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Experimental Analysis of Axially Compressed Precast Concrete Pressure Pipes Filled with Concrete

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Abstract

Humanity has always been at the mercy of natural disasters, which frequently result in widespread devastation and displacement. However, scientific advancements, technological innovations, and extensive research have significantly mitigated the loss of life, property, and essential resources. One of the critical challenges in the aftermath of disasters is providing adequate and timely shelter, food, and medicine to the affected populations, often under constrained resources and logistical difficulties. In response to these pressing needs, current research has increasingly focused on developing efficient, economical, and sustainable solutions for emergency shelters. The innovative columns being tested in this project represent a breakthrough in disaster management solutions. These cost-effective structural components do not require highly skilled labour for their construction, making them ideal for deployment in disaster-affected regions where resources and expertise are often scarce. Furthermore, these columns are designed to be exceptionally durable, versatile, and long-lasting, ensuring they can withstand substantial loads, extreme environmental conditions, and natural stresses. The overarching goal of this project is to bridge the gap between temporary emergency shelters and permanent infrastructure by providing a scalable and adaptable solution. These columns not only simplify and accelerate the construction process but also enhance the structural integrity of shelters, enabling the rapid and resource-efficient development of essential infrastructure. Consequently, they offer a promising long-term solution for disaster relief, empowering communities to recover and rebuild more effectively and sustainably in the aftermath of natural disasters.

Keywords: Natural disasters, emergency shelters, disaster relief, innovative columns, cost-effective construction, durable infrastructure, sustainable solutions, post-disaster recovery, rapid construction, load-bearing structures, resource efficiency, temporary to permanent housing, structural integrity, disaster management

INTRODUCTION

Precast concrete pressure pipes are a vital component in modern infrastructure, commonly employed for water distribution, wastewater management, and industrial applications. These pipes are favoured for their durability, structural strength, and resistance to environmental degradation. However, the increasing demands placed on infrastructure necessitate innovative approaches to improve the structural performance of these systems, particularly under axial compression, a critical load scenario often encountered in practice.

The structural behavior of precast concrete pipes under axial compression has garnered significant attention from researchers and engineers alike. Axial compression occurs in scenarios such as pipe culverts subjected to earth and vehicular loads or during handling and installation. Understanding and

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improving the axial load-carrying capacity of these pipes is crucial to ensuring their reliability and longevity. One promising method to enhance their performance is filling the pipes with concrete, which can provide additional confinement and increase their load-bearing capacity [1, 2].

Background and Motivation

The structural integrity of precast concrete pressure pipes is primarily governed by their ability to withstand combined loading conditions, including axial, radial, and bending stresses. Traditional design approaches often focus on optimizing the pipe geometry, material properties, and reinforcement layout. However, these approaches may not fully address the demands of high axial loads encountered in certain applications. Filling the pipes with concrete represents a practical and cost-effective solution to enhance their structural capacity without requiring significant changes to manufacturing processes [3].

Several studies have explored the structural performance of hollow precast concrete pipes under various loading conditions. However, limited research has been conducted on the experimental behavior of these pipes when filled with concrete and subjected to axial compression. This knowledge gap underscores the need for a systematic investigation to evaluate the potential benefits and limitations of this technique. By understanding the behavior of concrete-filled precast pressure pipes, engineers can develop design guidelines that optimize their performance and ensure safety in critical applications [4].

LITERATURE REVIEW

The mechanical behavior and performance of axially compressed precast concrete pressure pipes filled with concrete have been extensively studied through various experimental and theoretical frameworks. The Bureau of Indian Standards (BIS), in IS 458:2003, provides the foundational guidelines for precast concrete pipes, addressing both reinforced and unreinforced varieties. This standard emphasizes the importance of material properties, quality control, and production processes to ensure structural integrity under compressive loads. By establishing benchmarks for durability and strength, these guidelines serve as a reference for experimental investigations of precast concrete pressure pipes subjected to axial compression [5-7].

A significant body of research focuses on the enhanced performance of concrete-filled tubular structures under axial loads due to confinement effects. Nonlinear analyses of axially loaded concrete-filled tube (CFT) columns have demonstrated the substantial increase in load-carrying capacity and ductility provided by confinement. Theoretical stress-strain models for confined concrete integrate the effects of lateral confinement in predicting structural behavior. Empirical and triaxial stress-strain data have been used to validate these theoretical models, underscoring the vital role of confinement in improving the strength and ductility of concrete-filled structures, which is critical for the design and analysis of precast pressure pipes [8-10].

Foundational studies on failure mechanisms and stress-strain behavior offer essential insights into the performance of concrete under combined stress states. Early theoretical models remain relevant for analyzing complex stress conditions in pressure pipes. Subsequent research expanded on these models by proposing failure theories and design criteria tailored for plain concrete, emphasizing safety and reliability in structural applications. These theories are complemented by compression field modeling approaches, which combine experimental data and simulations to predict the behavior of confined concrete under axial loads [11].

Further studies delve into the structural behavior and optimization of concrete-filled tubular systems. Research has highlighted the composite action between concrete and steel in concrete-filled steel tubes, demonstrating how this interaction significantly improves axial load capacity and stiffness. Investigations into rectangular CFT stub columns with binding bars showcase the role of binding in improving load distribution and delaying failure. Studies examining the effects of geometric and material parameters, such as length-to-diameter ratio and concrete strength, on the axial capacity and efficiency of CFT columns provide a comprehensive framework for optimizing the design of concrete-filled pressure pipes [12].

In summary, the reviewed literature collectively emphasizes the critical importance of confinement, stress-strain relationships, and composite action in understanding and enhancing the performance of concrete-filled structures. The integration of theoretical models, empirical data, and computational analyses offers a robust foundation for investigating the behavior of precast concrete pressure pipes under axial loads. These insights guide the experimental and design approaches necessary for improving the structural performance and safety of these systems, ensuring their suitability for diverse applications [13].

METHODOLOGICAL APPROACH

To achieve the research objectives, a series of controlled laboratory experiments will be conducted on precast concrete pressure pipes. The experimental program includes the fabrication of precast concrete pipes with varying diameters, wall thicknesses, and reinforcement configurations, including both hollow and concrete-filled specimens. Concrete materials will be tested to determine their mechanical properties, such as compressive strength. Axial compressive loads will then be applied using a universal testing machine (UTM) to evaluate the load-carrying capacity and deformation behavior of the pipes. Finally, the experimental results will be analyzed to identify performance trends and establish empirical relationships. This methodological approach ensures a comprehensive understanding of the behavior of concrete-filled precast pipes under axial compression, enabling the derivation of practical recommendations for their design and application.

SPECIMEN DETAILS

Total 30 number of specimen of precast concrete pressure pipes with the average diameters (D) of 200 mm and 250 mm were cut in 900 mm length (L). The wall thickness (t) of precast pipes was 30 mm and 35mm for P2 and P3 pipes respectively. A Nomenclature like 200M25P2S1 is used. 200 stand for diameter of pipe, M25 stand for grade of concrete, P2/P3 stand for type of pipe used and S1 indicates first specimen. Three Grade of concrete M25, M30, M45 were prepared as per code IS: 10262–1982 (Reaffirmed -2004) to fill the precast pipes. The compressive strength testing of sample was performed on INSTRON make UTM machine having capacity of 250tn. In this experiment load was applied only on the concrete core of Specimen with the help of metal spacer of specific dimension equal to the specimens' inner diameter. The experiment was performed on displacement control method with a loading rate of 0.4 mm/min. the bottom jaw of machine was stationary while the upper jaw moved in downward direction. The test setup used for performing experiment is shown below Figures 1-3.

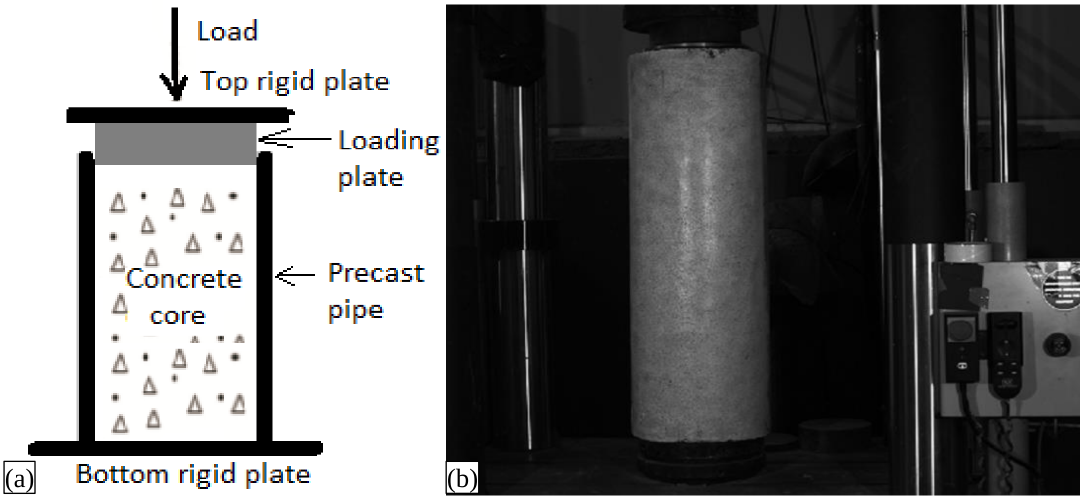

Figure 1. Experimental setup. (a) Diagrammatical representation of experimental setup; (b) Actual experimental setup.

Figure 2. Specimen before and after preparing concrete core. (a) Specimen before preparing concrete core; (b) Specimen after preparing concrete core.

Figure 3. Compresive testing machine and casted cubes. (a) Compresive testing machine; (b) Casted cubes.

Before Filling of Concrete core, we performed some test for concrete Strength of different grades, for that we casted six numbers of 150x150x150mm simultaneously at the time of casting of Test Specimen to confirm the strength of the concrete being used for the experiment. After 28 day of curing; cubes were taken out of water and dried gently with the help of cloth. After that, sample was tested by 200 ton capacity cube testing machine. The load was applied until the cube was broken down. The maximum reading was noted Table 1. The test setup is shown in below Figure 3.

RESULTS

Failure Pattern for Sample Having Diameter 200 mm

Test was conducted under gradual loading rate of about 0.4m/min. All the data (i.e. Deflection and Axial Load) was recorded in data logger afterwards using this data load vs deflection graph was plotted in MS Excel. All the six specimens have shown a similar type of failure. The samples have primary failed due to loss of confinement being provided to the inner concrete core from the external pressure concrete pipe. Cracks were observed along the complete height of the confining concrete pipe. The cracks were originated from the reaction plate side of the sample. The average deflection observed were 0.65% reduction in height of the inner concrete core at peak load. Though the failure pattern of P2 & P3 pipe is almost similar but failure load for P3 pipe was far more than that for P2, main reason for which is percentage of steel used in P3 pipe is higher than that in P2 Figures 4 and 5.

Table 1. Detail of grade of concrete.

Grade of concrete	Water (Kg/m^3)	Cement (Kg/m^3)	Sand (Kg/m^3)	Aggregate (Kg/m^3)	Super plasticizer (l/m^3)	Cylinder Strength F_c
M25	203	361	721	1157	-	25.08
M30	202	479	638	1145	-	39.04
M45	148	478	530	860	0.84	47.84

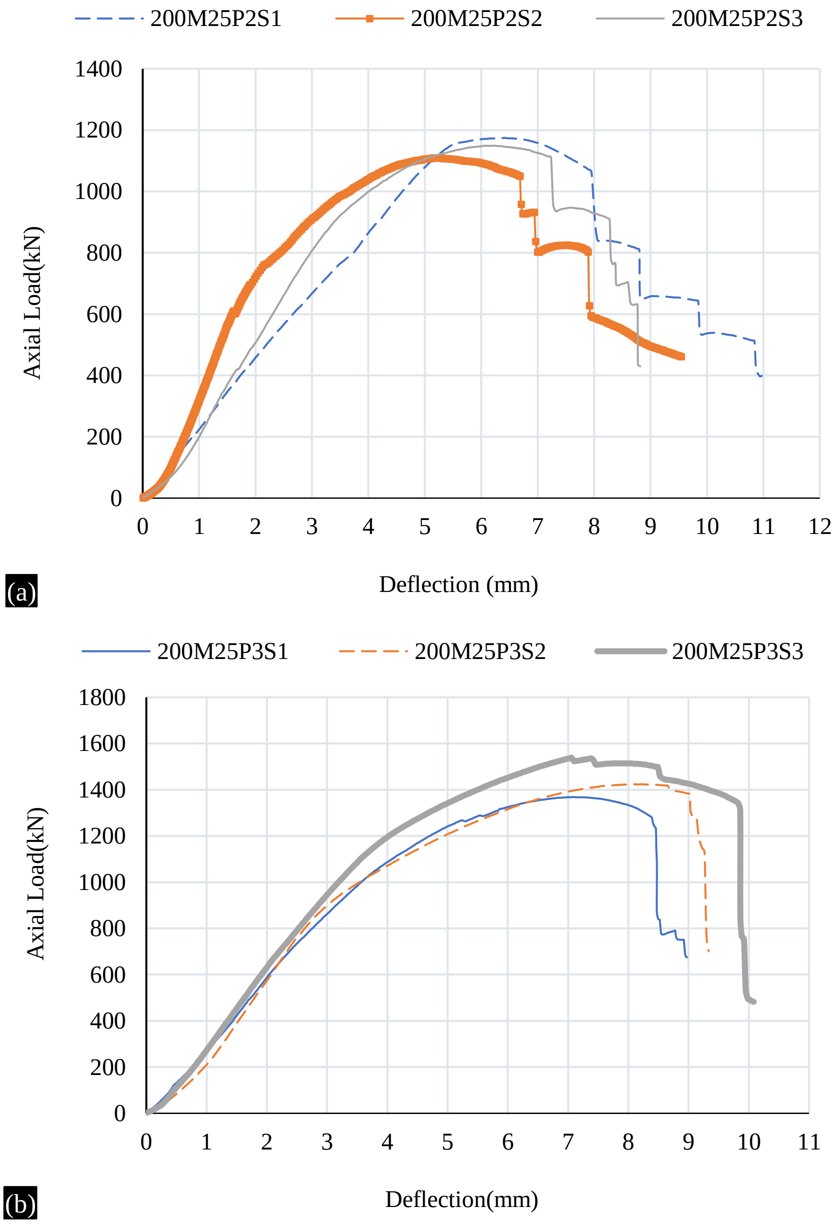

Figure 4. (a and b) Load vs Deflection graphs for M25 grade of concrete samples.

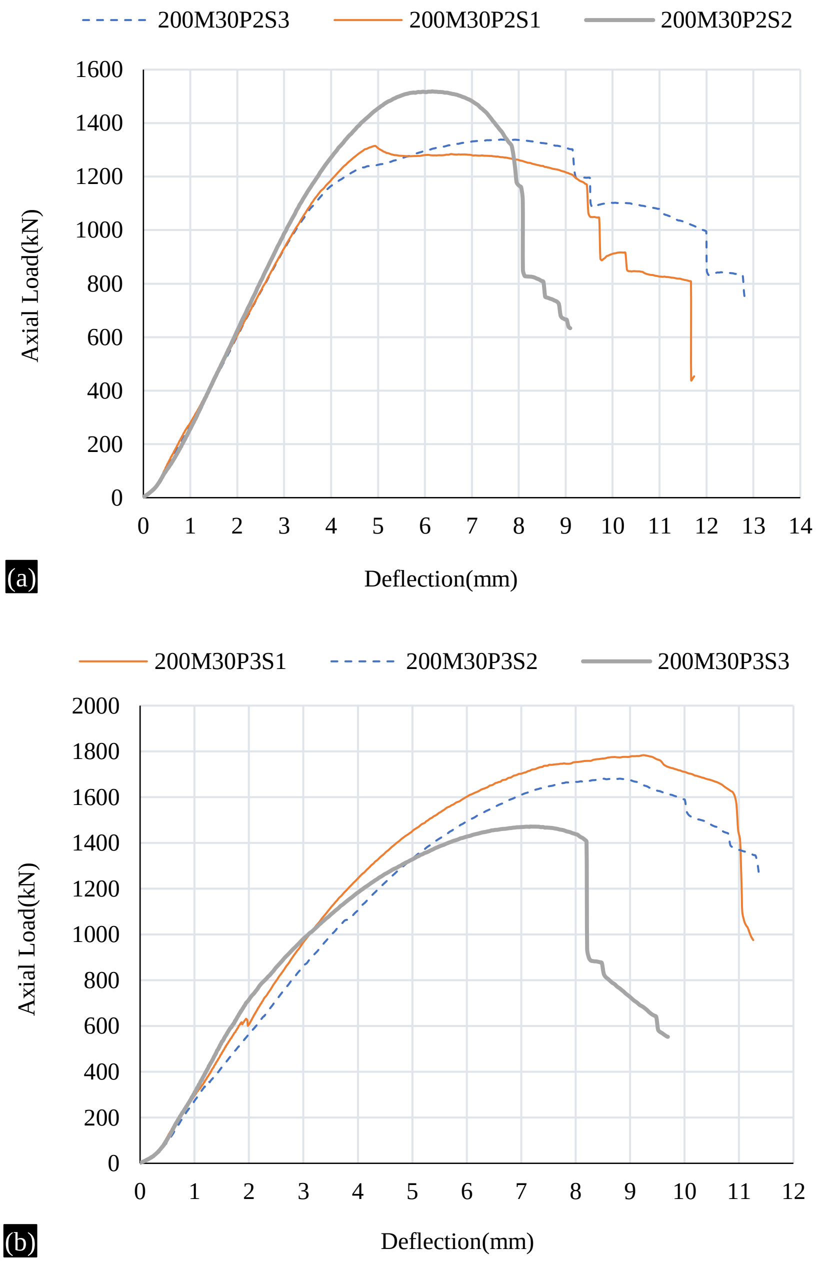

Figure 5. (a and b) Load vs Deflection graphs for M30 grade of concrete samples.

All the six specimens have shown a similar type of failure. The samples have primary failed due to loss of confinement being provided to the inner concrete core from the external pressure concrete pipe. Cracks were observed along the complete height of the confining concrete pipe. The cracks were originated from the reaction plate side of the sample. The average deflection observed is 0.65% reduction in height of the inner concrete core at peak load and average increase of 33% and 57% in the compressive strength in P2 and P3 type of Pipes are observed Figure 6.

All the six specimens have shown a similar type of failure. The average deflection observed was 6.52 mm i.e. 0.65% reduction in height of the inner concrete core at peak load Enhancement in the strength, ductility and energy absorption capacity observed was lower than samples with M25 and M30 grade concrete. Average increase of 24% and 39% in compressive strength of P2 and P3 respectively was observed. Percentage increase of compressive strength is lower in case of M45 series of samples as compared to M25 and M30 series of samples Figures 7 and 8.

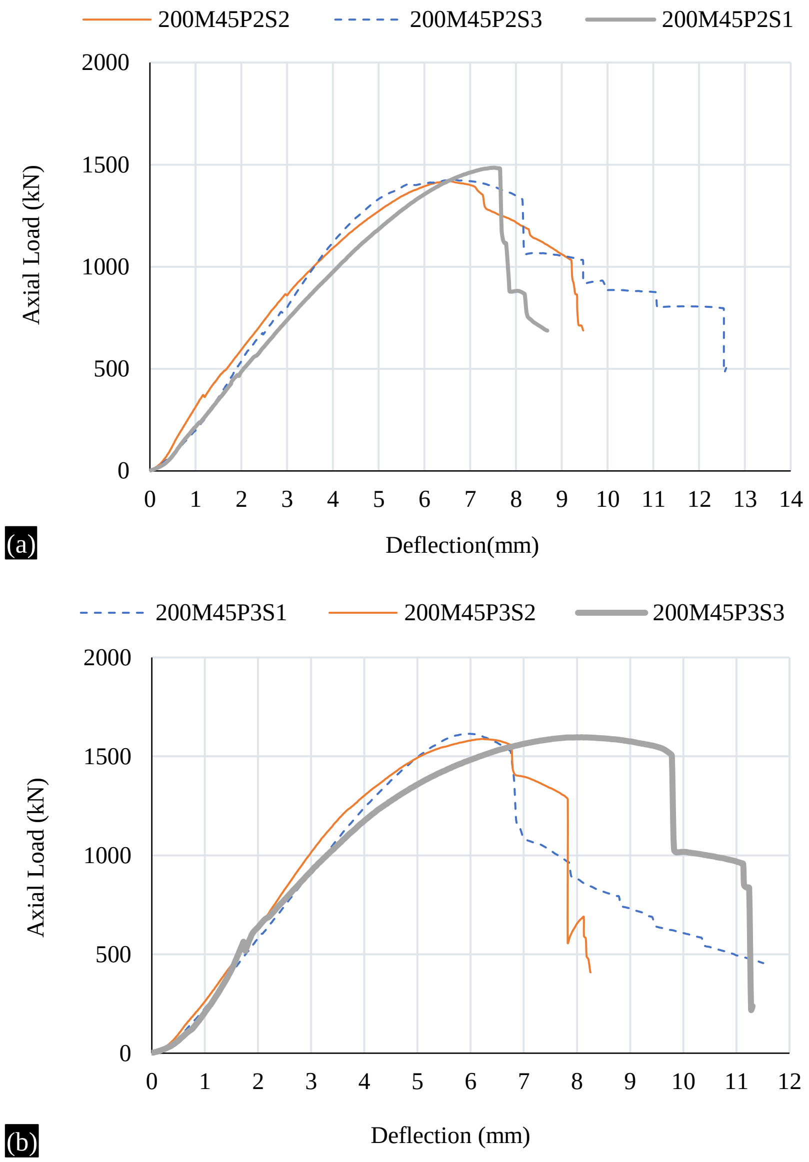

Figure 6. (a and b) Load vs Deflection graphs for M45 grade of concrete samples.

Figure 7. Failure pattern of samples.

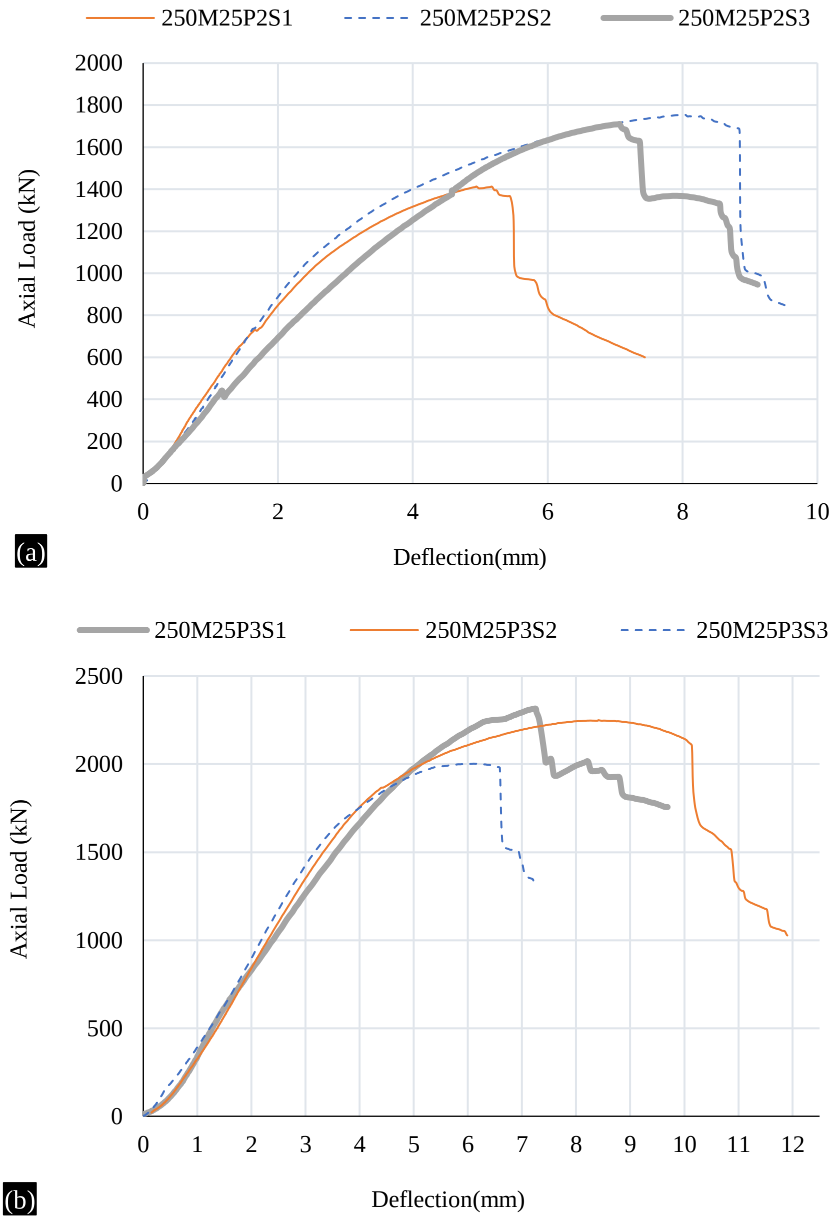

Figure 8. (a and b) Load vs Deflection graphs for M25 grade of concrete samples.

Failure Pattern for Sample Having Diameter 250 mm

All the six specimens have shown a similar type of failure. The samples have primary failed due to loss of confinement being provided to the inner concrete core from the external pressure concrete pipe. Cracks were observed along the complete height of the confining concrete pipe. The cracks were originated from the reaction plate side of the sample. Large enhancement in the strength, ductility and energy absorption capacity was observed. Average increase of 45% and 87% in compressive strength of P2 and P3 respectively was observed. P3 pipes were providing exceptionally good confinement Figure 9.

All the six specimens have shown a similar type of failure. The samples have primary failed due to loss of confinement being provided to the inner concrete core from the external pressure concrete pipe. Cracks were observed along the complete height of the confining concrete pipe. The cracks were originated from the reaction plate side of the sample. Average increase of 37 in compressive strength of P2 pipe was observed Figure 10.

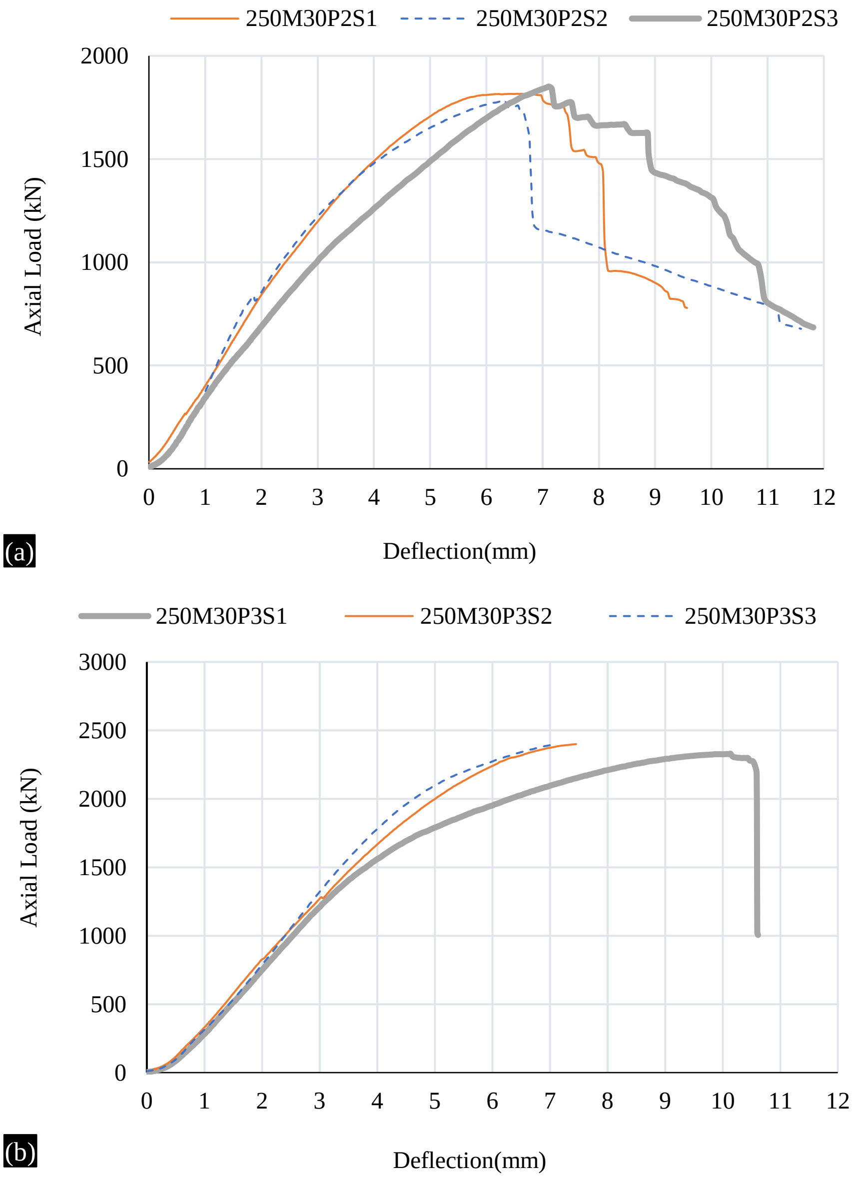

Figure 9. Load vs Deflection graphs for M30 grade of concrete samples.

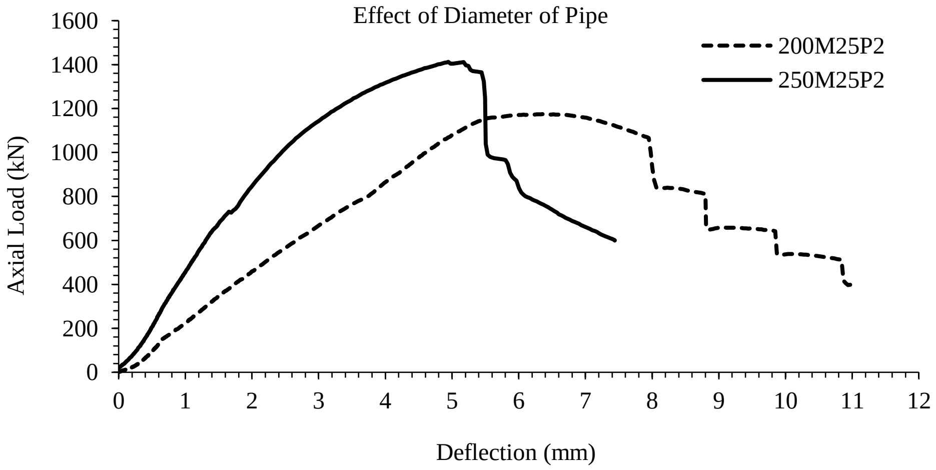

Figure 10. Effect of diameter of pipe.

250M25P2 is taking higher load as compared to 200M25P2, confinement provided by P2 pipes is not enough for making failure of 250 mm dia. pipe gradual. In 250M25P2 pipe failure of inner concrete core and confining pipe was at the same time, there was very little help from outer pipe to prevent its sudden failure. Failure curve of 200M25P2 is of ladder type which may be due to the failure of wire in pipe one by one.

CONCLUSION

The experimental investigation conducted in this study analyzed two types of precast concrete pressure pipes, P2 and P3, used as confining jackets under axial compression. A total of 30 samples were prepared, with the concrete cores filled using three different grades of concrete: M25, M30, and M45. Load was applied directly to the concrete core during the experiments. The observed failure patterns differed between the two pipe types: P2 pipes exhibited "elephant foot" type bulging, while P3 pipes failed in a shear mode. The results demonstrated that precast concrete pressure pipes provide effective confinement, with P2 and P3 pipes increasing the load-carrying capacity by an average of 15 MPa and 25 MPa, respectively. Additionally, the pipes enhanced both the ultimate load capacity and ductility of the specimens. The average deflection recorded was a 0.66% reduction in the height of the inner concrete core at peak load. Notably, P2 pipes exhibited a gradual failure pattern after reaching peak load, characterized by a ladder-type load-displacement curve, unlike the sudden failure observed in unconfined concrete. This behavior is attributed to the sequential fracture of the wires in the pipe, which provides a warning before failure.

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