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EVALUATION OF STRUCTURAL LIGHTWEIGHT HIGH STRENGTH SELF-COMPACTING CONCRETE IN CONSTRUCTION APPLICATION

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الملخص العربي

مع استمرار الزيادة السكانية إتجهت الأنظارإلي تشييد المباني العالية التي تكون عناصرها الإنشائية أكثر تعقيدا و تسليحها أكثر كثافة. وأحيانا يتطلب التصميم المعماري إستخدام عناصر إنشائية غير منتظمة الشكل أو نحيفة وتحتاج إلي تسليح كثيف أو موزع بشكل مزدحم يتسبب في مشاكل صب وملء وتكثيف الخرسانة بالعنصر الخرساني باستخدام الهزاز الميكانيكي مما يؤثر علي في النهاية علي كثافة الخرسانة بالعناصر الإنشائية وكفاءتها. والذي يحتاج إلي إبتكار أفكار ومفاهيم تصميمية جديدة لإنتاج خرسانة قادرة على الانسياب بين شبكة حديد التسليح الكثيفة بشكل متجانس دون حدوث انفصال حبيبي.

ونظرا للإحتياج إلي مبان تقاوم الزلازل، كان لزاما دراسة إنتاج خرسانة عالية المقاومة خفيفة الوزن تستخدم في هذا النوع من المباني وتتميز أيضا بتكلفة إقتصادية منخفضة لأقصي درجة ممكنه.

وفي هذا الصدد، فإن تطوير نوع مبتكر من الخرسانة عالية الأداء يجمع بين مميزات الخرسانة ذاتية الدمك (SCC) ، خفيفة الوزن (SLWC) عالية الاجهاد ويستجيب لبعض الاحتياجات العاجلة لقطاع التشييد وخاصة تشييد المباني العالية يمثل هذا تحديا جديدا ومعقدا حيث توجد علاقة عكسية بين مسامية الركام خفيف الوزن وإجهاد الخرسانة و هذا أمر بالغ الأهمية لاتساق الخرسانة ذاتية الدمك.

يهتم البحث الحالي بالسلوك الإنشائي لـ (SLWHSSCC) بإستخدام البيوميس كركام طبيعي خفيف الوزن (LWA) متاح محليا بشمال سيناء في مصر. ثم عمل مقارنة بين الخرسانة (SLWHSSCC) التي تم الحصول عليها مع الخرسانة العادية خفيفة الوزن عالية القوة والتي تحتاج لدمك اثناء الصب من حيث سلوكها مع التسليح المزدحم. كما يركز هذا البحث علي دراسة تأثير كلا النوعين من الخرسانة ذاتية الدمك (SCC) والخرسانة العادية التي تحتاج لدمك (NVC)على السلوك الإنشائي للكمرات الخرسانية المسلحة. لتحقيق هذه الأهداف تم تجهيز ثلاث كمرات واختبارها وتقييمها. حيث تم إختبار اثنان منهم في الإنحناء والثالثة في القص. وأكدت النتائج أن السلوك الانشائي للكمرات المسلحة بإستخدام الخرسانة ذاتية الدمك (SCC) أفضل من سلوك الكمرات المسلحة بإستخدام الخرسانة العادية التي تحتاج لدمك (NVC). من حيث قدرتها علي تحمل الاحمال المصممة ومقاومتها لكلا من الانحناء والقص.

في النهاية ، تم دراسة حالة برج يقع في العاصمة الإدارية الجديدة في مصر لتقييم الخرسانة SLWHSSCC المنتجة من البحث من حيث تأثيرها على التكلفة الأولية للمشروع. كان الهدف هو تقييم الخرسانة ذاتية الدمك في مشاريع الانشاءات من حيث قيمتها وتكلفتها. وتشير النتائج إلى أن تطبيق الخرسانة SLWHSSCC المنتجة من البحث في المشروع أدي الي تخفيض الميزانية الإجمالية للمشروع بنسبة 54.8٪ من التكلفة الأولية.

الكلمات المفتاحية: الخرسانة ذاتية الدمك، الخرسانة خفيفة الوزن، الخرسانة عالية الاجهاد، كمرات مسلحة، بيوميس، الخرسانة الانشائية خفيفة الوزن عالية الاجهاد ذاتية الدمك، المباني العالية، العاصمة الادارية الجديدة.

ABSTRACT

In the last decades, the demand for the construction of high-rise buildings increased. In this type of buildings, the structural elements' sections are becoming more complicated and their reinforcement is being denser and more blocked. On the other hand, irregular or slender architectural members with heavy or closely distributed reinforcement were probably used. The over-crowded arrangement of re-bars causes problems in casting, filling, and compacting the concrete element. Where it is impossible to compact concrete properly with the use of a mechanical vibrator between obstacles. Deficient compaction might lead to lower performance of concrete in terms of strength and durability. Therefore, concrete produced for such members must be able to pass through the dense rebar net without blocking or segregation.

In addition, it will be more beneficial to add the advantages of structural lightweight concrete which reduces the effect of seismic forces on high-rise buildings and have a great commercial effect on the total cost without a negative effect on the strength of concrete.

In this regard, the development of an innovative type of high-performance concretes, combines the advantages of self-compacting concrete (SCC), lightweight concrete (SLWC), and high-strength concrete, responds to some of the urgent needs of the construction sector, especially high-rise buildings construction. This represents a new and intense challenge as there is an inverse relationship between the porosity of lightweight aggregate and the concrete strength otherwise it is critical for the consistency of the self-compacting concrete.

This paper investigates the structural behavior of (SLWHSSCC) incorporating pumice as a locally available natural lightweight aggregate (LWA). A comparative study between (SLWHSSCC) and the structural lightweight, high strength, and normal vibrated concrete in terms of its behavior with a congested reinforced section was performed. This study investigated the influence of both types of concrete, self-compacting concrete (SCC) and normal vibrated concrete (NVC) on the structural behavior of reinforced concrete beams. To achieve these targets, three beams are equipped, tested, and assessed. Two of them failed in compression and the third beam failed in shear. The results approved that the beam made of (NVC) can`t withstand the designed loads compared with beams made with (SCC). Which had better ultimate load-carrying capacity than NVC concrete in reinforcement congested structural beam elements.

At the same time, a case study of a high-rise building located in the New Administrative Capital in Egypt was selected to evaluate the SLWHSSCC proposed in the present study. The objective of this value-engineering study is to quantify the impact of the decision to implement this innovative concrete in an Egyptian construction project in terms of its value and cost. The results indicate that the total budget of the project can be reduced by 54.8% of the initial cost with SLWHSSCC implementation.

Keywords: Self-compacting concrete, normal-vibrated concrete, Structural lightweight concrete, High-strength concrete, concrete beams, Pumice, High-rise buildings, New Administrative Capital.

1. INTRODUCTION

The objective of using self-compacting concrete is to ease the construction of heavy reinforced structural elements and eliminates errors during the pouring without reducing structural performance and durability. Although numerous studies were conducted on SCC, most of them deal with mixture proportioning and characterization of concrete properties in the fresh and hardened state. There is a lack of information about the structural behavior and performance of SCC concrete. There were few theoretical and experimental investigations on the structural behavior of reinforced beams and slabs casted with SCC.

In recent years, many research groups have investigated the mechanical properties and structural behavior of SCC. A lot of questions were answered showing that the characteristics of coarse aggregate have an impact on the mechanical properties of both NVC and SCC. The interfacial transition zone (ITZ) between the aggregates and the surrounding paste matrix is directly influenced by the size and volume of the coarse aggregate. The ITZ is considered the weakest area in the concrete matrix; it has a low cement density, which contributes to reducing the overall strength of the mixture [1]. The increase in the coarse aggregate size influences the increase of the thickness of the ITZ which decreases the compressive strength [2, 3]. The ITZ has also an impact on the overall mechanical properties of the concrete. It affects the splitting tensile strength, modulus of elasticity, and flexural strength as well as compressive strength [4]. The addition of SCMs to the SCC mixtures can improve the fresh properties of SCC concrete and the mechanical properties of SCC concrete. Increasing cementitious materials in the SCC mix increases the binder content in SCC mixtures making certain to increase compressive strength. Consequently, all the mechanical properties of the concrete will be improved [5].

High-strength self-compacting concrete (HSSCC) is a type of high-performance concrete, that has reasonable workability, very high strength, and durability properties. In this area of concrete technology, serious attempts are being made to achieve self-compacting concrete with special features. Many trials were carried out on adding Silica fume, Quarry Dust, and admixtures to concrete mixes to achieve high-strength self-compacting concrete. In such conditions, cement consumption should be increased [6]. The reduction of the W/B ratio (water-binder ratio) increases the compressive strength. The optimum dosage of chemical admixture was about 1.5%-2%. A dosage lower than 1.5% of superplasticizer would affect the workability and over dosage would affect setting time; the dosage of superplasticizer would vary linearly with the weight of cementitious materials. Water content should be selected carefully before adding viscosity modifying agent because rheological behavior is more sensitive to water [6].

Structural lightweight self-compacting concrete (SLWSCC) combines the properties of filling and passing ability through reinforcement without segregation, and the advantages of a structural lightweight aggregate concrete (SLWC), which reduces mass, formwork pressure, high insulation capacity, improves durability, resisting fire and chemical attacks. The topography of the interfacial zone and the characteristic of the surface pores of lightweight concrete with 450 kg/m3 cement content were scanned by an electron microscope [6]. The porous surface of lightweight aggregates (LWA) improved the interfacial bond between the aggregate and cement paste by providing interlocking sites for the cement paste forming a dense and uniform interfacial zone [23]. Additionally, the interlocking of the aggregates has an essential influence on the shear strength of the concrete. Thus, it has a major impact on the shear behavior and shear capacity of the reinforced concrete beams [6]. The relative costs and the potential savings that can occur by using a lighter material will determine whether the structural lightweight concrete (SLWC) is used for a floor slab in a multi-story building rather than normal-weight concrete (NWC). (SLWC) is about 25% lighter than normal-weight concrete. It can reduce energy-intensive steel reinforcement by 15% in designs where the dead load is equal to the live load. Columns and footings have higher cost savings. In the case of long-span bridge construction, the live load does not constitute a value to the total load. Therefore, a reduction in density is translated into reductions in section size [7, 8].

LABORATORY EXPERIMENTS

GENERAL

Experimental work was conducted in this investigation. Three beams were subjected to structural evaluations with dimensions (120mm x 300 mm*2000 mm). The beams were casted by two different types of concrete. Each mixture of both types contains the typical proportions of cement and aggregates. Two beam specimens were casted with self-compacted concrete with low density and high strength (SLWHSSCC) [9]. The last beam specimen was casted with a structural lightweight high strength normal vibrated concrete (SLWHSNVC). The two types of concrete contained the same amount and type of cement and aggregates. All beams were tested for failure; Beam (NVC-B1) and Beam (SCC-B2) were designed to fail in bending through the failure of the compressive chord. Beam (SCC-B3) was designed to fail in shear. The three beams were cast as shown in table 1. The following structural observations were made: Mode of failure and crack pattern, load at first crack and failure, load-deflection behavior at the mid-span and under the two loading points for each increment, and strain development at mid-span for load increment.

BEAMS DETAILS

All the RC beams were rectangular cross-sections of (12 mm x 300 mm) and length of 2000 mm. The reinforced beams (B1) and (B2) were designed to fail in compression with over and dense reinforcement. As shown in Fig. 1, congested reinforcement was selected on purpose to show the properties of the self-compact ability of concrete. Both beams were provided with sufficient stirrups of spacing of 50 mm. The bottom reinforcement consisted of six bars of 16 mm and five bars of 12 mm in diameter. The top reinforcement of the beams was two bars of 8 mm diameter (mild steel 240/420). The reinforced beam (B3) was designed to fail in shear. It was reinforced with six bars with a diameter of 16 mm and five bars of 12 mm as bottom reinforcement. The shear reinforcement (stirrups) was of 8 mm diameter (mild steel 240/420) and spacing of 200 mm for beams. The layout of stirrups and reinforcement is detailed in Fig 2.

Table 1: Classification of Beams

Beam No.	Beam Code	Mix	Fcu (MPa)	Bottom reinforcement bars	Stirrups	Mode of failure
1	B1	NVC	60	6 Φ 16+ 5 Φ 12	20 Φ 8/m`	Compression failure
4	B2	SCC	60	6 Φ 16+5 Φ 12	20 Φ 8/m`	Compression Failure
2	B3	SCC	60	6 Φ 16+5 Φ 12	5 Φ 8/m`	Shear Failure

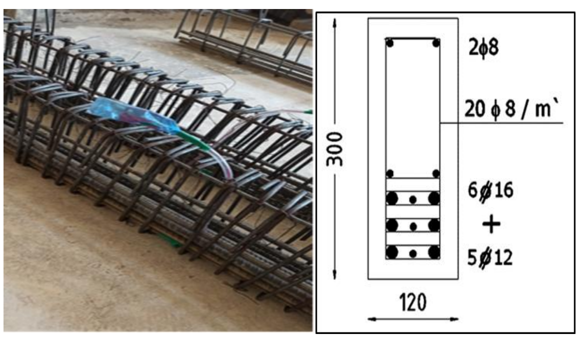


Fig.1: Cross-section and reinforcement Details of the beams B1, B2

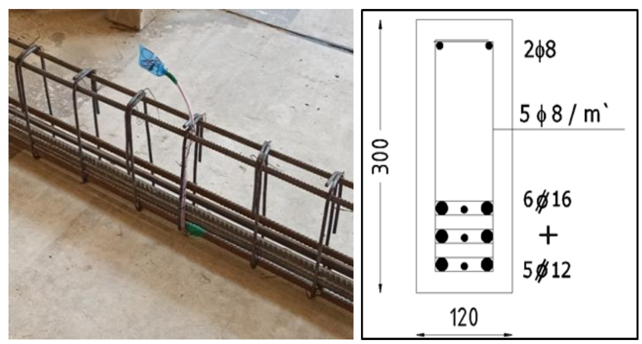


Fig. 2: Cross-section and reinforcement details of the beam B3

FABRICATION OF TEST SPECIMENS

The beams were fabricated at the Concrete Laboratory of the Civil engineering Department, Faculty of Engineering, Al-Azhar University. The reinforced concrete specimens were fabricated where reinforcement cages were prepared, and installed in a formwork of thick plywood. Beam (B1) was casted with lightweight high-strength normal vibrated concrete (SLWHSNVC). It was poured into layers and compacted using a mechanical vibrator. Where beams (B2 and B3) were casted with (SLWHSSCC) concrete. They were poured without any compaction, as shown in Fig 3. Three cubes were casted and tested for each mixture to determine the compressive strength of the concrete. The unit weight of both types of concrete was1980 kg/m^3 and the average cubic compressive strength was about 60MPa. The curing of specimens with water started 24 hours after casting.

Fig. 3: Casting of B1 with compaction by the vibrator, B2, and B3 without any compaction.

MATERIAL PROPERTIES

Pumice was used as a lightweight aggregate of a maximum nominal of about 12 mm, as shown in Fig.4. The typical properties of pumice were tabulated in table 2. Natural siliceous sand was used as a fine aggregate. It satisfies the Egyptian Code (E.S.S. 1109/2008) and ASTM C-33 specifications [10]. Superplasticizer, (Sika Viscocrete 3425) was used as a viscosity-enhancing agent (VEA) to enhance the workability of the SCC mixes. The physical and chemical properties of Sika Viscocrete 3425 as provided by the manufacturer are given in Table 3. It meets the requirements for superplasticizers according to Swiss specification [SIA 162(2989)], European specification [EN 934-2], and American specification [ASTM- C-494 type G and F]. Ordinary Portland cement (CEM I 52.5 N) and silica fume (Micro silica) were used as the binder materials in all SCC mixtures. Cement meets Egyptian Standard Specification (E.S.S. 4756-1/2013) [11]. Normal mild steel with a yield strength 240MPa and high tensile steel with a yield strength 400MPa were used as stirrups and flexural reinforcement, respectively. The main characteristics of the used steel bars were listed in table 4.

Fig. 4: Pumice

Table 2. Typical properties of pumice

Description	Water absorption	Specific gravity
pumice	20 %	1.0

Table 3. Typical Properties of superplasticizers

Properties	Value
Appearance	Clear liquid
Density	1.08 kg/Lit (ASTM C494)
PH Value	4.0
Solid content	40% by weight
Chloride content	Zero

Table 4. Mechanical characteristics of high tensile steel

Mechanical properties	Mild steel	High tensile steel
Yield Strength (N/mm^2)	246.8	443.8
Tensile Strength (N/mm^2)	433.925	620.018
Elongation (%)	21.4	13.2

SPECIMENS PREPARATION AND TEST SET-UP

As shown in Fig. 7, the beams were simply supported with a clear span of 1800 mm and tested under a two-point load with a spacing of 600 mm. A steel stiff beam was used to distribute the jack load into two equal loads. Three linear variable displacement transducers (LVDT) were placed at the bottom of the beam to measure the deflection at the loading points, and in the midpoint of the beam. Electrically bonded strain gauges were glued to the concrete surface and the steel bars to measure the strains in concrete and steel during the test. The strain gauges and LVDTs were connected to the data acquisition system. All beams were loaded gradually at increment of 50 KN up to failure using a hydraulic jack of 1000 KN capacity. Load increments, deflections, and strain readings were recorded up to failure. Cracking patterns and failure modes were closely monitored during the test. Fig. 8 presents a general view of the test setup.

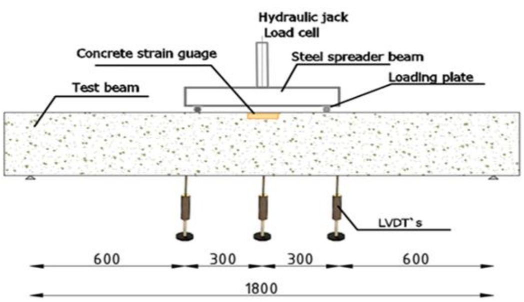


Fig. 7: The loading setup for the RC beam

Fig. 8: Instrumentation used

RESULTS AND DISCUSSION

OBSERVATIONS DURING CONCRETE CASTING

The test results showed that SCC performed better in congested reinforcement beams than the referenced NVC. The experimental study showed that the surface finish produced by self-compacting concrete is very good and patching is not necessary. As shown in Fig. 9, no bug holes or honeycombs were observed on the surface of the concrete. There are no other surface imperfections that can be detected on the finished surface obtained. It is a smooth surface finish. This property becomes very useful when pre-cast architectural panels are made. On the opposite, it was found multiple segregated areas in the beam casted with NVC as per Fig 10, especially at the bottom of the beam in the area of congested reinforced steel. Although the beam made with NVC is properly vibrated and the beams made with SCC are casted with any compaction or vibration, the segregations and voids appear in the beams vibrated.

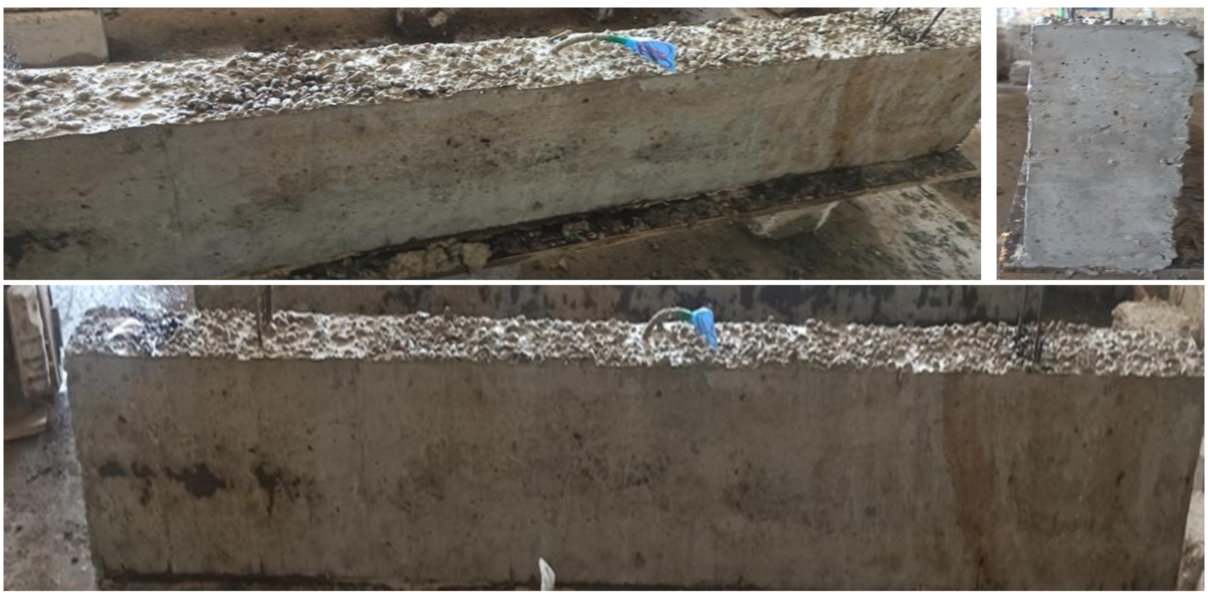


Fig. 9: The surface finish of RC beams casted with SCC

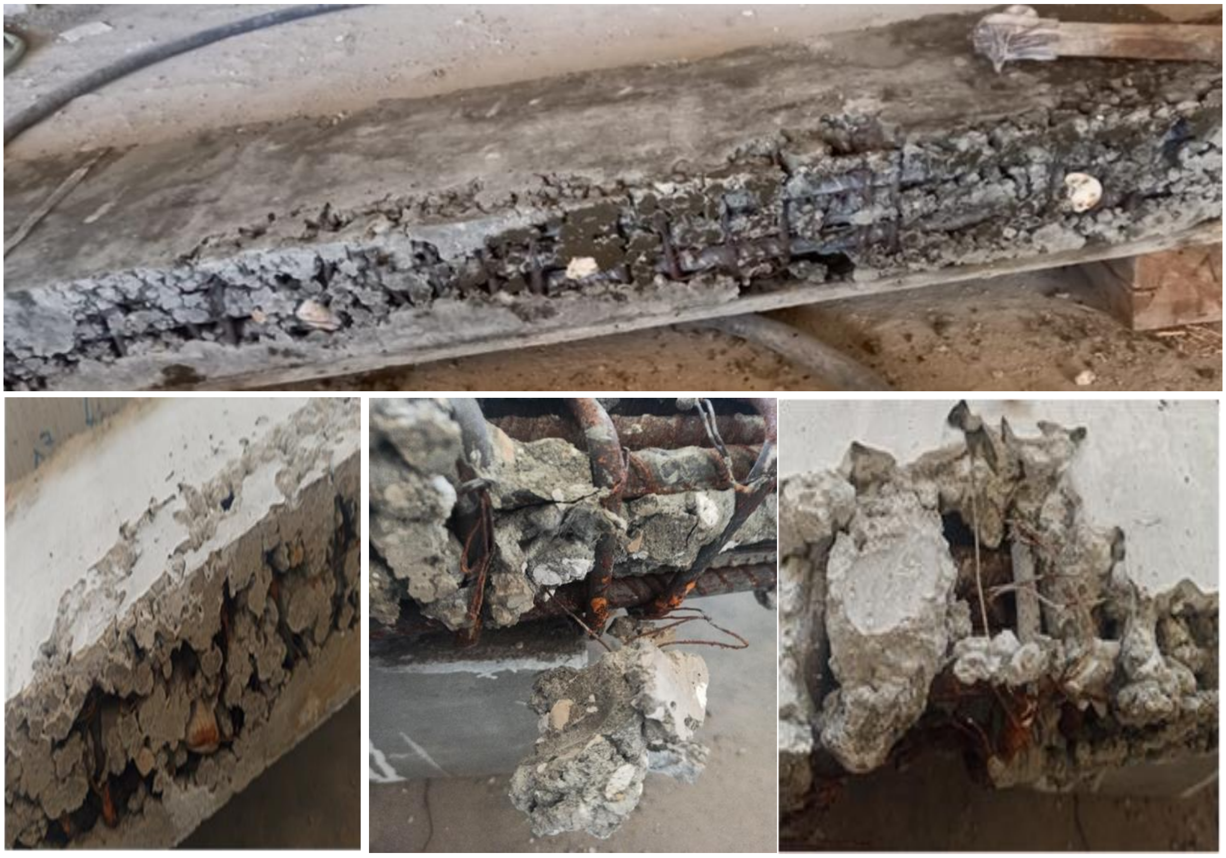


Fig.10: The surface finish and segregation on the bottom of the RC beam with NVC

FIRST CRACK AND FAILURE LOADS

The average value of the compressive strength for tested samples is equal to 60 MPa with a standard deviation (STD) equal to 2 MPa for all beam mixes. The cracking load for the beam SCC – B2 was greater than that of NVC-B1 by 25%, and the ultimate load for the beam SCC – B2 was greater than that of NVC-B1 by 320%. This means that the use of self-compacting concrete gave a higher ultimate load, but had little effect on the cracking load. On the other side, for SCC beams B2 and B3, the ultimate load increased 4 times the cracking load. While it increased the cracking load just 1.5 times for the beam made with NVC-B1, as shown in Table 5. From Table 6, it is shown that the ultimate moments obtained from experimental results were greater than that of the theoretical ultimate moments in the case of beams casted with self-compacted concrete. While the use of conventional concrete with vibration affects negatively the compressive strength of the concrete beam due to the presence of multiple segregated areas in the concrete. In this case, the ultimate moment obtained from experimental results was smaller than that of the theoretical ultimate moments. This means that the beam B2-NVC cast with normal vibrated concrete can`t withstand the designed loads. In this Table, it is also observed that the ratio of ultimate moments of SCC beams (average ratio value of 1.36 and 2.61) is higher than the NVC beam (average ratio value of 0.426). Fig. 11 represents a comparison between the cracking and ultimate load and another one between the designed and experimental moments.

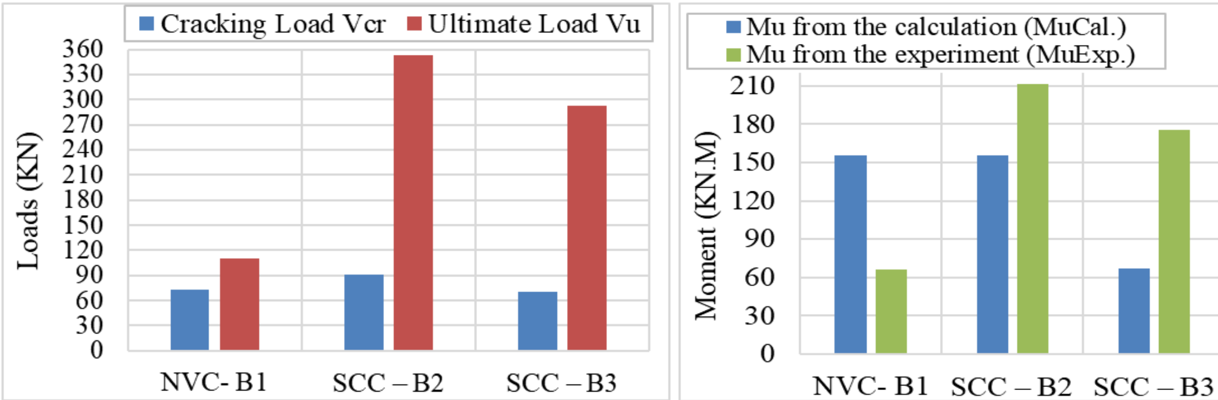


Fig.11: Comparison between the Cracking and Ultimate loads and moments tested beams

Table 5. Experimental cracking load and ultimate loads for the tested specimens.

Specimen Symbol	Mix type	Cracking Load Vcr (KN)	Ultimate Load Vu (KN)	Vcr / Vu
B1	NVC	72.3	110.79	0.653
B2	SCC	90.7	353	0.257
B3	SCC	70	293	0.238

Table 6. Experimental and theoretical ultimate bending moment (Mu) (in KN.m).

Specimen Symbol	Mix type	Mu from the calculation (Mucal.)	Mu from the experiment (MuExp.)	Ratio (MuExp./Mucal.)
B1	NVC	155.96	66.474	0.426
B2	SCC	155.96	211.8	1.36
B3	SCC	67.38	175.8	2.61

RACK PATTERNS AND MODES OF FAILURE

The cracks configuration and distribution were monitored and assigned with their corresponding loads during the test up to the specimen's failure. As expected, flexural cracks are initiated in the pure bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. In the case of the beam (SCC-B2) with the over-tensile reinforcement ratio, some of the flexural cracks in the shear span turned into inclined cracks due to the shear effect of shear force. A sudden failure of the beam occurred when the concrete in the compression zone was crushed. The crack pattern and failure mode of the beam (SCC-B2) are shown in Fig. 12 Beam (NVC – B1) showed a dense crack pattern as presented in Fig. 13. First shear cracks opened from these existing cracks. It had a first crack at 70 KN total load. This beam lost its strength quickly. Fig. 14 represents the crack pattern of SCC-B3 after shear failure near support.

Fig.12: Crack pattern of beam SCC-B2 after failure

Fig.13: Crack pattern of beam NVC-B1 after failure

Fig.14: Crack pattern of beam SCC-B3 after shear failure

LOAD DEFLECTION BEHAVIOR

The relations between the loads and deflections are also described by deflection shapes for all beams as shown in Fig. 15. The deflection shape at the ultimate load was experimentally done by taking the readings of LVDTs that were installed under the mid-span and point load at the right and left points.

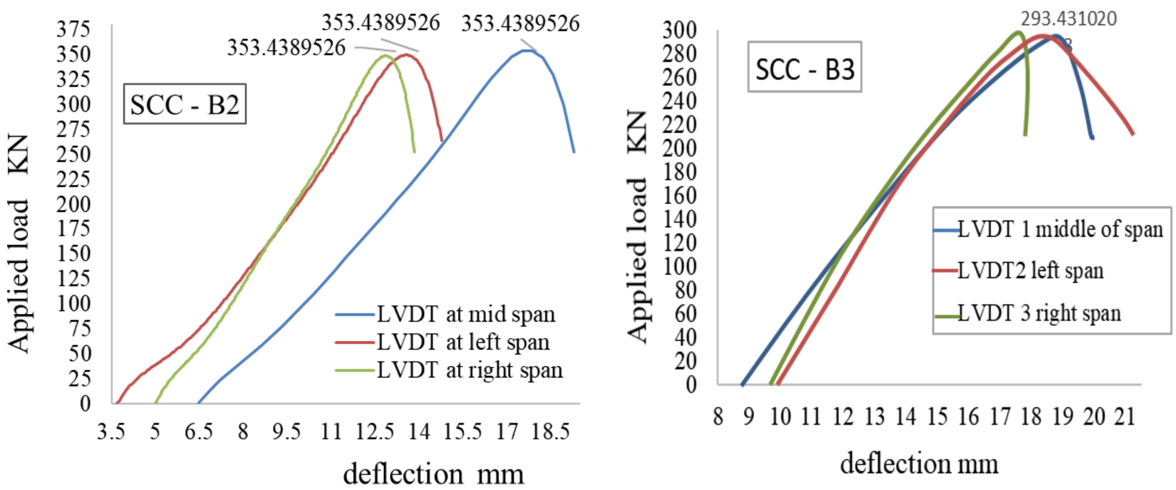


Fig.15: Load deflection of beam SCC beams after failure

CASE STUDY: (HIGH-RISE BUILDING – NEW CAPITAL)

A high-rise building located in the downtown area of the New Administrative Capital in Egypt was selected as a case study to evaluate the SLWHSSCC produced in this investigation. The goal of this value-engineering study is to evaluate the impact of the decision to use this innovative concrete in an Egyptian construction project in terms of its value and cost. As per Fig. 16, the selected project is “Mall Vera Tower” It is a tower with a total area of 2025 m^2 and 55 m of total height. It consists of 16 floors. The existing tower was designed to be constructed with conventional concrete with normal weight and Fcu = 300 kg/cm^2. The current design would be modified by changing the concrete properties to SLWHSSCC instead of the conventional concrete with normal weight and strength. A comparison between the original and alternative designs was done.

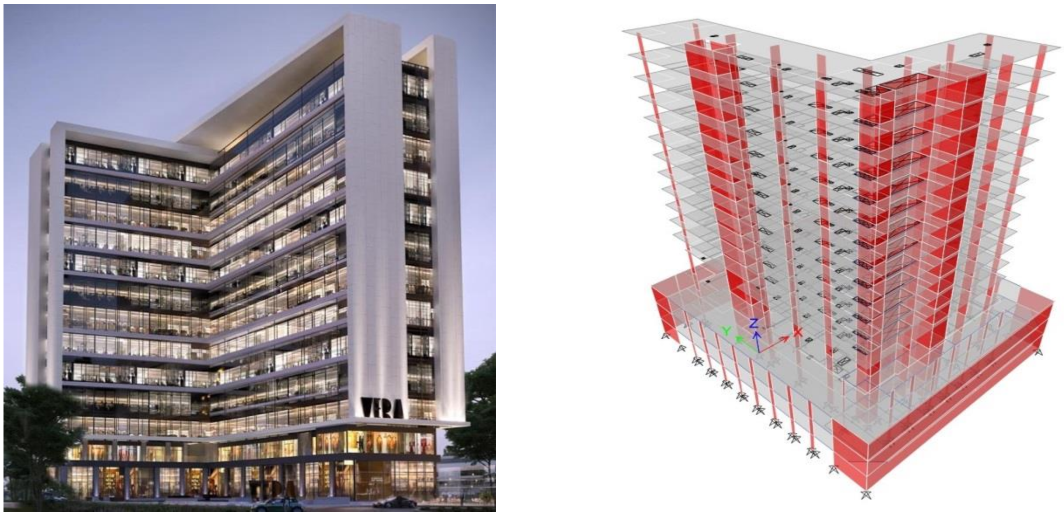


Fig.16: Mall Vera Tower New Capital layout and ETAPS model

THE IMPACT OF SLWHSSCC ON THE STRUCTURAL ELEMENT SECTIONS

Due to the loads of a high-rise building, there are many structural elements in the project designed with congested reinforcement steel, especially in columns. Fig. 17 represents an example of a section for two columns designed in the project. Over blocked arrangement of rebars in columns makes it difficult to compact concrete properly with the use of a mechanical vibrator. The benefit of self-compatibility of SCC is more useful in this case to prevent any segregation or concrete voids. A change also appears in the sections' dimensions and the reinforcement after the alternative design. A numerical model was used to investigate the structural performance of SLWHSSCC reinforced slabs using SAFE software. Generally, the recorded deflection improved due to the use of SLWHSSCC in the opposite of the conventional concrete in the initial design. This indicates the behavior of SLWHSSCC in enhancing the deflections. Fig. 18 represents the change in slab thickness due to the alternative design.

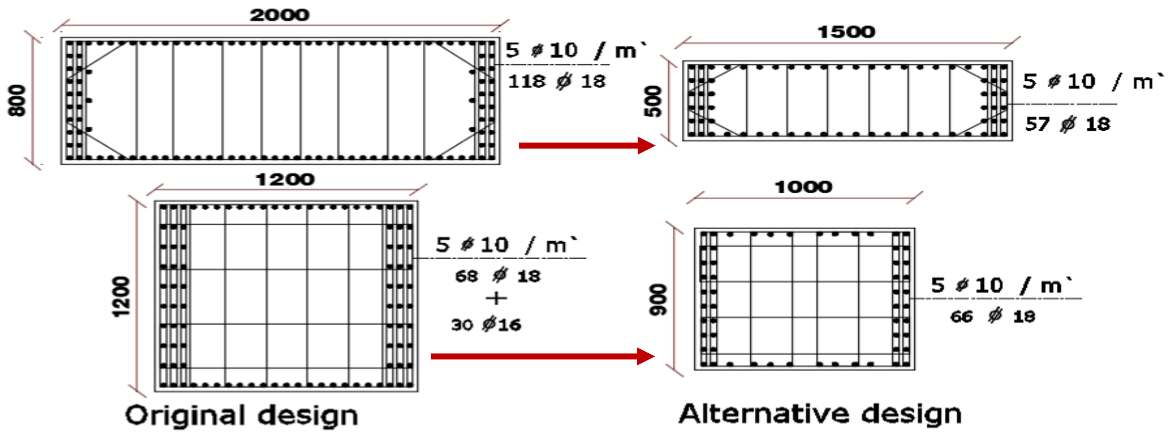


Fig.17: The change in section and its congested reinforcements in columns

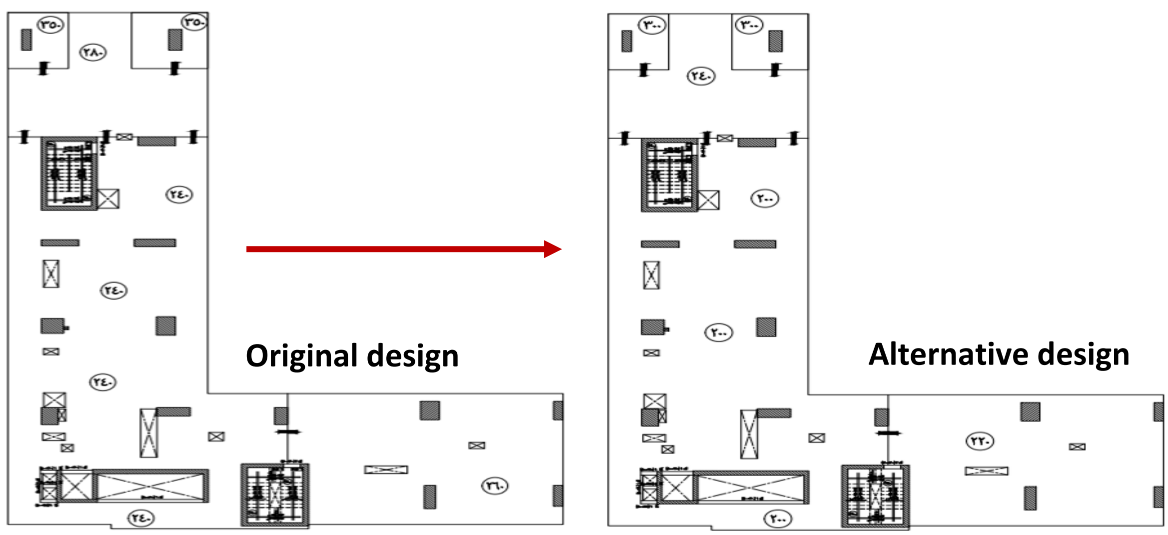
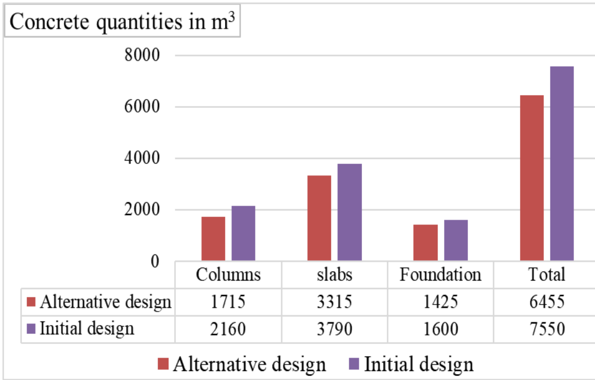


Fig.18: The change in slab thickness due to the alternative design

THE IMPACT OF SLWHSSCC IN TERMS OF BUILDING QUANTITIES AND COSTS

Fig.19, summarizes the quantity of each structural element for two design cases. The total volume of concrete used in the initial design was 7550 cubic meters. While the total volume of concrete for the alternative design was 6455 cubic meters. A reduction in concrete quantities was appear at 15 %. At the same time, a reduction appears also in the total volume of reinforcement steel bars from 2180 tons to 870 tons with a percentage in reduction of 60 %.



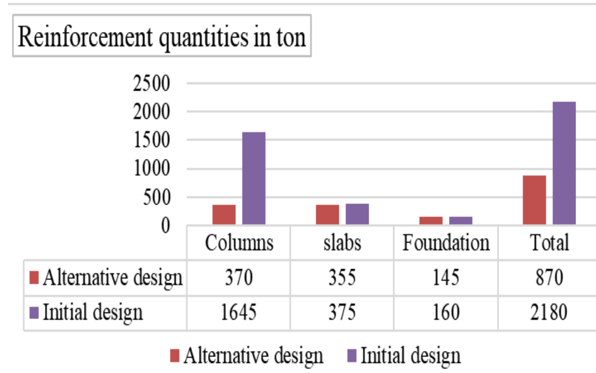


Fig.19: Quantity variations between initial and alternative design

The percentage cost saved for each design can be seen in Fig.20. The total budget of the project will reduce by 54.8% of the initial cost with SLWHSSCC implementation

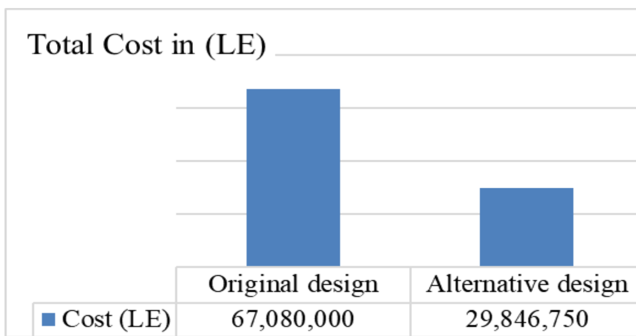


Fig.20: Cost savings by the alternative design

CONCLUSIONS

Based on the results and observations of the experimental study presented, the following conclusions could be drawn as follows:

1. The surface finish produced by self-compacting concrete is very good and patching is not necessary.
2. The use of normal vibrated concrete affects negatively the compressive strength of the concrete of the beam due to the presence of multiple segregated areas in the concrete.
3. SCC concrete had better ultimate load-carrying capacity than NVC concrete in reinforcement congested structural beam elements.
4. For SCC beams B2 and B3, the ultimate load increased 4 times the cracking load. While It increased the cracking load just 1.5 times for the beam made with NVC-B1.
5. The SCC-B2 beam made of self-compacted concrete has an ultimate load 3.5% higher than the NVC-B1 beam made of normal vibrated concrete.
6. The beam B2-NVC casted with normal vibrated concrete can`t withstand the designed loads.
7. The use of self-compacting concrete gave a higher ultimate load but had little effect on the cracking load.
8. For beams made of SCC, the ultimate moments obtained from experimental results were greater than that of the theoretical ultimate moments. On the opposite, in the case of the beam made of NVC, the ultimate moment obtained from experimental results was smaller than that of the theoretical ultimate moments.
9. A reduction in concrete quantities was appear at 15 %. At the same time, a reduction appears also in the total volume of reinforcement steel bars with a percentage in reduction of 60 % in the case of SLWHSSCC implementation in a construction project.
10. The total budget of the project will reduce by 54.8% of the initial cost in the case of SLWHSSCC implementation in a construction project.
11. It is recommended to:
    - Study the (SLWHSSCC) on other types of building such as; bridges as a value engineering case study.
    - Reconsider the high-strength concrete, especially 60 MPa and over in the thickness limits in the Egyptian code for concrete design ECP 203-2018.

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