

# Experimental Evaluation of Shear Behaviour in Reinforced Concrete Beams Using Different Transverse Reinforcement Layouts

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## Abstract

In reinforced concrete members, inadequate resistance against shear forces often leads to sudden failure, which is structurally unsafe compared to flexural failure. The present experimental investigation focuses on the shear response of reinforced concrete beams intentionally designed to be shear-dominant. Two beam specimens with identical geometry, concrete mix, and longitudinal reinforcement were prepared, while varying only the configuration of transverse reinforcement. One specimen employed conventional vertical stirrups, whereas the other incorporated helically arranged stirrups. Both beams were tested under monotonic loading using a two-point loading system until failure. Observations related to load resistance, deflection development, crack formation, crack widening, and failure characteristics were carefully recorded. The experimental outcomes revealed that the beam provided with helical reinforcement exhibited delayed shear cracking, improved load capacity, and a more gradual failure process when compared to the beam reinforced with vertical stirrups. The study highlights the effectiveness of transverse reinforcement orientation in improving the shear performance of reinforced concrete beams.

**Keywords:** 1.Shear behaviour; 2. Reinforced concrete beam; 3.Helical stirrup; 4.Shear cracking; 5.Experimental study

## 1. Introduction

Shear resistance in reinforced concrete beams plays a critical role in ensuring structural safety. While flexural behaviour is generally well understood and predictable, the shear response of concrete beams remains complex due to its dependence on several interacting parameters such as concrete contribution, reinforcement detailing, and confinement effects. When shear resistance is insufficient, beams may fail abruptly, providing very limited visual warning prior to collapse.

Several existing structures contain beams that are vulnerable to shear failure due to inadequate transverse reinforcement, construction limitations, or design practices based on older codes. Conventional design approaches rely heavily on vertical stirrups to resist shear forces. However, such reinforcement may not always provide sufficient confinement to control diagonal cracking effectively. Alternative shear reinforcement arrangements, such as helical reinforcement, have been suggested to

improve confinement and enhance energy absorption. Unlike discrete vertical stirrups, helical reinforcement provides continuous restraint to the concrete core and longitudinal bars. The present study experimentally examines how such confinement influences the shear response of RCC beams.

## **2. Objective of the Investigation** The experimental study was carried out with the following objectives:

- To examine the shear-dominant behaviour of reinforced concrete beams with different transverse reinforcement arrangements.
- To evaluate the influence of vertical and helical stirrups on crack initiation and crack growth.
- To compare load-deflection characteristics of the beam specimens.
- To assess the effectiveness of helical reinforcement in improving ductility and delaying shear failure.

## **3. Experimental Parameters**

Ordinary Portland Cement of 53 grade was used for casting the beams. River sand served as the fine aggregate, and crushed stone of 10 mm and 20 mm sizes was used as coarse aggregate. Fe-500 grade steel was adopted for both longitudinal reinforcement and stirrups. A superplasticizer (SP-430) was added to achieve workable concrete.

### **Beam Details**

Two reinforced concrete beams were cast with dimensions of 1500 mm length, 200 mm width, and 300 mm depth. The longitudinal reinforcement consisted of three 16 mm diameter bars at the bottom and two 12 mm diameter bars at the top in both specimens.

The transverse reinforcement configuration was varied as follows:

SV specimen: Vertical stirrups of 8 mm diameter spaced at 100 mm

SH specimen: Helical reinforcement of 8 mm diameter with a pitch of 100 mm

Apart from shear reinforcement arrangement, all other parameters were kept identical.

## **4. Test Procedure**

After casting and curing, the beam specimens were tested under a simply supported condition. A two-point loading arrangement was employed to generate a constant moment region at mid-span and higher shear forces near the supports. Load was applied incrementally using a hydraulic loading system. Mid-span deflection was measured using dial gauges. The development of cracks was traced visually at each load level, and crack widths were measured at critical stages until ultimate failure occurred.

## **5. Observed Behaviour**

### **5.1 Load and Deflection Response**

The beam reinforced with helical stirrups exhibited reduced deflection at service load levels when compared to the beam with vertical stirrups. This indicates improved stiffness due to enhanced confinement. At higher load levels, the helical-reinforced beam sustained larger deformation prior to failure, reflecting improved ductility.

### **5.2 Crack Development**

In the specimen with vertical stirrups, diagonal cracks appeared at an early load stage and widened rapidly. Failure occurred suddenly soon after the formation of major shear cracks. In contrast, the beam

with helical reinforcement showed delayed crack initiation and slower crack propagation. Crack widths remained smaller even at higher load levels.

### 5.3 Failure Mode

The vertical-stirrup beam failed in a brittle shear-dominant manner. The helical-reinforced beam demonstrated a more gradual failure process, with better stress redistribution and visible warning prior to collapse.

## 6. Test Results and Discussion

### 6.1 Load Carrying Capacity

Both beam specimens were tested under monotonically increasing load until failure. The recorded loads corresponding to first visible crack, service load, and ultimate failure are presented in Table 1.

**Table 1. Experimental Load Results**

| Specimen               | First Crack load (kN) | Service load (kN) | Ultimate load (kN) |
|------------------------|-----------------------|-------------------|--------------------|
| SV (Vertical stirrups) | 100                   | 201               | 300                |
| SH (Helical Stirrups)  | 150                   | 201               | 350                |

The specimen reinforced with helical stirrups (SH) exhibited a **50% higher first crack load** compared to the specimen with conventional vertical stirrups (SV). This indicates that helical reinforcement was more effective in resisting early tensile stresses responsible for diagonal cracking.

Both specimens sustained similar service load values. However, the **ultimate load capacity of SH was 16.7% higher** than SV, demonstrating improved shear resistance due to enhanced confinement.

### 6.2 Load–Deflection Behaviour

Mid-span deflection was measured at various load stages during testing. The measured deflections are presented in Table 2.

**Table 2. Deflection Measurements**

| Specimen               | Deflection at 1 <sup>st</sup> crack (mm) | Deflection at service load (mm) | Deflection at Ultimate load (mm) |
|------------------------|------------------------------------------|---------------------------------|----------------------------------|
| SV (Vertical stirrups) | 12                                       | 15                              | 80                               |
| SH (Helical Stirrups)  | 5                                        | 8                               | 95                               |

The beam with helical reinforcement showed **lower deflection at initial and service load stages**, indicating higher stiffness. At ultimate load, the helical-reinforced beam exhibited greater deformation capacity, suggesting improved ductility.

This behaviour confirms that helical stirrups delay stiffness degradation and allow the beam to undergo larger deformation before failure.

### 6.3 Moment Capacity

Based on the applied loading arrangement, bending moments at different load stages were calculated and are

Table 3. Summarised In

| Specimen               | moment at 1 <sup>st</sup> crack (mm) | moment at service load (mm) | moment at Ultimate load (mm) |
|------------------------|--------------------------------------|-----------------------------|------------------------------|
| SV (Vertical stirrups) | 45                                   | 104                         | 135                          |
| SH (Helical Stirrups)  | 67.5                                 | 104                         | 158                          |

The beam with helical reinforcement developed a **higher moment capacity at first cracking and at ultimate stage**, confirming the positive influence of continuous confinement on load redistribution and shear resistance.

#### 6.4 Crack Width Development

Crack widths were measured at critical loading stages to assess crack control performance. The results are presented in Table 4.

Table 4. Crack Width Measurements

| Specimen               | Crack width at 1 <sup>st</sup> crack (mm) | Crack width at service load (mm) | Crack width at Ultimate load (mm) |
|------------------------|-------------------------------------------|----------------------------------|-----------------------------------|
| SV (Vertical stirrups) | 0.5                                       | 3.0                              | 6.0                               |
| SH (Helical Stirrups)  | Nil                                       | 1.0                              | 4.0                               |

The specimen reinforced with vertical stirrups exhibited visible cracking at early stages, with crack width increasing rapidly under load. In contrast, the helical-reinforced specimen showed **no visible cracks at first cracking load**, indicating delayed crack initiation. Even at ultimate load, crack widths in SH remained smaller, demonstrating superior crack control.

#### 6.5 Failure Mode

The failure of specimen SV was characterized by the sudden formation of wide diagonal shear cracks near the support zones, leading to brittle shear failure with minimal warning.

Specimen SH failed in a comparatively gradual manner. The presence of helical reinforcement restricted diagonal crack widening and provided continuous confinement, resulting in a **ductile shear-dominant failure with visible distress before collapse**.

#### 6.6 Overall Performance Comparison

A comparative assessment of both specimens shows that:

- Helical reinforcement improved initial crack resistance
- Shear capacity increased significantly
- Crack widths were effectively controlled
- Failure mode shifted from brittle to relatively ductile

These results clearly demonstrate that **shear reinforcement orientation plays a crucial role** in governing the shear performance of RCC beams.

### 7. Conclusions

**From the experimental investigation, the following conclusions are drawn:**

1. Orientation of transverse reinforcement significantly affects the shear behaviour of RCC beams.
2. Helical reinforcement delayed the formation of diagonal shear cracks and increased first-crack load.

3. Beams reinforced with helical stirrups exhibited improved load-carrying capacity.
4. Crack widths were consistently smaller in the helical-reinforced specimen, indicating effective confinement.
5. Helical reinforcement contributed to a more ductile failure mechanism compared to conventional vertical stirrups. The study confirms that modifying shear reinforcement layout is an effective approach to enhancing the structural performance and safety of shear-critical reinforced concrete beams.

## 8. Acknowledgement

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