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# EXPERIMENTAL STUDY TO PRODUCE MANHOLE COVER USING ULTRA-HIGH PERFORMANCE CONCRETE

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**ABSTRACT:** Ultra-High-Performance Concrete (UHPC) has been increasingly widely applied in civil and infrastructure engineering because of its outstanding properties in strength and durability. In particular, the research and application of UHPC in structures requiring high load-bearing capacity and high impact resistance, such as manhole covers, will have great practical significance. This paper presents experimental results of some properties of UHPC and uses the finite element method (FEM) to analyze and design two types of UHPC manhole covers according to the requirements for BS EN 124 classes A15 and B125. The research results show that the UHPC manhole covers need only 30 mm thickness without steel bar can ensure class A15. However, to meet the requirements of class B125, the UHPC manhole covers with a thickness of 60 mm need a steel mesh of diameter size 10 mm reinforcement. The test results prove that the load-bearing capacity of the UHPC manhole covers from the experiments is consistent with the theory.

*Keywords: Ultra-High-Performance Concrete, Manhole cover, FEM, Thin-slab, Impact resistant*

## 1. INTRODUCTION

Manhole covers have been used commonly for traffic infrastructure with different types, cover-size, and standard classes. They can be made of cast iron, composite, or reinforced concrete. However, the use of these traditional materials currently has some disadvantages. First, cast iron manhole covers and their cast iron structure systems are very heavy, poor impact resistance caused by the brittle characteristic, and susceptible to corrosion in aggressive environments. When using special cast iron such as cast iron to increase load-bearing capacity, avoid corrosion, etc., leading to a higher product cost. While manhole covers made of gray cast iron are cheaper than cast iron, they have low bending and effect resistance and are susceptible to corrosion due to the impact of corrosive agents in aggressive environments.

In addition, the handle and installation of heavy cast iron manhole covers also cause many difficulties. In recent years, social reality in many countries occurs the phenomenon of manhole cover theft and leaves large empty holes [1]. This causes damage to public property, endangers human life, unsightly the city, and pollutes the environment by the odors from the sewer systems released when no manhole cover is available (Fig 1). One good solution is to replace cast iron manhole covers with composite ones are usually made from synthetic materials, with organic resins as a substrate. This type has a rather slender and light structure; besides, the manufacturing of composite manhole covers will make it less noisy than that of cast iron [2]. However, composite is a non-recyclable material, so the manhole cover of this type does not happen to be stolen. It should also be noted that the main disadvantage of composite manhole covers is that it is not durable when exposed to atmospheric factors such as rainwater, surface water, sunlight containing many UV rays. After a few years of use, composite manhole covers are often discolored, brittle, easily broken and damaged when subjected to dynamic and environmental loads [3, 4]. In the case of a normal concrete manhole cover, this type of manhole cover has a low bearing capacity, thick and heavy structure, low environmental durability, and poor impact resistance (Fig 2).

Fig 1. The cast iron manhole cover stolen

Fig 2 The reinforced concrete manhole cover broken

In Vietnam, the research and development of UHPC have been conducted for the past ten years, and the published research results mainly focus on the assessment of manufacturing capabilities in Vietnamese conditions. In 2006, Tuan et al. [5] conducted a study on the possibility of manufacturing UHPC in Vietnam. The authors suggested that UHPC could be produced by using existing materials in Vietnam. Up to now, the highest compressive strength of 200 MPa can be achieved from published studies on UHPC in Vietnam [6]. Besides, studies using mineral additives such as rice husk ash [7, 8], blast furnace slag [9], fly ash, zeolite [10] to improve strength, reduce shrinkage, studies on predicting bending behavior of UHPC materials [11] have also been studied. In addition to laboratory studies, the research and application of UHPC materials in bridge construction has been developed recently in Vietnam [12, 13]. Recently, in 2019, one of the research projects to successfully apply UHPC to the construction of the An Thuong (Hung Yen province) residential bridge with a length of 21m, this is the most extended UHPC beam in Vietnam up to now [14].

The studies on materials and practical application of the structures mentioned above reveal that the application of UHPC with excellent durability and high impact resistance to produce manhole covers is appropriate and valuable. UHPC manhole covers have the following advantages: (1) Overcoming the phenomenon of manhole covers being stolen, reducing damage to public property, and reducing accidents; (2) Reducing the production cost of manhole covers; (3) Increase the durability of the structure; (4) Greatly reduce the construction costs. Zhang et al. [15] studied on low-cost Reactive Powder Concrete and proposed three types of flat, ribbed, and fish-belly meeting the similar requirements of Class A15, B125, C250, respectively. However, the published technical information is not clear, and it needs to be optimized with the quality requirements of the manhole cover complying with Vietnamese standards.

Therefore, this paper presents the research and producing the UHPC manhole cover with outstanding properties such as compressive strength of concrete above 120 MPa, high flexural strength, to optimize following the quality requirements of Vietnamese standards.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The materials used in this research included Portland cement with the physico-mechanical properties are shown in Table 1 which meets the requirements complying with Vietnamese standard TCVN 2682:2009 [16]. The mean particle sizes of cement were 11.4µm; Condensed Silica fume, Elkem, with a mean particle size of 0.15µm and a $SiO_2$ content of 92.3%, the reactivity index of SF over 113.5%; Quartz sand with a mean particle size ranging from 100 to 600 µm, the void volume of non-compacted quartz sand was 45%; Steel fiber with 0.2mm in diameter, 13mm in length and tensile strength of 2700 MPa; Polycarboxylate-based Superplasticizer (SP) and Tap water were used in the study.

Table 1 Physico-mechanical properties of Portland cement

| Properties | Unit | Value | Specification |
|---|---|---|---|
| Retained on 0.09mm sieve | % | 0.6 | ≤ 10 |
| Fineness (Blaine) | $cm^2/g$ | 3870 | ≥ 2800 |
| Standard consistency | % | 29.5 | - |
| Compressive strength | MPa | | |
| *- 3 days* | | 29.8 | ≥ 21.0 |
| *- 28 days* | | 52.2 | ≥ 40.0 |

### 2.2 UHPC mix proportions

The mixtures proportion of UHPC were used in the study which is given in Table 2. Steel fiber was 2% by the volume of the UHPC mixture.

Table 2 Mix proportion of UHPC mixtures

| Ingredients of UHPC mixture ($kg/m^3$) | | | | | Fiber, % vol. |
|---|---|---|---|---|---|
| Water | Cement | Silica fume | Sand | SP | |
| 162 | 886 | 222 | 1109 | 39.5 | 2.0 |

### 2.3 Mechanical properties of UHPC

*2.3.1 Workability of UHPC mixtures*

The workability of mixtures was measured using a mini cone according to ASTM C1437 [17]. The flowability diameters were between 200 and

230 mm.

*2.3.2 Compressive strength and Elastic modulus of UHPC*

The compression test of UHPC was determined with a sample size of 100×200 mm. The samples were cast into the molds and cured at 27±2ºC. The compressive strength was determined at 28 days with a load increment of 1.0±0.05 MPa/s. The compressive strength of UHPC at 28 days was over 120 MPa.

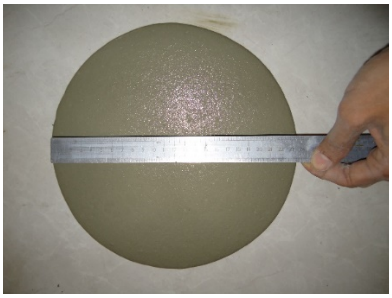


Fig 3. The flowability of UHPC mixtures

The elastic modulus of UHPC was determined with a sample size of 100×200 mm. The compressometer and extensometer shall use linear variable differential transformers (LVDTs), or other sensors of equal or greater accuracy for measuring displacement. The load shall be applied at the rate of 1.0±0.05 MPa/s. The UHPC elastic modulus test image was shown in Fig 4. The elastic modulus of UPHC was reached 45 GPa. The mechanical properties of UHPC are shown in Table 3.

Table 3 Mechanical properties of UHPC

| Compressive strength $f'_c(MPa)$ | Flexural strength $f_t(MPa)$ | Elastic modulus $E\ (GPa)$ |
|---|---|---|
| 120 | 15 | 45 |


Fig 4. Elastic modulus test for UHPC samples

*2.3.3 Flexural tests of UHPC*

The flexural strength test of UHPC was determined with a sample size of 100×100×400 mm. The span length between the support was 300 mm. The samples were cured at standard condition (t=27±2ºC, RH ≥98%) and tested using a beam with Four-Point Loading at 28 days. The flexural strength was determined using a hydraulic press with a load increment from 0.025 - 0.075 mm/min at deflection lower than L/900, and the load rate from 0.05 – 0.20 mm/min at deflection of a beam was over L/900. The flexural strength of UHPC was 15 MPa (Table 3). Image of UHPC sample after fracture is shown in Fig 5.

Fig 5. The sample of UHPC after fracture

## 3. DESIGN AND ANALYSIS OF UHPC MANHOLE COVERS

The load-bearing capacity of manhole covers according to European Standard BS EN 124: 1994 [18], the manhole covers are classified into four common classes A, B, C and D based on their locations on the road cross section as given in Table 4.

Table 4 Classification of the load of the manhole cover

| Weight class | Maximum load (kN) | Application |
|---|---|---|
| A15 | 15 | Pedestrian and cyclist |
| B125 | 125 | Occasional light traffic and driveway duty |
| C250 | 250 | Slow movement of cars and vans (For example in car parks) |
| D400 | 400 | Main road traffic-fast moving traffic |

According to Vietnamese standard TCVN 10333-3:2014 [19], the manhole covers are divided on size and load-bearing capacity class as shown in Fig 6 and Table 5.

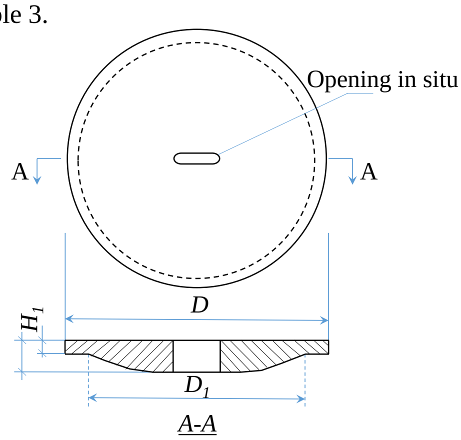
Table 5. Some common basic dimensions of manhole covers [19]

(Unit: mm)

| Load-bearing capacity Class | D | Dev. | $D_1$ | Dev. | H | Dev. | $H_1$ | Dev. |
|---|---|---|---|---|---|---|---|---|
| A15 | 643 | + 3 | 580 | - 2 | 45 | + 4 | 20 | + 2 |
| B125 | 643 | | 580 | | 65 | | 30 | |
| C250 | 643 | | 580 | | 75 | | 35 | |
| D400 | 643 | | 580 | | 75 | | 45 | |

Based on the regulations on load level and the common scale of the application range, the round manhole cover with a diameter of 643 mm was selected for the experimental research, in which the design thickness ensures the bearing capacity when using the UHPC for load classes A15 and B125.

The Finite Element Method (FEM) was used to model the structure of the manhole cover and analysis its internal force under load. The manhole cover is a round plate with a diameter of 643 mm and modeled using 2D plate elements. A steel plate 300×300 mm ($A_{plate}$=0.09 m$^2$) was used as a cushion plate. The manhole cover was placed freely on the manhole at points around the circumference, so the boundary conditions are assumed as follows: (1) Around the circumference of the manhole cover is considered as hinged movable supports (rollers); (2) One point is considered as hinge; with this restraint, the model is not horizontal unstable also not rotationally unstable around the horizontal axis. Material parameters used in the model were taken based on the experimental results, as shown in Table 3.




*Note:*
*D – outside diameter;* *H - height;*
*D1 – inside diameter;* *$H_1$ – height of support*

Fig 6. Manhole cover (Vietnamese standard TCVN 10333-3:2014) [19]

From the analysis results, the internal forces of the manhole covers were obtained as follows:
The A15 manhole cover with a thickness of 30mm: With a test load $P_{jack}$=15 kN=1500 daN, the equivalent distribution load on cushion plate p=$P_{jack}$ / $A_{plate}$=1500/0.09=16667 daN/m$^2$.
The B125 manhole cover with a thickness of 60mm: With a test load $P_{jack}$=125 kN=12500 daN, the equivalent distribution load on cushion plate p=$P_{jack}$ / $A_{plate}$=12500/0.09=138889 daN/m$^2$.
The structural analysis model, internal force diagram and stress analysis results of the UHPC manhole cover class A15 and B125 are shown in Fig 7 – Fig 11 (with system units of daN and m).

It can be seen that with class A15, the maximum tensile elastic stress reaches 13.5 MPa, which is within the tensile capacity of UHPC, so there is no need to be added reinforcement. Therefore, it is possible to use UHPC without rebar steel reinforced to design manhole covers according to load class A15. With load type B125, the maximum tensile elastic stress is 28.1 MPa, much larger than the tensile capacity of UHPC. Thus it is necessary to arrange steel rebars to ensure the required load level of the manhole cover.

A steel mesh of diameter size of 10 mm with a tensile strength $R_s$ of 280 MPa was calculated for the UHPC manhole cover B125. The arrangement of steel rebars is shown in Fig 12. The structural analysis results show that with class B125 kN, 60mm-thickness, 10mm-diameter steel rebars, the maximum combination moment of 813 daN.m, the UHPC manhole cover as designed above can meet the requirements of class B125.

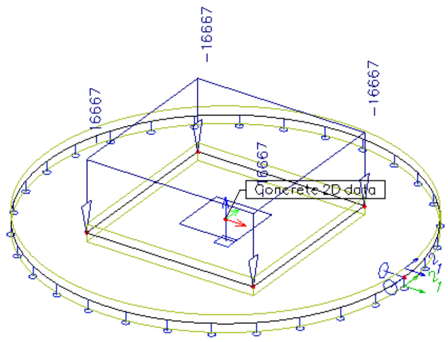



Fig 7. Structural analysis model of UHPC manhole cover with class A15

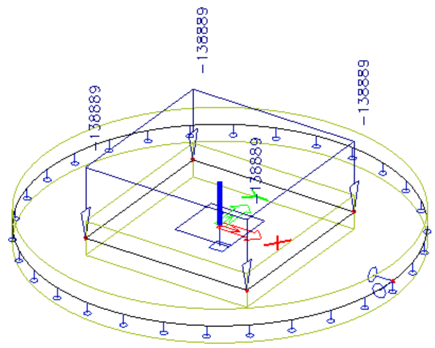
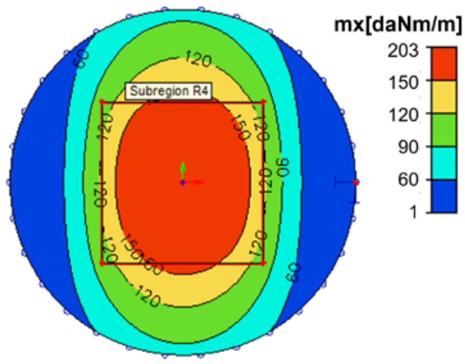
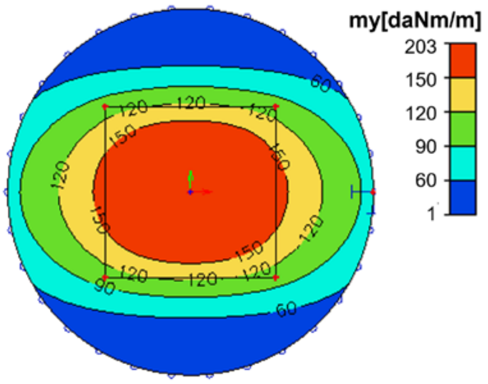



Fig 8. Structural analysis model of UHPC manhole cover with class B125

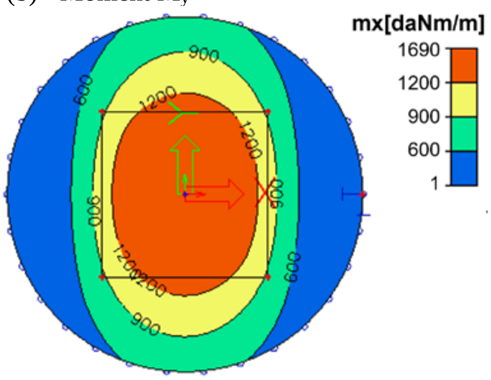



(a)

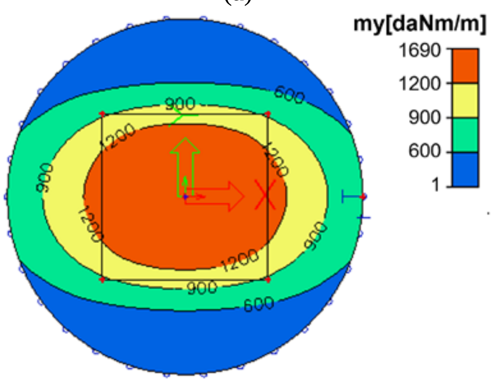



(b)

Fig 9. Bending moment with class A15: (a) Moment $M_x$; (b) - Moment $M_y$

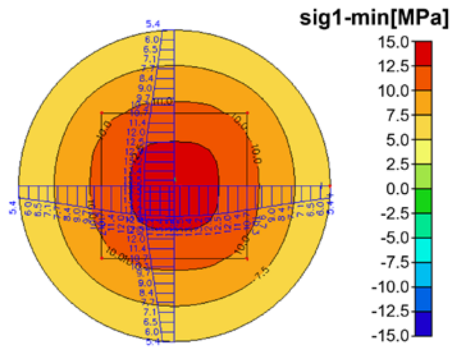



(a)

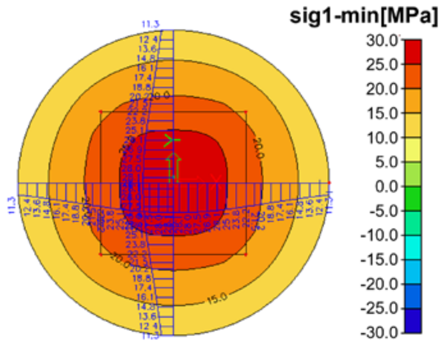



(b)

Fig 10. Bending moment with class B125: (a) Moment $M_x$; (b) - Moment $M_y$




(a)




(b)

Fig 11. Stress distribution of manhole cover with different classes (a) A15 and (b) B125

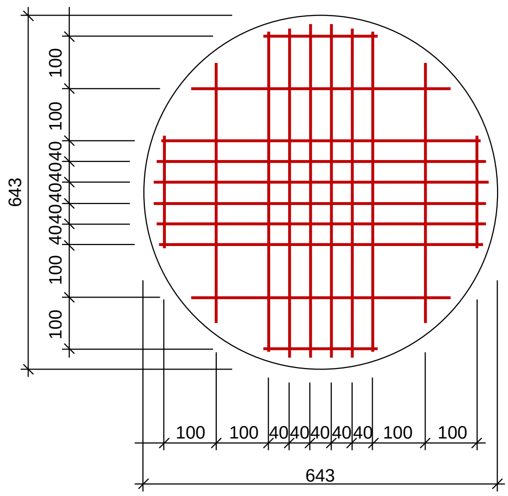



Fig 12. Arrangement of steel rebars for the UHPC manhole cover with class B125

## 4. EXPERIMENTAL DETERMINATION OF LOAD BEARING CAPACITY OF UHPC MANHOLE COVER

### 4.1 Casting the UHPC manhole cover

Based on the design as shown in Section 3, for each load class, i.e. A15 and B125, 02 groups of the UHPC manhole covers were produced. The installation work placing steel bars for class B125, the process of mixing and the casting UHPC for the manhole covers are shown in Fig 13 and Fig 14.

**Fig 13.** Mixing the UHPC.

Fig.14. Installing manhole cover using steel reinforcement with class B125

**4.1 Experimental evaluation of the load-bearing capacity of UHPC manhole covers**

The load test of the manhole cover samples was performed according to Vietnamese standard TCVN 10333:2014 [19]. A hydraulic press with a tolerance of ± 3 % was used for the test load. The test procedure for the UHPC manhole cover was carried out as follows:

Apply force to the midpoint of the steel spacer, increasing the load to 10% of the design loading. Check the stability and ensure good contact of the whole system.

Continue to increase the load at a loading rate of 200 kN/min until 3/4 of the design load was reached, increasing at a load rate of 44 kN/min. When the design load was reached, hold the load for 5 minutes and observe. If there is a crack, measure the crack width, and stop the test when the sample was damaged. During the experiment, the force value on the jack was measured through a load cell electronic force measuring instrument, and the displacement of the UHPC manhole cover was measured by 01 LVDT, which was placed in the center of the manhole cover. The measurement results from LVDT, load cell and displacement measuring device were recorded automatically by computer.


Fig 15. Testing UHPC manhole cover and samples after testing

The relationship between load and deflection of the UHPC manhole cover with class A15 is shown in Fig 16 and Table 4. When the design load is reached the value of 15 kN, the deflection of the sample is very small (less than 3 mm). The relationship of load and deflection in this period is still linear, and this is consistent with the design for UHPC manhole covers class A15. In this case, the manhole is not needed the rebar reinforced because the material is just still working in the elastic region. Besides, the test results also show that the load and deflection relationship is similar to the flexural test results of the UHPC sample. After this period, the load was still capable of increasing until the sample is damaged, and the load reaches 1.6 times the design load. It should be noted that the structure causes cracks for normal concrete and will be damaged quickly when reaching the limit state. However, for the UHPC sample, when cracks appear, the member still maintains the bearing capacity to ensure the structure's safety. The experimental results show that because the reinforced concrete contains dispersed steel fibers and when many cracks appear and the energy is distributed, the destructive mechanism occurs slowly, not suddenly to ensure safe use.

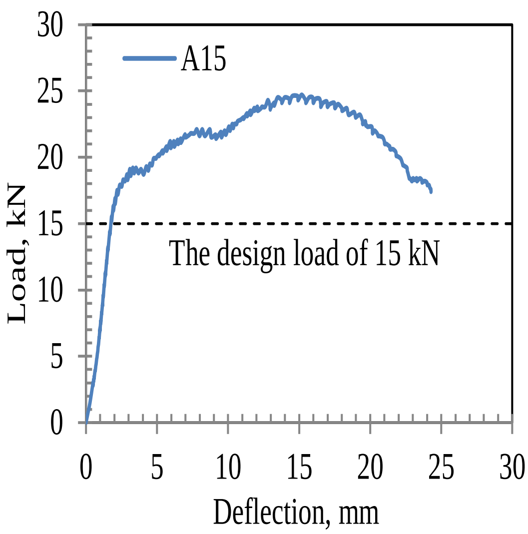



Fig 16. Relationship between load and defection of samples with class A15

For the UHPC manhole covers with class B125, when reaching the design load of 125 kN, the deflection of the sample is about less than 5 mm. The relationship of load and deflection of the B125 sample in this period is still linear. The load reaches twice the design load, the slope of the graph decreases markedly, and then the maximum value of the test piece is reached. Displacement is 12.0 mm until the specimen is damaged (Fig 17 and Table 6).

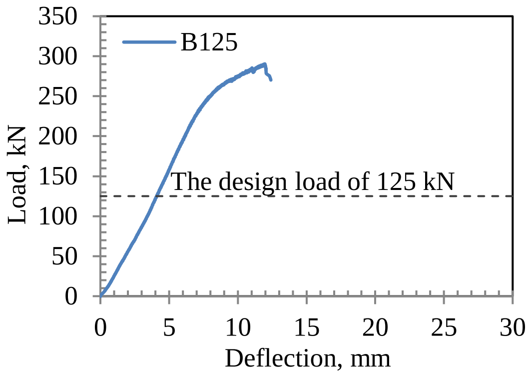



Fig 17. Relationship between load and defection of the sample with class B125

Table 6. Test results of manhole covers with different thicknesses with different loads.

| Sample | Thickness (mm) | Maximum deflection $f_{max}$ (mm) | Load at allowable deflection $P_f$ [f]=l/200= 3,22 mm | Destructive load $P_{ph}$ |
|---|---|---|---|---|
| | | | $P_f$ (kN) | $P_{ph}$ (kN) |
| A15 | 30 | 24.3 | 19.2 | 24.6 |
| B125 | 60 | 12.4 | 94.1 | 290 |

When reaching the design load of 125 kN, the deflection of the sample is about 4.1 mm. The load and deflection relationship during this period remains linear for the B125 samples. After this period, until the load reaches about 2 times the design load, the slope of the graph decreases markedly, and then the maximum value of the test piece is reached. Displacement is about 12.1 mm when the sample is damaged.

It is assumed that the member is subjected to the standard load with a controlled deflection of 1/200. The experimental results show that the behavior is different with samples having different thicknesses. For example, for samples with a thickness of 30 mm without reinforcement, the destructive load is higher than the load corresponding to the allowable deflection; however, significantly higher for samples with a thickness of 60 mm. When the thickness of the manhole covers increases from 30mm to 60 mm, the load corresponding to the allowable deflection increases from 19.2 kN to 94.1 kN.

To achieve such outstanding properties is due to that the UHPC contains dispersed steel fibers to increase the ductility of concrete. Therefore, the structure still ensures its bearing capacity when the deflection exceeds the limit of normal concrete standards. Besides, the failure mode of the samples using dispersed steel fibers is a gradual failure that does not suddenly ensure safe use.

Therefore, when using UHPC, it is necessary to accept a much larger deflection than conventional concrete, and only then will the steel fiber reinforcement begin to exert its tensile strength. This is like the concrete slabs appearing to crack and the steel fibers "bridging" through the crack. It can be observed that the destructive phenomenon occurs either by breaking the wire or pulling out the wire (but usually, the steel has very high strength, so breaking or it happens mainly because the wire is pulled out). When the sample is damaged, the bearing capacity is much larger than the load corresponding to the allowable deflection, so it is safe to use. The obtained experimental results show that the results are entirely consistent with the theoretical calculations.

## 5. CONCLUSIONS

The design and analysis of the UHPC manhole covers using the FEM have shown that the theoretical calculation results are relatively convergent. With the same size, UHPC material, and same steel content, the results obtained have a mean deviation of 5% to 15%. The UHPC manhole cover models are manufactured in accordance with the requirements for BS EN 124 classes A15 and B125.

Based on the experimental results of the UHPC manhole covers, some conclusions can be drawn as follows:

- For class A15, the UHPC manhole cover was designed and produced with a thickness of 30mm without steel reinforcement. For class B125, the UHPC manhole cover can be fabricated with a thickness of 60mm and a steel rebar mesh of diameter size 10 mm reinforcement.
- With class A15, when reaching the design load of 15 kN, the deflections of the samples are very small (less than 3 mm). With class B125, at the design load value of 125 kN, the deflections of the samples are less than 5 mm. The maximum load achieved is 1.6 times higher than the design load.
- When considering the load bearing and deflection limit span l/200, the results show that for the UHPC sample without reinforcement according to class A15, the destructive load is larger than the load corresponding to the allowable deflection. However, for class B125, the destructive load of the UHPC samples is significantly higher than the load corresponding

to the allowable deflection. When the thickness increases from 30 mm to 60 mm, the load of the UHPC manhole cover samples corresponding to the allowable deflection increases from 19.2 kN to 94.1 kN or increases by 160%.

## 6. ACKNOWLEDGMENTS

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