

Concrete Ventilated Ground Slabs

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ABSTRACT: Ventilated ground slabs are used to eliminate the problems caused by humidity and radioactive gases released from the earth below. The system allows the passage of pipes and drains beneath it and when constructing the system it is imperative that the cavity is linked to the exterior of the building via tubing. In this study the IGLU modules created by Daliform were used to create the reinforced concrete ground slabs. The study focused on three main parameters consisting of differently sized IGLUs, different concrete toppings and different types of reinforcement. Two types of IGLU modules were used namely the 45cm and 20cm high modules, whilst the concrete toppings used were a 6cm and a 10cm topping. Fabric and steel fibre reinforcement was used for the tests which were carried out on 8 slabs each 150cm by 150 cm in size. Each slab accommodated nine IGLUs. Each of the samples was submitted to a concentrated load which was applied to the top of the central element using a compressor with dimensions 22cm by 22cm. The results proved that the slabs consisting of the 45cm modules and the 10cm concrete topping could withstand a larger load whilst the fibre reinforced and the fabric reinforced slabs produced varying results when compared, depending on the steel fibre to concrete ratio used. The results were also compared to those carried out by Daliform at the University of Padova and conclusions were drawn up in order to gain a better understanding of how the modules work.

Keywords: Ventilated ground slabs, reinforced concrete slabs, steel fibre concrete, IGLU, humidity, radon gas.

1 INTRODUCTION

1.1 *General*

Humidity problems have been associated with buildings for a very long time and it is known that the Romans started using ventilated ground slabs thousands of years ago.

Although various materials and construction methods can be used to create ventilated cavities, the IGLU system designed by Daliform s.r.l. of Italy was used for this study. IGLU modules were first used in 1993 and have been used in a wide range of civil and industrial projects.

The main advantage of the system is that the modules are easily fitted together and can be utilised to create a platform that is able to support both human weight and the concrete used to provide the flooring surface. Another advantage is that compared to other flooring systems, the IGLU modules can be set up in a relatively short time.

The cavity beneath the IGLUs makes it possible to install technical links such as electrical wiring and water pipes without burying them in the foundations. The larger units are also accessible, beneath the system, allowing inspections and repairs to be made when necessary. The cavity is also, advantageous for health reasons too, as it consists of a barrier of circulating under-floor air that can be connected to tubing outside the building, thus allowing radon gas released from the earth, to be dispersed.

Five work phases are required to construct ventilated floors. The first phase would be the excavation and the subsequent levelling of the ground, whilst the second phase would be to cast a layer of concrete for the sub-base and to add any reinforcement necessary for the imposed loads. The IGLUs are then placed using the procedures described in chapter five whilst the fabric reinforcement (unless steel fibre) is then added. Traditionally, a mesh with a spacing of 20cm by 20cm is used with a thickness of six millimetres. The final stage of the process is the

casting of concrete to cover the IGLU modules and to form the floor slab, the thickness of which varies according to the designed loads.

1.2 Testing Parameters

- Type of IGLU
- Type of Reinforcement
- Thickness of Slab

By experimenting with these three parameters, interesting conclusions and observations could be obtained as regards ventilated ground slabs. The type of IGLU to be used was an important parameter to experiment with as Daliform produces a wide range of differently sized IGLU modules.

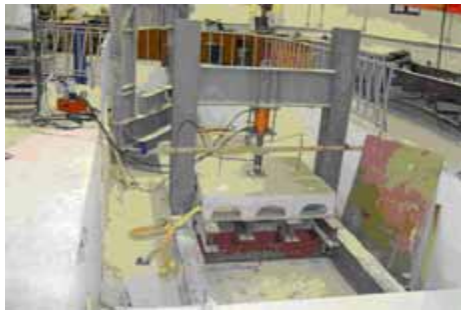


Figure 1.1: Testing Setup

However, it is not clearly defined whether the load carrying capacity of these different modules is similar. Daliform stress that the load carrying capacity of these units is provided by their dome like shape and that all modules have similar load carrying capacity regardless of their height. When carrying out research on the topic it was realised that the larger modules might fail in other modes (besides shear and flexural) such as column buckling. There were other concerns that the columns in the larger modules might suffer a compressive failure.

Therefore, it was felt that it was important to experiment with two different types of modules that were to be found at both ends of the table (Figure 2.11), so that a clear analysis could be made regarding the shape of these units. However when choosing the units, although differently sized units were used, it was decided that modules commonly used in construction would be chosen. Units of height $H = 20\text{cm}$ and $H = 45\text{cm}$ were chosen.

Regarding the type of reinforcement, it was felt that it would be interesting to experiment with fibre concrete since all past research regarding ventilated

ground slabs was made using fabric reinforcement. Fibre concrete would be very useful when designing ground slabs, and therefore, it was important to study how well fibre reinforced slabs compared with fabric reinforced slabs.

The third testing parameter is the slab thickness; perhaps this is the parameter that has been mostly tested by Daliform. Daliform argue that by using this module, lower thicknesses of concrete could be used for similar spans compared to normal ground supported slabs. However, in previous research there has never been any experimentation regarding this specific parameter with differently sized IGLUs or with differently reinforced IGLUs. Therefore it was decided through this study to prove Daliform's claim.

Table 1.1: Characteristics of IGLU
H= outer height and h= inner height

H	4	8	12	16	20	27	35	40	45	55
h	3	4.5	8	11	13	21	29	34	39	44

Table 1.2: Testing Programme

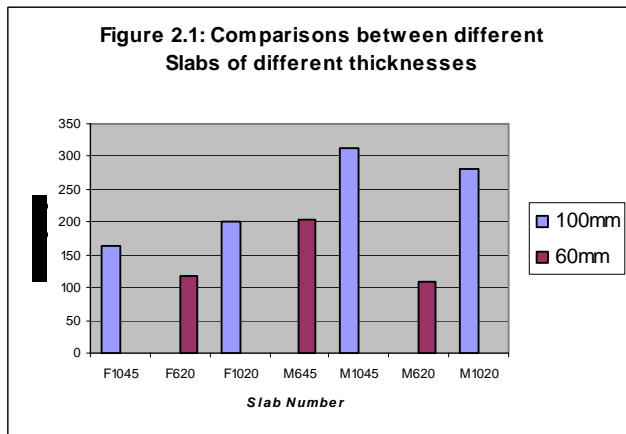
Slab No.	Reinforcement	Thickness	Grade of Concrete	IGLU H
F-6-45	Steel Fibre	60mm	25	45cm
F-10-45	Steel Fibre	100mm	25	45cm
F-6-20	Steel Fibre	60mm	25	20cm
F-10-20	Steel Fibre	100mm	25	20cm
M-6-45	Steel Fabric	60mm	25	45cm
M-10-45	Steel Fabric	100mm	25	45cm
M-6-20	Steel Fabric	60mm	25	20cm
M-10-20	Steel Fabric	100mm	25	20cm

2 RESULTS

Table 2.1 Testing Results

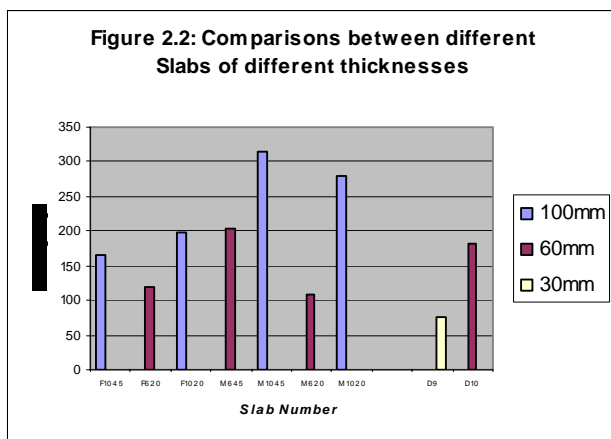
Slab No.	Max. Load KN	Mode of failure	Reinforcement
F-10-45	164.4	shear	1 %
F-6-20	118.8	shear	1.7%
F-10-20	199.4	shear	1.7%
M-6-45	203	shear	A 142
M-10-45	313.6	shear	A 142
M-6-20	109.6	shear	A 142
M-10-20	280.4	shear	A 142

2.1 Comparisons between slabs of different thicknesses



As can be seen in Figures 2.1 and 2.2, it is evident that the thicker slabs have a greater load capacity than thinner ones. This was known beforehand as Daliform achieved similar results in their tests

What is of invaluable importance to Daliform, is that ventilated ground slabs (IGLU units) are advantageous when compared to other ground supported slabs that (apart from other aspects) they can afford longer spans or rather thinner slabs. The experiment revealed that the 60 millimetres slabs did not withstand great loads, whilst the 100mm slabs achieved significantly positive results. Results showed that when comparing the average maximum loads, the 100mm slabs achieved a fifty five per cent gain over the 60mm slabs. A 100 millimetre slab cannot be considered as a thick slab and this study has proved that IGLU supported floors (ventilated slabs) can afford thinner slabs than ground supported floors. This is due to the fact that in a ventilated ground slab, its dome shape design provides the load capacity for the unit as a whole.



The results obtained in this study were compared to those obtained by Daliform. Daliform experimented with slabs of different thicknesses namely 30 millimetres slabs and 60 millimetres slabs. Both sets

of results were then plotted (figure 2.3). Results obtained by Daliform are represented by slabs **D9** and **D10** for the 30 millimetres and 60 millimetres slabs respectively. Therefore, after careful analysis of the results it can be noted that the 60 millimetres concrete topping (for IGLU units) can be taken as a threshold, as satisfactory results were obtained in this study and also by Daliform. However, due to the fact that there was a significant increase in load carrying capacity between the 100 millimetres slabs and the 60 millimetres slabs, it can be advised that the concrete topping thickness should be designed according to the expected design loads. Although greater design loads require thicker slabs, it has been proved that ventilated ground slabs can afford considerably thin slabs in comparison to ground supported slabs.

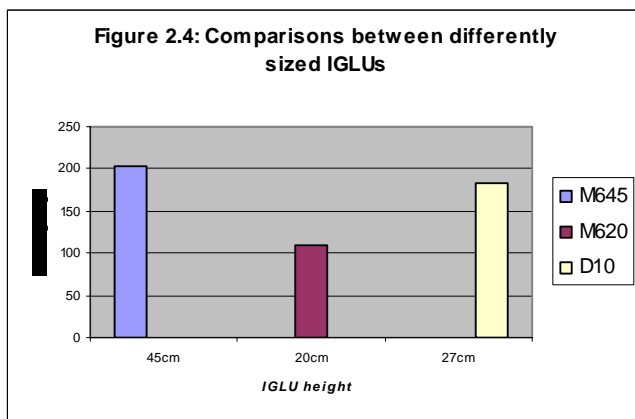
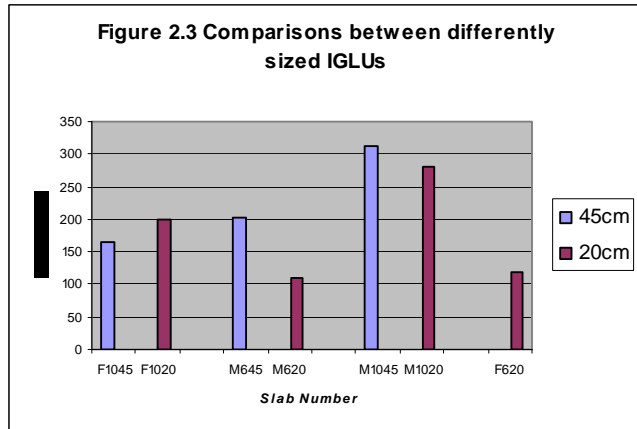
The mode of failure has been described, previously, as a *shear failure* for all the slabs and it evident that the slabs' thickness contributed significantly to their failure. What can also be noted from this study is that the thick slabs (namely the 100 millimetre ones) underwent a greater deflection than the thinner ones and this is explained by the fact that the 60 millimetres slabs reached their breaking point in a shorter time than the thick slabs. With regard to the 45 millimetres high slabs, the average deflection was quite low due to their rigidity though it is evident that the thicker slabs achieved the most positive results.

2.2 Comparisons between differently sized IGLUs

A graph illustrating the results obtained by different sized IGLUs can be seen in Figure 2.3. It is suggested that one should be careful not to interpret these results rashly as there are various factors which could have contributed to the outcome. Firstly, Daliform argue that there is no difference in the load carrying capacity between differently sized IGLUs. People involved in this field had come up with different theories concerning the expected behaviour of these IGLUs. One leading theory for the 45cm IGLU was that its mode of failure would result from a compressive failure or buckling of the legs/columns.

It is observed that none of the slabs failed as a result of compressive failure in any of the legs and it was only in one of the slabs (slab **M-10-45**) that one of the outer legs failed. This occurred after the breaking point was reached. However, it must be stressed that the cracks in the leg appeared and increased at a rate simultaneously to those in the surface of the slab. Regarding the behaviour of the interior legs (of the large slabs), the observations were

quite interesting and varied for all three slabs. In slab **F-10-45** it is observed that none of the legs underwent any buckling and all the legs remained in perfect condition.



With regards to the other two slabs (**M-10-45** and **M-6-45**), it can be noted that there was some form of buckling in the central (interior) legs though it did not affect the failure mode (or load capacity) of the slab. In slab **M-10-45**, it was the plastic formwork that buckled, whilst the concrete did not suffer any damage.

On the other hand in slab **M-6-45**, both the concrete and the plastic formwork buckled although whilst the plastic buckled considerably, the concrete only suffered minor failure and it is clear that this did not contribute to the failure of the slab. When viewing the results in Figure 2.3, one can compare them in pairs although they can be compared as a whole set of results as well. When comparing the results of slab **F-10-45** and slab **F-10-20** one could note that the load carrying capacity of the smaller slab was greater than the other. However, one must immediately note that the 45 cm slab was by far less reinforced than the other slab. Slab **F-10-20** was reinforced with an A142 mesh whilst the larger slab only had a 1 per cent steel fibre to concrete ratio, thus rendering its tensile capacity very low compared to the other slab.

possible to reach better conclusions. Both slabs were reinforced with fabric reinforcement and it is evident that the larger slab has a greater load carrying capacity than the other. In fact, the smaller slab achieved a load carrying capacity which is only 53 per cent of the other slab. This is a very large difference and is probably due to the fact that these slabs were tested on different sub-bases. The sand base was found to be a weaker base than the steel base as explained previously. Therefore, although it is evident that the larger slab has a greater load carrying capacity, the difference between the two should not have been that evident.

Results from slabs **M-10-45** and **M-10-20** provided a clearer picture. As resulted previously, the larger slab had a greater load-carrying capacity than the smaller slab, however, the difference was not very evident as the larger slab has achieved only an 11 per cent increase over the other slab. Therefore, it is evident that the larger IGLU has a greater load carrying capacity than the smaller one.

The results obtained for the 60 millimetres IGLUs were compared to the results obtained by Daliform in Italy for their 60 millimetre slab. Daliform tested their samples using IGLU modules of height 27 cm. The results were plotted in Figure 2.4 and as predicted, the larger the IGLU the greater the load carrying capacity. The difference is not so evident between the 27cm and the 45 cm modules and an increase of 11 per cent is noted. One must note that the support conditions were different for the three results obtained and slab **D10** was tested on a concrete base.

Regarding the slab's mode of failure, it can be concluded that there are differences between the types of slabs. Although, the breaking point for all the tests has been attributed to shear failure, one can observe how the smaller (20cm IGLU) slabs underwent a greater deflection than the larger ones (45cm IGLU). Therefore, the flexural stress in the smaller slabs was significantly greater than in the larger slabs. It is interesting to note that with the larger slabs, after breaking point was achieved, the load cell punched through the slabs leading to significant punching failure. This mode of failure differs from that of the smaller ones, as in this case after breaking point was achieved; the smaller slabs underwent significant deflections caused by flexural action.

2.3 Comparisons between different types of Reinforcement

The results of this analysis can be seen in Figure 2.5 and the results obtained need to be explained in detail. It has to be mentioned, that it was intended to compare slab **M-6-45** with slab **F645**, though prob-

lems during the production stage prevented this from happening.

Different results were obtained during the experiments with slabs **F-10-45** and **M-10-45**. In fact, although the maximum load obtained for slab **M-10-45** was high, one must take into account that slab **F-10-45** had a very low fibre to concrete ratio (1%) thus making it under-reinforced. This did not allow for fair comparison between both slabs. It is however possible to compare the results obtained during experiments with slabs **F-6-20** and **F-10-20** which had different concrete to fibre ratios.

Testing slabs **F-10-45**, **F-6-20** and **F-10-20** showed that when slabs were reinforced with a one per cent steel fibre to concrete ratio, negative results were achieved. However, more positive results were realised when a 1.7 per cent ratio was used.

The study proved that the larger 450 millimetre slabs can withstand larger loads than the 200 millimetre ones. This result enabled interesting comparisons to be made between the different fibre reinforced slabs. Prior to testing, one was curious as to what the adequate fibre to concrete ratio would be, in order to achieve similar results between fibre reinforced slabs and fabric reinforced slabs (when using an A142 mesh). This question can perhaps be better answered when observing the next two pairs of results.

Comparing slabs **F-6-20** and **M-6-20**, it can be observed that similar results were obtained, though it must be noted that the slabs were tested on different sub-bases. The boundary conditions contributed significantly to this result however experiments showed that had the slabs been tested on the same base, results would not have been that different. It can therefore be concluded that a 1.7 per cent fibre ratio is adequate and compares better to fabric reinforcement (A142 mesh) than when using a one per cent ratio.

When comparing slabs **M-10-20** and **F-10-20**, it can be observed that the load capacity of the fabric reinforced slab is considerably greater than the other. This proves, that although satisfactory results were achieved when using a 1.7 per cent fibre ratio, in order to achieve results on par with the fabric reinforced slabs, (using an A142 mesh) a greater fibre to concrete ratio must be used to reinforce the slabs.

With regards to the slabs' failure mechanism it must be noted that the reinforcement played a crucial role. This can be clearly observed when studying the results obtained for slab **F-10-45** which underwent a sudden failure after reaching its breaking point. In fact, on reaching 164KN the slab immedi-

ately collapsed as seen in figure 6.2. This can also be noted by the small deflection changes obtained after the breaking point was reached.

On the other hand, the other fibre-reinforced slabs underwent gradual deformations as the load was applied. Throughout the experiment, the fibres were found to span the cracks until complete deformation was achieved. However, the manner in which the slabs deflected is more a reflection on the size of the slabs (size of IGLU) rather than the type of reinforcement.

2.4 Comparisons between results obtained by Daliform and results obtained in this study

In their experiment, Daliform utilised 27 cm modules and these can best be compared to the 20 cm modules used in this study.

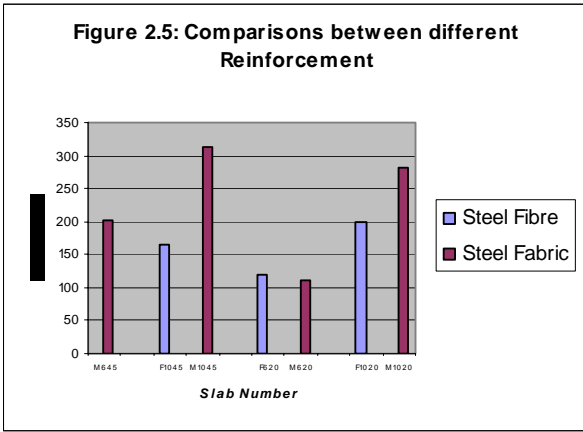
In the experiments carried out for this study using a load imprint of 22cm the slabs underwent both flexural and shear deformations, though the failure was attributed to shear stresses for all seven slabs.

Daliform, in their experiments, used a 20cm load imprint and it resulted that both the 6cm and 10cm slabs underwent flexural failure. Also, the 4cm thick slabs (or any thinner slab) underwent a punching shear failure. They also reported that when using a 25cm load imprint all the slabs underwent a flexural failure. Daliform's results are not reflected in the results obtained in this study as although the 20cm slab did undergo significant flexural deformations, all failures were attributed to shear. The large slabs (45cm IGLU) underwent a complete punching failure.

This study showed that during testing, the 10cm slabs underwent greater deflections than the 6cm slabs a fact evident in the results published by Daliform. Also, when Daliform used smaller load imprints the thinner slabs underwent a punching failure thus proving that the flexural stresses were considerably low.

It can therefore be concluded from table 4.1 that when the load imprint is increased the flexural stresses in the slabs increases considerably.

When using the 20cm high IGLU modules it can be observed that none of the slabs underwent any punching failure.



2.5 Conclusion

It can therefore be concluded that the larger modules have a greater load carrying capacity than the smaller ones. It has also been improved that a ventilated floor has a great load carrying capacity. Fibre concrete slabs (using significantly low fibre percentages) did not achieve such good results when compared to the fabric reinforced slabs.