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Experimental Study on the Structural Behavior of Cast in-situ Hollow Core Concrete Slabs

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Abstract

An experimental work has been carried out to study the flexural behavior of cast in-situ Hollow Core Reinforced Concrete (HCRC) slabs constructed by using easy, cost effective and implementable techniques in field. The precast elements made of different easily available affordable material i.e. concrete, polyvinyl chloride (PVC) and plaster of paris having voided cross- sections of circular, rectangular and triangular shapes were incorporated in one direction during pouring of concrete with minimum flexural reinforcement to construct HCRC slabs. A total of 14 slab specimens including 02 specimens per specification were tested with third point loading for the assessment of flexural behavior as per ASTM standards C78/C78M. The flexural behavior of HCRC slabs with polyvinyl and plaster of paris elements having hollow cross-sections was comparable with the control solid slabs, however, HCRC slab with concrete pipes showed 7 to 8 percent reduction in flexural strength with 19 to 20 percent reduction in self-weight. All the tested specimens performed well in shear as no shear failure was observed. This study reveals that HCRC slabs with locally available material having hollow cross section elements can be used for the construction of cast in-situ monolithic construction of one-way slabs with ordinary construction techniques.

Keywords: Hollow Core Reinforced Concrete Slab; Flexural Strength; Cracks; Deflection; Ductility.

1. Introduction

Providing shelter is the very basic need and necessary facility for humans to survive their lives. Shelter is the initial form for refugee and gradually converts to indoor comfort facility. HCRC Slab is such a sheltering facility that not only reduces the dead load of a structure and make it light weight, but also provides thermal comfort which saves considerable heating and cooling energy and also mean of sound insulation [1, 2]. Historically, HCRC Slab units were developed in the 1950s and commonly used throughout the world to construct floors and roofs of residential buildings, industrial units and car parking facility [3, 4]. It has good economic aspects, thermal and sound insulation properties [1, 3]. Due to less dead load of HCRC slab as compared to the solid slab units, slabs of longer spans can be designed and constructed [2]. Slab is very important structural part of a building. It consumes large volume of materials. With the increase of load demand, the thickness of slab increases which causes additional expenditure of construction [5].

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To make cost effective slabs with small depths and long span without intermediate support in single as well as multistory buildings, HCRC slabs were introduced [2 ,3].

In the rural areas of developing countries pre-cast HCRC units are not commonly used due to lack of casting facilities, elevating equipment and expertise. It is, therefore, necessary to develop an easy and implementable technique for cast in-situ HCRC slab floor system using local available materials, equipment and expertise. By this technique the inhabitants and constructors of rural areas can be encouraged to convert their construction manners to new one and to adopt the trends of engineering and modern technologies.

It has been recorded that the performance of buildings with HCRC slabs are not good due to the premature failure of floor in the structural test and highlighted the need of further research in this area [6]. Many researchers have evaluated the capacity of hollow core slab in terms of flexure [5-7] web shear [4, 5], fire resistance [8], seismic resistance [6, 9], torsion [10] and many more, using different formats of hollow core slab systems. The hollow slab provided with PVC pipes and styrophoam, to create cavity in the slab, failed in shear instead of flexure while reducing self-weight up to 24% [7]. With the provision of pipes in hollow core slab, the behavior changes from flexure to shear that indicates further experimental work to assess the cause and reason for this behavior [7].

Diameter and type of pipes has considerable effects on the structural behavior as well as in weight reduction of HCRC slab units. The HC slab with PVC pipes has less flexural capacity as compared solid slab [7] while HCRC slab with steel pipes [11] has greater load carrying capacity than solid slab. HCRC slab with PVC pipes deflects more as compare to HCRC slab with steel fibers. There is a considerable difference in weight reduction by using PVC and Steel pipes in HCRC slabs. HCRC slabs with PVC pipes reduce the weight up to 24% while the HCRC slab with steel pipes reduces the weight by 1.5% [7, 11].

Thickness of slab also affects the web shear capacity of HCRC slab and further experimental work is recommended [4]. Share span to depth ratio changes the mode of failure from flexure to shear depending on the magnitude of ratio. Span to depth ratio up to 5 gives pure flexural failure mode and the crack pattern is like a well-designed flexural member [5].

Unlike pre-cast HCRC slab units, the cast in-situ HCRC slab units will provide monolithic construction with supporting structures which will provide axial restraints at the ends. The axial restraints at the ends reduce the chances of shear failure and ductile failure will occur due to flexure [6, 9]. Cast in-situ HCRC slab has many advantages over the other slab system, such as no need of elevating equipment, no damage due to placing and handling, rapid construction, low self-weight, economical use of concrete and reliable quality while having almost same flexural behavior as that of conventional slab units [2, 4, 12]. The underside of slab can be used as a finished ceiling for painting and acoustical spray. The voids in HCRC slab may be used for conceal electrical and mechanical runs. HCRC slabs can be detailed to distribute the heated/cooled air through the cores [1]. Structurally, HCRC slab units have good efficiency for load capacity, span range, and deflection control [2]. In addition, a basic diaphragm is provided for resisting lateral loads, good flexural behavior during fire is another attribute of the HCRC slabs [13].

In this research work HCRC slab panels have been constructed with precast elements of different materials and shapes having voided cross sections. The materials with voided cross section were introduced to create cavities in the slab unit with desire and suitable dimensions. The HCRC slab panels were tested under third point loading to evaluate its flexural capacity. The Hollow Core and solid control reinforced concrete Slabs were tested as a one-way slab for flexure, having cavities of different shapes and of different materials. The spacing and dimension of pipes were designed to allow the components to act effectively as an integral element of the slab units. This paper is organized as follows. Section 1 is about the introduction of the current research study. Materials and methods are explained in detail in Section 2. Experimental results of test specimens and discussions are covered in Section 3 and 4. Recommendation, conflict of interest and references are listed in section 5, 6 and 7 respectively.

2. Materials and Methods

To achieve the objectives of research, the experimental work has been carried out as per the following flowchart. Total of 14 specimens were constructed in two batches and tested as per ASTM standards [21]. Four specimens were prepared as solid slab panel (two for each batch) and were used as a control specimen while ten specimens were constructed as hollow core slab units in five sets, two specimens for each type of pipes as described in the following flowchart.

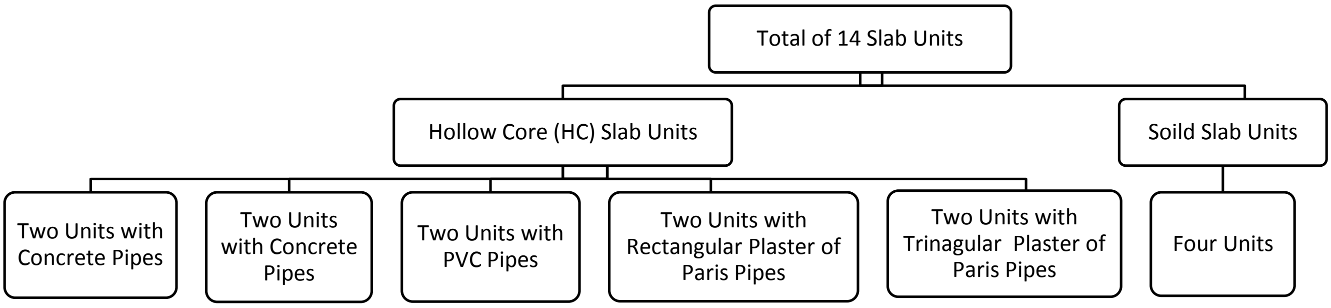


Figure 1. Flowchart for research methodology

In first batch of testing, concrete pipes were placed at a spacing of 152.4 mm (two pipes) and 114.30 mm (three pipes) on centers respectively, in 457.20 mm width of slab. After testing of first batch, it was noticed that flexural behavior of hollow slab with two and three pipes are almost same while slabs with three concrete pipes have more hollow area, resulting in more reduction of self-weight. It was therefore decided, to use three concrete pipes in hollow slabs instead of two. In the second batch, PVC and Plaster of Paris pipes of different cross-sectional shape were used. The cross-sectional area of cavity for all types of pipe was same. Based on the availability of space in the laboratory, the total length of specimens was selected as 2.44 m and x-section as 457.20×152.40 mm.

To investigate the effect of shape of hollow core, pipes with circular, rectangular and triangular x-sections were used in the research. Pipes made of different materials were used to see the effect of pipes on flexural capacity of hollow core slab. All circular pipes have diameter of 3 inches while pipes with other shape have the same x-sectional area as that of circular one. Steel of grade 420 (60) and concrete with compressive strength of 13.34 kN were assumed in design. To compare the flexural strength of solid and hollow core slab units, all the specimens were designed with minimum steel ratio as per the ACI-code [20].

$$As_{\min} = 3\frac{\sqrt{f'_c}}{f_y}bh \geq \frac{200}{f_y}bh \tag{1}$$

For the estimated theoretical loads the neutral axis was well above the cavity and laid in the solid portion of the slab, therefore flexural rectangular design criteria was used for the calculation of reinforcement area as per the ACI-318 code [11, 20]. The design details of the specimens are given in Table 1.

Table 1. Design detail of specimens

Specimen	Mark	Thickness (mm)	No. of Specimen	Reinforcement
Solid Slab	HCS	152.40	4	#3@228.60 mm C/C
Hollow core with concrete Pipes with 152.40 mm on centers (two pipes in 457.20 mm width of slab)	HCC1	152.40	2	#3@228.60 mm C/C
Hollow core with concrete Pipes with 114.30mm on centers (three pipes in 457.20 mm width of slab)	HCC2	152.40	2	#3@228.60 mm C/C
Hollow core with Rectangular plaster of Paris Pipes	HCRP	152.40	2	#3@228.60 mm C/C
Hollow core with PVC Pipes	HCP	152.40	2	#3@228.60 mm C/C
Hollow core with triangular plaster of Paris Pipes	HCTP	152.40	2	#3@228.60 mm C/C

The pipes of 76.20 mm diameter were placed at equal spacing of 152.40 mm on centers along the longitudinal direction of slab units as shown in Figure 2.

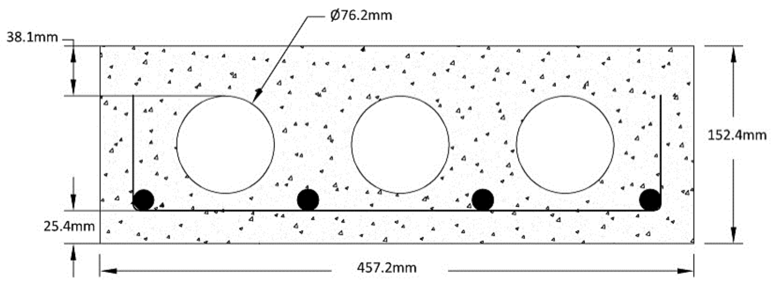


Figure 2. Cross section of hollow core slab

The slabs were casted and are shown in Figure 3. After 28 days, samples were tested for flexure strength, under third point loading as per ASTMC78/C78M. For investigation of displacement, Linear Variable Displacement Transducers (LVDTs) were attached at the bottom of slab in the region of maximum bending moment as shown in Figure 4. All the tests were performed in the Material Testing Laboratory of Civil Engineering Department University of Engineering & Technology Peshawar, PKP Pakistan.

Figure 3. Casting of slab units

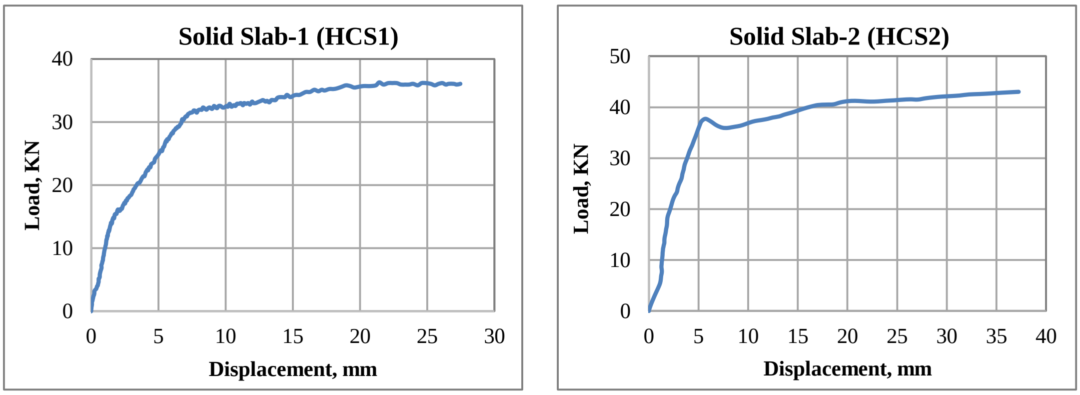
Figure 4. Test setup of slab units

3. Results and Discussion

The slab units were tested as a simply supported with clear span of seven feet. The load cell and loading arrangement was such that to achieve the third point loading condition. To avoid any chance of data missing, three LVDTs were attached for deflection calculation in the region of maximum bending moment.

3.1. Test Result of Control Specimen

Control specimens were tested in two batches, first for hollow slab with concrete pipes and secondly for hollow core with PVC and Plaster of Paris pipes. Control specimens from both the batches showed same behavior; therefore only two graphs out of four are shown for comparison of results. The solid slab units (control specimen) showed elastic behavior up to a load of 13.34 KN. The corresponding deflection at elastic load was 1.52 mm. The first crack was initiated at a load of 13.78 KN in the region of maximum bending moment and propagated upward with the increment of loads. After a load of 13.78 KN the yielding was started. The corresponding deflection at yield load was 1.79 mm. The stiffness decreased beyond the elastic load and becomes linear up to a load of 31.14 KN with corresponding defection of 7.62 mm. Maximum load and corresponding deflection is 39.14 KN and 30.48 mm respectively. The load deformation relationship is shown in Figure 5. The combined force deformation curve of all the specimens is given in Figure 6.



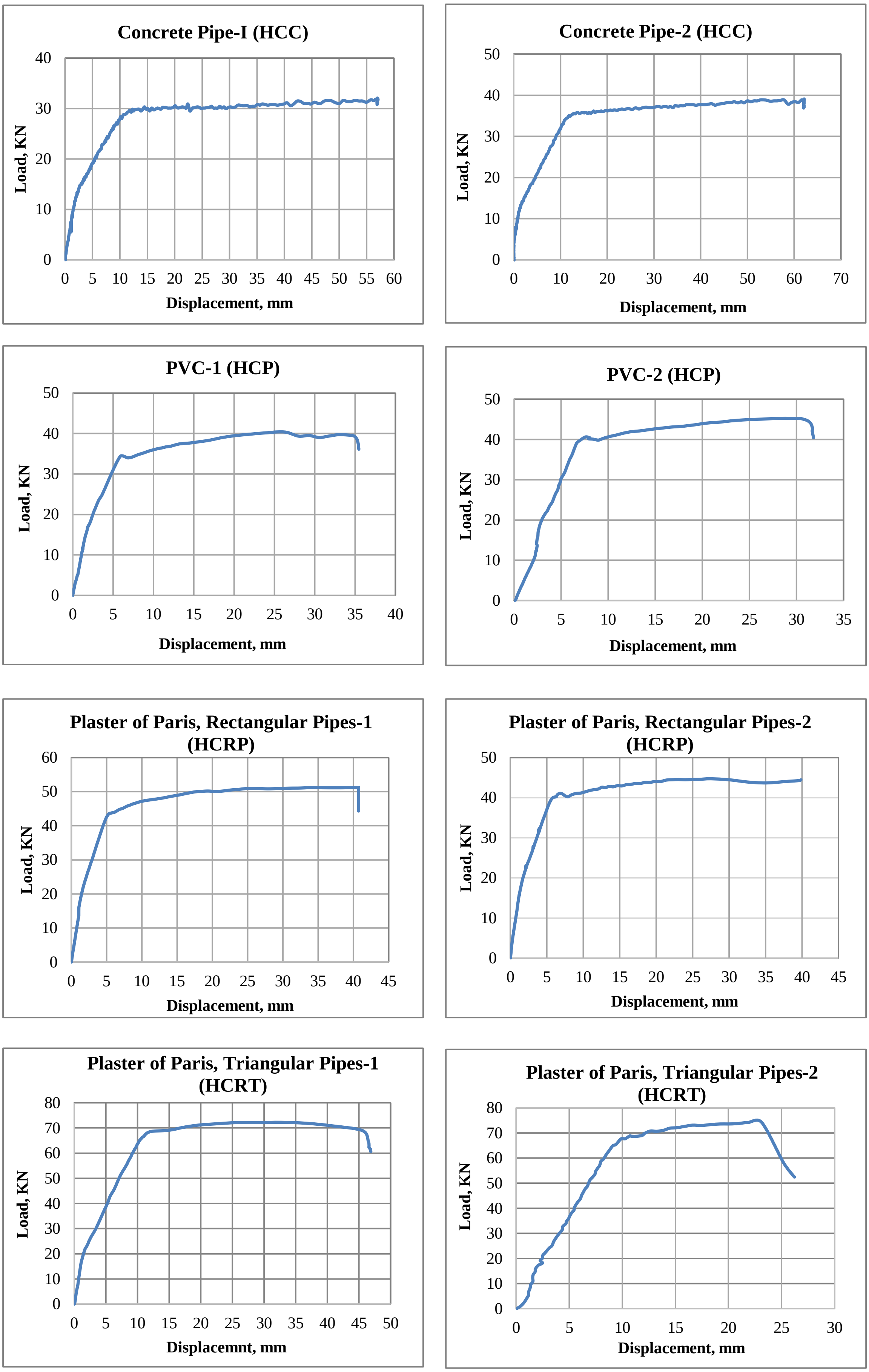


Figure 5. Experimental Force-Deformation Curves of the individual Specimen

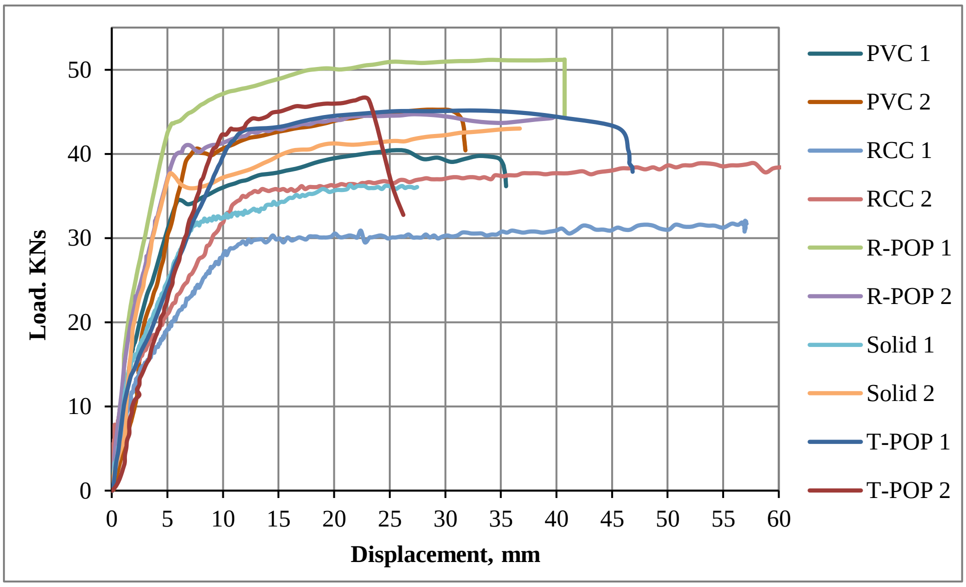


Figure 6. Experimental Force-Deformation Curves of the Specimens

3.2. Flexural Strength and Elastic Behavior of Hollow Core Slabs

The HCRC slab units provided with concrete pipes i.e. HCC1 and HCC2 behaved in elastic manner, almost similar to that of solid slab. However the overall load carrying capacity of HCC1 and HCC2 is less than other HCRC slabs. This can be stated that the quality of concrete used in pipes is of low quality. The elastic loads for HCC1 and HCC2 are 14.01 and 16.00 KN respectively. The corresponding deflections at elastic loads are 1.48 and 1.80 mm. First crack in each unit was a flexural crack appeared in the region of maximum bending moment. The load and displacement relationship of HCC1 and HCC2 are shown in Figure 5.

All slab panels except those provided with concrete pipes, showed same elastic behavior. HCRC slab with PVC and Plaster of Paris pipes showed first crack at an average load of 17.79 KN with corresponding deflection of 1.27 mm. All slab specimens failed in flexural manner.

It was observed that hollow slab units containing with PVC pipes, were cracked at bottom face and resulted in spalling out of concrete as shown in Figure 7. This phenomenon shows the weak bond between PVC pipe and surrounding concrete. At higher loads the flexural cracks changed their path to shear pattern, especially in HCRC slab with concrete and PVC pipes and the same failure scenario was reported by Wariyatno et al. (2017) [7].

It was observed that the flexural capacity of HCRC slab provided with Plaster of Paris pipes which have rectangular and triangular section, showed relatively high flexural strength as compared to other HCRC slab units. This increase in flexural strength can be justified as due to the lateral confining effect of pipes due to their shapes, which in other words can be referred as reduction in poisons ratio effect.

Figure 7. Testing of hollow core slab

3.3. Ductility Behavior of Slabs

The balance between increasing or decreasing flexural strength of RC members and ductility is a common discussion of researchers [14]. Ductility is the capacity of a structural member to absorb energy when it undergoes inelastic deformation. Ductility can be found in the form of rotation, displacement and curvature [14-16]. The method of ductility by displacement has been employed in this research work. Displacement ductility ratio was found by dividing deflection at ultimate load by yield point deflection as shown in Table 2. Slab with high value of ductility ratio means that it can bear large deflection before failure, which is comparable to Wariyatno et al. (2017) and Rajeshwaran et al. (2018) studies [7, 17].

Table 2. Ductility ratio of slab specimens

Sample	Ultimate load "Fy" (MPa)	Deflection at yield load "Δy" (mm)	Deflection at ultimate load "Δu" (mm)	Ductility= Δu/ Δy
Solid 1	56.23	8.48	21.44	2.53
Solid 2	66.65	9.59	37.25	3.89
PVC 1	62.60	8.34	25.31	3.03
PVC 2	70.12	9.69	28.37	2.93
Concrete 1	49.70	13.16	56.96	4.33
Concrete 2	60.58	14.25	62.15	4.36
POP 1 Rect.	79.32	7.38	40.75	5.52
POP 2 Rect.	69.25	6.74	26.94	3.99
POP 1 Triang.	111.89	10.55	32.70	2.98
POP 2 Triang.	114.90	10.96	21.88	2.00

From the above table it can be noticed that the ductility ratio ranges from 2 to 5.52, for HCRC slab units, with an average value for all slab units greater than 3, which shows comparatively good ductility performance. Many researchers claimed that structural elements with ductility in the range of 3-5 have satisfactory performance and can withstand to a large deflection during sudden forces of earthquake and can redistribute moments [15, 18, 19]. In this research project all the slab units has adequate ductility ratio and can perform well during lateral forces. Unlike flexural strength, the ductility ratio of HCRC slab provided with Plaster of Paris triangular pipes is not good as compared to other HCRC slab units.

4. Conclusions

In this research study cast in-situ hollow core reinforced concrete (HCRC) slabs were constructed by using easy, cost effective and implementable techniques in field. The slabs were tested under third point loading to study their flexural behavior. Based on the above experimental work, following are the conclusions.

- Cast in-situ HCRC one way slabs with locally available material can be made easily by using ordinary conventional construction techniques;
- The flexural behavior of HCRC slabs with Polyvinyl chloride and plaster of paris hollow sections was comparable with the control solid slabs while that with concrete pipes showed 7 to 8 percent reduction in flexural strength;
- The self-weight of HCRC slabs were reduced by 20 to 21 percent compared to their control solid slabs;
- In general a more ductile behavior of HCRC slabs with concrete, Polyvinyl and plaster of paris hollow sections has been observed as compared to solid slab, except the HCRC with triangular Plaster of Paris pipes;
- At higher loads, debonding of concrete was observed in the HCRC slabs provided with polyvinyl pipes resulting in spalling of concrete;
- The HCRC slabs with triangular plaster of paris pipes have greater flexural capacity as compared to other HCRC slabs;
- In general all tested specimens performed well in shear and no critical shear failure was observed;
- The studied Cast in-situ HCRC one way slabs with locally available material can be used with confidence in construction.

4.1. Recommendations

- More work can be carried to check if using pipes with high concrete strength can increase the flexural strength of the HCRC slabs.
- The spalling of concrete at high loading in case of HCRC slabs with polyvinyl pipes can be investigated in order to improve bond between concrete and polyvinyl pipes.

5. Acknowledgement

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6. Conflicts of Interest

The authors declare no conflict of interest.

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