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Performance Analysis of Coupling Beam in Coupled Walls

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ABSTRACT: *In this study, performance analysis of coupling beam coupled walls with coupling beams made with reinforced concrete and made steel profiles has been made. Firstly, displacement generated in the structure by varying the dimensions and materials of the coupling beam were investigated. The cross reinforcements and embedded depths of the coupling beams foreseen in the regulations were calculated by selecting according to the overstrenght shear force obtained by the performance analysis of the reinforced concrete coupled walls. The analyzed reinforced concrete coupling beams were compared according to the TBDY-2018 Earthquake Code and the steel coupling beams according to the design principles of the American Regulations (ACI 318-14, ANSI/AISC 341-16), and the foreseen reinforcements and steel profile dimensions were obtained. In the comparisons obtained, the effect of reinforced concrete coupled walls on the building behavior was determined. In reinforced concrete coupling beams of coupled walls; It was aimed to investigate the coupling beams made with the steel profile embedded in the coupled wall due to the cross reinforcements providing resistance against shear forces, the reinforcement frequency during construction, the difficulty of assembly and the failure to performance as in the design. Therefore, structural steel members are sized for the maximum calculated shear force. Steel coupling beams; It is designed to provide ease of assembly, to design coupling beams with lower dimensions and to function the same as reinforced concrete coupling beam.*

Keywords: Cross reinforcement, Coupled wall**,** Steel coupling beam, Reinforced concrete coupling beam, Stiffness.

1. INTRODUCTION

In the reinforced concrete shear walls of the buildings, door or window gaps are required to leave according to the architectural requirements. In case the spaces left are vertical and continuous, the horizontal elements connecting the two shear wall parts between them are called coupling beams, and the shear wall system is called a coupled wall. Under earthquake behavior, plasticization of shear walls occurs only at the base of the shear wall, while the plastic behavior can spread along with the shear wall height if an appropriate design is made in coupled walls. Thus, they can contribute to the damping of energy by achieving more ductile behavior. During the action of the coupled wall system under horizontal loads, the shear forces generated in the coupling beams are transferred that It is connected as axial pressure force to one of the walls to which it is attached, and to the other as an axial tensile force. Thus, part of the overturning moment transferred to the system by external loads is met by the moment of normal forces of the shear wall consisting of the sum of shear forces at both ends of the coupling beams. The ratio of this provided moment, to the total overturning moment affecting the structure, is called the coupling beam contribution ratio. The coupling beam contribution ratio depends on the stiffness of the shear walls. before it can not be calculated before the completion of the element sizing and analysis in the design made according to the linear elastic analysis method. In practical applications, this coupling beam contribution ratio obtained from the analysis provides in event of providing the minimum value required by the regulations for the coupled wall, it is not examined again after the design is made. On the other hand, depending on whether the coupling beam contribution ratio is low or high, large differences occur in the internal forces and non-linear behavior of the shear walls.

1.1. OBJECTIVE AND METHOD

As two different examples in this study; 10-storey and 14-storey buildings were analyzed with reinforced concrete coupled walls made with interlocking diagonal reinforcements, and coupled walls with steel coupling beams embedded in the shear wall , and at the same time, the effect of coupling beam dimensions on their displacement behavior was investigated. In reinforced concrete coupling beams; By changing different coupling beam heights, reinforcement amounts, embedded depth of cross reinforcement and horizontal angles and in steel coupling beams; By changing the carcase height by keeping the headpiece widths and steel thicknesses constant, two-dimensional analyzes were made using the SAP2000 package program. As a result of the comparisons obtained from the analyzes, the changes in the displacement and rotation values of the coupling beams designed according to the same shear forces were investigated. By modeling coupled walls, lateral story displacements, shear moments and shear forces were found with analysis. The analyzed reinforced concrete coupling beams are equipped with cross reinforcements envisaged in TBDY-2018 and compared with the steel profile embedded in the reinforced concrete shear wall in ANSI / AISC 341-16. In the comparisons, the effect of coupled walls on structural behavior has been investigated. As a result of the push-over analysis performed in the SAP2000 program, the comparison with the reinforced concrete shear wall, reinforced concrete coupling beams made with diagonal reinforcements and coupling beams made of artificial steel profiles were interpreted. The interoperability of coupled walls with coupling beams or the effects of these shear walls on each other determine the degree of interaction between reinforced concrete shear walls, in other words, the relative behavior. In two reinforced concrete shear walls connected by non-rigid elements so that the load can be transferred to each other only in an axial manner, the moment is distributed in proportion to the bending stiffness of the shear walls, and the stress distribution is linear in the two shear walls as shown in Figure 1.2b. However; In reinforced concrete shear walls connected to each other with rigid elements, the moment distribution behaves such that the two shear walls are composite elements, that is, a single shear wall. Here, the stress distributions are distributed such as a single shear wall along the two shear walls planes such that the stresses are linear as shown in figure 1.2a [1].

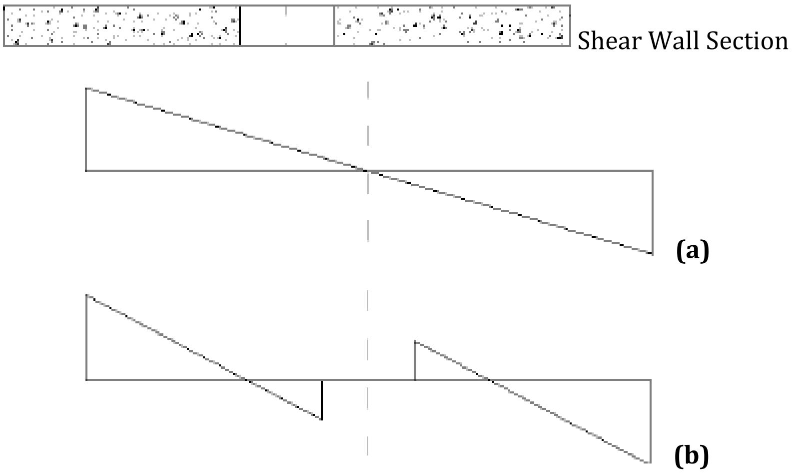

Fig - 1: Stress distribution according to the behavior that exhibited of shear walls [2].

These link elements are that Sometimes this part of the floor slab, sometimes beams in a rod behavior, sometimes shear wall pieces (plate) that do not conform to the rod behavior. Generally, the dimensions of the said link elements are arranged to be fixed on all floors in terms of both architectural requirements and ease of solution. However, in this case, the link elements of the coupled walls may be insufficient in some areas (the sections where the shear wall is fixed). In order to verify the competence, the plastic behavior of the link elements should also be known.

2. RELATED WORK

2.1. Coupling Beams

2.1.1. Reinforced Concrete Coupling Beams

In order to ensure that reinforced concrete tie beams have a high shear strength and to be arranged with cross reinforcement bundles, the net span / height ratio should not exceed 2 [3].

$$\ell_n \geq 2\ h_k \qquad (2.1)$$

$$V_d \leq 1.5\ b_w\ d\ f_{ctd} \qquad (2.2)$$

In coupled walls, the shear force V_d acting on the coupling beams should not exceed the upper limit given.

$$V_d \leq 0.85 \times b_w \times d \times \sqrt{f_{ck}} \qquad (2.3)$$

If the design shear force is equal to or less than the oblique cracking strength ($V_d \leq V_{cr}$) shear reinforcement calculation is not required. However, in this case, it is necessary to have the minimum stirrup provided.

$$V_{cr} < V_d < V_{r\,max} \tag{2.4}$$

In the earthquake case, if both Eq. (3.1) and Eq. (3.2) do not occur, cross reinforcement is used.

The condition to meet the shear force with reinforcement:

$$V_{cr} = 0{,}65\ f_{ctd}\ b_w\ d \tag{2.5}$$

$$V_{r\,max} = 0{,}22\ f_{cd}\ b_w\ d \tag{2.6}$$

$$\frac{(h_k - 2d')}{2} = \tan\gamma \tag{2.7}$$

$$A_{sd} = \frac{V_d}{2 \text{ x } f_{yd} \text{ x } \sin\gamma} \tag{2.8}$$

Cross reinforcement interlock length calculation:

$$L_b = 1{,}5\ \ 0{,}12\ \ ø\ \ f_{yd} / f_{ctd} > 1{,}5\ \ 20\ ø \tag{2.9}$$

The amount of reinforcement of the coupling beam:

$$A_{smin} = \frac{0{,}8 \text{ x } f_{ctd}}{f_{yd}} \text{ x } b_w \text{ x } d \tag{2.10}$$

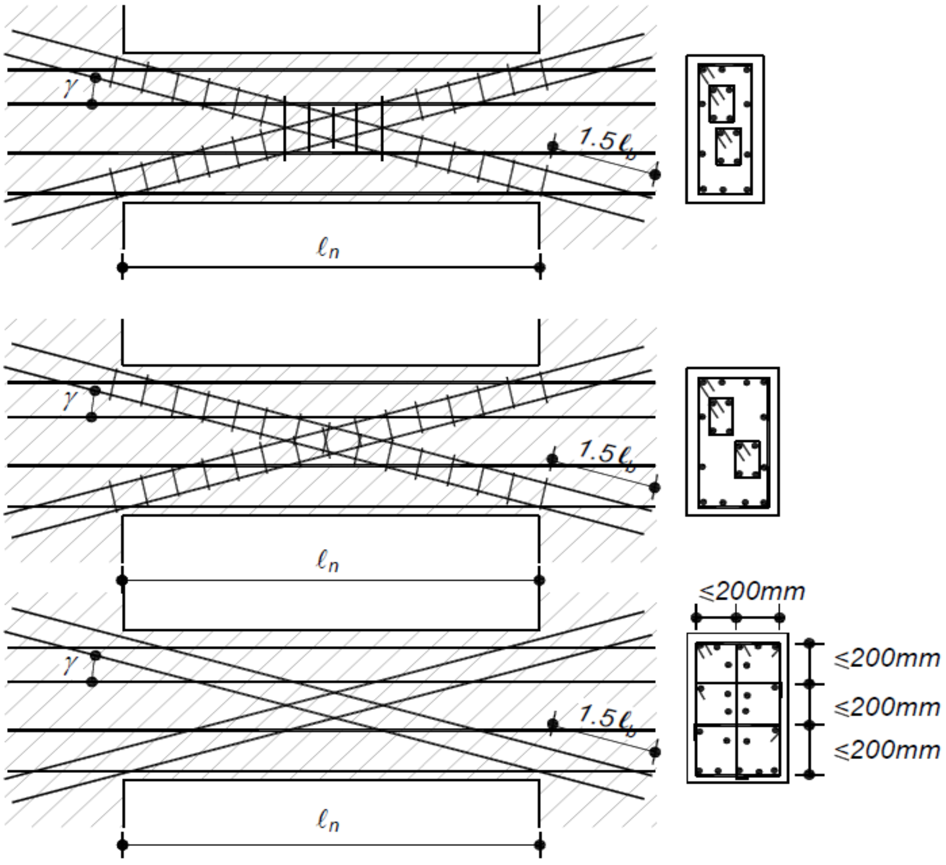

Fig - 2.1: Examples of coupling beam reinforcement in coupled wall [3].

2.1.2. Steel Coupling Beam

Structure; during the earthquake, serious deformations is occured in the coupling beams that provide the force transfer between the shear walls. In order for these coupling beams to provide the desired ductility, it has been observed that in the reinforced concrete coupling beam design, a large amount of reinforcement placement and thus the beam dimensions are very large [4].

For this reason, instead of reinforced concrete coupling beam, structural steel elements were preferred in the design of coupling beams in order to meet the desired deformations with a smaller rod element and because the building floor height is limited. The advantages that will arise when using steel coupling beams are given below [5].

- It increases the energy absorption capacity and ductility of the structure.
- Ductility increases if the embedment area is well detailed in the steel coupling beam.
- Compared to the reinforced concrete coupling beam, there do not occur difficulties such as manufacturing error and placing the interlocking beam reinforcements.
- The ductility increases when local and lateral buckling is prevented in the steel steel beam.

2.1.2.1. Design Rules for Steel Beam Shear Walls İn Accordance With AISC 341-16

The design and detailing of steel coupling beams must compensation the following:

The embedment length of the Steel coupling Beam L_e will be calculated from equations 3.1 and 3.3 [6].

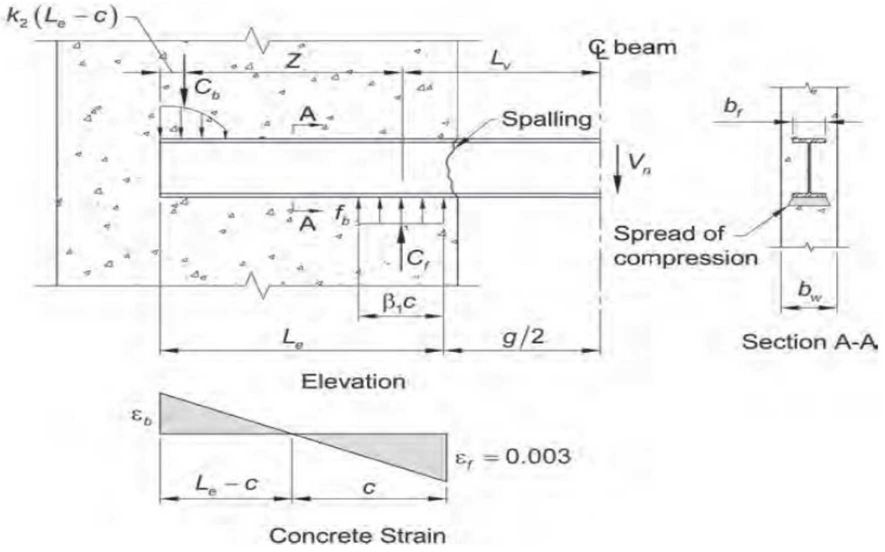

Figure 2.2: Methods for determining the embedded capacity [6].

$$V_n = 1{,}54\sqrt{f_c'}\,\left(\frac{t_{duvar}}{b_f}\right)^{0.66}\beta_1\, b_f\, L_e\left[\frac{0.58-0.22\beta_1}{0.88+\frac{L}{L_e}}\right] \qquad (3.1)$$

Where;

L_e = The embedded length of the steel coupling beam in the reinforced concrete shear wall (mm)

L = Length of steel coupling beam between two reinforced concrete shear walls (mm)

V_n = The expected shear force (N) of the steel coupling beam calculated in Equation 3.3

t_{wall} = Shear wall width, (mm), b_f = Steel coupling beam profile headpiece width, (mm)

f_c' = Compressive strength of shear wall concrete, (MPa)

β_1 = Factor associated with the depth to the neutral axis depth of the equivalent rectangular pressure stress block, as defined in ACI 318-19

The concrete stress of 0.85fc ′ parallel to the neutral axis with the edges of the cross-section shall be assumed to be evenly distributed on an equivalent compression zone located at a distance (a) from the fiber that it has maximum compressive stress as calculated in the following figure. The distance (c) from the fiber with the maximum pressure stress to the neutral axis shall be measured perpendicular to the neutral axis [7].

$$a = \beta_1 c \tag{3.2}$$

The lower limit of b1 is based on experimental data from beams constructed with concrete strengths greater than 55 MPa [7].

Table 3.1: B_1 table according to concrete strength [7].

f_c' , MPa	β_1	
$17 \leq f_c' \leq 28$	0.85	(a)
$28 \leq f_c' \leq 55$	$0.85 - \frac{0.05\,(f_c' - 28)}{7}$	(b)
$f_c' \geq 55$	0.65	(c)

$$V_n = \frac{2\,M_p}{L} \leq V_p \tag{3.3}$$

Where;

A_{tw} = Body area of steel coupling beam, (mm^2), F_y = Steel profile minimum yield stress, (MPa)

$M_p = F_y Z$, (N-mm), $V_p = 0.6\, F_y A_{tw}$, (N), W = Elastic strength moment, (mm^3),

Z = Plastic strength moment, (mm3)

3. METHODOLOGY

In the study, designs of reinforced concrete and steel sectioned coupling beam were made according to the condition of the coupling beams exposed to shear forces of 500, 600 and 700 kN in 10 and 14 storey buildings. By applying 500, 600, 700 kN forces to each of the 30x100 cm, 30x125 cm, 30x150 cm sections selected in the reinforced concrete coupling beams separately, the amount of cross reinforcement belonging to the sections and the embedded depths of the cross reinforcement were calculated for 9 different reinforced concrete coupling beam combinations. In steel profiles, 3 different sections were found for the steel profile area required by each shear force of 500, 600, 700 kN. While finding the sections, the headpiece widths of the steel profile (2.5 bf ≤ bw = 30 cm → bf = 12 cm) and the headpiece and body thicknesses are accepted as fixed, and the body height is variable. Accordingly, the embedded depths of each steel section were calculated. The following graphics have been drawn according to the findings obtained.

4. DEPLACEMENT GRAPHICS OF STEEL AND CONCRETE COUPLED WALLS

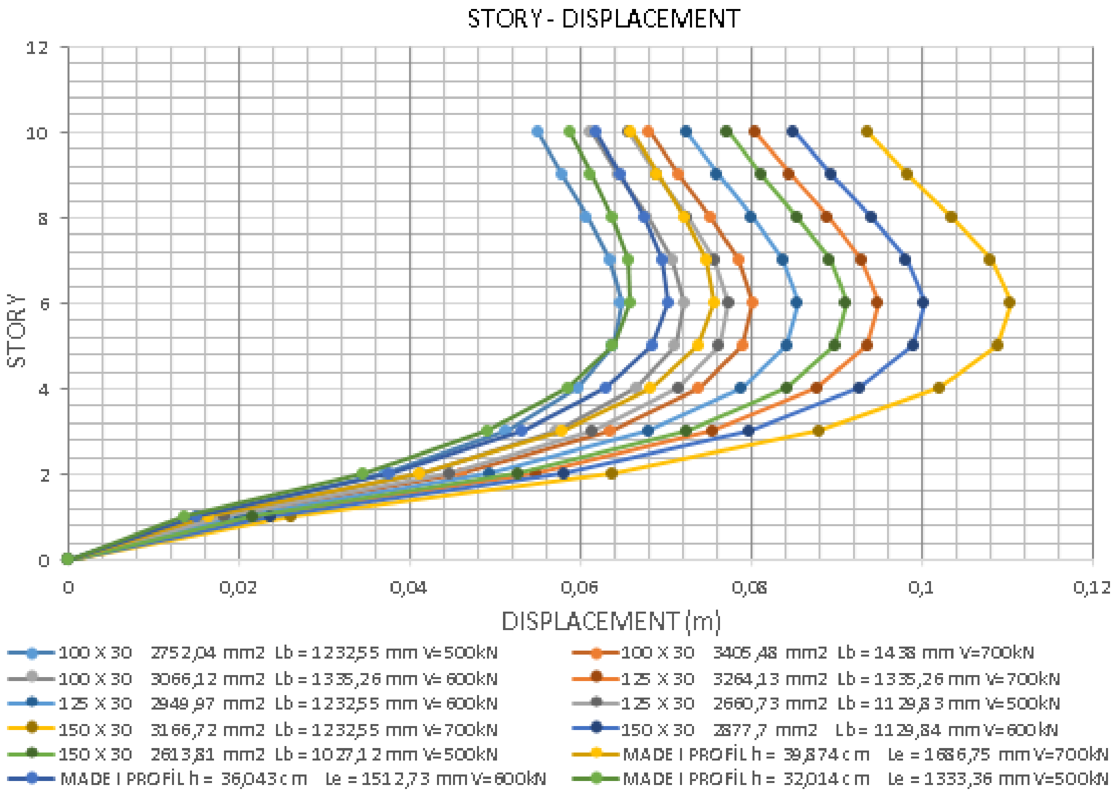

Chart - 4.1: 10-storey building's Displacements according to floors

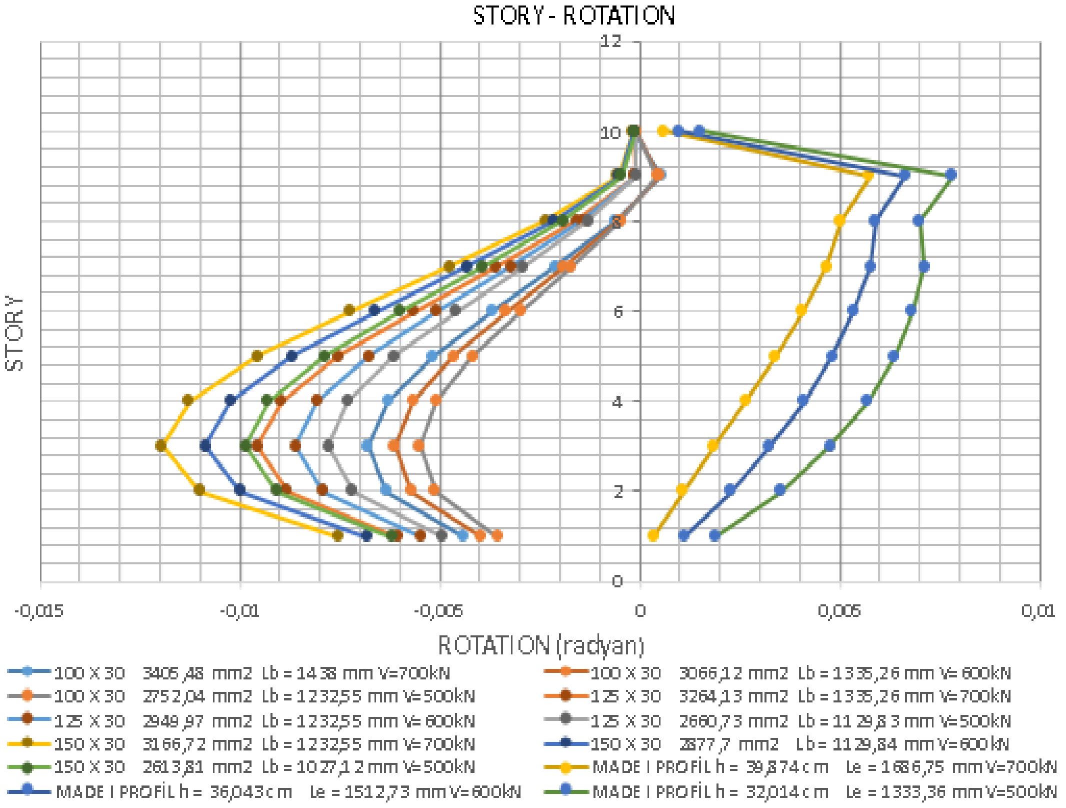

Chart - 4.2: 10-storey building's rotations according to floors

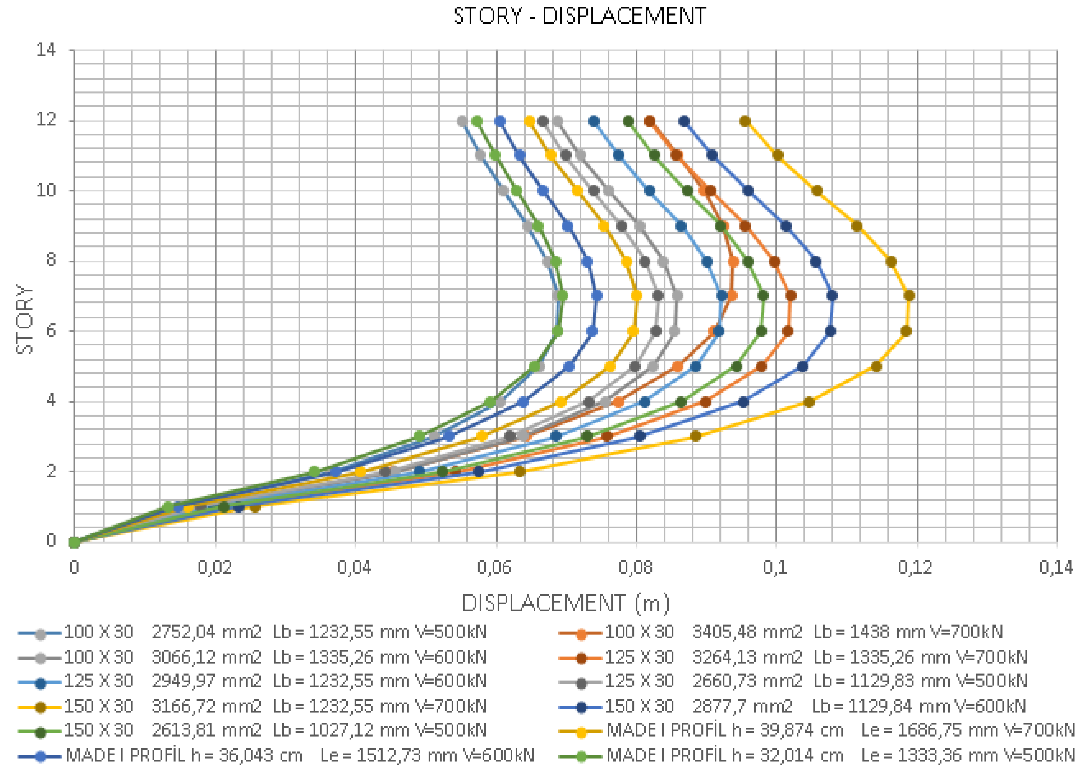

Chart - 4.3:12-storey building's displacements according to floors

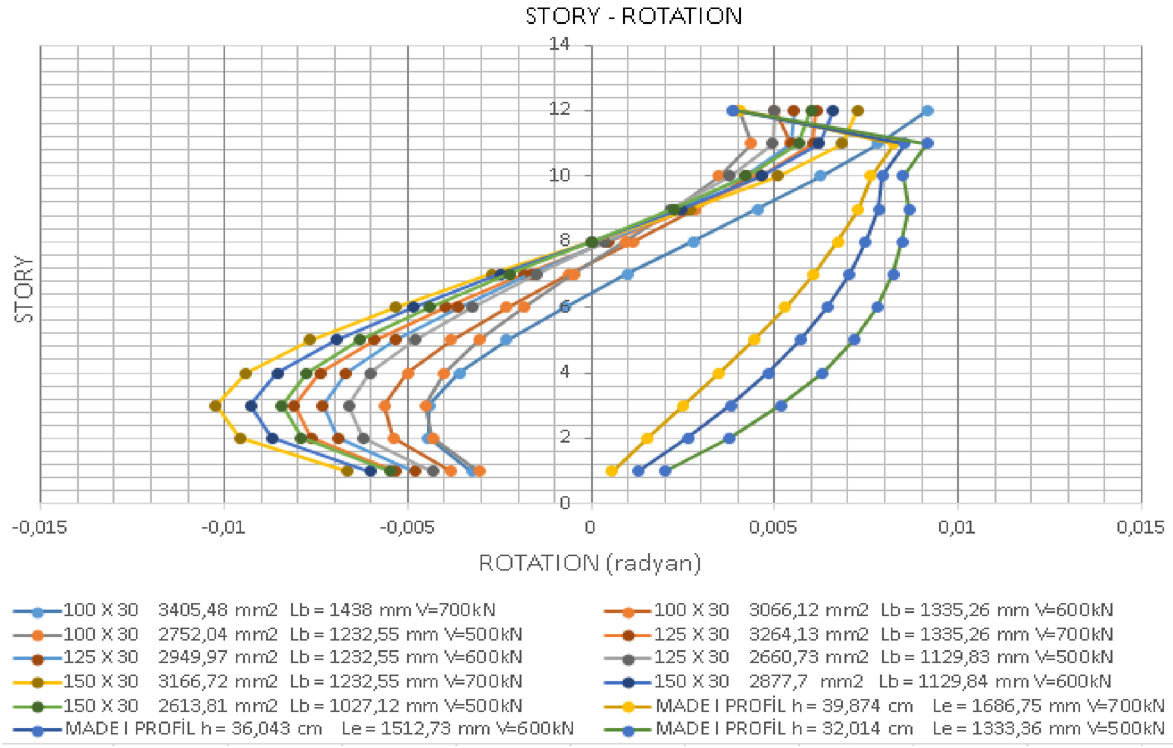

Chart - 4.4: 12-storey building's rotations according to floors

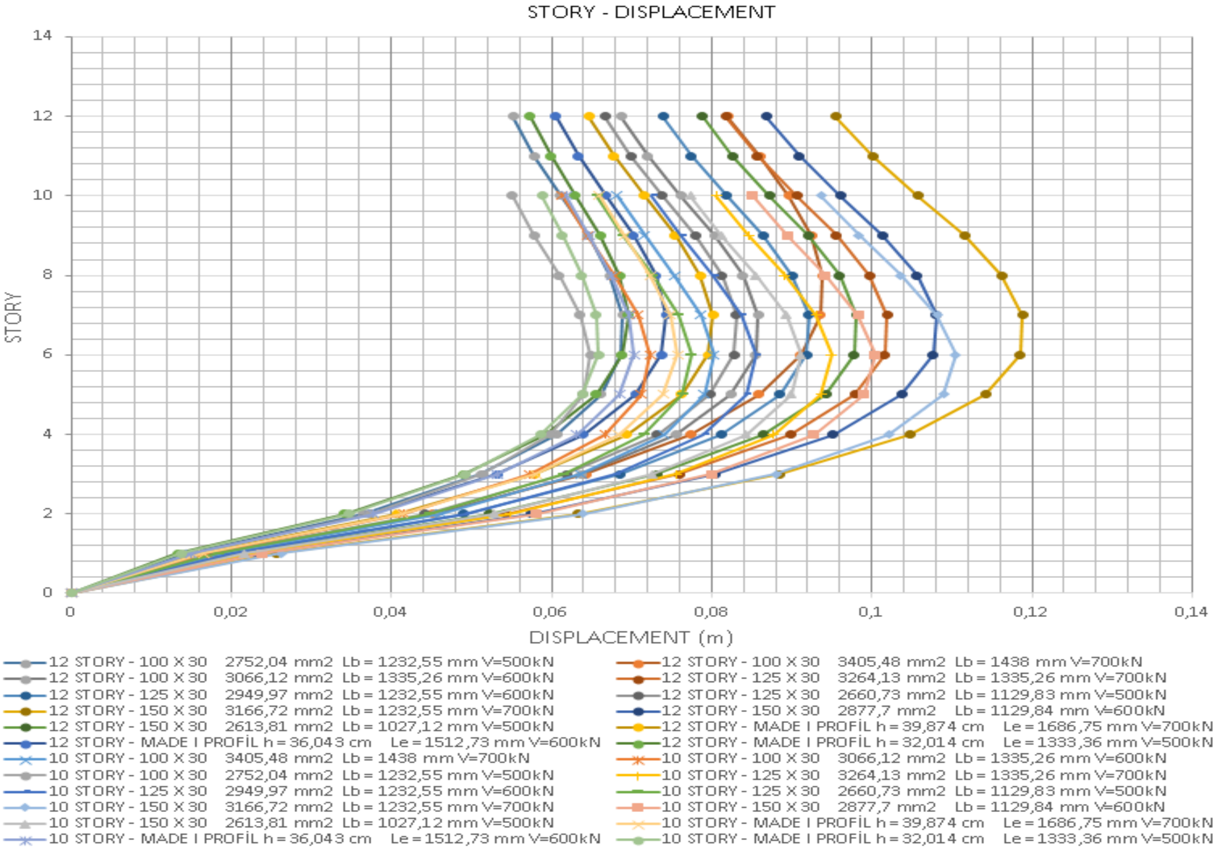

Chart - 4.5: Comparison displacements of 10-storey building and 12-storey displacements building according to the floors

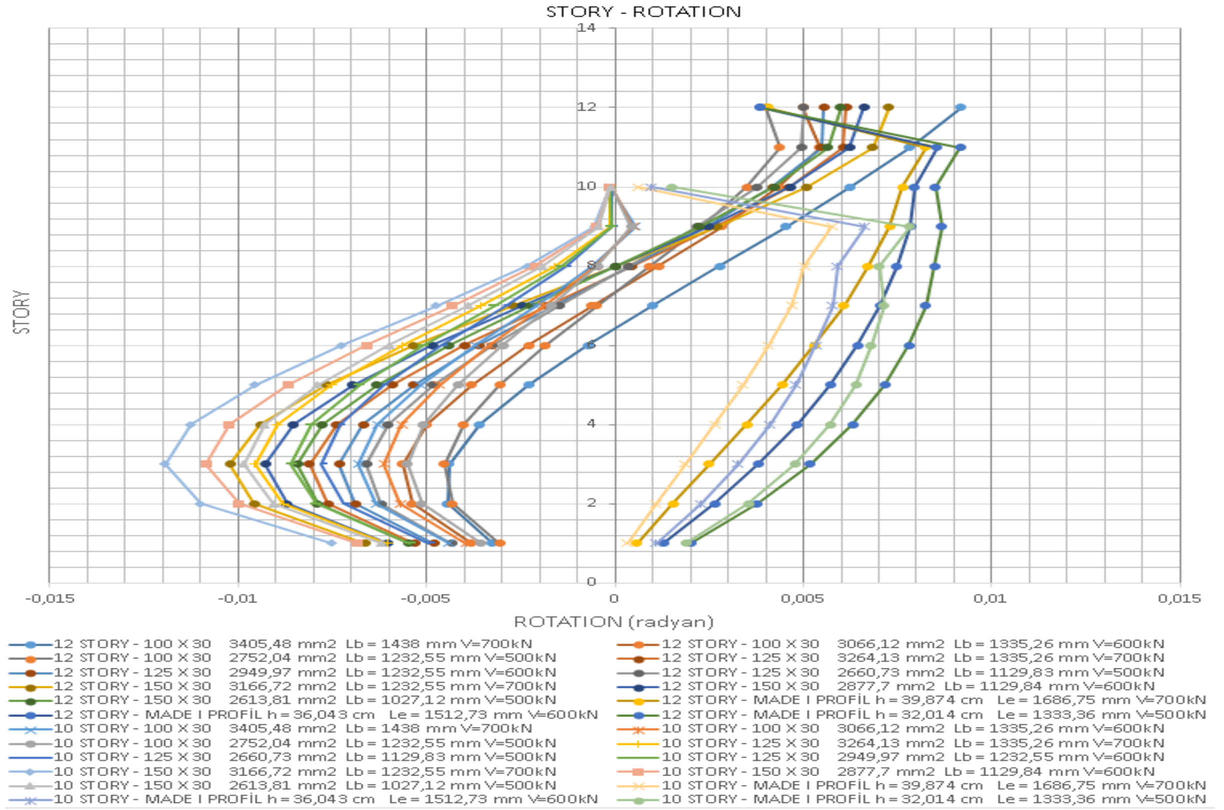

Chart - 4.6: Comparison rotations of 10-storey building and 12-storey displacements building according to the floors

Table 4.1: Dimensions of coupling beams

Shear Wall Thickness	30 cm
Shear Wall Length	180 cm
Floor Height	300 cm
Reinforced Concrete Coupling Beam Thickness	30 cm
Steel Profile Headpiece Widths	12 cm
Concrete class	C30
Rebar	S420
Structural Steel	S355

5. CONCLUSIONS

In this study, it is aimed to develop the design of coupled wall structures according to the coupling beam height of the parts of the coupling beams embedded in the reinforced concrete shear wall. For this, in SAP2000, two-dimensional 10-storey and 12-storey coupled wall structures were investigated by modelling according to ASCE 7-16. Reinforced concrete coupling beams are designed according to TBDY-2018 earthquake regulation, steel coupling beams are designed according to ANSI / AISC 341-16 regulation; the amount of reinforcement, element dimensions, embedded depths, cross-section strengths have been verified depending on the bearing force. The performance of the structure was determined by nonlinear push-over analysis. It was observed that under the equivalent earthquake load acting on the structures at the same heights (by changing the dimensions of the coupling beams), the shear forces reaching the floor levels and the shear forces that the coupling beams are exposed to are very small their variations according to the cross-sections. However, in reinforced concrete coupling beams, it was found that the displacement and rotation of the coupling beams of the same cross section and with different reinforcement amounts are different. Likewise, it was observed that reinforced concrete and steel coupling beams have different rotation and displacement values under the same shear force.

As a result of the study, the design of the building and coupling beams, the building, which is designed by considering the formulas based on the experiments in the studies made on the issue with TBDY-2018 and international regulations;

- Although the steel coupling beams are designed according to the same shear force, the steel coupling beam can be preferred instead of the reinforced concrete coupling beam, as it affects the floor height less because the height of the steel coupling beam is shorter than the height of the reinforced concrete coupling beam.
- The plastic hinge formation of the reinforced concrete coupling beam is more than the steel coupling beam.
- Steel coupling beams exhibited a more rigid performance to structure than reinforced concrete coupling beams.
- It was observed that the higher the height of the reinforced concrete coupling beams, the more ductile the structure is.
- As the dimensions of the reinforced concrete coupling beams increase, the embedded depth of the cross reinforcement decreases, and as the dimensions of the steel coupling beams increase, the depth of the embedded steel profile increases.
- Reinforced concrete coupling beams make more rotation than steel tie beams.
- It was noticed that the displacement is higher in the middle floors of the building in the coupled wall systems.

- It was noticed that the whip effect on the top floor of the building in the coupled wall system with steel coupling beams is more effective than the coupled wall system with reinforced concrete coupling beam.

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