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REVIEW

Shear Wall Design within the Light of Prominent Standards

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Abstract

Reinforced concrete (RC) structures have their own weight, earthquake, wind, dead loads, live loads, creep, etc. throughout their service life. They are exposed to internal and external load effects. In order to meet the horizontal forces such as earthquake and wind from these loads affecting the structure, shear wall structures with high lateral rigidity are needed. Therefore, shear walls are one of the most important structural elements that can resist earthquake forces due to their high lateral rigidity and load bearing capacities. Most of the buildings today are designed according to the old regulations. Therefore, the shear wall was sized and reinforced according to these old regulations. However, to date, standards have been renewed in certain periods. Despite this, shear walls designed according to the old regulations continue to resist seismic forces. In this study, the design and behavioral differences of the reinforced concrete shear walls between the Turkish Regulation that came into force in 2019, and the old regulation were compared. In addition, RC shear walls were evaluated according to ACI-318-19 and EuroCode-2 regulations.

Keywords: RC shear wall, Turkish Code-2019, ACI-318-19, EuroCode-2

1.Introduction

In parallel with the developments in other disciplines, progress is being made in concrete technology day by day. But reinforced concrete is still a mystery as a result of the studies carried out for hundreds of years. Although various scientist's experiments with reinforced concrete elements under different load combinations, developments in building and building material trigger academic studies towards new horizons. However, it continues to be widespread, especially in our country for reasons such as the cheapness of the concrete price and its ability to be shaped. Reinforced concrete shears are the most suitable and inexpensive solution that can be taken against earthquakes experienced in buildings to be designed both in our country and worldwide. Earthquakes experienced in the past years have shown that shear walled structures have shown more resistance to severe earthquakes.

Technology developing over time, job opportunities, social-economic, etc. For reasons, people's desire to migrate from rural areas to cities has increased. As a result, the increasing population of the city has made the construction of multi-story buildings a must [1].]. With the invention of the right elevators in the late 19th century, the interest in tall buildings increased. Today, high-rise buildings are the symbols of the cities in which they are located and even become one of the factors showing the development levels of the countries. Besides, these tall buildings also allow for high-density urban settlements, especially in cities with large populations. With each passing day, along with the developing technological possibilities, construction technologies are developing, and they allow more reliable, more detailed design methods. With each passing day, along with the developing technological possibilities, construction technologies are developing, and they allow more reliable, more detailed design methods. As a result, higher and more delicate structures appear. The desire to make the structures higher and more delicate also brings about a more sensitive situation against the horizontal load. In carrier systems, relative floor displacement increases with the number of floors. As a result, it has become almost mandatory to use shear walls in high-rise buildings to keep relative floor displacement within the limits set by regulations and to reduce relative floor displacement that may occur with torsional irregularities. In fact, as a result of the researches carried out at the end of the destructive earthquakes, it was observed that the structures with reinforced concrete shears did not migrate or received slight damage. Reinforced concrete shears also prevent non-structural damage as well as prevent the building from collapsing [2-4]. Each member counteracts the horizontal forces acting on the carrier system at the rate of stiffness. Since the horizontal stiffness of the shear walls are more than other structural elements, they meet a large part of the horizontal forces acting on the structure. In fact, according to the studies carried out, the infill walls, which crack and take permanent shape change by taking the first effects of the earthquake load, play a role in damping the first effects of the earthquake. Thus, the earthquake force affecting other carrier elements is reduced[5].

The purpose of this study is to show engineers or researchers the criteria of RC shear walls that change according to the old regulation in the new Turkish regulation. In addition, ACI318-19 [6] and EuroCode-2 [7] regulations were compared with the Turkish Regulations [8].

2. The behavior of Reinforced Concrete Shear Walls

The shear strength of RC shear walls consists of contributions of horizontal reinforcement and the concrete. In beams under repeated loads, friction in the cracks and leverage effect of the reinforcement disappeared. However, the vertical and horizontal reinforcement webs in the shears prevent the cracks from expanding. Thus, friction and leverage effect in concrete continuous. Therefore, even when the shear wall reaches its bearing power, it contributes to the concrete shear strength. The shear strength of the shear should be greater than the bending strength. Because ductile behavior is possible by ensuring that the bending fracture occurs before the shear fracture.

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The vast majority of researchers [9, 10] agree that vertical reinforcements have a greater effect than transverse reinforcements on shear strength in squat shears with an H/L ratio equal to or less than 0.5. Some researchers stated that the effects of transverse and longitudinal reinforcements are inconsistent when the pitch H/L ratio is around 1.0, and vertical reinforcements contribute more to crack distribution, energy absorption, and post-peak behavior than peak shear strength [11]. On the other hand, if H/L> 2.0, the contribution of transverse reinforcement is known in the literature.

Although there are many equations in the literature and specifications for determining the shear strength of the shear walls, the equations for the calculation of the displacement capacities are limited. While brittle failure occurs under the shear effect in squat shear walls, flexural collapses in delicate (thin) shear walls are less affected by shear deformations since they exhibit a more ductile behavior. Some researchers have proposed different equations for calculating the displacement capacities of shear walls with the calibration of past experimental studies [12, 13]. Although the studies on squat shear walls in previous years have focused on the displacement capacities of the shear walls, a better account estimate is needed today. In the load-displacement behavior of squat shear walls, a precise poured point cannot be observed since it is shear controlled. Only a significant stiffness reduction in peak strength, low ductility is encountered. Hidalgo et al. (2000)[12] developed a hysteretic model for the analysis of lateral load-displacement behavior for squat shear walls. The researchers developed the model in the shape of shear failure, peak strength and ultimate displacement from the experimental results.

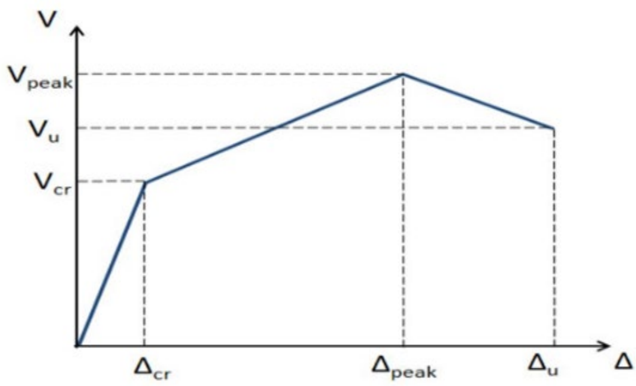

Figure 1. Curve model with three arms

They revealed that for critical, peak and ultimate displacements, the calculation would be calculated based on M/VL_w ratios. Sanchez (2010) [13], developed a displacement capacity model, similar to Carillo and Hidalgo. However, it has been developed with a first stiffness reduction due to flexural crack and a second stiffness reduction due to diffuse diagonal cracking.

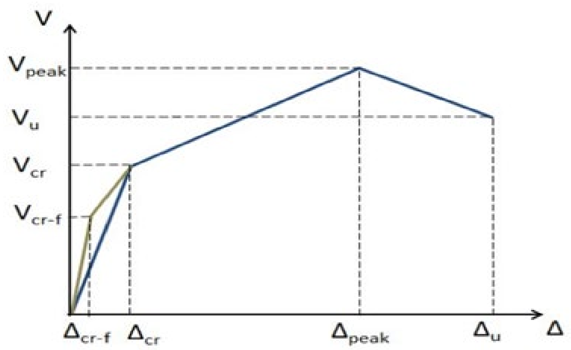

Figure 2. Curve model proposed by Sanchez

Shear walls, whose ratio of height to width is more than 2, show console beam behavior. Floors serve as a support for these types of shear walls on each floor, which allows these shear walls to be delicately designed. Due to the bending behavior, it is easier for the shear walls to form plastic hinges in the base areas and display ductile behavior. The ratio of their height to their width is described as squat shear walls for shears smaller than 2. Squat shear walls, on the other hand, exhibit truss analogy behavior. In other words, they meet horizontal loads with tension and pressure elements. Since the squat shear walls have a small H/L ratio, horizontal loads cause shear forces. In cases where these shear forces are critical, it can be difficult to achieve ductility in squat shear walls. Since the horizontal loads (earthquake, wind, etc.) cause shear forces on the squat shear walls, this shear force creates high moments due to the geometry of the shear. As a result of previous studies, it has been stated that earthquake forces cause diagonal shear cracks in squat shear walls.

The most important parameters affecting the behavior in shear walls are the ratio of shear height to shear length, axial load level, horizontal reinforcement ratio, longitudinal reinforcement ratio, effective shear length. In the literature, these parameters affecting the behavior of shear walls have been examined experimentally, numerically and analytically by exposing the shears to cyclic loading [1, 14-16]. Some of these studies [17, 18] have simulated earthquake forces through the shaking table on the shear walls. However, the shear walls, which have been the focus of researchers since the 1940s, have been cyclic loading in a large part. Considering both building symmetry and loading conditions, shear walls can also be exposed to torsional moment. Few studies in the literature examine the torsional behavior of shear walls. Researchers have focused more on the effects of torsional behavior on beam members in the past years[19-22]. One of the studies involving the torsional behavior of shear walls is the study of Peng (2011) [23] investigating the failure mechanisms of the shear walls only when the torsional moment and torsional moment act together with other loads (bending, axial load).

However, there are studies in the literature with hybrid shear walls where reinforced concrete and steel are used together [18, 24-26]. In these studies, the behavior of hybrid shear walls under cyclic loading was investigated. However, the hybrid concept mentioned here is the use of concrete and structural steel together.

3. Evaluation of RC Shear Walls According to Related Standards

3.1. Comparison of RC Shear Walls According to 2019 Turkish Regulation and Old Regulation

In this section, the new earthquake regulations that entered into force on 01.01.2019, and the changes made in reinforced concrete shear walls in the earthquake regulation to be repealed were compared.

In the new earthquake regulation that entered into force on 01.01.2019, shear walls are defined as “Shears, vertical bearing system elements with a ratio of at least six to the thickness of the long edge in the plan." The striking point here is that this rate was changed to six under the new earthquake regulation that came into force on 01.01.2019. With the enforcement of the new earthquake regulation, the seven aspect ratio was reduced to six.

Another cross-section condition that the shears must meet is the N_{dm} force that will be applied to the net cross-section area remaining after the shears have been removed. In experimental studies carried out on RC shear walls, axial load force has been reported to be highly effective in shear behavior [27-31].]. It has been stated that increasing the axial load level increases shear strength. However, the axial load level also significantly affects the parameters that affect the behavior, such as crack distribution and drift ratio. However, in some studies in the literature, the axial load can be neglected in experimental studies since the axial load increases the strength of the shear wall. ACI-318-14 mentioned in the comment's section for the users that the axial load can be neglected in laboratory conditions since the shear capacity of the shear walls increases the shear capacity of the axial load in the pressure direction. Taking into account the coefficients of mobile loads defined in the TS498 for moving loads, it is stated that G and Q vertical loads and the earthquake effect E will be the largest axial pressure forces calculated under G + Q + E. It must meet the $A_c \geq N_{dm}/(0.35 f_{ck})$ condition. The coefficient value was changed from 0,25 in the old regulation to 0,35 in the new regulation. It is stated that RC shear walls can carry a more axial load with this change. It is accepted that the axial load will affect the pressure direction. However, Ji et al (2018) [32] reported that shear walls may also be exposed to axial load in the tension direction. It is stated that in the calculation of Ac and Ndm values in coupling shear walls, it is necessary to take into account the entire hollow shear section (total of shear parts).

Except for some special cases, the thickness of the shears such as U, L and T in the body area of the shears shall not be less than 1/20 of the floor height and not less than 200 mm in the regulation that is repealed. It has been changed.

However, in the regulation to be repealed regarding the shear thickness, "For shears whose floor height is greater than 6 m and, which are at least 1/5 of the floor height, the shear thickness in the lateral direction between the points of the horizontal length between the points where it is held in the lateral direction may be less than 1 / 20th. However, this thickness cannot be less than 300 mm. "The condition has been removed 6m. In the new regulation, these statement states, "The thickness of the rectangular shear or shear arm will not be less than 1/30 of the length of the shear or the shear arm that is not kept in the lateral direction in the plan. If the shear arm is held in both sides with shear in the lateral direction, the thickness of the shear arm will not be less than 1/20 of the floor height and 250 mm." Has been changed to.

Another change in the new regulation was made in the section of the body reinforcement of RC shear walls. It has been stated that horizontal reinforcements and/or crossover reinforcements used as winding reinforcements must be hooked to the longitudinal reinforcement in the shear end region by 135 degrees. There is no 135-degree hook condition in the old regulation. In addition, there is an expression that horizontal reinforcements can be made at 90 degrees miter at the shear end areas. The 90-degree condition does not exist in the old regulation. It is added that the distance between the ends or squares of the horizontal body reinforcements, and the outer edge of the shear should not be greater than 150 mm, and in cases where an overlapped joint should be made on the horizontal body reinforcements in the shear body, the overlapped joints can be made as a surprise along the length of the shear body. The overlap length should not be less than 1. 5lb. 90-degree hooks will be formed at the ends of the horizontal reinforcements. If hooks are not used at the ends of the horizontal body rebar, this rebar will be arranged to remain inside the longitudinal body rebar, there will be at least six longitudinal body rebar along the overlap joint, and the horizontal distance between the longitudinal body rebar in the overlap joint area will not exceed 200 mm.

In the Turkish Regulation, in cases where the height of the RC shear wall in the plan (H/L) is greater than 2, there is a condition to make the boundary element. In the new regulation, new reinforcement arrangements have been added in the shapes of the shear end zones (Figures 3 and 4)

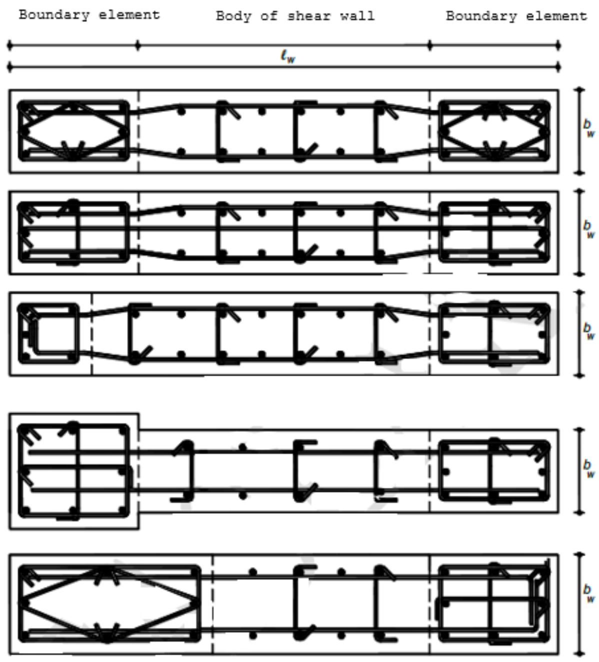

Figure 3. Reinforcement layout on the boundary element zone in canceled regulation

In the new regulation, the friction shear force capacity of the RC shear wall has been changed. In the old regulation, the conditions to be fulfilled with Equation 1 were changed to Equations 2 and 3.

$$V_e \leq \min\ [0{,}2\ f_{ck}A_c,\ \ (3{,}3 + 0{,}08f_{ck})A_c,\ \ 10A_c] \qquad \text{Equ.1}$$

$$V_e \leq f_{ctd}A_c + \ \mu A_s f_{yd} \qquad \text{Equ.2}$$

$$V_e \leq \min\ [0{,}2\ f_{ck}A_c,\ \ (3{,}3 + 0{,}08f_{ck})A_c,\ \ 10A_c] \qquad \text{Equ.3}$$

Another amendment in the new regulation was made to the section of the coupling shear walls. In the coupling shear walls, the reinforcement arrangement of the coupling beams connecting the shear pieces has been changed. It was stated in the old regulation that the reinforcement arrangement of coupling beams can be made with special shear reinforcement that has been proved by experiments. However, it was stated in the new regulation that the cross-reinforcement layout should be used instead.

The opening can be left on RC shear walls due to architectural reasons such as doors and windows. However, the location, size, etc. of these opening situations significantly affect the strength of the shear wall. In the studies in the literature [33-39] The opening can be left on RC shear walls due to architectural reasons such as doors and windows. However, the location, size, etc. of these opening situations significantly affect the strength of the shear wall. In the studies in the literature [30, 31] it was also stated that special reinforcements should be placed around these opening. In the new earthquake regulation, more details are given on the spaces to be left in the RC shear walls. It is stated that opening such as windows and installations can be left for the middle third of the shear. It is also stipulated that the horizontal dimension of the opening cannot be greater than 20% of the shear width, and the opening height cannot be greater than 20% of the floor height.

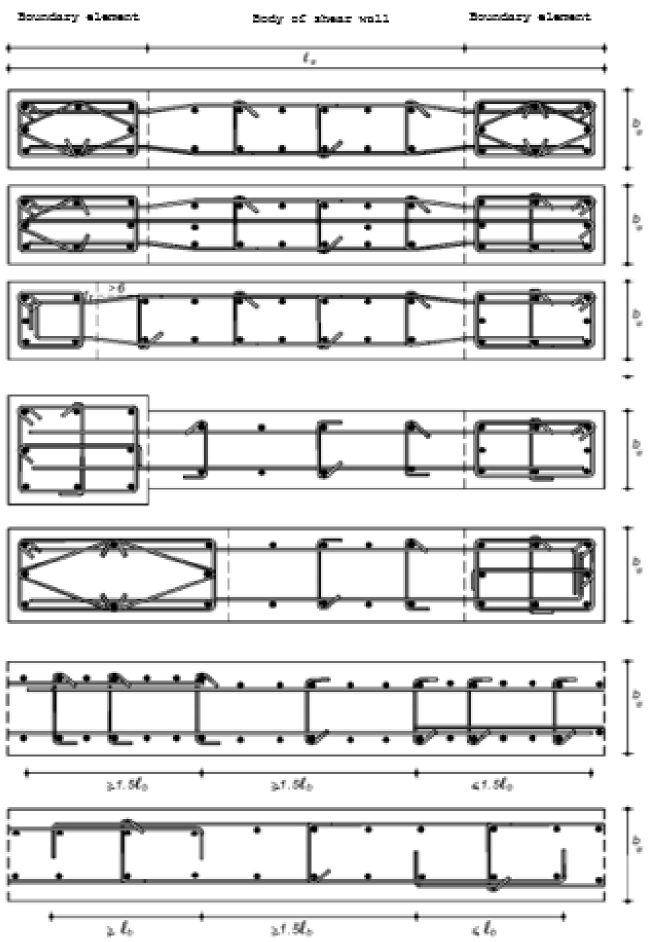

Figure 4. Reinforcement layout on the boundary element zone in the renewed regulation

3.2. Evaluation of Reinforced Concrete Shear Walls According to ACI318-19

One of the first noticeable factors between the American and Turkish Regulations; It is stated in ACI318-19 that RC shear walls can be installed either on or off-plane (Figure 5). In the Turkish Regulation, no distinction has been made between in-plane or out-of-plane.

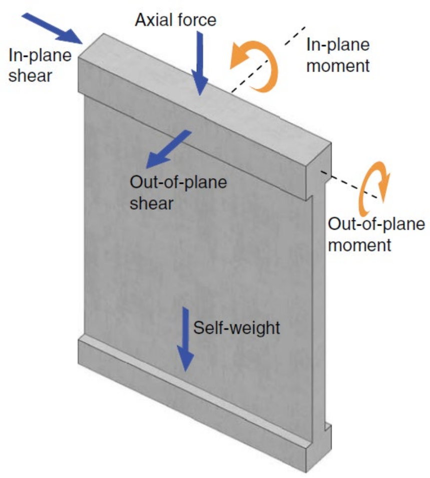

Figure 5. In-plane and out-of-plane forces of RC shear walls

According to the old regulation ACI-318-14 [35]in ACI-318-19, a substance was added in the axial load capacities of the shear walls. In the new regulation, Pu> $0.2f_cA_g$ condition has been added for the axial load capacity of RC shear walls. No changes were made to the design limits of shear walls. Limit values of shear wall thickness have not been changed. In addition, ACI-318-19 stated that RC shear walls can be exposed to an eccentric axial load, and these forces must be taken into consideration while designing shear walls. Strength reduction coefficients for axial force and moment forces that shears walls can carry are specified in ACI318-19. It is stated that the calculated axial force and moment value should be used in the design phase after multiplying these resistance reduction coefficients. In Turkish regulation, the strength reduction coefficients appear in both material and load combinations.

In ACI-318-19, when calculating the shear strength of RC shear walls, both inside and outside the plane must be calculated. It is also stated that strut-and-tie analogy can be used in the design of H/L<2 shear walls. In the Turkish Regulation, there is no material such as a truss beam analogy that can be used for the design of RC shear walls.

For the shear strength of RC shear walls in ACI-318-19, ACI-318-14 changed $V_n<10\sqrt{fc}$ hd condition to $V_n<8f_cA_{cv}$. The coefficient has been reduced due to changing hd to hl_w. Because the effective cutting area is increased, the coefficient is reduced. Equation 4 not included in ACI-318-14 in ACI318-19 was added for the shear strength of RC shear walls.

$$V_n = \left(\alpha_c\lambda\sqrt{f_c} + \rho_t f_{yt}\right)A_{cv} \qquad \text{Equ.4}$$

α_c, H/L≤1,5 for shear walls 3; correlations can be made between 2 and 3 for H/L≥2 shear walls and 2 to 3 for H/L≤2 shear walls. However, if the shear wall is exposed to axial pulling force, α_c must be calculated with Equation 5.

$$\alpha_c = 2\left(1 + \frac{N_u}{500\,A_g}\right) \geq 0 \qquad \text{Equ. 5}$$

It should be noted that N_u will be taken as negative here. The shear strength calculations of out-of-plane shear walls are given and defined in Limit values in Acı-318-14. However, only the conditions in Section 22.5 are proposed for the shear strength of out-of-plane shear walls in ACI-318-19.

The requirement for minimum reinforcement ratios to be used in RC shear walls was changed in ACI318-19. Instead of $0{,}5\emptyset V_c \leq V_n \leq 0{,}5\emptyset V_c$ condition in ACI-318-14, $5\emptyset\alpha_c\lambda\sqrt{f_c}A_{cv} \leq V_n \leq 0{,}5\emptyset\alpha_c\lambda\sqrt{f_c}A_{cv}$ in ACI-318-19 condition is added. If $V_n \leq 0{,}5\emptyset\alpha_c\lambda\sqrt{f_c}A_{cv}$, table values or minimum reinforcement ratios can be used for horizontal and vertical reinforcement. If $5\emptyset\alpha_c\lambda\sqrt{f_c}A_{cv} \leq V_n$, the ratio of horizontal and vertical reinforcement should be greater than 0.0025. In addition, the longitudinal reinforcement ratio must provide Equation 6.

$$\rho_l \geq 0{,}0025 + 0{,}5(2{,}5 - h_w/l_w)(\rho_t - 0{,}0025) \qquad \text{Equ.6}$$

In ACI 318-19, no changes were made for the reinforcement details of both cast-in-place and pre-cast shear walls.

3.3. Evaluation of Reinforced Concrete Shear Walls According to EuruCode

In EuroCode-2, RC shear walls are defined as structural elements bearing load, bending moment and shear force. In addition, it is stated that the strut-and-tie method can be used in the design of shear walls as in ACI-318-19. Figure 6 shows the classic shear wall and the forces it meets in EuroCode-2. However, in order for a structural element to be designed as a RC shear wall, the ratio of the shear length to the shear width must be at least 4.

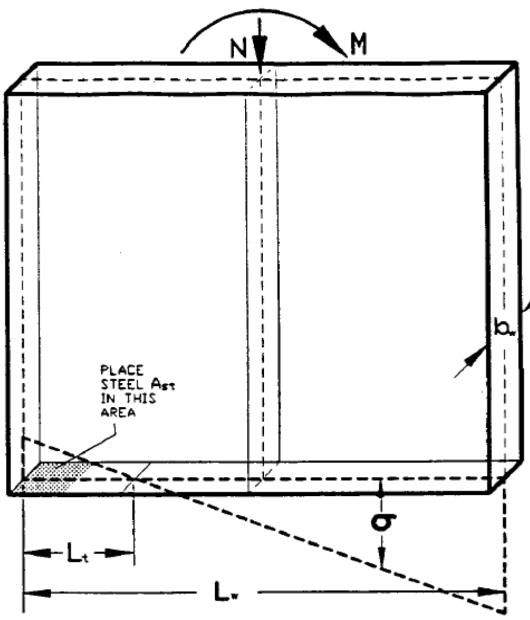

Figure 6. The geometry and stresses of RC shear wall at EuroCode-2

The stress (σ) affecting the RC shear wall under N axial and M bending moment is calculated as in Equation 7.

$$\sigma = \frac{N}{L_w b_w} \mp \frac{6M}{b_w L_w^2} \qquad \text{Equ.7}$$

Maximum stresses in the pressure zone must ensure the following equation.

$$\sigma_{max} < 0,57 f_{ck} + [A_{sc}/(L_w b_w)] 0,87 f_{yck} \qquad \text{Equ.8}$$

Here $A_{sc}/(L_w b_w)$ shows the reinforcement ratio in the pressure zone. In addition, the reinforcement ratio in the drawing region must also provide Equation 9.

$$\frac{A_{st}}{L_w b_w} > 0,5\,(L_t/L_w)\left[\frac{\sigma_{max}}{0,87 f_{yk}}\right] \qquad \text{Equ.9}$$

It is stated in EuroCode-2 that the minimum reinforcement ratio on RC shear walls can be 0.004. It was emphasized that the maximum longitudinal reinforcement ratio could be 0.04. However, in cases where the longitudinal reinforcement ratio is 0.02 and above, considerable attention should be paid to wind it with sufficient stirrup reinforcement. It is stated that the ratio of horizontal reinforcement should not be more than half of the ratio of vertical reinforcement, and the diameter of horizontal reinforcement should not be less than 1/3 of the diameter of vertical reinforcement. The distance between the horizontal reinforcements should be 2 times the thickness of the shear and 300 mm less.

In EuroCode-2, it has been noted that in the design of coupling shear walls, plastic hinges should be formed on the shear base and coupling beams.

The formula defined for the maximum axial load force that shear walls can carry in EuroCode-2 is a bit more complicated than the formula defined by other standards. Parameters such as floor height, second-degree moments and moment of inertia are taken into account. The maximum axial force that the shear wall can carry is shown in Equation 10.

$$F_{V,Ed} \leq 0,517 \frac{n_s}{n_s + 1,6} \frac{\sum E_{cn} I_c}{L^2} \qquad \text{Equ.10}$$

Table 1. Limits values for RC shear walls according to the relevant codes

Parameters	ACI318-19		EuroCode-2	Turkish Standard
Minimum horizontal reinforcement ratio	0.0025		0.0040	0.0025
Minimum longitudinal reinforcement ratio	0.0025		0.0040	0.0025
The formula for plastic hinge length	None		None	None
Spacing of horizontal reinforcement	cast-in-place	3h 18 in	300 mm	250 mm
	precast	5h 18 in		
Height-to-length ratio to define as RC shear wall	None		4	6
Alternative design method	Strut-and-tie method		Strut-and-tie method	Finite element method

Table 2. Design and behavior parameters of RC shear walls according to the relevant standards

Parameters	ACI318-19	EuroCode-2	Turkish Code
Compressive strength of concrete	+	+	+
Characteristic compressive strength of concrete	+	-	-
Yield strength of reinforcement	+	+	+
Height of wall	+	+	+
Length of wall	+	+	+
Thickness of wall	+	+	+
Critical height of wall	-	-	+
H/L<2 or H/L>2	+	+	+
Cross section area of concrete	+	+	+
Reinforcement ratio	+	-	+
Strength reduction factor	+	-	-
Effective length factor	+	-	-
Axial load	+	+	+
Modulus of elasticity	+	+	-
Moment of inertia	+	+	-

4. Conclusion

In this study, the comparison of old new versions for RC shear walls in Turkish, European and American regulation was made. As a result of the evaluation, the following results were obtained.

Table 1 presents the comparison of the design and limit values of the three regulations for curtain walls.

In American regulation, it was emphasized that the shear walls can meet the load inside and outside the plane. However, such a distinction was not found in Turkish regulation. In addition, in the American regulation, reinforcement detail conditions are presented for on-site casting and pre-casting situations of RC shear walls. In the Turkish regulation, RC shear walls are not handled differently, as pre-casting and on-site casting.

In all three regulations, especially the plastic hinges on the area that directly affects the behavior of RC shear walls is not emphasized. No formula for the plastic hinges on length is offered for engineers and researchers. However, in Turkish regulation, the critical shear height definition is made for shear walls. It is stated that for H / L> 2 shear walls, border elements should be formed in both end regions of the shear. The reinforcement detail and arrangement of these regions are subject to special conditions.

In all three regulations, there is not much information about the calculation and reinforcement arrangement of shear walls with different geometries such as U, L and T. The design and reinforcement boundaries of this type of shear walls have not been determined.

As can be seen from Table 2, regulations can consider different parameters in the calculation and strength of RC shear walls. Each regulation proposes its own formula for calculating both shear and flexural strength of RC shear walls. In addition, height, thickness and length of shear wall, reinforcement and concrete characteristics parameters and aspect ratio are proposed to use to design and calculation steps in three regulations. Especially the 2 determined for the H/L ratio is taken into consideration in the regulations. This ratio, which effects the behavior of shear walls, is taken into account by both researchers and regulations. In addition, the yield strength of the reinforcement is especially used in shear wall strength calculations. Longitudinal reinforcements meet the flexural moment. Transverse reinforcements are very effective elements in carrying shear forces. Another important parameter is the characteristic features of concrete. It is especially used in concrete compressive strength calculations.

The regulations have different parameters as well as common parameters. ACI regulation proposes a strength reduction coefficient in shear strength calculations. The critical shear height definition is taken into consideration by the Turkish regulation. Different reinforcement layouts are recommended at the critical wall height. The modulus of elasticity and moment of inertia parameters are taken into account by ACI and Eurocode.

Although there are differences between regulations in the design of curtain walls, the geometry of shear walls and reinforcement and concrete characteristics are invariable parameters.

Although there are many studies in the literature about hollow shear walls, there is not much emphasis on opening shear walls in all three regulations.

In particular, the necessary details are not given for coupling beams, where plastic hinges are formed on the coupling shear walls and directly affect the shear behavior. In particular, no-limit value has been found on dampers used in tie beams in recent years.

In recent years, researchers have turned to different types of reinforcement to control cracks as well as increase strength instead of conventional steel reinforcement. Especially, fiber-reinforced polymer (FRP) bars such as carbon, glass and aramid tend to be used as reinforcement. There is no assessment for FRP reinforcements in regulations. Reinforcement details and limit values are made for classic steel reinforcements.

It is stated that the strut-and-tie method can be used for the design of shear walls in ACI318-19 and EuroCode-2. In fact, a separate section is defined for the strut-and-tie method in these regulations. However, in the Turkish Regulation, this method could not be encountered for shear walls. However, since a 3-dimensional solution is requested with the finite element method, which is a more detailed solution method in Turkish regulation, the strut-and-tie method is not required.

Table 2 presents the parameters taken into account in the calculation of the shear and flexural strength of the RC shear walls in terms of ACI, Turkish and European regulations. The parameters with a plus sign in the table represent that they are used in the regulation and negative signs represent that they are not used in the regulation.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest

Nomenclature

A_c : gross cross-sectional area of boundary of RC shear wall
A_{cv}: gross area of concrete section bounded by web thickness and length of the section in the direction of shear force considered in the case of walls
A_g : gross area of the concrete section
A_s : area of longitudinal reinforcement
d : distance from extreme compression fiber to center of force of all reinforcement in tension
E_{cm}: is the mean modulus of elasticity
f_{ck}: compressive cylindrical strength of concrete
f_{ctd}: tension strength of concrete
f_{yd}: yield strength of reinforcement
f_{yt}: specified yield strength for non prestressed reinforcement
$F_{V,Ed}$: is the total vertical load
h : the thickness of shear wall
h_w and l_w: height and length of shear wall, respectively
I_c: is the second moment of area (uncracked concrete section) of the wall(s).
L : is the total height of building above level of moment restraint
N_{dm}: axial compressive force at the Turkish Code
n_s: is the number of stories
N_u : factored axial force at American Code
P_u : axial force at American Code
V_e : shear force for horizontal reinforcement of shear walls
V_n : nominal shear strength
μ : shear friction coefficient
α_c : coefficient defining the relative contribution of concrete strength to nominal wall shear strength
Λ : modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normal weight concrete of same compressive strength
ρ_l and ρ_l : ratio of the area of distributed longitudinal and transverse reinforcement, respectively.
$\emptyset$: strength reduction factor

References

[1.] Şenel, M.S., Tünel kalıp perde duvarlarının deprem davranışının deneysel olarak araştırılması, PhD Thesis (2001) Institute of Science Technology, Pamukkale University, Denizli, Turkey.

[2.] Baş, E., FRP Sargılı perde duvarın yükler altındaki davranışının incelenmesi, PhD Thesis (2015) Institute of Science Technology, Pamukkale University, Denizli, Turkey.

[3.] Çalışkan, Ö., Mevcut Betonarme binaların dış perde duvar ile güçlendirilmesinde ankraj uygulamalarının deneysel olarak araştırılması, PhD Thesis (2010) Institute of Science Technology, Orhangazi University, Eskişehir, Turkey.

[4.] Erdemli, M.E., Sönümleyiciler ile bağlı betonarme perde duvarlı yüksek yapılarda eşdeğer sönümleme yöntemlerinin incelenmesi, Master Thesis (2015) Institute of Science Technology, İstanbul Technical University, İstanbul, Turkey.

[5.] Ji, X., et al., Cyclic shear behavior of composite walls with encased steel braces. Engineering Structures, 2016. 127: p. 117-128.

[6.] ACI318-19. Building code requirements for structural concrete (ACI 318-19) and commentary. 2019. American Concrete Institute.

[7.] Reinforced concrete design: to Eurocode 2. 1992.

[8.] Yönetmelik, D.B.Y.B.H., Bayındırlık ve İskan Bakanlığı. 2019, Ankara.

[9.] Barda, F., Shear strength of low-rise walls with boundary elements[Ph. D. Thesis]. 1972.

[10.] Greifenhagen, C. and P. Lestuzzi, Static cyclic tests on lightly reinforced concrete shear walls. Engineering Structures, 2005. 27(11): p. 1703-1712.

[11.] Cardenas, A., H. Russell, and W. Corley, Strength of low-rise structural walls. Special Publication, 1980. 63: p. 221-242.

[12.] Hidalgo, P.A., R.M. Jordán, and R. Martínez. Development and use of an analytical model to predict the inelastic seismic behavior of shear wall, reinforced concrete buildings. in Proc., 12th World Conf. on Earthquake Engineering. Upper Hutt, New Zealand: New Zealand Society for Earthquake Engineering. 2000.

[13.] Sánchez-Alejandre, A. and S.M. Alcocer, Shear strength of squat reinforced concrete walls subjected to earthquake loading—trends and models. Engineering Structures, 2010. 32(8): p. 2466-2476.

[14.] Bahadır, F., Düzlem dışı perde duvarla güçlendirilmiş deprem davranışı yetersiz betonarme çerçevelerin davranışına pencere boşluklarının etkisi, PhD Thesis (2012) Institute of Science Technology, Selçuk University, Konya, Turkey.

[15.] Şahin, H., K.E. Alyamaç, and A.S. Erdoğan, Perdeli Ççerçeveli yapılarda zemin sinifi ve kat adedi dikkate alınarak gerekli perde oranının tespiti. SDU International Journal of Technological Science, 2013. 5(1).

[16.] Ünal, A., TDY 2007'ye göre tasarlanmamış betonarme çerçevelerin düzlem dışı perde duvarla güçlendirilmesi, PhD Thesis (2012) Institute of Science Technology, Selçuk University, Konya, Turkey.

[17.] Carrillo, J., J.M. Lizarazo, and R. Bonett, Effect of lightweight and low-strength concrete on seismic performance of thin lightly-reinforced shear walls. Engineering Structures, 2015. 93: p. 61-69.

[18.] Zhao, J., et al., Hysteretic behaviour of steel fibre RC coupled shear walls under cyclic loads: Experimental study and modelling. Engineering Structures, 2018. 156: p. 92-104.

[19.] Aydin, A.C. and B. Bayrak, The torsional behavior of reinforced self-compacting concrete beams. Advances in concrete construction, 2019. 8(3): p. 187-198.

[20.] Bernardo, L. and S. Lopes, Plastic analysis and twist capacity of high-strength concrete hollow beams under pure torsion. Engineering structures, 2013. 49: p. 190-201.

[21.] Chalioris, C.E. and C.G. Karayannis, Experimental investigation of RC beams with rectangular spiral reinforcement in torsion. Engineering structures, 2013. 56: p. 286-297.

[22.] Pawlak, W. and M. Kamiński, Cracking of reinforced concrete beams under torsion—theory and experimental research. Archives of Civil and Mechanical Engineering, 2012. 12(3): p. 368-375.

[23.] Peng, X., Study of torsional behavior of reinforced concrete walls, PhD Thesis (2012), The Hong Kong Polytechnic University, Hong Kong.

[24.] Cheng, M.-Y., R. Fikri, and C.-C. Chen, Experimental study of reinforced concrete and hybrid coupled shear wall systems. Engineering Structures, 2015. 82: p. 214-225.

[25.] Park, W.-S. and H.-D. Yun, Seismic behavior and design of steel coupling beams in a hybrid coupled shear wall systems. Nuclear Engineering and Design, 2006. 236(23): p. 2474-2484.

[26.] Xu, L., Seismic study of hybrid shear wall system. 2013: Illinois Institute of Technology.

[27.] Dazio, A., K. Beyer, and H. Bachmann, Quasi-static cyclic tests and plastic hinge analysis of RC structural walls. Engineering Structures, 2009. 31(7): p. 1556-1571.

[28.] Dong, Y.-R., et al., Seismic behavior and cross-scale refinement model of damage evolution for RC shear walls. Engineering Structures, 2018. 167: p. 13-25.

[29.] Farvashany, F.E., S.J. Foster, and B.V. Rangan, Strength and deformation of high-strength concrete shear walls. ACI structural journal, 2008. 105(1): p. 21.

[30.] Nie, J.-G., et al., Experimental study on seismic behavior of high-strength concrete filled double-steel-plate composite walls. Journal of Constructional Steel Research, 2013. 88: p. 206-219.

[31.] Su, R. and S. Wong, Seismic behavior of slender reinforced concrete shear walls under high axial load ratio. Engineering Structures, 2007. 29(8): p. 1957-1965.

[32.] Ji, X., X. Cheng, and M. Xu, Coupled axial tension-shear behavior of reinforced concrete walls. Engineering Structures, 2018. 167: p. 132-142.

[33.] Husain, M., A.S. Eisa, and M.M. Hegazy, Strengthening of reinforced concrete shear walls with openings using carbon fiber-reinforced polymers. International Journal of Advanced Structural Engineering, 2019. 11(2): p. 129-150.

[34.] Wang, J., et al., Shear behavior of reinforced concrete structural walls with eccentric openings under cyclic loading: experimental study. The Structural Design of Tall and Special Buildings, 2012. 21(9): p. 669-681.

[35.] ACI318-14. Building code requirements for structural concrete (ACI 318-14) and commentary. 2008. American Concrete Institute.

[36.] Aydın, A.C., Maali, M. , Kılıç, M., and Sagiroglu, M., Experimental Investigation Of Sinus Beams With End-Plate Connections, Thin-Walled Structures, Vol:97, December 2015, pp.35-43.

[37.] Maali, M., Kılıç, M., Aydın, A.C., Experimental model of the behaviour of bolted Angles connections with stiffeners, International Journal of Steel Structures, 16(3), 2016, pp.719-733.

[38.} Maali, M., Kılıç, M., Sagiroglu, M., Aydın, A.C., Experimental model for predicting the Semi-rigid Connections' Behaviour with Angles and Stiffeners, Advances in Structural Engineering, 2017, Vol 20, Issue 6, pp. 884 – 895.

[39.] Kurt M, Kotan, T., Gül, M.S., Gül, R., Aydin, A.C., The Effect of Blast Furnace Slag to Self-Compactability of Pumice Aggregate Lightweight Concrete, SADHANA Academy Proceedings in Engineering Sciences, 41(2), February 2016, pp.253-264.

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