Predict the Ultimate Shear Capacity of Deep Beams by Using SPSS Software

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Abstract:

This research aims to develop an accurate prediction model for shear strength in deep beams to improve the design of these vital structural elements. Various experimental data were collected for several beams, including variables such as beam dimensions, concrete type, and reinforcement type.

The data were analyzed using SPSS, where multiple linear regression analysis was performed to determine the relationship between these variables and shear strength. The results showed a strong relationship between some variables and shear strength, such as reinforcement ratio and cross-sectional dimensions. However, the results also showed significant differences in data quality, which negatively affected the model's accuracy.

The results indicate that the lack of available data has led to weak prediction power. Compared to previous studies, this research has demonstrated the importance of considering the effect of concrete type on shear strength.

Keywords: Prediction, shear strength, deep beams, data analysis, linear regression, SPSS program.

الملخص

يهدف هذا البحث إلى تطوير نموذج تنبؤ دقيق لمقاومة القص في الكمرات العميقة لغرض تحسين تصميم هذه العناصر الإنشائية الحيوية. جُمعت مجموعة متنوعة من البيانات التجريبية لعدة كمرات، بما في ذلك متغيرات مثل أبعاد العوارض ونوع الخرسانة ونوع التسليح.

حُلّلت البيانات باستخدام برنامج SPSS، حيث أُجري تحليل الانحدار الخطي المتعدد لتحديد العلاقة بين هذه المتغيرات ومقاومة القص. أظهرت النتائج وجود علاقة قوية بين بعض المتغيرات ومقاومة القص، مثل نسبة التسليح وأبعاد المقطع العرضي. ومع ذلك، أظهرت النتائج أيضًا اختلافات كبيرة في جودة البيانات، مما أثر سلبًا على دقة النموذج.

تشير النتائج إلى أن نقص البيانات المتاحة قد أدى إلى ضعف قوة التنبؤ. وبالمقارنة مع الدراسات السابقة، أظهر هذا البحث أهمية مراعاة تأثير نوع الخرسانة على مقاومة القص.

الكلمات المفتاحية: التنبؤ، مقاومة القص، الكمرات العميقة، تحليل البيانات، الانحدار الخطي، برنامج SPSS.

1. Introduction.

Deep beams are a type of reinforced concrete beam that has a large height-to-width ratio. These beams are used in a variety of engineering applications, including buildings, bridges, and tunnels [Russo, G., Venir, R., & Pauletta, M. (2005)]. The shear resistance of RC beams, especially shear-critical elements such as RC deep beams, is a challenging issue that is still the subject of academic debate. This is because the shear behavior of RC beams is affected by many parameters, the interdependence of which is very difficult to model. Additionally, shear forces always act in combination with other types of loads such as flexure, axial load, and sometimes torsion, further complicating the problem. Accurate shear capacity prediction is paramount since shear failure is catastrophic and could occur without warning [Osman, B. H. (2008)].

They behave differently from ordinary beams, as phenomena such as lateral bending and axial compression play an important role in determining their ultimate capacity. It provides wide open spaces without internal columns, which increases the efficiency of space use. It has high rigidity and a large load-bearing capacity, which makes it suitable for use in structures with high loads.

It also provides great flexibility in design, allowing the design of structures of complex shapes. In the deep beam, a significant portion of the applied load is transferred to the support point through a compressive force that combines the load and the reactions. This leads to the strain distribution being non-linear, and shear deformations are more pronounced than flexural deformations. Particularly, the use of deep beams at the lower levels in tall buildings for both residential and commercial purposes has increased rapidly because of their convenience and economic efficiency. Generally, deep beams are regarded as members loaded on their top extreme fibers in compression and supported on the opposite side [U. Obinna . (2023)].

The ultimate capacity of a deep beam refers to the maximum load that it can bear before failure occurs. Determining the ultimate capacity is crucial to ensuring the safety and structural integrity of deep beam design; however, predicting the maximum capacity of deep beams is complex and requires careful analysis.

The maximum capacity of deep beams is affected by several factors, including the dimensions of the beam [Length, width, and height] the type of concrete [Compressive strength, soil properties], the type of reinforcement, [Amount of reinforcement, distribution of reinforcement, type of steel] and the loading conditions [Type of loading, loading value, loading site] therefore predicting the maximum capacity of deep beams is complex and requires careful analysis [KHAIR, E. I. A. M., & Ahmed, E. I. (2005)].

Figure 1: Some applications of deep beams.

By comprehending the factors affecting shear strength and developing more accurate design methods, engineers can design safer and more qualified concrete structures. Shear strength is an internal force that acts parallel to the cross-section of a beam and causes the members of the beam to slide relative to each other. In deep beams, which are characterized by their large length relative to their height and thickness, shear strength plays a critical role in determining their load-bearing capacity [Ochshorn, J. (2009)].

The purpose of studying the shear strength of deep beams is structural safety: Understanding shear strength is essential for designing beams that can withstand loads without failure. Improving design: Knowing how shear strength is distributed in a beam helps engineers to improve its design and reduce the amount of material used. Troubleshooting: If a beam has a problem, understanding the shear strength helps to determine the cause of the problem and find the appropriate solution. In general, predicting the ultimate capacity of a deep beam requires careful consideration of various factors and perhaps a combination of analytical and experimental approaches [Ochshorn, J. (2009)].

Reinforced concrete deep beams have many useful applications in building structures such as transfer girders, wall footings, foundation pile caps, floor diaphragms, and shear walls. Especially the use of a deep beam at the lower level in high buildings for both residential and commercial purposes [Al-Asady, A. S .(2018)].

The method of distributing the load on beams influences the distribution of the resulting stresses, and thus the shear strength [Park, R., & Paulay, T. (1991)].

The proposed method can accurately predict different failure modes, calculate the corresponding shear strength, and then determine the failure mechanism and shear strength. The process is as follows:

1. **Crushed concrete at node 1:** Under the condition of load distribution, the upper and lower load distributions of shear stiffness must be satisfied when concrete at node 1 is being crushed.
2. **Crushed concrete at node 2:** When concrete is being crushed at node 2, we can obtain the shear strength of the lower load path and also the shear strength of the upper load path under the condition of load distribution.
3. **Steel yielding at node 3:** When the flexural steel yields at node 3, the equilibrium requirement of the vertical forces must be satisfied at node 3. The upper load and lower load distributions of shear stiffness must also be satisfied.
4. **Steel yielding at node 4:** When steel yields at node 4, we can obtain the shear strength of the upper load path. Then, the shear strength of the lower load path will increase continually until failure occurs. We can calculate the minimum value of the shear strength out of node 1, node 2, and node 3, to find the failure location and the corresponding shear strength of the lower load path [8].

The two main patterns of failure that deep beams suffer from are shear and flexural failures. The shear failure is divided into four patterns [Fu Chai, and et. al (2013)]:

1. Shear tension failure. this type of failure is due to the influence of the flexural load, which causes the tensile crack expansion in the compressive zone. The beam fails by flexural failure in the compressive zone.
2. Shear compression failure, this type of failure is the result of a decrease in the compressive zone due to the presence of diagonal cracks and their expansion in the

compression zone, also, concrete crushing that occurs because of compressive stresses exceed.

3. Struts compressive or shear proper failure, this type of failure often occurs in deep beams that have a low value of (a/h), in which arc formation is evident. The deep beams fail by compressive crush in the direction of the strut axis or by sudden tensile crack parallel to the strut axis.
4. Flexural compression failure occurred after yielding of the main flexural steel reinforcement, due to crushing of the concrete in the constant moment region.

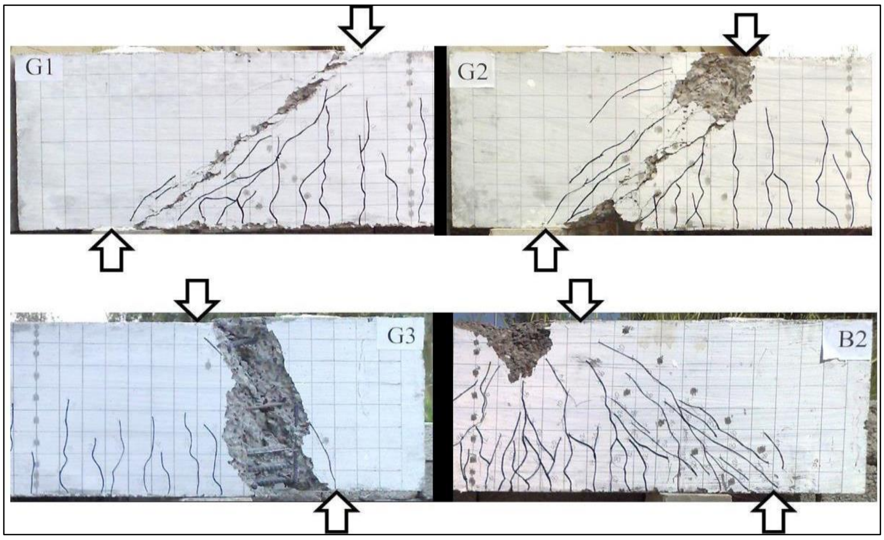

Figure 2: Modes of failure, G1-shear tension failure, G2-shear compression failure, G3-strut compression failure, and B2-flexural compression failure.

Understanding the ultimate shear capacity of deep beams is essential for structural engineering and designers. It allows them to design deep beam structures that can safely support the intended loads without failure. Accurate prediction of the ultimate capacity also helps in optimizing the design and reducing material and construction costs. The main aim of the present study is to develop a numerical and analytical model to predict the shear behavior and capacity of RC deep beams more accurately than the available models, and this is achieved through the following objectives:

1. Gain an understanding of the effect of key parameters such as shear span to depth ratio, concrete compressive strength, shear reinforcement, and size effect on the behavior of RC deep beams.

2. Develop a mathematical model for predicting the maximum capacity of deep beams using statistical analysis.
3. Compare the accuracy of the developed model with other prediction models from various codes.
4. Evaluating the accuracy of a mathematical model to predict the bearing capacity of a beam using statistical analysis.

2. LITERATURE REVIEW.

There are many studies and research that deep beams, using different methodologies, some of them including the following:

[Chan and et al. (2019)] Summarized to separate and determine the effects of bearing plate size on the effect of shear size. Existing deep beam tests on the effect of shear size were classified. It is verified that the effect of shear volume for deep beams with a fixed bearing plate size is stronger compared to deep beams with relatively varied plate sizes.

[Kim and et al. (2011)] Presented experimental studies of the behavior of deep reinforced concrete beams under combined axial and bending loads. To study the effect of axial loads on the structural behaviors of deep RC beams, specimens were prepared for different shear-to-depth ratios and subjected to axial loads of 235 kN or 470 kN. Through experiments, structural behaviors such as failure modes, load-deflection relationships, and strains of steel bars and concrete were observed. Reported results of tests, for deep beams with a shear-to-depth span ratio of 0.5, the load at beam failure decreases as the applied axial load increases, while deep beams with shear-to-depth span ratios of 1.0 and 1.5 show that the applied axial load delays the failure of the beam. In addition, the failure mode of deep beams changes from shear failure to concrete cracking due to compressive stress at the upper corners of RC beams as the shear span-to-depth ratio decreases.

[Rao and et al. (2011)] Presented experimental investigations on the shear behavior of reinforced Concrete (RC) deep beams without and with shear (web) reinforcement. Twelve large-scale deep beams made of 60 MPa concrete were tested. Three different beams of depth 250mm, 500mm, and 750 mm were tested to understand the size effect. The behavior of deep beams, including load-deflection curves, web strains, crack Width, shear ductility, and reserve strength, has been investigated. The beams tested under three-point loading failed in shear, and failure modes were influenced by the beam depth and amount of shear reinforcement.

3. COLLECTING AND ANALYSIS OF DATA.

Many methodologies can be used to predict shear strength in beams. These methodologies depend on the type of beam, materials used, and theoretical, numerical, and experimental boundary conditions. Understanding the shear behavior of deep RC beams has been a difficult problem for several decades, and the problem is still not completely solved. A better understanding and exploration of the influence of different design factors and the ultimate shear capacity of deep reinforced concrete beams is obtained using SPPS analysis software.

3.1 Data collection from the literature review.

A total of 235 data sets were obtained aiming to evaluate the ability of the beams to withstand lateral loads caused by shear forces. By collecting and examining previous literature; specimens were tested and different parameters were examined for their effect on specimen behavior. These variable parameters were shear extend soon to depth ratio (0.0024 – 2.49), beam height (250 mm – 1905 mm), Ultimate load (0 N – 12588400 N), shear span of beam (1.125 mm – 4375.2 mm), area of tension steel reinforcement (84.82 mm^2 – 32572 mm^2) and area concrete of beam (40000 mm^2 – 933482 mm^2), including geometric dimensions, reinforcement information, and concrete strength, are selected by combining a set of random experimental data that varies in terms of dimensions (Longitudinal and cross-section), loading (Central load), and factors (Reinforcing steel). And others, for the shear bearing capacity of deep reinforced concrete beams with simple supports.

3.2 Data analysis using SPSS.

SPSS is a windows-based program that can be used to enter and analyze data and create tables and graphs. It offers a comprehensive set of capabilities, providing flexibility and ease of use beyond traditional statistical software. SPSS is capable of handling large amounts of data, can perform all the analyzes covered in the text, and much more. SPSS is commonly used in engineering mathematics and requires a range of analytical tools to solve problems and make decisions. Correlation and regression analysis serve as useful tools, helping engineers predict and improve results based on different variables. Whether it is understanding the effects of different factors on the manufacturing process or analyzing the performance of a structure over time, correlation and regression can provide valuable insights [Sedgwick, P. (2013)].

3.3 Estimating the regression curve.

Curve estimation allows you to quickly estimate regression statistic and produce relevant plots for 11 different models.

Curve estimation is most appropriate when the relationship between the dependent variable (s) and the independent variable is not necessarily linear [Sweet, S. A., & Grace-Martin, K. (1999)].

4. RESULTS.

The results of statistical and engineering analysis of deep structural elements (Deep beams) will reveal a set of complex relationships between various engineering and mechanical factors and the ability of these elements to bear the applied loads. The study showed that the beam's height, width, shear span, concrete cross-sectional area, and steel reinforcement area have a direct and indirect effect on the beam's final bearing capacity.

The results aim to understand the relationship between various engineering factors and the ability of deep structural elements to bear loads. These results can be used to develop more accurate analytical models to evaluate the bearing capacity of these elements, thus improving the design of structural structures.

4.1 Prediction results for ultimate capacity.

Results of predicting deep beam behavior using advanced statistical methods:

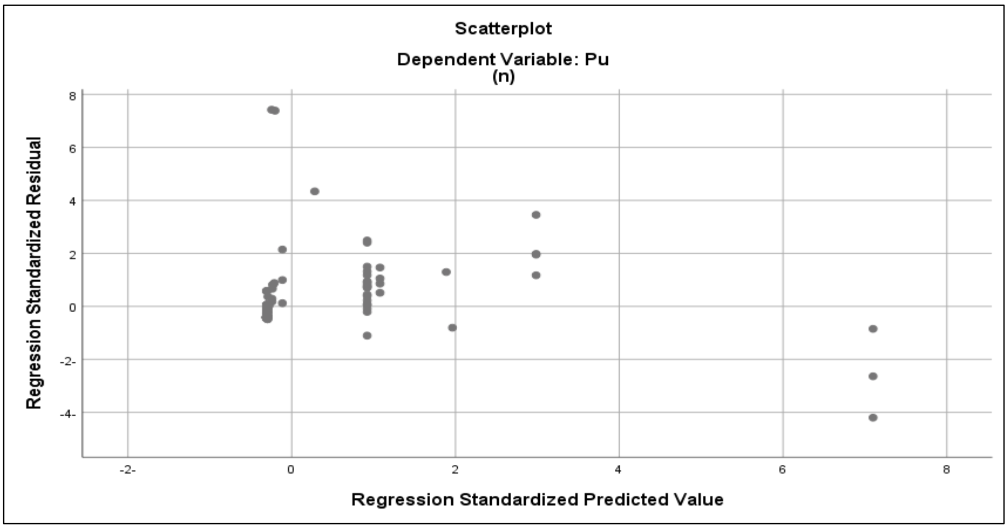

Figure 3: Scatterplot Dependent Variable: pu (regression).

4.2 Curve estimation results

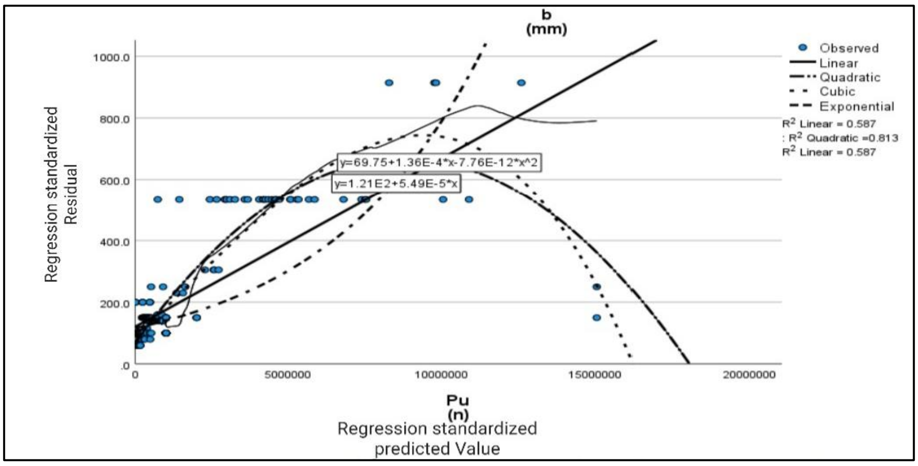

Figure 4: Scatterplot dependent variable: pu (Curve estimation).

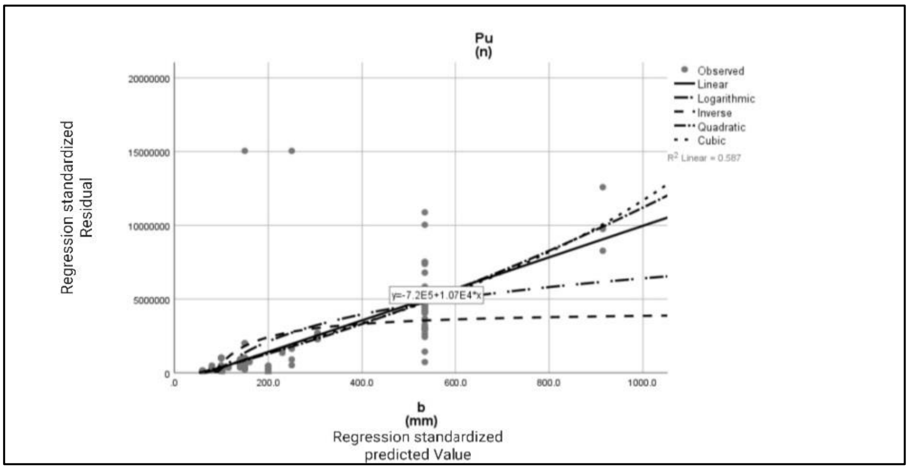

Figure 5: Results of the curve estimation for coefficient b using the SPSS program.

4.3 Equations derived from results from SPSS.

4.3.1 b vs pu.

Linear: $y = -719667.136 + 10688.197x$ **Eq (1).**

Logarithmic: $y= -11971884.5 + (2660225.726 \ln(x))$ **Eq (2).**

Inverse: $y = 422952.411 – (362051788 / x)$ **Eq (3).**

Quadratic: $y = -419504.695 + (7815.90x) + (3.812 x^2)$ **Eq (4).**

Cubic: $y = -715618.950 +(11473.508x) + (-5.922 x^2) + (0.007 x^3)$ **Eq (5).**

To estimate the shear capacity of deep beams reinforced concrete simple supporters, a simple linear equation can be used if the relationship between shear capacity and cross-sectional area is approximately linear. But if the relationship is more complex and affected by other factors such as concrete type and reinforcement ratio, you will need a more complex nonlinear equation.

4.4 Scatter diagrams for our developed models.

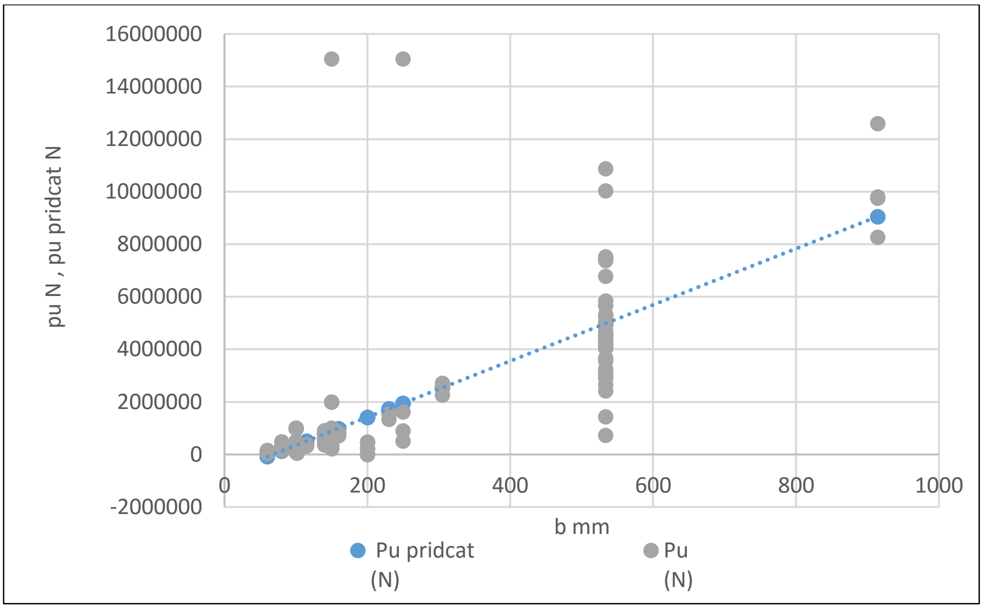

Figure 6: Comparison between pu and pu prediction used from the b vs pu linear equation.

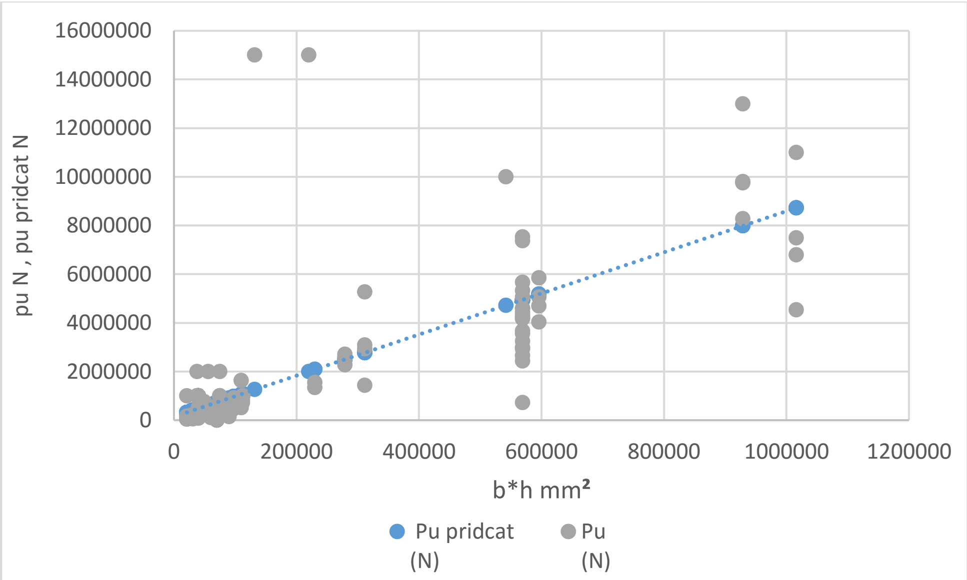

Figure 7: Comparison between pu and pu prediction used from the b*h vs pu linear equation.

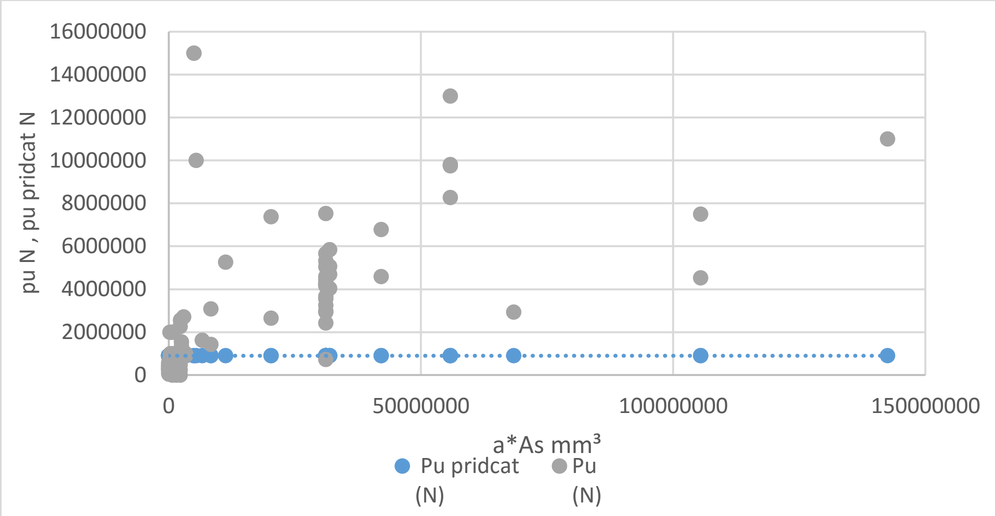

Figure 8: Comparison between pu and pu prediction used from the a*As vs pu linear equation.

5. DISCUSSION OF THE RESULTS.

The results obtained were discussed, focusing on the impact of each of the identified factors on final capacity, and comparing these results with previous studies. Possible deviations between the current and previous results will also be discussed, and possible explanations will be provided. Finally, recommendations will be made for future studies that can build on the findings of this research.

Due to their high bearing capacity and adaptability to different loads, deep structural elements are considered essential in many engineering facilities. However, there is still a lack of complete understanding of the behavior of these elements and the Influence of various factors on their ultimate capacity. The results aim to fill this knowledge gap by predicting the ultimate capacity of deep structural elements using a set of influencing factors that have a strong relationship with the ultimate capacity. These factors were selected based on an in-depth statistical analysis using SPSS, where the focus was on the factors most closely related to final ability according to previous studies.

Prediction discussion of the results for the ultimate capacity:

1. The results showed that the maximum load is strongly affected by the dimensions of the beam, the shear span of the beam, the concrete area of the beam, and the area of the reinforced steel in tension, and they have a strong relationship, as the results ranged from
    - d vs pu = 0.763
    - h vs pu = 0.757
    - a vs pu = 0.806

- Ac vs pu = 0.944
- As vs pu = 0.932

The results showed that the maximum load is weakly affected by the ratio of shear span to depth, as the strength of the relationship was a\d = 0.427. This indicates that these parameters play an important role in predicting the shear strength**.**

2. From the equations, it is clear that the best linear equation (Eq 4.21), and that the results of all linear equations have a large difference between them concerning the prediction values pu and pu, such as (The linear equation (Eq 4.21), for the parameter (Ac), and its values (Pu= 84000 N, Pu prediction= 514332.676 N), (Pu= 89600 N, Pu prediction= 437187.63 N) and, (Pu= 1000000 N, Pu prediction= 1133555.176 N) and these are weak results.
3. The weak results negatively affected the accuracy of the model, and one of the reasons for this is the lack of data. To improve the accuracy of future predictions, it is recommended to increase and diversify the sample size, improve the quality of the data, and use advanced analytical techniques. It is also recommended to conduct additional experimental studies to evaluate the effect of other variables on shear strength. Through these efforts, more accurate design tools for deep beams can be developed, contributing to improved structural integrity**.**
4. This research is an important step towards developing accurate prediction models for shear strength in deep beams. Despite the challenges faced in the research, the results obtained provide a good basis for future studies. By addressing the proposed limitations and developing the model, more accurate design tools for deep beams can be developed, which contributes to improving the safety of structures.

6. CONCLUSION AND RECOMMENDATION.

The most important results reached will be summarized, and finally, a set of recommendations will be presented that can be built upon in future research. Which aims to predict the final capacity of deep structural elements (Deep beams) using the SPSS statistics program.

6.1 Conclusions:

1. Deep structural elements are essential elements in many engineering structures, due to their high load-bearing capacity and adaptability to different loads. However, understanding the shear

behavior of deep RC beams has been a difficult problem for several decades, and the problem is still not completely solved.

2. Statistical sampling is considered the best way to predict data or information, as it saves time and effort for the researcher.

3. Engineering mathematics often requires a set of analytical tools to solve problems and make decisions. Correlation and regression analyses serve as useful tools, helping engineers predict and improve results based on different variables. Whether it is about understanding the effects of different factors on the manufacturing process or analyzing the performance of a structure over time, correlation and regression can provide valuable insights. The statistical analysis program SPSS is the best way and the most widely used tool to obtain the classification and analysis of all data, which provides:
    - Description of all variables related to the study.
    - Analysis of data related to the study.
    - Reaching the most important results related to the study.
    - Generalizing the results.

4. The results present that the maximum load is highly affected by the dimensions of the beam, the shear span of the beam, the concrete area of the beam, and the area of the reinforced steel in tension, and they have a strong relationship, as the results ranged from 0.7~0.9. The results showed that the maximum load is weakly affected by the ratio of shear span to depth, as the strength of the relationship was 0.3. This indicates that these parameters play an important role in predicting the shear strength.

5. The results of the comparison between the prediction and Pu that were extracted from previous studies show a significant difference. This indicates weakness in the results, one of the reasons for which is the lack of data.

6. To improve the accuracy of future predictions, it is recommended to increase and diversify the sample size, improve the quality of data, and use advanced analytical techniques. It is also recommended to conduct additional experimental studies to evaluate the effect of other variables on the shear strength. Through these efforts, more accurate design tools for deep beams can be developed, which contributes to improving the safety of structures.

6.2 Recommendations:

1. **Increase sample size:** More experimental data should be collected to increase sample size and improve model accuracy**.**

2. **Improve data quality:** Attention should be paid to improving data quality by using accurate measuring devices and following standard procedures.
3. **Include additional variables:** Additional variables can be included in the analysis, such as reinforcement type, connection method, and the effects of fires and earthquakes.
4. **Use advanced analytical techniques:** Advanced analytical techniques, such as artificial neural networks or machine learning, can be used to develop more accurate predictive models.
5. **Validate the model:** The model should be validated using an independent dataset to ensure its ability to generalize.

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