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FOAM CONCRETE THE LIGHTWEIGHT SOULUTION TO HEAVY WEIGHT PROBLEMS.

INTRODUCTION;

SO WHAT IS FOAM CONCRETE?

Foam Concrete (FC) or Lightweight Cellular Concrete (LCC) as it is also called, is a member of the family of lightweight concretes. This unique versatile material has a number of specific qualities that make it ideal for many applications. Due to the various volumetric designs of the material, ranging from 400 -1600 kgs/m^3 and compressive strength from 0.4-10+ MPa. It has been used for many years now in the construction industry.

FC is an artificial light weight building material, usually composed of the following ingredients;

- Cement (binder);
- Water (for its reaction with cement and also to dilute the foaming agent);
- Foaming agent and air (to obtain the minute bubble structure in the product)

Additives and fillers such as building/sharp sand, limestone dust, pulverised fly ash (Pfa) and ground granulated blast furnace slag (GGBFS) can be used in the FC mix. These may be added for financial or technical reasons.

FC is formed by generating and injecting thick foam (like shaving lather) into cement paste or cement sand slurry by mechanical process.

Typical FC densities lay in the range of 400-1600 kg/m^3. Physical properties are related to density/strength and a balance must be sorted to achieve the desired material characteristics for each specific application.

FC strengths range from 0.4 – 10+MPa @ 28 days.

FC is primarily used as a fill material not a replacement solution for lower strength concrete.

By using sand as a filler, the higher densities can be manufacture more competitively then by just using a cement paste.

1) FC can be made with densities from 400 kgs/m^3 to 1600 kgs/m^3, however with these low densities *comes a trade off with strength*. Normal concrete with strengths from 15-50+ MPa with densities between 2400-2500 kgs/m^3.

2) FC is designed for low strengths ideal for mass infilling of voids (subways, sink holes, abandoned pipelines) or used for road construction.

3) Lower densities can be achieved down to 400 kgs/m^3 by using just CEM1 or CEM 2 only, no sand in the base mix. However sand can be used as a filler in the FC, so keeping the selling price down. (Sand is around £60 ton cheaper than CEM1.)

4) Since the strength of soil is around 0.5-1.0 MPa, and blue clay is around 3 MPa FC is an ideal product to use on soft ground construction.

5) By using a low density, FC will *not cause any settlement to the surrounding soil*. However, if placing normal concrete into an area with soft soil, it may cause the ground to move after a period of time due to the weight of the material. (2400+ kgs/m^3 against 400-1600 kgs/m^3 FC).

6) If high strengths and high densities are needed from the FC, then there is a likelihood that the FC may fail due to thermal cracking or structural integrity. This is due to the high cement contents required to give high strengths. (S**ee table 1**).

7) The main product of the binding of cement is water which when mixed produces ***heat***, this is given off during the hardening of the FC. This is known as the heat of hydration. When heat of hydration is taken into consideration while designing and pouring FC, it can be managed properly during the curing and hardening process. However, if the designers do not allow for the heat, it can cause issues with thermal cracking and possibly even compromise the structural integrity of the FC. It is extremely important to know about heat of hydration and its effects on FC from the time it is poured and throughout its lifetime does cause problems with the heat generated from cement. Since FC has excellent thermal insulation properties this exacerbates the problem when pouring large quantities of FC. Temperatures of 100°C degrees can be reached which can last for many days. This is impounded when thick layers are poured day upon day, the FC would set quicker from the heat generated from the pour below. Therefore, exasperating the heat problem even more.

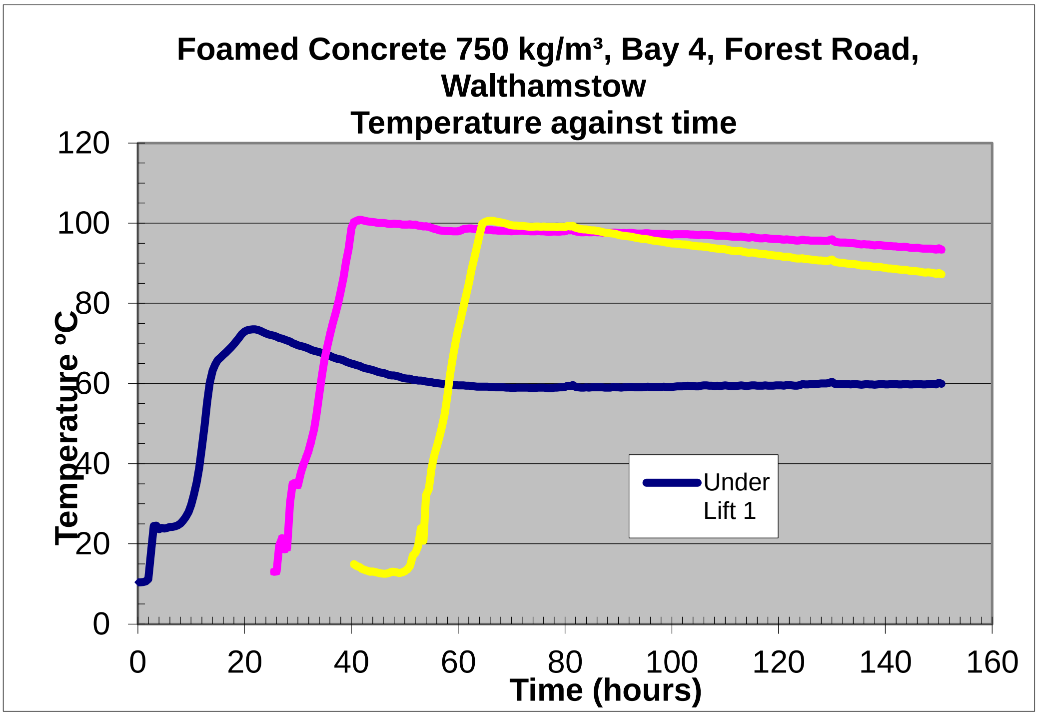
   (See Table 1 of actual recorded temperatures taken on a project over a period of 150 hours).

8) As FC hardens a reduction in mass (density) takes place this is due to the heat of hydration which evaporates water from the material. Evaporation stops when the FC has reached a balanced moisture content value that equals the air humidity of the environment. When the FC is conditioned in a more or less dry environment a mass loss of 40-70 kgs/m^3 after 28 days is common.

9) Once FC has been poured and hydrated, if water enters the area and the bottom and sides of the FC structure is in contact with water, capillary water absorption may occur. On average 1-5 kg/m3 of water is absorbed by capillary water absorption on the bottom and sides that are in contact with water. This depends on the composition of the mix design and volumetric mass of the FC.

TABLE 1

TABLE OF ACTUAL HEAT RECORDED FROM A FC POUR ON A PROJECT



10) To alleviate some of the heat of hydration in the mix a cement powder replacement can be used such as Granulated Blast Furnace Slag (GGBFS) or Pfa (Pulverised Fuel Ash). Up to 50% replacement can reduce the heat BUT this retards the setting time. During the summer months it is not a concern due to the high ambient temperatures. Thus, slowing the hydration and temperature down of the FC so it will not be damaged. However, during the winter months using a cement replacement can cause problems with setting times. Hardening of the FC can be extended up to 24 hours before the pour finally sets hard. This may have a detrimental effect on the poured material as the foam structure could be compromised from damage by collapsing. Resulting from the foam breaking down before the cement has hydrated.

11) Cold weather hampers the setting of cement taking extra time to hydrate. Low temperatures will hold back the setting time and will retard the 7 day and 28 days strengths in FC. **(see TABLE 2**)

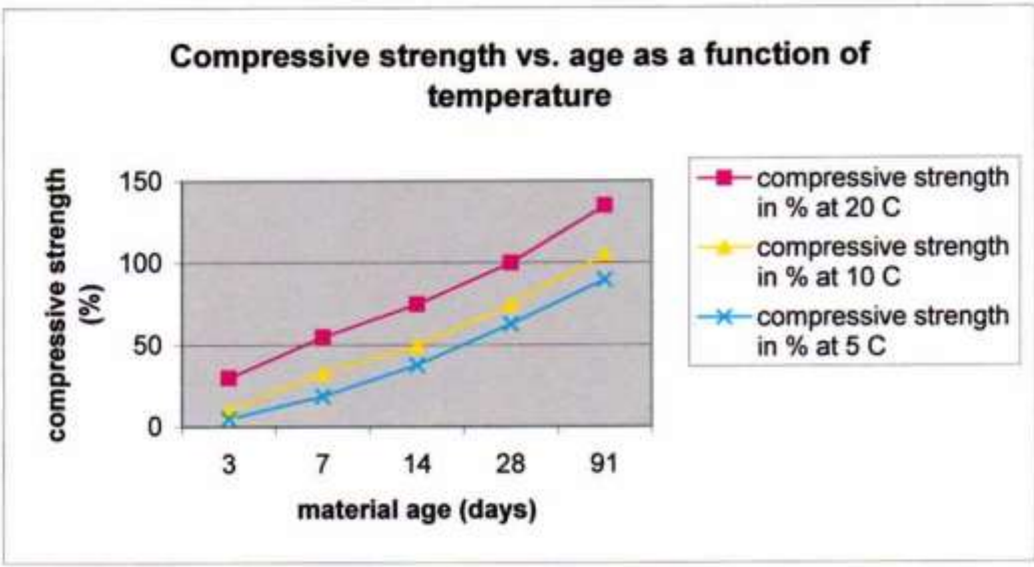
12) Below is a chart **(TABLE 2)** showing the loss of strength in FC against ambient temperature. This chart shows the normal curve at 20°C down to 5°C, however if pouring FC in temperatures lower than 5°C degrees, then this will cause even lower strengths. Like normal concrete FC needs to be protected if poured in low temperatures by using a thermal blanket or some other means of covering.

13) The pouring of FC in low temperatures at 1-3 °C that if left overnight with no protected covering will result in damage to the FC. Should the temperature fall below zero degrees this would cause the water in the FC mix to freeze, once this happens the material would expand creating large fissures in the surface of the pour. This damage would then have a detrimental effect on the strength and integrity of the finished product.

TABLE 2

Typical relationship between compressive strength and material age for foam concrete as a function of of the ambient temperature.

age (days)	compressive strength in % at 20 C	compressive strength in % at 10 C	compressive strength in % at 5 C
3	30	10	5
7	55	33	19
14	75	50	38
28	100	75	63
91	135	105	90



14) Apart from low temperatures causing problems, wet weather and standing water can also have a detrimental effect on low density FC.

15) An example is a FC exhibiting a density of 400 kgs/m^3 is manufactured which is 2+ times lighter than water (water being 1000 kgs/m^3). Therefore if placing FC in the rain and it is not covered then the rain would penetrate the material falling through and settling underneath the bottom of the pour. This would then make the FC float on top of the water standing in the bottom of the pour. The water would also break the material down. Since foam is the lightest material in the mix (42 kgs/m^3) the water would breakdown the FC, with foam floating on the surface and heavier materials falling to the bottom. So when pouring in conditions of precipitation the FC must be covered with a cloche tunnel to prevent damage.

GENERAL MAKE UP OF FC

FC possesses excellent thermal insulation properties, fire resistance properties and is not susceptible to freeze/thaw cycles. Commercially the use of FC in the UK has increased rapidly, following a lead taken in recent years by Holland.

FC requires a base mix design, this comprises of cement, sand (if required in the mix) and water to give the require density and strength of the finial FC mix.

Different types of Cement can be used, CEM1, CEM2, CEM3 which are now readily available from concrete plants.

Sand all concrete plants have a concreting sand available but due to the large grading envelope of the material. This can mean that 5mm size grains can be a normal makeup of the material giving it a gap grading. This type of material will give problems in making good FC due to the lack of fines in the mix. Most concrete plants will offer another material to complement the sand grading this being limestone or granite dust.

Soft sand (mortar sand) is the ideal material as it is well graded and makes good FC.

The downside is that only plants that are sited in aggregate quarries carry this material. A concrete plant in an Industrial Estate will not carry soft sand due to the number of overhead aggregate bin capacity available on the plant carrying other materials.

Unless a mortar plant is available in the area which would hold the soft sand as standard.

Even better is silica sand as it is finer than soft sand. The only drawback with using silica sand is the very high cost per ton as it is normally dried and bagged.

Only potable water is used to make FC. Contaminated water can adversely affect the foaming agent and lead to breakdowns of the entrapped bubbles.

Foaming agents that are used to make the FC can be either protein based or a synthetic concentrate.

MIXING AND PLACING

Foam is generated using a liquid foaming agent, water and compressed air. The mixture of water and admixture is then blended with compressed air and forced through a narrow constriction to create a micro-cellular foam with millions of bubbles. The consistency of the generated foam can best be compared to thick shaving foam. The density of the foam should be between 40-60 kgs/m^3.

WET METHOD

a) For heavy densities sand cement slurry is ordered from the concrete plant and supplied to site via truck mixers. A gun is placed into the rear of the mixer the foam dosage is controlled by the operator on a timed application. The operator injects a known quantity of foam into a known quantity of base mix that will give the required density. After waiting for a few minutes for the base mix and foam to mix toughly it can then be discharged. (**as shown in illustration 1**)

Illustration 1 loading the truck-mixer with foam gun.

b) For lighter densities the slurry is ordered from the concrete plant. When it arrives the truckmixer is reversed on to the rear of a special FC pump. As the slurry is discharged in to the rear hopper it is drawn through a peristaltic pump as it is pumped through the discharge lines via a ‘T’ piece foam is added to the line. As the slurry is pumped to the discharge point the foam would have mixed with the slurry making the FC.

DRY METHOD

c) For high volume low densities a batching plant is sited on the construction site. The powder is delivered by cement tanker into an onsite silo. The batching plant manufactures the powder in to slurry. Once made it sits in a holding tank then it is pumped out. The foam is made from a compresses air supply, water and liquid admixture. Once the slurry is made and held in a hold tank then it is pump out through discharge lines as it leaves the mixer a T piece has been added to the discharge line. Through this ‘T’ piece thick foam is added to the slurry. As the foam and slurry runs through the discharge line the foam is mixed with the slurry making a light weight FC. To ensure that the correct mix is being made densities of the material at the discharge point are taken and weighed to ensure they comply with the specification requirements. (**batching machine as shown in illustration 2)**

Illustration 2 Batching plant and silos on site. Making light density FC (400 kgs/m^3).

d) The maximum distance FC can be pumped is around 1000 linear meters via the pump through 75/100 mm o/d rubber lines. For lesser distance pipelines, 63 mm o/d can be used.

POURING OF FOAM CONCRETE

a) Due to the large number of evenly divided micro bubbles within the FC mix, the internal friction of the material is limited as a result the final product is very liquid.

b) If a thick FC layer is required. It must be cast in several layers each around 1.0 meter in depth. This is to alleviate the heat of hydration combined with the heat –insulating properties of the FC.

c) In the case of large surfaces that require in-filling the FC should be completed before the setting phase commences. During the summer months this can be within 2 hours due to high ambient temperatures.

d) During the summer months if pouring large volumes of FC, they must be poured into smaller areas to prevent the FC from hydrating too quickly. If the material starts to set and material is still being poured in to the area the bubble structure would start to collapse. This causes the FC to increase in density as the bubble structure will start to breakdown and decrease the yield. Thereby supplying more volume to complete the pour.

e) Due to the advantageous flow behaviour of the FC, the surface can be quickly and evenly finished by using a floating straight edge. (As shown in illustration 3)

Illustration 3 finishing a foam concrete pour with a floating straight edge.

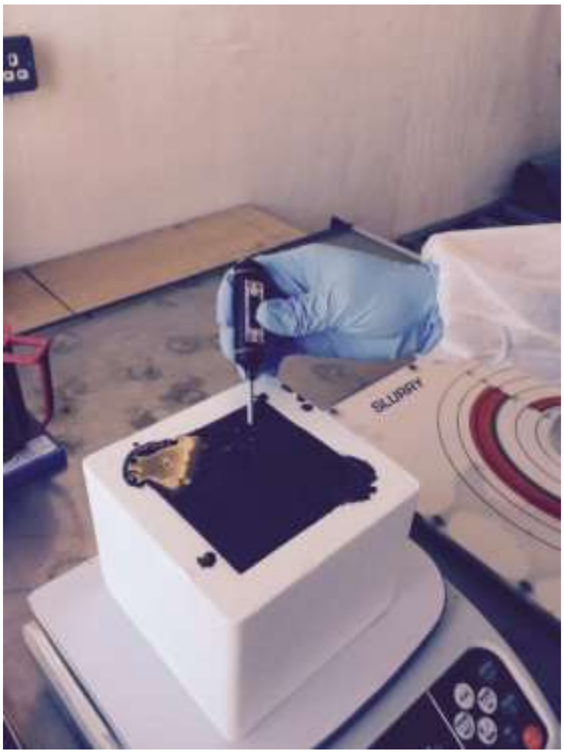
QUALITY CONTROL

a) Quality Control.
QC: Testing procedures are designed to ensure that all aspects of the product, from the base mix to final FC product are carried out as specified.

b) Quality Assurance.
QA testing should confirm that the end product has been made to the required specification. Samples should be taken of the wet FC and placed and weighed in a 10 x 10 x 10 cm cube mould. This should first be tarred off (empty weight), then in filled with the wet foam concrete. Please note that no compaction of the material with a bar as it will breakdown the bubble structure. Once the cube is filled to capacity it should be rocked from side to side to allow any air bubbles to rise to the surface. If low top up to the required height. Then in one movement place on the weigh balance and read off the weight. i.e. if 800 grams then 1 m^3 of the FC would weigh 800 kgs/m^3. (As shown in illustration 5)

Illustration 4 cube being tarred off prior to filling with FC to obtain density of the finished product.

Illustration 5 cube infilled with material for weighing to obtain density of FC also temperature.



c) Flow cone testing
A sample of the FC is taken and placed in to a beaker. The material is poured in to a cup which is placed on a special board. This will give the workability of the slump for the material. Once cup is fill it is lifted up and the material flows over the board giving an indication of the flowing ability of the material. (as shown in illustration 6 &7).

Illustration 6 flow test of FC

Illustration 7 flow test of the material

d) Cube Manufacture
   Once the cubes have been made, they should be wrapped in cling film to prevent premature drying of the material.
   The cube should then be placed in a warm area away from vibration. If cubes are moved prior to setting then hairline crakes can appear which would then have a detrimental effect on the cube strength. When the material has hardened, they should be stored in a cabinet in a warm room of 20 degrees Centigrade +/- 2 degrees NOT in water.
   Then at the required day for crushing they are taken from the cube mould and crushed.
   (The FC is left in the mould as light weight FC can be easily damaged.)

PROPERTIES OF FOAM CONCRETE

As with normal concrete the properties of FC are related to density, strength, water cement ratios (w/c) and amount of cement in the mix. FC is influenced by the bubble structure of the entrained foam in the base mix. Although the compressive strength of the FC is dependent upon density, it is important to understand that high compressive strength is NOT always the important ultimate goal of FC production. Indeed several of the advantageous qualities of FC are achieved with low strengths, low density mixes.

COMPRESSIVE STRENGTHS

Within the normal range of densities, FC has a compressive strength of 0.4 -10+ MPa @ 28 days, this is based on densities of 400 kgs/m^3 to 1600 kgs/^{m3}.

SHRINKAGE

Shrinkage in FC tends to increase with a decrease in density. A FC with a density of 400 kgs/m^3 can have shrinkage of 0.3%. This is in the order of ten times greater than normal concrete at 2400 kgs/m^3.

THERMAL CONDUCTIVITY

Tests carried out have shown that thermal conductivity of FC drops as the density is reduced. Clearly the low conductivity, and therefore the high insulation quality, of FC is due to entrapped air within the mix. The typical value obtained for a 400 kgs/m3 is 0.1 W/m deg C, which is around 20 times lower than normal concrete which is around 1.8-2.0 W/m deg C.

MODULUS OF ELASTICITY

The modulus of elasticity also decreases with density. At low densities the value reduces to practically zero. At higher densities the value ranges from 2-3 times lower than normal concrete.

ADVANTAGEOUS QUALITIES IN FC

One of the most obvious benefits of FC is the ease with which it can be placed. FC does not require any compaction or vibration and need little in the way of finishing.

By using a low-density FC, once placed and hardened it can be easily removed by mechanical means or by a chain saw. (face masks must be worn due to the dust from the cement in the hardened mix).

Since low density FC has a very low footprint against normal concrete 2400 kgs/m^3. It can be used on land which is soft (peat bog) by using a 500 kg/m^3 FC it is lighter than the surrounding land so it will float on the surface.

1. **High strength with low density** – Typical cast densities range from 400-1600 kgs/m3 with compressive strengths of 0.4 -10+ N/mm2, respectively. With its low density, foam concrete imposes little vertical stress on the substructure, a particularly important issue in areas sensitive to settlement. Due to its low density, foam concrete is a viable solution for reducing loading on burdened soil. Additionally, foam concrete is less susceptible to differential settlement. Heavier density foam concrete with higher strengths is produced and used for special applications.

2. **Rigid, well-bonded body** – Foam concrete forms a rigid, well-bonded body after gelling (hydrating); thus, it is effectively a free standing structure on its own and does not impose lateral loads on adjacent structures. The material can be constructed into various formations and profiles by forming and stepping of successive lifts.

3. **No Compaction Required** – In some cases mechanical compaction can be difficult and unsafe due to limited or inaccessible areas. In excavations with poor soils that are not easily or incapable of being compacted, foam concrete forms a 100% compacted foundation over the soft soils. When compaction of conventional backfill against retaining structures or deep foundations, traditional methods can cause damage or movement to the adjacent structure or just be too time consuming. In these instances foam concrete is a great solution.

4. **High Fluidity** – Foam concrete pumps easily with relatively low pressures via hoses over long distances. For applications over 500 mtrs such as pipe and tunnel backfill, the slurry is pumped through pipelines with pre-formed foam injected near the point of placement. The material is naturally self-levelling and fills the smallest voids, cavities and seams. When placing in excavations, foam concrete conforms to every sub grade contour.

5. **Rapid Installation** – High volume production and placement (via hose) of foam concrete is a continuous operation from the mobile batching plant on location. Since the foam is the largest volume contributor in the foam concrete, limited deliveries of the raw materials are required, which results in minimal disruption to the construction site. With our patented high-rate production equipment, BMSL can produce and install foam concrete on location at rates of 50-75 m^3 per hour, per operating unit.

<u>OPERATIONAL & COST EFFICIENCIES</u>

1. **Settlement Free Construction** – The principle of equilibrium and the use of foam concrete aims for settlement-free construction. When higher density soils are excavated, they are replaced with foam concrete, so that the combined weight of the foam concrete and the new construction is less than or equal to the weight of the removed soil. Thus the effective stress of the underlying soil has not changed, preventing settlement.

2. **Ease of Removal** – Foam concrete can be designed for specific strengths to allow for future removal for maintenance of utilities or excavation. Sometimes excavation of flow able fill materials can be difficult due to the unpredictable gains in strength *due to delivery and production methods.* Foam Concrete is normally produced on location to exact requirements, and can be excavated with common construction equipment.

3. **Time Savings** – The application of foam concrete can be a great time saver over conventional ground treatment methods for settlement free construction.
    - No waiting period for consolidation of sub soils, eliminating the need for surcharging.
    - No need for removal and replacement with large amounts of borrow soil.
    - Removal of minimal amount of soil to be replaced with foam concrete.
    - Can be applied directly on existing marginal ground such as peat or poor soils.
    - Reduce or eliminate the need for piling, sand drains, or grade beams.
    - Deeper placement of lifts, due to reduce lateral loading and no compaction steps.
    - Eliminate the need to correct completed construction which has settled.

4. **Cost Savings** – FOAM CONCRETE is an economically viable solution, particularly in large volume applications. Its use can also have an effect on other aspects of construction.
    - Mix designs are tailor-made for each project and budget requirements
    - Minimal lateral loading enables reduced building costs for earth retaining structures
    - Construction on marginal ground reducing the need for piled foundations
    - Lower maintenance costs because durability of foam concrete and lack of settlements
    - Innovative methods to correct or prevent subsidence in lieu of expensive treatments
    - High volume equipment with rapid installation reduces installed unit cost

<u>CHARACTERISTICS OF FOAM CONCRETE</u>

1. **Low coefficient of permeability –** The hydraulic conductivity of porous materials generally decreases with an increasing amount of air in the pores of the material. Foam concrete is made up with a matrix of interconnecting micro bubbles, or air voids, thus the material has a relatively low permeability. For special applications foam concrete can produce a draining foam concrete. Typical coefficient of permeability of foam concrete is $<1x10^5$ m/s.

2. **Low water absorption** – The solid matrix of cementitious slurry surrounding the fine cell structure of foam concrete greatly reduces the capillary action of moisture through the material. From our research and testing program, we have produced data on the effects of water ingress due to external water pressure on the foam concrete. With the data, we can calculate what the in situ density of foam concrete will be over time (up to 100 years). Dutch CUR 59, Water Ingress Due to External Water Pressure.

3. **Good freeze/thaw resistance** – Primarily due to the low water absorption of foam concrete, the capillary water absorption (actual saturation degree) into accessible pours of the material never reaches a point of critical saturation (critical saturation degree), at which point damage could occur. Fagerlund Method (Rilem 4 CDC), Determination of Frost/Thaw Resistance of Porous Materials.

4. **Thermal insulating properties** – Since the makeup of low density foam concrete contains a very large air content in the closed cell structure (up to 80% air), the material provides for very good insulating properties. The high air content also provides for good sound insulating and excellent fire resistance qualities of the material.

5. **Energy absorbing qualities** – Due to the dense cell structure of foam concrete as the material is compressed during an impact, the resistance of the foam concrete increases absorbing kinetic energy. And since hardened foam concrete forms a solid matrix, the material is not vulnerable to seismic shock waves, thus ideal for bridging over soils susceptible to liquefaction.

6. **Susceptibility to breakdown** – Unlike some synthetic lightweight fill materials, hardened foam concrete is not susceptible to breakdown due to hydrocarbons, bacteria, or fungi and is insect and rodent proof. The foaming agent, which is synthetic based, forms a durable micro bubble and is not affected by hydrocarbons or other chemicals that may be present during placement of the foam concrete when it is in its liquid state. With some foaming agent there may be detrimental effects of the finished foam concrete.

HEALTH & SAFETY WHEN POURING FOAM CONCRETE.

Risk of drowning

If the poured FC has a volumetric mass lower than 1000 kgs/m^3 then there is a **HIGH RISK** that anyone falling into a pour can drown. The human body cannot float in material that is less than 1000 kgs/m^3. Therefore all deep FC pours must be covered or have herras fencing around the pouring area to prevent people accidentally falling in the pour. The risk subsides when the FC starts to harden which is around 3-4 hours during the summer months and 8+ hours in winter.