Abstract

Reinforcement detailing rules describe the shape, geometrical dimensions and amount of steel to be placed in reinforced concrete structures. These rules allow for simple and fast designs, account for several effects neglected in the design, ensure a satisfactory behaviour under serviceability conditions, a sufficient robustness and an adequate behaviour in case of unexpected actions. Over the past decades, most detailing rules provided in codes of practice have not been updated to correspond to current manufacturing processes (automatization of the bending of bars), material performances (increasing steel and concrete strengths) and scientific knowledge. They are often based on "rules of good practice" which, while deemed satisfactory, lack a sound scientific basis and may not be needed. This is one reason why detailing rules may significantly differ amongst countries and design codes. Some of these rules are in many cases overly conservative, in particular when evaluating existing structures, while others may neglect significant effects. Even though these rules play a major role in the economy and safety of concrete structures, little research has been performed in this domain in recent years.

Several detailing rules have been identified needing additional investigations to verify their adequacy to current practical needs and recent technological evolutions. This thesis presents a comprehensive research programme on three main detailing rules: bend detailing and required mandrel diameter, anchorage of shear reinforcement with bends and hooks and minimum amount of shear reinforcement. This research aims developing mechanical models, simplified formulas and detailing provisions and is supported by experimental results. These were obtained using state-of-the-art measurement techniques such as Digital Image Correlation measurement or Fibre-Optic Measurements and lead to a better understanding of the structural response.

Bends and hooks of steel reinforcing bars are usually obtained by plastic bending of the bars against mandrels. Codes specify minimum mandrel diameters to ensure a safe transfer of forces and to avoid splitting or spalling failures that may potentially limit the resistance of the detail. The thesis includes a comprehensive research programme on the detailing of bends and the required mandrel diameter to avoid local concrete failures leading to spalling of the concrete cover. A mechanical model for the design of bent reinforcement was developed, together with corresponding detailing rules. A simplifying standard bending procedures is proposed, in which details formerly requiring various bend diameters can be obtained by using a single mandrel, allowing for faster automated manufacturing of bent reinforcement.

Bends and hooks at the end of the bars are simple and cost-efficient solutions for the anchorage of reinforcement. However, these details are relatively sensitive to the cracking state of the surrounding concrete. For shear reinforcement, brittle failures can also occur due to spalling of the concrete cover for bars close to the concrete surface. The thesis includes an investigation on the mechanical response and performance of bend and hook anchorages. On that basis, a mechanical model as well as practical considerations on the activation of shear reinforcement in beams are presented to update current detailing rules.

The required minimum amount of shear reinforcement in beams and slabs has been discussed for decades. It is crucial to ensure economic and safe new structures and to accurately assess existing ones. The results of an experimental investigation shows that the shear behaviour is strongly dependent on the amount of shear reinforcement and the post-yield response of the reinforcement (ductility class of the shear reinforcement).

For all investigated detailing rules, the implementation of these findings into codes of practice is discussed, highlighting the consistency of the recent changes, particularly with reference to the new generation of Eurocode 2.

Keywords: reinforced concrete structures, detailing rules, mandrel diameter, anchorage, spalling, splitting, bond, hooks, bends, shear reinforcement, minimum shear reinforcement, Fibre-Optic measurements, Digital Image Correlation.