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Vertical Development With Light Weight Structures - An Insight

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ABSTRACT:

The feasibility and advantages of vertical development with light weight structures is presented in this paper. The necessity of this topic is in context with the recent recommendations of various governments across the world ,including the Indian government to promote vertical development over horizontal development. The use of light weight structures is recommended especially for vertical development because it reduces the load on the soil and cost of building and maintenance which have been supported and illustrated. The paper also deals with the use of admixtures like Auramix,Masterease and Nano technological materials like glas-fiber mesh and steel fibres which cater to the required properties for efficient development of tall structures. The rheology of concrete has also been discussed and the grades of concrete used are in the range of M100 to M200.the final recommendation obtained from this paper is to use light weight structures and increase vertical development for a better and sustainable future.

INTRODUCTION:

The need for vertical development surfaced with increasing population and rapid urbanisation across the world. The first of the worlds tall structures started to give shape in the early 19th century and as time progressed many new structures came across the skylines of the western hemisphere. The current tallest structure being Burj Khalifa. The rapid increase of these structures was possible due to invention of new technologies and materials into the field of construction and these structures were seen as great challenges both economically and workably and are still seen as the same ,so let us not go into the forum of worlds tallest structures and restrict ourselves for time being with structures up to a height of 500 meters.

The second main problem was usage of materials in these structures, with the introduction of steel many tall buildings started engulfing it into them but this rapid engulfing led to the buildings becoming heavier and the foundations going deeper which in turn resulted in drainage of huge volume of funds. The solution to all the above topics discussed will be building tall structures with minimal usage steel and hence reducing the load on the structure which in turn reduces the cost on the foundation and on the total cost and maintenance of the structure.

VERTICAL DEVELOPMENT:

Vertical development is the process in which the construction is done vertically rather horizontally. With increased pressure on the available land, it has become imperative now for us to grow vertical for better optimisation of scarce land resources.

In fact going vertical helps create more open and green spaces around us and yet provide more housing stock. High rise structures use multiple floors to increase total floor space without increasing the size of the building's footprint, making the design ideal for a congested city where real estate is sold at a premium. The cost of the land, which is the biggest cost in construction, gets distributed when there are more floors and occupants in a building. Also the maintenance cost works to the advantage of the occupants with more residents in the building.

The local infrastructure needs to be fully equipped to take the burden of the increased density in a particular area. With new construction coming up

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either vertically or horizontally, infrastructure needs to be upgraded constantly.

For vertical development to be a success the government needs to bring major policy reforms and regulations need to be relooked at. Most importantly increase in the current FSI limits will help in high rises going even higher. Therefore, in a nutshell there is no alternative but to go vertical if we are really serious about solving the shortage of housing in our cities.

Construction of any high rise structure has its own challenges. The cost of construction increases as one goes higher. The Indian construction industry is going through a changing phase, the need of the hour for developers is to employ latest construction techniques, but at the same time it should be cost effective and safe to the final home buyer. Deploying latest technology also needs trained and skilled workers who can be highly productive. This is one big challenge that real estate is facing. One of the successful approaches adopted to address these problems is lean construction. Lean construction is fast gaining prominence in the construction industry.

The benefits to company are immense. Implementing lean processes in construction helps reduce costs to a sizeable extent. It is all about doing more with less time, inventory, space, labour, and money. Lean production is a systematic elimination of waste like overproduction, waiting, transportation, inventory, and over-processing. There are five attributes that drive lean construction that is cost, quality, delivery, safety, and morale.

LIGHT WEIGHT STRUCTURES:

Light weight structures are those structures which are relatively lesser in weight and have a smaller ratio between a structure's dead load and the supported live loads.The basic principles of lightweight bridges also apply to buildings such as roofs over large sports arenas or fair pavilions or industrial plants lending an individual character and a human scale to these structures. Since the gap between these cable girders still has to be spanned with transversal girders using bending and thus resulting in semi-heavy or semi-light roofs, the final step is inevitable

the lightweight spatial structures, the double curved space structures with pure axial stress, called membrane stresses (Fig. 1). These structures are not only extremely light but they also open up a whole new world in architecture, an unsurpassable variety of forms which is not yet exhausted, by no means. Just like bridges, these structures transfer their loads predominantly by compression shells or domes (Fig. 1, left), or by tension cable nets and membranes (right). In between are the plane space structures - the slabs and the space frames.

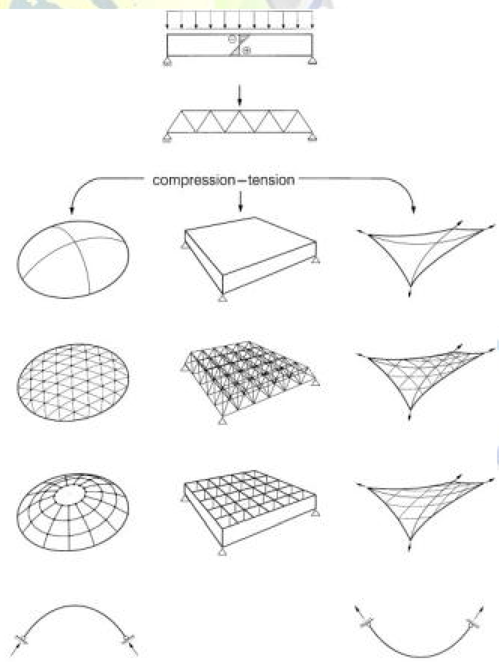

Fig. 1: The evolution of lightweight spatial structures

Despite the extremely thin walls of shells and space domes their curved shape stabilizes and prevents them from the dreaded buckling. And applying prestress protects the extraordinarily lightweight nets and membrane from the effects of wind-induced vibrations. The two principal directions of the nets and membranes are

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mechanically stressed against each other resulting in the typical saddle-shape with an anticlastic curvature, or, if pneumatically stressed by creating an internal air pressure or a vacuum, resulting in a dome shape with synclastic curvature. This can be mastered with modern computers. Manufacture and, as a consequence, costs are more likely to limit the scope of these lightweight spatial structures. Expensive formwork and complicated cutting patterns are required for the manufacture of these double-curved surfaces (Fig. 2). The details of tensile structures and membranes are complicated and have to be manufactured with extreme precision.

But in recent years the textile membrane structures have made a remarkable progress. Since they may be folded they are even used as convertible structures. This marked the beginning of a whole new era in structural engineering completely changing life in our capricious climate.

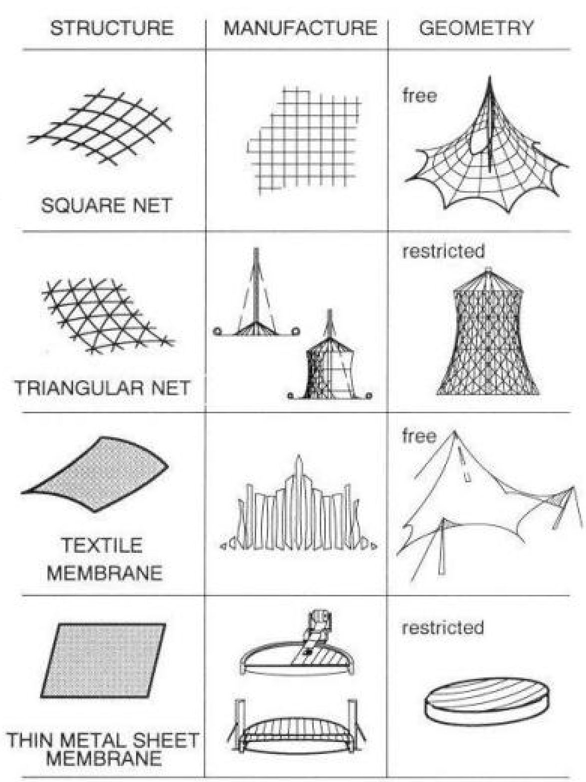

Fig. 2: The geometry and manufacture of typical double-curved lightweight structures

Achieving lightness is a heavy burden, because lightweight structures challenge the boundaries set by the theories of statics and dynamics. The fancy materials put the technologies to the test and the complicated three-dimensional structures dare the manufacturing procedures.

Lightweight structures tempt the dedicated engineer, because they - exemplary for this profession - equally and simultaneously address his knowledge, his ability and his experience as well as his imagination and his intuition. With lightweight structures the engineer is able to award the adequate visual expression to an ingenious and efficient structure thus contributing to building culture.

ULTRA HIGH PERFORMANCE CONCRETE:

Figure 1: Goosebridge, fiber-reinforced UHPC, no steel bar reinforcement inside; production: Romein Beton, NL; material development: G.tecz Engineering, Germany

Ultra High Performance Concrete – Sustainable and Cost-effective

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Ultra High Performance Concrete (UPHC) is one of the most modern concretes developed during the last decade. It's a material generally characterized by (although not limited to the one) having a high compressive strength from 120MPa to 200MPa. Of late, more projects are being constructed worldwide which demonstrate the potential of this new kind of cement bonded material.

Modern cement bonded high-tech materials that are developed by employing Nano technology optimizing materials do have better mechanical properties than ordinary concretes or HPC. UHPC not only has the structural performance which is much higher than HPC, but also have ceramic like surface behaviors, impermeability to water and gas, very high heat resistant or work as insulation material. Hence, UHPC will be the next generation high performance material that can be used in classical building applications like structural pre-cast elements, facades, columns etc. That is not all; UHPC can be used in machinery-industry e.g. form-giving tools and integrated parts of machineries. Further, inspiring designers, architects, and engineers see UHPC for new applications where concrete wasn't a choice before.

It is a material technology by matching the physical and chemical complex interactions, such as packing density, water film thickness, interparticle forces, as well as the stoichiometric coordination of all raw materials reserve potential in the concrete. Due to the densification, UHPC is characterized by a dense micro structure with a very low amount of capillary pores (< 1.8 vol.-%) that leads to increasing the corrosion resistance, which increases the compressive strength from 80 MPa to 500 MPa are possible. UHPC reinforced by a sufficient amount of steel, other high performance fibers or fiber mesh can reach a tensile strength of more than 20 MPa and in particular cases, a flexural strength upto 75 MPa for a 6 mm thick panel. Especially, the high compressive strength allows a high grade of pre-stressing that is very interesting for pre-fab columns or monolithic bridges like the Goosebridge in Germany.

The Goosenbrueck, Utrecht, NL, is made with a maximum grain size of 5 mm with a span of about 20 m. It has a cross section with a minimum amount of reinforcement and pre-stressing steel. It is pumpable grade Ultra-High Strength Concrete. Except for the pre-stressing reinforcement and the steel fibers, no additional steel reinforcement is used in the bridge. The concrete including steel fibers was pumped with a conventional rotor-mounted concrete pump into a closed mould.

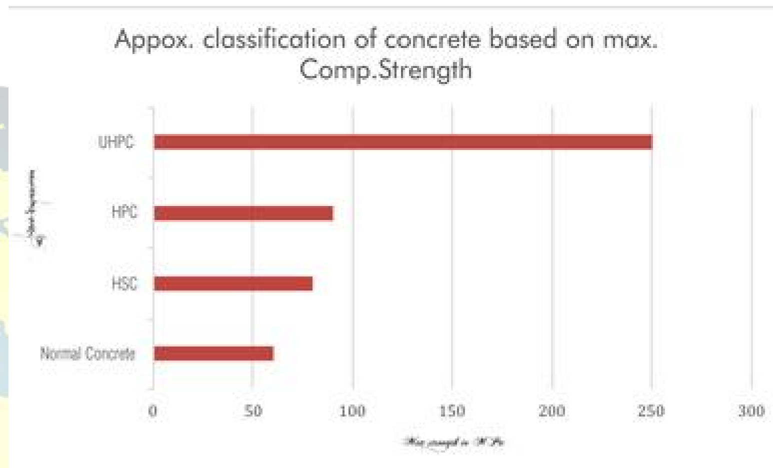

Figure 2: Range of performant concrete

The interesting part of development of UHPC is that all the material parameters can be influenced individually. This means, for example: workability, early strength, compressive strength, flexural strength and even costs can be adapted to required levels. 'Performance' doesn't only represent compressive strength but all the other essential parameters that are fundamental for high-tech products. UHPC is engineered by a) using mathematical algorithms to calculate the optimal packing density in combination with the optimal water film thickness around each particle in the mix and b) by using the locally available raw-materials and the available production technologies. The raw-materials and their properties are characterized by laser-diffraction, SEM and EDX. Also, their rheological compatibility with other fines, water and admixtures are investigated, so that their advantages or disadvantages can be used for the design of the concrete formulation. By using this technology, the ratio of the reactive binder, add-ons

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and chemical additives can be reduced. In general, the developed material consists only of 4 or 5 components, which make it easy for the production. At the same time, the UHPC formulation will be developed regarding e.g. the mixer-technology to guaranty that the developed material works in production as well as in the final product. Due to the usage of local raw materials, the transportation and necessary concrete material costs and emissions can be reduced significantly.

All given raw materials are analyzed by laser diffraction, optical and scanning electrons Microscope methods and characterized by derived mathematical entities. With these input data, the optimal packing density in the range of 0 to 0.125 mm can be calculated by including the water film thickness in an evolutionary, non-linear cross-over computational process.

The special effect of water film thickness related to the packing density is shown in the following example–

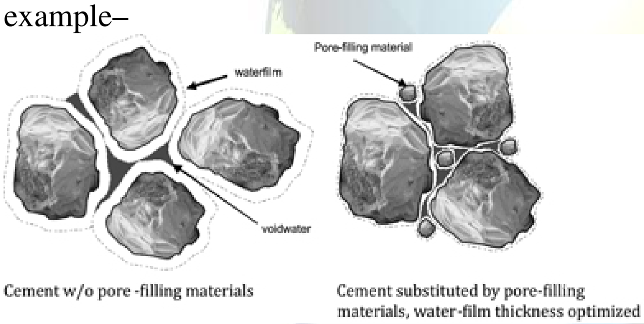

Figure 3: scheme for demonstration of the effectiveness of gap-filling materials.

a) the water film thickness around the cement grains with the pore water is shown. When replacing the cement by a pore-filling substitute, the solid content is increased and displaces the water from the cavities. This water can then be saved and used to optimize the water film thickness b). The scheme shows that in addition to the cavity filling, the reduction of the water film thickness is essential to ensure that the increased computational density can be effective.

Often in concretes, a high flexural strength instead of a high compressive strength is required. Through the targeted combination of high tensile strength, bond strength, a flexible non-metallic reinforcement of a 6mm thick, plate-like element, having a flexural strength of 70 MPa has been developed. These have already been used in the industries and opens up wide areas of application far beyond the conventional application.

Figure 4: UPHC panel with a glas-fiber mesh, flexural strength: 73 MPa

Often, planetary mixers are available in precast plants, with insufficient mixing intensity in fine graded concrete systems. By intelligently controlled mixing and dosing processes also, these mixers are processable to mix a concrete with a compressive strength of above 180 MPa. Shortest mixing times, even below one minute, are possible with high-performance intensive mixer with increased efficiency.

Figure 5: M170 with 0.99 vol.-% steel fibers

Figure 5 shows a highly flowable TalrakcreteUltra™ concrete M100 with 5 mm maximum particle size, produced in a commercial pan mixer. The workability was assessed with a slump flow of 95 cm and a low dynamic viscosity

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(t500 < 5 sec.). The mix is free from segregation or sedimentation in a number of experiments. The compressive strength after 28 days without heat treatment was 125 MPa. With respect to a smallest possible shrinkage, the content of hydraulically active substances (i.e. cement, puzzolana) was kept as low as possible without compromising the cohesiveness and durability of the material.

Table 1: Development of the early age strength of acc. UHPC, no fibers, max. grain size < 5 mm

Concrete age	2h	4h	8h	24h
Compr. Strength, cube, 10x10x10 cm	15 MPa	30 MPa	50 MPa	110 MPa
Flex. Strength, prism 4x4x16 cm	1.5 MPa	3.0 MPa	4.5 MPa	10.0 MPa

Other positive side-effects when using UHPC in the precast production are the high early age strength. After 2 days, the compressive strength is usually about 90 MPa, whereby the storage in the factory can be substantially reduced.

Through the use of ultra-fine and finer cements, the strength development could be accelerated significantly, as Table 1 shows. Especially the rapid development of flexural strength is remarkable and allows a very early demoulding of the concrete elements. The specimens were stored thermally, insulated to simulate the state of the element.

Next to the material costs itself, the new design of the pre-cast elements can lead to more filigree, lighter and 'greener' products. By downsizing dimensions and sections, the costs per element are equal or lower, compared to regular concrete because of lower concrete volume. Not only volume but also using these new high-tech concretes means reduction of steel-reinforcement, mold costs, labour costs, and so on. Finally, the overall costs of a Quantz or UHPC pre-cast element are the essential factor for calculating the economic efficiency and the return of investment in these new technologies.

The economic effects, structural advantages and the overall performance of the new materials are directly related to each other. The whole development from concrete production to casting to installation e.g. a pre-cast element, must be seen holistically.

Together with the structural engineers from Bollinger+Grohmann located in Frankfurt, Germany, a calculation for a mega-column of a skyscraper was carried out. Originally, the 2x2m column is planed with a M60 grade concrete and was intended by substituting it with a M190 concrete. The amazing result was a downsizing of the section to a 1x1m column. Over, about 75% of material could be saved by just substituting the M60 concrete with UHPC; that's about 100 ton of concrete only for one mega-column. Further to this, the carbon footprint as well as the necessary primary energy to produce the materials and column can be reduced. Now imagine that it's not only one mega-column but all columns and also the floor beams. By saving concrete volume for all the structural members of a high-rise building, also decrease costs for the foundation because of the reduced dead weight of the structure as a whole.

For the last 10 years, a lot of new cement bonded materials such as High Strength Concrete, High Performance Concrete, Self-compacting Concrete were developed; mostly focused on the standard concrete business. Outstanding materials like the Ultra High Performance Concrete are now getting common worldwide and are door openers for new applications and inventions. Based on industrial development and scientific research projects in the laboratories, a wide variety of different materials are being developed. High compressive strength materials with about 300MPa are used for preparing moulds for casting components in the automotive industries. OPC based UHPC with a temperature resistance upto 1600°C is the obvious material choice for metallurgical and other industries, where high temperature is an issue. Light weight concrete and foam concrete with high strength that can be used for insulation or acoustic barrier elements. For example, the new developed Aerogele Quantz does have an insulation factor of lambda 0.07, that is comparable to the newest three-glass window systems. 15-25cm thin Pre-fab walls can be produced endlessly with this material and no other insulation materials will be needed. One of the latest scientific research projects together with a German company is the development of a ceramic like Quantz that is used in 3D rotation moulds to

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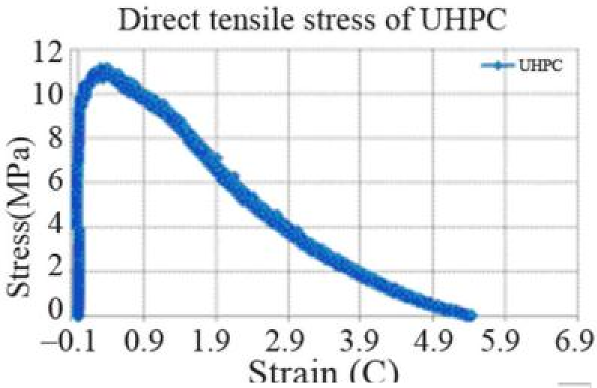
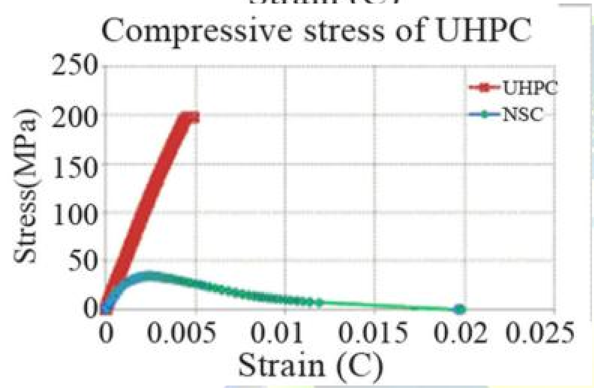
produce hollow casings with a wall-thickness of only 2-3mm thickness. The market development shows that cement bonded materials are thus getting more accepted by other industries.





RHEOLOGY OF CONCRETE:

The study of rheology of concrete provides information on properties of fresh concrete such as deformation, behavior of mix, and placement of mixed concrete.

Rheology is a term that is mainly used for fluids whose flow properties are complicated in nature, other than fluids like liquids or gases. The term rheology may be defined as the study of the science of the flow and deformation of materials.

In the concrete study, the concept of rheology may be applied to analyze the hardened concrete deformation, the behavior of cement paste and slurries, handling and placing of mixed concrete in its fresh state. Hence rheology is applied in all states of concrete (fresh to hardened).

Rheology of Fresh Concrete

When we deal with the rheology of fresh concrete, parameters that are to be considered are stability, mobility and compactability. These are the main factors which measure the suitability of a concrete mix. Now when dealing with rheology, the measurement is more based on stress, strain or rate of strain and the time factors.

The stability, mobility and the compactability factors are expressed in terms of the forces or stresses dealing with the concrete mix. These are caused due to the transmission of mechanical stresses within it.

The rheology of fresh concrete can be expressed by means of following flow chart in fig.1.

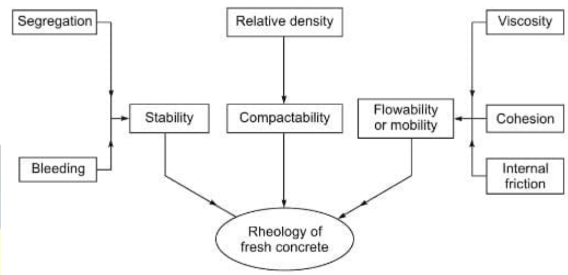


Fig.1. The Rheological Parameters of Fresh Concrete

Stability Parameter in Fresh Concrete Rheology

Stability is the property of a concrete mix when the aggregate particles within the mix possess a homogeneous dispersion and resemble a sampling in a random manner. This property is shown during its conveyance, placement as well as during compaction. Now there are two factors that measure the stability of the mixture. They are

- Segregation
- Bleeding

The segregation can be defined as the phenomenon of the settlement of aggregate mixture in the homogeneous dispersion due to the weak concrete mix. The weak concrete mix is termed to be an unstable mix.

Now how to extend the mix can resist the failure through segregation depends upon the cohesion between the individual particles. Segregation is not limited to wet consistencies alone. It can appear in the dry mix too.

Now in wet mix, the segregation mainly occurs when the water content level in the mix is such a way that throughout the course of transportation, placing and compaction, the paste cannot hold the aggregate in a well-distributed manner.

A lower water-cement ratio results in a crumbly mix that results in dry segregation. This mainly appears

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during its handling. Now the dry segregation cope up slowly during compaction. During compaction with vibration, they gain fluidity and cohesion with time as well as resistance to shear.

Bleeding is a phenomenon of water release when the concrete mix has an unstable mortar. The bleeding has to be under controlled or its chances of occurrence have to reduced.

Mobility Parameter in Rheology of Concrete

The ability of the concrete fluid mix to flow is defined as its mobility. This mobility is happening by the action of mechanical stresses, which is also called as moment transfer. There are many factors that restrict the concrete flow like:

- Cohesive forces
- Frictional forces
- Viscous forces

The adhesive forces between the aggregates and whole matrix result in increasing cohesiveness, which in turn restricts the flow of concrete mix. The cohesiveness is a factor that results in increasing tensile strength of the concrete mix. This parameter as discussed above is a factor that avoids the possibilities of segregation.

The viscosity is defined as the resistance to flow. Now this parameter would measure how to extend the concrete mix are movable. This also shows the capability of the concrete mix to arrange them within the matrix (Mostly during the placement of mix in the mould).

There won't be any flow under lower stresses with the mixing behavior like a solid. This means it will be having a higher viscosity. With the increase in stress, the strength that binds the matrix together would decrease.

This decrease will be insufficient to resist the flow, thereby decreasing the viscous forces within the fluid. Hence the solid behavior is converted into liquid form.

The frictional force internally within the mix occurs when the mixture gets displaced. This situation will make the aggregates to translate and rotate. The main governing factors that would help the concrete mix to have resistance against deformation are:

- Shape and Texture of the aggregates used in the concrete mix
- The extent to which the mixture is rich
- Water – cement ratio
- The type of cement

Another factor that governs the mobility of concrete mix is the angle of friction. The triaxial compression test is performed to find the mobility of the concrete mix. Vee – Bee test along with compacting factor test to find the relative mobility of the mix at the site.

Compactability Parameter in Rheology of Concrete

The ease with which the concrete is compacted can be represented by the parameter compactability. The compaction process involves the expulsion of air bubbles within the concrete mix and repositioning the aggregates so that a dense mass is obtained. Care is taken to avoid segregation.

Compactability is measured by means of compacting factor test. The method has certain limitations as it sticks to the hopper test apparatus. This test show variation in the result when the mix is high or low workable in nature.

The proper measurement of the compaction can be determined by two stages. The first stage of measurement determines the density of the mix in its loose or un-compacted state. Here the mix is simply placed on the hopper without any kind of compaction.

The next stage involves the measurement of compacted mix. The mix is placed in three layers, each compacted with a 25mm diameter internal vibrator.

The above two values compared with the standard compaction factor test, would give us transmission of the mixture from its loose stage to compacted state. This gives the measure of void content present tin the concrete. The extent of void content will help to give an indication of durability, permeability and the strength of concrete.

The concrete mixture is best chosen by knowing the rheological properties of concrete. The test like workability, Vee – Bee and compaction factor tests are found to have limited scope as they measure

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only a single parameter and are called single point tests.

EFFECT OF MASTEREASE ON RHEOLOGY:

It gives robustness to water which gives a cohesive mix even at higher slump flow, it also gives a v4 funnel test time of 11 seconds compared to 22 seconds of PCE. It maintains extended workability and rheology while maintaining early strength. The rheology at one hour is studied using V funnel and the time obtained is 18 seconds. It gives better pump ability at lesser cementitious and fine aggregate content, help in minimising variation due to moisture content, increase productivity by 20% lesser wear and tear reduce cost by 20%. It also has lower yield stress. Maintains safety saving in piping and man hour cost reduce concrete wastage. Avoid costly repairs.

CONCLUSION:

Thus it can be concluded that vertical development with light weight structures obtained using various techniques is better and more economical than other methods and can be practiced and developed with ease and minimal maintainance will be required.

It is also found using rheology of concrete that placing of concrete at great heights is not a problem and can be effectively done with the help of admixtures like Masterease.