the resistance capacity of the beam causing tensile cracks. The shear failure is difficult to predict accurately despite extensive experimental research. Retrofitting of reinforced concrete beams with multiple shear cracks is not considered an option [1]. Shear failures in beams are caused by the diagonal cracks near the support providing no shear reinforcement. Beams fail immediately upon formation of critical cracks in the high-shear region near the beam supports. Whenever the value of actual shear stress exceeds the permissible shear stress of the concrete used, the shear reinforcement must be provided. The purpose of shear reinforcement is to prevent failure in shear, and to increase beam ductility and subsequently the likelihood of sudden failure will be reduced [2].

In reinforced concrete building construction, stirrups are most commonly used as shear reinforcement, for their simplicity in fabrication and installation. Stirrups are spaced closely

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at the high shear region. Congestion near the support of the reinforced concrete beams due to the presence of the closely spaced stirrups increases the cost and time required for installation. Bent up bars are also used along with stirrups in the past to carry some of the applied shear forces. In case where all the tensile reinforcement is not needed to resist bending moment, some of the tensile bars were bent-up in the region of high shear to form the inclined legs of shear reinforcement. The use of bent-up bars is not preferred nowadays [3]. Piyamahant [4] showed that the existing reinforced concrete structures should have stirrup reinforcement equal to the minimum requirement specified the code. The theoretical analysis shows that the amount of stirrups of 0.2% is appropriate. The paper concluded that small amount of web reinforcement is sufficient to improve the shear carrying capacity.

High-strength concrete is a more brittle material than normal-strength concrete. This means that cracks that form in high-strength concrete will propagate more extensively than in normal-strength concrete. This is due to the fact that cracks tend to propagate through the aggregates in the higher strength concretes rather than around the aggregates as in normal-strength concrete. The result is a much smoother shear failure surface meaning that the shear carried by aggregate interlock tends to decrease with increasing concrete strength. The total shear force V_u is distributed between the concrete V_c and the stirrups V_s. Initially upon loading, the shear reinforcement carries only a small portion of the shear force which is carried by the concrete .On the formation of the first inclined crack, redistribution of shear stresses occurs, with some part of the shear being carried by concrete, and the rest being carried by stirrups. It is assumed that the total shear is resisted by concrete until the formation of diagonal cracks [5–7].

Swimmer bar system is used as shear reinforcement, and the main advantages of this type are flexibility, simplicity, efficiency, and speed of construction. The swimmer bars form plane – crack interceptor system instead of bar – crack interceptor system when stirrups are used. Asha et al. [8], tested four reinforced concrete beams using new shear reinforcement swimmer bar system and the traditional stirrups. Several shapes of swimmer bars are used to study the effect of swimmer bar configuration on the shear load carrying capacity of the beams. It was found that the use of swimmer bar system improved the shear load carrying capacity in the reinforced concrete beams. The width and length of the cracks were observed to be less using swimmer bars compared to the traditional stirrups system.

2. Normal and high strength concrete

Use of high strength concrete in construction sector has increased due to its improved mechanical properties compared to ordinary concrete. One such mechanical property, shear resistance of concrete beams is an intensive area of research [9]. The difference between high strength concrete (HSC) and normal strength concrete (NSC) is:

– The fracture surface in NSC is rough. The fracture develops along the transition zone between the matrix and aggregates. Fewer aggregate particles are broken.
– The fracture surface in HSC is smooth. The cracks move without discontinuities between the matrix and aggregates.

An increase in the strength of concrete produces an increase in its brittleness and smoother shear failure surfaces, leading to some concerns about the application of HSC [10]. In this study HSC is used as a result of the above and compared with NSC due to NSC is still used in many applications.

3. Research significance

The present study demonstrates the effect of using swimmer bars instead of traditional stirrups on improvement of shear performance in reinforced concrete beams, as well as studying the effect of concrete strength in normal and high strength concrete and to identify the most efficient shape and number of swimmer bar planes to carry shear forces.

4. ACI code provision for shear design

According to ACI Code [11], the design of beams for shear is to be based on the following relation:

$$V_u \leqslant \phi V_n$$

where V_u is the total shear force applied at a given section of the beam due to factored loads and $V_n = V_c + V_s$ is the nominal shear strength, equal to the sum of the contributions of the concrete and the web steel if present. Thus for vertical stirrups

$$V_u \leqslant \phi V_c + \frac{\phi A_v f_{yt} d}{s}$$

and for inclined bars

$$V_u \leqslant \phi V_c + \frac{\phi A_v f_{yt} d(\sin\alpha + \cos\alpha)}{s}$$

where A_v is the area of one stirrup, α is the angle of the stirrup with the horizontal, and S is the stirrup spacing. The nominal shear strength contribution of the concrete (including the contributions from aggregate interlock, dowel action of the main reinforcing bars, and that of the un-cracked concrete) can be simplified as shown in the following equation:

$$V_c = 0.17\,\lambda\,\sqrt{f'_c}\,b_w\,d$$

where b_w and d are the section dimensions, and for normal weight concrete, $\lambda = 1.0$. This simplified formula is permitted by the ACI code expressed in metric units.

5. Experimental program

In order to investigate the above mentioned objectives, an experimental program was carried out to test ten simply supported reinforced concrete beams. Five beams were made of normal concrete compressive strength and the remaining five were made of high concrete compressive strength. Detailed description of the specimens, the material properties, mix proportions, test set-up, test procedure, and measurements were presented in this section.

5.1. Test specimens

The details of the tested beams are shown in Fig. 1 and are listed in Table 1. All beams were 250 mm height, 150 mm width, and overall length 1600 mm. Five beams had three