

# Shear behavior of slender geometry RC coupling beams in seismic response

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**Abstract.** Coupling beams have geometric sizes with special heights known as deep beams, and the design usually takes up more space. Focus of this research is to analyze slender coupling beams with a diagonal reinforcement angle design of less than 20 degrees to the longitudinal reinforcement. New alternative design for slender coupling beams was experimentally investigated where the parameter was the span-to-depth ratios (2.75; 3.0; 3.25). Coupling beams should not be considered as load receiver, but instead as connector between the couple shear walls for working together. The result of the test indicated that coupling beams with a slenderness ratio of 3.25 has capacity to behave as coupling beams which function is to distribute the energy.

## 1. Introduction

In high-rise buildings, it is common to construct couple shear wall to function as structure wall. To meet the needs of openings on the structural wall, a structural element above the opening position that is able to behave resisting to lateral load is required. Coupling beams should also be used on short beams that receive horizontal loads, for instance corridor beams, since generally the design in such area is not considered as coupling beams. However, coupling beams are only designed as conventional flexural beams with longitudinal and shear reinforcement on the concrete so that fail frequently occurs, especially in diagonal areas. Currently, coupling beams with high geometry ratios are in demand along with the need for shortening the height of a floor on the building so that the dimensional need of the coupling beams must be able to adjust. Figure 1 shows the coupling beams element.

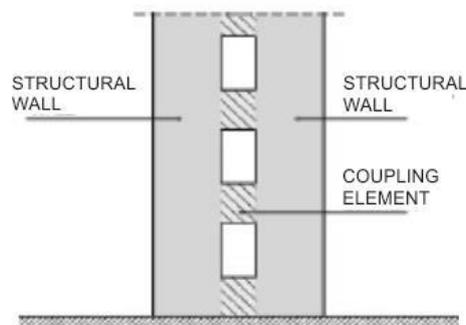


Figure 1. Coupling beams element [1].



Damages occur on conventional coupling beams can be identified by its incapability to withstand shear failure and its less optimal seismic performance. Observation on coupling beam with diagonal reinforcement group with confinement indicated the failure of coupling beams in the tension diagonal mode and yet it is able to maintain its seismic behavior [2]. The problem of the existence of transverse reinforcement on the diagonal reinforcement group the installation of the reinforcement.

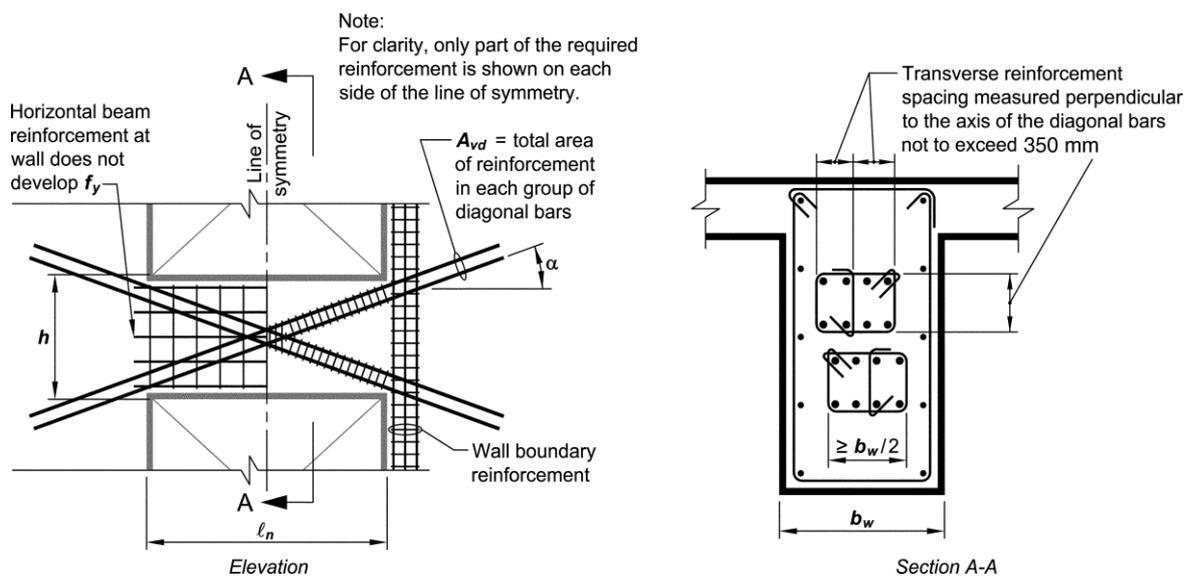
Santhakumar examined the seven-story structure model with the couple shear wall. Laboratory results show that the failure of the coupling beam is the shear failure and buckling which occurs in the diagonal reinforcement [3]. Barney and Tassios tested eight reinforced concrete coupling beams with ratio 2.5 and 5.0 under reverse cyclic loading [4, 5]. Coupling beams with a ratio of 5.0 show an increased strength, although relatively low, but yet provide good seismic performance. Some disadvantages that may arise are the existence of diagonal reinforcement in a group leading to the broader beam width and thicker walls. In addition, the transverse reinforcement for diagonal reinforcement is quite difficult in the installation.

Galano carried out testing on short coupling beams with a ratio 1.5, specifically diagonal reinforcement without confining and with rhombic configuration [6]. The results showed that beams with diagonal reinforcement or rhombic configuration can provide better performance. Rhombic configuration is effective than diagonal reinforcement based on the value of ductility and strength.

### 1.1. Reinforce concrete coupling beams

Coupling beam is defined as a beam between two shear walls or a structural wall that serves to transfer horizontal force from the structural walls during lateral load occurrence, for example during an earthquake. The diagonal reinforcement concrete coupling beams (DRCCB) was initially developed after the 1964 Alaska earthquake to solve considerable damage to conventional coupling beams that have weaknesses in their shear capacity and seismic performance.

Provision that refers to ACI 318M-11 [1], coupling beams with  $l_n/h < 2$  and with  $V_u$  exceeding  $0.33 \lambda \sqrt{f'_c} A_{cw}$ , shall be reinforced with two groups of intersecting diagonal bars symmetrically across the center of the span [1]. Coupling beams with two groups of intersected diagonal bar must satisfy to  $V_u = 2A_{vd} \cdot f_y \cdot \sin \alpha \ll 0.83 \sqrt{f'_c} \cdot A_{cw}$ , where  $\alpha$  is the angle between the diagonal reinforcement bar and the longitudinal axis of the coupling beams. Figure 2 shows the confinement of individual diagonals.



**Figure 2.** Confinement of individual diagonals [1].

### 1.2. Analysis of coupling beam

Analysis of coupling beam to the flexure and shear stresses to the behavior of structures formed by shear failure can be idealized by the force system as in figure 3, which is the half part of the triangle-shaped beam [7]. The force system is calculated using equation (1) – (5).

$$\text{Vertical force equations,} \quad P_u = 2.V + f_{tc}.b.a + P_v \quad (1)$$

$$\text{Horizontal force equations,} \quad P_{st} = f_{tc}.b.h' + P_h + C \quad (2)$$

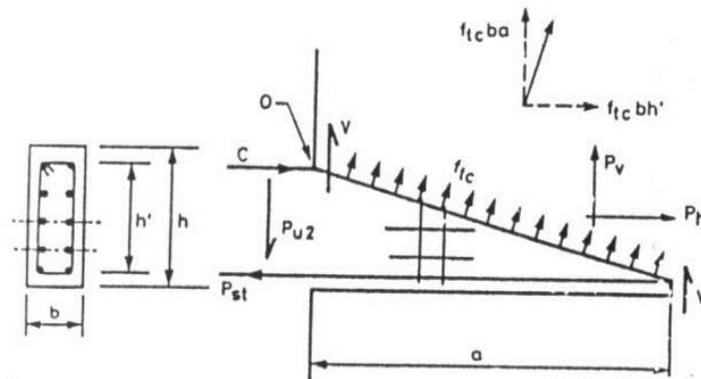
$$\text{Moment force equations (M=0),} \quad P_{st}h' = V.a + f_{tc}.\frac{b.(h'^2+a^2)}{2} + P_h.\frac{h'}{2} + P_v.\frac{a}{2} \quad (3)$$

from equations (1), (2), (3), the ultimate load of the beam can be formulated as follows:

$$P_u = (f_{tc}.b.h' + 2.C + P_h).\frac{h'}{a} \quad (4)$$

One of the important deformation criteria in a coupling beam is when the concrete crush at the end of the compression area at  $\frac{(h-h')}{2}$  when the greatest force occurs.

$$\text{Compression force,} \quad C = 0.67.f_{cu}.b.\frac{(h-h')}{2} \quad (5)$$



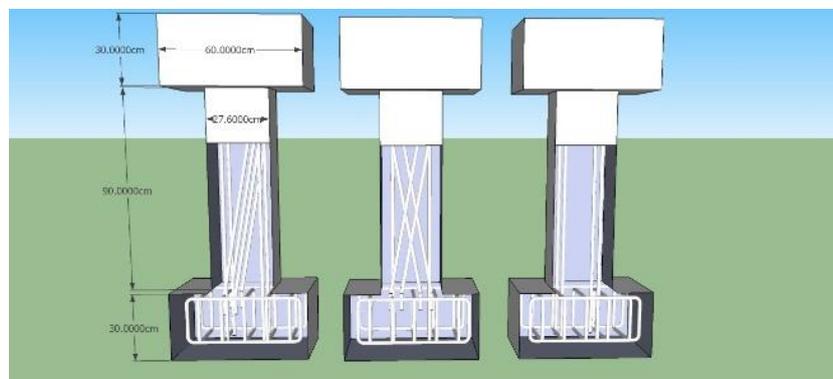
**Figure 3.** Idealization of triangular equations on coupling beams [7].

## 2. Experimental details

This section explains the detail of the experiment conducted on laboratory at Universitas Muhammadiyah Surakarta.

### 2.1. Specimens design

The design of specimens is shown in figure 4 where the span-to-depth ratio:  $l_n/h = 2.75$  ( $\alpha = 19.98^\circ$ );  $l_n/h = 3.00$  ( $\alpha = 18.43^\circ$ );  $l_n/h = 3.25$  ( $\alpha = 17.10^\circ$ ).



**Figure 4.** Detail of specimen reinforcement.

## 2.2. Specimens construction

The specimens were constructed at structures laboratory at Universitas Muhammadiyah Surakarta. Prior to the establishment, quality checks were performed on all materials (cement, sand, gravel, water and steel). These materials must meet the quality requirements of the regulations. The concrete mixture design method was according to Indonesian standard regulation with 0.5 water cement ratio. The quality of concrete was tested through compression test of concrete cylinder 15 x 30 cm. A day before the test of concrete compressive strength, the cylindrical test object was removed from the immersion bath for drying. Concrete cylinders were lifted and placed centrally on the Universal Testing Machine (UTM), specifically on testing machine holder. Once ready, it started loading with loading speed set 15 MPa/min. During the test, the size of the load and the shortness of the specimen were recorded.

The coupling beams test object was divided into four variables, which consisted of a non-diagonal reinforcement and a coupling beam with diagonal reinforcement with an angular slope below 20 degrees against its longitudinal reinforcement. The specimens were carried out after the final computation of the mixed design and the preparation of test instruments and materials were all endured in good condition. In order, concrete curing was carried out in order to keep the concrete surfaces always fresh in humid conditions. Concrete weight testing was intended to determine the density of a concrete.

## 2.3. Coupling beams testing

Preparation testing was done a few days before the main testing, which was intended to ensure all the equipment were ready and could be directly utilized during the testing. Placement of the test object on the Loading frame, it was positioned according to the setting up so that it had enough space to deform. Preparation of tables of plans for loading and recording of observations was also performed. LVDT and Yoke extensometer to measure the deformation must in zero position as well as to record the initial value on the strain indicator that showed the strain gauge's initial strain.

The test is performed in accordance with the designed load interval. The result of deformation and strain of each measuring instrument according to the load interval was read visually. During the testing process, observation of the crack pattern was started at first crack up to the maximum load and marked them with markers on the test specimen and noted the value of load at each of the crack stages. The test specimen was marked on both sides of the beam and the grid lines as a guide to determine the location of the crack was also done. The record of the loads and deformations that worked out and the observation at crucial moments, such as first crack and spalling (peeling of concrete cover), were also conducted. Before, during and after test, the entire results on each specimen that has been coded according to its characteristics were documented with photographs and camcorders. Subsequently, the devices were removed, to be installed on the next specimen.

## 3. Results and discussion

As composite materials, the structure of reinforced concrete coupling beams has several elements designed to withstand shear forces, such as  $V_c$  which is the contribution of the concrete material;  $V_s$  which is the contribution of transverse reinforcement; and  $V_d$  which is the contribution of diagonal reinforcement. So,  $V_n = V_c + V_s + V_d$ . Table 1 shows the coupling beams capacity.

At ratio 3.0, the load capacity that can be retained by coupling beams without diagonal reinforcement was 100 kN. After the installation of diagonal reinforcement into coupling beams structure, the load capacity was 113.33 kN, or there was an increase by 13.33 %. At ratio 2.75, coupling beams with diagonal reinforcement contributed to the load capacity of 146.67 kN while at ratio 3.25, the diagonal reinforcement group of steel contributed to 100 kN load capacity. Coupling beams with a slenderness ratio of 3.25 was still able to maintain its behavior according to the function of the coupling beams as shown in table 1.

**Table 1.** Coupling beams capacity.

| Type of Test | Test objects                                     | $l_n$<br>(cm) | H<br>(cm) | Ratio<br>( $l_n/h$ ) | Load Capacity<br>(kN) |
|--------------|--|---------------|-----------|----------------------|-----------------------|
| Lateral Load | Coupling Beams without<br>diagonal reinforcement | 90            | 30.00     | 3.00                 | 100.00                |
|              |  |               | 32.75     | 2.75                 | 146.67                |
|              | Coupling Beams with<br>diagonal reinforcement    | 90            | 30.00     | 3.00                 | 113.33                |
|              |  |               | 27.60     | 3.25                 | 100.00                |

### 3.1. Shear behavior

Shear stiffness,  $G'$  analysis was performed based on laboratory data, referring to ASTM E564,  $G' = \frac{P}{d} \times \frac{a}{b}$ . This stiffness analysis was carried out at load resistance where the wall had reached the maximum peak load. Ultimate shear strength,  $S_u$  analysis was also done based on the results of laboratory testing, referring to ASTM E564,  $S_u = \frac{P_u}{b}$  as shown in table 2. The most dominant of shear behavior occurred in coupling beams with aspect ratio span-to-depth 2.75. Along with the shorter height of the coupling beams, the shear stiffness and shear strength were also getting weaker, but still in predicted behavior capacity of distributing energy.

**Table 2.** Shear stiffness and ultimate shear strength.

| Type of objects                   | $\alpha$<br>(°) | Length<br>(mm)<br>a | Wide<br>(mm)<br>b | Deformation<br>(mm)<br>d | $G'$<br>(kN/m) | $S_u$<br>(kN/m) |
|-----------------------------------|-----------------|---------------------|-------------------|--------------------------|----------------|-----------------|
| without diagonal<br>reinforcement | 18.43           | 90                  | 30.00             | 60.82                    | 4.93           | 333.33          |
|                                   | 19.98           |                     | 32.75             | 58.27                    | 6.86           | 444.44          |
| with diagonal<br>reinforcement    | 18.43           |                     | 30.00             | 58.17                    | 5.79           | 377.78          |
|                                   | 17.10           |                     | 27.60             | 58.74                    | 5.55           | 362.32          |

The calculation with method analysis in [7] as in table 3 obtained two values of ultimate load  $P_u$ . Flexural failure was obtained from the flexural failure model formula, whereby this flexural strength was only held by its longitudinal reinforcement capacity alone. Shear failure is a value that represents the entire cross section. Thus, by comparing the two values of load above, it can be seen that shear failure has a lower value than flexural failure, or in other words, shear failure value is more decisive to predict the type of collapse that may occur.

The final failure model of a coupling beam is a shear failure, characterized by a diagonal directional crack followed by a split on the crack path. The coupling beam does not only indicate a shear phenomenon, but long before the shear cracking pattern occurs, there is also a flexural crack pattern characterized by a directional crack almost perpendicular to the longitudinal plane of the beam. However, as long as the flexural crack pattern is still within the load capacity of the service, it will not lead to the coupling beam flexure failure.

**Table 3.** Failure analysis.

| Experiment Analysis         |   |             | N. K. Subedi Analysis Method  |                               |                                      |                                    |  |
|-----------------------------|---|-------------|-------------------------------|-------------------------------|--------------------------------------|------------------------------------|--|
| $f'_c$<br>N/mm <sup>2</sup> | Description of Failure  | $P_u$<br>kN | $f_{cu}$<br>N/mm <sup>2</sup> | $f_{tc}$<br>N/mm <sup>2</sup> | $P_{u,1}$<br>(Flexure Failure)<br>kN | $P_{u,2}$<br>(Shear Failure)<br>kN | Failure Prediction   |
| 21.073                      | Shear Failure, very wide of split, damage on concrete and bars at the tip of compress area. | 113.33      | 26.60                         | 1.267                         | 115.093                              | 71.769                             | Shear Failure at 71.769 kN. $P_{u,2}$ has the potential to fail earlier than $P_{u,1}$ . |

#### 4. Conclusions

The following conclusions are drawn based on the experimental results. The coupling beam with diagonal reinforcement angle below 20 degrees to the longitudinal reinforcement is still capable of behaving according to the function of the coupling beam. The  $l_n/h$  ratios of 2.75, 3.0 and 3.25 as the geometry parameter of the coupling beam in this research are able to produce data that provide an alternative that the coupling beam with the slender geometry is still able to distribute the lateral force. It meets the purpose of shortening the height of the building floor, especially in buildings for business and apartment designations, so as to reduce the cost of construction.

#### References

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