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DESIGN FACTORS AND THE ECONOMICAL APPLICATION OF SPHERICAL TYPE VOIDS IN RC SLABS

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Abstract

In a general way, the slab was designed only to resist vertical load. When span of the building is increasing, deflection of slab is more important. Therefore, the slab thickness is on the increase. The increasing of slab thickness makes slab heavier, and it leads to increase column and base size. Thus it makes building consume more material. To avoid these disadvantages which were caused by increasing of self-weight of slabs, the biaxial hollow slab system (void slab) was suggested. This slab system could optimize the size of vertical members like walls and columns by lightening the weight of slabs. The behaviors of biaxial hollow slab are influenced by the shape of void and cage. Long span flat slab systems with internal void formers have been used in Europe for a decade now. Nautilus® is the brand name of successful system, recently introduced in Turkey. It's a bi-axial reinforced concrete fat slab system, with a grid of internal void formers. The main advantage is the possibility of long spans due to the significant reduction in own weight, as well as the fast construction sequence with the use of flat lab formwork systems. This research is based on the modeling of void slabs using different structural analysis program (SAP 2000 etc) due to TS 500 (Requirements for Design and Construction of Reinforced Concrete Structures-Turkish Standard). Also this study scrutinizes the economy of various slab systems (waffle, mushroom, rib etc.), exposed to different load intensities and practical span ranges.

Key words

Spherical void formers; concrete floor systems; modelling; economy; span ranges; structural analysis

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1 INTRODUCTION

When designing a reinforced concrete structure, a primary design limitation is the span of the slab between columns. Designing large spans between columns often requires the use of support beams and/or very thick slabs, thereby increasing the weight of the structure by requiring the use of large amounts of concrete. Heavier structures are less desirable than lighter structures in seismically active regions because a larger dead load for a building increases the magnitude of inertia forces the structure must resist as large dead load contributes to higher seismic weight. Incorporating support beams can also contribute to larger floor-to-floor heights which consequently increases costs for finish materials and cladding.

A new solution to reduce the weight of concrete structures and increase the spans of two-way reinforced concrete slab systems was developed in the 1990s in Europe and is gaining popularity and acceptance worldwide. Plastic voided slabs provide similar load carrying capacity to traditional flat plate concrete slabs but weigh significantly less. This weight reduction creates many benefits that should be considered by engineers determining the structural system of the building.

Plastic voided slabs remove concrete from non-critical areas and replace the removed concrete with hollow plastic void formers while achieving similar load capacity as solid slabs. Voided slab principles have been applied in different applications dating back to the early 1900s.

This study examines a two-way, reinforced concrete slab with plastic voids construction in comparison to traditional flat plate, ribbed, mushroom concrete slab construction. The design process for plastic voided slab is directly compared with traditional two-way flat plate; ribbed, mushroom reinforced concrete slabs through a design comparison of typical bays 6m by 6m, 8m by 8m, 10m by 10m, 12m by 12m, 14m by 14m and 16m by 16m. Also the economical range of spans in which Nautilus flat slabs can be used for a certain load criteria, as well as addressing the safety of critical design criteria of Nautilus slabs in terms of TS 500.

Reinforced concrete slabs are one of the most common components in modern building construction. Reinforced concrete slabs with plastic voids slabs are a new and innovative type of structural, concrete slab system developed to allow for lighter self-weight of the structure while maintaining similar load carrying capacity of a solid slab. Plastic voided slabs are capable of reducing the amount of concrete necessary to construct a building by 30 percent or more.

Design requirements of TS 500 are affected. Also stiffness and own weight are reduced due to the voids, Nautilus slabs had smaller absolute deflections than solid slabs with the same thickness. Nautilus research factors are safe to apply to TS 500.

Nautilus® was recently introduced to the Turkey market, after being used for a decade in the European market. This system consists of hollow plastic spheres cast into the concrete to create a grid of void formers inside the slab. The result is a flat slab soffit with the benefit of using flat slab formwork. With the reduction in concrete self-weight, large spans can be achieved without the use of prestressed cables, providing the imposed loads are low.

Finite element (FE) models were generated with different software for different span lengths and load intensities. These FE models consisted of single span or multiple spans by five span layouts, and were generated for Nautilus and coffer slabs. For a specific layout, all spans were equal in length. Obtaining a fair comparison between the these systems, loading of the slabs needed to be approached in a similar manner. Live loads and additional or super-imposed dead loads were applied to all slabs in the normal manner. No lateral, wind or earthquake loads were considered. The self-weight of the different systems was the main concern.

2 LITERATURE REVIEW

Shear behaviour of SVF slabs will be different from that of solid concrete flat slabs due to the presence of internal spherical voids in SVF slabs. Two main criteria that need to be considered are the loss of aggregate interlock due to the fact that a diagonal shear crack will encounter voids in the central part of the beam, and the presence of steel reinforcement cages that hold the spheres in position and that act as partial shear reinforcement. It is therefore necessary first to briefly investigate the general shear behaviour of concrete slabs before discussing the unique behaviour of SVF slabs. Equilibrium in the shear span of a beam is described by [1].

Theoretical calculations for the shear strength of SVF slabs were compared with force-controlled shear tests performed on SVF specimens in the concrete laboratory of the University of Pretoria,[2] in 2007. This comparison had to be conducted to establish the shear strength reduction factor for SVF slabs compared to a solid slab with the same thickness, tension reinforcement and concrete properties.

Earlier research at the TUD indicated that a lower-bound SVF shear strength reduction factor of 0,55 times the shear strength of a solid concrete slab with the same thickness, and without shear reinforcement, approximated the shear strength of SVF slabs [3]. The shear strength of the solid slabs was calculated in accordance with [4].

The SVF steel cages were omitted in the TUD tests. These steel cages, which hold the SVF spheres in position during construction, act as shear reinforcement inside the slab, resulting in a higher shear strength reduction factor.

The experimental work at up ,[2] comprised the testing of 12 beam specimens of equal length and width, but having varying thicknesses and quantities of tension reinforcement, some with SVF spheres, and some solid. All the beams, simulating strips of flat slabs 600 mm wide, were set up to fail in shear before failing in flexure in accordance with the work of Park and [1] discussed above, to allow conclusions to be drawn regarding their shear capacities.

A formwork cost analysis was done by Jan Kotze at Wiehahn Formwork (Pty) Ltd for both SVF flat slabs and coffer slabs. No column heads were used for the purposes of this research. All formwork material, delivery on site and labour were included in this analysis, but VAT was excluded. The analysis was based on large slab areas with 3 m floor heights, where repetition of formwork usage resulted in 5-day cycle periods for both flat-slab (SVF and post-tensioned slabs) and coffer formwork. Coffer formwork worked out to be approximately R50/m^2 more than flat-slab formwork for large slab areas in 2007.

3 METHODOLOGY

Finding a practical method to compare costs of different slab systems is complex in the sense that the lay out and application of most structures vary significantly, leaving the designer with almost endless possibilities. Many different techniques have been tried in the past, most of them with valid application in practice. For slab analysis a FEM computer program is used, [5].

Plastic voided slab systems are an alternative to traditional concrete slab construction. Plastic voided slab systems are significantly lighter than solid concrete slabs while maintaining the ability to have large spans. Slabs are lighter because less concrete is used in voided slab construction than traditional slab construction. This section discusses how plastic voided slabs are constructed and how lighter weight and larger spans affect building design.

3.1 Construction (using NEW NAUTILUS)

Depending on the manufacturer, plastic voided slab systems are constructed by two primary methods: a filigree method in which part of the system is precast off site, and a method in which the entire system is constructed on site. Both methods use the same three basic components. In both methods, the main component is the plastic void. These voids are often spherical, hollow, and made of recycled plastic. The voids allow the slabs to be lighter than traditional concrete slabs since the voids are nearly weightless and replace concrete in the center of the slab. The next main component is the steel cage. Steel reinforcement is added to resist flexure for the slab, but a cage of thin steel is also used to hold the voids in place, keeping them in the center of the slab. The third main component is the concrete, which surrounds the voids and forms the slab. The concrete ultimately determines slab strength. Though both methods use each of these components, the two methods use different approaches.

NEW NAUTILUS® is a modular lost form in recycled polypropylene (PP*) developed for lightweight voided reinforced concrete slabs. Conceived and developed by Geoplast S.p.A., the system is manufactured using the most modern injection molding technology in the company's plants and following rigorous quality standards.

The NEW NAUTILUS® caissons are incorporated into the concrete, creating voids within a regular grid of orthogonal beams between two slabs, obtained with a single concrete pour. This technique allows a flat-soffit slab over large spans capable of bearing high loads. Structural elements such as drops and beams can be included within the slab thickness, creating a vast flat surface with the greatest flexibility of use. Thanks to the high inertia of the structure, this technology makes it possible to design large buildings cost-effectively. The NEW NAUTILUS®, system, made of recycled material, is simple to lay and fast to move in the jobsite and contributes to the overall sustainability of the building, Figure 1, [6].

Fig. 1: Axonometric View Of New Nautilus® Single and Double

3.2 Advantages of NEW NAUTILUS

Design Freedom: Flexible design adapts to irregular and curved plan layouts, longer spans and fewer supports.

- Gives the architects high flexibility in design.
- Downstand beams and bearing walls eliminated.
- Spans up to 20 m.
- No beams between columns.
- Fewer columns.

Reducing Overall Costs: Reduced material consumption and faster construction. The increased flexibility will secure lifelong savings concerning envelope, internal work, interior design as well as continuous usage.

Process Optimized: Tail or made semi-fabricated elements; fast erection with large elements up to +100 m^2; easy concreting and fast placing of services due to the beamless flat soffit.

Environmentally Green and Sustainable: Compared to a solid slab with same thickness, NEW NAUTILUS flat slabs saves 40 % of concrete in the slab, and saves 50 % with the same bearing effect. This will lead to further reductions through the entire structure. The production of one ton of cement causes emission of about 800 kg of CO_2. One m^3 of concrete causes CO_2 emissions close to 300 kg. This figure does not even include emissions due to quarrying, transport, etc. Other GHG and natural ressources (water, sand, stone)are reduced proportionally. NEW NAUTILUS biaxial deck system uses recycled plastic spherical voids and all materials can be reused upon demolition. The biaxial nature of NEW NAUTILUS slabs allows for any internal layout to be reconfigured.

Earthquake Resistance: Seismic forces impacting a building are proportionally to the horizontally accelerated mass, which has to be absorbed by the vertical structure. A NEW NAUTILUS slab with its reduced dead load will consequently reduce these forces. The NEW NAUTILUS concept, the biaxial flat slab system with columns and shear walls, is an effective concept for earthquake resistant concrete constructions.

Once the deck formwork is erected and the lower armature placed, the site is ready for the installation of NEW NAUTILUS®. The universal geometry of the forms, which don't require any laying direction, makes installation simple and fast. Correct form alignment and concrete cover are guaranteed by the conical feet integrated in the caissons, while the correct spacing between the forms is ensured by the tear-off spacer strips. The fast coupling features on the lower edge of the forms make assembly of caissons taller than 24 cm (h32, h36, h40, h44, h48) very easy and reliable. Before the pour the steel armature will be placed completely, including the welded mesh in the top slab. The pour should be performed in two stages: a first layer of concrete must cover the conical feet and the outer edge of the forms, and rest until it starts to set; the second stage will complete the pour of the slab, Figure 2.

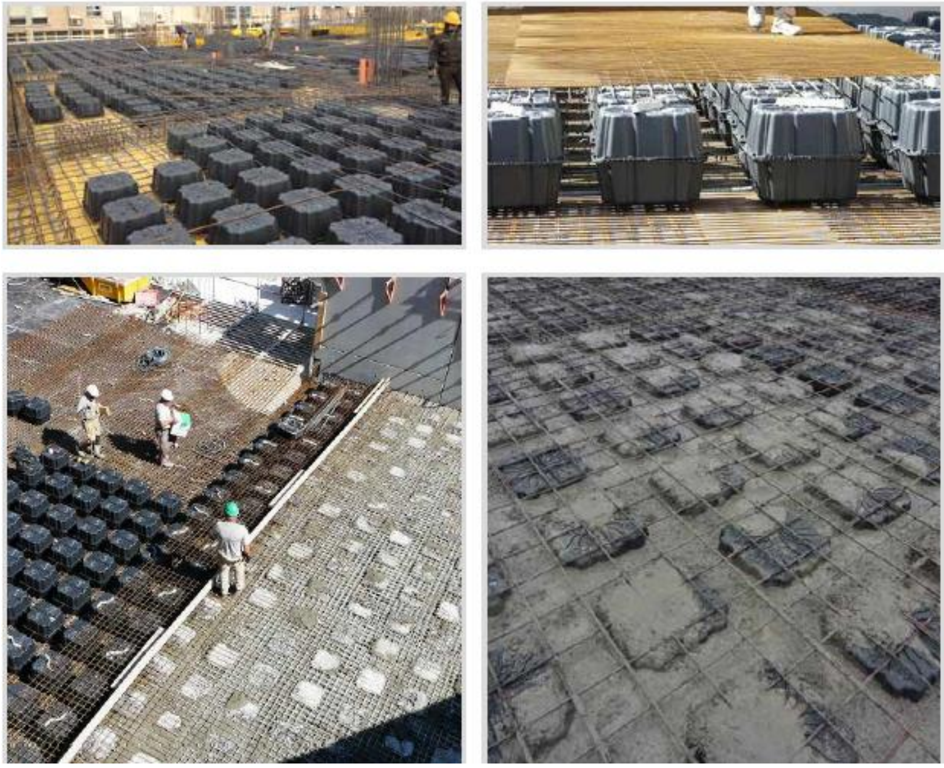

Fig. 2: Formwork and layout of NEW NAUTILUS spherical voids,[6]

3.1 Dimensions of Voided Slab, Stiffness Modification Factor and Weight Reduction

Plastic voided slabs using spherical void formers behave isotropically, meaning their properties are the same in all directions, allowing for the same methods of structural analysis used for traditional, solid two-way slabs. Slight adjustments must be made to a few variables from solid slab design, but the overall concept is the same for both solid slab and plastic voided slab design.

Accordingly, for a module of hollow flooring system effective normal force and shear force and the effective area moment of inertia is calculated based on the unit size analysis account size conversion is done and is detected in this way. Determined correction factors account for the stiffness and mass appropriately in programs and parameters used for the reduction of. Flooring unit mass and weight of hollow core slabs must be decreased to reflect.

The second moment of inertia is a key variable when performing structural analysis of slab. The untracked moment of inertia is dependent on the thickness and width of the flat plate slab and the contribution made by steel can be ignored since steel is not taking part prior to cracking. In addition, the values in Nautilus Handbook are taken by calculating second moment of inertia in uncracked state and in cracked state . The results have revealed that the stiffness reduction factor in state-1 is the determining factor. The stiffness reduction factor can be derived from the calculation of second moment of inertia of voided slab and solid slab. With the help of this reduction factor and taking into account the reduced self-weight of voided slab deflection of voided slab can be calculated. The first step in the design of plates used in the design is to determine the main geometry and load parameters Figure 3 and Figure 4.

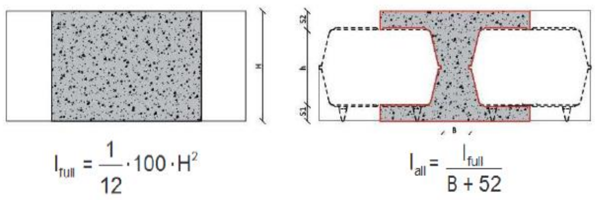

Fig. 3: Comparing moment of inertias for flat and hollow core slabs

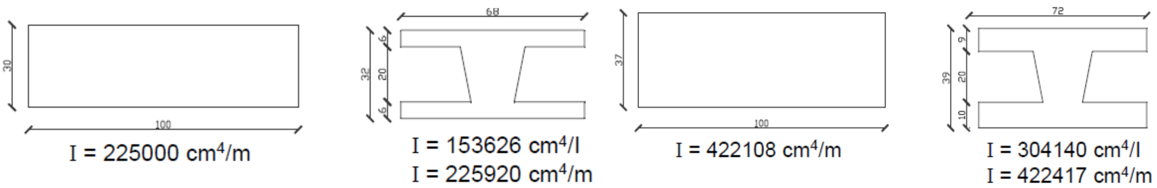

Fig. 4: Calculation of moment of inertias for flat and hollow core slabs

4 PARAMETRIC STUDY

Though plastic voided slabs can be compared to conventional one-way slabs, plastic voided slabs are most efficient when designed similar to two-way slabs without support beams. For this reason, the parametric study compares interior bays of a flat plate system to interior bays of a plastic voided slab system. The primary goal of the study was to compare the relative weight of a plastic voided slab to the relative weight of a flat plate.

Many parameters must be considered when designing a concrete slab. For a comprehensive comparison between two-way slabs and plastic voided slabs, a study must consider not only different bay sizes but also span conditions and different weights and strengths of concrete. However, the purpose of this study was to provide a quick, illustrative comparison between flat plate slabs and plastic voided slabs.

Each bay was designed as an interior span with no support beams which is typical for flat plates. An interior span was chosen since the majority of the structure is an interior span condition for buildings. In addition, each side of the bay will behave similarly.

When it comes to the implementation stage, investigated for hollow core slab system design, local and international design codes need to be followed common denominator steps are summarized below.

4.1 Types of Slab

In different types of structural slab systems, [7] and other mandatory minimum requirements of the regulations (of the requirements) by providing primarily taking into account the size and other parameters optimization models have been developed numerical analysis made. Results of the analysis examined the applicability of reinforcement and cross-sectional effects were studied. If as a result of internal forces if there is a mismatch in terms of ordinances; Models made to deal with the consequences of turning optimization elements are used. The available 720 numerical analysis model created from nine different slab system type, Table 1.

Tab. 1: Type of Slabs

	Slab Type
BS	Beam Slab
BS1	Beam Slab 1
BS2	Beam Slab 2
RIB	Ribbed Slab

WFF	Waffle Slab
FLT	Flat Slab
MSH	Mushroom Slab
NAU1	Nautilus- Considering Mushroom Slab
NAU2	(Nautilus)-Considering Ribbed Slab

4.2 Types of Live Loads

Live loads used in this study, are based on the [8] and [9] regulations. These load values are given in Table 2. For all types of slabs the dead load was accepted t/m^2 0.200.

Tab. 2: Type of Live Loads

	Live Load (t/m^2)	**Description**
Q200	q=0.200	Offices, Buildings
Q350	q=0.350	Schools
Q500	q=0.500	Shopping Malls
Q750	q=0.750	Stadiums
Q1000	q=1.000	Hangar, Big Stores

4.3 Geometry and Continuity of Slabs

Geometry in the selection of types, sizes and structures widely used in practice in architecture will help to create alternative solutions are used in large openings, Table 3. Great opening of a portion of the costs taken into consideration to create solutions to problems point to a particular part of the structure will be found in the singular mind laying one span to take into consideration the discontinuity is solved.

Tab. 3: Geometry and Continuity of Slabs

	Dimension in X and Y Directions	**Continuous of slabs**
6x6M	lx=6 m, ly=6 m	Multiple- 5 x 5 (Five slabs in each direction)
8x8M	lx=8 m, ly=8 m	Multiple- 5 x 5 (Five slabs in each direction)
10x10M	lx=10 m, ly=10 m	Multiple- 5 x 5 (Five slabs in each direction)
12x12M	lx=12 m, ly=12 m	Multiple- 5 x 5 (Five slabs in each direction)
14x14S	lx=14 m, ly=14 m	Single
16x16S	lx=16 m, ly=16 m	Single
6x9M	lx=6 m, ly=9 m	Multiple- 5 x 5 (Five slabs in each direction)
6x12M	lx=6 m, ly=12 m	Multiple- 5 x 5 (Five slabs in each direction)
8x12M	lx=8 m, ly=12 m	Multiple- 5 x 5 (Five slabs in each direction)
8x16M	lx=8 m, ly=16 m	Multiple- 5 x 5 (Five slabs in each direction)
10x15S	lx=10 m, ly=15 m	Single
10x20S	lx=10 m, ly=20 m	Single
12x18S	lx=12 m, ly=18 m	Single

12x24S	lx=12 m, ly=24 m	Single
14x21S	lx=14 m, ly=21 m	Single
16x24S	lx=16 m, ly=24 m	Single

5 RESULTS

5.1 Cost Comparison Charts (TL/m^2)

Material quantities, analysis metering module that is integrated within the program was obtained from. Concrete, formwork, reinforcement and Nautilus blind mold plastic items as much as possible considering the current unit prices only without the inclusion of vertical structural costs are calculated per m^2 of floor coverings same moving load carrier systems for the different costs were compared m^2, Figure 5-6.

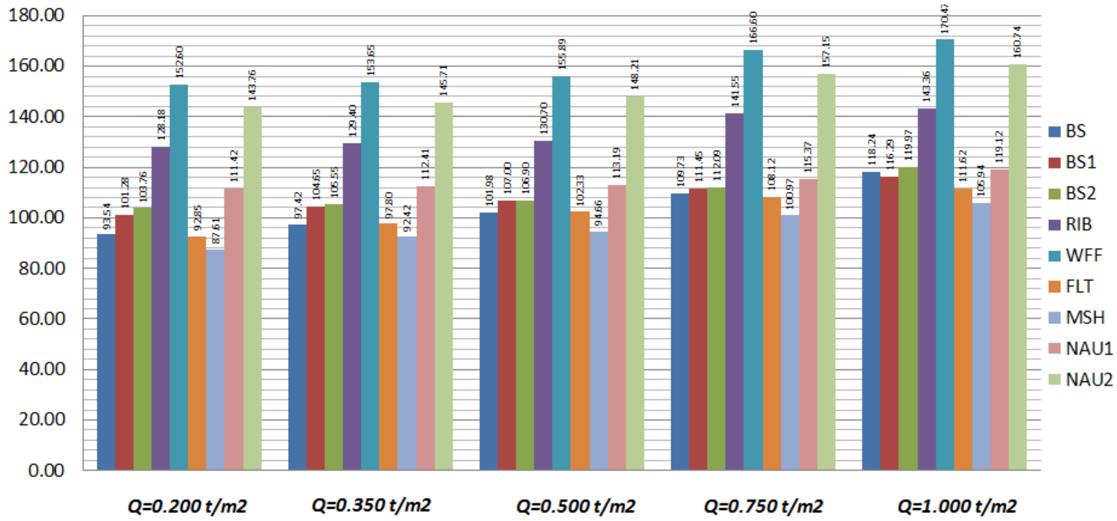

Fig. 5: 6m x 6m-Multiple Slab System Cost Comparison Chart

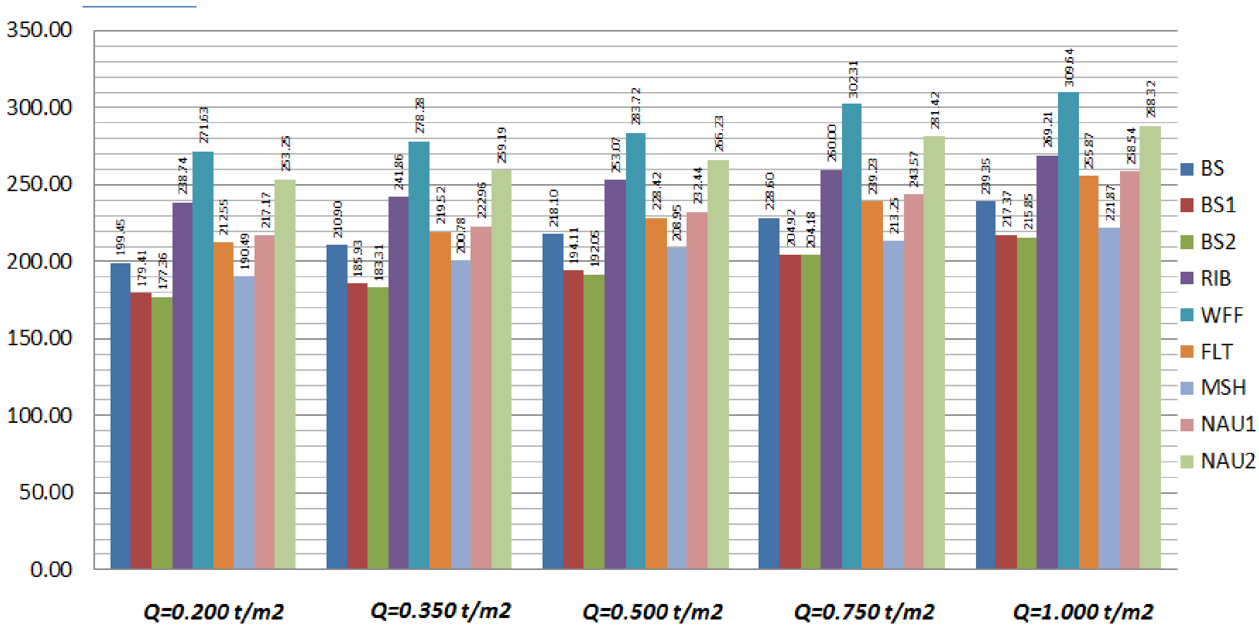

Fig. 6: 14m x 14m-Single Slab System Cost Comparison Chart

5.2 Concrete Odds Comparison Chart (m^3/m^2)

For the same moving load, without including the vertical loads, vertical loading systems of different tiles per m^2 of concrete ratios were compared, Figure 7-8.

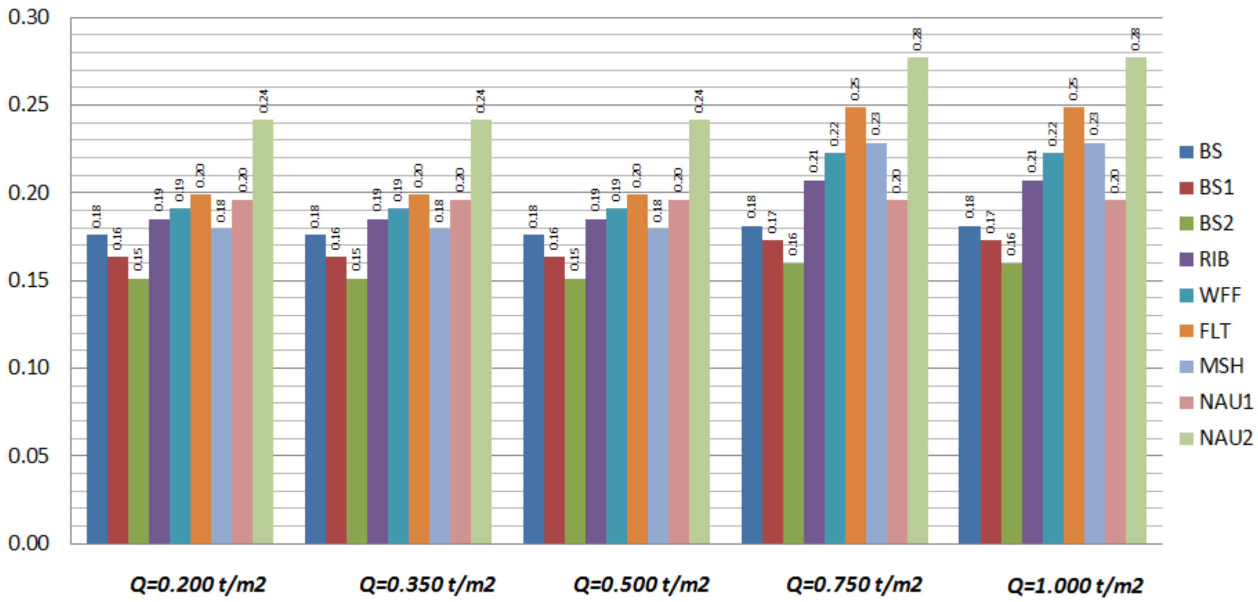

Fig. 7: 6m x 6m-Multiple Slab System Concrete Odds Comparison Chart

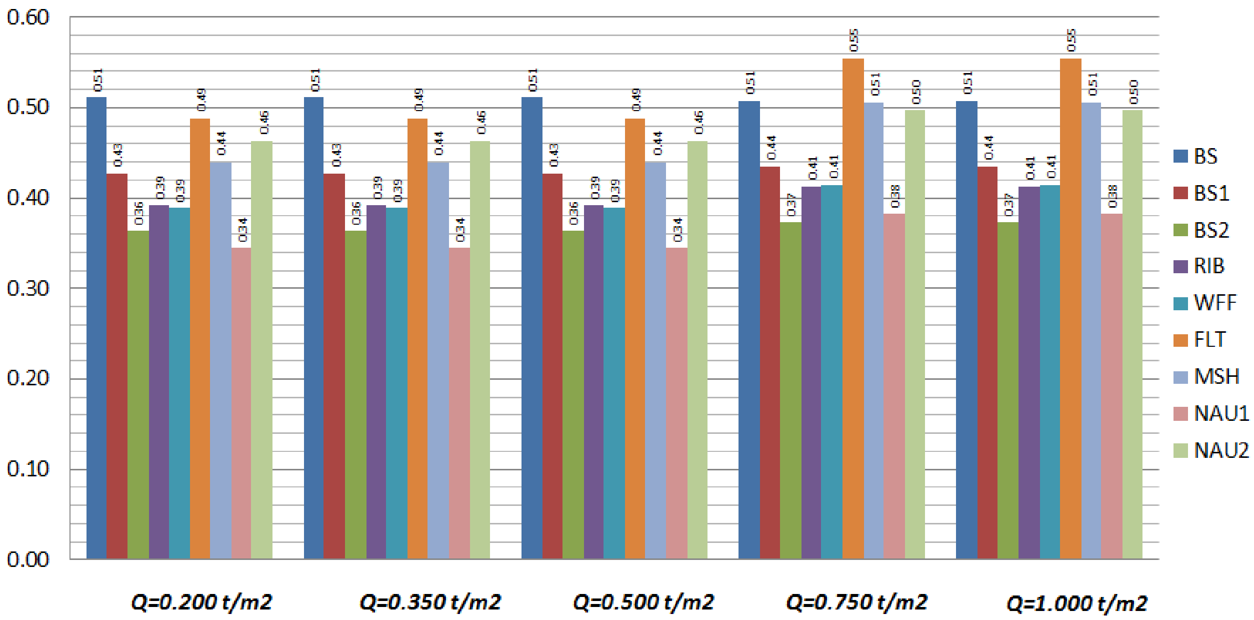

Fig. 8: 14m x 14m-Single Slab System Concrete Odds Comparison Chart

6 CONCLUSIONS

Reinforced concrete slabs are used in many modern buildings. As architects attempt to use more open layouts by utilizing larger column-to-column spans, concrete slabs can become thick and heavy when designing a traditional flat plate. As illustrated in the parametric study, plastic voided slab systems can be used to reduce the structure weight with minimal impact to the overall building design.

he benefits of using plastic voided slabs rather than solid slabs are greater for larger spans. Smaller spans do not require substantially thick slabs, therefore only small voids can be utilized and minimal savings are achieved. Larger spans are capable of using larger voids that greatly reduce the overall weight of the slab while meeting load capacity requirements.

Construction of plastic voided slabs requires more steps than solid slabs, but the construction process is not significantly more complicated. For bays of the same size, plastic voided slabs typically require less reinforcement. The only major change is placement of the plastic void formers. The void formers are placed above the bottom layer of reinforcement and are usually contained in a cage of very thin steel bars. The cage of void formers is typically constructed at the manufacturer's facility and shipped to the construction site, allowing for quick placement of the void formers and minimal changes to the construction schedule compared to solid slab systems.

Architectural freedom can also be achieved by utilizing plastic voided slabs. Plastic voided slabs make it possible to achieve longer spans with the same amount of concrete in the slab, allowing for less columns and a more open interior space.

Overall, plastic voided slab systems provide an excellent alternative to solid concrete slabs for many applications. Weight and cost savings as well as architectural flexibility can be achieved with plastic voided slabs.

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REFERENCES

[1] Park, R & Paulay, T (1975). *Reinforced concrete structure*, New York: Wiley.

[2] Marais, C C 2008. Design adjustment factors and the economical application of concrete flat-slabs with internal spherical voids in South Africa. MEng Dissertation, University of Pretoria.

[3] Schellenbach-Held, M & Pfeffer, K 1999. Transverse force capability of the BubbleDeck, Technical University Darmstadt's Institute for Solid Construction (in German), Germany.

[4] Eurocode 2. (1992). Design of concrete structures - Part 1-1: General rules and rules for buildings, Europen Standarts, Brussels.

[5] SAP 2000, Integrated Software for Structural Analysis and Design, *Computers and Structures Inc.(CSi).*

[6] Catalogue New Nautilus (2014) - GEOPLAST S.p.A. 35010 Grantorto PD - Italia - Via Martiri della Libertà, 6/8

[7] TS500 (2000) Requirements For Design And Construction. Of Reinforced Concrete Structures.

[8] TS EN 1991-1-1 (2002) Eurocode 1 - Actions on structures - Part 1-1: General actions - Densities, self-weight and imposed loads for buildings.

[9] TS498 (1997) Design loads for buildings.