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Detailing aspects of the reinforcement in reinforced concrete structures retaining wall: A case study

Vipin Singh
negibipin416@gmail.com
Faculty of Technology, Suddhowala, Dehradun, Uttarakhand

Pooja Semwal
singhvipi92@gmail.com
Faculty of Technology, Suddhowala, Dehradun, Uttarakhand

ABSTRACT

This thesis studies the impact of reinforcement detailing the behaviour of a reinforced concrete structure. Using a retaining wall as a case-study, the performance of two commonly used alternative reinforcement layouts (of which one is wrong) are studied and compared. Reinforcement Layout 1 had the main reinforcement (from the wall) bent towards the heel in the base slab. For Reinforcement Layout 2, the reinforcement was bent towards the toe. This study focused on the reinforcement details used in the D-region, and on how it impacts the capacity, joint efficiency and failure mode of the structure.

Keywords— *Modeling, Analyzing, Reinforced concrete structure, D-region*

1. INTRODUCTION

1.1 Background

Structure Detailing is an important aspect of the design process. It makes communication in between engineer's design & the contractor that oversees the construction on the site. Structural failure mode like that of Word trade centre, Hyatt Regency (in 1981) etc. might have been prevented if attention had been paid on the structural detailing. Detailing has a vital role in a reinforced concrete structure for describing structural behaviour. Steel location has a substantial influence on the stress distribution within the structure, and consequently on its behaviour. Due to poorly designed of a reinforced concrete structure localized stress concentrations within the structure may occur. Which could result in failure? Even after meeting code requirements such type of premature failure of structure generally occurs. Failures mode of these type frequently occurs in corners (where there is an abrupt change in section), connection regions or in regions subjected to concentrated loading (like supports etc.). These regions are referred to as disturbed regions (or D-region). Sometime, however, poor detailing might not result in structural failures but lead to a deterioration of the structure. Some typical deteriorations in reinforced concrete include the formation of large cracks, spallation of concrete, corrosion of embedded steel etc. All these can be prevented or controlled with adequate detailing of the structure.

2. LITERATURE REVIEW

First, a literature review is carried out which focused on the behaviour of corner joints from experimental works available in the literature. Next, a strut and tie model of the D-region is made. From the strut and tie model, the opening moments acting on the structure subjects the re-entrant corner region to a concentration of tensile stresses, while a compressive stress field acts concurrently with transverse tension within the core of the joint. The internal forces within the D-region are evaluated, and the required steel areas computed. Afterwards, ATENA FEM software is used to model the structure, and to study the impact of the alternative reinforcement layouts on the capacity and behaviour of the structure. Some aspects of the structural behaviour studied include the stress and strain distribution in the concrete, crack width, crack pattern, steel stress and strain distribution etc.

A key objective in structural design is to produce structures that have adequate capacity for the load they would be subjected to in their design life. How does the reinforcement detailing aid or prevent the achievement of this objective? In this report, a study is undertaken into the detailing aspects of reinforced concrete structures. The focus would be on the corner joints (or connections) between structural members in the D-regions. Some typical corner joints often seen in practice include beam-column, joints, wall-base joints in retaining walls and liquid retaining structures, wing-walls of abutments etc. The behaviour of these regions would be studied with the aim of understanding some key issues that would help a designer to achieve a satisfactory detail design.

3. AIM OF STUDY

Since there are many types of structures available in practice, it would be impossible to cover all possible joint and detail types in a thesis work like this. For that reason, a specific case study would be utilized in this study.

4. METHOD OF STUDY

The three approaches that would be used for this study include:
(a) A literature review that focuses on the behaviour of corner joints.

(b) Strut and tie modelling of the case study section, with the intention of gaining insight into the structural behaviour of the joint.
(c) Finite element method (FEM) using ATENA finite element software

5. FINITE ELEMENT METHOD

The Finite Element Method (FEM), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The Finite Element Method (FEM) is a numerical technique used for solving field problems. Field problems usually entail the determination of one or more dependent variables spatially, e.g. stress distribution in a corbel, heat distribution in a non-homogenous body etc. Mathematically, such problems are usually described by differential or integral equations. Sometimes, however, analytical solutions to these equations could be time-consuming or cannot be obtained, and we revert to approximate solutions from numerical analysis. FEM is one of such numerical techniques. It is thus applicable for section complex geometries (like our D-regions) where our analytical approach from mechanics could not be depended upon. In this thesis work, it is used alongside the strut-and-tie model to study the impact of detailing the performance of D-regions. Numerical methods give approximate solutions (not exact), and thus need to be validated with experiments or analytical results before being adapted for use. The main idea in FEM is that the structure can be discretized into a number of finite elements connected at their nodes and along the inter-element boundaries. This process of discretization is known as meshing and should do in such a way that there is no gap or overlap between elements. The elements usually have physical properties like thickness, Poisson ratio, elastic modulus etc., and a specific shape which could be triangular, quadrilateral, tetrahedral etc. Nodes are usually on the boundaries of the element, and connect an element to adjacent finite elements, and are where the degree of freedom is defined. The desired field variable is usually calculated in the nodes, and the result is approximated (by interpolation techniques) to get values at non-nodal points. This way, the distribution of the field quantity is approximated element-by element over the entire structure. The finite element approach is well suited to a computer application, thus resulting in many FEM software including ATENA, DIANA, ANSYS, ABAQUS etc. In this report, some knowledge required to use available FEM software for this work would be discussed. The main topics discussed here are material models and the approaches used for nonlinear modelling. An overview of the FEM process would be discussed first in the next section.

6. SOFTWARE USED

(a) **ATENA F**inite element software
(b) STADE PRO.
(c) STRAP
(d) ADHINA structure.
(e) CIVIL FEM

7. TOPIC TO BE ANALYZED

7.1 Detailing of structures and strut and tie model

(a) Extent and behaviour of D-regions (shown in figure 1).
(b) Developing the strut and tie model

7.2 Behaviour and detailing of corner joints

(a) Detailing requirements for corner joints
(b) Failure modes of monolithic concrete joints
(c) The behaviour of different corner joint details

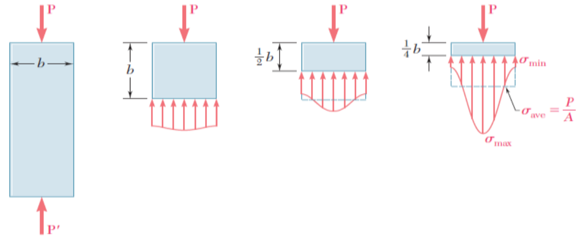


Fig.1: D-Region

7.3 Cantilever retaining wall

(a) Corner detail with the main bar bent towards the heel
(b) Retaining wall with hairpin reinforcement:
(c) Corner detail with the main bar bent towards the toe

7.4 Solution for short toes

7.5 T-Joints

7.6 Impact of reinforcement ratio on corner joint efficiency

7.7. Behaviour of concrete, steel and their composite

7.8 Non-linear analysis

7.9 Finite Element Analysis of the D-region

8. OUTLINE TO REPORT

With corner joints typically being D-regions, beam theory cannot be utilized for their design. Eurocode 2 (subsequently called EC2) recommends the use of strut and tie methods for designing and detailing them. This thesis starts with a literature review on strut and tie methodology. The concept of struts, ties and nodes, and how to dimension them are discussed in the next chapter. With strut and tie understood, its application to typical D-regions like corbels and corner joints is researched from literature. Different patterns of the reinforced layout to be carried out and their impact on the structure behaviour is analyzed. For this purpose we are going to do the case study of retaining wall.

9. BACKGROUND TO STUDY CASE

To study the role of detailing in a structure, a case study structure would be required. The case used for this work is a cantilever retaining wall supporting a 4.5m high backfill of granular material with a saturated density of 1700 kgm2⁄ and a surcharge of 10 kNm2⁄. The geometrical details of the wall are shown in figure 2 below:

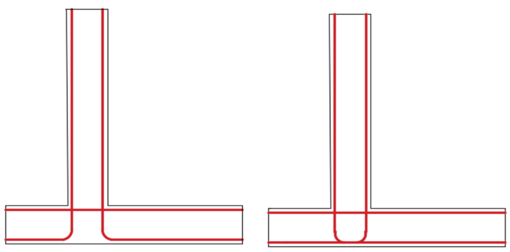


Fig. 2: Typical reinforcement layout

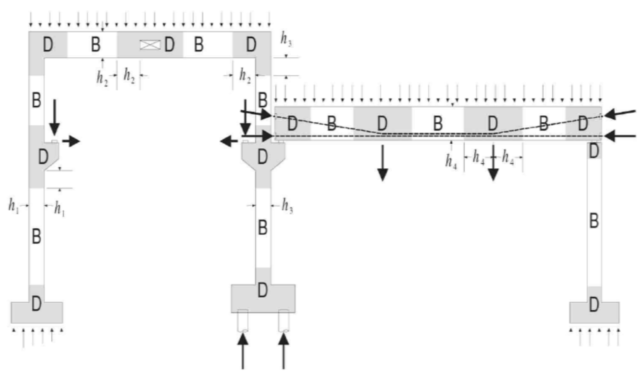


Fig. 3: B and D Regions on the structure

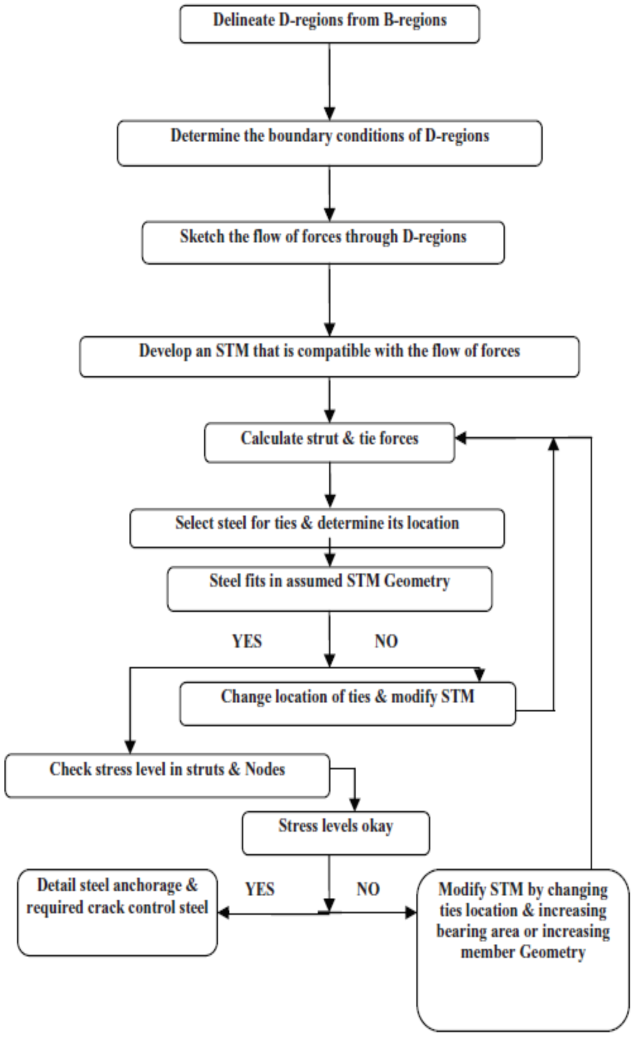
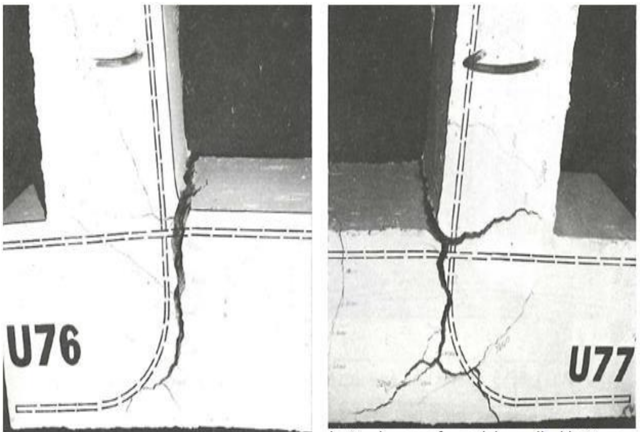
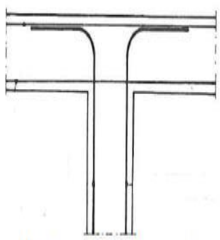


Fig. 4: a Flow chart for designing D region

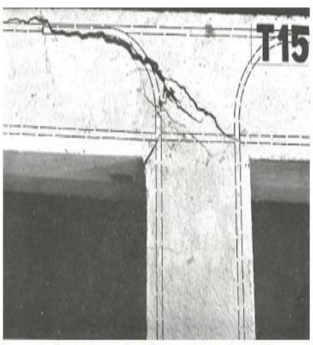


a. Crack pattern for retaining wall with 10cm toe b. Crack pattern for retaining wall with 20cm toe

Fig. 5: Crack pattern in retaining wall



a). The conventional layout



b). Crack pattern for the conventional layout

Fig. 6: T Joint

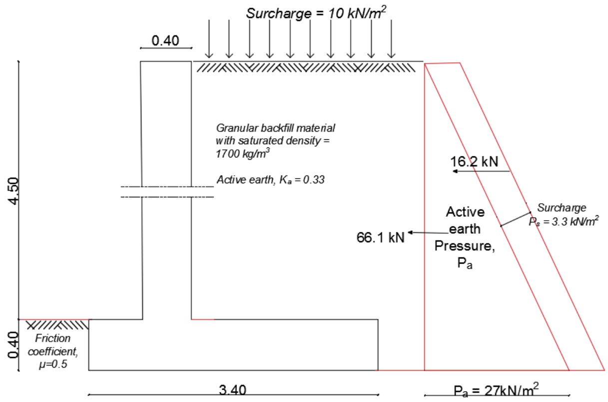


Fig. 7: A case study of retaining wall

In this section, I would undertake a preliminary sizing of the wall, and check for stability against overturning and sliding. The loads and resulting moments acting on the structure would also be computed. Stresses from these moments would constitute the boundary stresses for the strut and tie model.

Concrete: C30/37 Steel: fyk=500 N/mm2
Coefficient of friction (μ)=0.50 Active earth pressure ka=0.33

10. CONCLUSION AND RECOMMENDATION

The performance of the retaining walls shown in the figure has been the object of this study. With their reinforcing bars detailed differently, the joint behaviour has been studied in this thesis to provide an answer to the following questions:

- **(a)** How efficient are the joints made with these reinforcement layouts?
- **(b)** In what way does the reinforcement detail affect stress and strain behaviour within the joint?
- **(c)** What is the mode of failure of these joints? and
- **(d)** What improvement can be made to the detail if the joint efficiency is less than 100%?

The combination of lateral loads (acting on the wall) and gravity load (acting on the slab) subjects the joint to an opening moment. This opening moment acting on the retaining wall causes a tensile stress concentration at the re-entrant corner. It also causes transverse tensile stress to act concurrently with compressive stresses within the core of the joint. T. These stress state and the cracks caused by them play a vital role in determining the behaviour and eventual capacity of the joint. After taking different aspects of detailing it was found that we can make our structure more efficient by analyzing the structure in different mode. New design patterns of reinforcement can be used in place of old patterns for every element of the structure

11. ACKNOWLEDGEMENT

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BIOGRAPHY

Vipin Singh
M. Tech Student, Structure engineering
Faculty of Technology, Suddhowala, Dehradun, Uttarakhand