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Experimental analysis of static capacity of fibrous concrete cambered slabs after impact loading effect

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Abstract. Fibrous concrete is an enhanced material by adding fibers to the ingredients of normal concrete. This addition improved some properties of the regular concrete, which are growing concrete ductility, decreasing concrete shrinkage, and raising concrete resistance to the dynamic attacks. The aim of this paper is more investigating the properties of fibrous concrete by finding out the effect of impact loading induced by a free fall ball on flexural capacity of fibrous concrete from one side, and finding out the importance of camber construction in reducing the influence of impact loading on the flexural capacity of concrete slabs from another side. For that purpose, three concrete slabs of (80X80X4) cm dimensions were dynamically and then statically loaded. The three specimens had the same steel fiber dosage of 0.5%, but they had different slab camber at the mid span where one specimen had no camber, the second specimen had 10 mm camber, and the third specimen had 20 mm camber. In addition to the difference in the slabs’ camber, the three slabs were subjected to a different number of impacts and from various heights to get a better explanation. Tests results showed that presence of fibers and increasing slab camber caused an improvement in the specimen resistance to both of impact and flexural loads, decreased the specimen crack width and number, and provided a safer residence for tenants.

1. Introduction
What is called researchers all over the world for improving the weak properties of the normal concrete is to achieve the building’ structural integrity. Normal concrete is renowned in providing enough strength for compression loading, but it is not good in resisting impact loading, increasing the rate of causing structures collapse and disasters.
In the last years, the world suffered some actions that threatened both of structures and people. Most affecting actions on buildings comprise terrorist threats and global warming actions which generate sudden dynamic loads in addition to the static ones; the thing that inspired specialists in concrete to produce a new type of concrete with enough capability in absorbing the created energy on structures by dynamic loads [1, 2].

Published studies categorized dynamic loads into two sets depending on the source that are generated from: naturally and humanly dynamic loads [3, 4]. Naturally dynamic loads include loads produced by natural world sources, such as winds, tornados, earthquakes, etc. while humanly loads comprise loads created by man-made sources, such as rockets, and blasts. Fibrous concrete is the most preferred concrete for situations like these where it can provide 50 Mpa strength when it is compared with normal concrete that can achieve less than 50 Mpa strength [5]. And, it is more durable and can provide more strength for tensile loading comparing with normal concrete [6, 7].
Hence, to have a clear idea about how dynamic loading will influence the behaviour of fibrous concrete, how presence of camber will stand the dynamic loading, how height of impacting weight and number of impacts will reduce the flexural strength of the slabs, and how the failure type will be under these fluctuant parameters, authors of this paper intended to test three concrete slabs with different characteristics.

The three concrete slabs had the same dimensions of (80X80X4) cm and had the same content of steel fiber of 0.5%. Next, one of the slabs had no camber, which is named T4Ftest, where the bottom surface was plane, while the other two slabs had cambers of 10 mm, which is named T4C1, and 20 mm, T4C2. Moreover, the flat slab, T4Ftest was subjected to three impacts from a 90 cm height, T4C1 was subjected to one impact from a height of 120 cm, and T4C2 was subjected to four impacts; one from a 120 cm height and the others from 90 cm height as performed by the author Al Zahid [8]. After testing the three slabs dynamically, the same slabs were loaded and tested statically to get answers for all the questions listed in the previous paragraphs and to have a better explanation regarding structures loading capacity and behaviour when they experience unexpected dynamic loads plus static loads.

2. Materials and method

In this section, a brief description for all the used ingredients for casting the three fibrous concrete slabs is included, and the way of performing dynamic and static loading is summarized; comprising a description for the testing machines and the way of installing the slabs.

2.1. Materials

Fibrous concrete studied in this paper is produced by mixing all of: cement, sand, silica fume, steel fiber, and glenium.

- Cement: Ordinary Portland cement is the type of cement that is used for producing the three slabs, and it is manufactured locally by Al Najaf Al Shraf factory in Najaf, Iraq. This type of cement meets the Iraqi standard specification No. 5- 1984.

- Fine Aggregate: The particle sizes used for these slabs are within the range (600 μm) to (150 μm), and the physical properties are 2.65 specific gravity and 1.3% absorption.

- Silica Fume: Sika-Fume S92D is used for this work as illustrated in figure 1. It is useful as a binder and filler in concrete [9].

- Steel Fiber: WSF 0213 is used to enhance concrete ductility [10]. This type of fiber is made in China and meets (ISO 9001/2008) specifications. Fibers are with brass coated surface, with 2300 MPa tensile strength, straight, of 13 mm average length, of 0.2 mm diameter, and with 65 aspect ratio. figure 2. shows sample of steel fiber that was used.

- Glenium: The type of superplasticizer that was used is Glenium 54 as shown in figure 3 to improve the performance of concrete where it works on reducing water.
2.2. Impact testing machine
The drop-weight testing equipment was fabricated locally by the author Al Zahid [8] to find out the strength of the fibrous concrete slabs for impact loading as illustrated in figure 4.

![Image of impact testing machine]

Figure 4. Drop-weight testing equipment.

The testing equipment was made up by using I and rectangular steel sections, and other supplements were needed as well to perform the test and get the required data, such as a dropping weight, an electronic ultrasonic sensor, an electronic accelerometer sensor, and an electronic infrared sensor. A 5 Kilograms drop-weight was required to apply impacts on the set up slabs on the equipment where a steel ball was used for that purpose. Next, the reason for setting up the electronic accelerometer sensor is to know the acceleration of the drop weight by recording the impacting force made by the drop weight with time. And, the electronic infrared sensor was necessary to record the specimens’ displacement with time. While, the electronic ultrasonic sensor was set up to measure the specimens’ lateral displacement with time.

2.3. Methodology of performing impact loading test
After installing the fibrous concrete slabs on the drop-weight testing machine by the researcher Al Zahid [8], the impacting weight, steel ball, was fallen freely by the effect of its own weight on the top faces of the cambered slabs and at the center from different heights (90 and 120 cm) as illustrated previously. While the electronic sensors were put at the following positions: the electronic accelerometer sensor was put on the drop-weight to record the impacting force and time data, electronic infrared sensor was installed at the center of the bottom faces of the cambered faces to provide the author with the slabs deflection with time data, and the electronic ultrasonic sensor was fixed in a position where the lateral displacements of the cambered slabs can be obtained.

2.4. Static load testing methodology
Some researchers all around the world conducted a number of studies to define the characteristics and behaviors of both fibrous concrete and normal weight concrete from one side, and to well specify the differences between them. For instance, Aravind et al. [11] performed experimental research about the static capacity of reinforced fibrous concrete beams with dimensions of (1.5X1.5X0.18) m. Moreover, Jia et al. [12] conducted a laboratory investigation regarding the behavior of fibrous concrete under impact loads influence by subjecting two-ways reinforced concrete slabs to blast loading. However, these experimentally conducted searches and other studies did not investigate deeply the properties and behaving ways of concrete after applying concrete to dynamic loads. The reason that inspired the authors of this paper to perform a laboratory study and then provide a complete
interpretation concerning the flexural capacity and behavior of fibrous concrete after applying impacts forces to those who are interested in designing structures. Therefore, the same slabs that were applied to impact loading where installed one more time on the hydraulic flexural strength testing machine, which is shown in figure 5.

![Figure 5. The hydraulic static testing machine.](image)

A solid square cube with dimensions of (15X15) cm was set up at the center of the top face of slabs to distribute the applied load by the hydraulic machine in two directions of slabs and realize the condition of two-way slabs.

### 3. Results and discussions

In this section, the results of the three tests: compression test, impact loading test, and flexural loading test are included. In addition, the outcomes of the tests are discussed in details.

#### 3.1. Compression test results

Three cubes for each slab were cast on the same day of casting the slabs and tested for knowing their compression strength by the author Al Zahid [8]. The average of each three cubes and for each slab is calculated and included in table 1. The cubes set of the slabs were tested at different ages as it can be noticed from table 1.

| Slab     | Compression Strength (MPa) | Age (Day) |
|----------|---------------------------|-----------|
| T4Ftest  | 84.265                    | 47        |
| T4C1     | 89.313                    | 62        |
| T4C2     | 85.280                    | 63        |

#### 3.2. Impact loading test results

Table 2 comprises the following information: the maximum impact loading capacity in Kilo-newton for each slab, the number of impacts, the height of dropping weight, and the corresponding deflection for the maximum load in mm.
Table 2. Impact test results.

| No. of Impacts | T4Ftest | T4C1 | T4C2 |
|----------------|---------|------|------|
|                | 90 cm   | 120 cm | 90 cm | 120 cm | Deflection | Deflection | Deflection |
| 1st Impact     | 4.45    | 3.40  | 8.91 | 2.71 | N/A | 11.87 | 1.79 |
| 2nd Impact     | 3.71    | 4.3   | N/A  | N/A  | 7.92 | 2.07 | N/A | N/A |
| 3rd Impact     | 3.36    | 3.21  | N/A  | N/A  | 7.17 | 2.25 | N/A | N/A |
| 4th Impact     | N/A     | N/A   | N/A  | N/A  | 6.68 | 4.28 | N/A | N/A |

As it is clear from table 2, the slab with the biggest camber, T4C2, stood the highest impacting load in the first loading for approximately 11.87 kN with the least corresponding deflection of 1.79 mm when it is compared with the other two slabs. While, the slab with a less camber, T4C1, provided less strength for the impacting force which is 8.91 kN with a higher corresponding deflection of 2.71 than T4C1. And, the slab with zero camber, T4Ftest, endured the least impact loading for nearly 4.45 kN with the highest corresponding deflection of 3.4 mm comparing with the other two slabs, although it was subjected to the dropping weight from a lower height of 90 cm when it is compared with the height of the drop-weight of the T4C1 and T4C2 that is 120 cm in the first loading.

Next, the cracks progression after each impact loading is photographed for all the slabs. Figures 6 (a through c) show the cracks growth of the slab T4Ftest where the crack width was not specified by the author Al Zahid [8] because of an electronic problem. The figures illustrate the slab’s stiffness is decreasing after each dynamic loading.

![Figure 6](a) ![Figure 6](b) ![Figure 6](c)

**Figure 6.** The crack pattern of the slab T4Ftest after a) the first impact loading, b) the second impact loading, and (c): the third impact loading.

Moreover, figure 7 shows the created cracks after freely applying a drop-weight on the slab T4C1. The average cracks width was 0.0362 mm.
Finally, figures 8 (a through d) exhibit the cracks development of the slab T4C2 after freely dropping a weight from a 120 cm height in the first time and from a 90 cm height in the other three subsequent stages of dynamic loading. The average cracks width was 0.0175, 0.02, 0.02, and 0.025 mm in the 1st, 2nd, 3rd, and 4th loading stage, respectively.

Figure 7. The crack pattern of the slab T4C1 after applying an impacting load.

Figure 8. Crack pattern of the slab T4C2 after (a): the 1st stage of loading, (b): the 2nd stage of loading, (c): the 3rd stage of loading, and (d): the 4th stage of loading.
3.3. static load testing results
As specified in the previous sections, the three impacts loaded fibrous concrete slabs were loaded one more time statically. The slabs were progressively statically loaded where the static load was increased gradually by 0.5 kN till slabs failure, and the corresponding deflection for each load increment was recorded. Table 3 includes the maximum flexural capacity of the slab T4Ftest after being impacted for three times from a height of 90 cm, the maximum flexural capacity of the slab T4C1 after being impacted one time from a height of 120 cm, and the maximum flexural capacity of the slab T4C2 after impacting it from a height of 120 cm for one time and from a height of 90 cm for three times. Besides, Table 3 comprises the deflection corresponding to the maximum flexural loading of each slab.

Table 3. Static test results.

| Slab      | Static Load (kN) | Deflection (mm) |
|-----------|------------------|-----------------|
| T4Ftest   | 19.5             | 13.6            |
| T4C1      | 16.5             | 4.91            |
| T4C2      | 17.0             | 4.21            |

From the results of static loading in Table 3, the relationship among the maximum flexural strength, deflection, and camber height of the slabs was a non-uniform relation since the slabs were subjected to a different number of impacts and from different heights. And so, the slab with no camber, T4Ftest, provided the highest flexural strength of 19.5 kN, and it was the most deflected slab for about 13.6 mm, the slab with 1 cm camber, T4C1, stood a less static loading than T4Ftest which was 16.5 kN and deflected less for approximately 4.91 mm, and the slab with 2 cm camber provided a higher flexural strength than T4C1 but less than T4Ftest, and it was the least deflected slab than the other two slabs for nearly 4.21 mm. Figure 9 illustrates the develop of load-deflection curves of the three fibrous concrete slabs.

Figure 9. Load-deflection curves of the fibrous concrete slabs.

The average crack width and number generated by flexural loading were specified and compared for all slabs. For that purpose, the cracks created during impact loading were drawn using a blue marker, and the cracks caused by flexural loading were marked using a red marker to recognize the two generated cracks. Loading the slab T4Ftest statically led to more expanding the impact loading cracks and to creating new cracks. The average cracks width generated by the flexural loading is 1.718 mm. Moreover, new five main cracks showed up; the cracks started from the loading point toward the slabs edges. As it is shown from figure 10 a, the new cracks were spread out on the bottom face of the slab through the four quarters of the slab.
Figure 10 b shows the cracks distribution and number of the slab T4C1 after the flexural loading. For this slab, some of the new cracks tracked the impact cracks and then continued their way to the slab edges starting from the loading point. While, the other new cracks started from the center of the slab deriving new paths to the slab edges. The average cracks width is 1.023 mm. Finally, the slab T4C2 had a different cracks pattern and distribution as shown in figure 10 c. This slab had a circular crack extending around the center of the slab with a number of diagonal cracks where some of them started from the center of the slab, and the others developed from the boundaries of the circular crack. Almost all the diagonal cracks extended through different paths of the impact loading cracks paths on the bottom face of the slab. The flexural loading cracks have an average width of 1.69 mm.

Figure 10. Impact-Flexural cracks pattern of the slab a): T4Ftest, b): T4C1, and c): T4C2.

3.4. Results discussion

Based on the experimental observations and outputs, discussion the results of dynamic and static tests of the fibrous concrete slabs is performed.

As it can be seen from the previous sections, the height of camber represents the most affecting parameter on specifying the maximum impact loading, maximum static loading, deflection, width of cracks and numbers, and failure type.

Concerning maximum loading capacity, increasing slabs camber height led to increasing the slabs resistance to the applied loads. For example, increasing slab camber by 10 mm (T4Ftest and T4C1) led to increasing impact resistance by 100.25% although the free weight was dropped from a higher elevation on the slab T4C1 which is 120 cm, and increasing the slab thickness by 20mm (T4Ftest and T4C2) led to increasing impact resistance by 166.74% from a higher elevation (120) cm in the first dynamic loading comparing with impacting distance of the slab T4Ftest which is 90 cm. Figures 11 through 14 show the influence of increasing slabs camber on the dynamic loading capacity of fibrous concrete slabs in the 1st, 2nd, and 3rd loading stages. Since, the slabs T4C1 was impacted from a distance of 120 cm for one time and the slab T4C2 from the same distance for one time and 90 cm for three times, these slabs withstood less static loading than the slab T4Ftest as illustrated in figure 14, but they deflected less as it would be explained in the deflection section.
Figure 11. The relation between camber height and dynamic loading capacity in the first loading stage.

Figure 12. The relation between camber height and dynamic loading capacity in the second loading stage.

Figure 13. The relation between camber height and dynamic loading capacity in the third loading stage.

Figure 14. Static loading capacity of the three after dynamic loading stages.

From figure 14, T4Ftest resisted the highest flexural load while the flexural load of the slabs T4C1 and T4C2 was 15.4% and 12.8% less than the load of the slab T4Ftest, respectively; the impacting load was dropped from a higher distance than the impacting distance of the slab T4Ftest.

Regarding deflection, what was found from the results that the relation between slabs deflection and camber is an inverse relation where increasing the slabs camber leads to decreasing slabs deflection. For instance, in the 1st dynamic loading stage increasing the slab camber by 10 mm (T4Ftest and T4C1) and 20mm (T4Ftest and T4C2) led to decreasing deflection by 20.3% and 47.4%, respectively, although these slabs, T4C1 and T4C2, were impacted from a higher distance and withstood more loading as explained previously. Figures 15 (a through c) illustrate the importance of raising up slabs camber in decreasing slabs deflection. Moreover, deflection of slabs caused by static loading was decreasing with increasing slab camber, see figure 15 d.
Respecting crack width, the developed cracks during dynamic loading is a dependent function of three variables, which are height of impacting weight, number of impacts, and slab’s camber. Figure 16 shows how camber height affects the width of the developed crack where increasing slab’s camber by 100% led to decreasing the average crack width by 51.7% when they impacted from the same height and by the same weight. Moreover, the average crack width of the slab T4C2 was increasing gradually by repeating the dynamic loading in the following loading stages where crack width was 0.02, 0.02, and 0.025 mm in the 2nd, 3rd, and 4th loading stage, respectively. The same concept is applicable for the static loading case where slab camber is the key parameter in controlling the width of the developed cracks; increasing slab camber by 10 mm (T4Ftest and T4C1) led to decreasing crack width by 40.5%, and increasing crack width by 20 mm (T4Ftest and T4C2) led to decreasing crack width by 1.6%. For the slab T4C2, the decrease percentage was less because as explained previously this slab was impacted for three more times than the slab T4C1.

Figure 15. The relation between slab camber and deflection in the (a): 1st stage of dynamic loading, (b): 2nd stage of dynamic loading, (c): 3rd stage of dynamic loading, and (d): static loading.
Failure type, a number of factors specifies failure type of concrete slabs, such as concrete type: normal weight or fibrous concrete, loading type: dynamic or static, position of loading, loading amount, etc. For dynamic loading, Jia et al. [12] found that failure type depends mainly on weights of explosives and hitting points or positions of the slabs; whether explosives will impact slabs at their borders or center. Moreover, they proved that degree of damage of slabs will increase by increasing explosive weight and/or by moving the impacting position toward slab borders away from center, and the type of failure will change gradually from flexural to flexural shear failure. Consequently, these factors are the key factors in specifying slabs failure when they will be statically loaded after being dynamically loaded. For this study, different slabs failure was observed; that is because of differences in height of impacting loading, number of impacts, and camber height. Hence, failure type of the slabs T4Ftest and T4C1 is flexural, while the slab T4C2 failed in punching shear.

Finally, buildings collapse is the main concern of designers. Buildings that may be exposed to explosions threaten their residents’ life to the risk of sudden collapse. Therefore, structures which are constructed by slabs with cambers as it was noticed from the previous results are the safest structures where more loads can be withstood and less crack number and width would be caused; consequently, the cost of repairing of this kind of structures is less.

4. Conclusions

Researchers all around the world are inspired to more investigate and improve concrete properties attempting by that providing safe structures after increasing the risky rates on residents because of collapse cases as a result to the terrorism attacks. Hence, three concrete slabs with dimensions of (80X80X4) cm, steel fiber of 0.5%, and with different camber height: 0, 10, and 20 mm were dynamically and statically loaded. The results showed that concrete slabs with the highest camber are the most resisting slabs to impact and static loads and the safest slabs for tenants where deflection and cracks number and width are less. Moreover, slabs with the highest camber can be maintained and with a less cost after being exposed to attacks.

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