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Interaction Charts for Rectangular Reinforced Concrete Shear Walls under Axial Force and In-Plane Moment Based on Eurocode Principles

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Abstract

Reinforced concrete (RC) shear walls are very essential elements in the design of buildings for the lateral loads due to wind and earthquakes. Understanding of the interaction between axial forces and in-plane moments in RC shear walls are required to predict their performance and failure patterns. Inadequate design can lead to catastrophic failures, highlighting the need for a comprehensive analysis and design procedure. This study aims to develop interaction charts for RC shear walls based on Eurocode principles, providing engineers with a reliable tool to design and assess these structural elements. Using a combination of analytical, numerical, and software tools, interaction charts were generated for various combinations of normal strength concrete classes and steel reinforcement classes. In total, 27 interaction charts have been developed, looking at a range of values of the quantity of reinforcement and strain distributions. Comparisons with results from specialized software, CSI ETABS and GaLa Reinforcement Software, and benchmarking against previous studies validated the charts. The developed interaction charts provide a comprehensive representation of the ultimate limit state behavior of RC shear walls subjected to uniaxial bending moments and axial forces. These charts can be used as design aids for straight structural walls, regardless of their size, and will enable engineers to quickly identify safe design limits for shear walls. The study's findings highlight the importance of considering detailed material behavior and full interaction domains in structural design, ensuring more accurate and reliable design outcomes.

Keywords: RC shear walls, Interaction Charts, Axial Forces, In-plane moments, Eurocode Principles, Ultimate Limit State.

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1. Introduction

Reinforced concrete (RC) shear walls are essential features of any building structure in providing resistance to wind and seismic loads. Similar to RC columns shear walls resist axial loads and moments, and unlike to columns shear walls are primarily proportioned to resist lateral loads from wind and earthquake. Strategically located walls add rigidity and strength to the building's skeleton, improving structural integrity.

The combined axial force and in-plane bending moment responses of RC shear walls are complex, involving the nonlinear interaction of these loads. Axial forces can result from gravitational force acting on the building or other vertical loads, but in general terms, the in-plane moments are systematically due to lateral loads caused by wind or seismic action. Proper prediction of the structural performance and failure patterns of shear walls requires an understanding of the interaction of these loads. Inadequate design can result in catastrophic failures, especially during earthquakes, which points to the need for a complete analysis and design procedure.

Interaction charts become important design tools, especially for such vertical structural elements as columns and RC shear walls. It is through these charts that axial force and in-plane bending moment capabilities are graphically represented for interaction. The charts offer engineers the ability to quickly identify whether a certain combination of axial load and moment lies within the safe design limits for the shear wall. Alternatively, the designer may select the suitable area of reinforcement from a set of charts specifically developed for design purpose. This can be done when designers have computed a number of interaction curves for different reinforcement quantities in the section and primary objective of this study is to prepare a comprehensive shear wall design chart based on Eurocode recommendation principles. Conformance to Eurocode requirements permits engineers to check their designs against the required safety and performance criteria, ensuring homogeneity and reliability for different projects. Axial force and in-plane bending moment interaction charts can be constructed based on Eurocode principles so that RC shear wall designs can be conducted with code compliance.

2. Literature Review

Designing reinforced concrete shear walls under axial forces and bending moments is a complex process, which needs to take into account various interaction effects. A few approaches have been proposed for analyzing and designing such elements; for instance, (Thakkar, 2012) developed a methodology for generating interaction diagrams for shear walls providing an enhanced ability on determining their capacity. Mondal & Bhanja (2023) indicated interaction charts based on limit state philosophy to take over the deficiencies in available design equations. Chandrasekaran et al. (2010) provided analytical expressions for axial force-bending moment yield interaction based on Euro Code, checking plastic flow rule in various modes of failure. Hernández-Montes et al. (2005) contributed reinforcement sizing diagrams, RSD, an alternative design methodology that allows engineers to pick the optimal reinforcement configuration. The foregoing mechanisms materialize into very valuable tools for engineers in the design and analysis of shear walls, other reinforced concrete structural elements under combined axial, flexure, improving the accuracy and efficiency of the design process.

Thakkar (2012) develops a methodology to generate interaction diagrams for shear walls that enables more accurate descriptions of the capacity of shear wall cross-sections under the combined effects of axial compression and lateral bending. Whereas a research project that investigated the interaction of in-plane and out-of-plane forces on the design of structural walls, particularly reinforced concrete (RC) and steel-plate composite (SC) shear walls, with the goal of developing an analytical approach and numerical tool to analyze wall behavior and formulate design recommendations had been conducted by (Bhardwaj & Varma, 2017). Experimental investigations are

involved to evaluate the influence of out-of-plane forces on in-plane shear behavior of structural walls, development and benchmarking of detailed 3D finite element models using the experimental results, use of the benchmarked models to conduct parametric studies and gain additional insights, and development and validation of an analytical approach and numerical tool to analyze the wall cross-section response under combined forces. The study focused on developing and validating an analytical approach and numerical tool to analyze the behavior of structural walls under combined in-plane and out-of-plane forces.

(Chandrasekaran et al., 2010) presents a comprehensive set of tools and techniques for the seismic design and analysis of reinforced concrete structures, including the development of mathematical models, numerical studies, and procedures for analyzing moment-curvature relationships, moment-rotation relationships, and collapse loads of building frames under seismic loads. The study includes the development of mathematical models and numerical procedures for analyzing the axial force-bending moment interaction, moment-curvature relationship, and moment-relative rotation relationship of reinforced concrete structures, identification of subdomains and verification of the flow rule for axial force bending moment interaction domains, comparison of collapse loads of building frames subjected to seismic loads using nonlinear static pushover analysis, and the provision of a spreadsheet program and step-by-step procedures to implement the developed methods. A recent study regarding the development of axial force - bending moment interaction for RC shear walls is presented in (Mondal & Bhanja, 2023). The study involved developing interaction charts for rectangular shear walls based on fundamental principles, using a bilinear stress-strain relationship of HYSD steel bars, considering vertical reinforcements as an equivalent steel plate, utilizing stress blocks of both steel and concrete to calculate force and moment capacities, and designing the interaction charts using the limit state philosophy as per IS 456-2000, rather than using the shortcut design methodology provided in the Indian standard. For classifying regions in the interaction chart three cases of neutral axis location expressed in terms of ratio of neutral axis depth to total length of the wall is considered as stated in (Bhatt et al., 2014). Bhatt et al. (2014) proposes three design approaches for structural RC walls bearing in-plane moments in addition to axial loads. Using an interaction chart, assuming elastic stress distribution and assuming that only end zones resist moment are the approaches described in the book. The interaction chart developed in (Bhatt et al., 2014) considers three cases based on the ratio of neutral axis to total length of the wall (for the first case the ratio ranges from 0 to 0.6169, for the second case the ratio ranges from 0.6169 to 1, for the third case the ratio ranges from 1 to 2.6392). Even if the technique proposed in (Bhatt et al., 2014; Mondal & Bhanja, 2023) follows the general principle to determine the failure envelope of RC shear walls, it failed to take in to account the ultimate limit state (ULS) possible strain distribution given in section 6 of Eurocode 2. The other limitation of these studies is it doesn't include tension axial loading conditions. It is not nonetheless rare to meet columns or walls under stress, for example in zones of severe seismicity, or symmetrically reinforced concrete walls of liquid retaining structures (Girma Zerayohannes, 2015).

For RC shear walls supporting transverse moment (moment in minor axis) and uniform axial load a unit length of wall can be designed as a column utilizing column design charts (Bhatt et al., 2014). Girma Zerayohannes, 2015) presented 26 uniaxial chars and 58 biaxial charts for solid and hollow rectangular and circular columns. The design-aid also offers design tables that has been produced using concepts and assumptions of Eurocode 2, intended to facilitate the design of RC structures utilizing ULS design philosophy. For walls under the action of bending in minor axis (transverse bending) it is feasible to utilize uniaxial charts presented in (Girma Zerayohannes, 2015).

3. Methodology

3.1 Assumptions and Design Considerations

Assumptions stated in section 6 of (EN 1992-1-1, 2004) for analysis and design of reinforced concrete structures carried out in the ULS are considered in this study. The assumptions include:

1) Linear strain distribution along the depth of the section (plane sections remain plan)
2) Tensile strength of concrete is neglected,
3) Stress-strain curve for concrete under compression assumes parabolic-rectangle diagram for concrete under compression as shown in *Figure 1*,
4) Stress-strain curves for reinforcing steel assumes design stress-strain curve for reinforcement bars with a horizontal top branch without the need to check the strain limit as shown in *Figure 2*,
5) The maximum tensile strain in reinforcing steel is assumed to be 25‰ (assuming Class A reinforcement) and
6) The strain diagrams are assumed to pass through either point A, B or C which are shown in *Figure 3*.

Unlike beams and columns, vertical reinforcement bars on walls are positioned at particular spacing along the length of the wall and for simplicity of analysis the vertical bars are substituted by uniform strips of steel running the complete length of the wall (Bhatt et al., 2014; Mondal & Bhanja, 2023). Similarly in this study the total area of vertical reinforcement provided in the section is divided to the section depth (length of shear wall) to get the uniform strips of steel per meter length.

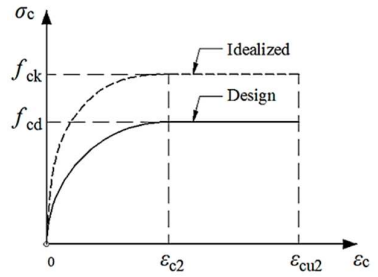


Figure 1: Parabolic-rectangle diagram for concrete under compression

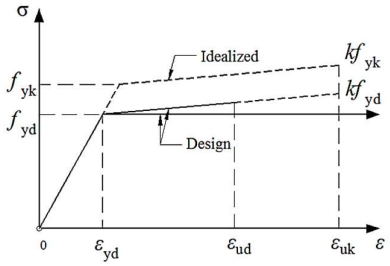


Figure 2: Idealized and design stress-strain diagram for reinforcing steel

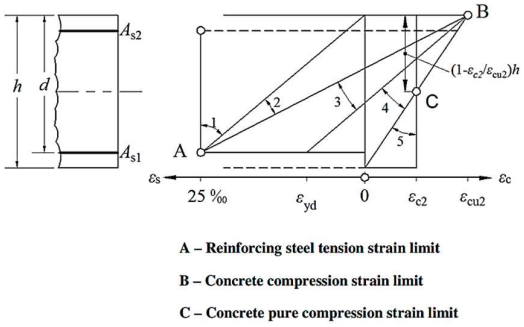


Figure 3: Possible strain distribution in the ultimate limit state

3.2 Stress Strain Relationship for Concrete and Steel

The total compression force in concrete can be estimated by analyzing strain distribution, known as stress blocks, derived from cylinders tested under uniaxial compression. Based on (EN 1992-1-1, 2004), Parabolic-rectangular stress block is considered that can be expressed by equations Equation 1 and Equation 2 depicted by Figure 1.

$$\sigma_c = f_{cd}[1-(1-\frac{\varepsilon_c}{\varepsilon_{c2}})^n] \quad \text{for } 0 \le \varepsilon_c \le \varepsilon_{c2} \qquad (1)$$

$$\sigma_c = f_{cd} \quad \text{for } \varepsilon_{c2} \le \varepsilon_c \le \varepsilon_{cu2} \qquad (2)$$

The total concentrated compressive force for the given strain condition for the corresponding neutral axis location can be computed by integrating the entire compression stress on the compression region area.

According to (EN 1992-1-1, 2004), the stress-strain diagram of reinforcing steel adopted for section design is shown in Figure 2, where there are two types. First, one which does not include the increase in strength due to strain hardening; it does not put any limitation on the strain in the reinforcing steel at ultimate limit state. The second assumption, however, incorporates the gain in strength from strain hardening by limiting the maximum strain to ε_{uk} for various ductility classes of reinforcing steel. It is assumed that equation (3) and (4) define the first assumption, which restricts the maximum strain to prevent convergence problems in interaction chart generation. The code rule specifies the minimum value of maximum strain ε_{uk} as 25‰, 50‰, and 75‰ for Class A, Class B, and Class C reinforcing steel, respectively. The analysis in this study is done for Class A reinforcing steel, which has the lowest ductility, and the ultimate strain is limited to 25‰. According to Section 3 of (EN 1992-1-1, 2004), the maximum design strain of reinforcement, ε_{ud}, is defined to be equal to 90% ε_{uk}, equivalent to a value of 22.5‰.

$$\sigma_s = E_s \varepsilon_s \quad \text{for} \quad 0 \le \varepsilon_s \le \varepsilon_{yd} \tag{3}$$

$$\sigma_s = f_{yd} \quad \text{for } \varepsilon_{yd} \le \varepsilon_c \le \varepsilon_{ud} \tag{4}$$

3.3 Preparation of Wall Interaction Chart

Charts representing the interaction between axial force and bending moment in vertical reinforced concrete members are created by building a sequence of smooth curves that take into account various neutral axis depths (from -∞ to +∞) and incorporate critical conditions for varying vertical reinforcement percentages. A section is considered to reach its ULS, per (EN 1992-1-1, 2004), if the strain profile touches one of the three points (points A, B, or C), as shown in Figure 3. In general, there are five zones that make up the strain profile. Zone 1 is characterized by small eccentricities along with axial tension. The neutral axis is outside the cross-section in this zone, the cross-section is under tension throughout, and the reinforcement steel yields. Zones 2, 3, and 4 are zones of pure bending and bending plus axial load. "Steel failure" is the type of failure that occurs in Zone 2. The neutral axis is located inside the cross-section. The concrete exhibits reserve with $|\varepsilon_{cu}|$=3.5‰, but the steel reinforcement reaches its maximum strain (ε_{s1}=22.5‰). "Concrete failure" is the failure type that characterizes Zone 3. The concrete is fully exploited (ε_{cu}=-3.5‰). The strain in the steel lies between the yield strain and the ultimate strain (ε_{s1}=22.5‰). The concrete is completely utilized in Zone 4. The steel strength is not yet fully exploited. The steel strain lies between 0 and ε_{yd}. The cross-section's neutral axis is located in a much lower portion of the section. On Zone 5, the entire cross-section is under compression. The strain in the most compressed concrete fiber lies between -2‰ and -3.5‰ on the more compressed edge of the cross-section and between 0 and -2‰ on the other edge. In this region, all stain profiles pass through point C, which is located at 3/7 of total section depth from the more compressed edge of the cross-section.

General condition of equilibrium and stress-strain compatibility principles can be employed for determining the section resistance capacity of a wall section. Similar to columns, wall sections are subjected to axial forces in conjunction with bending moment. To ensure structural safety of the section in terms of strength, the capacities to carry axial loads and moments must be equal to or greater than the axial force and moment applied to the wall section. The axial load capacity and moment capacity of a structural wall can be summarized in the following equations 5 and 6.

$$N_{Total} = (N_{compressed\ concrete}) + (N_{compressed\ steel}) - (N_{tensioned\ steel}) \tag{5}$$

$$M_{Total} = (N_{compressed\ concrete} \times Lever\ arm\ from\ centroidal\ axis) + (N_{compressed\ steel} \times Lever\ arm\ from\ centroidal\ axis) - (N_{stressed\ steel} \times Lever\ arm\ from\ centroidal\ axis) \quad (6)$$

Where "N" stands for axial force resistance capacity and "M" represents uniaxial bending moment resistance capacity of a section.

Table 1: Matrix of concrete class, reinforcement class and percentage of vertical reinforcement provided in wall section

Concrete Class		Steel Class	Percentage of Reinforcement		
C12/16	C35/45	S-400	0	1.4	2.8
C16/20	C40/50	S-500	0. 2	1.6	3
C20/25	C45/55	S-600	0. 4	1.8	3.2
C25/30	C50/60		0. 6	2	3.4
C30/37			0. 8	2.2	3.6
			1	2.4	3.8
			1.2	2.6	4

A modest amount of work is put into this study to develop interaction charts for three classes of reinforcing steel (S-400, S-500, and S-600) and nine normal strength concrete classes (C12/16 to C50/60). It is best to take into account a range of values for the quantity of reinforcement, from the minimum area of reinforcement to the maximum area of reinforcement given in (EN 1992-1-1, 2004). In accordance with Section 9 of the code, a shear wall must have a minimum of 0.002Ac and a maximum of 0.04Ac of reinforcement outside of lap positions. Table 1 displays the matrix of data that was taken into consideration for this study. As a result, five zones that represent various stress states, indicated as Figure 3, are considered to write Python code that creates charts by assuming a range of strain distributions. There are twenty-seven prepared charts available for use in design.

A flow chart showing the general procedure for writing the python script is shown in Figure 4.

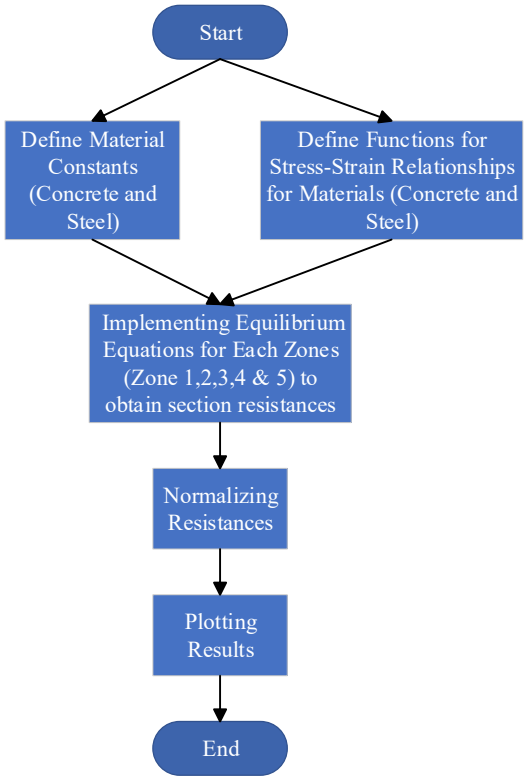


Figure 4: Flow chart for writing python script

3.4 Tools Employed in the Study

The interaction charts for RC shear walls are prepared using a combination of analytical, numerical, and software tools to guarantee accuracy and dependability. In this study, the following tools were employed:

i) Python Programming Language

The interaction charts were generated using customized scripts that are written in Python. The main reasons why Python would be an ideal language for handling complex mathematical calculations with performative plotting requirements is due to its flexibility and computational efficiency. Hence, NumPy, Matplotlib, and Pandas libraries were used.

ii) Software Tools

GaLa Reinforcement is a specialized software that calculates and draws interaction failure surfaces of RC cross-section with predefined reinforcement. This software can be used to generate interaction charts to validate the results obtained from the Python scripts. The GaLa Reinforcement Software offers

reliable and accurate interaction diagrams based on Eurocode principles and is specifically made for the analysis and design of reinforced concrete elements (Alashki, 2002).

CSI-ETABS is a comprehensive software package used for structural analysis and design (Computer & Structures, 2017). In order to provide secondary validation for the interaction charts produced by the Python script, ETABS was utilized to simulate the behavior of shear walls under combined axial and in-plane moments. Reliable outcomes are guaranteed by the software's sophisticated modeling features and adherence to design codes.

3.5 Validation of Wall Interaction Charts

The developed interaction charts for this research work were verified for accuracy and reliability through several verification and validation methods. The primary checking was done by comparison of the interaction charts obtained in the Python scripts with the ones developed in CSI ETABS and GaLa Reinforcement Software. As part of the validation process, a comparative analysis of the interaction charts produced by these tools has been presented for a shear wall with its detailed geometric and material properties given in Table 2.

A sensitivity analysis was carried out to further validate the effect of employing enough points in the Python script for each of the five regions based on the varying strain distribution. In this study, the approached multi-facet validation confirmed the accuracy and applicability of the developed interaction charts for designing reinforced concrete shear walls.

Table 2: Shear Wall Geometric and Material Properties for Verification

Geometric Properties
Section length of wall (L) = 1000mm Section width of wall (b) = 300mm Reinforcement (0.2%) = 600mm^2
Material Properties
Concrete class = C30/37 Steel class = S-500 (Type A)

4. Result and Discussion

4.1 Result Validations

As shown in Figure 5 sensitivity analysis was conducted to check the validity of using enough number of points by the Python code for every different strain distribution in each of the five zones. The number was initially set at 6, corresponding to the limiting points of each zone, and that did not give an accurate description of the failure surface of the structural wall and did not capture the maximum moment point normally occurring somewhere in Zone 3.

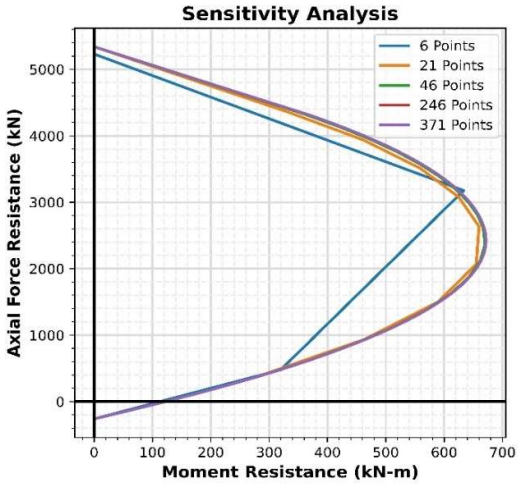


Figure 5: Sensitivity Analysis

As the number of points considered by the code was increased, the failure plot of the wall became smoother and smoother, and the curve started to converge. This is shown in Figure 5 depending on the different considered points. Therefore, it was concluded that 371 points (75 for each of the five zones) would represent the interaction diagram more precisely and reliably. Hereinafter, this distribution will only be used for the analysis.

The interaction charts generated by the Python scripts were validated against those produced using GaLa Reinforcement software and ETABS software as shown in Figure 6. The comparisons showed a high degree of agreement, confirming the accuracy of the developed charts.

A very small discrepancies were observed on locations where the moment resistant capacity of the section attains its maximum

value. This observation was attributed to differences in numerical precision and modeling assumptions. Overall, the validation results support the reliability of the Python-generated charts.

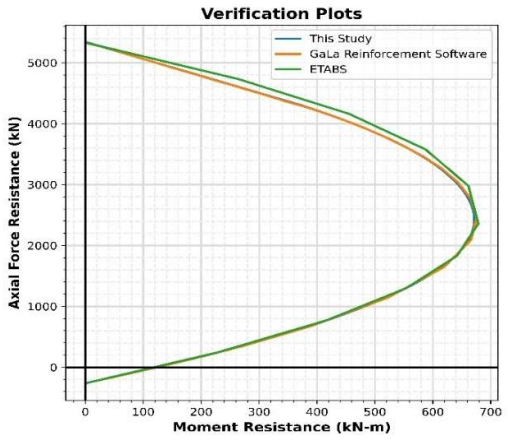


Figure 6: Interaction charts generated from Python script, GaLa reinforcement Software and ETABS Software

Moreover, the comparison with results obtained from ETABS software, as depicted in Figure 6, shows differences in compression-controlled failure region (Zone 4 and Zone 5 in possible strain distribution as shown in Figure 3). As stipulated in (Computer & Structures, 2017), the strain profile considered in the software is different from the strain profile provided by (EN 1992-1-1, 2004).

4.2 Result Comparisons

The developed interaction charts were also compared to some previous interaction charts for bench-marking of accuracy and their applicability, as shown in Figure 7 and Figure 8. In comparison with (Bhatt et al., 2014), very good consistency is shown with the charts generated using the Python script, indicating a high level of consistency and reliability in the developed charts.

However, compared to (Mondal & Bhanja, 2023), the agreement was less comparative in nature as shown in Figure 8. This could be due to variations in the consideration of the steel stress-strain relationship and the position of the neutral axis.

Comparison with (Bhatt et al., 2014), Figure 7, shows a very minor deviation in the compression zone of the interaction chart. As can be seen, the pure axial compression load-carrying capacity of the section is slightly overestimated by charts generated using Python script. One possible explanation for this discrepancy could be the different guiding principles used in the two approaches.

(Bhatt et al., 2014) makes the assumption that the section reaches its ultimate limit state when the strain profile passes through point B, ignoring points A and C of Figure 3. In order to comply with Eurocode guidelines, a Python script was prepared for this study that included points A, B, and C along with a more comprehensive strain profile. Such a holistic approach provides interaction charts to accurately describe the behavior of rectangular RC shear walls under various axial and bending moments.

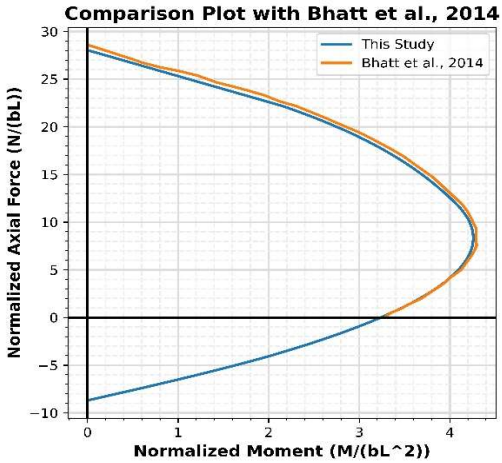


Figure 7: Comparison of interaction charts generated from Python script and (Bhatt et al., 2014)

Conditions of tension axial force also set apart the charts developed in Python script from those of (Bhatt et al., 2014), giving completeness to graphs picturing varied performances of the section.

This further inclusion of tension axial force conditions in the charts developed using Python makes the behavior of the structural wall under different loading conditions more comprehensively represented. The practical applicability of the charts generated through Python is improved with

a broader coverage of loading conditions, hence making them a more versatile tool for design engineers. Plot comparisons with (Mondal & Bhanja, 2023) in Figure 8 show close behaviors for this interaction chart being in Zone 4 in the possible strain distribution related to ULS and significant differences in another four zones.

The charts by (Mondal & Bhanja, 2023) for Zone 5 seem to underestimate the pure axial compression resistance capacity of the section. The underestimation, in turn, may arise due to the different modelling assumptions or simplifications that these authors have used in their analysis. It is from this analysis that the underestimation was noted, and it is quite evident that Python-generated charts in this study are more accurate in the capacity of the section under purely axial compression conditions. Zone 3 and parts of Zone 2 have a big difference as, in the charts presented in (Mondal & Bhanja, 2023), the real capacity of the section is overestimated by an appreciable value. This is critical, since the maximum moment capacity for the section is being overestimated by 20%, while the pure moment resistance capacity is overestimated by 35.7%. Such differences can be due to the various considerations of the steel stress-strain relationship and/or the position of the neutral axis.

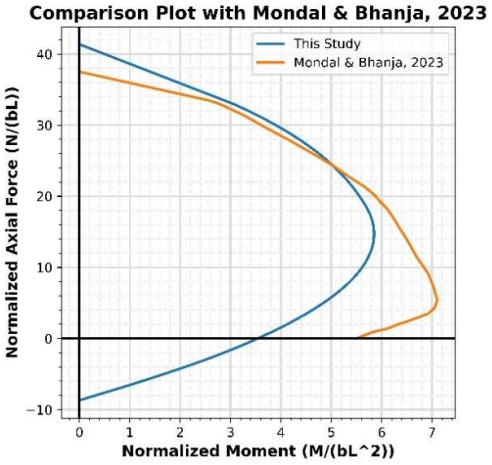


Figure 8: Comparison of interaction charts generated from Python script and (Mondal & Bhanja, 2023)

These huge overestimations in the maximum moment capacity and the pure bending moment capacity show the need for the very detailed and rigorous modeling of structural behavior. Design engineers are typically presented with much more reliable tools by the Python-generated charts than by those that reflect a full strain profile and include all possible loading conditions within their range.

Although the comparison with (Bhatt et al., 2014), showed that the charts obtained with Python are correct, the differences found against (Mondal & Bhanja, 2023), prove the need to consider detailed material behavior and full interaction domains in structural design.

4.3 Result Presentation and Inferences from the Output

All RC shear wall capacities have been normalized with respect to geometric cross-sectional parameters to make them comprehensive and versatile. Such normalization allows for the same evaluation of structural performance in different scales of the structural element being under study, providing universal application of results. Proper normalization of capacities would enable interaction charts to be used as design aids for straight structural walls, regardless of their size.

Interaction charts have been prepared for various combinations of normal strength concrete classes and various steel reinforcement classes, and in total, there are 27 such graphs, as indicated in

Table 3. These graphs depict the ultimate limit state behavior of the RC shear walls subjected to uniaxial bending moment and axial loads. These interaction charts become an important tool in understanding the interaction between axial forces and bending moments for the structural design and assessment of straight RC shear walls. In the Appendix section, sample interaction charts have been included (Figure A1 to A3).

Table 3: List of Charts Generated on this Study

Chart No.	Concrete Class	Steel Class
Chart No. 1	C12/16	S-400
Chart No. 10		S-500
Chart No. 19		S-600
Chart No. 2	C16/20	S-400
Chart No. 11		S-500
Chart No. 20		S-600
Chart No. 3	C20/25	S-400
Chart No. 12		S-500
Chart No. 21		S-600
Chart No. 4	C25/30	S-400
Chart No. 13		S-500
Chart No. 22		S-600
Chart No. 5	C30/37	S-400
Chart No. 14		S-500
Chart No. 23		S-600
Chart No. 6	C35/45	S-400
Chart No. 15		S-500
Chart No. 24		S-600
Chart No. 7	C40/50	S-400
Chart No. 16		S-500
Chart No. 25		S-600
Chart No. 8	C45/55	S-400
Chart No. 17		S-500
Chart No. 26		S-600
Chart No. 9	C50/60	S-400
Chart No. 18		S-500
Chart No. 27		S-600

5. Conclusion and Recommendation

The objective of the work was to present universal interaction diagrams for RC shear walls in accordance with the principles outlined in Eurocode. Graphically, it represents the axial force and in-plane moment capabilities of RC shear walls, giving engineers a fast way to identify whether a given combination of axial load and moment lies within safe design limits.

The study employed a combination of analytical, numerical, and software tools, including Python programming language, GaLa Reinforcement software, and CSI-ETABS software, to ensure accuracy and reliability. The developed interaction charts were validated through comparisons with existing charts and software tools, demonstrating a high degree of agreement and confirming their accuracy and applicability.

It is shown that the developed charts accurately capture the behavior of RC shear walls for a wide range of axial and bending loads. Therefore, the developed charts can be considered as a reliable design tool for design engineers. The findings from this study underline the importance of detailed material behavior and full interaction domains accounted for in structural design. These charts can then be used directly as design aids for straight RC shear walls of any size and for different combinations of normal strength concrete classes and steel reinforcement classes.

In general, the present study is conducted to complete a design tool for RC shear walls that will permit engineers to design and check the aforementioned structural element more accurately and efficiently.

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Appendix

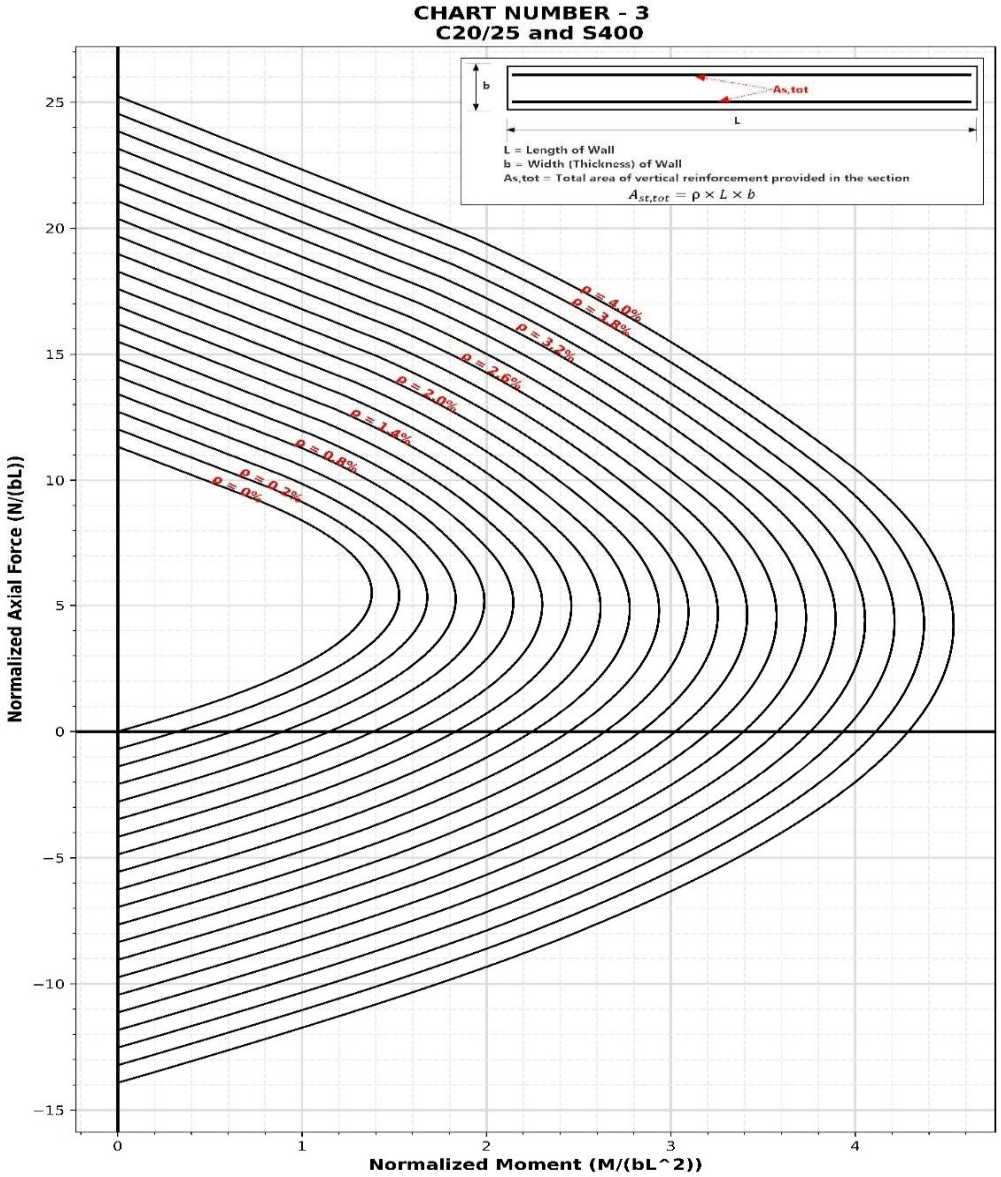


Figure A1: Interaction chart for concrete class of C20/25 and steel class of S400

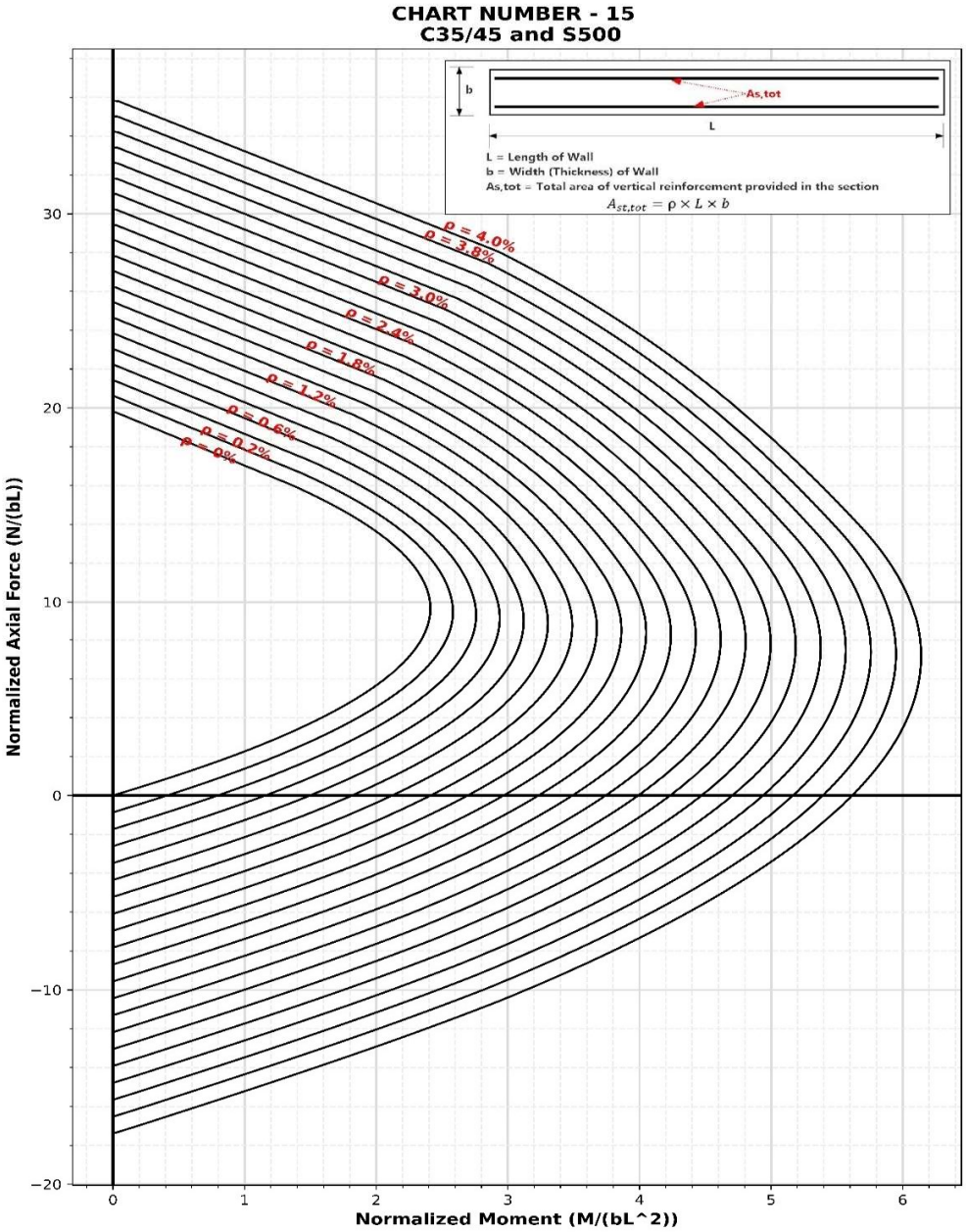


Figure A2: Interaction chart for concrete class of C35/45 and steel class of S500

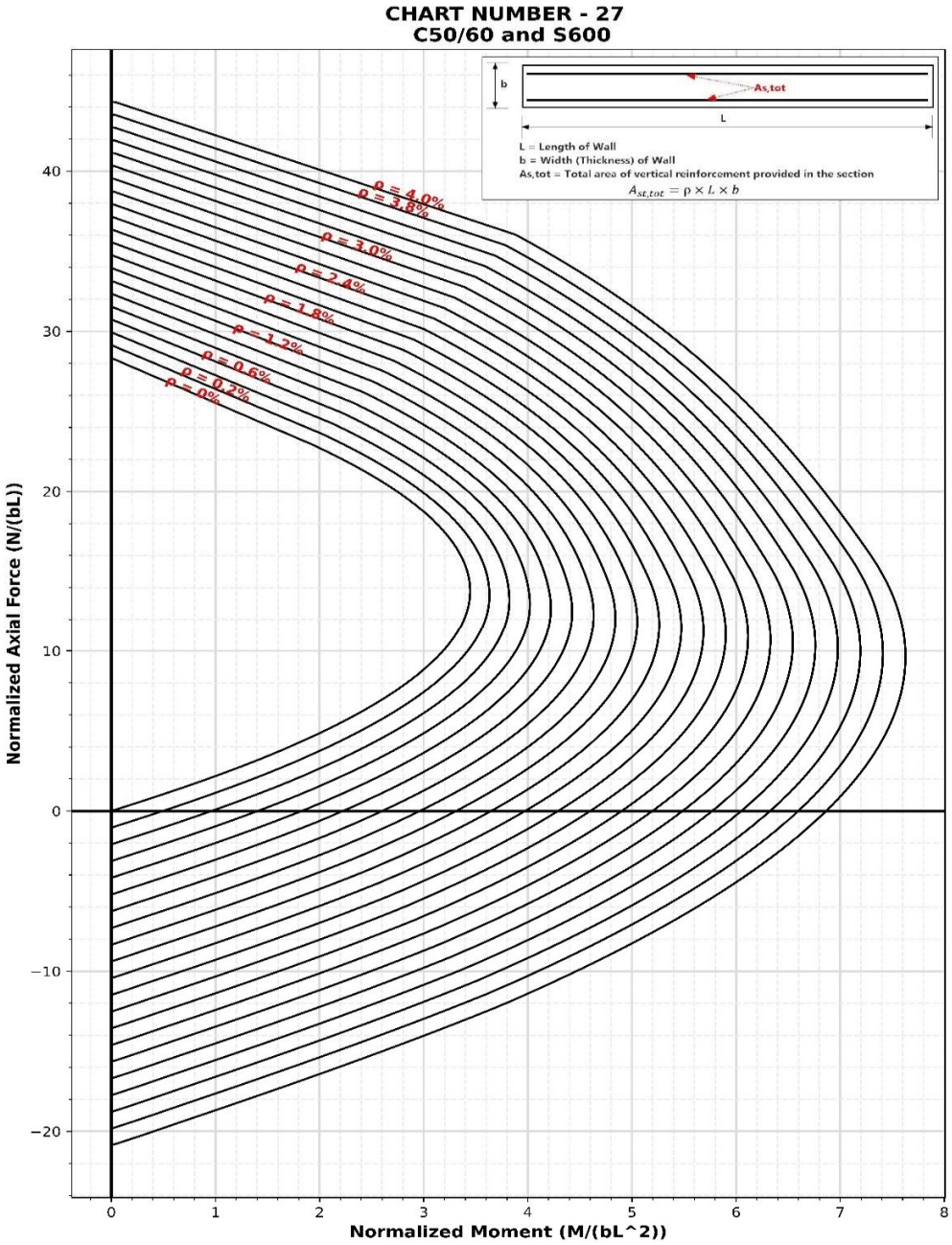


Figure A3: Interaction chart for concrete class of C50/60 and steel class of S600