Online ISSN: 2249-4596
Print ISSN: 0975-5861
DOI: 10.17406/GJRE

Global Journal of Researches in Engineering: E

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VOLUME 23 ISSUE 2 VERSION 1.0

Global Journal of Researches in Engineering: E
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Civil And Structural Engineering
Volume 23 Issue 2 (Ver. 1.0)

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USA Tax ID: 98-0673427

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Framingham Massachusetts Pin: 01701,
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Offset Typesetting

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Contents of the Issue

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 23 Issue 2 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

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By Monica Beatriz Kolicheski

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Keywords: costs, constructive criteria, economic and financial.

GJRE-E Classification: LCC: TD 428

ATMOSPHERICSTORAGECYLINDRICALTANKSPROJECTOPTIMIZATIONCONSIDERINGENVIRONMENTALCRITERIA

Strictly as per the compliance and regulations of:

Atmospheric Storage Cylindrical Tanks: Project Optimization Considering Environmental Criteria

Monica Beatriz Kolicheski

Abstract- Atmospheric tank projects cover a wide range of technical characteristics, ranging from their purpose, according to the regulatory framework, the type of product stored, the technical characteristics of the tank to serve this storage with structural safety and finally the devices and technical resources to make the equipment financially and economically viable and sustainable. As a basis for criteria for this assessment, the correct regulatory framework for each type of tank, based on its application, as well as the correct selection of material for its performance and life expectancy, were addressed. Performance improvement criteria were also evaluated, such as the correct sizing of the tank inlet, outlet and vent nozzles, the use of sensors and devices and equipment to avoid overpressure or vacuum and the use of internal floating roofs. In addition, environmental criteria were also presented, such as the correct selection of tank colors and the assessment of their area of incidence of solar radiation. The list of criteria and technical, performance and environmental details can be further complemented and developed with other characteristics of the tanks and the objective of this article was to evaluate the main parameters of analysis to guide the developer of the tank project to execute it seeking to optimize technical data with immediate execution and operating costs and the environmental impact of project decisions for welded vertical cylindrical atmospheric storage tanks.

Keywords: costs, constructive criteria, economic and financial.

I. Introduction

Equipment classified as atmospheric tanks for storing products in general has a long history and importance in supplying industrial and urban centers around the world. Its conglomerates (tank parks) usually have a very specific objective and are usually directly related to the petrochemical industry (CASTILHO, 2018). However, the applicability of atmospheric tanks is very wide, having strong importance in several industries such as chemistry, paper, bioenergy, thermoelectric and sugar and alcohol plants, biofuels, food and even in firefighting, which can range from industrial to commercial.

The design of atmospheric storage tanks can be basically divided into: bottom, side, roof, metal structures and nozzles (GUIZZE, 1989). In addition to the different design variables, ranging from dimensional, stored product, temperature and pressure conditions, construction material and others, there are also conditions for each component of the tank.

The bottom can be classified by patterns of “annular plates” or rectangular plates, depending on the welding characteristics between the bottom and the side, as this is the most fragile region of the tank (MAIA and AURELIO, 2012; CONTEC, 2010). The sidewall has different methods of calculating sheet thickness: like the more traditional 1-foot method; the variable point method, the appendix A and the appendix S methods (LIMA et al., 2014; COSTA, 2011). The metallic structures, which are usually selected according to the customer's standard, must observe the minimum loads of standards such as NBR 8800 (ABNT, 2007), as well as safety standards NR 18 (BRASIL, 1978).

With regard to accessories, for example for nozzles, which are generally directly linked to the operating standard of the place where the tank is installed, they may have manholes and cleaning ports meeting the minimum quantities required or according to the customer's standard, generally being 180º out of phase around the tank, to ensure air flow (BARROS, 2003).

The different types of ceilings vary according to project definitions, stored product, and local characteristics. The influence of the choice of roof type on the composition of the tank has consequences on the storage efficiency during the useful life of the equipment (API-650, 2010). The main types of ceilings (self-supporting conical, supported conical, self-supporting dome, external floating, internal floating and aluminum geodesic dome). According to Oliveira (2017), the proper choice of the roof of storage tanks reduces the emission of volatile organic compounds (VOC).

The fugitive emission of VOCs from storage tanks can lead to different air pollution problems, with harm to people's health, impacts on flora and fauna, degradation of materials and climate change. Studies carried out by Wei et al (2014) at an oil refinery in Beijing showed that the tank park contributed with 18.3% of the refinery's VOC emissions. Chen et al (2019) evaluated the presence of VOCs in a region close to an industrial complex in central Taiwan and found that 23 to 32% of the pollutants identified in the region came from an industrial source – refinery and petrochemicals. In addition, to the environmental issue, according to Oliveira (2017) the release of these compounds means economic loss of volatilized products.

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The establishment of environmental criteria, in addition to economic ones, are important for the development of hydrocarbon storage tank projects to minimize the environmental impact of tank parks due to the fugitive emission of VOCs. In this context, the objective of this study was to propose a preliminary analysis that considers financial costs, technical and structural safety, as well as the environmental impact of tank sizing. The analysis also included suggestions for accessories that improve the tank's performance and promote the reduction of energy losses and fugitive emissions from the tank throughout its useful life.

In this way, the tank design parameters were organized to establish a methodology for the project that considered in its development, the normative framework, the product characteristics, the construction materials and boundary conditions (accessories for performance improvement), without forgetting the environmental impacts. This analysis will enable the dimensioning of equipment with adequate costs in its construction (financial criterion), guarantee of durability during its period of operation (technical criteria) of operation and better energy conditions (environmental criteria), bringing environmental and economic gains throughout its operation. In this sense, this study presents some important guidelines in relation to the framework in technical standards; product features; material selection, accessories for performance improvement; painting; adequate selection of the irradiation area to contemplate the environmental criteria in the design of hydrocarbon storage tanks.

II. Establishment of Design Criteria for Storage Tanks

When checking the construction standards for tanks, the design criteria for the equipment are predominantly functional and economic, with no emphasis on issues related to air pollution caused by emissions related to this equipment. The evaluation of VOC emissions in different types of hydrocarbon storage tanks indicates that the application of some constructive criteria can represent considerable environmental advantages, with associated economic advantages.

a) *Criterion in Relation to Compliance with Technical Standards*

Atmospheric tanks have a wide range of applications, and their designs range from small low-volume tanks (from 1 to 100 m^3) used in small industries for storing small amounts of oil, chemical products and even water to large volume tanks (above 60,000 m^3) applied to the petrochemical, oil and gas industry.

Therefore, it is essential to have a correct normative framework to establish a project optimized. Among the most widely used and well-known Brazilian standards for tank design, the NBR-7821 is cited (ABNT, 1983) and the complementary standard N-270 (PETROBRÁS, 2020), Petrobras' internal standard, which is most used as a reference. In addition to these, the standards of the American Petroleum Institute, USA, API-650 (API, 2010) and API-653 (API, 2009) are considered, the first being aimed at new projects and the second for tank renovations. These four standards deal specifically with tanks for the oil and gas industry.

However, in addition to these four standards, we can also cite other standards, such as the American standard NFPA 22 (NFPA, 2013) for tanks of fire-fighting systems, the European standard EN-1993-4-2 (EN, 1999) and the American standard AWWA D-100-96 (AWWA, 1997) intended for water storage tanks. These standards apply only to welded tanks, there are also specific standards for bolted, riveted, helical mounting and "Australian" type tanks.

In these standards, the methodology and calculation have the same technical basis. In general, the hydrostatic pressure of the product to be stored is related to the mechanical resistance of the thickness of the cylindrical body of the tank. What differentiates the standards is the safety factor adopted by the standard, which normally allows for the determination of minimum working thicknesses of the tank. With the exception of the EN-1993-4-2 (EN, 1999) standard, which, in addition to basic calculations, allows for a more refined dimensioning since it considers the calculation of resistance by finite elements that allows a more precise calculation when performed by experienced designers, as it does not apply simplifications common in standards to its design, which, as they always work with a safety margin, normally end up over-dimensioning the project.

Therefore, observe it should be noted that, for each tank application, the standard that best fits its functionality must be correctly selected, in order not to oversize the tank thicknesses when applying a more rigorous standard, incurring in greater consumption of metal for the construction of the tank and unnecessary costs. In this way, the use of an adequate standard makes the project sustainable and of lower cost. The study of the cited norms provided the elaboration of Table 1, which allows a comprehensive vision and an initial reference for the analysis of the designer. In this analysis, it was considered that small tanks are those with a capacity of less than 200 m^3. This type of tank can be purchased ready-made, that is, without the need for assembly at the installation site.

Table 1: Normative framework criteria depending on the usefulness of the tank

Application	Product	Size	Standard
Chemical alcohol plants Biofuels Thermoelectric	Naphtha (Gasoline) Diesel aviation kerosene Biodiesel Alcohol	Big	API-650, API-653, NBR 7821 and N-270
		Small	
Paper And Cellulose Heavy Chemical Industry		Big	API-650 (Appendix A)
		Small	
Paper And Cellulose Water treatment	White liquor Black Liquor Assorted chemicals (acids, caustic soda, solvents, etc.)	Big	API-650, API-653, NBR 7821 and N-270
		Small	API-650 (Appendix A)
Chemical alcohol plants Biofuels Thermoelectric	Industrial Water	Big	AWWA D-100-96
		Small	EN-1993-4-2
Water for industrial use	Industrial Water	Big	AWWA D-100-96
		Small	EN-1993-4-2
Drinking water	drinking water	Big	AWWA D-100-96
		Small	EN-1993-4-2
Food industry	Processed and Ultra-processed for consumption	Big	AWWA D-100-96
		Small	EN-1993-4-2
Fire Fighting	Firefighting system water	Big	NFPA-22
		Small	

Source: The authors (2023)

b) *Criterion in Relation to the Selection of Materials*

Similarly, each design has an optimal solution for tank construction materials, considering the product stored and the expected service life of the tank. Fuel storage is done in carbon or stainless-steel tanks to reduce corrosion problems, but according to Komariah et al (2023) corrosion is still one of the main problems found in fuel tanks. In this way, the selection of the correct material is fundamental in the sizing of the storage tank. The analysis of the most suitable types of steel for the construction of storage tanks for different products in order to avoid corrosion processes led to the elaboration of Table 2.

Table 2: Criteria for choosing construction material depending on the application of the tank

Application	Product	Material	Internal painting	Corrosion over thickness	Observation
Oil and Gas	Naphtha (Gasoline) Diesel aviation kerosene Biodiesel Alcohol	Carbon steel	Yes	1 to 2 mm	Preferably A-36 due to its normative condition of greater resistance
Chemical alcohol plants Biofuels Thermoelectric					
Paper And Cellulose Heavy Chemical Industry	White liquor Black Liquor Miscellaneous chemicals (acids, caustic soda, solvents)	Carbon steel	Yes	above 3mm	Preferably A-36 due to its normative condition of greater resistance
		304L stainless steel	No	-	The use of stainless steel only due to the corrosivity of the chemical
Paper And Cellulose Water treatment	Industrial Water	Carbon steel	Yes	1 to 2mm	Preferably A-36 due to its normative condition of greater resistance
Water for industrial use	Industrial Water	Stainless Steel 439.	No	-	The use of stainless steel depending on water quality

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drinking water	drinking water	Stainless Steel 304 or 316.	No	-	The use of stainless steel due to the potability of the water
Food industry	Processed and Ultra-processed for consumption				
Fire Fighting	Firefighting system water	Carbon steel	Yes	1 to 2 mm	Preferably A-36 due to its normative condition of greater resistance

Source: The authors (2023)

Based on Table 2, the designer obtains initial guidance on the most suitable materials and finishes for the project. However, it should be noted that the designer's final decision must consider the specifications and particularities of the product (if any) and the minimum requirements of the customer.

c) *Criteria for using Accessories to Improve Performance*

Although the influence of tank accessories, for example nozzles and internal floating roofs, is low when considering the total weight of the tank. Consequently, the direct cost of acquiring the tank is little affected, but the correct sizing of the accessories and their application can bring benefits in the operation of the tank and increase its useful life.

In order to assess the influence and impact of accessories on the performance of the tank, these criteria were subdivided into sizing of the inlet and outlet nozzles and the breather valve, use of accessories and sensors and use of internal floating roofs.

i. *Inlet, Outlet and Tank Breather Nozzles*

The filling, outlet and breather nozzles directly interfere with the exchange of emissions with the environment and, consequently, must be well dimensioned to avoid air pollution. Incorrect sizing of these can deform the structure of the tank (see Figure 1), in addition to increasing emissions into the environment, with consequent environmental and economic impact. To guarantee the performance and safeguard the integrity of the tank against operational damage such as: corrosiveness in the nozzles due to abrasion, under pressure or vacuum; proper sizing of nozzles and vents is essential.

(A) Vaporization of stored liquid due to steam or condensate leakage from heating system in REPAR – Curitiba/PR – BRAZIL. (B) High temperature variation in RNEST – Ipojuca/PE – BRAZIL. (C) Pumping above the pressure admitted by the tank in RLAM – São Francisco do Conde Bahia/BA – BRAZIL. (D) Tank inertization with racket relief valves, preventing its operation in REFAP – Canoas/RS – BRAZIL. (E) Sudden vaporization of water inside the tank in LUBNOR – Mucuripe/CE – BRAZIL. (F) Start of fire, flow through the emergency valve in LAMESA TEXAS – USA.

Source: Vector-Mathias (2015)

Figure 1: Examples of overpressure or vacuum situations in tanks

The dimensioning of nozzles and vents for fuel storage tanks – and other chemical products – is essential for reducing emissions. And, when associated with the other criteria evaluated in this study, emissions losses are minimized. The use of criteria provides sustainability and economy during the useful life of the tank, especially in tank farms.

The correct sizing of the inlet and outlet nozzles and the tank vent is carried out based on the flow rates of the pumps used for filling and temperature variations. The sizing of breather valves is done by API-2000(2009). Table 3 indicates the factors that must be evaluated for sizing the nozzles and the vent depending on the fluid that will be stored inside.

Table 3: Optimum fluid velocities, for calculating the pipe size based on the flow of the filling and emptying pumps

Fluid	Economy Speed (m/s)	Piping Material
Water for general services	0.9 to 2.5	Steel
Water for industrial network	0.9 to 2.2	Steel
pump suction line	0.9 to 2.2	Steel
Pump discharge line	2.1 to 3.0	Steel
Hydrochloric acid	15	rubber coating
Sulfuric acid 88% to 98%	1.2	Cast iron
Ammonia	1.8	Steel
Benzene	1.8	Steel
chlorine	1.5	Steel
Chloroform	1.8	Copper and Steel
Sodium Hydroxide 30%	1.8	Steel
30% to 50% Sodium Hydroxide	1.5	Steel
Sodium hydroxide from 50% to 73%	1.2	Steel
Lubricant	1.8	Steel
Fuel oil	1.8	Steel
Brine ($CaCl_2$)	1.2	Steel
Carbon tetrachloride	1.8	Steel
ethylene trichlor	1.8	Steel

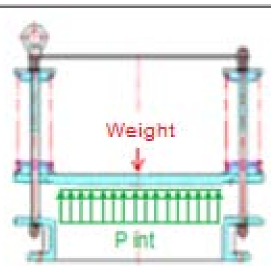
Source: Adapted from Telles (1999)

ii. *Using Accessories and Sensors*

Just as it is good sizing is necessary for the inlet and vent nozzles of the tanks, it is necessary to use sensors and devices for redundant guarantees against overpressure or vacuum, such as: pressure and vacuum relief valves, emergency pressure valves, high-level, high-high sensors, level radars, measuring rod and or pressure sensors, combined to guarantee overpressure or vacuum and temperature control. In this way all these items must be considered by the designer.

Accessories ensure efficient work of tanks, balance fluid fluctuations in the tank and regulate its internal pressure. The use of sensors allows activating and opening the accessories only, when necessary, thus reducing losses due to VOC emissions - air pollution - and, consequently, the environmental impact.

Therefore, care must be taken when calculating the thickness of the pressure relief valve cover, so that it does not cause mechanical damage due to non-opening or environmental damage due to unnecessary opening. The following example shows the correct sizing of the thickness of the pressure relief valve cover. Figure 2 shows the actions of pressure on the cover of an emergency valve, basically counterbalanced with the cover's own weight.



Therefore, we have the internal pressure P int = 37mmca or 37 kgf/m²
Considering the lid of a metal with a density (ρ) of 7850kg/m³ (carbon steel or stainless steel, for example), we will have its thickness determined by:
Thus, the pressure provided by the lid is its force weight divided by the area of the lid, or
Lid pressure = Ptamp = F/A, with Weight Force F = ρ V, or ρ*e*A, with:
V = lid volume and lid area and . So, Ptamp = P int = ρ*e, from where:
e = P int / ρ (in m) (1)
in our of our example: e = 37 / 7850 = 4.71mm
(4.75mm commercial thickness)

Figure 2: Examples of emergency relief valve sizing (Oliveira, 2020b)

iii. *Internal Floating Ceilings*

The internal floating roof has the objective of eliminating the vapor space between the seal and the surface of the stored liquid, to avoid the fugitive emission in the storage of fuels and chemical products with low vapor pressure. In this way, the use of this type of accessory reduces the emission of VOCs. According to Oliveira (2015), the application of internal floating roofs compared to fixed roofs provides a reduction in VOC emissions of up to 98% on average, depending on the application conditions.

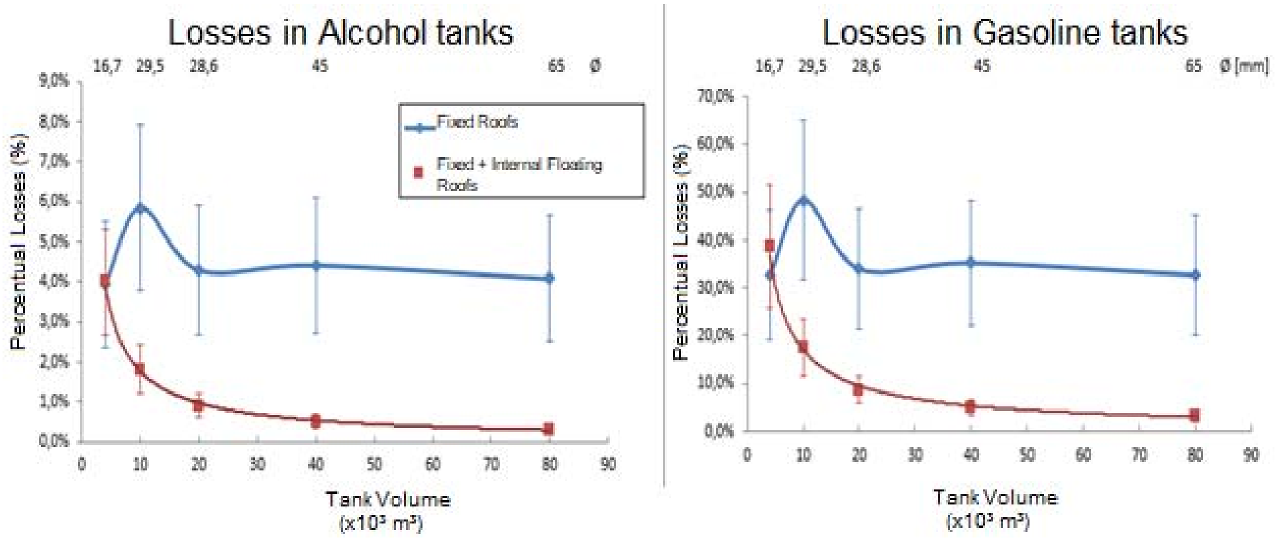
The application of internal floating roofs, in accordance with Appendix H of API-650 (API, 2010), has become a more practical alternative in terms of design, manufacture, assembly and costs in sizing tanks (LIMA et al., 2014). This type of ceiling is a simple construction device, lightweight and an excellent financial alternative for reducing emission losses (OLIVEIRA, 2017; OLIVEIRA, 2020a). Figure 32 illustrates the constructive details of the internal floating roof.

Source: Vector-Mathias (2015)

Figure 3: Constructive details of internal floating roof

Studies carried out by Oliveira (2020a; 2015) show that the more volatile the product stored and the larger the tank diameter, the efficiency of the internal floating roof will be better. Figure 4 illustrates the reduction in losses due to VOC emissions in tanks with and without floating roofs for alcohol and gasoline storage tanks.

Floating roofs bring benefits in firefighting in the NBR 17.505e (ABNT, 2006), because by reducing VOC emissions, it also reduces the area subject to explosion risks. The use of this type of ceiling can also be applied to other specific cases, such as the reduction of contamination of products with water - biodiesel or demineralized water - however these applications still need specific studies to prove the efficiency of internal floating ceilings.



Source: Adapted from Oliveira, 2020a

Figure 4: Reduction of emission losses in tanks with and without floating roofs

d) Environmental Criteria

In order to alert the designer to environmental and not only economic efficiency for the design of storage tanks, but this study also evaluated the influence of the external painting of the tanks and the area of solar irradiation.

i. *Appropriate Choice of Exterior Paint*

The external painting of the fuel storage tank can have a big impact on the evaporative loss of stored products. According to Castilho (2018) losses can be reduced by up to 25%. According to the author, the darker the color of the paint adopted for the external painting, the greater the energy absorbed, and, consequently, the loss by evaporation of VOCs will increase.

Other factors must be considered when sizing the tank, such as the volatility of the stored product and the area to be painted in the tank, since the larger the area to be painted, the greater the influence of the choice of paint to reduce losses due to evaporation. The use of light colors – white or gray – is the most suitable for fuel storage (Table 4) and the choice of these colors for painting tanks with floating roofs is relevant for reducing VOC emissions during the useful life of the tanks. It is observed that in the case of fixed roof tanks the influence is very relevant, especially for gasoline storage.

For Castilho et al (2023) the use of white color in storage tanks, instead of gray, relatively common in tank parks, can represent a reduction of up to 40% in VOC emissions. However, if there is an interest in the tank absorbing greater thermal energy to keep the product warm, such as the storage of biodiesel obtained from animal tallow, the use of dark colors will reduce the need for adding heat by through internal coils, with consequent environmental gain for the tank design.

Table 4: Influence of tank color to reduce losses from VOC Emissions

Product	Roof type	Color	Relevance
Gasoline	Fixed	White	H
	External Floating		A
	Internal Floating		A
Diesel	Fixed	White	A
	External Floating	White or Gray	L
	Internal Floating	White or Gray	L
Crude Oil	Fixed	White	A
	External Floating		A
	Internal Floating		A

H – High Relevance // A – Average Relevance // Low Relevance

Source: Adapted from Castilho (2023)

ii. *Evaluation of the Solar Irradiation Area*

The solar irradiation area is obtained by evaluating the diameter/height ratio of the storage tank. With this analysis, it was concluded that, for the same volume, tanks with a smaller diameter/height ratio – smaller area of solar irradiation – provide reductions in VOC emissions. According to Castilho et al (2023) the reduction of emissions in gasoline storage tanks was around 40% for tanks with an external floating roof and above 50% in tanks with an internal floating roof.

The option for the smallest irradiation area allows the designer to obtain tank dimensions close to those that occupy a smaller surface area. And, therefore, the amount of sheet necessary for the construction of the tank and maintenance of the external coating will be smaller, consequently the cost for the construction of the tank will be lower. According to Castilho et al (2023) the use of tanks with the smallest irradiation area and in the appropriate amount can lead to reductions of up to 80% of VOC emissions in the storage of gasoline and oil in a tank park, regardless of the type of ceiling adopted.

III. Conclusions

The universe of data and information necessary for the proper sizing of a storage tank is very wide and the current tendency of projects is to use the API-650 and API-653 standards, which are complete standards, but designed for sizing tanks. to be installed in an industry where operational risks are greater and, consequently, the rigor required in sizing is also greater. However, it is observed that, in general, designers do not observe the other existing normative frameworks, which are equally competent in their specialties. This mistaken decision leads to the dimensioning of greater thicknesses, which increases the cost of the storage tank, due to the greater amount of metal for construction, which becomes unnecessary both from an economic and environmental point of view.

The sizing criteria, even being a preliminary analysis, will allow tank designers to avoid increasing the construction cost of the tank and minimize the environmental impact due to reduced emissions and energy loss. It is worth mentioning that for some situations of greater risk, such as flammable products, location of installation with unfavorable weather conditions and specificities of the industry, the analysis criteria must be complemented with specific information, however these do not invalidate the criteria proposed in this study. The environmental criteria identified in this study should not override other relevant criteria for the entrepreneur, such as logistics, maintenance, operational facilities and construction or installation. It is recommended that they be evaluated together with these, that is, that tank designs consider emission estimates when deciding on the best constructive alternative.

The list of criteria established in this work can also be complemented with the evaluation of other parameters, such as types of sealing, roofs supported by columns, types and number of accessories, relief valves with different pressures and tanks with geodesic fixed roofs according to the designer's assessment deems relevant for specific cases of tank sizing.

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Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 23 Issue 2 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Efficiency of Self-Healing Cementing Materials

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GJRE-E Classification: ACM: D.2.8

EFFICIENCYOFSELFHEALINGCEMENTINGMATERIALS

Strictly as per the compliance and regulations of:

Efficiency of Self-Healing Cementing Materials

Эффективность самовосстанавливающихся цементирующих материалов

Wang Mingyuan [α], Tang Dyunyan [σ], Rudnov Vasily Serrgeevich [ρ] & Xiao Xinyuan [ω]

Annotation- In order to meet the special requirements (for the strength and conductivity of concrete structures) that arise during the transmission of electricity to remote areas of the Russian Federation, a variant of using self-healing concrete is proposed. In this material, it is proposed to use microcapsules obtained by the physical method, consisting of sodium silicate and bentonite clay coated with ethyl cellulose with graphene. The mechanism of action of the capsule is as follows: after external mechanical destruction, access to graphene appears and it acts as a conductive medium, resulting in the cementing properties of the capsule core. In the course of the work, the optimal ratio of graphene and the capsule core was established, which was determined during a number of experiments and microstructure studies. The dependences of the compressive strength and conductivity of the composite on the graphene content in the capsule, the number of microcapsules in concrete and the time of strength gain were also revealed. In the experiments, the average size of microcapsules was 1.25 mm, the grain shape is predominantly spherical with a rough surface and dense structure. The optimal microcapsule content was 2% of the cement binder weight, which corresponds to 0.1% graphene oxide. With an increase in the graphene content, the conductivity of the concrete composite monotonically increases, and the compressive strength increases to a certain limit, and then decreases. After partial destruction of the samples (discontinuity) at the microlevel, the composite material recovered, while the recovery coefficient was 81%, and the recovery coefficient of compressive strength was 57%.

Keywords: graphene; microcapsules; self-healing cementing materials, compressive strength; conductivity.

***Аннотация-* С целью удовлетворения специальных требований (по прочности и проводимости бетонных конструкций), которые возникают при передаче электроэнергии в отдаленные районы РФ предложен вариант применения самовосстанавливающегося бетона. В этом материале предлагается использовать микрокапсулы, получаемые физическим методом, состоящие из силиката натрия и бентонитовой глины покрытые оболочкой из этилцеллюлозы с графеном. Механизм действия капсулы следующий: после внешнего механического разрушения появляется доступ к графену и он выступает в качестве проводящей среды в результате чего проявляются цементирующие свойства ядра капсулы. В ходе работы установлено оптимальное соотношение графена и ядра капсул, которое определялось в ходе ряда экспериментов и исследованием микроструктуры. Также выявлены зависимости прочности на сжатие и проводимости композита от содержания графена в капсуле, количества микрокапсул в бетоне и времени набора прочности. В экспериментах средний размер микрокапсул составил 1,25 мм, форма зерен преимущественно сферическая с шероховатой поверхностью и плотной структурой. Оптимальное содержание микрокапсул составило 2% от массы цементного вяжущего, что соответствует 0,1% оксида графена. При увеличении содержания графена проводимость бетонного композита монотонно возрастает, а прочность на сжатие до некоторого предела возрастает, а затем снижается. После частичного разрушения образцов (нарушения сплошности) на микроуровне композитный материал восстановился, при этом коэффициент восстановления составил 81%, а коэффициент восстановления прочности на сжатие – 57%.**

Ключевые слова: графен; микрокапсулы; самовосстанавливающиеся цементирующие материалы, прочность на сжатие; проводимость.

I. Введение

В настоящее время быстрыми темпами увеличивается количество энергопотребителей по всей территории РФ, что в свою очередь стимулирует активный рост линий передач и преобразования электроэнергии, в том числе в отдаленных районах страны (рис.1) с суровыми климатическими условиями.

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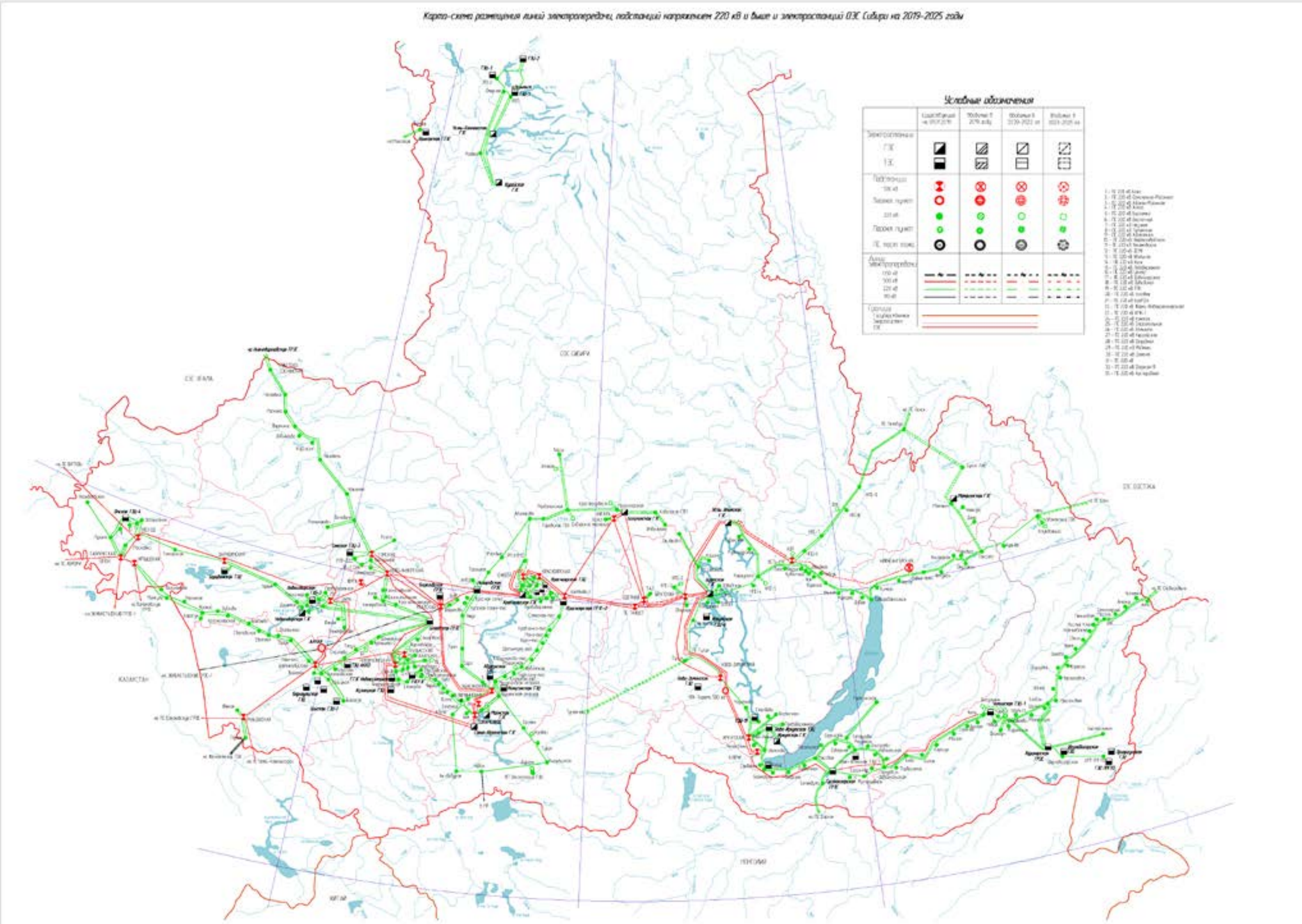

Рис. 1: Принципиальная схема линий передачи и преобразования электроэнергии в РФ

Fig. 1: Schematic diagram of transmission and conversion lines of electricity in the Russian Federation

При этом на фундаменты опор ЛЭП влияют как погодные условия (большое количество дождей, экстремальные температуры), так и сложные геологические условия (засоленные или слабые грунты), что приводит к разрушению бетонной конструкции, морозному пучению, неравномерным осадкам, трещинам и другим повреждениям. В то же время, фундаменты являются «скрытыми работами», что затрудняет выявление образовавшихся дефектов, трещин, снижает долговечность и сроки безопасной эксплуатации конструкций. Также фунжаменты должны обладать определенной электропроводимостью для обеспечения безопасности людей и оборудования и для повышения надежности работы энергосистемы. Рядовой тяжелый бетон имеет удельное сопротивление $10^4 \dots 10^9$ Ом×м и для использования его в конструкциях фундаментов ЛЭП его необходимо снижать. Все перечисленные факторы определяют требования, предъявляемые к бетону фундаментов.

Созданный коллективом авторов интеллектуальный самовосстанавливающийся бетон разработан на основе бионической теории. Ремонтный материал при изготовлении смеси располагается внутри монолита и когда конструкция повреждена, запускаются триггерные механизмы (температура, изменение pH среды или трещины) запускают восстановление поврежденного участка, что продлевает срок службы конструкции и повышает ее долговечность. Микрокапсульная технология самовосстановления материалов на основе портландцемента обладает преимуществами, которые заключаются в возможности массового применения, низкой себестоимости (по сравнению с ремонтными работами), простоты управления процессом и прекрасной диспергируемостью по телу бетона [1-3]. В настоящее время, аналогичные материалы состоят из карбамидоформальдегидные смолы/эпоксидные микрокапсулы [4-7], микрокапсулы фенольной смолы/дициклопентадиена [8-10], обладающие более низкой адгезией и незначительным расширением материала ядра в совокупностью с недостаточной прочностью стенки капсул, что существенно ограничивает возможность их применения в цементных композициях [11]. Способы изготовления таких капсул основаны на физическом [12-14], химическом [15], физико-химическом [16-21] и других методах (табл. 1). Ян Гокунь [22], Чжан Мин [23], Ван Жуй [24], Ху Хунлинь [25], Л. Чжун [26] и другие проводили экспериментальные исследования и математическое моделирование в области нефтехимии, дорожного машиностроения, мостостроения, полимерных материалов, покрытий и других областях. Однако, для фундаментов линий электропередач, работающих в сложных геологических и метеорологических условиях удаленных районов Крайнего Севера таких исследований выполнено не было, не смотря на высокую потребность.

Таблица 1: Способ приготовления микрокапсул [12-21]

Table 1: Preparation method of microcapsule [12-21]

Способ приготовления	способ производства	Материал сердцевины	Материал стен	Свойства материала
физика	Метод распылительной сушки	CSA	PVA	E_d (↑)
химия	Микрофлюидика/фотополимеризация	CS、SS	AE	σ_{bc} (↓) 、C_r (↑)
	Химически активированная эмульсионная полимеризация	SF	PS	C_r (↑) 、E (↓) 、pH (↑)
	Агрегация излучения	BS	MA	σ_{bc} (↓) 、σ (↓)
Синтез физики и химии	Метод экструзии	CH、MFP、Ag+	EC、MA	pH (↑) 、C_r (↓)
	Золь гель	BS	SiO_2、M	σ_{bc} (↓) 、σ (↓)、f_{cf} (↓) 、K (↑)
	Метод плавления и диспергирования	SS	G	σ_{bc} (↓) 、f_{cf} (↑)、K (↑)
	Комплексный метод эмульсии	PER、SS、DCPD、MMA、CS	UF、PU、PUF、PS、PF、MF	σ_{bc} (↓) 、f_{cf} (↓)、E (↑) 、K (↑)

Примечание: Аббревиатуры в таблице имеют следующие значения: E: модуль упругости, Ed: динамический модуль упругости, Cr: скорость коррозии, K: скорость заживления трещин, BS: бактериальные споры, MA: альгинат, G: желатин, PER: эпоксидная смола, AE: акрилат, CH: гидроксид кальция, CS: силикагель, CSA: тиоалюминат кальция, DCPD: дициклопентадиен, EC: этиленцеллюлоза,M: меламин, MF: меламиндальдегид, MFP: монофторфосфат, F: фенолформальдегид, PS: полистирол, PU: полиуретан, PVA: поливиниловый спирт, SF: фторфосфат натрия, SS: силикат натрия, UF: карбамидоформальдегид.

В то же время, специальные проектные требования к фундаментам опор ЛЭП усложняют запросы к материалу бетона. Наиболее часто в практике для повышения проводящих свойств бетона используют дополнительные компоненты смеси, такие как графит, углеродное волокно, стальной шлак, стальное волокно и технический углерод. Использование графена (с высокой проводимостью и большой удельной поверхностью) позволяет значительно улучшить электропроводность цемнтных композиций, однако снижает прочностные характеристики материала и увеличивает его себестоимость, что ограничивает его применение. При этом, стоит отметить, что и другие токопроводящие компоненты негативно влияют на технологические свойства бетонных смесей. Поэтому применение микрокапсул, как решения данного технико-технологического вопроса весьма актуально при проектировании и строительстве ЛЭП в России и на северо-западе Китая.

В представленном исследовании авторы изготавливали физическими методами ядро микрокапсулы на основе силиката натрия и бентонита, а оболочку – на основе этилцеллюлозы и ксилола с добавлением графена. В ходе работы изучали зависимость прочностных характеристик цементных композитов от содержания микрокапсул в бетоне, графена в микрокапсулах и времени твердения. На микроуровне процесс восстановления дефектов (трещин) бетона исследовали методами оптической микроскопии и методами рентгенофазового анализа.

II. Изготовление образцов цементного композита, микрокапсул и механизм их действия

Для изготовления образцов цементного композита был принят состав цемент : песок = 1 : 3 с водоцементным соотношением 06. Содержание в композиции варьировали и оно составляло 1, 2, 3, 4 и 5%, вводили фторсиликат натрия в количестве 15 % от массы микрокапсул и раствор оксида графена в количестве 0,025; 0,05; 0,1; 0,25 и 0,5 % от массы цемнта. Из контрольного и экспериментальных составов цементных композиций изготавливали образцы-кубы размером 70×70×70 мм и через 7, 14 и 28 суток твердения проводили их испытания на определение пределе прочности при сжатии и определяли скорость восстановления структуры как отношение прочности после восстановления к прочности контрольных образцов.

Изначально изготавливают ядро микрокапсулы, для чего силикат натрия, микрокристаллическую целлюлозу, бентонит и метилцеллюлозу берут в соотношении 25, 30, 10 и 2 % соответственно и перемешивают до однородности в сухом состоянии (рис.2). Затем добавляют 29% дистиллированной воды и

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4% Tween 80 и перемешивают при температуре 40°C. Из полученной массы методом экструзии с последующей грануляцией получают частицы. Материал оболочки из этилцеллюлозы, этилового спирта и ксилола (10, 18 и 72% соответственно) после тщательного перемешивания наносят на поверхность капсул. Сами капсулы подсушивают в воздушном потоке с одновременным диспергированием. Для дальнейших экспериментов отбирают методом скрининга частицы размером 1-1,25 мм. При замачивании случайного количества капсул дистиллированной водой только несколько капсул растворилось, а большая их часть осталась неповрежденной, что говорит о целостности составной структуры капсул.

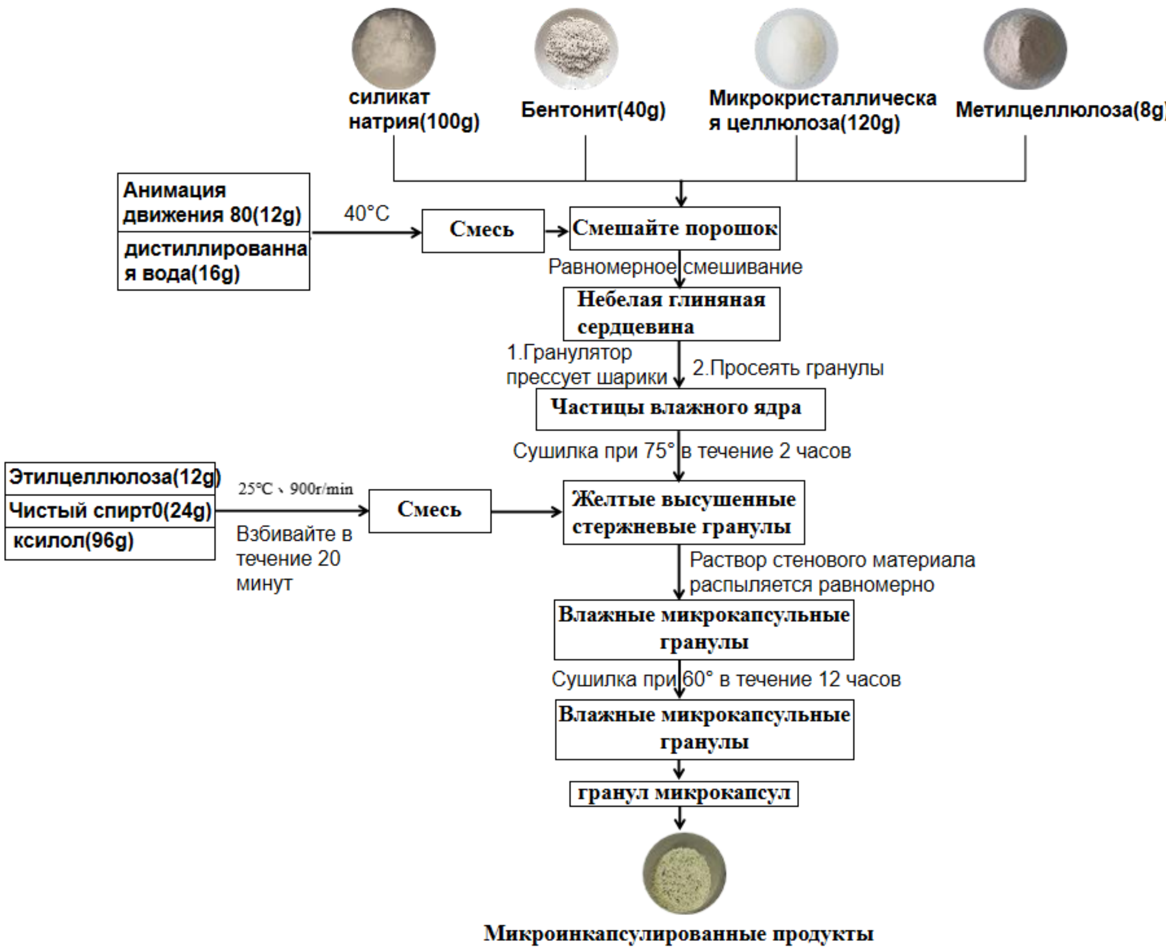

Рис. 2: Схема изготовления микрокапсул

Fig. 2: Microcapsule production process

Микрокапсулы перемешивают с другими компонентами цементной композиции в обычных мешалках принудительного действия, затворяют и формуют образцы, которые после затвердевания готовы к дальнейшим экспериментам. Когда образец подвергается внешнему воздействию, в его структуре возникает микротрещина, которая разрывает оболочку микрокапсул, к ядру проникает влага из окружающего бетонного камня и запускает химические реакции с силикатом натрия (формула 1). В результате образуется гелеобразный гидроксид кремния $Si(OH)_4$, который в свою очередь заполняет свободное пространство, связывается со стенками трещины и новообразования имеют определенную прочность.

$$Na_2SiO_3 + Ca(OH)_2 = CaSiO_3\downarrow + 2NaOH \qquad (1)$$

По мере поглощения воды, бентонит расширяется в цементном композите и заполняет трещины, что препятствует дальнейшему проникновению коррозионных веществ из окружающей среды. Происходит химическая реакция (формула 2) и трещины склеиваются продуктами новообразования, жесткость и непроницаемость цементной матрицы восстанавливается (рис. 3).

$$2Na_2{\cdot}nNa_2SiF_6{+}2(n{+}1)H_2O{\rightarrow}6NaF{+}(n{+}1)Si(OH)_4 \qquad (2)$$

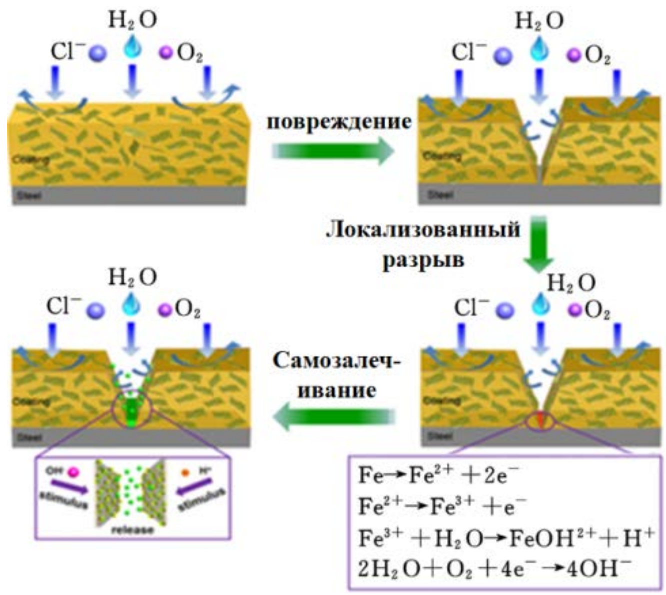

Рис. 3: Принципиальная схема механизма самовосстановления микрокапсул

Fig. 3: Schematic diagram of microcapsule self-healing mechanism

III. Методика экспериментов и результаты работ

На первом этапе определяли прочность образцов только с песком (контрольных) и регистрировали как K_0. Затем образцы нагружаются без разрушения до усилия 60% от разрушающего (K_1), после чего твердеют и восстанавливают структуру в условиях тепло-влажностной обработки. Определение скости восстановления структуры и прочности (ремонтопригодности) проводили после определения после дополнительного твердения (K_2) в течение расчетного количества времени и определяли по формулам:

$$K_x = \frac{K_2 - K_1}{K_0 - K_1} \times 100\% \qquad (3)$$

$$K_h = \frac{K_2}{K_0} \times 100\% \qquad (4)$$

Использовали четырехэлектродную вольтамперометрию, которая позволяет устранить контактное сопротивление между листом электрода и цементным основанием, снизить поляризационный эффект. Электроды из нержавеющей стали равномерно располагали на образце на расстоянии 20 мм друг от друга (рис.4), подключали источник постоянного тока, амперметр (I) и вольтметр (U).

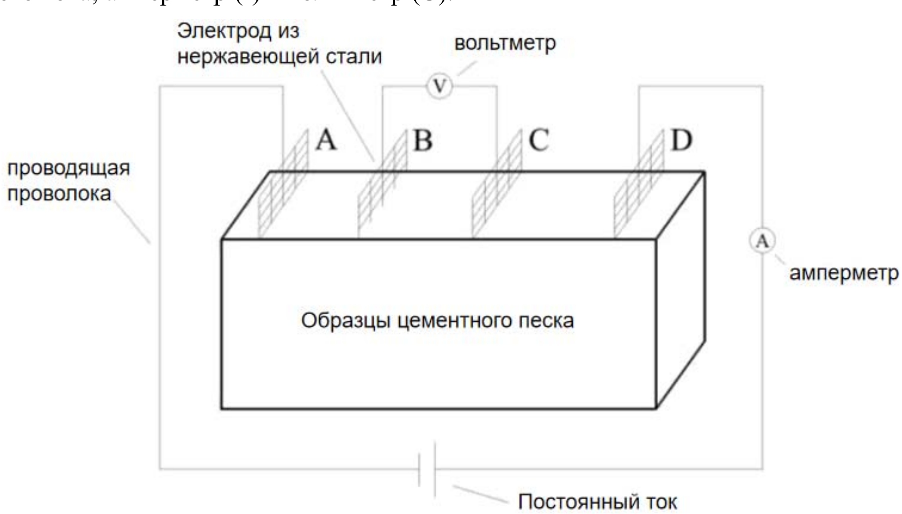

Рис. 4: Рабочий механизм метода сопротивления

Fig. 4: Working mechanism of resistance method

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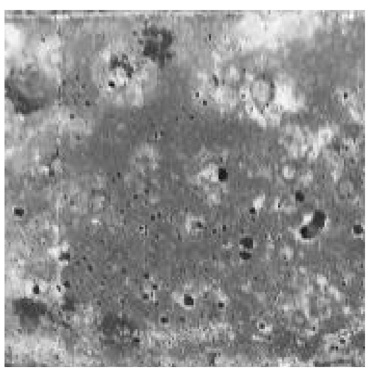
Площадь поперечного сечения через сегмент BC составляла S, а расстояние между электродами L. Удельное сопротивление ρ рассчитывали по формуле 5:

$$\rho = \frac{US}{IL} \tag{5}$$

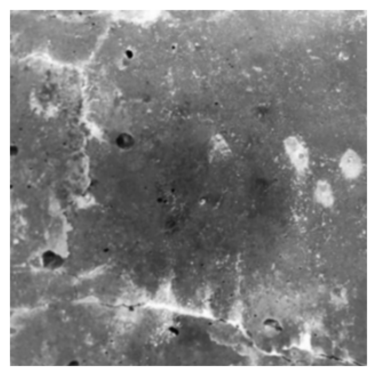
Микрокапсулы равномерно распределены по поперечному сечению образца (рис. 5), частицы отлично встраиваются в структуру композита, оболочка большинства микрокапсул остается неповрежденной, у некоторых частиц под действием разрушения образца разрушается оболочка. Присутствующий оксид графена не вступает в реакции с микрокапсулами, что не влияет на способность к самовосстановлению композита. При наблюдении за микродефектами разрушения некоторых образцов, установили наличие в промежутках кристаллических веществ молочно-белого цвета определенной толщины, что объяснялось повышением адгезии за счет расширения материала микрокапсулы и свидетельствовало о способности микрокапсулы к восстановлению всего цементного композита.

(a) Поперечное сечение с 1% микрокапсул

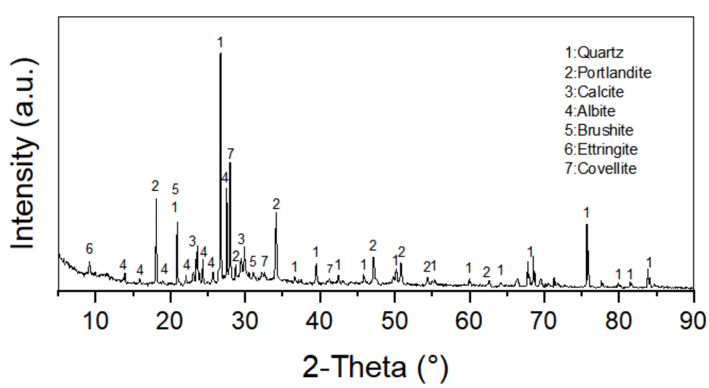
(b) 0,5% графена + 5% микрокапсул



c) Предварительное сжатие создает трещины



d) Восстановление трещины после нагружения



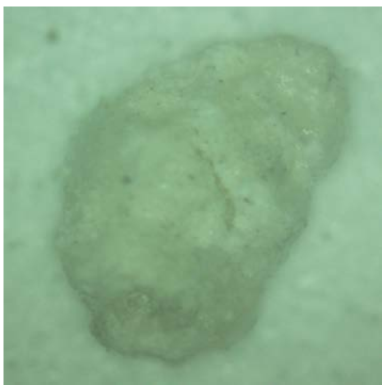
e) Состав образцов с микрокапсулами

Рис. 5: Макроскопическая характеристика и состав образцов

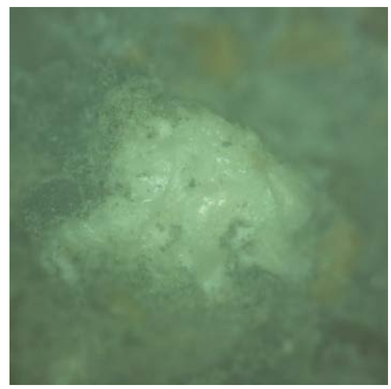
Fig. 5: Macroscopic characterization and composition of specimens

Рентгенофазовый анализ цементных композитов с микрокапсулами показал наличие в них следующие минералов: альбит, акадит, кварц (19%), гидроксид кальция, кальций-пермеалит, алюминаты и клинкерные минералы (73%). В них содержание кварца, альбита и аластита увеличилось на 2, 22 и 23% соответственно по сравнению с контрольным составом. Это доказывает, что материал ядра высвобождается после «вскрытия» микрокапсул и образует дополнительное количество гидросиликатов кальция (основных продуктов гидратации портландцемента).

Кроме рентгенофазового анализа были также сделаны микрофотографии микрокапсул и цементирующих продуктов реакции (рис.6). Форма микрокапсул преимущественно сферическая, неповрежденная оболочка полностью покрывает гладкую поверхность ядра (рис. 6a). При большем увеличении проявляется, что поверхность оболочки микрокапсулы неровная, что способствует повышению адгезии с цементной матрицей (рис. 6b). При образовании микротрещины в композите за счет адгезионных сил капсула также вскроется и освободит доступ к материалу ядра, продукты гидратации которого затем заполнят пространство микротрещины. После предварительного нагружения образца микрокапсула под давлением высвобождает основной материал (рис. 6c), который реагирует с водой и проводит работу по восстановлению. Цвет композиции с графеном и микрокапсулами темнее и при этом конгломерации графена не обнаруживается (рис. 6d). При этом структура материала становится более плотной (рис. 6d). Графен интенсифицирует реакции гидратации, объединяет продукты гидратации и увеличивает прочность.

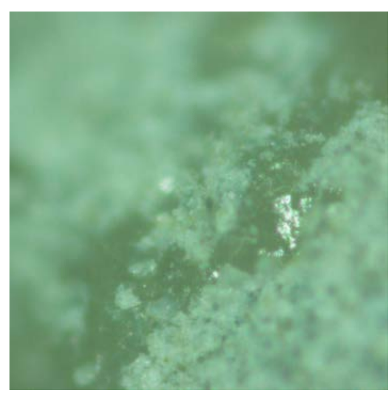


a) Морфология микрокапсул



b) Морфология стенки

c) Дробление микрокапсул для устранения зазоров



d) Морфология графена

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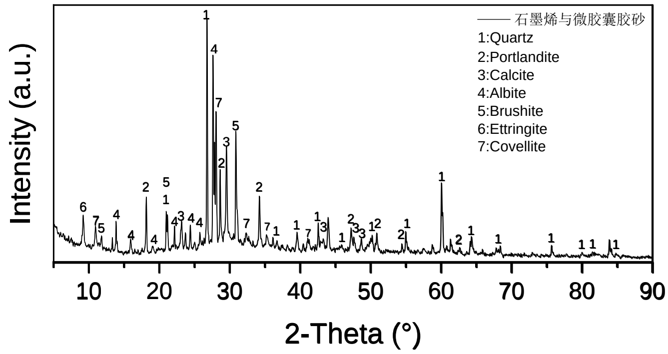

e) Композиция цементирующего материала графен-микрокапсула

Рис. 6: SEM фотографии и XRD-анализ самовосстанавливающейся растворной матрицы

Fig. 6: SEM photos and XRD analysis of self-healing mortar matrix

Отличная диспергируемость в сочетании с гидрофильностью ускоряют высвобождение и гидротацию основных компонентов ядра микрокапсулы, увеличивает содержание ионов кальция, а минеральные образования заполняют микротрещины. При небольшой диэлектрической проницаемости (55%) и высокой удельной прочности снижается удельное сопротивление цементного композита и реализуется потребность в низком удельном сопротивлении для сети передач энергии.

Прочность на сжатие образцов цементных композиций твердевших 28 суток, при увеличении содержания микрокапсул постепенно снижается до 1% при 5% микрокапсул (рис. 7), что не может удовлетворять потребности. Предполагаемые причины снижения: низкая прочность микросферы (на уровне поры бетона) нарушает первоначальную прочность композита; добавление микрокапсул снижает содержание других компонентов (в том числе и портландцемента) и ослабляет бетон. Однако небольшое содержание микрокапсул (до 2%) приводит к некоторому росту прочности по сравнению с контрольным составом. Происходит это по следующим причинам: фторсиликат натрия добавляемый в образцы замедляет кинетику твердения; микрокристаллическая целлюлоза и этилцеллюлоза замедляют коагуляцию и повышают прочность при небольших содержаниях; при приготовлении цементного композита незначительная часть капсул разрушается и материал ядра начинает взаимодействовать заполняя усадочные трещины.

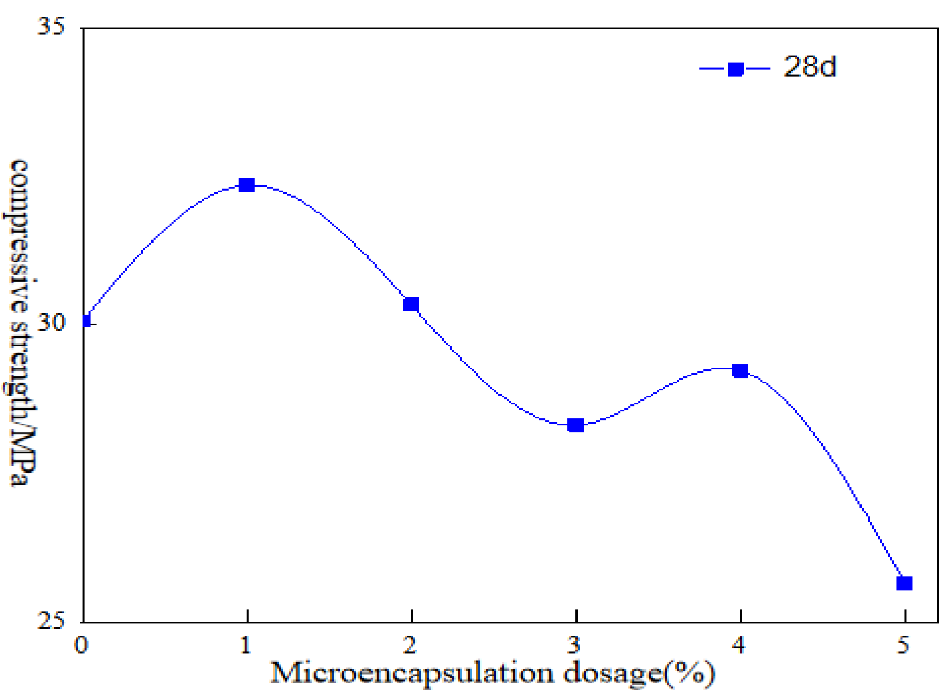

Рис. 7: Прочность на сжатие образцов твердевших в течение 28 дней

Fig. 7: Compressive strength of specimens cured for 28 days

Микрокапсулы снижают темпы набора прочности композита, что проявляется на прочности после 7 суток твердения: с микрокапсулами прочность составляет 70% от контрольного состава. Однако, в дальнейшем прочность активном возрастает и через 28 суток превышает контрольные образцы. Поэтому для дальнейших экспериментов брали образцы, твердевшие 28 суток, после чего образец подвергали испытанию водному твердению в течение 10, 20 и 30 дней, после чего определяли прочность на сжатие и рассчитывали скорость и коэффициент восстановления.

Скорость восстановления прочности на сжатие $К_х$ плавно возрастает с увеличением содержания микрокапсул (рис. 8). Установлено, что силикат натрия в цементной матрице взаимодействует с водой и фторсиликатом натрия с образованием цементирующих веществ, количество которых увеличивается с повышением содержания микрокапсул, что объясняет рост прочности (самовосстанавливающий эффект). Однако следует учитывать, что с повышением содержания микрокапсул также увеличивается количество точек концентраций напряжений и вероятность появления дефектов – трещин. Но при этом также увеличивается количество вовлеченных в самовосстановление микрокапсул.

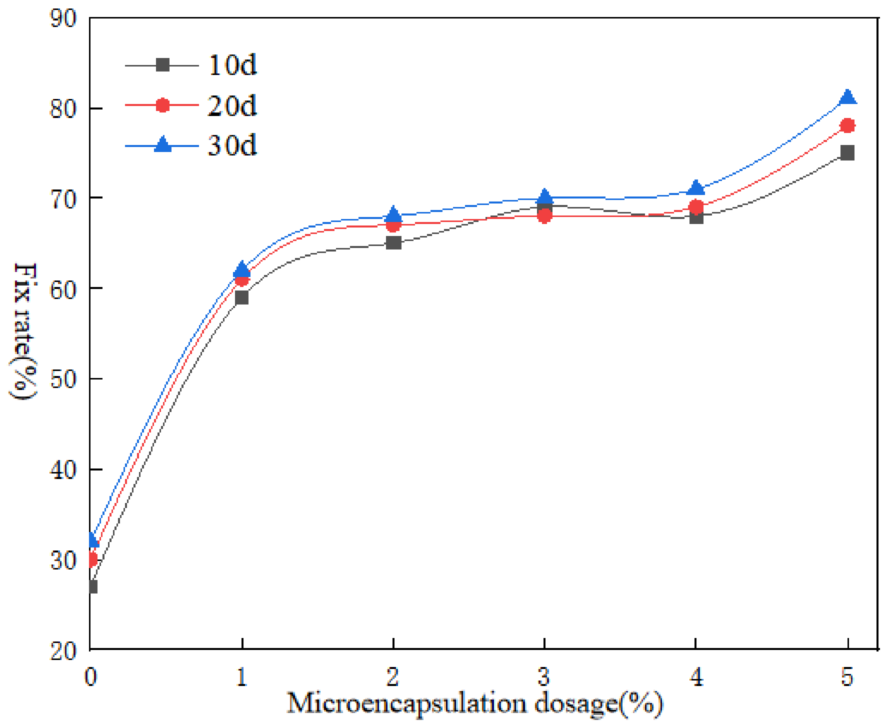

Рис. 8: Коэффициент восстановления прочности на сжатие

Fig. 8: Compressive strength recovery rate

Установлено, что скорость восстановления прочности у образцов дополнительно твердевших 30 дней в тепловлажностных условиях самая большая, а твердевших 10 дней – наименьшая. Причина такого увеличения эффекта самовосстановления может быть объяснена ограниченностью скоростью реакции силикаты натрия в материале ядра микрокапсулы и чем меньше частиц полностью гидратированного цемента, тем больше скорость восстановления. Замедление роста $К_х$ объясняется ограниченностью не вступивших в реакцию микрокапсул, а увеличение длительности восстановления не дает нужный эффект. Параллельно с этим расширение бентонита уже вступившего в реакции приводит к заполнению трещин новообразованиями и уменьшению поступления воды извне.

На прочность на сжатие и скорость восстановления бетона в большей степени влияют микрокапсулы, а графен служит добавкой улучшающей проводящие свойства цементной композиции. Поэтому влияние графена изучали при прочих постоянных условиях: содержание микрокапсул составляло 2%, цементный композит твердел 28 суток.

При увеличении содержания графена в композите, прочность бетона стабильно возрастает до состава с 0,1% графена и достигает значения 121,6% от контрольного (рис. 9). Дальнейшее увеличение доли графена приводит к уменьшению прочности и при содержании 0,5% бетон имеет прочность на сжатие всего 92%. Полученные результаты объясняются тем, что графен при небольшом содержании ускоряет процессы гидратации цемента, заполняет пустоты на микроуровне, а также изменяет структуру продуктов гидратации.

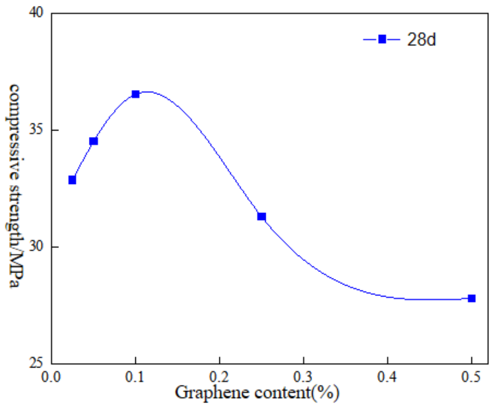

Рис. 9: Прочность на сжатие 28-дневного образца

Fig. 9: Compressive strength of a 28-day specimen

Еще один механизм воздействия графена может быть объяснен его высокой удельной поверхностью, что способствует связыванию воды, распределяя ее равномерно по всей цементной матрице. При дальнейшем повышении содержания частицы оксида графена агрегируются и образуют микроячейки с нулевой прочностью, что создает точки с повышенным внутренним сопротивлением.

Поверхностное сопротивление определяли также на образцах твердевших 28 суток. Установили, что минимальные содержания графена существенно не влияют на сопротивление, а состав с 0,1% графена имеет сопротивление всего 48% от контрольного (рис. 10). Дальнейшее увеличение доли графена существенно не влияет на сопротивление и оно даже незначительно возрастает, что также объясняется агрегированием дисперсных частиц и одновременным снижением пластичности цементной смеси, что приводит к снижению качества формования и образованию воздушных пустот с высоким сопротивлением.

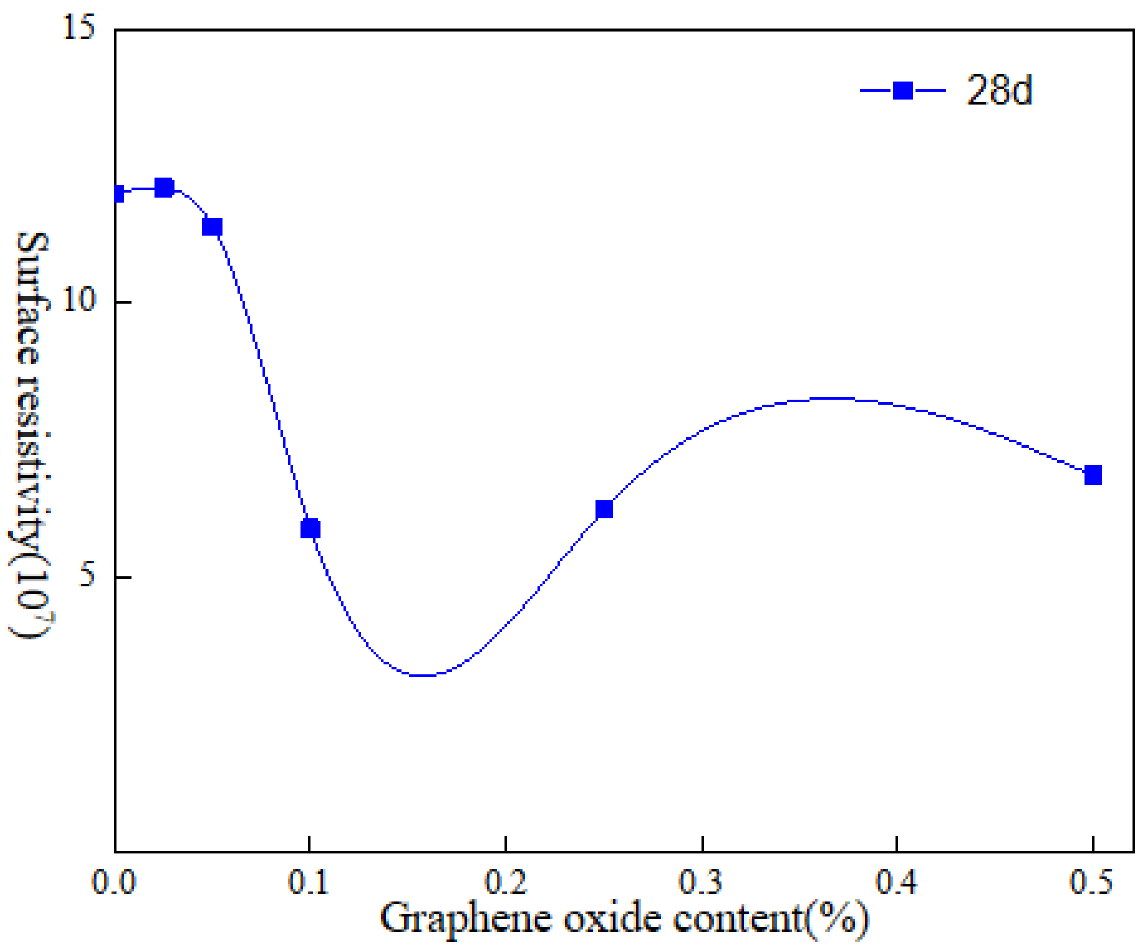

Рис. 10: Распределение поверхностного сопротивления образцов

Fig. 10: Surface resistance distribution of specimens

IV. Выводы из результатов экспериментов

1. Разработанные микрокапсулы содержащие силикат натрия и бентонит и получаемые физическим методом могут повысить эффективность самовосстановления цементной композиции (скорость восстановления прочности на сжатие выше, чем у обычных образцов). Методами Микроскопии и рентгенофазового анализа

установлено, что микрокапсулы имеют сферическую форму с качественной оболочкой шероховатой поверхности. После растрескивания оболочки материал ядра капсулы высвобождается и его продукты реакции осаждаются в трещинах, заполняя их и тем самым ремонтируя.

2. Введение микрокапсул до 1% повышает прочность на сжатие, однако при дальнейшем увеличении доли микрокапсул прочность постепенно снижается и при содержании 3,0% она оказывается ниже контрольного состава. Рекомендуемое содержание микрокапсул составляет 2%, что дает оптимальные показатели прочности на сжатие и самовосстанавливающего эффекта.
3. Введение в композицию оксида графена сначала повышает прочность бетона, а затем снижает. Оптимальное содержание оксида графена в бетонной композиции составляет от 0,05 до 0,15%, что позволяет наиболее полно использовать данное преимущество.
4. Добавление оксида графена улучшает проводимость цементного бетона, оптимальное содержание составляет 0,1%: ниже этого графен меньше улучшает проводимость, а превышение не улучшает данную характеристику и с учетом стоимости материала является экономически нецелесообразным.

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Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 23 Issue 2 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Topology Optimization: Applications of VFLSM and SESO in the Generation of Three-Dimensional Strut-and-Tie Models

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GJRE-E Classification: DDC: 624

TOPOLOGYOPTIMIZATIONAPPLICATIONSOFVFLSMANDSESOINTHEGENERATIONOFTHREEDIMENSIONALSTRUTANDTIEMODELS

Strictly as per the compliance and regulations of:

Topology Optimization: Applications of VFLSM and SESO in the Generation of Three-Dimensional Strut-and-Tie Models

Hélio Luiz Simonetti [α], Valério S. Almeida [σ], Virgil Del Duca Almeida [ρ], Luttgardes de Oliveira Neto [ω], Marlan D. S. Cutrim [¥] & Vitor Manuel A. Leitão [§]

Abstract- This article presents the analysis of Strut-and-Tie Model (STM) in reinforced concrete 3D structures based on the study of topological optimization, so that the problem is formulated with the Smooth-ESO (SESO) discrete method, whose removal heuristic is bidirectional with discrete optimization procedure, and the Velocity Field Level Set Method (VFLSM), which is an inheritance of the classical continuum Level Set Method (LSM), but advances the design limits with a velocity field constructed from the rate of the design variables and base functions. The proposed approach is to couple both methods in conjunction with the Method of Moving Asymptotes (MMA), used to control the various design constraints that are the minimization of compliance and the Von Mises stress that has demonstrated more rational STM results. Additionally, it has been formulated a methodology for the automatic generation of optimal of 3D STM by using sensitivity analysis obtaining via derivatives of the Von Mises stress fields, finding the force paths prevailing compression in the directions of the strut and the tensile in the directions of the ties for the reinforcement insertion. All the codes are implemented with Matlab software and several comparison examples: Deep beam with opening, a pile cap, a bridge pier, and a single corbel, are presented to validate the present formulations and the results are compared with the literature.

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I. Introduction

In the field of structural engineering, most concrete linear elements are designed by the classical theory of Bernoulli hypothesis. For a real physical analysis about behavior of these bending elements it is common to use the Strut-and-Tie Model (STM) that is a generalization of the classical analogy of the truss beam model. This analogy is shown by Ritter and Morsch at the beginning of the twentieth century, associated with the Reinforced Concrete (RC) beam in an equivalent truss structure (regions B, Fig. 1). The bar elements represent the fields of tensile and the compressed struts emerged inside the structural element as bending effects. The analogy has been improved and is still used by the technical standards in the design of reinforced concrete beams in flexural and shear force and laying down various criteria for determining safe limits in its procedures. However, the application of this hypothesis for any structural element can lead to over or under sizing of certain parts of the structure.

The Bernoulli hypothesis is valid for parts of the frame that there is no interference from other regions, such as sections near the columns, changing in geometry or other areas where the influence of strain due to shear efforts is not negligible. In this line, there are regions where the assumptions of Bernoulli do not adequately represent the bending structural behavior and the stress distribution. Structural elements such as beams, walls and pile caps and special areas such as beam-column connection, openings in beams and geometric discontinuities are examples. These regions, denominated "discontinuity regions D", are limited to distances of the dimension order of structural adjacent elements (Saint Venant's principle), that the shear stresses are applicable and the distribution of strains in the cross section is not linear. From the 80's, a Professor at the University of Stuttgart and other collaborators presented several researches that evaluated these regions more adequately, as [1], [2], [3], and other researchers as [4], [5] and [6]. The pioneering work by [1] describes the STM more generally, covering the equivalent truss models and including these regions and special structural elements. The analogy used in the STM uses the same idea of the classical theory in order to define bars representing the flow of stress trying to create the shortest and more logical path loads. Several experimental evaluations have been studied to validate the STM applied to the RC design, as [7], [8], [9] and [10].

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The STM is recognized as a rational approach to the design of discontinuity regions and is incorporated in several current codes, such as ASCE-ACI 445 on Shear and Torsion [11], [12], [13] and [14]. These code provisions still require improvement due to uncertainties in the selection of optimal struts-and-ties, especially in the case of complex geometry or general load application conditions. Because of its simple model and needs the experience of the designer to select and distribute the elements of the model in order to represent the stresses path in a better way, it becomes evident the use of more reliable and automatic tools for defining its geometric and structural configuration.

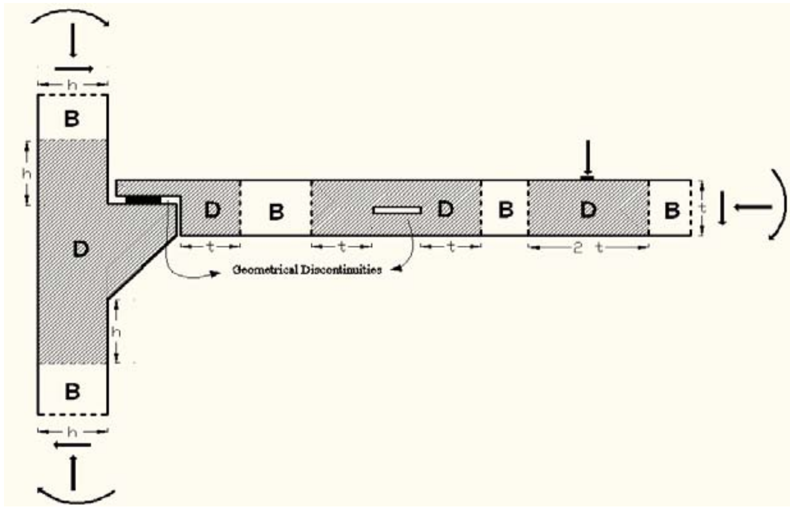


Fig. 1: D and B regions

To overcome these difficulties and improve the efficiency in building the optimal STM in RC structures, the theory of Topology Optimization (TO) has been used for two decades as an alternative and systematic approach consolidating itself as a fruitful path of design related research, once facilitates the shaping of materials under certain conditions. Many methods have been proposed for the solution of TO applied to STM, highlighting the use of the classical SIMP: [15], [16], [17], or ESO (Evolutionary Structural Optimization): [18], [19], [20], Liang et al. [21,22,23], Chen et al. [24], Zhong et al. [25], or variants, like BESO, Shobeiri et al. [26], RESO (Refined ESO), Leu et al. [27] or SESO proposed by the present authors, Almeida *et al.* [28]. SESO is based on the philosophy that if an element is not really necessary for the structure, its contribution to the structural stiffness is gradually diminished until it does not have any influence in the structure; that is, its removal is done smoothly, not radically as in the ESO method, that have been showed more efficient and robust and less sensitive to the discretization than ESO and faster than BESO, causing a decrease of the checkerboard formation.

In the last decade, the Level Set Method (LSM) has been highlighted in the field of TO, different from the conventional element wise density-based methods. LSM has clearer and smoother results and are flexible for complex topological changing, citing the pioneer's works of [29], [30] and [31]. The method describes the topological path by an implicit shape evolutive sequence by using a higher dimensional function to the design space for achieving the minimum energy under design constraints. Several other schemes have been included in the standard LSM to improve performance and achieve better results for general applications, like [32], [33]. Wang and Kang [34,35] proposed the Velocity Field Level Set Method (VFLSM) which has been proved to be more efficient to deal with multiple constraints and design variables than LSM, but few works have been applied to STM by using VFLSM.

OT in solving problems in the field of 3D STM is not much explored for general D-regions, discouraged by the instabilities (checkerboard problem) inherent to SIMP, ESO/BESO or the complex formulation and high processing time of LSM/VFLSM. Thus, for stabilizing and accelerating the TO solution, several mathematical optimization methods have been proposed, such as Optimality Criteria, by Huang et al. [36] with BESO, Augmented Lagrangian [37] or [38] with Level-Set, Lagrangian multiplier by [39] and [40] with LSM, or the Method of Moving Asymptotes (MMA), by [41] with SIMP.

In the present work, aiming at the solution of 3D STM in general reinforced concrete problems, the SESO methods whose advantages are easy implementation and decrease of the checkerboard effect and the VFLSM, which deals well with shape and topological optimizations, are formulated together with the MMA optimization method to accelerate and stabilize 3D STM. It is also noteworthy new approach of sensitivity analysis is incorporated in these formulations for the automatic generation of struts-and-ties based on partial derivatives with respect to Von Mises stresses. The volume constraints are considered in the analyses, as the implementation of a spatial filter and the conjugate gradient method with the incomplete Cholesky preconditioner to speed up the solution of the linear system of each step of the search.

a) Problem Formulation

Considering the classical topology problem for the maximum stiffness of statically loaded linear elastic structures, a TO mathematical formulation for continuum structure can be discussed. Considering the TO problem as minimizing the deformation energy of a given structure considering the equilibrium, it follows that W=2U. The problem can then be defined as:

$$\begin{aligned} &\text{Minimize:} \quad U(X) = \frac{1}{2}u^T K u = \sum_1^{NE} \frac{1}{2}\int_{Ve} \varepsilon_e^T E_e(x)\varepsilon_e \, dV_e \\ &\text{Subject to:} \quad Ku = F \\ &\qquad V(X) = \sum_{i=1}^{NE} X_i V_i - \underline{V} \leq 0 \\ &\qquad X = \{x_1 x_2\ x_3\ \ldots\ x_n\},\ x_i = 1\ or x_i = 0 \end{aligned} \tag{1}$$

with E_e being the element's elasticity matrix, ε_e is the element's strain vector, V_e is the volume of an element, *NE* is the number of finite elements of the mesh, K is the stiffness matrix, $Ku = F$ is the equilibrium equation, F is the vector of loads applied to the structure, x_i is the design variable of the *i-th* element, X is the vector of design variables.

b) Smooth Evolutionary Structural Optimization (SESO)

The ESO method, which heuristic is based on the gradual and systematic removal of elements whose contribution to the stiffness of the structure are insignificant, was proposed by Xie and Steven [42]. The SESO method proposed by Simonetti et al. [43] is based on the ESO philosophy and applies a weighting to the constitutive matrix so that the element that would be eliminated is maintained and receives a smoothing characteristic. This treatment procedure applies a degradation in the value of its initial stiffness in such, during the removal process, its influence can contribute and determine its permanence or its definitive withdrawal from the design domain. Thus, the elements located near the limit to the left of this maximum strain energy are kept in the structure, defining a smoother heuristic removal. In Fig. 2, $D(j)$ is the constitutive matrix of element j, $\underline{\Gamma} = \Gamma_{LS} + \Gamma_{GS}$ is the domain of elements that can be withdrawn, Γ_{LS} is the domain of elements that must be effectively removed, Γ_{GS} is the domain of elements that are returned to the structure, $0 \leq \eta(\underline{\Gamma}) \leq 1$ is a weighted function.

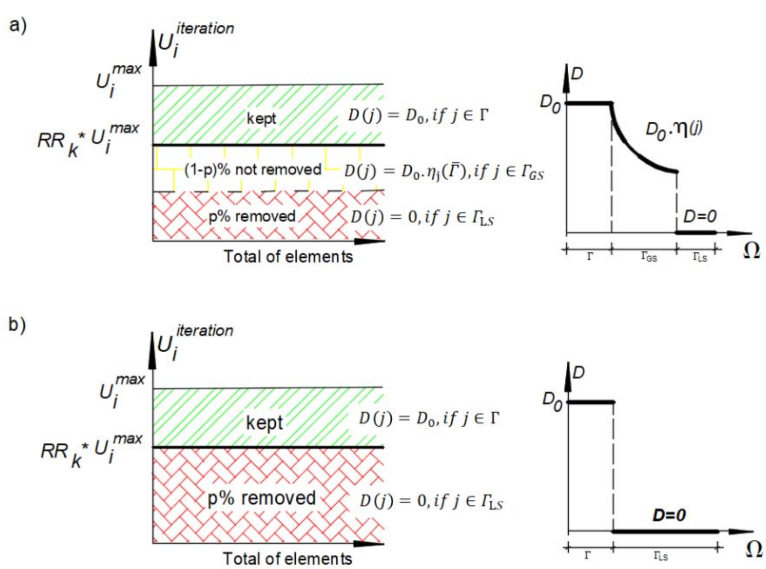


Fig. 2: Classic procedure in strain energy: (a) SESO and (b) ESO

c) The Level Set Method (LSM)

LSM is a technique for representing moving interfaces or boundaries using a fixed mesh. The dynamics of the interfaces can be formulated as the evolution of the level function defined by $\phi(x(t), t)$, which is continuous Lipschitz and is usually defined as follows

$$\phi(x,t) = \{\, \phi(x,t) > 0 \quad \forall\, x \in \Omega \backslash \partial\Omega \,; \quad \phi(x,t) = 0 \quad \forall\, x \in \partial\Omega \,; \quad \phi(x,t) < 0 \; \forall\, x \in D \backslash \Omega \,\} \tag{2}$$

with $x \epsilon D \subset \{(x,y) \epsilon R^2\}$ is any point in the design domain D and ∂Ω is the solid domain boundary as shown in Fig. 3 for a 2D case.

In classical LSM for TO, such as [30] and [31], the design evolution is based on the solution of the Hamilton-Jacobi partial differential Eq. (4). Thus, it needs an appropriate choice of finite difference methods on a fixed cartesian mesh. In general, the design update involves differentiation, resetting and velocity extension.

$$\frac{\partial \emptyset}{\partial t} - V_n |\nabla \emptyset| = 0 \tag{3}$$

$$V_n = V.\left(-\frac{\nabla \emptyset}{|\nabla \emptyset|}\right) \tag{4}$$

with $\nabla \emptyset$ denotes the gradient of a function, t is the pseudo time that represents the evolution of the function $\phi(x,t)$ defined, $V_n(x,t)$ is the normal velocity vector (pointing outwards) based on the derivatives of the shape functions in the TO problem.

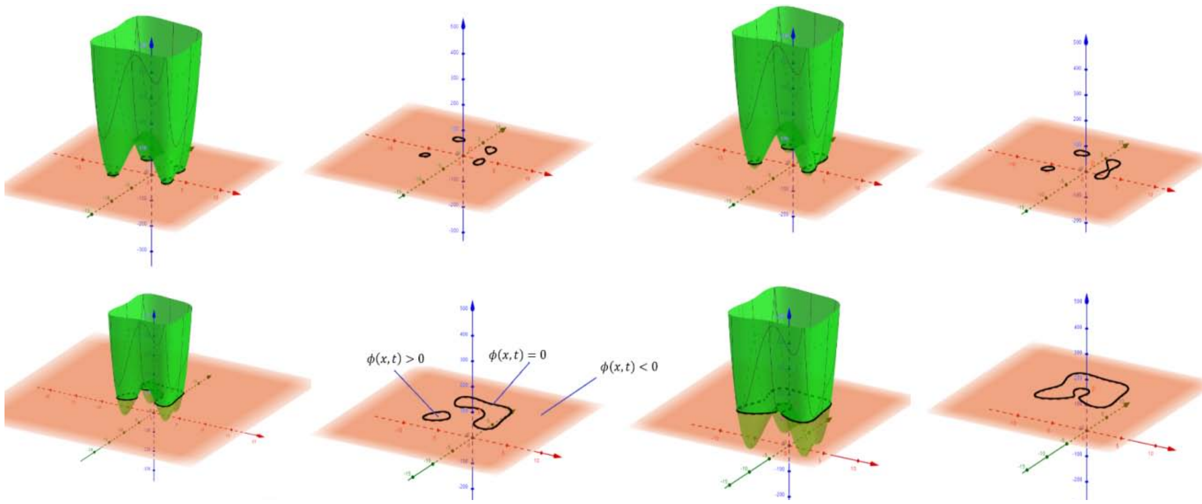


Fig. 3: Evolution history of the 2D geometry to a 3D level

Recently, Wang and Kang [34, 35] proposed a 100-line Velocity Field Level Set (VFLS), implemented in Matlab code. The structural shape and topology are updated by a velocity field constructed with the base function and velocity design variables defined throughout the domain. Then, the velocity field determines the search direction of the shape and the topological evolution can be obtained by a generic mathematical programming algorithm, which makes it more convenient and efficient to deal with multiple constraints and types of design variables. For VFLS, we have:

$$V_n(x) = \sum_{j=1}^{N} \beta_j p_j(x) \tag{5}$$

with $\beta_j\,(j = 1,2,\ldots,N)$ are the velocity design variables at N velocity points distributed throughout the main design, and $p_j(x)$ are the basic functions. It is observed that when p_j satisfies the properties of the Kronecker delta it has $\beta_j = V_n$ of Eq.(3).

II. Optimization Algorithm - Moving Asymptotes Method

To accelerate and stabilize the present 3D STM in this paper, MMA is employed, which is a mathematical programming algorithm suitable for TO, capable of handling optimization of many constraints and design variables. At each step of the algorithm's iterative process, a convex approximation subproblem is generated and solved. The generation of these subproblems is controlled by the moving asymptotes, which can both stabilize and accelerate the convergence of the overall process, [44].

The optimal solution of the subproblem may or may not be accepted: if so, the outer iteration is completed; if not, a new inner iteration is performed, in which a new subproblem is generated and solved. The iterations are repeated until the values of the approximations of the objective function and the constraints become greater than or equal to the values of the original function when evaluated in the optimal solution of the subproblem, that is, until the conservative condition is satisfied for the functions involved. The approximations that characterize the MMA are rational functions whose asymptotes are updated at each iteration. It is noteworthy that the use of rational approximations is justified by the fact that in several structural engineering problems where reciprocal variables arise, that is, interaction and mutual effort, given the objective function or a constraint $C(x)$, the approximation functions are given by:

$$C(x) \approx C(x^k) + \sum_{1}^{n} \left(\frac{r_i}{U_i^{(k)} - x_i} + \frac{s_i}{x_i - L_i^{(k)}} \right) \tag{6}$$

where r_i e s_i are defined as:

$$If \ \frac{\partial C(x)}{\partial x_i} > 0 \ then \ r_i = \left(U_i^{(k)} - x_i^{(k)}\right)^2 \frac{\partial C(x)}{\partial x_i} \quad and \quad s_i = 0 \tag{7}$$

$$If \ \frac{\partial C(x)}{\partial x_i} < 0 \ then \ s_i = -\left(x_i^{(k)} - L_i^{(k)}\right)^2 \frac{\partial C(x)}{\partial x_i} \quad and \quad r_i = 0 \tag{8}$$

For the optimization problem in compliance Eq. (8), it is known that it is satisfied because $\frac{\partial C(x)}{\partial x_i} < 0$. Then the MMA provides the current design with an approximation of a linear programming problem of the type:

$$\begin{aligned} &Minimize \quad -\sum_{1}^{n} \frac{\left(x_i^{(k)} - L_i^{(k)}\right)^2}{x_i - L_i^{(k)}} \frac{\partial c}{\partial x_i}\left(\tilde{x}^{(k)}\right) \\ &Subject\ to \quad \tilde{x}^T v - \underline{v} \leq 0 \\ &\qquad\qquad\quad x \in \chi^k \end{aligned} \tag{9}$$

with $\chi^k \ = \{x\epsilon\chi | 0.9L_i^{(k)} + 0.1x_i^{(k)} \leq x_i \leq 0.9U_i^{(k)} + 0.1x_i^{(k)}\} \ \forall \ i = 1,2,\ldots,n$

with $L_i^{(k)}$ and $U_i^{(k)}$ being lower and upper asymptotes, respectively, *k* is the current iteration, *n* the number of design variables, x^k the design variable and $\underline{v}$ the prescribed volume. The following heuristic rule is used by [44] for updating the asymptotes, for the first two outer iterations, when k =1 and k = 2 are adopted:

$$U_i^{(k)} + L_i^{(k)} = 2x_i^{(k)} \tag{10}$$

$$U_i^{(k)} - L_i^{(k)} = 1$$

For $k \geq 3$

$$U_i^{(k)} + L_i^{(k)} = 2x_i^{(k)}$$

$$U_i^{(k)} - L_i^{(k)} = \gamma_i^{(k)}$$

with

$$\gamma_i^{(k)} = \begin{cases} \zeta\left(x_i^{(k)} - x_i^{(k-1)}\right)\left(x_i^{(k-1)} - x_i^{(k-2)}\right) < 0 \\ \xi\left(x_i^{(k)} - x_i^{(k-1)}\right)\left(x_i^{(k-1)} - x_i^{(k-2)}\right) > 0 \\ \varsigma\left(x_i^{(k)} - x_i^{(k-1)}\right)\left(x_i^{(k-1)} - x_i^{(k-2)}\right) = 0 \end{cases} \tag{11}$$

where the values of ζ, ξ and ς were fitted in the respective numerical ranges $0.65 \leq \zeta \leq 0.75$, $1.15 \leq \xi \leq 1.25$ and $0.9 \leq \varsigma \leq 1$.

It can be seen in Eq. (11) that the MMA saves the signal of three consecutive iterations. Thus, when the signals alternate, the MMA detects that the values of the design variables are oscillating, i.e., $\left(x_i^{(k)} - x_i^{(k-1)}\right)\left(x_i^{(k-1)} - x_i^{(k-2)}\right) < 0$, the asymptotes approximate the design point $x_i^{(k)}$. If the values of the design variables do not oscillate, i.e., $\left(x_i^{(k)} - x_i^{(k-1)}\right)\left(x_i^{(k-1)} - x_i^{(k-2)}\right) \geq 0$, then the MMA moves the asymptotes away from the design point in order to accelerate up convergence. There are two approaches to solving subproblems in MMA, the "dual approach" and the "primal-dual interior point approach". The dual approach is based on the dual Lagrangian relaxation corresponding to the subproblem, which seeks the maximization of a concave objective function without other constraints and the non-negativity condition on the variables. This dual problem can be solved by a modified Newton method, and then the dual optimal solution can be translated into a corresponding optimal solution of the primal subproblem, which is used in this paper.

III. Methodology for Generation 3D Strut-and-Tie Models and the Final Flowchart

To determine the path load of the 3D bars of the STM from the TO analysis, this paper employs a new procedure to evaluate the struts and ties by the signs of the derivatives of the Von Mises stress components. It is known that for 3D problems they can be written as

$$(\sigma_e^{vm})^2 = \frac{1}{2}[(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2] + 3(\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2) \tag{12}$$

Taking the local calculation of the derivative of the von Mises stress of the element with respect to the components of the stress vector described respectively as:

$$\begin{gathered}
\frac{\partial(\sigma_e^{vm})}{\partial\sigma_{e11}} = \frac{1}{2\sigma_e^{vm}}(2\sigma_{e11} - \sigma_{e22} - \sigma_{e33}) \\
\frac{\partial(\sigma_e^{vm})}{\partial\sigma_{e22}} = \frac{1}{2\sigma_e^{vm}}(2\sigma_{e22} - \sigma_{e11} - \sigma_{e33}) \\
\frac{\partial(\sigma_e^{vm})}{\partial\sigma_{e33}} = \frac{1}{2\sigma_e^{vm}}(2\sigma_{e33} - \sigma_{e11} - \sigma_{e22}) \\
\frac{\partial(\sigma_e^{vm})}{\partial\sigma_{e12}} = \frac{3\sigma_{e12}}{2\sigma_e^{vm}} \\
\frac{\partial(\sigma_e^{vm})}{\partial\sigma_{e23}} = \frac{3\sigma_{e23}}{2\sigma_e^{vm}} \\
\frac{\partial(\sigma_e^{vm})}{\partial\sigma_{e31}} = \frac{3\sigma_{e31}}{2\sigma_e^{vm}}
\end{gathered} \tag{13}$$

Considering Eq.(13) and making $\frac{\partial(\sigma_e^{vm}(x))}{\partial\sigma_{e11}} > 0$ then the elements are preponderantly tensioned (blue color - ties) while $\frac{\partial(\sigma_e^{vm}(x))}{\partial\sigma_{e33}} < 0$ are preponderantly compressed (green color - strut). The flowchart presented in Fig. 4 shows the original methodology presented in this section with the approach of using element sensitivity for automatic generation of STMs via stress derivatives, when a target volume is reached, the stopping criterion is reached. A set of techniques has not yet been presented in scientific articles on 3D models, so the results obtained in item 4 are compared with those proposed by [16], [26] and [45]. Highlights that the VFLSM method required a neighborhood filter to define the tensile (blue) and compression (green) regions. This filter is due to intermediate values that occur in continuous TO methods such as the intermediate densities that occur in the SIMP methodology.

IV. Numerical Examples

The following examples of structures engineering focus on TO base on minimizing compliance for STMs. The geometry and boundary conditions for numerical applications are represented for each case. All numerical examples were processed on a Core i7-2370, 8th Gen notebook, 2.8 GHz CPU with 20.0 GB (RAM).

a) *Example 1 – Deep Beam with Opening*

The example presents a simply supported deep beam with an opening at the bottom left corner. The beam has its span three times its height and it is defined in [46], where the simple bending structural behavior is no longer considered. A vertical downward force F=3000 kN is applied eccentrically at the top edge as shown in Fig. 5. The structure is discretized with a total of 65,420 hexahedral elements (SESO) and 65,420 tetrahedral elements (LSM) (Fig. 5 shows the design domain and its boundary conditions). In this configuration, the force in off-center position and the opening positioned near the left low end create a situation that changes the internal stress flow in the structure, between the load and the supports. The tie elements, resulting from tensile stresses, are positioned at the extremities of the strut elements, resulting from compressive stresses, geometrically defining the final model.

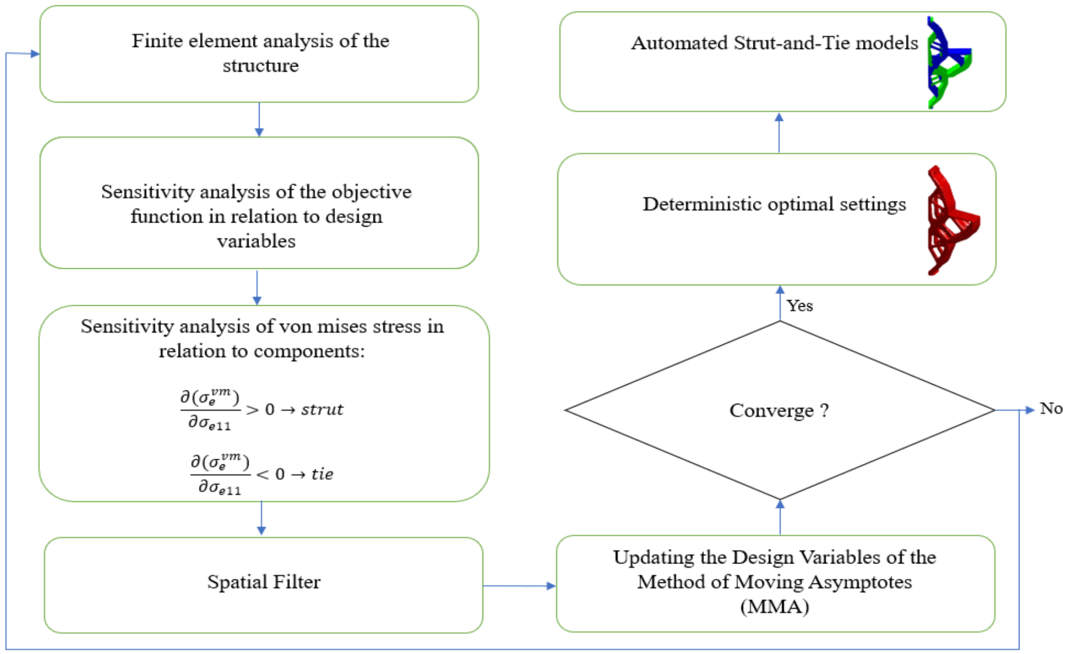


Fig. 4: Flowchart of the STM via TO

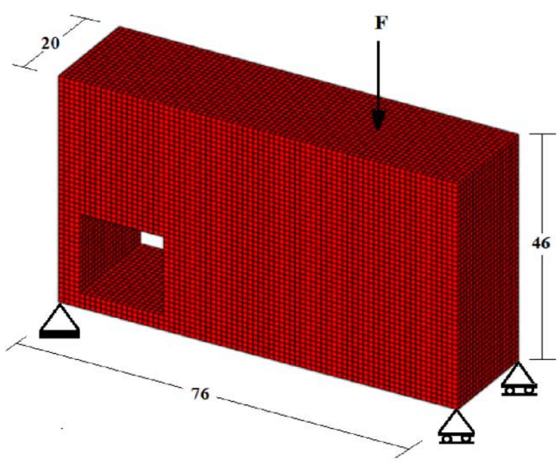


Fig. 5: Design domain and boundary conditions (measuring in cm)

Fig. 6 provides the optimal topologies of the optimization procedures for the SESO (Fig. 6a and Fig. 6b) and VFSLM (Fig. 6c) methods, with a final volume fraction equal to 32%. The optimal configurations have similarity to the classical STM presented by [1] and later by [20]. The computational cost presented by SESO using Optimality Criteria [47] is approximately 40% lower than the SESO and VFLSM methods using the MMA. It can be also noticed in Fig. 6 that the optimal settings obtained by the VFLSM formulation clearly defines distinct elements (strut or tie) near the lateral faces of the deep beam, resulting in a more discrete STM, compared to the optimal settings presented by the SESO method. The classic model, Fig. 7, denotes three diagonal struts starting from the region of load application, one of them external directed to the closest support, another contouring the opening and directed to the support, and a third internal one. The ends of the struts are connected by tie composing the final structure of the STM.

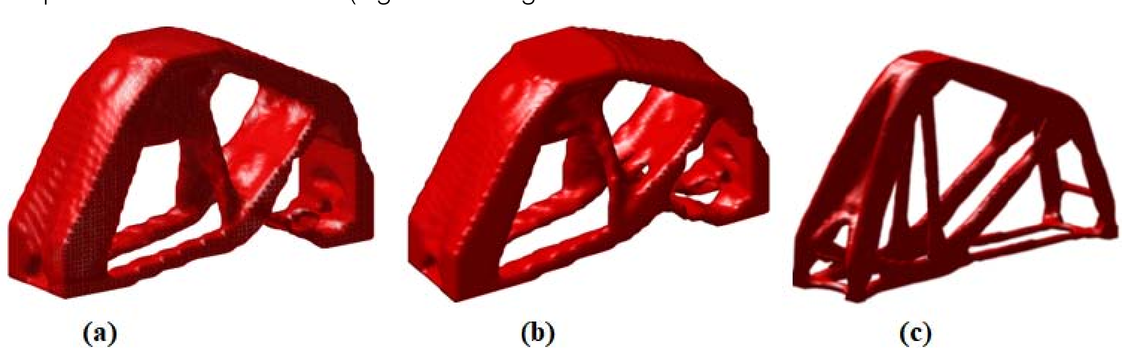


Fig. 6: Topology optimal for deep beam: (a) SESO-MMA; (b) SESO – OC and (c) VLSM-MMA

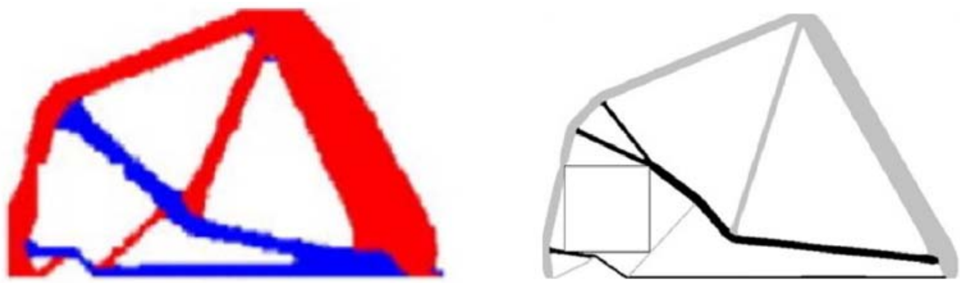


Fig. 7: Topology optimal for deep beam with opening: classical model (a) [28]; (b) [45]

In Fig. 8 it can be seen that the SESO formulation (Fig. 8a) results in a setting similar to the classical model, but the VFLSM formulation (Fig. 8b) presents a model with a discretely simpler setting, with the internal strut in the vertical direction, unifying at a lower point the two ties. This setting simplifies the design procedure and the reinforcement detailing of the reinforced concrete structure, in the practical and executive sense, although the classic model makes it possible to calculate the complementary reinforcement around the opening.

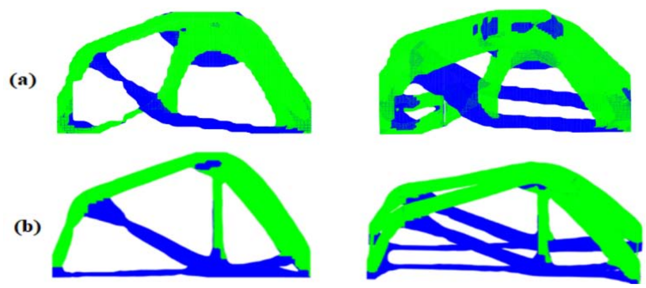


Fig. 8: Strut-and-tie models: (a) SESO; (b) VFLSM

b) Example 2 – Pile Cap

In this example, a building foundation structure is dimensioned as a pile cap according to the dimensions shown in Fig. 9, for consideration as a rigid block and to enable the analysis by the STM concept. The pile cap is subjected to a vertical force of 4,000 kN located at the center of the upper face. The material properties used are the compressive strength of the concrete cylinder is 32 MPa. The Young's modulus of the concrete E_c = 25,000 MPa and Poisson's coefficient $\nu = 0.15$. The filter radius $r_{min} = 1.5\, mm$ mm and the volume fraction of 22.5%, a rejection ratio, RR = 1% and the evolution ratio ER = 2% were specified in the optimization process.

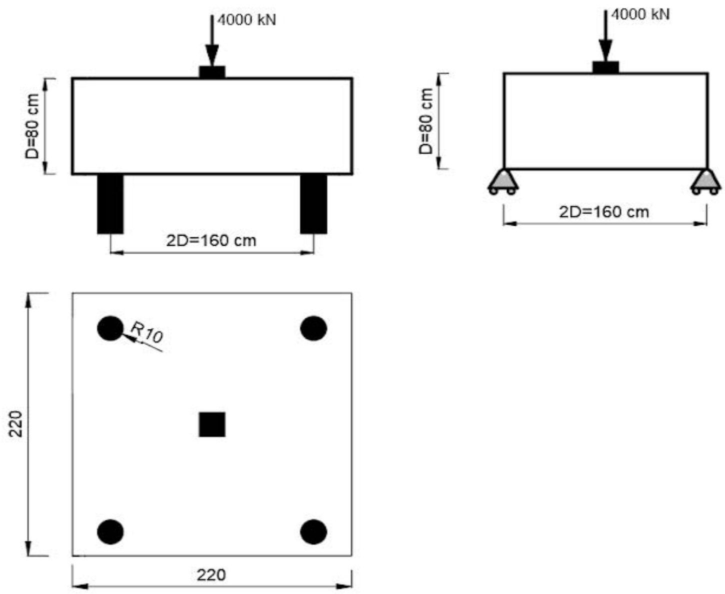


Fig. 9: Design domain and boundary conditions of pile cap

In the numerical simulations, to discretize the domain of the structure, a refined mesh of 40x20x40 was used, totaling 32,000 hexahedral elements (SESO) with 1mm reference side was used and a mesh of 32,000 tetrahedral elements (VFLSM). The results obtained as final optimal topologies of this problem for these meshes are represented in Fig. 10 and can be compared with the results with those presented by [16] and [26], see Fig. 11.

The optimal topology is basically composed of discrete elements represented in the principal stress flows. These optimal settings are adequate to perform the detailing and dimensioning of the required reinforcement, as well as strength checks. In this structure, the vertical load is distributed in four struts inclined toward the supports represented by vertical piles. The models highlight elements at the base of the pile cap, representing the tensile stresses, where a plane frame of ties balances the strut ends generated by the 3D structure in both horizontal directions, Fig. 10, where it can be seen the optimum topologies for the two methods, SESO and VFLSM. In the automatic generation of the strut models, it was considered the main flows of distinct stresses by colors, where the region of compression struts is green color and the region of tensile ties is blue.

a) b)

Fig. 10: Optimal topology: (a) SESO; (b) VLSM (present formulation)

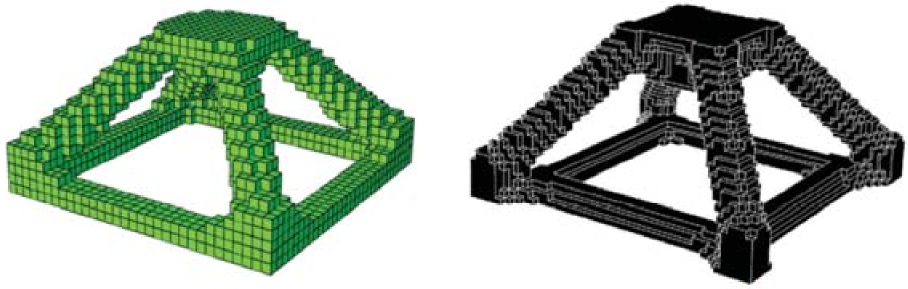


Fig. 11: Optimal topology: (a) BESO by [26]; (b) SIMP by [16]

Although the models result quite similar, when approaching this problem, one must consider the increased computational burden associated with a 3D structure; a solid mesh usually requires that many elements be investigated at an adequate level of detail, with notable consequences on the number of equations and variables. Seeking to minimize this aspect of the processing, the system of equations received the implementation of a sparse approximation preconditioner for the inverse matrix. With this routine active, the computational cost of SESO-3D for this problem was decreased from 8,000 sec to 1,854 sec (4.3 times less) while VFLSM had a decrease from 8,000 sec to 3,851sec (2.1 times less).

The dimensioning of the reinforcement of this model is performed, as already presented in [28]; in the calculations of the dimensions of the model elements, namely, inclined compression strut - column-pile and horizontal tension tie - pile-pile, the geometry of the problem presented [26] is used:

$$force\ in\ Strut\ -\ C_1 = \frac{\frac{4,000}{4}}{sin(29.5)} = 2,031\ kN$$

$$force\ in\ Tie\ -\ T_1 = C_1 \frac{\cos(29.5)}{\sqrt{2}} = 1,250\ kN$$

Two evaluations need to be performed, the limits of stresses in the steel bars (CA50) for the tie and stresses in the concrete (C32) of the struts. According to the Brazilian technical standard, we have the following expressions:

$$A_{sd,tie} = \frac{\gamma_f * T_1}{f_{yd}} = \frac{1.4*1,250}{50/1.15} = 40.25\ cm^2 \text{ (3 layers of 4 } No.\ 22)$$

adopting steel bar with diameter $d = 22\ mm$ with 12 bars ($A_{s,effective} = 45.60\ cm^2$)

In the inclined strut, the verification of the compressive stresses is performed according to

$$Concreto C32 - f_{ck} = 32\ MPa$$

$$E_{ci} = \alpha_E * \alpha_i * 5600 * \sqrt{f_{ck}} = 1.0 * 0.88 * 5600 * \sqrt{32} = 27,877\ MPa$$

and the area of the strut required for the design strength of the concrete not to be exceeded:

$$A_{cd,strut} = \frac{\gamma_f * C_1}{0.8 * f_{cd}} = \frac{1.4 * 2,031}{0.8 * (3.2/1.4)} = 1.555\ cm^2$$

By way of comparison, in [26], the results of this sizing are $A_{sd,tie} = 41.66\ cm^2$ and $A_{cd,strut} = 1,659\ cm^2$. The differences in values (3.5% and 6.3, respectively) are due to different calculation criteria between the technical standards used, but values of the same order of magnitude can be considered. Fig. 12 shows the reinforcement arrangement for the pile cap.

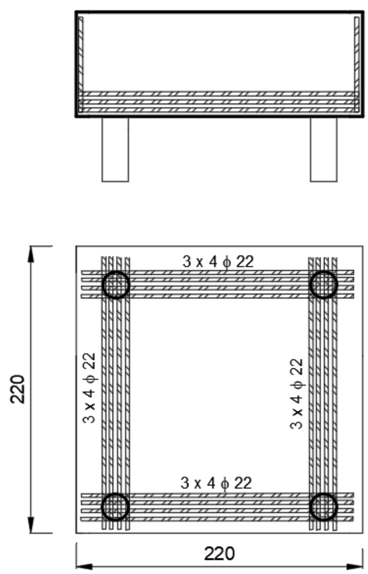


Fig. 12: Reinforcement arrangement for the pile cap

c) Example 3 – Bridge pier

The SESO and VFLSM methods using the MMA as accelerator are applied to a structure representing a column receiving loading from the bridge superstructure, represented by four vertical forces, as shown in Fig. 13. The concrete material properties, rejection ratio (RR), evolutionary ratio (ER) and filter radius are the same as in the previous example. For the numerical simulations, in the SESO method the bridge support is discretized using a fine mesh of 85x55x20 hexahedral elements of eight nodes, with reference side of 1 mm, while in the VFLSM method the mesh used has 85x20x55, totaling 93,500 tetrahedral finite elements.

The compliance history and the performance of the methods during the optimization procedure are plotted in Fig. 14. It can be seen in Fig. 14b that the performance index perfectly captures the changes in compliance and increases from unity to a maximum value of 2.3, stabilizing quickly around 2.1, the value at the optimal iteration.

The history of the optimization procedure via SESO and VFLSM for the bridge pier are shown in Fig. 1 and Fig. 16. The optimal topologies were achieved at iterations 82 and 100 with final volumes equal to 20% of the initial volume and a computational cost of 4,315.8 sec for SESO while VFLSM showed a computational cost of 5,486.5 sec.

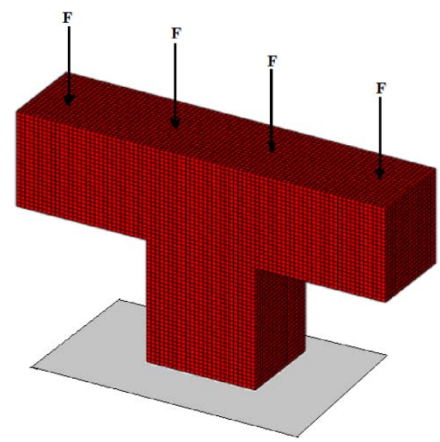


Fig. 13: Project domain of the Bridge pier

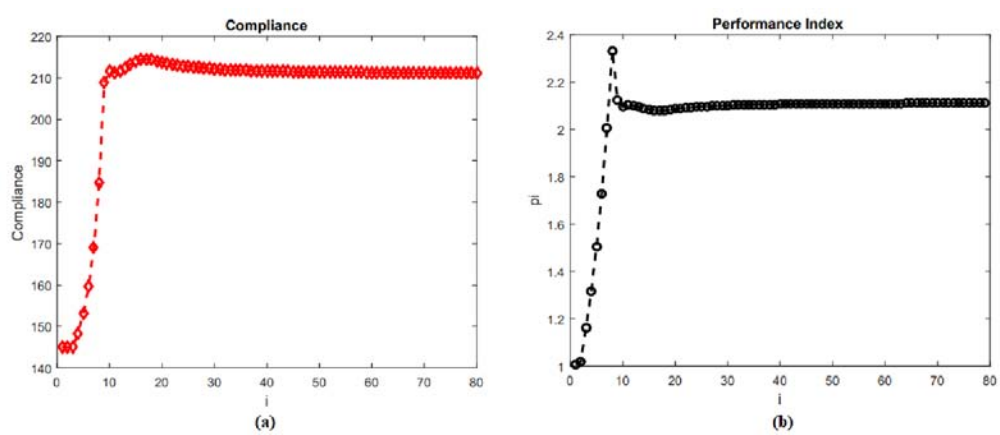


Fig. 14: Performance Index: topological history

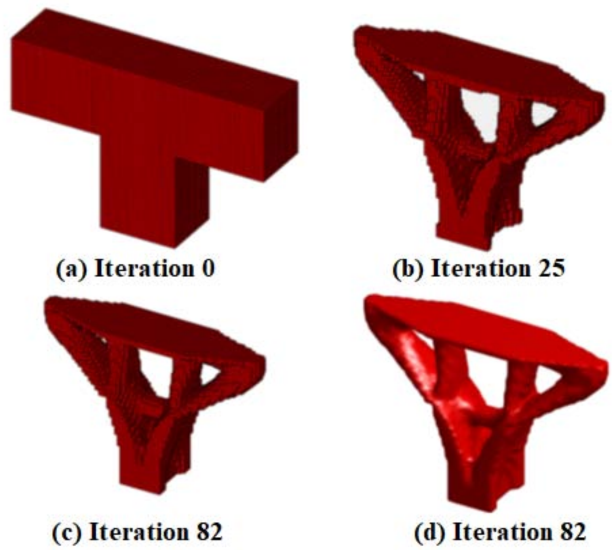


Fig. 15: Optimization history of bridge pier with SESO: (a) initial structure; (b) topology at iteration 25; (c) optimal topology at iteration 82; (d) optimal topology (hexahedral elements)

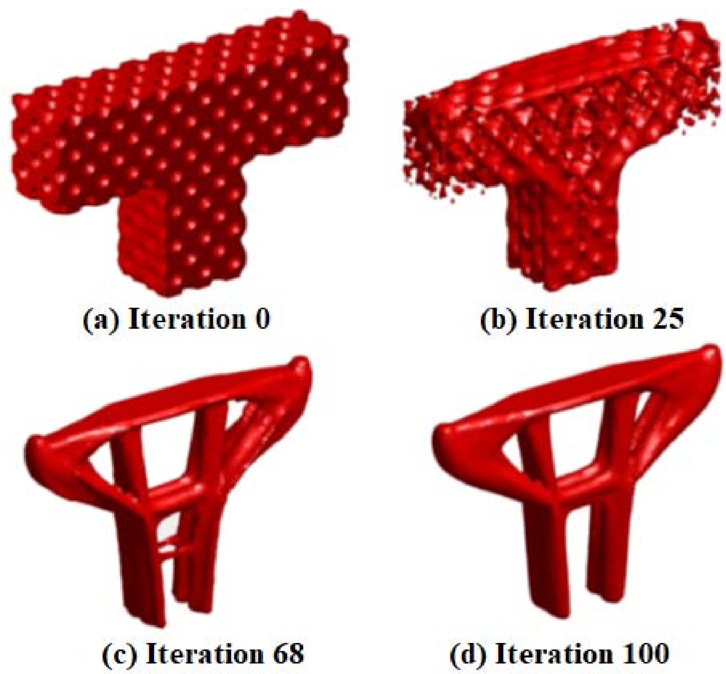


Fig. 16: Optimization history of bridge pier VFLSM: (a) initial structure; (b) topology at iteration 25; (c) optimal topology at iteration 68 (d) optimal topology (tetrahedral elements)

The optimal settings with highlights of the distinct regions by colors are presented in Fig. 17 for the two methods proposed in this paper. In these representations, a vertical axial force is expected to balance the symmetric external loads in the region of the base constraint. The applied vertical forces, in fact, are transferred to the column axis by means of two inclined struts and two vertical struts that merge into two in the proximity of the top region of the vertical element, driving the load distribution to the lower region where are the base supports. Note that the SESO method creates a unified region at the base while the VFLSM method sets up two parallel vertical paths. In addition, a horizontal tensile tie is arranged at the top of the body receiving the applied forces, which ensures the "T" geometry of the structure and configures the struts equilibrium in the load application zones. From a numerical point of view, the result obtained is optimal and configures the symmetry defined by the position of the design load. For automatic generation of STM models in the VFLSM method, it was necessary to implement the derivatives of von Mises stresses in the code proposed by [34]. Fig. 17b exhibits an optimal topology of VFLSM with tensile stress flows (blue) in the upper part and compression stress flows (green) similar to those of the SESO method, Fig. 17a, highlighting the robustness of both methods for creating strut-and-tie models. With the objective of investigate the effects of D-regions, three holes were inserted in the horizontal element of the bridge pier structure, and the number of finite elements of the mesh was reduced to 88,700, as shown in Fig. 18. The optimal topologies of the SESO and VFLSM models are represented in Fig. 19, where the struts are represented by green color and the ties by blue color.

The optimum results obtained demonstrate that the presence of geometric discontinuities produces changes in the stress flows, that seek to contour the discontinuities, describing practically vertical struts in the horizontal body of the bridge pier from the points of load application. These struts bend below the openings to meet at the top of the vertical element, creating points of deviation that need to be equilibrated by tensile ties. In Fig. 19, it can be seen the representations of STM elements created as described.

This modification with the presence of the openings affects the STMs models significantly, and the real load transfer mechanism can change with the dimensions of the openings. The optimization histories are shown in Fig. 20 and Fig. 21, by the SESO and VFLSM formulations, respectively.

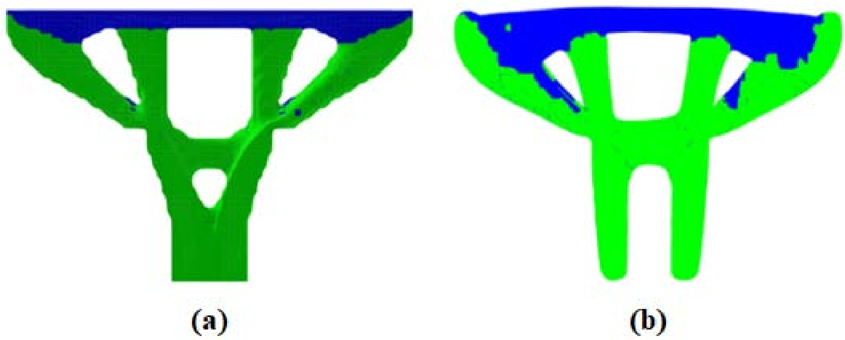


Fig. 17: Bridge Pier: Strut-and-tie models (a) SESO and (b) VFLSM

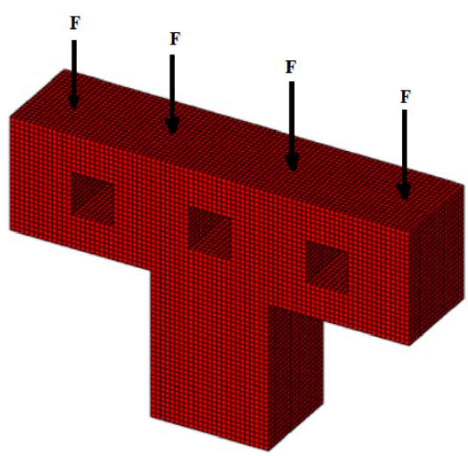


Fig. 18: Bridge pier with three holes as structural discontinuities in horizontal braces

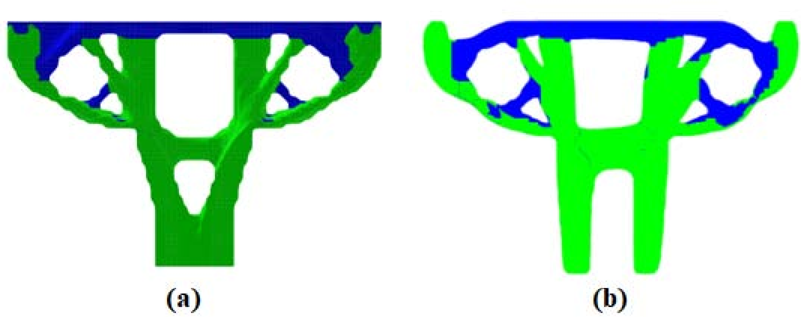


Fig. 19: Strut-and-tie model: (a) SESO and (b) VFLSM

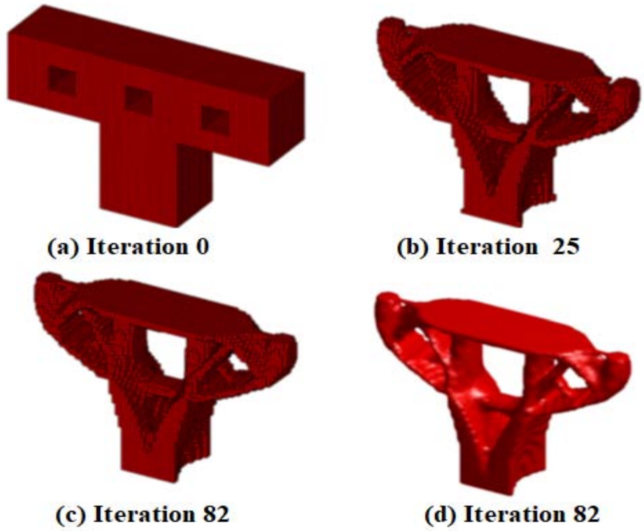


Fig. 20: Optimization history of bridge pier with openings SESO: (a) initial structure ; (b) topology at iteration 25; (c) optimal topology at iteration 70; (d) final optimal topology

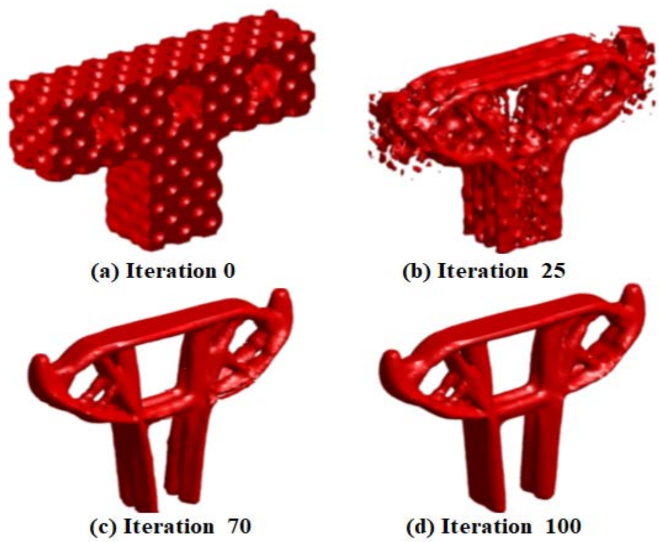


Fig. 21: Optimization history of bridge pier with openings VFLSM: (a) initial structure ; (b) topology at iteration 27; (c) optimal topology at iteration 70; (d) optimal topology

d) Example 4 – Single Corbel

The SESO and VFLSM methods were also experimented with for modeling struts-and-ties in a single corbel attached to a column. A simple structure can eventually result in an intricate STM as the dimensions and load arrangements can be defined. The geometry and dimensions of the structure are shown in Fig. 22. This single corbel is subjected to a concentrated load of 1 kN. The compressive strength of the concrete used in this example is 32 MPa. Young's modulus of the concrete E = 28,567 MPa and the Poisson's ratio $\nu = 0.15$ were defined in the analysis. A prescribed fraction volume V = 0.22 m^3 and an evolution ratio of ER = 2% was specified in the optimization process.

In the SESO method the structure was discretized with a mesh of 44x12x108 unit hexahedral finite elements. The performance of the structure was monitored throughout the optimization procedure and, despite the breaks in the load transfer mechanisms due to element removal, the structure did not present failure modes and the performance index remained higher than 1, stabilizing at 1.6. In the VFLSM method, the same mesh was used, totaling 57,024 tetrahedral elements. Figures 23a, b, c and d show that the optimal topologies obtained by the two models are different and checkerboard patterns were not detected. It is noted in observation made in the deep beam example that both formulations, SESO and VFLSM, define settings differently for elements of strut-and-tie models. Discrete elements are configured on the side faces of the models in different regions, while complete planes are shaped in other regions, with no common convention between the two formulations. The presented results show that both SESO-3D and VFLSM-3D are able to provide the prediction of the load transfer mechanism in reinforced concrete structures, even considering the structural domain thickness in the configuration of the component elements of the models.

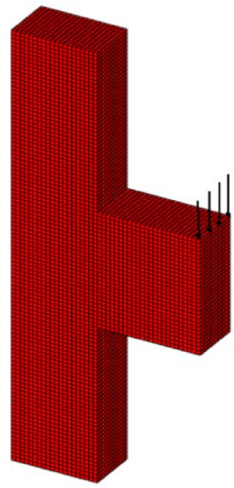


Fig. 22: Single Corbel: Project Domain

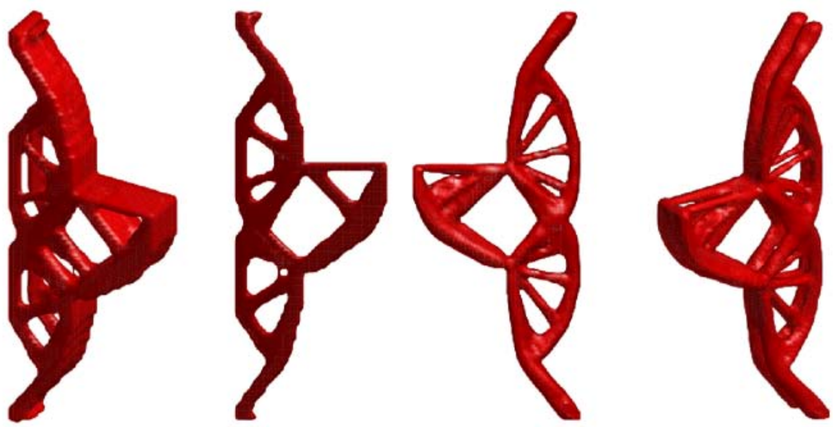
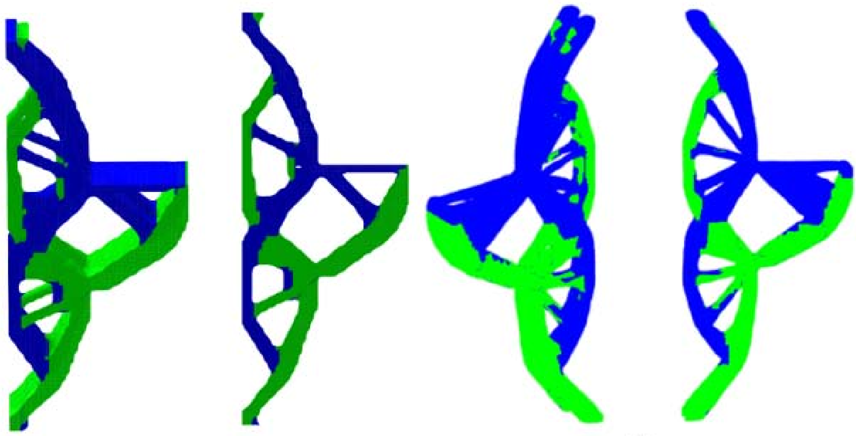


Fig. 23: Single Corbel, optimal topology: (a) e (b) SESO (c) and (d) VFLSM

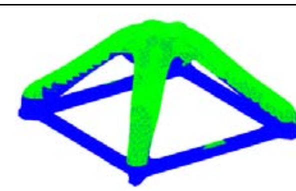
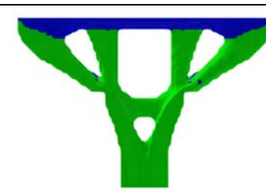
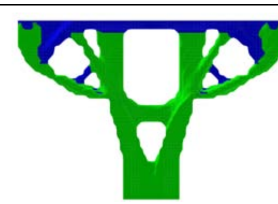
The STMs are presented in Fig. 24, it can be seen that these models are different and capable of clearly representing the location of the struts, ties and nodal zones. These results can be compared with those presented by [16] and [26]. It is also highlighted that the parameters of the MMA optimizer were changed to $\zeta \leq 0.98$, $\xi \leq 1.25$ e $\varsigma \leq 0.75$ proportion a more feasible topology for design. Fig. 24b shows the optimal setting of the VFLSM used for automatic creation of the STM models; both formulations exhibit distinct tensile (blue) and compressed (green) regions, even in the width of the structural domain. Table 1 highlights the computational cost of SESO and VFSLM in all the examples presented in this paper evidencing the better performance for SESO-OC and SESO-MMA compared to VFLSM-MMA.



(a) (b)

Fig. 24: Single Corbel, Strut-and-tie model: (a) SESO; (b) VFSLM

Table 1: Strut-and-tie Models and Computational Cost

Structure	Computational Cost (minute) (SESO-OC)	Computational Cost (minute) (SESO-MMA)	Computational Cost (minute) (VFLSM)	Strut-and-tie Models
Deep beam with opening	90.7	109.8	229.81	
Pile Cap	21.4	38.0	64.2	
Bridge pier	57.9	95.0	159.3	
Bridge pier with three holes	56.5	95.9	158.6	
Single Corbel	45.4	71.9	103.7	

V. Conclusions

This paper aimed to extend the application of TO in 3D elasticity to obtain the best solution to STM problems. It brought some processes as innovation, such as the use of the SESO method and the VFLSM employed in conjunction with the OC and MMA methods to accelerate and stabilize the analyses; so that, the first method demonstrated to be more efficient when employed with the SESO, about 2 to 3 times faster in all the examples evaluated. It is highlighted that in these processes the incorporation of the linear solution by the conjugate gradient method with the incomplete Cholesky preconditioner further enhanced the computational cost. In the automated generation of the final designs of the STM, the procedure of obtaining struts and ties computed by the partial derivatives of the stresses of each element was applied highlighting that this novelty is easy to implement and the use of a spatial modal filter in the stress field was enough to completely eliminate the checkerboard. From the automatic generations performed, it was possible to design an example according to the recurring norm in an expeditious manner, in which the required reinforcement areas were evaluated and compared, demonstrating a good similarity. All codes were implemented in the high level language Matlab, which is easily accessible and extensible for future incorporation of other more realistic models, such as a rheological model more suitable for concrete. The study of STM using optimization applied to both materials (steel and concrete), leading to dimensioning and detailing of RC structural elements under the reliability-based topology optimization (RBTO) paradigm, taking advantage of the efficiency and stability of the procedures, are the highlights in the formulations developed in this paper.

Acknowledgment

The authors acknowledge the Sao Paulo State Research Foundation (FAPESP) under Grant Number 2016/02327-5 for their financial support and CNPq (National Council of Scientific and Technological Development) under Grant Numbers 305093/2018-5 and Federal Institute of Education, Science and Technology of Minas Gerais under Grant Numbers 23792.001327/2022-49.

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Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 23 Issue 2 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

The use of Oil Shale for Road Coating

By Mohamed Amine Alouani, Dennoun Saifaoui, Abdelkader Alouani & Younes Alouani

Hassan II University

General Introduction and Background- The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tar sands and oil shale. This could bridge the gap between energy demand and supply. Several countries with oil shale deposits have launched projects to examine the possibility of exploiting these deposits. Morocco is one of these countries, with significant oil shale deposits in the Middle Atlas (Timahdit), Tarfaya, Tangier and Grand Atlas regions (Fig. 1) [1].

Morocco has a reserve of around 53 billion barrels of oil shale, in addition to a rich capacity for shale gas and oil. The exploration works for these unconventional hydrocarbons, which began several years ago, has proved highly encouraging. The first research into the development of oil shale in Morocco began in Tangier, with the creation of the oil shale company of Tangier. The company built a pilot plant with a daily capacity of 80 tons of oil shale. The Timahdit and Tarfaya deposits were discovered in the 1960's.

GJRE-E Classification: DDC: 553.28

Strictly as per the compliance and regulations of:

The use of Oil Shale for Road Coating

Mohamed Amine Alouani α, Dennoun Saifaoui σ, Abdelkader Alouani ρ & Younes Alouani Ѡ

I. General Introduction and Background

The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tar sands and oil shale. This could bridge the gap between energy demand and supply. Several countries with oil shale deposits have launched projects to examine the possibility of exploiting these deposits. Morocco is one of these countries, with significant oil shale deposits in the Middle Atlas (Timahdit), Tarfaya, Tangier and Grand Atlas regions (Fig. 1) [1].

Morocco has a reserve of around 53 billion barrels of oil shale, in addition to a rich capacity for shale gas and oil. The exploration works for these unconventional hydrocarbons, which began several years ago, has proved highly encouraging. The first research into the development of oil shale in Morocco began in Tangier, with the creation of the oil shale company of Tangier. The company built a pilot plant with a daily capacity of 80 tons of oil shale. The Timahdit and Tarfaya deposits were discovered in the 1960's. These last two deposits have been the subject of several geological and mining studies, laboratory studies, as well as pyrolysis and direct combustion tests. Their oil shales have been tested by several pyrolysis processes throughout the world mainly in the United States, Europe, the former USSR, Canada and Japan. They have been the subject of numerous technical and economic feasibility studies.

This geological, mining and laboratory work, which began in 1975 and continues to this day, has enabled us to identify the characteristics of these reserves in the deposits of Timahdit and Tarfaya oil shales. These studies showed that Moroccan shales could be upgraded by pyrolysis to produce hydrocarbons. This led Morocco to launch its own experiment and develop the T3 process (Acronym of the three deposits of Tangier, Tarfaya and Timahdit) [2].

Morocco has significant oil shale resources, ranking 6th worldwide after the USA, Russia, the Democratic Republic of Congo, Brazil and Italy, with a potential of 53 billion barrels of oil in field. This includes over 37 billion barrels in the two main deposits of Timahdit and Tarfaya.

Oil shale is used for a number of purposes, including conversion into hydrocarbons through the chemical process of pyrolysis and low-grade combustion for power generation. It is equally used as a raw material (chemical industries, agriculture, construction) for heavy oils particularly suited to diesel engines, lubricating oils and tar used in the manufacture of sealants and asphaltites.

At the international level, oil shale is exploited at a limited scale despite how important the reserves are. This is related to a double-fold problematic. The first one concerns economic challenges; the production of petroleum from oil shale does not become economically viable unless the price of a barrel is at a profitability threshold. The second issue is related to environmental challenges: the combustion and thermal processing of oil shale generate waste and emit carbon dioxide into the atmosphere.

In our studies and research program, we have developed solutions to exploit oil shale deposits within the framework of sustainable development, using renewable energy sources, unconventional waters and carbon dioxide collection techniques. In addition, we integrate other uses, to make the overall exploitation of oil shale deposits profitable, by reducing the impact on the global environment in a remarkable manner.

To make the exploitation of oil shale deposits profitable, our research has been directed towards the development of other possible uses, such as road and runway coating, cement production and the manufacture of carbon plates. In this article, we develop the use of shale for road coating.

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II. Definition and Characterization of Bituminous Shale

The distribution of oil shale deposits in Morocco is shown in the figure (Fig. 1) below:

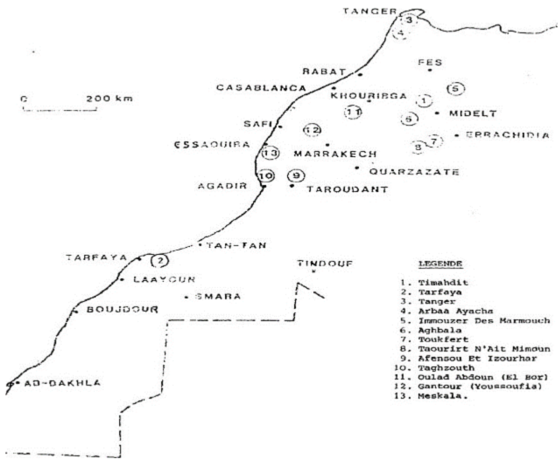

Fig. 1: Distribution of oil shale deposits in Morocco [1]

a) *General Definition of Bituminous Shale*

Bituminous shales are rocks capable of producing oil in commercial quantities when subjected to pyrolysis. A sedimentary rock containing an insoluble organic substance is referred to as pyro schist, pyrobitumen shale, kerogen rock or, more commonly, bituminous shale. It releases an oil with a general appearance similar to crude oil by non-oxidizing heat treatment at a temperature of between 400 and 500°C [3].

b) *Nature and Composition of Bituminous Shale*

- Organic and mineral matter. Despite certain similarities, the composition of the organic matter contained in oil shale varies from one deposit to another.
- Kerogen is a mixture of high-molecular-weight compounds containing mainly carbon, hydrogen, nitrogen, oxygen and sulfur. The oxygen and nitrogen content are generally higher than crude oils.

The organic matter in oil shale is richer in aromatic sulfur compounds (benzothiophene derivatives) and above all in resins and asphaltenes. They are normally heavy but constitute minority constituents in conventional oils (0 to 2% by weight), and a majority in shale.

c) *Chemical Reactions Produced during Shale Combustion*

The chemical reactions that occur during shale combustion can be presented as follows [1]:

For organic matter

$$C_nH_n + \left(\frac{5n}{4} O\right)_2 \rightarrow nCO_2 + \frac{n}{2} H_2O + Q \text{ (Exothermic)}$$

For terrigenous matter:

$$SiO_2 \rightarrow Si + O_2$$

For carbonate matter:

$$CaCO_3 \rightarrow CaO + CO_2 - Q \text{ (Endothermic)}$$

For other elements:

$$2FeS_2 + \frac{11}{2} O_2 \rightarrow 4SO_2 + (Fe_2O)_3 + Q \text{ (Exothermic)}$$

III. Global Experience and General Properties of Bituminous Shale

a) *Oil Shale Experience Worldwide*

Oil shales are fine-grained sedimentary rocks containing sufficient organic matter. They can be used to produce oil and fuel gas. Oil shale can be converted into liquid hydrocarbons by pyrolysis. It may be burned directly as a low-grade fuel for power and heat generation, or used as a base material in the chemical industries.

Figure 2: Example of an oil shale operation in Estonia (Eesti Energia)

Bituminous shale (also oil shales, pyro schists, Kero bituminous) are fine-grained sedimentary rocks containing enough organic matter, kerogen, to provide oil and gas fuel. Oil shales vary considerably from one another, in terms of their chemical composition, mineral content, age, type of kerogen and manner of deposition. The existing kerogen in oil shale can be converted into oil through the chemical process of pyrolysis; the decomposition of organic matter under the effect of heat. In fact, the kerogen in oil shale is a kind of "unfinished oil" that has not been exposed to the sufficient temperature and pressure conditions to be transformed into petroleum.

Oil shale can also be burned directly as a low-grade fuel for the supply of electricity and heating. It can be used as a raw material in the chemical industries for subsequent extractions (Sulfur, Ammonia, Sealants, Road Bitumen, Cement or Bricks). Oil shale contains kerogen, which must be processed before oil can be obtained, whereas tar sands and shale gas are directly exploitable, containing trapped bitumen and gas respectively. The following products can be obtained from oil shale oil:

- Conversion to hydrocarbons through the chemical process of pyrolysis
- Low-grade combustion for electricity generation
- Use as raw materials (chemical industries, agriculture, construction).

Oil shale is still minimally exploited despite the size of its reserves. This is due to a double fold issue. Oil production from oil shale becomes economically viable once the price per barrel reaches the profitability threshold.

As for the environmental challenge, the combustion and thermal processing of oil shale generate waste and emit carbon dioxide into the atmosphere. Despite these constraints, industrial processing has already been launched, such as:

- Liquid hydrocarbon production in Estonia, Brazil and China
- Electricity production in Estonia, China, Israel and Germany
- Cement production in Estonia, Germany and China.
- Chemical industry in China, Estonia and Russia.

b) The Timahdit Oil Shale Case in Morocco

The oil shales of Timahdit (Morocco) may constitute significant hydrocarbon resources, amounting to more than nineteen billion tons of raw rock. This is equivalent to around 8.9 billion barrels [1]. These argilo-carbonate sedimentary rocks were formed at the end of the secondary period.) They are essentially made up of [3]:

- 30 to 75% terrigenous (clayey) material: aluminosilicates predominate
- 25-50% carbonate matter: calcite is the main constituent
- Organic matter from 12 to 24%. One part is soluble in organic solvents, the other is insoluble in the same solvents and constitutes kerogen.

The mineral composition of an average sample of Timahdit oil shale [1] is shown in Table 1 below:

Table 1: Mineral composition of the Timahdit shale

Mineral	Pourcentage (%)
Dolomite ($CaMg(CO_3)_2$)	15,9
Calcite ($CaCO_3$)	41,5
Quartz (SiO_2)	19,5
Illite ($(OH)_4K_2(Si_6Al_2)Al_4O_{20}$)	13,4
Pyrite (FeS_2)	1,8
$FeCO_3 + FeO_3$	1,8
TiO_2 + Phosphate	2,4
Other elements	3,7

The concentration of dolomite is low when compared with that generally found in the Colorado shale in the USA. Thermal decomposition of dolomite and calcite is a highly endothermic reaction. Maximum temperatures in the combustion zone are, therefore, higher for Timahdit shales than for Colorado shales when the applied process is direct heating. Similarly, the kerogen composition of a sample of Timahdit shale [1] is shown in Table 2.

Table 2: Elemental composition of Timahdit and Colorado kerogen

Elements	% for Timahdit kerogen	% for Colorado kerogen
Carbon	69,2	80,5
Hydrogen	6,5	10,3
Azote	2,9	2,4
Sulfur	8,4	1,0
Oxygen	12,9	5,8

IV. Synthesis of the Simulation of the Use of Oil Shale as a Road Coating to Replace Road Bitumen

a) Application Techniques for Bituminous Shale

The sub-base course must be produced in strips, in accordance with the following procedure:

- Scraping soil in order to decompactify it and detect any mining waste, afforestation or scrap metal.
- A tractor-mounted stone crusher is used to size the largest schist blocks to 60 mm.
- Adjustment of water content by sprinkler and paver
- Binder spreading by spreader.

b) Summary of the Study on the Application of Oil Shale for Road and Runway Coating

On the basis of various reserve evaluation studies, geophysical, geological, mining, geochemical and chemical work studies, we have characterized the deposits according to the zones with profitable exploitation. In addition to the use of bituminous layers as a source of energy, we have identified their use in road coating by replacing road bitumen which is a residue of crude oil processing in an oil refinery.

Drawing on similar experience [5] and simulation results, the results obtained are encouraging, with very competitive repair costs.

c) Results Obtained from Studies, Simulations and Pilot Tests carried out on the Application of Bituminous Shale for Road and Runway Coating

Parameter optimization was based on experimental design techniques applied in a similar optimization case [4]. In addition to the economic advantages and local availability, the results obtained lead to the following conclusions:

- The products studied show reduced dry densities compared with other types of coating.
- Swelling is virtually non-existent
- The products show very good resistance to direct shearing, particularly in terms of very high angles of internal friction.
- Impact and wear resistance comparable to reference materials
- Oil shale-based materials have low degradability and fragmentability under hydric and mechanical stress.

A third phase was devoted to studying the technical feasibility and economic viability of industrial applications over long stretches of runways or roads to be coated. The study showed that surfaces covered with oil shale have comparable characteristics to those of asphalt roads usually covered with petroleum bitumen. The physico-chemical characteristics obtained were in line with required standards. Economic profitability was confirmed as well.

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Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 23 Issue 2 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Stabilization of a Sub-Saharan Laterite Soil using Calcium Silicate

By Babacar LY, Makhaly BA & Adama Dione

University of Thies-Laboratory of Mechanics and Modeling (L2M)

Abstract- The main objective of the research being conducted is, not only to achieve the required soil engineering properties by mixing this product but also to consider the effect of this product of soils stabilization on fine particles contained in lateritic and typically clayey soils. This research work presents the efficiency of calcium Silicate as an additive in improving the engineering characteristics of laterite aggregate soil and clayey soils. Investigations will be done to evaluate the effectiveness of this soil stabilizer which involved the use of calcium Silicate (CaSiO3) formula fixed by (Ndiaye et al, 2022). As a chemical additive the percentage of the binder will be respectively 4 and 6%.

These two types of soils are expected to be stabilized and their effectiveness will be observed from the expected results only in terms of strength and consolidation by constant rate of strain parameters like recompression index (Cr) and compression index (Cc).

Keywords: soil stabilization, chemical additive, calcium silicate, unconfined compressive strength and consolidation by constant rate of strain.

GJRE-E Classification: UDC: 624

STABILIZATIONOFASUBSAHARANLATERITESOILUSINGCALCIUMSILICATE

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Babacar LY [α], Makhaly BA [σ] & Adama Dione [ρ]

Abstract- The main objective of the research being conducted is, not only to achieve the required soil engineering properties by mixing this product but also to consider the effect of this product of soils stabilization on fine particles contained in lateritic and typically clayey soils. This research work presents the efficiency of calcium Silicate as an additive in improving the engineering characteristics of laterite aggregate soil and clayey soils. Investigations will be done to evaluate the effectiveness of this soil stabilizer which involved the use of calcium Silicate ($CaSiO3$) formula fixed by (Ndiaye et al, 2022). As a chemical additive the percentage of the binder will be respectively 4 and 6%.

These two types of soils are expected to be stabilized and their effectiveness will be observed from the expected results only in terms of strength and consolidation by constant rate of strain parameters like recompression index (Cr) and compression index (Cc).

The results of the tests conducted in Oregon State University on laterite aggregate soil showed that the compression strength (UCS) gives a value of 1,4 MPa for SH85 treated samples against 1,5 MPa for Portland cement ones but with a minimum of strain, under alternating temperature conditions. However, this evolution is even more important on clay samples, reaching 1.01 MPa of stress for ''dry black clay'' against 0.44 MPa for the ''dried black clay'' as peaks. The alternating wet and dried conditions were crucial as well as the specimens sizes.

Keywords: soil stabilization, chemical additive, calcium silicate, unconfined compressive strength and consolidation by constant rate of strain.

I. Aim & Objective of the Work

The present work is aimed at assessing the effects of Calcium Silicate ($CaSiO3$) in soil stabilization.

- We will be conducting an unconfined compressive strength test (UCS) on the laterite aggregate treated either by $CaSiO3$ or by cement.
- We will also be conducting a Consolidation by constant rate of strain (CRS) test on the black clay treated samples, untreated red clay and untreated black clay. The strengths of soils and their compression parameters will be observed and compared.

To fulfill the aim of this study, the following objectives have been framed.

1. To procure the 6% treated black clay soil with $CaSiO3$.
2. To procure the 4% treated laterite with $CasiO3$ and the 4% treated laterite with cement samples.
3. To procure the untreated black clay and the untreated red clay samples.
4. To study the results in term of UCS for laterite samples or in term of consolidation by CRS for the procured clayey samples.
5. To compare the performance of these soils when stabilized with Calcium silicate with the same soils when stabilized with Portland-cement.

II. Litterature

The Ngoundiane lateritic gravel borrow is located in the western part of the Senegal-Mauritania basin. The latter is the largest basin (340,000 km2) on the passive margin of Africa's Atlantic coast. It covers 3/4 of the surface area of Senegal.

The western domain extends west from the 16° 30' W meridian to the slope of the continental slope, as the basement has not yet been reached by drilling. The Meso-Cenozoic sedimentary cover is estimated to be 8,000 m thick in Dakar and 10,000 m thick in Basse Casamance. The oldest known borehole deposits in southern Cape Verde date from the Bathonian to Callovian periods. On the Thiès plateau, the sedimentary series is masked by the fini-Neogene ferruginous cuirass, which extends northwards beneath Quaternary eolian deposits. This cuirass developed on the soils of the Thiès plateau after chemical alteration of the Eocene sediments (Flicoteaux, 1982; Ducasse et al, 1978).

(Latifi et al., 2015) have conducted a study on a treated tropical laterite soil with calcium-based powder stabilizer (commercial name Sh85 we studied as *$CaSiO3$*). A series of compressive strength tests was performed to determine the strength performance of the treated soil. The strength test results showed that the Sh85 stabilized laterite soil was roughly five times stronger than the untreated soil at the seven days of curing period.

III. Methodology Adopted

- Firstly, aggregate soil samples have been collected from Senegal 02 sites (Bambey and Thiadiaye) in

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order to examine the elemental composition and the morphological images (see appendix). From where the Bambey laterite was chosen specifically from Ngoundiane pit.

– Secondly, sieve analysis test has been performed to determine each type of soil that we brought at the Oregon state university, Civil and Construction engineering facility.
– Once the mixture and compaction test were performed on the **laterite sieved at 0/20** to find out the optimum moisture content (OMC) at **10.2%** and Maximum dry density (MDD) at **2.06 g/cm^3**, and with obtained OMC and MDD:

- A certain concentration of calcium silicate (CaSiO3) has been fixed, mixed and compacted with each soil sample using standard molders 100/150 mm or 3.75' / 4.375'.
- The percentile of Calcium silicate is fixed to 4% added in the laterite specimen and 6% added in the black clay specimen soil, as which the studies have shown earlier.
- The unconfined compressive strength has been performed to find the unconfined compressive strength (UCS) of the laterite soil and the black clay treated soil.
- The consolidation part of test has been performed to evaluate the rate of compression for the untreated or treated black clay specimens and the untreated finest particles of clay found in the laterite specimen.

– Finally, the results are compared for each type with cement additives at the same percentiles.

IV. Expected Outcomes

It is expected that these soils specimens are stabilized, and their engineering properties are enhanced using that chemical additive at the appropriate content.

V. Results in UCS of Laterite Specimens

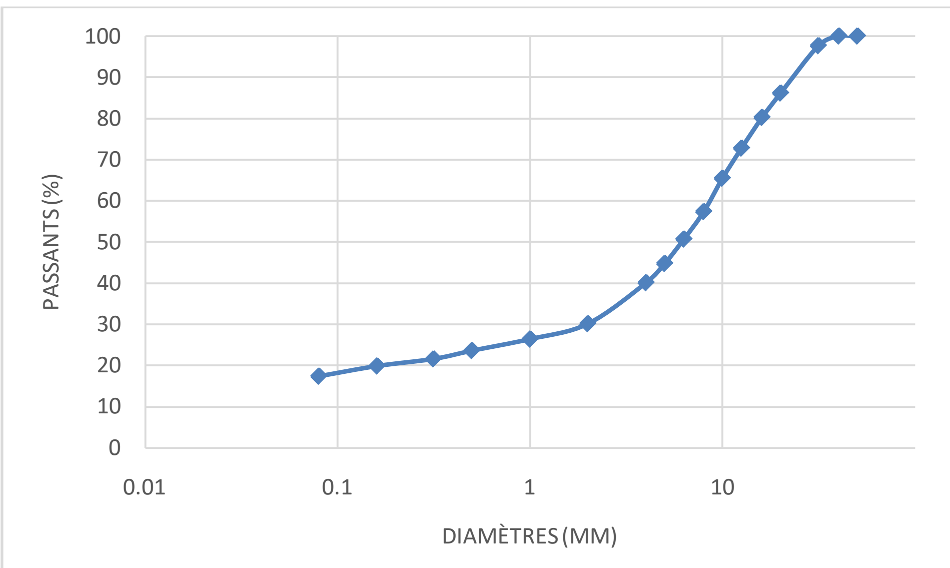

Figure 1: Particle size distribution curve of laterite

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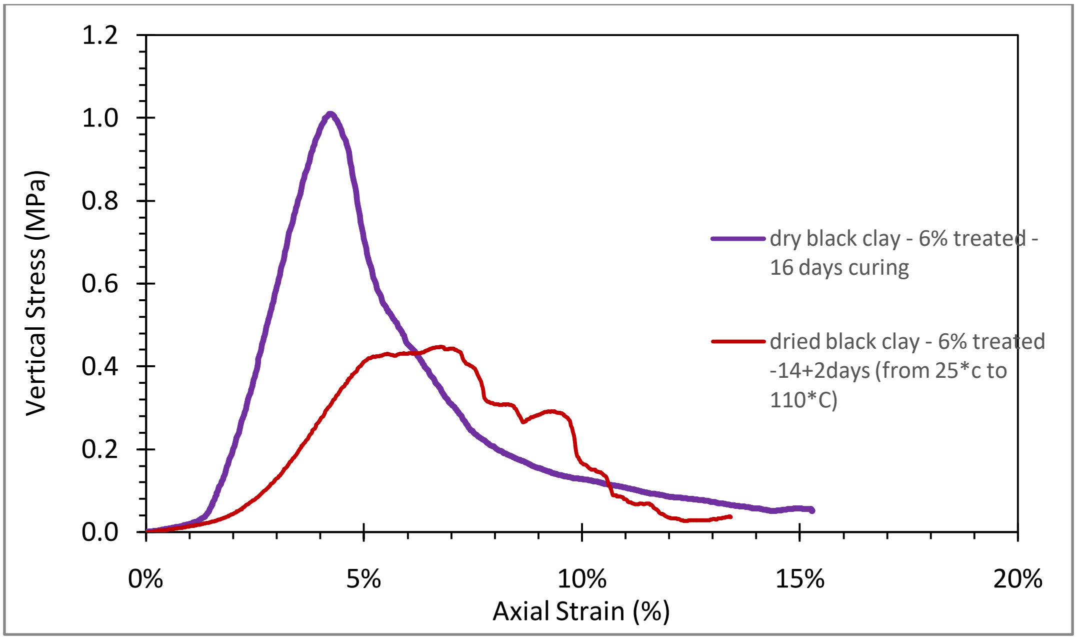


Figure 2: Evolution of the UCS of two (02) black clay specimens under different conditions

The analysis of the curve shows us a progressive evolution of the UCS of two (02) black clay specimens.

The ''dried black clay'' represents the specimen treated by 6% of CaSiO3 and after 14 days normal curing to which we added 2 days (24H in wet at 25*C and 24H in dry at 110*C).

The ''dry black clay'' curve represents the specimen treated by 6% of CaSiO3 and keeped in a dry conditions at 25*C during the same timing.

However, this evolution is even more important reaching 1.01 MPa of stress for ''dry black clay'' against 0.44 MPa for the ''dried black clay'' as peaks.

The black clay is a swelling material, consequently, its expansion in the presence of water weakens it and makes it unfit for construction (figure 2). The original swelling mechanisms of soils have been widely studied, but it is still difficult to establish a relationship between the progression of the issue and the time (Cisse and al., 2017).

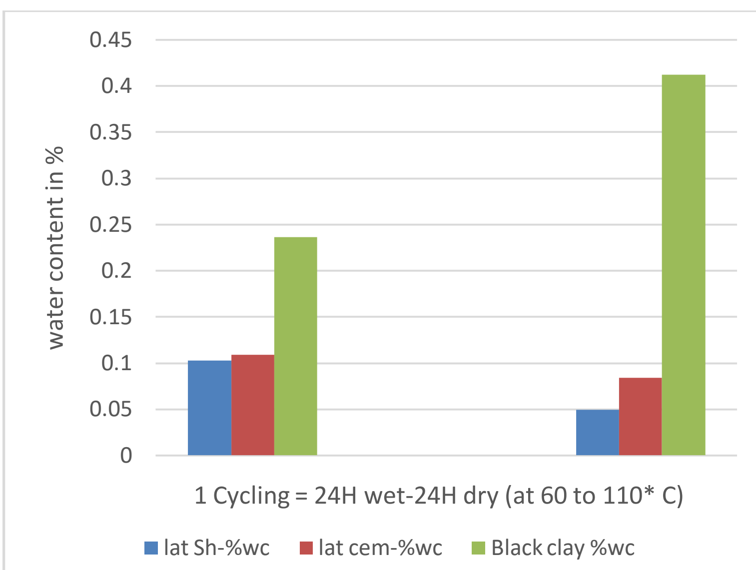


Figure 3: Water content per type of specimen (laterite 4% CaSiO3, laterite 4% cement and black clay 6% CaSiO3)

Alternating temperature between the wet environment at 25*C and the dried one at 110*C oven , during 2 cycles, showed the tendency of laterite samples treated with cement to absorb more water than those treated by calcium silicate (figure 3).

The black clay samples have showed much more absorbance even though they were treated at 6% with CaSiO3 and curing in that same process of alterning temperature.

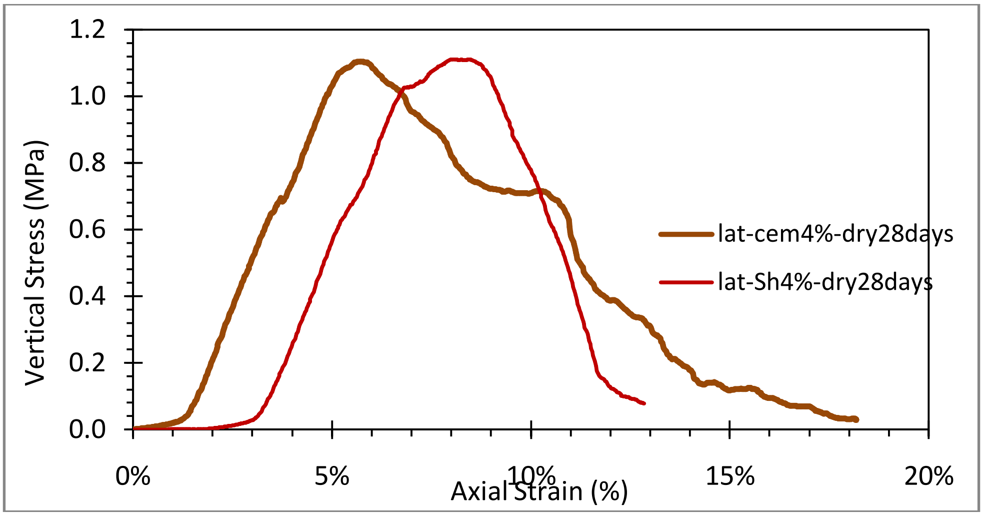


Figure 4: UCS of treated laterite samples after 28 days curing in dry and room conditions

Under room temperature (~25*C) and dry storage conditions, the laterite samples were crushed at 28 days, under these conditions (figure 4), the laterite treated with 4% cement (lat-cem4%-dry28days) reached a peak of 1.11 MPa with an elongation level of about 6% before collapsing to 18% elongation.

However, the calcium silicate-treated laterite (lat-sh4%-dry28days) in the same conditions, despite reaching 1.10 MPa with 8% elongation, only collapses to about 13% (figure 4).

But, this does not tell us much about the behavior in the natural environment with 3-4 months of rainfall out of 12.

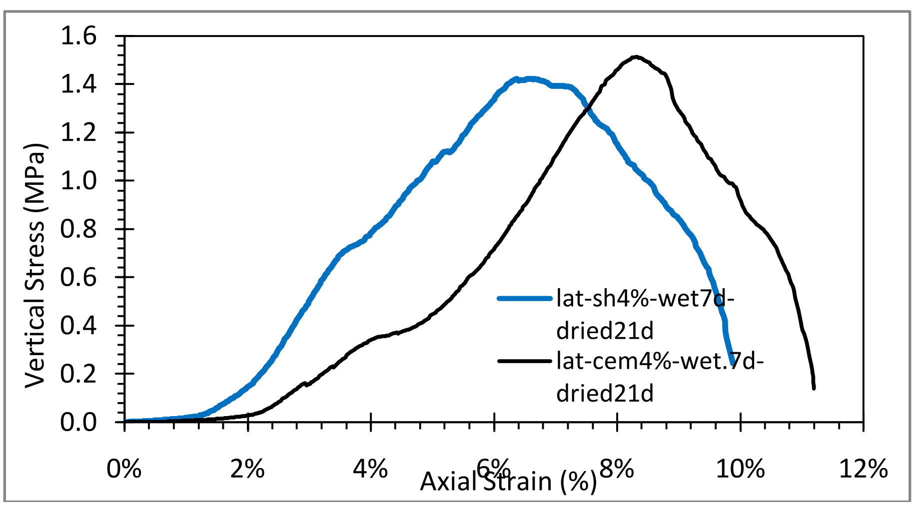


Figure 5: UCS of treated laterite samples after 28 days curing alterning a 24H storage in wet or a dried conditions

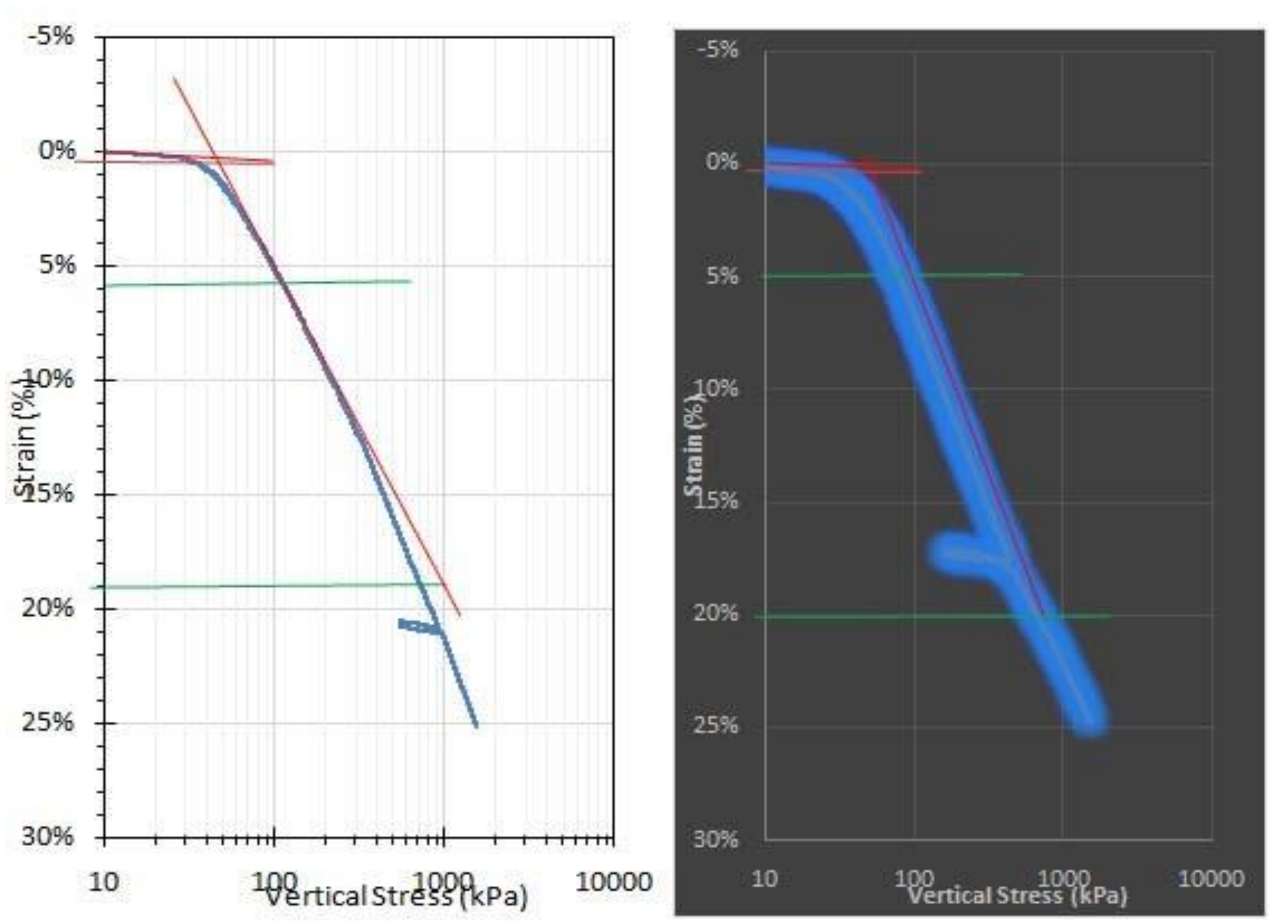
It was found that the **CaSiO3-treated laterite** reached its peak faster with a minimum elongation of about **6%** against **8.5%** for the cement-treated laterite, it collapsed well before the cement-treated laterite at about **10%** against **11%.**

Some complementary results in terms of consolidation rate for the untreated and the treated black clay samples once saturated can be used to support this thesis further.

VI. Results with a CRS of Consolidation for Treated and Untreated Clay Specimens

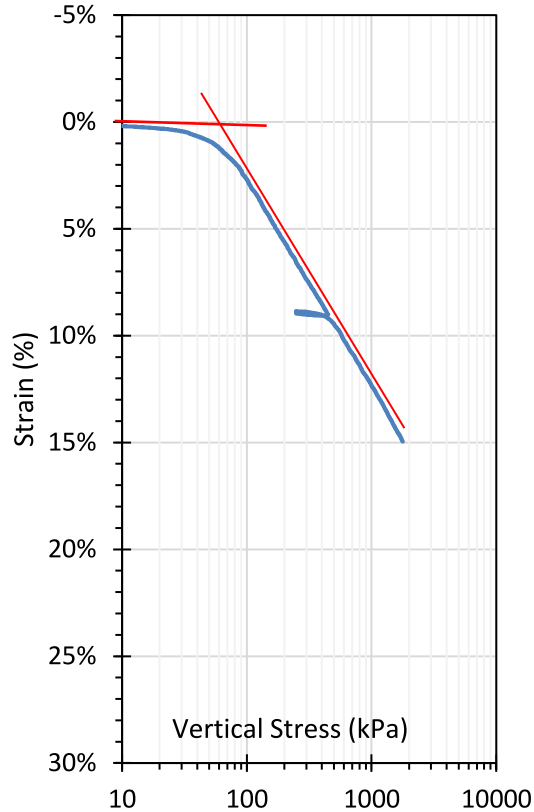
Table 1: Classification of Ngoundiane laterite

Characteristics	Latérite of Ngoundiane		Foundation Specifications	Base Layer Specifications
Sieve analysis	% Ø < 0,008 mm	17,33	-	-
	% Ø < 2 mm	30,15	-	-
Limits of Atterberg	W_l (%)	43	< 40	< 35
	I_p (%)	22	< 20	< 15
GTR Classification	B6			
USCS Classification	GC			



Curve (a): untreated black Cc=0.14 and Cr=0.005 *Curve (b):* treated black Cc=0.0875 and Cr=0.0025

Figure 6: Consolidation curves by oedometer of treated and untreated clays



Curve (c): untreated fine laterite Cr=0.0025 and Cc=0.100

***Figure 6** shows the strain, versus log stress, and the curve obtained from the oedometer test for both untreated and treated clay specimens of 6% CaSiO3 treated sample cured for 28 days.*

a) The values for untreated black clay of compression index, Cc and recompression index, Cr are 0.14 and 0.005, respectively.
b) While the Cc and Cr values for treated samples are 0.0875 and 0.0025, respectively.
c) Finally, the Cc and Cr values for untreated brown fine laterite specimen are 0.100 and 0.0025, respectively.

VII. Conclusion

Firstly, it was important to run the same UCS test carried out on samples treated with either cement or calcium silicate had to be carried out under alternating conditions of extreme temperature (heat transferred by a bituminous coating of about **110*C** for 24H) and relative humidity absorbance by capillary lift **at 25*C**.

It's shown that the specimen treated by cement absorbed much more water than the one treated by silicate.

Secondly, running the consolidation process, has shown that the compression index, Cc value of the treated black clay compared to the untreated black clay decreases by 0.0525, has indicated a significant improvement of the resistance to compressibility due to CaSiO3 treatment. Also, the water content percentile decreased from 47% to 44% after the consolidation process of the 02 specimens of black clay.

However, black clay has always been rejected in Senegal as a soil material that can support any construction. This study of its behavior in an environment of alternating heat and water makes it fragile and confirms its unsuitability for any use as a support soil or subgrade without other specific treatment.

Finally, the cement-treated sample was found to absorb much more water than the calcium silicate-treated sample. This would make it less resistant over time.

Acknowledgements

We would like to express our sincere gratitude to my hosting Professor, Matt Evans and his research assistant, Ehsan Yazdani for their invaluable guidance and support throughout the research process at Oregon State University (OSU). We also want to thank the Ageroute Senegalese Agency for their financial support, as well as the research technicians and students who participated to this work at the Merryfield 108 laboratory of the Civil and Construction Engineering department (CCE) at the OSU for their assistance in finding the necessary research materials. Finally, we are grateful to

Pr John Selker, who initiated and offered his 6-month sponsorship, as well as my mentor, Pr Makhaly Ba for his precious guidance and all the research participants who generously gave their time and effort to this project.

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Appendice in Terms of Elemental Composition for Laterites

Calcium Silicate as a chemical additive is found that it will act as a good compaction aid between the soil particles, and it is very soluble in water. The images obtained by scanning electron microscopy (SEM) show the elemental composition of the most representative samples based on the percentile of atoms:

sample 1_site1_laterite(1)

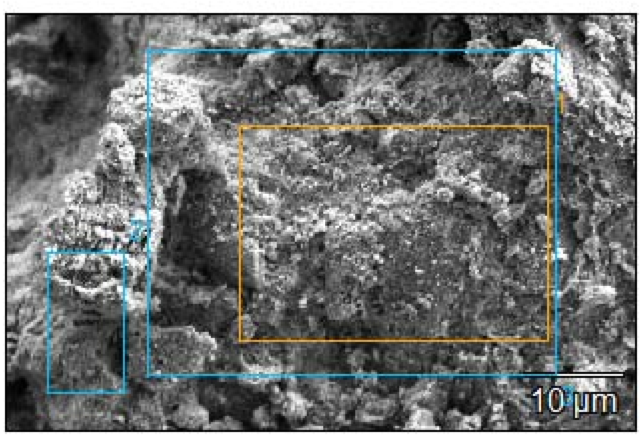


Figure 7: Image of the sample 1 as raw laterite from the Thiadiaye site

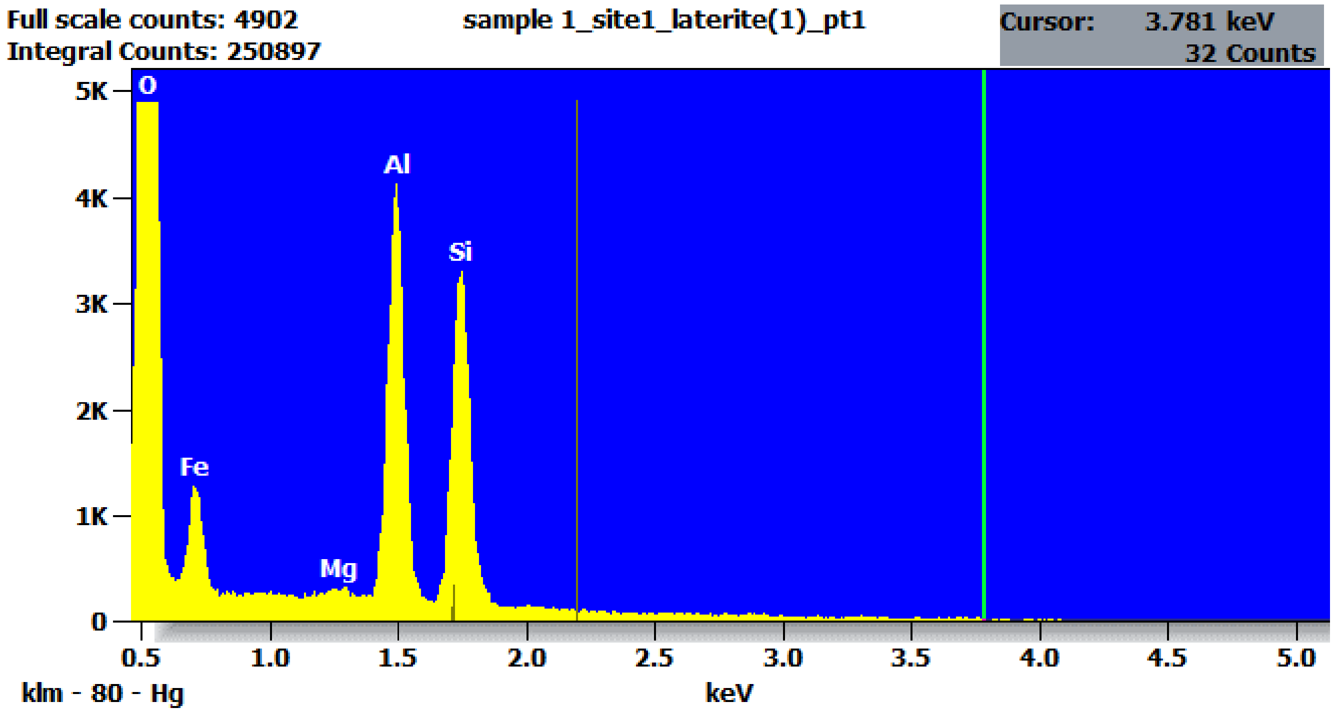


Figure 8: Elemental composition of the raw laterite from Thiadiaye site 1

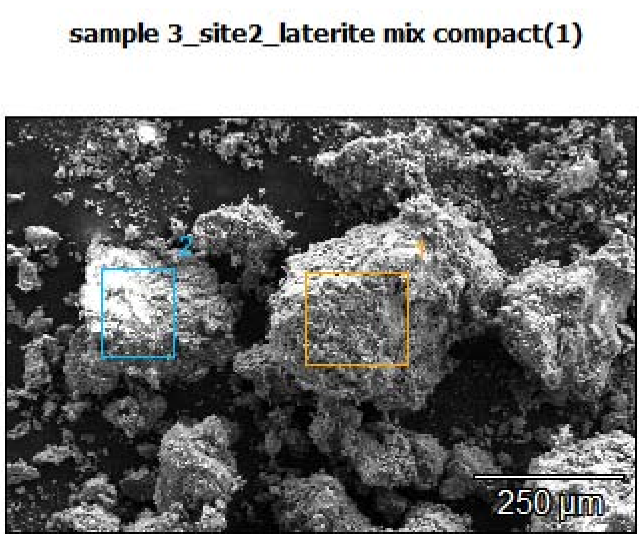


Figure 9: Image of the sample 3 compacted mix laterite from the Thiadiaye

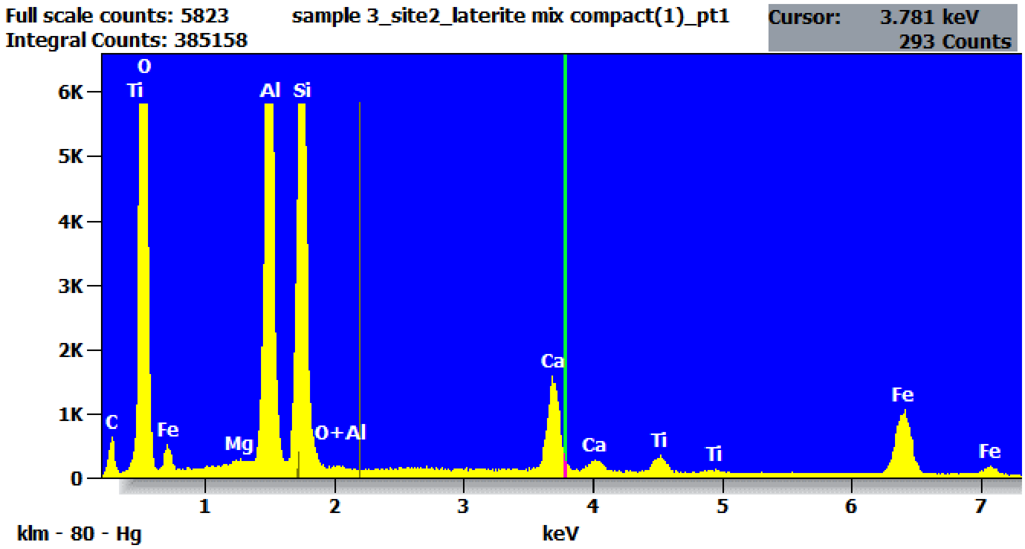
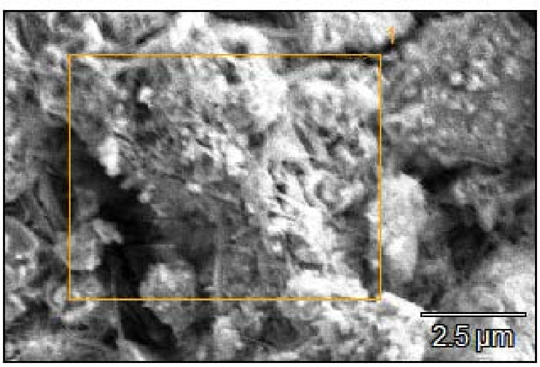


Figure 10: Elemental composition of the sample 3 compacted mix laterite from Thiadiaye

sample 5_site1_laterite mix3 (5)

sample 5_site1_laterite mix3 (1)



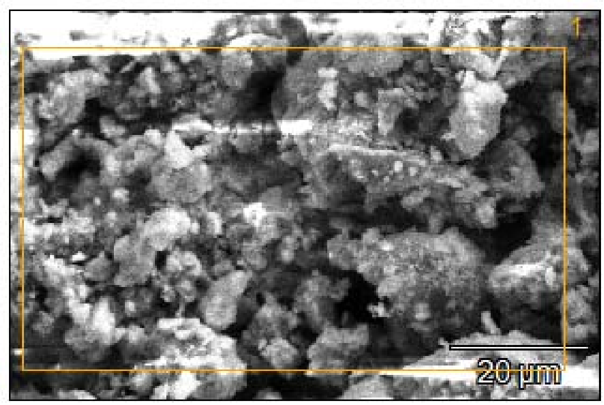


Figure 11: 2 images of the sample 5 of compacted mix laterite from bambey site

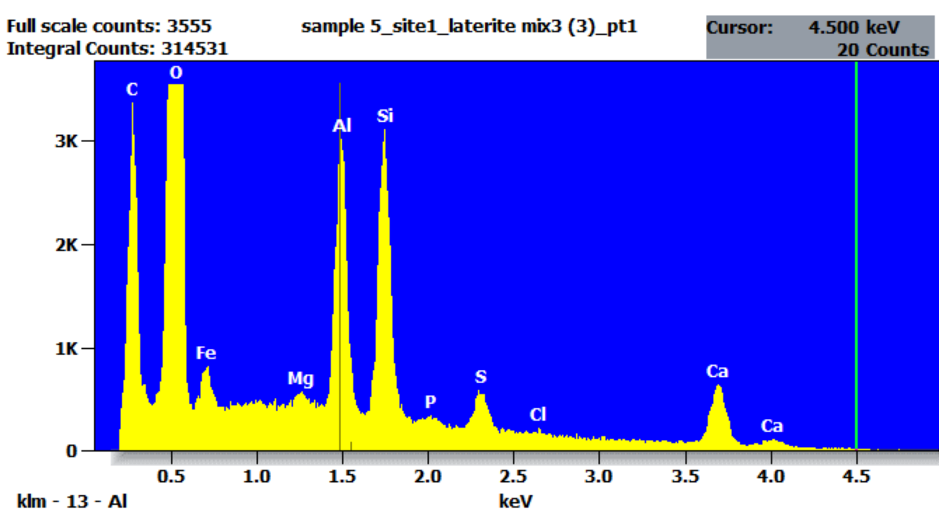


Figure 12: Elemental composition of the sample 5 compacted mix laterite from Bambey

sample 7_site1_binder (2)

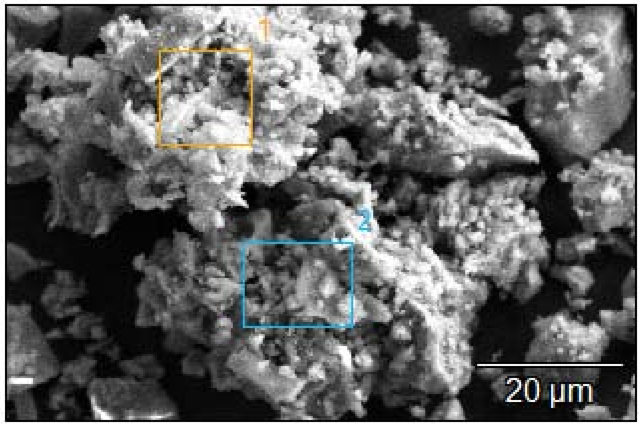


Figure 13: Image of the pure binder in powder as sample 7

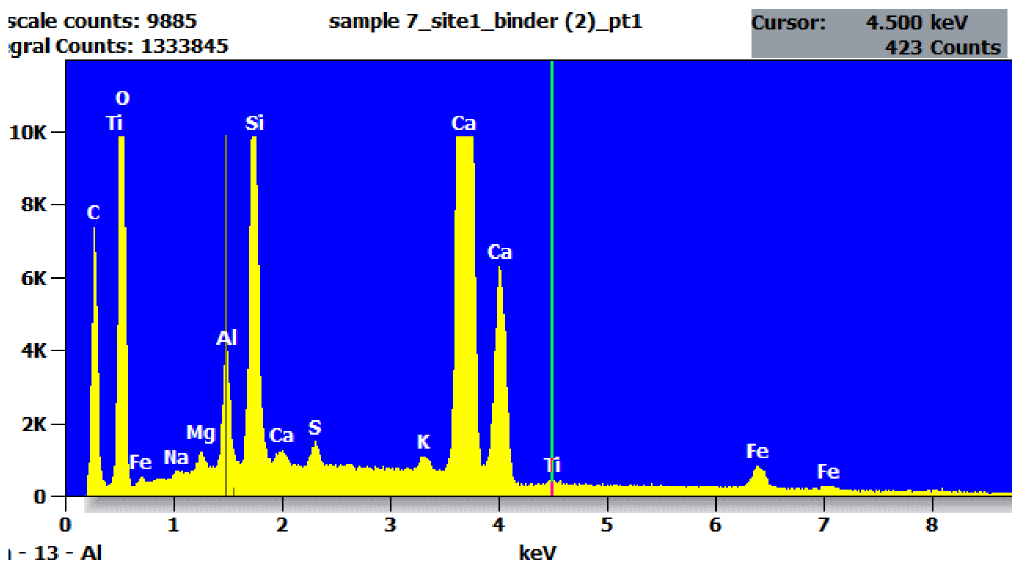


Figure 14: Elemental composition of the pure binder as sample 7

Tableau 1: Percentile of atoms in the pure binder as sample 7

	C	*O*	*Na*	*Mg*	*Al*	*Si*	*S*	*Cl*	*K*	*Ca*	*Ti*	*Fe*	*Cu*
sample 7_site1 _binder (2)_pt1	3.75	**30.40**	0.11	0.24	1.37	**5.71**	0.46		0.40	**54.40**	0.37	2.80	
sample 7_site1 _binder (2)_pt2	2.23	**39.19**		0.26	2.29	**3.76**	0.38	0.21	0.13	**46.78**	0.34	4.16	0.29

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 23 Issue 2 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Understanding the Factors Influencing Pedestrian Crossing Behavior and its Effect on Road Performance in Port Harcourt City

By Captain Gospel Otto, Chinonyerem B. Onyekaba & Peace Ifesinachi Okafor

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Abstract- In Port Harcourt city, the design of roads do not adequately accommodate pedestrians, leading to ongoing conflicts as motorists and pedestrians try to share the limited spaces on roads. However response time to control vehicles in Port Harcourt is minimal making pedestrian crossing behavior at intersections and midblock crossings significantly more complicated. These problems created the need for additional research into pedestrian crossing behavior at crucial roads in Port Harcourt. This study's primary goal is to discover the factors influencing pedestrian crossing behavior at signalized intersections and midblock crossings and its effect regarding road performance. Considering this reason, 520 questionnaires were developed and shared among road users (drivers and pedestrians) to determine the factors influencing pedestrian crossing behavior. Again, traffic survey was conducted using a camcorder, questionnaires were analyzed using the Likert scale to identify elements that may be critical. In addition, the level of service (LOS) was used to assess the effect on congestion.

Keywords: pedestrian crossing behavior, congestion, signalized intersection, midblock crossing.

GJRE-E Classification: DDC: 388.312

UNDERSTANDINGTHEFACTORSINFLUENCINGPEDESTRIANCROSSINGBEHAVIORANDITSEFFECTONROADPERFORMANCEINPORTHARCOURTCITY

Strictly as per the compliance and regulations of:

Understanding the Factors Influencing Pedestrian Crossing Behavior and its Effect on Road Performance in Port Harcourt City

Captain Gospel Otto [α], Chinonyerem B. Onyekaba [σ] & Peace Ifesinachi Okafor [ρ]

Abstract- In Port Harcourt city, the design of roads do not adequately accommodate pedestrians, leading to ongoing conflicts as motorists and pedestrians try to share the limited spaces on roads. However response time to control vehicles in Port Harcourt is minimal making pedestrian crossing behavior at intersections and midblock crossings significantly more complicated. These problems created the need for additional research into pedestrian crossing behavior at crucial roads in Port Harcourt. This study's primary goal is to discover the factors influencing pedestrian crossing behavior at signalized intersections and midblock crossings and its effect regarding road performance. Considering this reason, 520 questionnaires were developed and shared among road users (drivers and pedestrians) to determine the factors influencing pedestrian crossing behavior. Again, traffic survey was conducted using a camcorder, questionnaires were analyzed using the Likert scale to identify elements that may be critical. In addition, the level of service (LOS) was used to assess the effect on congestion. This study revealed that age, lack of crossing facilities, location of crossing facility, lack of educational awareness which had a mean value between 3.5-5.0 are considered critical factors influencing pedestrian crossing attitude. Gender with a mean value at 2.304 is not a critical factor, while the use of mobile phone which had a 2.626 mean value is a neutral factor. The volume to capacity ratio (V/C) value of the road segments ranging from 0.72 to 0.97 is shown by the LOS which means smooth to low traffic flow with an affected speed and high vehicular density. It is a true reflection of the roads in Port Harcourt. It was observed that at major roads with signalized intersection that 73.19% of pedestrians conform to signal indications at peak hours.

Keywords: pedestrian crossing behavior, congestion, signalized intersection, midblock crossing.

I. Introduction

Vehicles have traditionally been the focus of traffic research on roads in developing countries. In constructing roads, considerations for pedestrian comfort, convenience, and safety are usually not given priority in Nigeria. Some difficulties experienced are modeling of pedestrian behavior in Nigeria. So many complications are involved in trying to identify the characteristics that influence pedestrian behavior. For densely populated cities like Port Harcourt, pedestrian traffic at unsignalized crossroads, signalized crossroads and midblock crossings are very common with little or no provision for safe pedestrian crossing. For some intersections crosswalks where people and cars share the same road area, signal phases have been provided to regulate this interaction in Port Harcourt, collisions between pedestrians and vehicles still happen as a result of pedestrian disobedience with traffic signals. However, pedestrian non-conformance with traffic signals causes pedestrian-vehicle interactions. Poor-quality traffic management, high traffic volume, and extended cycle times (waiting time) are some of the causes of pedestrian non-conformance with traffic signals. There are numerous other variables that influence how pedestrians' respond to signals and interactions not included in previous research.

Analyses of pedestrian behaviour have significant consequences for transportation systems, as well as for urban planning principles and methods of design (Laxman et al. 2010). Many research studies according to Laxman *et al.* (2010) have focused on the characteristics of pedestrians and the features of pedestrian movement in sidewalks and walkways only. A hand full of the studies have looked at the pedestrian flow characteristics at signalized crossings in order to develop pedestrian models for evaluating walking facilities. There have been few studies that looked at pedestrian disobedience at signalized crossings in order to develop pedestrian speed flow relationships (Zhou et al. (2011) and delay models (Li et al. (2013); Marisamynathan & Vedagiri (2013)). For the purpose of increasing pedestrian safety at signalized crossings, pedestrian crossing habits were investigated, and factors affecting those behaviors were found (Ren *et al.* 2011).

Numerous characteristics have been overlooked in previous studies on pedestrian crossing behavior which is being found in the aforementioned investigations. A study that considers effective elements like pedestrian features, behavior, and traffic characteristics has not yet been done to analyze pedestrian crossing speed variation and pedestrian-vehicle interaction in crosswalks of signalized crossings. Here in Nigeria, studies of this kind are lacking. Thus, this study seeks to identify the factors influencing pedestrian crossing behaviors in Port Harcourt through a structured questionnaire method.

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According to the WHO (2013), 22% of all fatalities which results from traffic accidents involve pedestrians, with more than 270,000 fatalities annually. According to Naci *et al.* (2009) and ACI-ISTAT (2013), pedestrians hit by motor vehicles account for the most significant percentage of road user fatalities, while the majority of injuries take place in urban areas (Bella & Ferrante 2021). For a variety of reasons, a pedestrian might cross the street; some might be hurried and disobey the rules, which occasionally lead to traffic jams and accidents on the road. Drivers must moderate their speed to prevent accidents due to pedestrians' frequent road crossing behavior. It is well known that the driver's inability to yield to the pedestrian cause collision between pedestrians and vehicles. Lowering the vehicle's speed improves pedestrian safety. Random pedestrian crossings of the road force drivers to halt often, which congests the traffic. The effects of unrestrained pedestrian movement on road accidents have been discussed by several scholars [Bichicchi et al. (2017); Gitelman et al. (2017); Killi & Vedagiri, (2014)].

Traffic congestion has had significant negative social, economic, and environmental effects of recent. The economic effects of traffic congestion in developing nations have been the subject of numerous academic studies. Otto and Awarri (2022), Otto and Ogboda (2022), and Otto and Simon (2022) all discussed on achieving sustainability in the transportation and traffic engineering industry when discussing road traffic congestion in Port Harcourt city. A thorough analysis of the factors contributing to traffic congestion in Port Harcourt City is still lacking from the body of knowledge. This study is the first of its kind to address pedestrian crossing behavior in the city of Port Harcourt, in-order to better and more thoroughly formulate policies for a sustainable urban transportation system, this study filled a research gap by identifying the variables influencing pedestrian crossing behavior and road user safety along Port Harcourt's major roads. It also evaluated the impact of pedestrian behavior on traffic congestion along East-West Road, Port Harcourt-Aba Expressway, Ikwerri road, Ada George Road and Rumuokwuta-Choba Road since these roads are the most busiest in the city.

II. Materials and Method

a) Materials

Recording sheets, a pencil, a measuring tape, camcorder, and tripods were the materials utilized in this study.

b) Method

In order to ascertain the pedestrian crossing behavior along these major routes, a thorough field survey was conducted. The statistics were gathered utilizing camcorder in various traffic intersections and midblock crossings over various time intervals on weekdays (7am to 9am as the morning peak hour and 5pm to 7pm as the evening peak hour). The camcorder included data on pedestrian crossing frequency, pedestrian appearance (gender and age group), pedestrian crossing behavior (walking or running), pedestrian crossing locations (using the crosswalk or not), pedestrian crossing phase time (whether pedestrians cross during green phase or not), and pedestrian-vehicle interactions in crosswalks. Also, a well-developed questionnaire was distributed to 500 road users (pedestrians) along these major roads (East-West Road, Port Harcourt-Aba Expressway, Ikwerri road, Ada George Road and Rumuokwuta-Choba Road) to ascertain the factors influencing pedestrian crossing behavior. The responses were then analyzed statistically to determine the factors that are critical using the Likert Scale.

Rensis Likert, an American psychologist, developed the Likert scale in 1932. Likert saw that there was a need to measure people's opinions concerning diverse subjects, whereas scholars in the 1930s used closed ended questions and aims to make their research valid. In order to quantify people's thoughts and attitudes, Likert created the Likert scale, a psychometric scale (Sack, 2021). The Likert scale makes the notion that attitudes or views can be measured. The five-point Likert scale, which ranges from strongly disagree to strongly agree, is the one that is most frequently used. Each response receives a score, sometimes known as a number, ranging from 1 to 5 (McLeod, 2019). For example, "Strongly Disagree" may receive a score of 1, "Disagree" could receive a 2, "Neutral/Undecided" could receive a 3, "Agree" could receive a 4, and "Strongly Agree" could receive a 5.

In this study, the Likert scale as stated above was adopted. Respondents responded to the statements/questions by indicating their opinion based on the 5-point Likert scale of strongly disagree to strongly agree. Using the logic that a mean score of 3 on the Likert scale reflects a neutral, a mean score of less than 3 represents a non-critical effect, and a mean score of greater than 3 represents a critical effect was then calculated. The Likert scale mean score has the following interpretation ranges in this study: 1.0-2.4 (not critical), 2.5-3.4 (neutral), and 3.5-5.0 (critical). The mean score was determined using Equation 1.

$$Mean\ Score = \sum f_i x \div Number\ of\ Respondants \quad 1$$

Also, the level of service (LOS) of these roads was determined to assess the effect of pedestrian crossing behavior at midblock locations. When evaluating a transportation facility from the perspective of a traveler, LOS method is adopted. Due to its simplicity, LOS has become fairly common in practice. The volume to capacity (V/C) ratio, maximum service flow rate, vehicle speed, and other traffic parameters can all be used to determine LOS (Wang *et al* 2018).

The ratio of vehicles passing a point in an hour (V) to the maximum number of vehicles that can pass through that place, has been used in this study. LOS performance is assessed using the V/C ratio. The road segments where traffic mitigation measures are required can be identified by this indicator and made known to transportation operators. There are six service levels listed, and each is assigned a letter designation from A to F (Table 1) (Bhuyan & Nayak 2013). The best operational conditions are indicated by LOS A, and the worst operational conditions are indicated by LOS F. Utilizing information from the traffic volume survey, the average LOS of the road segments have been determined. The LOS of each chosen traffic segment was determined using equation 2 in order to evaluate the effects of pedestrian crossing behavior on traffic flow.

$$LOS = \frac{Volume}{Capacity} \quad (2)$$

Table 1: Level of Service Description (Zhou *et al* 1997)

V/C	LOS Class	Traffic State
0 - 0.6	A	Free flow
0.61 - 0.70	B	Stable traffic flow, speed is unaffected
0.71 - 0.80	C	Stable traffic flow, speed is affected
0.81 - 0.90	D	Stable flow with high vehicle density
0.91 - 1.0	E	Low speed
>1.0	F	Breakdown flow

III. Results and Discussions

a) Pedestrian Crossing Statistics at Midblock Crossing

The average pedestrian crossing statistics at midblock crossing observed along the major roads considered in this study are presented in Table 2.

Table 2: Pedestrian Crossing Statistics at Midblock Crossing

Observed Parameters		No. of Observed Pedestrians	Percentage (%)
Gender	Male	422	67
	Female	208	33
Age group	Children	92	14.6
	Adult	452	71.75
	Elderly	86	13.65
Crossing type	Running	432	68.57
	Walking	198	31.43

According to the statistics a total of 630 pedestrians were observed crossing at midblock crossings as shown in Table 2. More men (67%) than women (33%) walk during peak hours, and adult pedestrians make up the largest part (71.75%) as compared to children (14.6%) and the elderly (13.65%). This is in line with a study carried out by Olawole & Olayiwola (2018) and Marisamynathan & Perumal (2014). Also, 68.57% of pedestrians crossing at midblock prefer to run when crossing rather than walk (31.43%). This is because of the lack of crossing facilities which prompts the pedestrians to use the observed vehicle gaps as the safest time to cross. In a study carried out by Marisamynathan & Perumal (2014), 80.26% of pedestrian crossings walk because pedestrian crossing facilities are provided. From observation factors that make pedestrians to run while crossing include lack of crossing facilities, lack of road signs, improper educational awareness of road usage by drivers/pedestrians and behavior of drivers who do not consider pedestrians and other road users while driving. Also, most drivers in Nigeria are inexperienced, unqualified, and do not obey traffic/road rules. This has led to a lot of pedestrian vehicle accident which in most cases are not properly recorded in this part of the world.

b) Pedestrian Crossing Statistics at Signalized Intersections

The average pedestrian crossing statistics of 526 pedestrians at signalized intersection observed along the major roads considered in this study are presented in Table 3.

Table 3: Pedestrian Crossing Behavior at Signalized Intersections

Observed Parameters		No. of Observed Pedestrians	Percentage (%)
Crosswalk Utilization	Yes	334	63.5
	No	192	36.5
Compliance	Conformance with signal phase	385	73.19
	Non-Conformance with signal phase	141	26.81

The crosswalk is only used by 63.5% of pedestrians, according to the research. The 73.19% conformance rate for pedestrians with traffic signals shows that conformance is more common at peak hours in signalized intersections here in Port Harcourt. It is clearly seen that the conformance at signalized intersection is higher in Port Harcourt as compared to Mumbai in India according to Marisamynathan & Perumal (2014).

c) Factors Influencing Pedestrian Crossing Behavior along Major Roads in Port Harcourt

The factors influencing pedestrian crossing behavior in Port Harcourt were identified from a questionnaire survey of road users including drivers and pedestrians. This is shown in Table 4. From the survey results, age, gender, lack of crossing facilities, use of mobile phones, location of crossing facility, educational awareness are the major factors responsible for pedestrian crossing behavior. Using the Likert scale to analyze the responses of 500 respondence, age, lack of crossing facilities, location of crossing facility, educational awareness are critical factors while gender is not critical and the use of mobile phone is neutral. This result gives a true reflection of Port Harcourt roads. Major roads in Port Harcourt do not have pedestrian crossing facilities. In some cases where pedestrian crossing facilities are available, they are located at places where crossing is highly minimal. Example of such road is the Port Harcourt-Aba Expressway. In terms of age, older people have a better crossing behavior than young people.

Table 4: Factors Influencing Pedestrian Crossing Behavior Along Major Roads in Port Harcourt

Statement	Strongly Disagree (1)		Disagree (2)		Neutral (3)		Agree (4)		Strongly Agree (5)		Total Score	Mean Score	Remarks
	f	%	f	%	f	%	F	%	f	%			
Do you agree that age Influences Pedestrian crossing behaviour?	30	6	42	8.4	11	2.2	166	33.2	251	50.2	2066	4.132	Critical
Do you agree that gender influences pedestrian crossing behaviour?	145	29	173	34.6	99	19.8	51	10.2	32	6.4	1152	2.304	Not Critical
Do you agree that Lack of crossing facilities influences pedestrians crossing behaviour?	21	4.2	13	2.6	31	6.2	153	30.6	282	56.4	2162	4.324	Critical
Do you agree that the use of mobile phones influences pedestrian crossing behaviour?	121	24.2	106	21.2	161	32.2	63	12.6	49	9.8	1313	2.626	Neutral
Do you agree that the location of crossing facilities influences pedestrian crossing behaviour?	9	1.8	31	6.2	61	12.2	78	15.6	321	64.2	2171	4.342	Critical
Do you agree that education/awareness influences pedestrian crossing behaviour?	14	2.8	41	8.2	7	1.4	150	30	288	57.6	2157	4.314	Critical

d) Level of Service (LOS) of Road Segments along the Selected Roads

The results of the level of service of the road segments are presented in Table 5.

Table 5: Level of Service of Road Segments

Road	Segment	V/C	LOS
East-West Road	Rumuodara	0.90	D
	Rumuosi	0.96	E
	Alakahia	0.85	D
	Choba	0.95	E
Port Harcourt-Aba Expressway	Leventis	0.88	D
	Government Craft Centre	0.72	C
	St Johns	0.91	E
	Pleasure Park	0.74	C
	Air Force	0.92	E
Ikwerre Road	Mile 3 Market	0.97	E
	Nkpolu- Oruwurokwo	0.91	E
	Rumueperikom/Kala	0.82	D
	Rumueme	0.81	D
	Rumuigbo	0.77	C

Ada George Road	Agip	0.91	E
	Chinda	0.86	D
	Open Door	0.84	D
	Gateway	0.88	D
	Okilton	0.90	D
Rumuokwuta-Choba Road	GGSS Rumuokwuta	0.96	E
	NTA	0.91	E
	Ozuoba	0.93	E
	Choba	0.96	E

This study has utilized the LOS for the assessment of the impact of pedestrian crossing behavior. The LOS in Table 5 shows the V/C value of the road segments ranging from 0.72 to 0.97 which means smooth to low traffic flow with an affected speed and high vehicular density. This is a true reflection of the roads in Port Harcourt. However, at Rumuigbo, Pleasure Park and Government Craft Centre segments along Ikwerre road and Port Harcourt-Aba Expressway Road respectively, the speed are observed to be higher.

IV. Conclusion

The study identified the factors affecting pedestrian crossing behavior and has used LOS to illustrate how pedestrian crossing behavior affects the traffic flow characteristics of roadways in Port Harcourt City. This study found that age, gender, lack of crossing facilities, use of mobile phones, location of crossing facility, educational awareness are the major factors responsible for pedestrian crossing behavior. It has also been determined through analysis that more people cross the street during rush hours, which causes significant traffic congestion at the selected road segments as a result of no crossing facilities especially at midblock crossings. Also, at signalized intersections, the conformance rate of 73.19% shows that pedestrians here in Port Harcourt can obey traffic rules if the infrastructural systems needed are provided which is better when compared to the study of Mumbai in India according to Marisamynathan & Perumal (2014).

V. Recommendation

The following recommendations are put forward to improve pedestrian crossing behavior and traffic flow along roadways in Port Harcourt.

i. The government should carryout a proper traffic survey along major roads in Port Harcourt and provide crossing facilities at relevant locations.
ii. The government should carryout continuous educational awareness campaigns which will help road users to be acquainted with road signs, signals and regulations. This should start from the nursery school level.
iii. Data regarding road accident and pedestrian behavior are lacking in this part of the world. Hence, government should help in making such information available.

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Career Credibility Reputation

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> The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Associate membership can later be promoted to Fellow Membership. Associates are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Associate Members.

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Associate	Fellow	Research Group	Basic
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Certificate, LoR and Momento **2** discounted publishing/year **Gradation** of Research **10** research contacts/day **1 GB** Cloud Storage **GJ** Community Access	**Certificate,** LoR and Momento **Unlimited** discounted publishing/year **Gradation** of Research **Unlimited** research contacts/day **5 GB** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**Certificates,** LoRs and Momentos **Unlimited** free publishing/year **Gradation** of Research **Unlimited** research contacts/day **Unlimited** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**GJ** Community Access

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4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
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2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

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7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

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Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

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- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

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Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

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Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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ISSN 9755861