# AN EXPERIMENTAL STUDY ON PERFORMANCE OF PRECAST STRUCTURE WALL SLAB UNDER REVERSE-CYCLIC LOADING

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## Abstract:

The performance of precast concrete wall slabs under reverse cyclic loading is a critical concern in seismic engineering, as these elements play a key role in the lateral load resistance of structures. This research aims to thoroughly investigate the structural behaviour of these wall slabs when subjected to such loading conditions. The primary objectives include examining the load-deformation behaviour, strength, stiffness, and ductility of the slabs. By conducting a series of reverse cyclic loading tests, the study will provide detailed insights into the structural performance and resilience of precast concrete wall systems.

Additionally, this study seeks to understand the crack propagation and failure mechanisms in precast concrete wall slabs. Observing the development and progression of cracks during loading cycles will help identify the factors contributing to potential structural failures. This will aid in improving the design and construction practices for enhanced durability and safety.

Furthermore, the research will evaluate the influence of key parameters such as reinforcement ratio, concrete strength, and connection details on the overall performance of the slabs. By systematically varying these parameters, the study will identify the optimal configurations that maximize the structural efficiency and seismic resilience of precast concrete wall slabs.

The experimental approach involves preparing and testing a series of precast concrete wall slabs with different reinforcement ratios, concrete strengths, and connection details. The slabs will be subjected to reverse cyclic loading, simulating seismic conditions, to evaluate their load-deformation behaviour and overall performance. Advanced instrumentation and monitoring techniques will be employed to capture detailed data on crack propagation, failure mechanisms, and structural responses.

In addition to the experimental investigations, numerical modelling and simulations will be conducted to further analyse the behaviour of the slabs. These computational models will help validate the experimental results and provide deeper insights into the complex interactions between various parameters. The combined experimental and numerical approach will ensure a comprehensive understanding of the structural performance of precast concrete wall slabs.

The findings from this study will contribute valuable knowledge to the field of seismic engineering, enabling the design of more robust and resilient precast concrete wall systems. This research will ultimately aid in enhancing the safety and performance of buildings in earthquake-prone regions, providing engineers and designers with critical information for optimizing the design and construction of precast concrete structures.

## 1.Introduction:

Precast construction involves prefabricating structural members in a factory and assembling them on-site. This technique has been growing steadily due to its efficiency and quality control. Precast connections are critical as they influence the overall seismic performance of the structure, particularly in shear wall and slab connections.

Various types of precast connections have been studied, including emulative, dry, welded, and bolted connections. Wet connections involving dowel bars, shear keys, and interface friction are

common for transferring horizontal forces between members. The energy dissipation and ductility of precast connections have shown to be comparable or superior to cast-in-situ connections.
Finite Element (FE) modelling has been widely used to predict the performance of precast connections under seismic loading. Software such as ABAQUS allows for detailed simulation of the nonlinear behaviour of concrete using models like the Concrete Damaged Plasticity (CDP) model. The accuracy of FE models in predicting experimental results has been validated in various studies.
Several studies have focused on specific aspects of precast wall-slab connections. For instance, Soudki et al. (1996) examined the use of reinforcement and shear keys, while Feng et al. (2016) analysed the performance of grouted sleeve connections. The research by Arthi and Jaya (2020) adds to this body of work by providing experimental data and FE analysis on dowel connections, demonstrating their effectiveness in dissipating energy and maintaining ductility under cyclic loading.

## 2. Methodology:

**2.1. Preparation of Precast Concrete Wall Slab:**

Preparing precast concrete involves mixing concrete, reinforcing it with rebar, and curing it. The process also includes inspecting the concrete for defects and ensuring it's cured enough for surface preparation.

**2.2. Mixing Concrete: Concrete as the Primary Raw Material:**

- The quality of precast concrete is heavily influenced by the raw materials used. The concrete mix consists of cement, water, sand, and aggregates like gravel or crushed stone.

- **Concrete Mix Design:**
  - The mix design determines the proportions of each ingredient to achieve the desired properties, such as strength, durability, and workability. ○ Additives or admixtures (e.g., plasticizers, accelerators) may be included to enhance specific properties.
- **Production Process:**
  - Ensuring a consistent mix is vital. This is typically achieved using automated batching and mixing equipment.
  - The process impacts not only the quality but also the production speed, as a well-designed mix can reduce setting and curing times.

**2.3 Reinforcing with Rebar:**

- **Rebar Addition:**
  - Reinforcement is crucial for the structural integrity of the slab. Steel rebar (reinforcing bars) is placed within the mould before pouring the concrete.
  - The placement of rebar follows specific patterns and spacing to provide optimal strength and support.

- **Controlled Environment:**
    - This process occurs in a controlled environment, typically within a precast plant. This ensures precise placement and adherence to design specifications, minimizing variables that could affect quality.

- **Curing:**

- **Importance of Curing:**
    - Curing is a critical step that affects the final strength and durability of the concrete. It involves maintaining adequate moisture, temperature, and time to allow the concrete to fully hydrate.
- **Curing Methods:**
    - Several methods can be used, including water curing (keeping the surface wet), steam curing (using steam to maintain temperature and humidity), and applying curing compounds (which form a seal to retain moisture). ○ The chosen method influences the concrete's properties, such as surface hardness, permeability, and overall strength.

**Inspecting Concrete:**

- **Inspection Before Surface Preparation:**
    - Thorough inspection is essential to identify defects, such as cracks, voids, or surface imperfections. This can involve visual checks, non-destructive testing (e.g., ultrasonic testing), and moisture content analysis.
    - Ensuring the concrete has cured adequately prevents damage during surface preparation, where excessive grinding or treatment could compromise the slab's integrity.
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# 3. Experimental Investigations On Precast Structural Wall Slab

## 3.1 Precast specimens

The precast specimens consist of four parts namely prefabricated structural wall upper panel, lower panel, precast slab and screed concrete (cast-in-situ concrete). The specimens P1 and P2 was without nib portion. One-third scaled down dimensions of the precast specimens. Two connections were made in the precast specimens. Dowel connection was used for the connection between structural wall lower panel- precast slab and lower panel-upper panel in P1, and P2. Two numbers of 6mm diameter and five numbers of 10mm diameter Reinforcement bars are used for casting. The connection detailing of the two types of precast specimens. The reinforcement details of precast specimens.

The connections proposed in this study, half of the slab was precast and remaining portion was cast during the erection stage by connecting with the top reinforcement of the slab. Therefore, Screed concreting was done for the connection between wall and slab. If the precast elements are uneven, it will be more difficult for erecting the structural members on site. It was not possible to achieve proper connection between the elements. Therefore, quality of construction should be properly maintained starting from the casting process till the erection stage as follows:

- It is necessary to finalize the design at early stage itself because changes in design may lead to substantial abortive works and affect the construction process on site.
- Before concreting, covers and reinforcement should be checked and while casting, factors like details of mix proportions, consistency of the mix etc should be maintained properly.
- All the prefabricated members should be checked to meets quality standards, thereby preventing installation of poorly constructed or damaged units. Therefore, precast elements must be inspected thoroughly prior to installation.

The main challenge faced in this study was fixing duct in the upper panel in order to provide housing for the protruding dowel bars from the lower panel. The dimensions and the surface appearance are the major concerns in this work. Therefore, proper inspection has been carried out while preparing the reinforcement cage that is, the spacing of dowel bars in lower panel should be exactly matched with the spacing of duct provided in the upper panel. Most importantly, care has been taken in order to achieve straightness of duct provided in the upper panel. Because due to the self-weight of the concrete, there is a chance for duct to bend while casting and finally leads to the difficulty during erection process.

## 3.2 Casting Of Specimens

**Preparation of Formwork:** The formwork was prepared for the required shape and size of the monolithic and precast specimens. The reinforcements cage was placed inside the formwork and the concrete are cast. 12mm thick plywood was used for the preparation of formwork for the specimens and adequate support was given by using the runners and clamps in order to prevent bulging of the mould while casting and to maintain the required dimension of the specimen. Duct was placed inside the precast upper panel formwork to create housing for inserting the dowel bars from the lower panel. Oil was applied at the inner face of the formwork and cover blocks were placed inside the mould before placing the reinforcement cages.

**Fig.3.1 Plywood Mould for Precast wall Slab**

**Design Mix** All the specimens were cast with M-30 grade of concrete. They were cast with ordinary Portland cement (OPC) with maximum size of aggregate 10mm and river sand passing through

4.75mm IS Sieve used as a fine aggregate. Three control cubes (150 mm X150 mmX150 mm), Cylinders (150 mm diameter and 300 mm height) were cast and demoulded after 24 hours and then cured for 28 days. The cubes were tested on 28$^{th}$ day and the average compressive strength ($f_{ck}$) of the cube obtained was 39.2 N/mm$^2$ cylinder compressive strength was calculated by $f_c = 0.8(f_{ck})$ where f average compressive strength of concrete and obtained as 31.36 N/mm$^2$.

Reinforcing steel Tensile strength of reinforcements was tested using universal testing machine (UTM). Stress strain curve Fe 500 reinforcing steel bar used in this study was obtained by plotting tension test data.

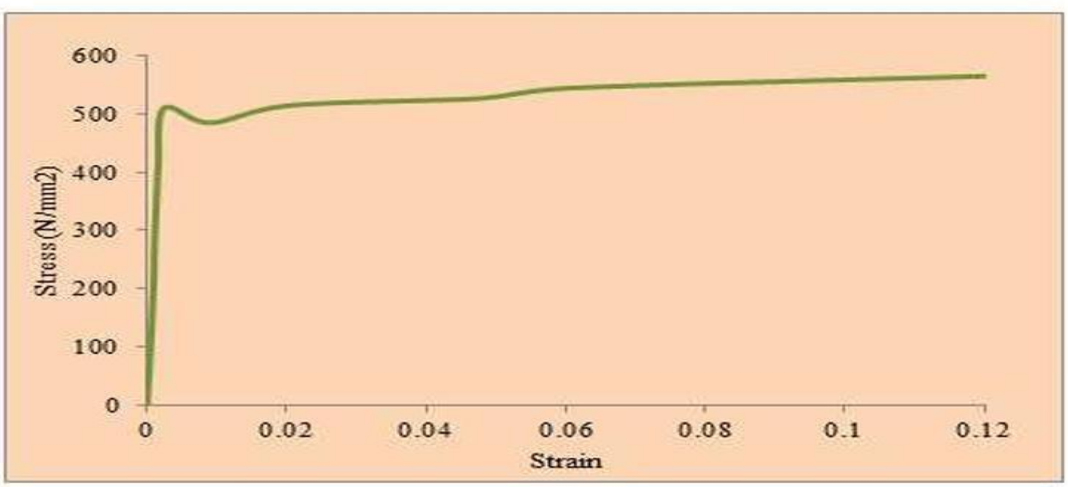


**Fig.3.2 Stress-Strain Curve of Steel**

**Concreting:**

Concrete was poured inside the formwork and then compacted using the needle vibrator. The casting of both the monolithic and precast specimen. The casted specimens were demoulded after 24 hours and then wet cured for 28 days.

Mesh reinforcement was provided above the precast slab and in situ concrete topping was done in order to maintain the diaphragm action of the structure. Epoxy was used in order to achieve a proper bonding between old concrete (precast slab) and newly laid concrete (screed concrete). The schematic representation of joint detailing of 58 four types of precast specimen. The erecting stages of all the four types of connections are as follows.

**Fig.3.3 Concreting of Precast Wall Slab**

**Type 1 Specimen (P1)**

The Steel bar protruding from the precast lower wall panel was bent above the precast slab and tied with the mesh reinforcement. Epoxy was applied to maintain the bonding between concrete cast at different times. The screed concreting was done above the precast slab.

**Type 2 Specimen (P2)**

Precast slab was provided with 20 mm diameter circular housing for inserting the dowel bars projecting from the precast lower wall panel and the gap was filled with non-shrinkage grout. Steel bars protruding from the precast slab was bent and tied with the mesh reinforcement provided above the precast slab.

# 4. TEST RESULTS

**4.1Ultimate Load Carrying Capacity:** The strength parameter was defined by the capacity of the structure to resist the design loads. The ultimate load carrying capacity of the tested specimens. The ultimate load carrying capacity of the ML specimen was found to be 10.9kN and 9.3kN in the push and pull direction loading respectively. The ultimate load carrying capacity of the precast specimens P1, and P2 in the push direction was found to be 13.35kN, and 15.15kN respectively. The ultimate load of the precast specimens P1, and P2 in the pull direction was found to be

12.6kN, and 14.1kN respectively. The comparison of ultimate load of both the monolithic and precast specimens in the push and pull direction loading. The average ultimate load carrying capacity of the precast specimens P1, and P2 was found to be 28.51%, and 44.85%higher than the ML specimen. On comparison with the two types of precast specimens, the average ultimate strength of P2 specimen was found to be 12.71% higher than the P1 specimens respectively. The precast specimen P2 performed better when compared with all the specimens due to the confinement in the joint region and the presence of nib supporting the precast slab.

| S. No | Specimen | Ultimate Load | | |
|---|---|---|---|---|
| | | Push | Pull | Average Load (KN) |
| 1. | ML | 10.9 | 9.3 | 10.10 |
| 2. | P1 | 13.35 | 12.6 | 12.98 |
| 3. | P2 | 15.15 | 14.1 | 14.63 |

**Table 4.1 Ultimate Load carrying capacity of the specimens**

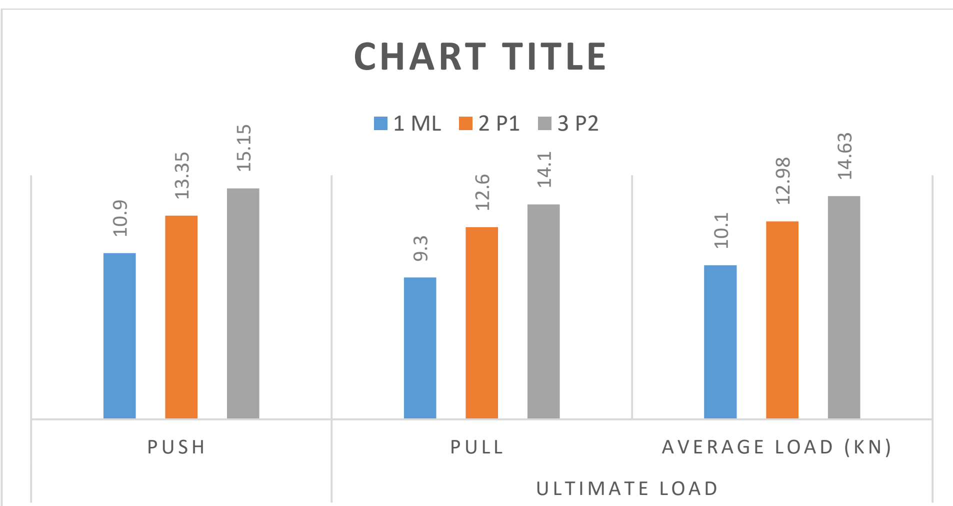


**Fig.4.1 Comparison of Ultimate Load carrying capacity of the specimens**

## 4.2 Ultimate Moment Carrying Capacity

The moment at the joint region was calculated by the product of ultimate load carrying capacity in the push and pull direction loading and the distance of loading point from the joint region. The loading was applied at a distance of 410mm from the joint region. The ultimate moment carrying capacity of the tested specimens. The moment carrying capacity of the precast specimen P2 subjected to reverse cyclic loading is found to be 37.29%, 12.78%, higher than the ML, P1 respectively. The precast specimen ML showed lower moment carrying capacity of about 23.57% compared to P1 specimen.

| S. No | Specimen | Ultimate Moment | | |
|---|---|---|---|---|
| | | Push | Pull | Average Moment (KN) |
| 1. | ML | 4.94 | 3.98 | 4.37 |
| 2. | P1 | 5.47 | 5.17 | 5.32 |
| 3. | P2 | 6.21 | 5.78 | 6.00 |

**Table 4.2 Ultimate Moment Bearing Capacity**

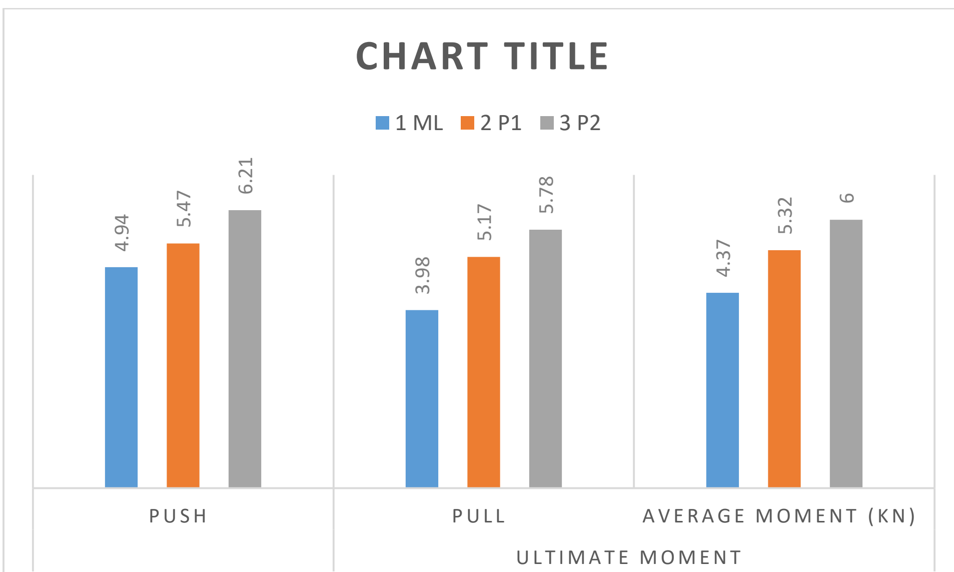


**Fig.4.2 Comparison of Ultimate Moment carrying capacity of the specimens**

## 4.3 Load-Displacement Behaviour:

The hysteresis behaviour of the monolithic and precast connection using dowel bars has been discussed in this section. The displacement, controlled loading were applied at the ends of the slab at 410 mm away from the joint region. The hysteresis loop of both the monolithic and the four types of precast specimens subjected to reverse cyclic loading. During the initial stage of loading, the hysteric behaviour of 71 the specimens showed linear load - Displacement response and later the pinching was observed in the hysteric loop of the specimens. Greater pinching was observed in the precast connections due to the predefined gap at the joint region. The increase in ultimate load and stiffness was observed in P2 specimen due to the resistance at the confinement in the joint region when compared with the ML specimen. The presence of dowels bars connected by the longitudinal reinforcement in P2 specimen increased the shear joint region during both push and pull direction loading.

## 4.4 Crack Pattern:

At reverse cyclic loading, the tested specimens experienced four stages: Crack emergence and development, specimen yield stage, ultimate stage and final failure of the connection. The joint core of the wall slab connection was in complex stress state in the combination of bending moment, axial load, and shear force. The crack in the specimens opened and closed on reverse cyclic loading. The cracks were also formed at both the top and bottom surfaces of the slab. The cracks got developed from the loading point and extended towards the joint core. With displacement increased, the cracks at the connection core expanded. With further increase of displacement, the gap between the screed concrete and precast slab kept increased in case of precast specimens P1, P2. The failure of the specimens was reached due to the crushing of concrete. The failure mode of ML and the precast specimens are explained in this section. The crack 75 propagation of both ML and precast specimens P1, and P2 for each displacement. In ML specimen, initial cracks were developed in the slab diagonally and extended towards the joint region. The first crack was formed in the slab at 2mm (8.7kN) displacement cycle, and the cracks were propagated in the slab region as the displacement increased. At 5mm (10.2kN) positive displacement cycle, visible shear cracks were observed in the joint region and got widened at 10mm (10.9kN) positive displacement cycle. The crack width of about 0.3 mm was formed at the joint region. The ultimate load carrying capacity was achieved at 10mm displacement. The maximum displacement reached by the ML specimen was 20mm. At the ultimate displacement, the crushing of concrete occurred at the loading point in the slab. The crack in the ML was narrower and number of cracks was formed when compared to precast specimens. In precast specimen P1, hairline cracks were developed along the upper surface of the slab in the initial stage.

The cracks developed diagonally from the loading point and these cracks expanded in the slab and the joint region. The first crack was formed in the slab at 2mm (10.37kN) displacement cycle and as the displacement increased the cracks got widened. The ultimate load carrying capacity was achieved at 20mm displacement cycle. The maximum displacement reached by this precast specimen was 28mm. The shear cracks at the joint region initially developed at the interface between the precast slab and screed concrete which gave clear evidence that the inelastic behaviour occurred at this location.

It was also observed that, there was a debonding between screed concrete and precast slab of width 0.2mm at 13mm (12.17kN) positive displacement cycle. The debonding at the interface occurred at 13mm displacement cycle which was higher than the displacement (10mm) of ultimate load achieved by the ML 76 specimen. The debonding between the precast slab and screed concrete widened as displacement increased and the crack width at the joint region reached 12mm at the failure stage. The crack width was generally high on the precast specimen and at higher displacement leads to crushing of concrete when the reverse cyclic load was applied. In precast specimen P1, the initial crack started from the left side of the slab. The crack propagation of the

precast specimen P1. The diagonal cracks from the loading point at 3mm (5.25kN) positive displacement cycle. At 3mm (5.50kN) negative displacement cycle, the crack extended and developed nearer to the joint region. Crack at the joint region starts at 10mm
(7.95kN) positive displacement cycle and got widened at 13mm (7.97kN) negative displacement cycle. At 16mm (7.50kN) negative displacement cycle, the crack widened at the right side of the interface between precast slab and screed concrete.
Finally, crushing of concrete occurred at the joint region. The crack width at the joint region in the left side of the slab was 4mm and at the top face of the slab was 2mm. The debonding between precast structural wall lower panel and precast slab occurs at 20mm (6.22kN) positive displacement cycle. In precast specimen P23, the initial crack was observed at 3mm (12.1kN), and the shear crack extended as displacement increased. The diagonal shear crack was formed in the joint region at both the ends of the slab. The cracks were initiated at the interfaces between the structural members provided at the connection region. There was a debonding between the precast lower panel-precast slab and the precast slab and screed concrete as displacement increased. Spalling of concrete was also observed in the slab at 10 mm (13.2kN) displacement. There was minor crack seen in the nib portion.
The shear crack occurred diagonally from the loading point towards the joint region at both the ends of the slab. There was no visible crack found in the structural wall. Debonding between precast slab and screed concrete was seen at 5mm positive displacement cycle (11.17kN). The crushing and spalling of concrete observed at the slab ends near the loading region. The crack widened at the lower wall panel with nib precast slab interface at 10 mm negative displacement (9.07kN). The ultimate load carrying capacity was achieved at 5mm displacement.

## 4.5 Elastic Stiffness:

The elastic stiffness of the connection was also known as secant stiffness and it was obtained using a response of load displacement envelope curve (Saqan 1995). The secant stiffness of the connection was calculated based on the procedure. The secant stiffness was calculated for both the monolithic and precast specimens in the push and pull loading direction and it is presented in the comparison of average secant stiffness of the tested specimens subjected to reverse cyclic loading. The elastic stiffness of precast specimens P1 was found to be 11.92% higher than the monolithic specimen. It was observed that the precast specimen P2 exhibited higher elastic stiffness followed by specimen P1 when compared with the ML specimen.

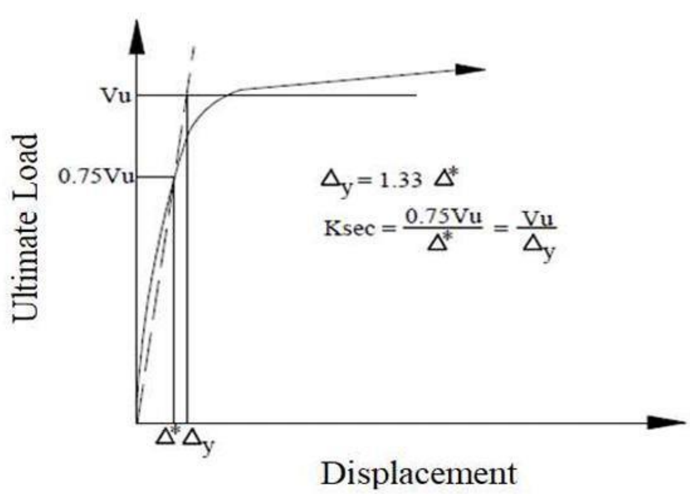


**Fig.4.3 Elastic Stiffness**

| S. No | Specimen | Ultimate Load(kN) | | Yield Displacement(mm) | | Secant Stiffness $K_{sec}=P_u/y$ | | Average secant Stiffness kN/mm |
|---|---|---|---|---|---|---|---|---|
| | | Push | Pull | Push | Pull | Push | Pull | |
| 1. | ML | 10.9 | 9.3 | 2.86 | 2.38 | 3.81 | 3.91 | 3.86 |
| 2. | P1 | 13.35 | 12.6 | 2.75 | 3.33 | 4.85 | 3.78 | 4.32 |
| 3. | P2 | 15.15 | 14.1 | 3.59 | 2.79 | 4.22 | 5.05 | 4.64 |

**Table 4.3 Flexural Stiffness test of the Specimens**

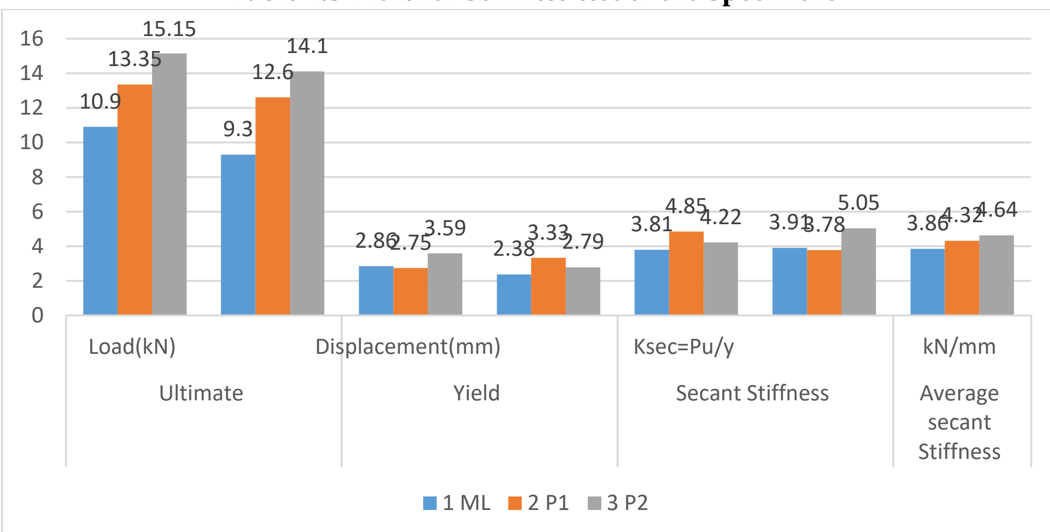


**Fig.4.4 Flexural Stiffness of Monolithic and Precast Wall Slab**

# 4.6 Ductility:

Ductility was an essential parameter in design consideration especially when a structure was subjected to reverse cyclic loading. The term ductility factor was defined as the ability of the connection to undergo extensive plastic deformation without a reduction in strength. It was calculated by the ratio of ultimate to yield displacement of the connection. The yield and ultimate displacement were taken corresponding to 75% (Park, 1975) of ultimate load in ascending branch and 80% (Park, 1975) of ultimate load in descending branch of the envelope response to obtain the ductility factor.

The calculated ductility factor for ML and precast specimens is shown in Table 3.11 and the comparison of average ductility factor of all the specimens is shown in Figure 3.31. The obtained average displacement, based ductility factor showed that, both the ML and precast specimens behaved in a ductile manner. The average displacement, based ductility factor of P2was found to be 89.27%, and 11.71%greater than ML, and P1 respectively. This was due to the higher confinement in the connection 96 zone of the specimen. The precast P1 and P2 behaved superior to the ML specimen concerning ductility. This implied that the proposed detailing for precast wall-slab connection enhanced the ductility behaviour of precast connection.

| S. No | Specimen | Yield Displacement(mm) | | Ultimate Displacement(mm) | | Ductility Factor | | Average Ductility factor |
|---|---|---|---|---|---|---|---|---|
| | | Push | Pull | Push | Pull | Push | Pull | |
| 1. | ML | 2.86 | 2.38 | 15.46 | 10.66 | 5.41 | 4.48 | 4.94 |
| 2. | P1 | 2.75 | 3.33 | 25.72 | 24.58 | 9.35 | 7.38 | 8.37 |
| 3. | P2 | 3.59 | 2.79 | 28.67 | 29.88 | 7.99 | 10.71 | 9.35 |

**Table 4.4 Ductility factor of Monolithic and Precast Wall Slab**

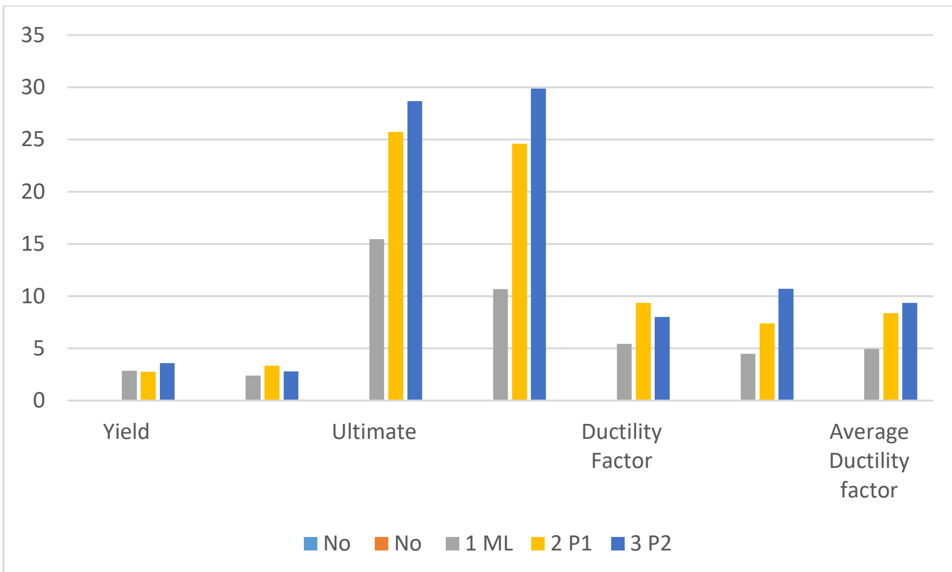


**Fig.4.5 Ductility factor of Monolithic and Precast Wall Slab**

## CONCLUSIONS

The conclusions drawn based on the experimental investigations and finite element analysis carried out to study the structural performance of precast structural wall slab under reverse cyclic loading are as follows.

1. The average ultimate load carrying capacity of the precast specimens P1 and P2 was found to be 28.51%, and 44.85% higher than the ML specimen. The moment carrying capacity of the precast specimens P1 and P2 was found to be 21.74% and 37.29% higher than the ML specimen. The precast specimen P2 with proposed joint detailing exhibited higher load and moment carrying capacity compared to the ML and other types of precast specimens.
2. Both the ML and precast specimens behaved in a ductile manner and exhibited damage in the slab under reverse cyclic loading. All the precast specimens have showed similar trend

as that of ML specimen. The shear cracks at the joint region initially developed at the interface between the precast slab and screed concrete which gave clear evidence that the inelastic behaviour occurred at this location in case of precast specimens. Plastic hinges were noticed at the loading area, wall-slab joint and finally failure of the slab. The crack in the ML was narrower and number of cracks was formed when compared to precast specimens. There was no visible crack found in the structural wall. This proved that the specimens are satisfying the strong wall- weak slab concept.

3. It was observed that both the monolithic and precast specimens behaved in a ductile manner. But, the average displacement based ductility factor of P1 and P2 was found to be 69.43 % and 89.27% greater than ML specimen.
4. The numerical results of the ML and precast specimens were compared with the load displacement envelope response obtained from the experimental study and it was observed that Finite Element Modelling exhibited higher load carrying capacity of the 157 connections with an average variation of 11%. The output from the Finite Element Modelling indicated that the developed finite element model of precast specimens exactly predicted the response of the connections regarding failure of the specimens and the deformations with reasonable precision.
5. It was observed that the specimens P1 and P2 performed better compared to ML specimen. On comparison with the four different detailing of proposed precast connections, the precast specimen P2 performed superior due to the confinement in the joint core and the presence of nib which supports the precast slab. It was also concluded that the provision of dowels as shear reinforcement in the precast wall-slab joint region would be effective in seismic risk regions.

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