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Research Paper

Investigating Structural Stability and Constructability of Buildings Relative to the Lap Splice Position of Reinforcing Bars

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ABSTRACT

The design principles and implementation of rebar lap splice in architectural structures are governed by building regulations. Nevertheless, the minimization of rebar-cutting waste (RCW) is often impeded by the mandatory requirements pertaining to the rebar lapping zone as prescribed in design codes. In real-world construction scenarios, compliance with these rules often falls short due to hurdles concerning productivity, quality, safety, time, and cost. This discrepancy between code stipulations and on-the-ground construction practices necessitates an academic exploration. The goal of this research was to delve into the effect of rebar lap splice placement on the robustness and constructability of building edifices. The study initially took on a review of the computation of rebar lapping length and the rules revolving around the lapping zone. Following this, a structural robustness and constructability examination was undertaken, focusing on adherence to the lap splice zone. The interpretations and deductions of the research led to the following insights: (1) the efficacy of rebar lap splice is not solely contingent on the moment, and (2) the implementation of rebar lap splice beyond the specified zone can match the structural integrity and robustness of those confined within the designated area. As a result, the constraints on the rebar lapping zone ought to be revisited and possibly relaxed. The conclusions drawn from this research are anticipated to reconcile the disconnect between building codes and practical construction conditions, furnishing invaluable academic substantiation to further the endeavor of achieving near-zero RCW.

Keywords : rebar, lap splice position, structural stability, constructability, rebar-cutting waste

1. Introduction

Lap splicing, or conventional lap splice methods, requires the overlap of two parallel bars and has been widely recognized as an efficient and cost-effective method of splicing for decades[1]. The utilization of lap splice joints is regulated by the building design code. The code usually specifies a permissible interval instead of a single-point zone for the lap splice position[2]. Due to the adoption of the lapping zone, which is provided by the code, the amount of rebar-cutting waste generated is still notably high. Chen and Yang[3] attempted to reduce the rebar-cutting waste in a continuous beam section by optimizing the lap splice position within the lapping zone provided in the ACI code, which yielded 8.4% of cutting waste. Nadoushani et al.[2] attempted to optimize the lap splice position in the columns and shear walls, in accordance with the lapping zone provided by the ACI code, to minimize the rebar-cutting waste (RCW). As a result, their efforts yielded 7.2% and 10.6% of rebar-cutting waste in columns and shear walls, respectively. However, this range of 7.2% to 10.6% is still significantly higher than the commonly accepted RCW range of 3% to 5%. This evidence implies that it is difficult to reduce

RCW by adhering to the lapping zone.

The provision of lap splices in reinforced concrete (RC) structures is regulated by various building codes, including the ACI, KDS, BS, and JGC codes. The ACI code[4], developed by the American Concrete Institute, and the KDS code[5], developed by the Korean Ministry of Land, Infrastructure and Transport, stipulate the specific allowable location for lap splices in the column and beam structures. In contrast, the BS code[6], which was developed by the British Standard Institute, provides greater flexibility through a simple recommendation regarding the lap splice placement for both columns and beams. The JGC code[7], which was developed by the Japan Society of Civil Engineers, takes this flexibility a step further by providing additional regulation in cases in which placing the lap splices in the recommended location is impossible. Despite their differences, all the building codes agree that the lapping zone is located in the area with the minimum amount of stress. These building codes fall into two distinct groups. In one group, the codes mandate a specific location for lap splices, and in the other they provide greater flexibility by allowing lap splices to be installed in locations beyond the suggested location.

In practice, construction projects do not strictly follow the regulations regarding the rebar lapping zone. For instance, contractors in most countries, including Korea, Singapore, and Malaysia, typically install and lap the main rebars in columns at the top of the foundation or slab to increase workability and productivity. Even in Indonesia, high-rise buildings, which are designed to withstand earthquakes of magnitude 9.0, do not follow the lapping regulation. Nevertheless, there have been no reports of buildings failing or collapsing due to this lapping zone issue. This reality has raised a contentious question: Why should engineers and construction workers comply with the lapping zone regulations?

The high generation of rebar-cutting waste seriously threatens the global environment. Global rebar-cutting waste is estimated to reach 47 million tons and to have emitted 16 million tons of CO_2 by 2019[8]. By lifting the restrictions in the lapping zone, the lap splice position can be adjusted and rebar-cutting waste can be reduced further, thereby reducing greenhouse gas emissions. As economic development and the demand for reinforced concrete structures continue to grow, the efforts to minimize rebar cutting waste will become a crucial task.

This study was conducted to assess the structural stability and the constructability of buildings, according to the lap splice position of the rebar and seeks to resolve the inconsistency between the lapping zone mandated by the codes and the actual situation on construction sites. To investigate the issues at hand, the remainder of this paper is structured as follows: The study begins with a definition of the research issues and this study’s originality. Finally, the study’s problems, discoveries, outputs, and potential avenues for future research are discussed.

2. Preliminary Study

2.1 Review of the lap splice length calculation equation

The rebar lapping length refers to the required minimum overlap length when joining two rebars in an RC structure. A lapping length is required to ensure that force can be transferred to adjacent rebars effectively to maintain structural continuity. The rebar lapping length is generally determined by the structural engineer and is based on the building design code’s provisions for many factors. In most countries, structural design should conform to specific codes or specifications, such as ACI or BS[9]. ACI[10] provides a set of equations to calculate the rebar lapping length, shown in Equations (1) to (5). Equations (1) and (2) were developed to accommodate the tension rebars, whereas Equations (3) and (4) were developed to address the compression rebars, as follows:

$$l_d = (\frac{f_y \psi_t \psi_e}{1.7\lambda\sqrt{f'_c}})d_b \tag{1}$$

$$l_{st} = 1.3 l_d, l_{st} > 300mm \tag{2}$$

$$l_{sc} > 0.071 f_y d_b, 300mm; f_y \leq 420MPa \tag{3}$$

$$l_{sc} > (0.13 f_y - 24) d_b,\ 300mm; f_y > 420MPa \tag{4}$$

where l_d is the development length; f_y is the yield strength of the rebar; ψ_t, ψ_e, and λ are the modification factors for the development of deformed bars; d_b is the diameter of the rebar; f'_c is the concrete's compressive strength; l_{st} is the lap splice length of the tension bars; and l_{sc} is the lap splice length of the compression bars.

The Korean Ministry of Land, Infrastructure, and Transport developed its building design code, KDS[5], which also provides a set of equations to determine the rebar lapping length, which are shown in Equations (5) to (8). Equations (5) and (6) were developed to accommodate the tension rebars, whereas Equations (7) and (8) were developed to accommodate the compression rebars, as follows:

$$l_d = \frac{0.6 d_b f_y}{\lambda\sqrt{f_{ck}}} \tag{5}$$

$$l_{st} = 1.3 l_d, l_{st} > 300mm \tag{6}$$

$$l_{sc} > 0.072 f_y d_b,\ 300mm; f_y \leq 400MPa \tag{7}$$

$$l_{sc} > (0.13 f_y - 24) d_b,\ 300mm; f_y > 400MPa \tag{8}$$

where l_d is the development length; f_y is the yield strength of the rebar; λ is the modification factor for the development of the deformed bars; d_b is the diameter of the rebar; f_{ck} is the concrete's compressive strength; l_{st} is the lap splice length of the tension bars; and l_{sc} is the lap splice length of the compression bars.

Moreover, the BS code[6] also provides a set of equations to determine the minimum required lapping length, as shown in Equations (9) to (11). Equation (9) is employed to determine both the tension and the compression rebar anchorage length. Equation (10) is employed to determine the lapping length of the tension rebars, while Equation (11) is employed to determine the lapping length of the compression rebars, as follows:

$$l_d = \frac{f_y d_b}{\gamma_m 4\beta\sqrt{f_{cu}}} \tag{9}$$

$$l_{st} = 1.4 l_d \tag{10}$$

$$l_{sc} = 1.25 l_d \tag{11}$$

where l_d is the development length; f_y is the yield strength of the rebar; d_b is the diameter of the rebar; γ_m is the partial safety factor; β is the value of the coefficient bond; f_{cu} is the concrete's compressive strength; l_{st} is the lap splice length of the tension bars; and l_{sc} is the lap splice length of the compression bars.

The Japan Society of Civil Engineers also devised a building design code, JGC[7], which provides a set of equations to calculate the rebar lapping length, shown in Equations (12) to (14). Equation (12) is used to determine the anchorage length of the tension rebar, whereas Equation (13) is used to determine the anchorage length of the compression rebar. Equation (14) is then applied to determine the lapping length of the tension or compression rebar, as follows:

$$l_d = \propto \frac{f_{yd}}{f_{bod}} \varnothing \tag{12}$$

$$l_d = 0.8 \propto \frac{f_{yd}}{f_{bod}} \varnothing \tag{13}$$

$$l_s = 1.3 l_d \tag{14}$$

where l_d is the development length; α is a constant, ranging from 0.6 to 1.0; f_{yd} is the design tensile yield strength of the reinforcement; $\varnothing$ is the diameter of the rebar; f_{bod} is the design bond strength of the concrete, and l_s is the lap length of the rebar, either in a tension or compression state.

As per the building design codes presented above, the effectiveness of the lap splice is heavily reliant on the bonding strength between the rebar and the concrete, which plays a crucial role in determining the rebar's lapping length. Almeida et al.[11] identified that the design of RC structures relied mainly on concrete–steel bonding to transfer forces between lapped splice rebars. In addition, the study reported that the effectiveness of lap splicing can be preserved, and that lap splicing failure can be prevented by providing an appropriate concrete cover, adequate transverse reinforcement, and adequate tensile strength. Hence, the impact of the moment on the effectiveness of rebar lapping cannot be found in any of the above equations.

2.2 Lap splice zone regulation review

Building design codes generally specify an allowable interval instead of a single point zone for the lap splice position[2]. The design codes advise that the zone should be located in an area with minimum stress and moment. Table 1 offers a detailed summary of the codes that regulate the lap splicing position.

Table 1. Positioning of lap splices according to the building codes

Building code	Structural Member	Description
American Concrete Institute ACI 318	Vertical members	The lap splices shall be permitted only within the center half of the member length[4].
	Horizontal members	- The bottom continuous reinforcement should be lapped within 1/4 of the clear span on both ends. - The top continuous reinforcement should be lapped in the center of each member element, with a clear span in the range of 1/4 to 3/4[3,4].
Korean MOLIT KDS 14-20-50	Vertical members	The rebar should be lapped within 1/2 of the member height from the adjacent floor[12].
	Horizontal members	- The bottom reinforcement should be lapped at, or near, the support[12]. - The top reinforcement should be lapped in the center of each member element or the center of the span[12].
British Standard Institute BS 8110	Horizontal and vertical members	The rebar, if possible, should be lapped away from the high-stress points and needs to be staggered[6].
Japan Society of Civil Engineers JGC 15	Horizontal and vertical members	- Lap splices shall not be provided in plastic hinge zones that are subjected to repeated stresses. - In cases where providing lap splices in plastic hinge sections are unavoidable, the length of the splice should not be less than 1.7 times the base anchorage length, and the splice zone should be reinforced by transversal reinforcement[7].

As shown in Table 1, the ACI and KDS codes specify a precise and stringent allowable zone for the rebar laps in horizontal and vertical members. Conversely, BS and JGC stipulate a straightforward recommendation for avoiding rebar overlap in high-stress areas, while also allowing for some latitude. Moreover, the JGC provides some flexibility regarding the location of the rebar lap splice, even when rebar lapping in the plastic hinge section is inevitable. The plastic hinge section itself is a yielding zone, which develops in a structural element that is subjected to loads that cause excessive stress, such as at the supports or the maximal bending moment.

2.3 Analysis of the structural stability, according to the lap splice zone

Structural stability is one of the mechanical disciplines that examine how structures respond to compression[13]. When a structure is subjected to excessive compressive forces or stresses, it typically becomes unstable due to a reduction in stiffness and an alteration in shape. Consequently, it is essential to analyze structures' stability to ensure their safety. This study delves into the structural stability of structural members that contained a lap splice positioned in a specific location, as depicted in Figure 1.

It is crucial for a structural lap splice to possess both adequate strength and proper ductility to prevent brittle (bonding) failure, resulting from increased deformation[14]. Lap splices commonly fail due to either yield failure or bonding failure. Yield or ductile failure occurs when the applied stress surpasses the rebar's yield strength. Conversely, bonding failure occurs when the bond between the rebar and the adjacent concrete is disrupted. Prior to the occurrence of yield failure in a lap splice, certain warnings and signs may be given, which allows a degree of force redistribution; therefore, the reinforcement could still provide a certain level of structural integrity. However, the occurrence of bond failure can lead to a complete loss of reinforcement capacity, and such failure can occur abruptly. Bar yielding must precede the failure of the lap splice[15].

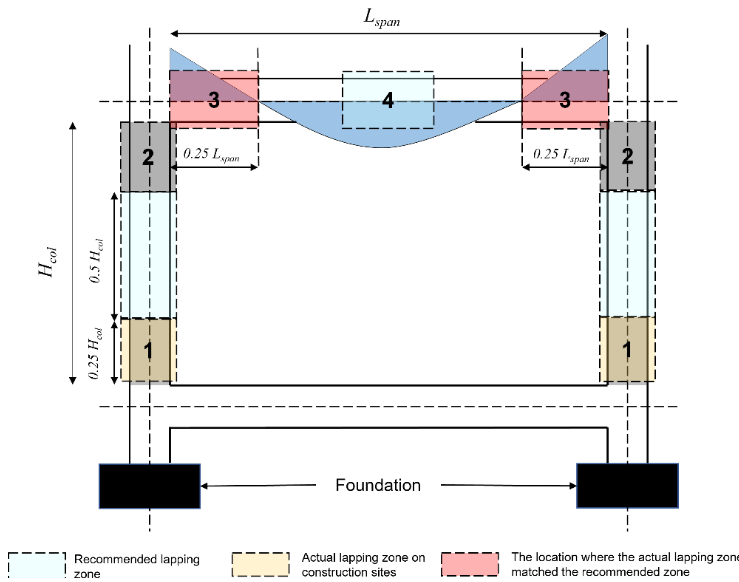

Figure 1. Positioning of rebar lap splice in standard RC frame

Regarding the placement of the lap splice in the first location, Pul and Senturk[16] conducted a study that examined the structural behavior of a lap splice located at the end of a column through displacement-controlled quasistatic tests. The lap splice of the specimen adhered to the industry practice, but it was not located within the mandated lapping zone, as stipulated by the ACI and KDS codes. Two specimens were compared, one with a lap splice and the other without, which served as the reference specimen. The lap splice specimen, which demonstrated lap splice placement at the bottom of the column, was evaluated due to its practical preference in construction sites. The researchers noted that a large crack occurred at the column-footing joint of the lap splice specimen, whereas the specimen with no lap splice exhibited evenly spread cracks, over a broader area. It was also observed that the behavior of plastic hinges is altered by lap-splicing at the bottom of reinforced concrete columns. The results suggested that the lap splice has no impact on bearing capacity and ductility, which determine the failure mechanism of the column[17]. Another study, by Haddad et al.[18], revealed that lap splices that are embedded near the base of a column should be designated as ACI's class A tension splice and should be reinforced with transverse reinforcement to withstand axial and seismic loads.

As in columns, the lap splice in RC walls is placed at the base, which is a plastic hinge zone, where stresses and strains are the largest[19,20]. Menegon et al.[21] examined an RC wall specimen that had a lap splice at the base of the wall. The researchers reported that a significant lateral displacement was attained, despite the generation of a two-crack plastic hinge model at the base of the wall. Observing buildings following an earthquake, Birely[22] and Sritharan et al.[23] identified that the failure of lap splices in RC walls is due to inadequate shear reinforcement and bond failure between the concrete and the rebar. Almeida et al.[11] concluded that proper concrete cover, adequate confinement by the transverse reinforcement, and high tensile strength are the key factors in the structural stability of RC walls. Furthermore, it should be noted that the lap splice must be sufficiently long for a proper bond to develop between the concrete and the rebar, which enables force to be effectively transferred from one bar to another[21]. From these studies, it can be inferred that, if designers consider the estimated cracks and design the rebar appropriately, using the key factors outlined by Almeida et al.[11], then it is acceptable to adjust the lap splice position. Moreover, experiments have acknowledged that stirrups or transversal reinforcement may significantly improve the ductility behavior and peak bond strength, as well as the lap splice length[24]. Therefore, positioning the lap splice at the first location is acceptable.

No studies have been conducted on the structural integrity of embedding a lap splice in the second location. Despite no studies existing for this location, it has been known if lap splice must be placed in the plastic hinge region, extra design regulations must be imposed by the building design codes, as they are in the JGC codes, to maintain structural stability. JGC mandates that the length of the splice cannot be less than 1.7 times the length of the base anchorage and that the splice zone should be reinforced with transverse reinforcement[7]. Thus, it is theoretically allowable to adjust the position of lap splices in the second location.

The third location calls for the lapping of bottom continuous rebars, as recommended by both ACI 318[4] and KDS 14-20-50[5]. In the event that the third location is identified as a plastic hinge region, JGC[7] provides supplementary design regulations when lapping in the plastic hinge region is inevitable. The code mandates that the length of lap splices cannot be less than 1.7 times the base anchorage length and that the splice zone should be confined with the transfer reinforcement[7]. In light of these, it can be inferred that rebar splicing in the third location is theoretically permissible.

Several investigations have been conducted to examine the structural stability of lap splice placement in the fourth location. Gillani et al.[15] examined the lap splices that were embedded in the middle of an RC beam specimen. Their study discovered that beams without a sufficient lap length, as mandated by ACI, fail in a brittle manner (bond failure); whereas beams with sufficient lap length fail in a ductile manner (yield failure)[15]. This discovery implies that a sufficient lap length ensures that the lap splice fails in a ductile manner, as the engineer and experts expect. Another experiment was conducted to investigate lap splices in RC beams, which involved the placement of lap splices in the middle of the beam. This revealed that the provision of the typical beam's transverse reinforcement generated a similar performance, in terms of the beam's ultimate strength and ductility, as the non-spliced rebar[25]. Thus, splicing rebars in the fourth location is appropriate.

In addition, this study highlighted the fact that building design codes have incorporated safety factors into the design criteria. Safety factors can be expressed as the ratio between an estimate of the maximum load that is unlikely to result in structural failure and an estimate of the applied load. Clausen et al.[26] remarked that, in certain circumstances, it may be preferable to define the safety factor as the ratio between the estimated design life and the actual service life. According to Nawaz et al.[27], ACI employs a high factor of safety in determining the rebar development length. Consequently, the calculation of the lap length specified by the building design code already incorporates a safety factor, thus ensuring reinforcement continuity and structural integrity. Furthermore, an experiment by Nawaz et al.[27] acknowledged that the design codes overestimated the development length of lap splices in self-compacting, lightweight concrete. As a result, the calculated lap length exceeds the requisite length, thereby ensuring the effectiveness of the lap joint mechanism.

2.4 Analysis of the constructability, according to the lap splice zone

Constructability refers to the ease with which structural structures or structural members can be constructed[28]. Reviewing the construction methods is essential to project management strategies. As a result, contractors can increase productivity and prevent unnecessary expenditures. While certain building codes, such as ACI and KDS, have explicitly stated the allowable lapping zone for structural members, others, such as JGC and BS, afford greater flexibility in the placement of lap splices.

This study analyzed the constructability of structural members that contained a lap splice positioned at specific locations (the first to the fourth locations), as depicted in Figure 1. Most of these locations were outside the lapping zone designated by the ACI and KDS codes. However, in industry practice, most structures are constructed by allowing flexibility in the lap splice position. Better constructability is the main reason for this.

In the case of a column, locating and measuring the lapping zone can be tricky and time-consuming. In practice, rebar subcontractors use their judgment to determine the lapping location along the column which might include the first location, the lapping zone, or the second location in the column. However, rebar subcontractors generally prefer to lap the main rebars of columns at the top of the foundation or slab[16], which is located directly above the column－beam joint and is easily identifiable, as depicted by the first location in Figure 1. When rebar subcontractors lap the rebar in the lapping zone or the second location, more attention must be given to the lapping process. The same applies to RC walls, which are also column-like, vertical members[19,20].

Regarding beams, if rebar subcontractors comply with the lapping zone regulations, they must exercise extra attention in identifying the distinct lapping zones of both the top and bottom rebar. This leads to complicated construction procedures and lower productivity. As with vertical members (columns and walls), rebar subcontractors use their discretion to determine the lapping position, provided that the lap splice for the top and bottom rebar are not located in the same spot. However, on construction sites, rebar subcontractors prefer to adjust the lap splice of the top and bottom rebar of the beam, if possible, within one quarter of the clear span from either column because it is convenient. This is shown by the third location in Figure 1. If rebar subcontractors lap the rebar in the lapping zone or the fourth location, they should exert more attention in the lapping process.

Several studies have investigated lap splice position optimization by following building codes that have lapping zone regulations. Chen and Yang[3] optimized the position of the lap splice in a continuous beam section, following the ACI code, and yielded 8.4% of cutting waste. Also following the ACI code, Nadoushani et al.[2] attempted to optimize the lap splice position in columns and shear walls. As a result, they yielded 7.2% and 10.6% of cutting waste for the columns and shear walls, respectively. It can be inferred from this that compliance with the lapping zone regulation leads to a restricted reduction in rebar usage. Thus, this study promoted the flexibility of the lap splice position, in alignment with other building codes (JGC and BS). The relaxation of the lapping zone restriction increases the possibility of reducing rebar-cutting waste, which leads to cost savings and a reduction in greenhouse gas emissions.

3. Discussions

The lap splice is required to maintain and guarantee the strength of steel reinforcing bars, which ensures the safety of a structure. The connecting part of a rebar is the weakest point in RC structures. Therefore, the length of the lap splice must be designed appropriately. Hence, the rebar lapping should be placed where the reinforcement is subjected to the least amount of stress. The structure may fail or collapse if the splice length is insufficient, posing a safety risk. Almost all engineers are aware of these facts, and RC design codes in many countries include them. However, in most construction sites, rebars are connected at construction joints. In other words, the rebar splice location for vertical members, such as columns and walls, is on the slab or foundation, whereas for horizontal members, such as girders and slabs, it is on the side of the columns or girders.

Moreover, it has been confirmed that many building projects that have been designed in accordance with the BS code have columns that are connected on the slab or foundation, and girders that are connected at the column's side on the structural drawings.

In this study, we also confirmed that the length of the rebar lap splice was unaffected by the moment, although the codes still mandate that the lap splice should be placed near the location with the lowest moment. Moreover, we verified that satisfying the calculated lapping length; ensuring appropriate concrete strength and cover; providing adequate confinement using transverse reinforcement, such as a hoop and stirrup; and high-tensile strength rebar usage are the key factors in ensuring structural stability.

In this section of the paper, we develop and compare three scenarios regarding lap splices. Scenario (1) maintains the location of the lap splice by adhering to stringent lapping zone regulations. Scenario (2) exhibits the flexibility of the lap splice position by allowing for variation in its location and using the calculated lap length. Scenario (3) is comparable to Scenario (2), except that it provides a slightly longer length than that calculated to secure the structural stability at the splice position. As shown in Table 2, the scenarios were compared qualitatively regarding structural stability, constructability, and the costs attributed to the generation of CO_2 emissions.

Table 2. Comparative analysis of scenarios

Description	Structural stability	Constructability	Cost/CO_2	Overall
Scenario (1)	◎	X	X	△
Scenario (2)	○	△	◎	◎
Scenario (3)	○	△	○	○

◎ : Excellent; ○ : Good; △ : Moderate; X : Bad

Scenario (1) exhibits better structural stability than Scenario (2) or Scenario (3), due to its adherence to the lapping zone, which is situated away from the maximum stress and moment region. Less moment is exerted in the lapping region; consequently, the failure possibility is minimal. However, Scenario (1) requires intensive attention to identify the lapping zone of structural members. This results in time-consuming construction procedures, which ultimately reduce constructability and productivity. In addition, a previous study has demonstrated that, by adhering to the lapping zone regulations, a significant amount of cutting waste is generated, which equates to tremendous CO_2 emissions.

Meanwhile, Scenarios (2) and (3) adjusted the lap splice at any location, which may be located in the maximum stress and moment area. As previously mentioned, the scenario has been anticipated by building design codes, such as JGC, which specifies that, in the event of its occurrence, the lap length should be extended and the lap splice should be confined[7]. Nevertheless, Scenarios (2) and (3) offer better constructability than Scenario (1). In practice, rebar subcontractors prefer to splice the rebars in columns, walls, and beams in the plastic hinge region since it is more convenient and saves time. Adjusting the lap splices of structural members with greater flexibility increases constructability and productivity, thereby reducing labor costs and installation duration. In addition, the lifting of the restrictions on the lapping zones increases the probability of reducing cutting waste, which results in cost savings and a reduction in greenhouse gas emissions.

Scenario (3) provides a longer lap length than the lap length calculated in Scenario (2), which corresponds with an increase in rebar utilization and CO_2 emissions. Among the three scenarios, Scenario (2) is more favorable for structural stability, high constructability, less rebar usage, and lower CO_2 emissions due to its compliance with building codes. However, a quantitative analysis related to this claim is necessary, and research should continue to provide proof.

4. Conclusion

This study addressed the discrepancy between the building codes and the actual practice in construction sites regarding rebar lap splices in reinforced concrete structures. In conclusion, this study has identified significant findings, which contribute to the assessment of rebar lapping positions in reinforced concrete structures, as follows:

1) The effectiveness of the rebar lap splice is not affected by the moment. Nevertheless, the bonding strength between the concrete and the rebar plays a crucial role in determining its effectiveness.
2) The effectiveness of the rebar lap splice is determined by three key factors: proper concrete, adequate transversal confinement, and high tensile rebar strength. In addition, the safety factor, which is included in the lapping length calculation codes, ensures its effectiveness.
3) The findings indicate that the provision of lap splices in areas beyond the designated area can offer an equal level of structural strength and stability as those within the designated area. Hence, adjusting the lap splice position is deemed acceptable.
4) Many RC projects, worldwide, do not comply with the lapping regulations mandated by the code. Adhering to the lapping zone mandated by the building code can pose several challenges on construction sites, such as difficulty in identifying the exact location, being time-consuming, and lower site productivity.
5) Several studies that have aimed to minimize rebar-cutting waste had limitations in their reduction rates because they adhered to the lapping zone regulations mandated by the building codes.

Based on the findings outlined above, this study recommends that the regulations and restrictions associated with the rebar lapping zone be relaxed or lifted. Adjusting the lap splices of structural members with greater flexibility increases constructability and productivity, thereby reducing labor costs and installation duration, which allows for a greater reduction in the costs associated with CO_2 emissions. However, future studies will be needed to prove and validate this claim. The flexibility of the lap splice position has been demonstrated as advantageous in terms of constructability and economic feasibility. Moving forward, this study also recommends that future studies should further explore the potency of this lap splice position flexibility. Kwon et al.[8] identified that the partial adjustment of the lap splice position to match the rebars with a special length can significantly reduce rebar-cutting waste. A special length is a rebar with a length range between 6 and 12 m, with 0.1 m intervals but with minimum order quantity and preorder time[29]. Nevertheless, this study has provided valuable insights, which can help the construction industry in resolving the discrepancies that exist related to the lapping zone, achieving near-zero RCW, and implementing sustainable construction practices.

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