Effect of Fibres on Ultra High Performance Concrete Wall Panels with Openings

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***Abstract*— This paper presents the results of an experimental investigation conducted to determine the effect of openings on the ultimate strength and behaviour of Ultra High Performance Concrete (UHPC) wall panels and Ultra High Performance Fibre Reinforced Concrete (UHPFRC) wall panels. Total twelve rectangular wall panels of scale ¼, six of UHPC and six of UHPFRC, were tested under one-way in-plane axial loads i.e. supported at top and bottom edges against lateral displacement. Representative door and window openings were given. First crack load, ultimate load, energy absorption capacity and crack patterns were studied. The results indicate that the openings reduce the ultimate strength and energy absorption capacity of the wall panels. By the addition of fibres, the strength enhancement observed in solid UHPFRC wall panels is not observed in those with openings.**

Keywords—wall panels; openings; ultra high performance concrete; one-way in-plane axial loads; fibre-reinforced

I. INTRODUCTION

Due to advances in concrete technology, a new class of cementitious composite, Ultra High Performance Concrete (UHPC) have been developed with superior mechanical properties. UHPC is characterized by its constituent material make-up: Silica fume, fine grained sand and special blends of high-strength Portland cement. It does not include any large aggregate. The optimized gradation of granular constituents and low water cement ratio contribute to its improved mechanical properties. Silica fume with extreme fineness and high amorphous silica content plays a very important role with physical (filler, lubrication) and pozzolanic effects. Addition of silica fume makes the concrete denser. The theory behind UHPC is that by making the concrete denser its strength and durability is improved. But this makes the concrete much more brittle. Addition of fibres makes the concrete ductile and this led to the development of Ultra High Performance Fibre Reinforced Concrete (UHPFRC).

In recent years, Reinforced Concrete (RC) wall panels have gained importance as load bearing structural members due to its application within the core of high rise buildings and in tilt-up constructions. They form integral part of box frames, box girders and folded plates. Wall panels made of UHPC could be advantageous due to significant cost reduction through the use of thinner sections as well as increase in net space of buildings. Some openings such as provision of windows, doors, ventilation system, etc. could not be avoided in walls. These openings will affect the ultimate strength of the walls. Large openings cause disturbance in the stress path when considerable amount of material is removed.

Most of the investigations were carried out on solid RC wall panels. Reference [1] conducted experiments on RC wall panels and found that the ultimate strength decreases with increase in aspect ratio and slenderness ratio. The cracking and ultimate loads of panels with openings were found to be almost equal when tested in one-way or two-way action [2]. A detailed comparative study on normal and high strength concrete wall panels was carried out by [3]. Studies reveal that the strength of UHPC wall panel increases with increase in horizontal reinforcement [4]. The strength of UHPC wall panels was found to depend on the concrete grade and percentage of steel used [5]. Reference [6] have shown that the increase in vertical reinforcement significantly improves the ultimate load and the energy absorption capacity. Studies on RC wall panels with openings strengthened with CFRP showed that CFRP applied in 45° to the opening corners gave better strength when compared to CFRP applied along the opening [7]. Reference [8] studied wall panels with openings and found that the increase in length of opening has significant effect on the reduction of ultimate strength compared to opening height. Studies on the effect of volume fraction of fibres on UHPC wall panels reveal that the increase in ultimate load was about 37.3% for an increase of volume fraction of fibres from 0 to 1.5 [9]. Studies on fibres show that UHPFRC produced from macro-fibres with twisted geometry provides the best performance with respect to post cracking strength, strain capacity and multiple micro-cracking behaviour, whereas UHPFRC produced with long, smooth macro-fibres exhibits the worst performance [10].

This paper presents the results of experimental investigation conducted on six UHPC wall panels and six UHPFRC wall panels with varying opening type under one-way in-plane loading.

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II. EXPERIMENTAL PROGRAMME

The experimental investigations were carried out to find the effect of different types of openings on the strength and behavior of UHPC and UHPFRC wall panels under one way in-plane action. Twelve numbers of square wall panels of size 750 mm and 35 mm thickness were cast and tested. Six wall panels were prepared from UHPC and six from UHPFRC. Hooked end steel fibres were used for the study. Size of window opening provided was 300 x 375 mm and that of door opening was 300 x 525 mm. Two specimens per each set were cast. The details of specimens are given in Table I.

A. Materials

Ordinary Portland Cement (53 grade) conforming to IS 12269-1999 and fine aggregate less than 4.75 mm size conforming to grading zone I as per IS 2386 (Part-III) -1973 having a specific gravity of 2.67 and potable water conforming to the requirements of water for concreting and curing as per IS 456-2000 were used for the present investigation. Cement was replaced by the micro-filler silica fume with a specific gravity of 2.2. Conplast SP 430 with a total solids content of 40% and specific gravity of 1.21 was used as superplasticizer to obtain the required workability. In this study, coarse aggregate was eliminated. For UHPFRC, hooked end steel fibres of aspect ratio 65 were added. Mild steel bars of 3 mm diameter were used as reinforcement for wall panels.

B. Mix Proportion

UHPC mix proportion of M80 grade taken from [5] is given in Table II. The 28th day cube compressive strength was obtained as 85 MPa. For UHPFRC, fibre volume fraction adopted was 0.75%.

TABLE I. SPECIMEN DETAILS

Name	**Type of opening**	**Area of opening (%)**	**Fibre condition**	**No of specimens**
WP	No opening	0	No fibre	2
WPF	No opening	0	With fibre	2
WPOW	Window	20	No fibre	2
WPFW	Window	20	With fibre	2
WPOD	Door	28	No fibre	2
WPFD	Door	28	With fibre	2

TABLE II. MIX PROPORTION FOR UHPC

Materials	**Quantity (kg/m^3)**
Cement	675
Silica Fume	75
Sand	1356
Water	192
Super plasticizer	10

C. Reinforcement Details

The reinforcement in the form of rectangular grid, fabricated using 3 mm diameter steel bars, was placed in a single layer at mid-thickness of the panel. Bars were provided in both directions with spacing not exceeding three times the panel thickness as per IS 456-2000, with a clear cover of 10 mm. The yield strength of reinforcement steel was 445 N/mm^2. The percentages of reinforcement and spacing provided in the panels are given in Table III. The spacing of bars in both directions were kept with spacing not exceeding three times the panel thickness with a clear cover of 10 mm. To prevent premature failure due to cracking at corners of the openings, 3 wires of 3 mm diameter were provided diagonally at 45° at the corners and along the opening as stiffeners. The reinforcement pattern for window and door openings are shown in Fig. 1 and Fig. 2. All dimensions are in millimeters.

D. Casting of Wall Panels

Cement, sand and silica fume were mixed in dry state in drum type mixer machine. The required quantity of super plasticizer was added along with 50% water. In case of specimens with fibre reinforcement, the required quantity of fibres was sprinkled carefully while the drum was in motion. Mixing was continued till a uniform paste was obtained. Then the mould was filled with concrete in two layers. The specimens were cast horizontally on a level floor. The two ends of the specimen were made wider for uniformly distributing the load and to obtain proper seating. The wall panels were moist cured with wet gunny bags for an initial period of three days and were then immersed in the curing tank. After 28 days of curing, the panels were taken out from the curing tank and were painted with white cement (for clearly marking the crack pattern) and made ready for testing.

TABLE III. REINFORCEMENT DETAILS

Reinforcement (%)		**Spacing of 3 mm GI wire (mm)**	
Horizontal	***Vertical***	***Horizontal***	***Vertical***
0.25	0.15	75	100

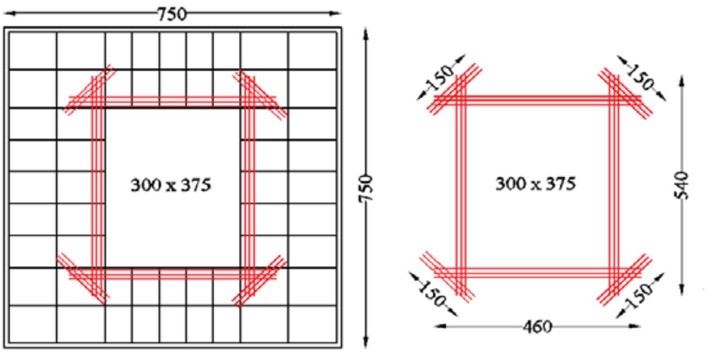

Fig. 1. Reinforcement pattern for specimens with window opening

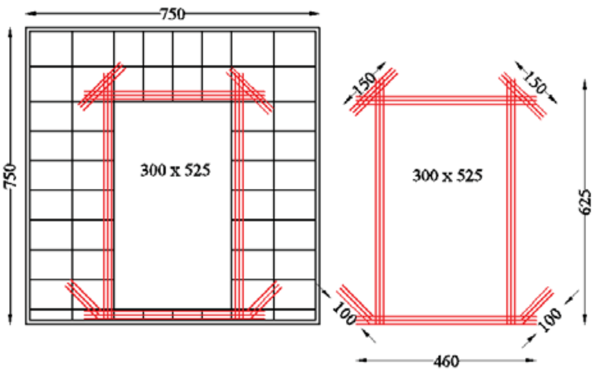

Fig. 2. Reinforcement pattern for specimens with door opening

E. Experimental Set-up

Prepared specimens were properly marked to measure the lateral deflection at mid-point, horizontal quarter point (HQPT) and vertical quarter point (VQPT). For panels with openings, deflection at HQPT and VQPT were taken. Arrangements were made to keep LVDTs and dial gauges to measure the deflection at required points. After marking the positions, the specimen was placed on a 300 t UTM. In order to transfer the load uniformly, an I-section was kept on the top of the specimen. After keeping the specimen with I-section in correct vertical position, the LVDTs and dial gauge were properly positioned. The test set-up for solid panel and panel with opening are shown in Fig. 3 and Fig. 4.

Fig. 3. Test set-up for solid panel

Fig. 4. Test set-up for panel with opening

III. RESULTS AND DISCUSSION

A. First Crack Load and Ultimate Load

Table IV shows the first crack load and ultimate load values for the specimens under one way in-plane loading. The percentage reduction in the loads for wall panels with openings, compared to solid wall panels are also tabulated. The first crack load was noted by visual observation. The maximum load just prior to failure was taken as the ultimate load.

The first crack and ultimate load were found to decrease non-linearly with increase in area of openings, for both UHPC and UHPFRC wall panels. The variation is plotted in Fig. 5 and Fig. 6. This decrease may be due to the reduction in stiffness of specimens due to openings. Openings cause abrupt changes in the geometry of the wall panel that affects the load transfer path and thereby causing stress concentration at the corners. Due to stress concentration at the corners of opening, cracks are initiated from these locations in the early stage itself, reducing the load carrying capacity of the panels.

The rate of decrease was found to be more for UHPFRC wall panels compared to UHPC wall panels. By the addition of fibres, there was considerable improvement in the first crack load and ultimate load of solid wall panels. This may be due to the presence of fibres which prevent the propagation of micro cracks which would otherwise form the macro cracks. But for wall panels with openings, the improvement in the first crack load and ultimate load due to fibres were negligible. This may be because, for wall panels with openings, the effect of addition of fibres to prevent the propagation of cracks becomes insignificant and the effect of openings forms the primary factor determining the load carrying capacity. So the strength enhancement observed in solid UHPFRC wall panels is not observed in UHPFRC wall panels with openings.

TABLE IV. FIRST CRACK LOAD AND ULTIMATE LOAD

Specimen	**Fibre Condition**	**First Crack Load**		**Ultimate Load**	
		Load (kN)	***Reduction (%)***	***Load (kN)***	***Reduction (%)***
WP	Without fibre	450	-	950	-
WPOW		375	17	750	21
WPOD		250	44	500	47
WPF	With fibre	1125	-	1540	-
WPFW		475	58	840	45
WPFD		350	69	630	59

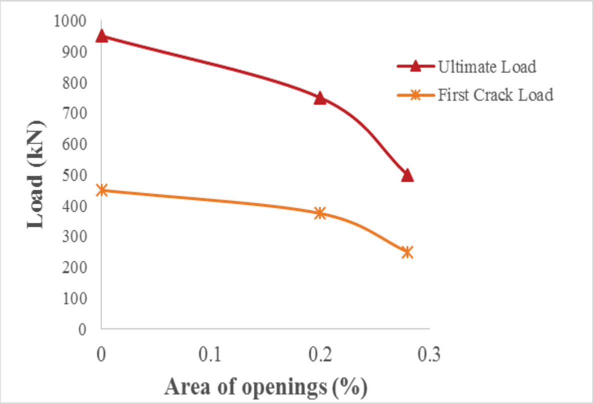

Fig. 5. Variation of first crack load and ultimate load for UHPC specimens

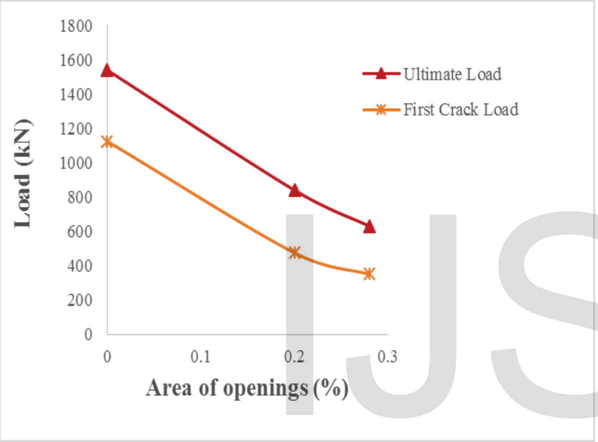

Fig. 6. Variation of first crack load and ultimate load for UHPFRC specimens

B. *Load Deflection Behaviour*

Based on the observations, the combined load-deflection graphs were plotted for the specimens and is shown in Fig. 7 to Fig. 10

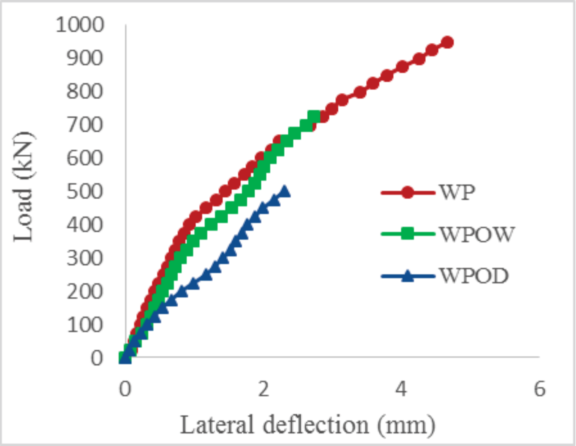

Fig. 7. Combined load deflection curve at the horizontal quarter points of UHPC wall panels

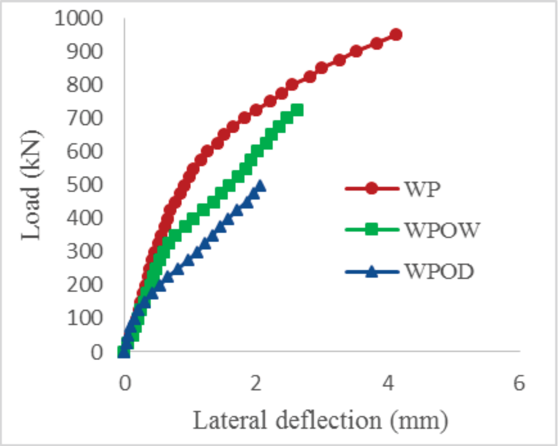

Fig. 8. Combined load deflection curve at the vertical quarter points of UHPC wall panels

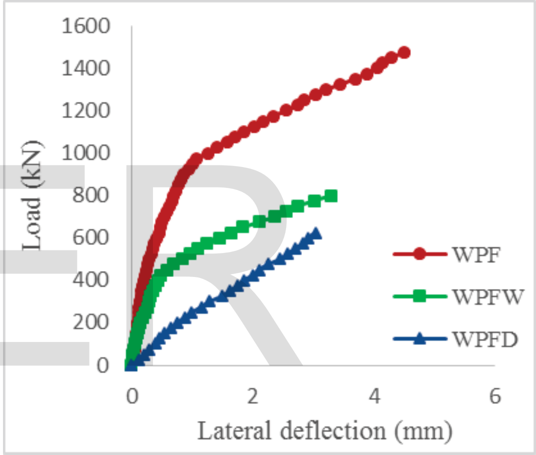

Fig. 9. Combined load deflection curve at the horizontal quarter points of UHPFRC wall panels

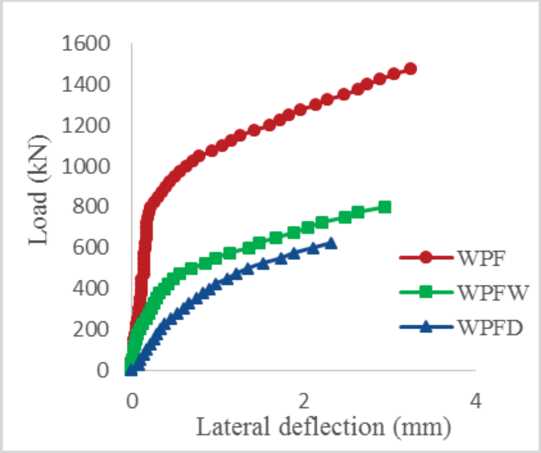

Fig. 10. Combined load deflection curve at the vertical quarter points of UHPFRC wall panels

The load deflection curves were linear in the initial stage. After the onset of cracking, it showed non-linearity. The

UHPC wall panels exhibited brittle mode of failure. Specimens with openings showed even more catastrophic failure with little plastic deformation, which may be the reason for the absence of significant yielding region in the respective curves. For solid UHPFRC wall panel there is considerable yielding portion which indicates the post cracking strength imparted by the fibres. The failure mode became comparatively more ductile by the addition of fibres.

C. Energy Absorption Capacity

The energy absorption capacity was calculated as the area under the load-deflection graph up to ultimate load of the specimen. Energy absorption capacity of specimens are shown in Fig. 11.

Energy absorption capacity was found to decrease with increase in area of openings. There was about 60% decrease in energy absorption capacity for panels with window openings and 78% decrease in energy absorption capacity for panels with door openings. The reduction in energy absorption capacity with openings was found to be same for both UHPC and UHPFRC wall panels.

Comparing specimens with and without fibre it could be noted that by the addition of fibres the energy absorption capacity increased significantly. For solid wall panels the increase was 55% and for window opening and door opening specimens the increase was 63%. Fibres delay the onset of cracks thereby making the specimen capable of absorbing more energy before failure. Addition of fibres makes the specimen more ductile due to which it can undergo more yielding before failure.

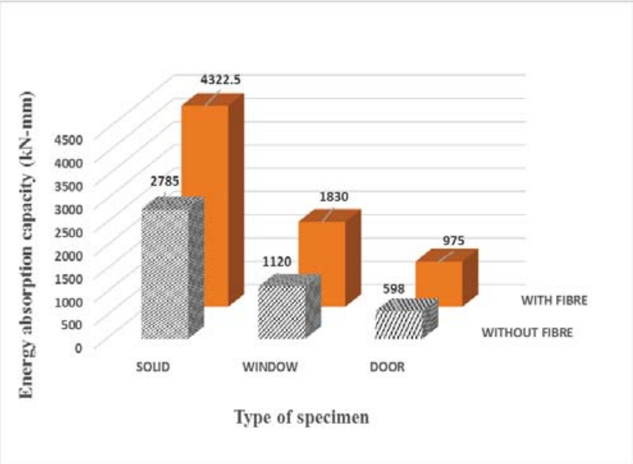

Fig. 11. Energy absorption capacities of all specimens

D. Crack Pattern

Crack patterns for different types of UHPC and UHPFRC specimens are shown in Fig. 12 and Fig. 13 respectively.

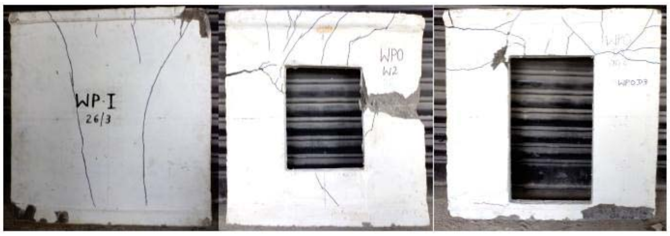

Fig. 12 Crack Patterns of UHPC wall panels

Fig. 13 Crack Patterns of UHPFRC wall panels

It could be observed that solid panels failed by large vertical cracks which indicated compressive failure. One or two major cracks caused the failure. UHPC wall panels exhibited sudden brittle failure without much warning. While in specimens with openings more number of cracks were found to concentrate around the openings especially above the openings and at the top corners. Diagonal cracks were developed from the top corners of openings extending towards the top corners of the wall panel. The horizontal strip of wall panels above openings exhibited bending action causing flexural and shear cracks at the top. For specimens with fibres it could be seen that cracks were more distributed. There were less number of wider cracks. This may be because fibres arrest the propagation of cracks preventing the formation of wider cracks.

IV. CONCLUSION

The following conclusions are derived from the study:

- The first crack load and ultimate load decreases non-linearly with the increase in the area of openings. For UHPC wall panels, the first crack load is found to decrease by 17% and the ultimate load by 21% for 20% reduction in area due to window opening. The reduction in strength is 44% and 47% respectively for first crack load and ultimate load corresponding to 28% reduction in area in case of panels with door opening.
- Provision of openings cause drastic reduction in strength in the case of UHPFRC wall panels. For UHPFRC wall panels the first crack load is found to decrease by 58% and the ultimate load by 45% for 20% reduction in area due to window opening. The reduction in strength is 69% and 59% respectively for first crack load and ultimate load corresponding to 28% reduction in area in case of panels with door

opening. This may be attributed to the fact that in case of UHPFRC wall panels with openings, arresting the propagation of cracks by fibres becomes less significant because of the presence of openings.

- By the addition of fibres, solid wall panels show significant improvement in strength. The first crack load is found to improve by 150% and ultimate load by 60% when compared to UHPC wall panels. But in the case of wall panels with openings such enhancement in strength with the addition of fibers is not observed. The improvement in ultimate load is only 12% for window opening and 26% for door opening when compared to corresponding UHPC wall panels.
- Energy absorption capacity is found to be decreasing as the area of opening increases. There is about 60% decrease in energy absorption capacity for panels with window openings and 78% decrease in energy absorption capacity for panels with door openings. The reduction in energy absorption capacity with openings is found to be same for both UHPC and UHPFRC wall panels.
- From the crack patterns observed, it is understood that cracks are concentrated around the openings, particularly in the region above the opening. The presence of openings causes part of the wall panel above the opening to behave as a beam and as a result flexural and shear cracks are developed. The UHPC wall panels exhibit brittle mode of failure and with openings the failure is even more catastrophic.
- When compared to UHPC wall panels, UHPFRC wall panels exhibit less number of wider cracks and the crack pattern is more distributed. Addition of fibres changes the mode of failure from brittle to ductile.

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