Journal of Engineering Research and Reports

Volume 26, Issue 3, Page 145-160, 2024; Article no.JERR.113832
ISSN: 2582-2926

Predictive Behaviour from Finite Element Analysis on PVC-Ducted Reinforced Concrete Column

Felix Kwarteng [a*], Charles K. Kankam [b], Jack O. Banahene [b], George Oti Boateng [c] and Edward Ceasar Mansal [d]

[a] *Bosome Freho District Assembly, Asiwa-Ashanti, Ghana.*
[b] *Civil Engineering Department, KNUST, Kumasi, Ghana.*
[c] *Civil and Environmental Engineering Department, UENR, Sunyani, Ghana.*
[d] *Civil Engineering Department, USET, the Gambia.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2024/v26i31101

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/113832

Original Research Article

Received: 26/12/2023
Accepted: 01/03/2024
Published: 05/03/2024

ABSTRACT

This research investigated the behaviour of square reinforced concrete columns with embedded PVC pipes, aiming to comprehensively analyze their performance. The study addressed the lack of significant research on the contributions and effects of embedded PVC pipes on structural performance compared to hollow columns. The objectives of the study sought to evaluate the contributions and effects of embedded PVC pipes on the structural performance of columns under loading conditions, determine how the presence of PVC pipes influenced the columns' ability to deform and dissipate energy, and identify the optimal size of PVC pipes to enhance column performance while maintaining stability and safety. Numerical analysis using ABAQUS CEA 2020 software was employed to simulate the behavior of reinforced concrete columns with embedded

---

**Corresponding author: Email: kwaflix2dat@gmail.com;*

PVC pipes. The computational model used the same cross-sections with varying diameters of PVC pipes (50mm, 75mm and 100mm). The analysis focused on assessing load-bearing capacities, deformation characteristics, and energy dissipation patterns under axial vertical displacement loading scenario. Findings indicated that PVC-embedded columns exhibit, on average, approximately 0.5% higher load-bearing capacities than Perforated columns. With a composite average of 0.00543 for plastic strains (LE) in PVC-Embedded columns compared to 0.00673 in Perforated columns, a composite average of 5.87E-03 for Equivalent Plastic Strains (PEEQ) in PVC-Embedded columns compared to 7.41E-03 in Perforated columns, and a composite average of 0.0091 for Magnetic Potential Energy (PEMag) in PVC-Embedded columns compared to 0.012 in Perforated columns, collectively suggested that PVC pipes positively impact controlled deformation and energy dissipation. The observed trend is particularly evident in specific instances, with PVC-Embedded-50mm exhibiting a marginal load-bearing increase of approximately 0.2%, PVC-Embedded-75mm indicating an improvement of about 0.5%, and PVC-Embedded-100mm manifesting a load-bearing capacity increase of roughly 0.7%. Overall, these findings highlight that smaller sizes of embedded PVC pipes result in better load-bearing performance. The study recommended meticulous attention to material composition and structural design during PVC-embedded column implementation, careful selection of PVC pipe sizes based on structural requirements and project specifications, further research on dynamic loading conditions to comprehensively understand column behavior, and implementation of stringent quality control measures during manufacturing and construction processes.

Keywords: PVC embedded column; perforated column; force-displacement relationship; plastic strains; equivalent plastic strains; magnetic potential energy.

1. INTRODUCTION

Columns are an essential part of any structural system as they support the beams and slabs and transfer loads to the foundations. In moment resisting structural systems, columns are considered critical members, and any failure or weakness can lead to the destabilization of the entire structure [1]. Hence, it is crucial to design and detail columns adequately to withstand both gravity and lateral loads [2]. The ability of columns to bear loads depends on various factors such as the properties of materials used, their length, cross-sectional area, and upper and lower bracing [3].

In recent times, there has been a growing trend of modifying structural elements to enhance their functionality while maintaining the aesthetics of the structure [4]. One such modification involves embedding Poly Vinyl Chloride (PVC) pipes into concrete structural elements to allow access for services such as electric wiring. Another practice involves positioning PVC pipes inside reinforced concrete (RC) columns to drain rain and waste water from high rise buildings and discharge at the ground [5]. However, these practices may lead to a reduction in strength, stiffness, ductility, and/or structural damage if not adequately considered during the design stage [6]. Introducing drain pipes inside columns can make them hollow, thereby reducing the effective cross-sectional area and load carrying capacity of the column [7]. It is worth noting that current literature concerning the issue reveals a lack of coherent information and guidance in the codes of practice for ACI 318 (American) and BS8110 (British Standard) regarding this particular problem.

Research on these varieties of columns suggests that no significant investigations have been undertaken to examine the real discount in load carrying ability of these columns. Previous works in this regard have been limited to studying the effect of constant axial load and eccentric load on the behavior of rectangular and circular hollow reinforced concrete columns [8,3]. It has been found that columns constructed with PVC pipes embedded in them not only have reduced load carrying abilities but can also be dangerous to the safety of the entire building structure and reduce its useful life. Problems caused by this practice may include formation of honeycombs around the drain pipe and leakage from the joint lapping part of the pipe causing corrosion of reinforcement.

Variables such as the diameter and thickness of the PVC pipes, size and shape of the column, and the kind and amount of applied stresses may affect how reinforced concrete columns with PVC pipes embedded in them behave as hollow columns [6]. The presence of PVC pipes may also impact the bond between the concrete and the reinforcing steel, which can significantly affect the behavior of the column.

This analytical research aims to investigate the behavior of square reinforced concrete columns (Models) having PVC pipes positioned inside them. The hysteric performance of the columns is evaluated using the same cross-sections with different diameters of PVC pipes.

2. MATERIALS AND METHODS

2.1 Study Overview

The primary aim of this study is to comprehensively analyze the behaviour of reinforced concrete columns embedded with PVC pipes and compare them with hollow columns without PVC pipes. The investigation utilizes a numerical simulation technique involving material characterization, column assembly, and testing under various loading conditions. The methodology involves modelling nonlinear mechanical analysis of concrete and reinforcement, treating them as time-independent. To address material non-linearity, the 3D Finite Element Analysis (FEA) software was adopted.

2.2 Benchmark Validation

2.2.1 Solid Reinforced Concrete Column

A solid reinforced concrete column served as a benchmark or control for validation (see Table1). The model, developed within Abaqus, underwent rigorous evaluation against internal consistency and convergence criteria. Cross-verification involved adjusting parameters like mesh density, convergence criteria, and element types.

2.3 Material Modelling Pre-processing Data

[9], a finite element package, was selected for its versatility. It provides multiple modes of execution, including ABAQUS/Standard for addressing static, dynamic, linear, and nonlinear problems.

Seven models were created, with details outlined in Table 1. These models comprised three configurations: three with embedded PVC pipes, three with perforations but without PVC pipes, and one singular reference model. Table 1 visually presents model identification, geometry, configuration specifics, reinforcement details, perforation diameters, and PVC pipe wall thicknesses for the different PVC sizes.

In terms of the material model employed, the Concrete Damaged Plasticity (CDP) material model was used for concrete. This model is suitable for capturing both tensile cracking and compressive crushing behaviour, providing a more comprehensive representation of concrete's response under various loading conditions. For PVC Pipe, an Elastic-Plastic model was employed to account for the non-linear behaviour of PVC under loading, especially considering the yield stress of 45 N/mm^2 that PVC exhibits.

2.4 Material Properties

Material properties, crucial for understanding material behaviour, were defined for concrete, steel, and UPVC (Table 2 and 3, Figs 1-5). These properties, such as mechanical, thermal, electrical, chemical, optical, density, and specific gravity, play a crucial role in defining a material's behaviour under various conditions. Mechanical properties, encompassing strength, stiffness, hardness, and elasticity, determine how a material responds to applied forces, influencing its structural integrity. Thermal properties, including thermal conductivity and heat capacity, provide insights into a material's ability to conduct heat and withstand temperature changes. Electrical properties, like conductivity and resistivity, detail a material's behaviour under electrical fields.

Chemical properties, such as reactivity and resistance to corrosion, are vital for assessing a material's durability and stability in different environments. Optical properties, covering transparency and reflectivity, focus on how materials interact with light. Additionally, density and specific gravity offer practical information about a material's mass and density concerning water, aiding in structural and design considerations. Overall, material properties guide decision-making processes in material selection, product design, and structural analysis, enabling the identification of the most suitable materials based on their performance attributes.

2.5 Element Type

The finite element analysis utilized three-dimensional solid elements for concrete and truss elements for reinforcement. Two-node truss elements (T3D2) were employed for the reinforcement, while eight-node brick elements (C3D8) were used for plain concrete.

2.5.1 Step Module

A comprehensive analysis in the step module focused on detecting non-linearities. Two steps were present: the initial step defined boundary conditions and interactions, and the analysis step focused on static stress analysis.

Table 1. Material modelling pre-processing data (UPVC high pressure pipes & fittings, n.d.)

Column Model id	Model Geometry	Model Configuration	Rebar Details Main	Rebar Details Stirrup	Perforation Diameter	UPVC Wall Thickness
FEMValidatio-Col.	300x300x2000	Solid	4R20	R8 165c/c	None	None
PVC-Embedded-50mm	300x300x2001	Hollow	4R20	R8 165c/c	60.32mm	6.20mm
Perforated-50mm	300x300x2002	Hollow	4R20	R8 165c/c	60.32mm	None
PVC-Embedded-75mm	300x300x2003	Hollow	4R20	R8 165c/c	88.90mm	8.53mm
Perforated-75mm	300x300x2004	Hollow	4R20	R8 165c/c	88.90mm	None
PVC-Embedded-100mm	300x300x2005	Hollow	4R20	R8 165c/c	114.30mm	9.58mm
Perforated-100mm	300x300x2006	Hollow	4R20	R8 165c/c	114.30mm	None

Table 2. Material properties for concrete [10,11]

Material's parameters	**Concrete grade C25**	**Plasticity parameters**	
		Dilation angle	**33**
Concrete Elasticity		Eccentricity	0.1
Elastic Modulus (GPa)	30	fb0/fc0	1.16
Poisson's ratio	0.2	K	0.67
Density	2.40E-09	Viscosity parameter	0.0001
Concrete compressive behavior		Concrete compression damage	
Yield stress (MPa)	Inelastic strain	Damage parameter C	Inelastic strain
7.09252	0	0	0
14.0799	0.00032	0	0.00032
19.4175	0.00064	0	0.00064
22.8183	0.00095	0	0.00095
24.5305	0.00127	0	0.00127
25	0.00159	0	0.00159
24.2867	0.00191	0.02853	0.00191
22.5346	0.00222	0.09862	0.00222
20.2873	0.00254	0.18851	0.00254
17.9385	0.00286	0.28246	0.00286
15.7147	0.00318	0.37141	0.00318
13.7182	0.00349	0.45127	0.00349
Concrete tensile behavior		Concrete tension damage	
Yield stress (MPa)	Cracking strain	Damage parameter T	Cracking strain
4.16667	0	0	0
2.3116	0.00017	0.44522	0.00017
1.63771	0.00035	0.60695	0.00035
1.28244	0.00052	0.69221	0.00052
1.06088	0.0007	0.74539	0.0007
0.90857	0.00087	0.78194	0.00087
0.79699	0.00105	0.80872	0.00105
0.71148	0.00122	0.82924	0.00122
0.6437	0.00139	0.84551	0.00139
0.58856	0.00157	0.85875	0.00157
0.54276	0.00174	0.86974	0.00174
0.50406	0.00192	0.87902	0.00192

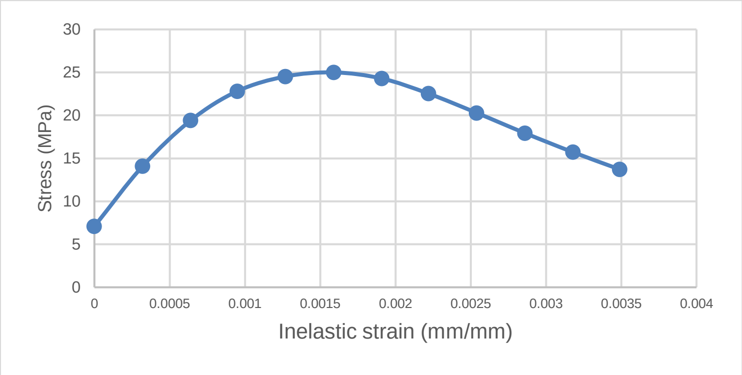


Fig. 1. Concrete compressive strength

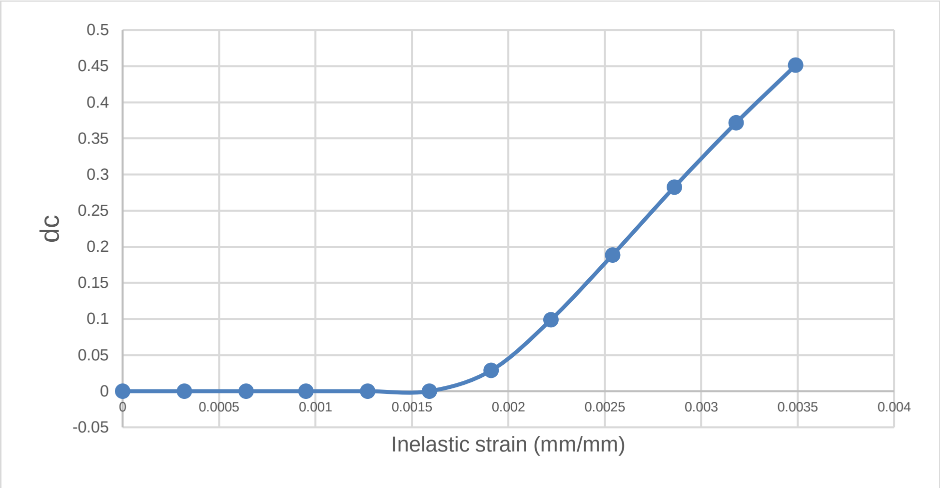


Fig. 2. Compression damage of concrete

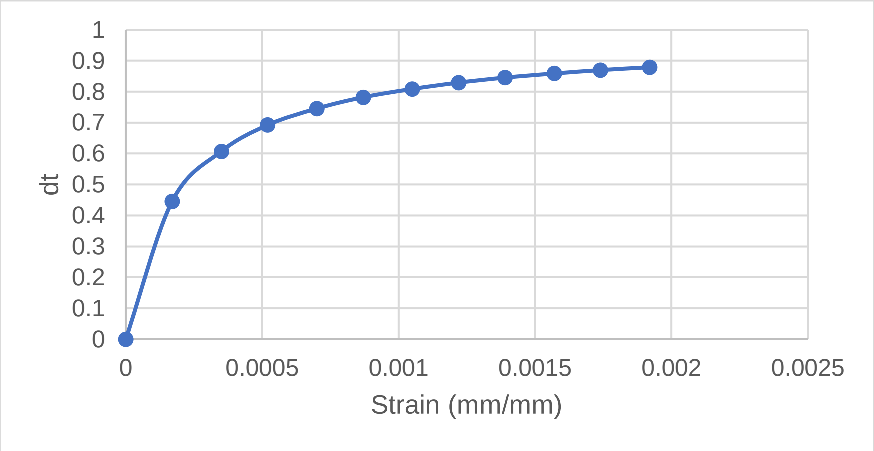


Fig. 3. Tensile stress vs Cracking Strain

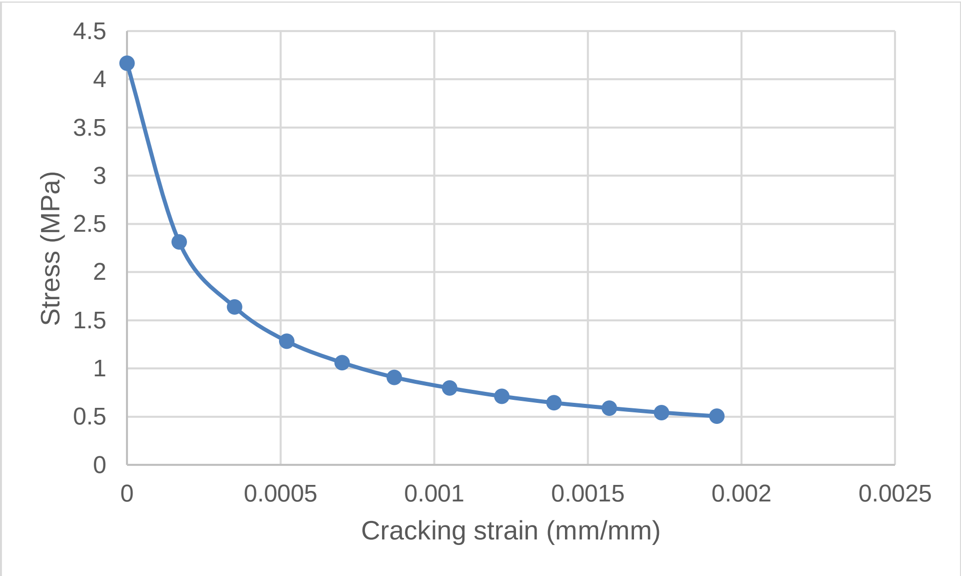
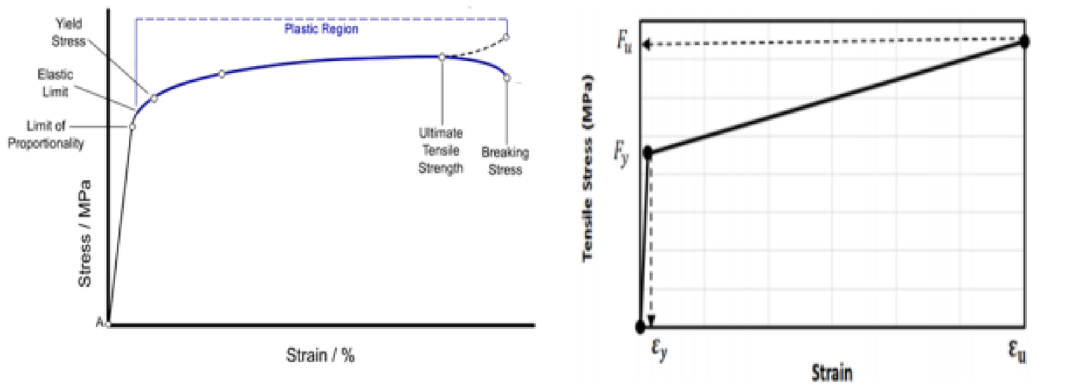


Fig. 4. Concrete tension damage - Cracking strain of concrete

Table 3. Material properties for Steel and UPVC [10,11 UPVC high pressure pipes & fittings, n.d.]

Material	Density	Elastic Behaviour		Plastic behaviour	
		Elastic Modulus E (GPa)	Poisson's ratio (v)	Yield Stress (MPa)	Plastic Strain
Steel	7.80E-09	200	0.3	159.458	0
				240.659	0.0227395
				271.991	0.0437627
				293.008	0.0648433
				309.155	0.0859509
				322.407	0.107075
				333.717	0.128209
				343.626	0.149351
				352.472	0.170499
				360.481	0.191652
				367.812	0.212809
				374.581	0.233968
UPVC	1.43E-09	3	0.4	45	0



a) Stress strain curve of mild steel **b) Simplified stress strain curve**

Fig. 5. Typical uniaxial stress strain behavior of reinforcement [12]

2.5.2 Interactions and Kinematic Constraints

In constructing the finite element model, the focus was on establishing kinematic relationships to ensure strain compatibility among its components. This harmony in deformation was achieved through two key interaction types:

Embedded Constraints were crucial for defining interactions between concrete and steel reinforcement. The use of a beam-in-solid embedded relationship facilitated the embedding of the reinforcing bar within the inelastic concrete. However, caution was exercised to avoid over-constraining issues when extending this constraint to elastic portions at the column's extremes. With regards to the interaction between concrete and PVC pipe, tie constraint was used for the master (concrete) and slave (PVC pipe) surfaces.

Surface Coupling Constraints played a vital role in ensuring proper interaction between different regions or surfaces within the model. Coupling column surfaces allowed for tie constraints, enabling realistic simulations of stress transfer, load distribution, and displacement compatibility. This approach effectively minimized stability issues often associated with combining nonlinear materials models with other interaction definitions. These interaction types collectively contributed to the consistent and accurate representation of structural behaviour and response throughout the analysis.

2.5.3 Mesh Density

The mesh density was adjusted, employing a finer mesh with a density of 20 in stress concentration zones, slots, notches, and holes (refer to Fig. 6). Meshing techniques were customized based on the presence of perforations in plain concrete. For plain concrete with openings, the initial approach involved partitioning by cell, followed by using extrude/swept edges to establish the sweep direction of the perforation. This sequential process aimed to isolate the hole part exclusively for meshing purposes. Alternatively, a cutting plane was defined using partition to splice the column, facilitating meshing by part.

Before adopting the mesh density, a mesh sensitivity analysis was conducted. The objective was to assess the impact of varying mesh sizes and configurations on the accuracy and reliability of the simulation results. This analysis entailed running the simulation multiple times with different mesh parameters, such as mesh density or element size. The goal was to identify the optimal mesh size that strikes a balance between computational efficiency and result accuracy.

Due to limitations in computational resources, including processing power and memory, and to ensure uniformity in the analysis, a consistent mesh size of 40mm was applied to all parts. These meshing strategies were implemented within the Abaqus simulation environment.

2.5.4 Loading and Boundary Conditions

Constraints were established to prevent rigid body motion within the column structure. The base of the column was firmly fixed at the initiation of the simulation, restricting all six degrees of freedom to zero (U1=U2=U3=UR1=UR2=UR3=0).

Loading in the model was applied through a reference point on the upper surface of the column using displacement/rotation boundary conditions. This configuration facilitated the imposition of loads or fixed displacements at the reference point while capturing the corresponding reaction forces.

The loading process involved inducing a fixed axial displacement of -20mm vertically through the reference point in the static step of the simulation (U1= U3=UR1=UR2=UR3=0, U2= -20). The static analysis conducted in Abaqus aimed to understand the structure's response under constant loads, excluding dynamic forces or time-dependent effects. The analysis focused on assessing various structural responses, such as stresses, strains, and displacements, to evaluate the stability and strength of the structure under steady conditions. This methodology provided insights into how the structure would behave when subjected to specific applied forces or loads in a static scenario.

In summary, this comprehensive methodology, supported by Tables 1-2 and Figs 2 to 7, ensures an accurate representation and analysis of reinforced concrete columns with embedded PVC pipes and hollow columns without PVC pipes.

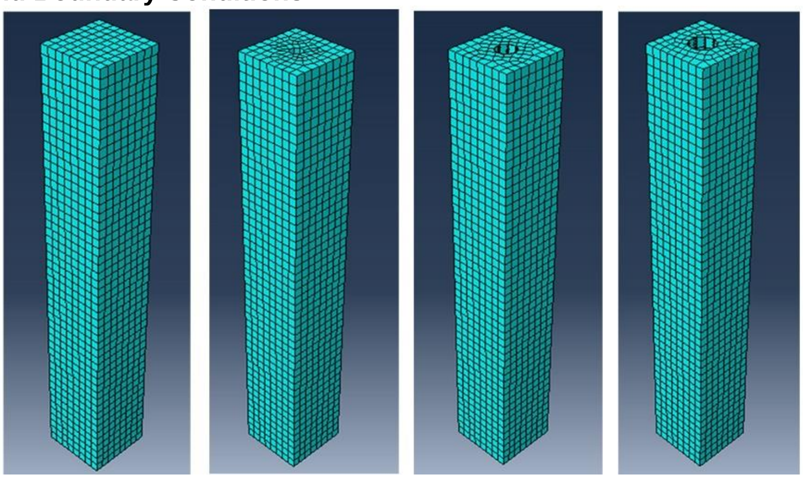


Fig. 6. Meshing of reinforced concrete columns

3. RESULTS AND DISCUSSION

3.1 Benchmark Column Results

This section presents the outcomes of the solid column used as a reference point for the subsequent analyses, where reinforced concrete columns with embedded PVC pipes and hollow columns without PVC pipes were modeled from under consistent conditions.

3.1.1 Force-displacement relationship

The force-displacement relationship, depicted in Fig. 7, demonstrates a substantial maximum force of 3092.45KN applied to the column, resulting in a maximum negative displacement of -4.11699 mm. Notably, despite the magnitude of the load, the column exhibited remarkable resilience, with minimal deformation, illustrating its ability to withstand substantial axial forces without structural failure.

3.1.2 Plastic strains (LE)

Fig. 8 illustrates the decreasing in-plane principal stress values along the column's direction, revealing a discernible pattern of stress distribution within the structural element. This sequence indicates a stress gradient along a specific plane or direction within the column.

The decreasing trend highlights a progressive reduction in stress values along the column's path or cross-section. Starting from higher stress values (1.85E-02) and gradually diminishing to zero (0.00E+00), this sequence suggests a gradual decline in stress levels.

The initial higher stress values (1.85E-02) denote areas in the column experiencing more significant stress concentrations, likely due to applied loads. These zones could be critical areas prone to deformation or failure under extreme loading conditions.

As the stress values decrease along the sequence, they signify regions with lower stress concentration. These areas might experience comparatively less deformation or strain, contributing less to the overall deformation and failure mechanisms within the column.

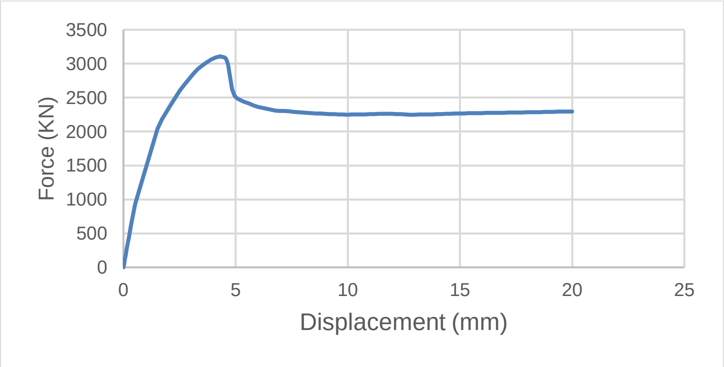


Fig. 7. Maximum force-maximum displacement curve

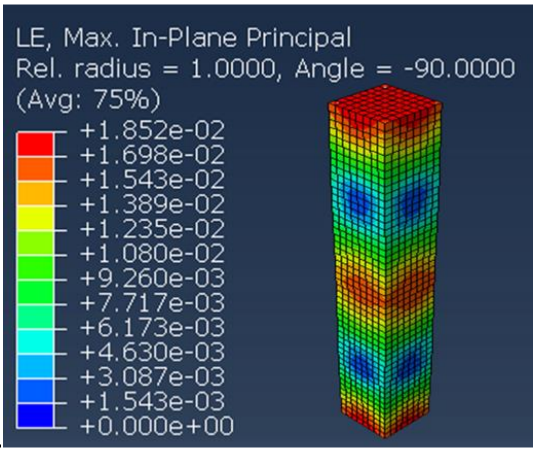


Fig. 8. Maximum in-plane principal plastic strains (LE)

3.1.3 Equivalent plastic strains (PEEQ)

Fig. 9 illustrates a sequence of decreasing equivalent plastic strain values, portraying the distribution of strain within the column. These values signify the degree of plastic deformation occurring at various points or sections along the column's length or within its cross-section.

The decreasing trend reflects a gradual reduction in plastic strain values along the column's path or across its section. Starting from higher strain values (2.08E-02) and gradually diminishing to zero (0.00E+00), this sequence depicts a progressive decline in the degree of plastic deformation.

Higher strain values at the onset of the sequence (2.08E-02) indicate areas within the column experiencing more pronounced plastic deformation. These zones may signify regions subjected to higher stress concentrations or susceptible to greater deformation under applied loads.

As the strain values decrease along the sequence, they denote areas with reduced plastic deformation. These regions experience comparatively lower plastic strain, suggesting diminished levels of deformation or yielding within the column.

3.1.4 Magnetic potential energy (PEMag)

Fig. 10 also presents sequence of decreasing magnetic potential energy values representing the distribution of magnetic potential energy along the column. These values indicate the varying levels of stored magnetic energy within different segments or points along the column's length or within its cross-section.

The descending trend suggests a gradual reduction in magnetic potential energy values across the column. Starting from higher energy levels (2.77E-02) and progressively decreasing to zero (0.00E+00), this sequence illustrates a gradual dissipation or decrease in stored magnetic energy.
Higher energy values at the beginning of the sequence (2.77E-02) suggest areas within the column with more significant stored magnetic energy. These zones might indicate regions where magnetic fields are stronger or where more magnetic energy is stored due to certain characteristics or materials present.

As the energy values decrease in the sequence, they signify areas with lower magnetic potential energy. These regions exhibit comparatively less stored magnetic energy, possibly indicating weaker magnetic fields or areas where the magnetic energy has dissipated.

3.2 Comparison of Force-Displacement Relationship of PVC Embedded Columns and Perforated Columns without PVC

The PVC-Embedded-50mm exhibited a marginally higher maximum force of 3045.220 KN compared to Perforated-50mm at 3039.220 KN, resulting in an increase in load-bearing capacity by approximately 0.2%. This enhancement in structural resilience is visually presented in Fig. 11. Similarly, PVC-Embedded-75mm demonstrated a slightly increased maximum force of 2975.940 KN compared to Perforated-75mm with a force of 2962.290 KN, reflecting a load-bearing capacity improvement of about 0.5%. This signifies enhanced structural strength and resistance to deformation for PVC-Embedded-75mm. In the case of PVC-Embedded-100mm, there was a slight elevation in the maximum force to 2880.660 KN compared to Perforated-100mm at 2859.820 KN, indicating a load-bearing capacity increase of approximately 0.7%. The consistent trend of higher load-bearing capacities in PVC-Embedded columns, highlights their potential for improved structural integrity. Despite variations in load, the comparable displacements emphasize that PVC-Embedded columns, while accommodating slightly higher loads, exhibit consistent deformation behaviour across all lengths.

3.3 Comparison of Plastic Strains (LE) of PVC Embedded Columns and Perforated Columns without PVC

From Fig. 12, the average Plastic Strain of PVC-Embedded-50mm was approximately 0.0058 while that of Perforated-50mm was approximately 0.0067. The average plastic strains for both PVC-Embedded-50mm and Perforated-50mm columns indicate relatively small values, suggesting limited plastic deformation during loading. The slightly lower average plastic strain in PVC-Embedded-50mm imply a marginally more rigid response compared to Perforated-50mm.

Similarly, the average Plastic Strain of PVC-Embedded-75mm and Perforated-75mm were approximately 0.0085 and 0.0098. Again, the average plastic strains for both configurations reveal a similar decreasing trend, indicating a reduction in plastic deformation. The slightly lower average plastic strain in PVC-Embedded-75mm suggest a more restrained deformation response compared to Perforated-75mm.

Also the PVC-Embedded-100mm with average Plastic Strain of approximately 0.0020 and Perforated-100mm with average Plastic Strain of approximately 0.0027 also highlight minimal plastic deformation. The slightly lower average plastic strain in PVC-Embedded-100mm implies a more controlled deformation response compared to Perforated-100mm.

Across all column configurations, the average plastic strains consistently show a trend of lower values in PVC-Embedded columns compared to Perforated columns. This suggests that PVC-Embedded configurations tend to undergo, on average, less plastic deformation, indicating a potentially more robust and resilient behaviour.

The decreasing trend in average plastic strains with increasing diameter of embedded PVC pipes in columns suggests a potential tendency toward stabilization or reduced plastic deformation in columns with larger diameters.

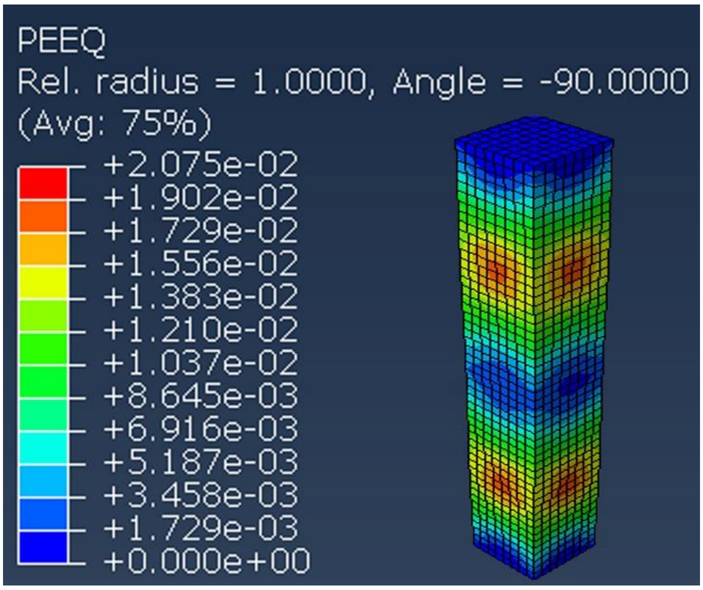


Fig. 9. Equivalent plastic strains (PEEQ)

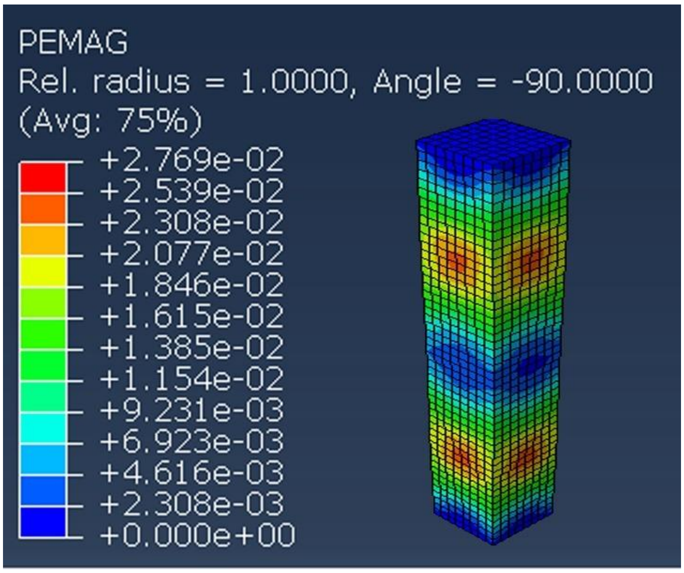


Fig. 10. Magnetic potential energy (PEMag)

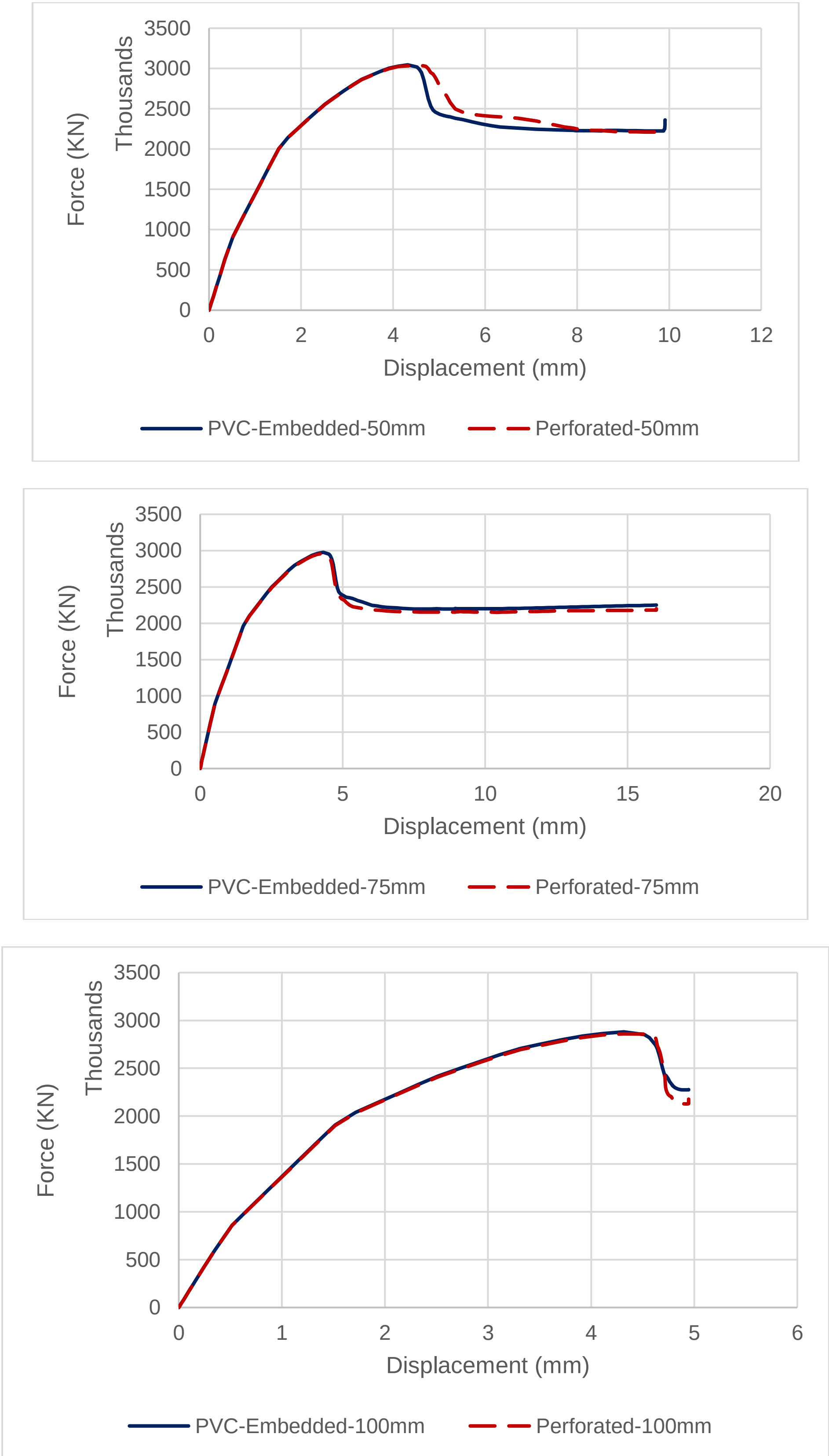
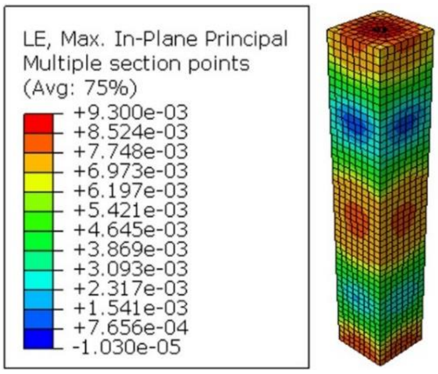
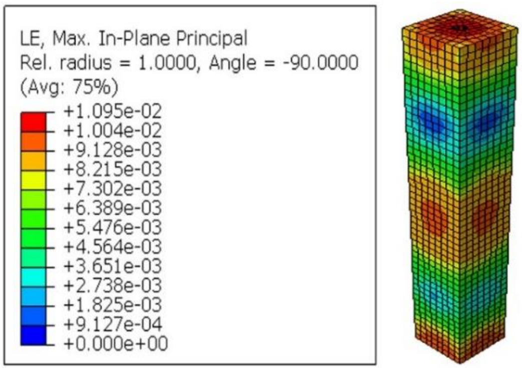


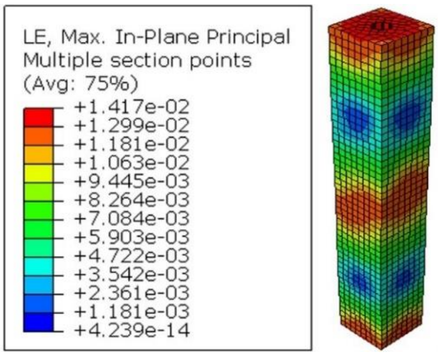
Fig. 11.Force-displacement relationship of PVC embedded columns and perforated columns without PVC



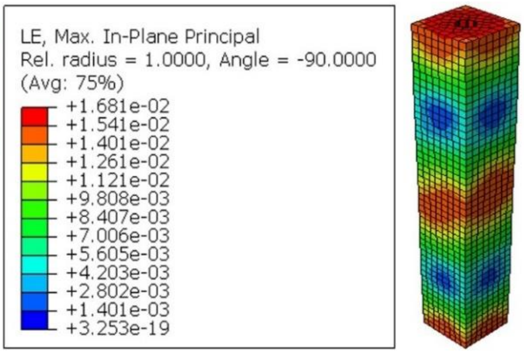
(a) PVC-Embedded-50mm



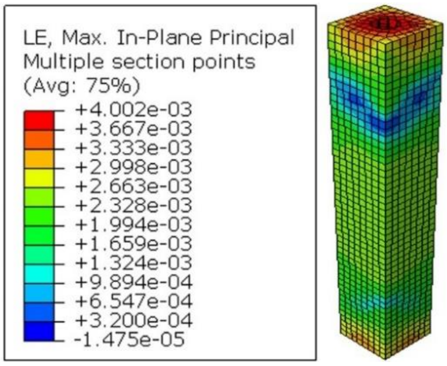
(b) Perforated-50mm



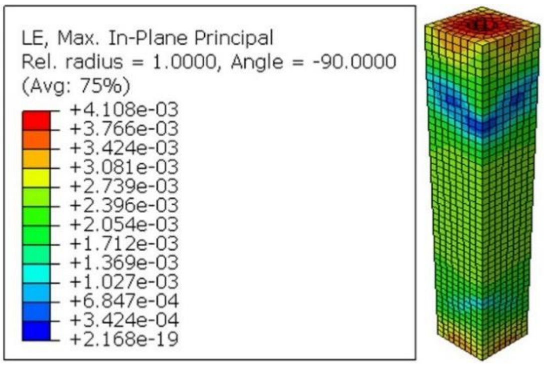
(c) PVC-Embedded-75mm



(d) Perforated-75mm



(e)PVC-Embedded-100mm



(f)Perforated-100mm

Fig. 12. Plastic strains (LE) of PVC embedded columns and perforated columns without PVC

3.4 Comparison of Equivalent Plastic Strains (PEEQ) of PVC Embedded Columns and Perforated Columns without PVC

In this section, the plastic deformation and energy dissipation aspects of columns across varying diameters are delved into. The averages of Equivalent Plastic Strains (PEEQ) in Fig. 13 were employed as a key metric for assessing structural performance.

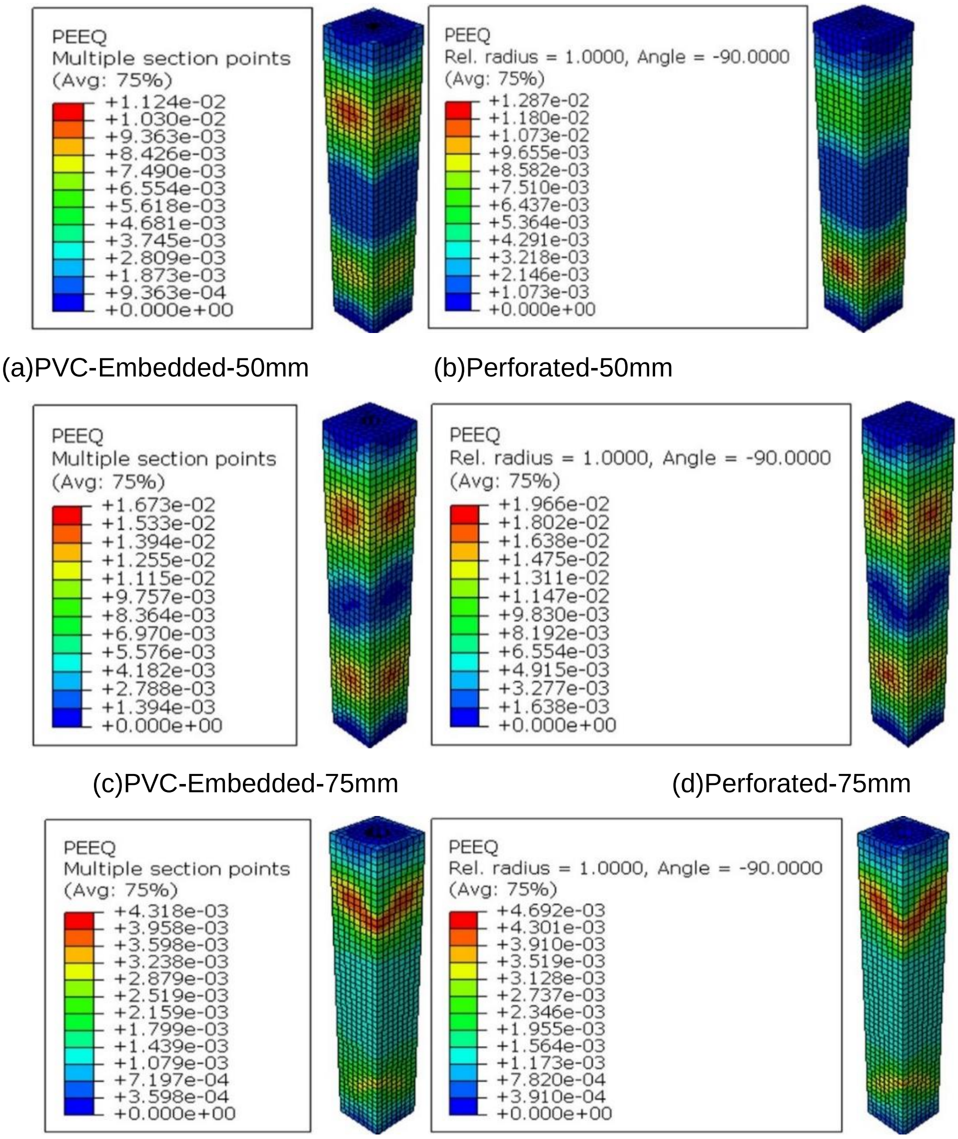
The PVC-Embedded-50mm configuration, with an average PEEQ of approximately 6.28E-03, displayed a marginally lower plastic deformation compared to the Perforated-50mm counterpart (average PEEQ of approximately 7.68E-03). This hints at a potential advantage for PVC-Embedded-50mm in terms of structural resilience.

The PVC-Embedded-75mm configuration exhibited a lower average PEEQ (approximately 8.71E-03) compared to the Perforated-75mm configuration (average PEEQ of approximately 1.17E-02). This suggests that PVC-Embedded-75mm columns may offer enhanced structural integrity.

Both PVC-Embedded-100mm and Perforated-100mm configurations demonstrated minimal average PEEQ values (approximately 2.62E-03 and 2.79E-03, respectively), indicating comparable structural stability and energy dissipation.

The results highlight the consistent advantage of PVC-Embedded configurations in terms of lower plastic deformation across all diameters and lengths. This suggests a potential for enhanced structural resilience in comparison to Perforated counterparts.

While Perforated columns exhibit a slightly more flexible response, the choice between configurations should align with specific project requirements. PVC-Embedded columns may be preferable for applications demanding higher structural integrity, whereas Perforated columns offer flexibility in scenarios where controlled deformation is acceptable.



(e)PVC-Embedded-100mm (f)Perforated-100mm

Fig. 13. Equivalent plastic strains (PEEQ) of PVC embedded columns and perforated columns without PVC

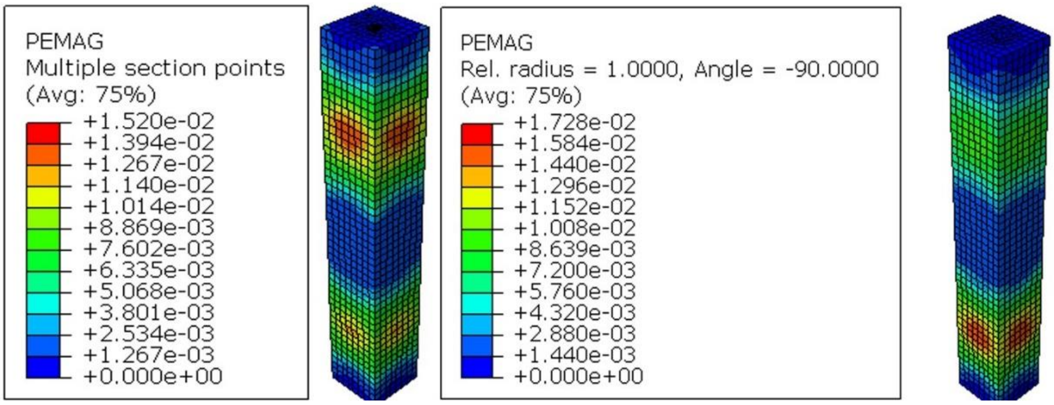
3.5 Comparison of Magnetic Potential Energy (PEMag) of PVC Embedded Columns and Perforated Columns without PVC

Fig. 14 highlights the differences in magnetic potential energy (PEMag) across various column configurations. The average PEMag of approximately 9.43E-03 for PVC-Embedded-50mm suggests a moderate level of magnetic potential energy, indicating a capacity for magnetic interactions within the material. However, with an average PEMag of approximately 1.09E-02, the Perforated-50mm configuration demonstrates slightly higher magnetic potential energy, indicating increased magnetic interactions within this particular design.

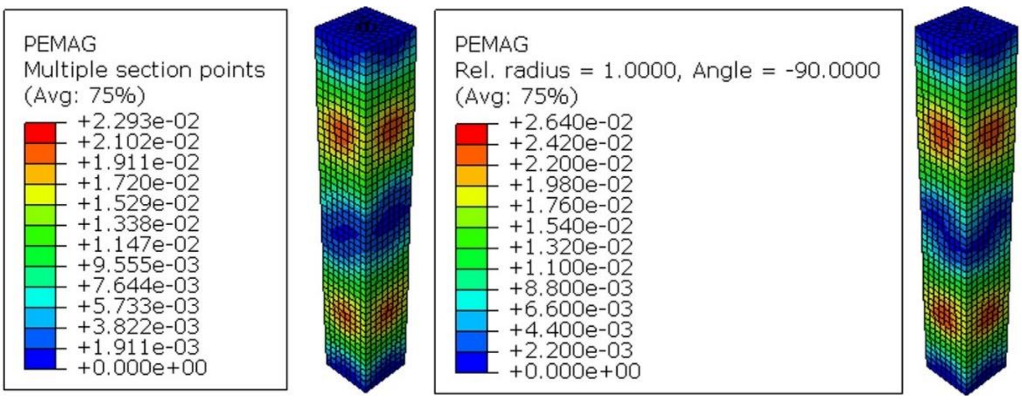
Displaying an average PEMag of approximately 1.55E-02, the PVC-Embedded-75mm configuration showcases enhanced magnetic interactions within its structure. The Perforated-75mm configuration, with an average PEMag of approximately 1.86E-02, exhibits slightly higher magnetic potential energy, reflecting increased magnetic interactions within this design.

Similarly, with an average PEMag of approximately 3.36E-03, the PVC-Embedded-100mm configuration shows a moderate level of magnetic potential energy, suggesting magnetic interactions within this specific design. Demonstrating an average PEMag of approximately 3.64E-03, the Perforated-100mm configuration indicates slightly higher magnetic potential energy, signifying increased magnetic interactions within this particular design.

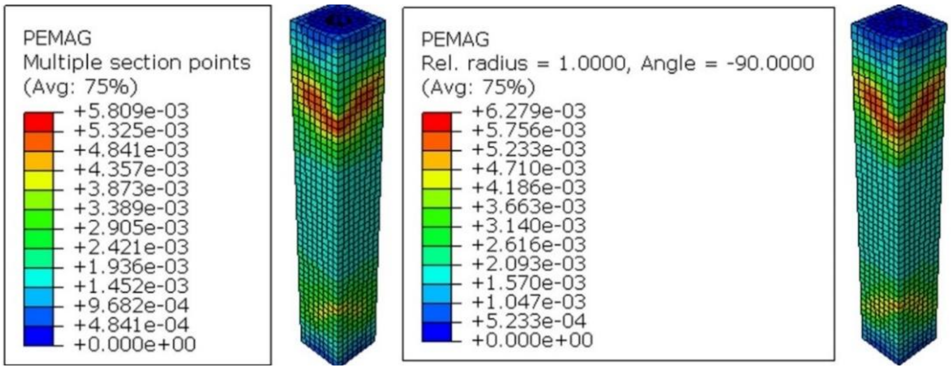
The variations in magnetic potential energy across different configurations underscore distinct levels of magnetic interactions within the columns. PVC-Embedded configurations generally exhibit moderate magnetic potential energy, indicating a balanced level of magnetic interactions within the material. In contrast, Perforated configurations, on average, show slightly higher magnetic potential energy, suggesting increased magnetic interactions within this design [13-18].



(a)PVC-Embedded-50mm (b)Perforated-50mm



(c)PVC-Embedded-75mm (d)Perforated-75mm



(e) PVC-Embedded-100mm (f) Perforated-100mm

Fig. 14. Magnetic potential energy (PEMag) of PVC embedded columns and perforated columns without PVC

4. CONCLUSION

1. The research findings unveiled a consistent pattern wherein PVC-Embedded columns consistently demonstrated superior load-bearing capacities and heightened structural resilience in comparison to hollow or perforated columns without PVC, spanning various diameters (50mm, 75mm, and 100mm). This observation is particularly pronounced in the specific instances of PVC-Embedded-50mm, showcasing a marginal load-bearing increase of approximately 0.2%, PVC-Embedded-75mm, indicating an improvement of about 0.5%, and PVC-Embedded-100mm, manifesting a load-bearing capacity increase of roughly 0.7%. These quantifiable values further reinforce the robustness and enhanced performance of PVC-Embedded columns across different dimensions.

2. The findings of plastic strains (LE), with a composite average of 0.00543 for PVC-Embedded columns and 0.00673 for Perforated columns, Equivalent Plastic Strains (PEEQ) with a composite average of 5.87E-03 for PVC-Embedded columns and 7.41E-03 for Perforated columns, and Magnetic Potential Energy (PEMag) with a composite average of 0.0091 for PVC-Embedded columns and 0.012 for Perforated columns, collectively suggest that the presence of PVC pipes positively influences the columns' ability to deform with limited plastic strain and dissipate energy efficiently. PVC-Embedded columns, while maintaining structural stability, tend to offer a more controlled and resilient response under loading conditions compared to Perforated columns without PVC. The observed patterns in plastic strains, equivalent plastic strains, and magnetic potential energy underscore the importance of PVC pipes in enhancing the overall performance and behavior of the columns during loading scenarios.

3. The research findings reveal a consistent trend where PVC-Embedded columns consistently exhibit superior load-bearing capacities and heightened structural resilience compared to hollow or perforated columns without PVC, spanning various diameters (50mm, 75mm, and 100mm). Notably, this trend is evident in specific instances such as PVC-Embedded-50mm, showing a marginal load-bearing increase of approximately 0.2%, PVC-Embedded-75mm, indicating an improvement of about 0.5%, and PVC-Embedded-100mm, manifesting a load-bearing capacity increase of roughly 0.7%. These quantifiable percentages further emphasize the robustness and enhanced performance of PVC-Embedded columns across different dimensions, supporting the conclusion that smaller sizes of embedded PVC pipes result in better performance in terms of load-bearing capacity, as observed in the Force-displacement relationship.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nilson AH, Darwin D, Dolan CW. Design of Concrete Structures (14th ed.). McGraw-Hill Education; 2010.
2. Ambrose J, Tripeny P, Ambrose B. Simplified Engineering for Architects and Builders (11th ed.). Wiley; 2010.
3. Rajkumar A, Madhavaraj K. Behaviour of Concrete Filled PVC Plastic Tubes (CFPT) Placed in Columns; 2016.
4. Hussien A. Numerical Investigation On the Effects of Embedding PVC Pipes in Reinforced Concrete Beams. Afribary. Accessed on [March 20, 2023]; 2019. Available:https://afribary.com/works/numerical-investigation-on-the-effects-of-embedding-pvc-pipes-in-reinforced-concrete-beams
5. Najafabadi SHM. Experimental study of reinforced concrete columns with embedded pipe: University Teknologi Malaysia; 2010.
6. Kani GN. Effect of Size and Shape of Hollow Concrete Column on Strength. International Journal of Scientific and Research Publications. 2013;3(10):1-4.
7. Elmaguid MA, El-Salakawy EF, Rizkalla SH. Hollow reinforced concrete columns: A review of research developments. Journal of Materials in Civil Engineering. 2021;33(1):04020306.
8. Basravi A. Finite element analysis of reinforced concrete column with longitudinal hole. Faculty of Civil Engineering Universiti Teknologi Malaysia; 2010.
9. Abaqus/CAE. Abaqus 6.11 Analysis user's manual (Elements) (Vol. IV). RI, USA: Dassault system simulia corporation; 2020.
10. Elkady A. "ABAQUS_CDP Generator: A tool for generating concrete damage parameters for ABAQUS" Zenodo, Version v23.04; 2023. DOI: 10.5281/zenodo.7755926
11. Elkady A. "ABAQUS_SteelMat_Generator: A tool for generating metal plastic and damage parameters for ABAQUS" Zenodo, Version v23.04; 2023. DOI: 10.5281/zenodo.7756886
12. Mosley WH, Bungey JH, Hulse R. Reinforced concrete Design, New York: Palgrave; 1999.
13. ACI 318. ACI 318-14. Building Code Requirements for Structural Concrete. Farmington Hills, Michigan.: American Concrete Institute; 2014.
14. Ayatullah Khomeni M. Experimental investigation and numerical simulation. Master of Science in Civil Engineering (Structural), Bangladesh University of Engineering & Technology, Department of Civil Engineering, Dhaka; 2018.
15. BS 8110. Structural Use of Concrete, Part:1 Code of Practice for Design and Construction, Part 2: Code of Practice for Special Circumstances. London, U.K: British Standards Institution; 1997.
16. Elwell DJ, Fu G. Compression testing of concrete: Cylinders vs. cubes; 1995.
17. Kim NH. Introduction to Nonlinear Finite Element Analysis. Gainesville, F L, USA; 2014. DOI:10.1007/978-1-4419-1746-1
18. UPVC high pressure pipes & fittings. (n.d.). Accessed on [November 21, 2023], Available:https://5.imimg.com/data5/SELLER/Doc/2020/10/TG/BL/QZ/650416/upvc-pipes.pdf

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/113832