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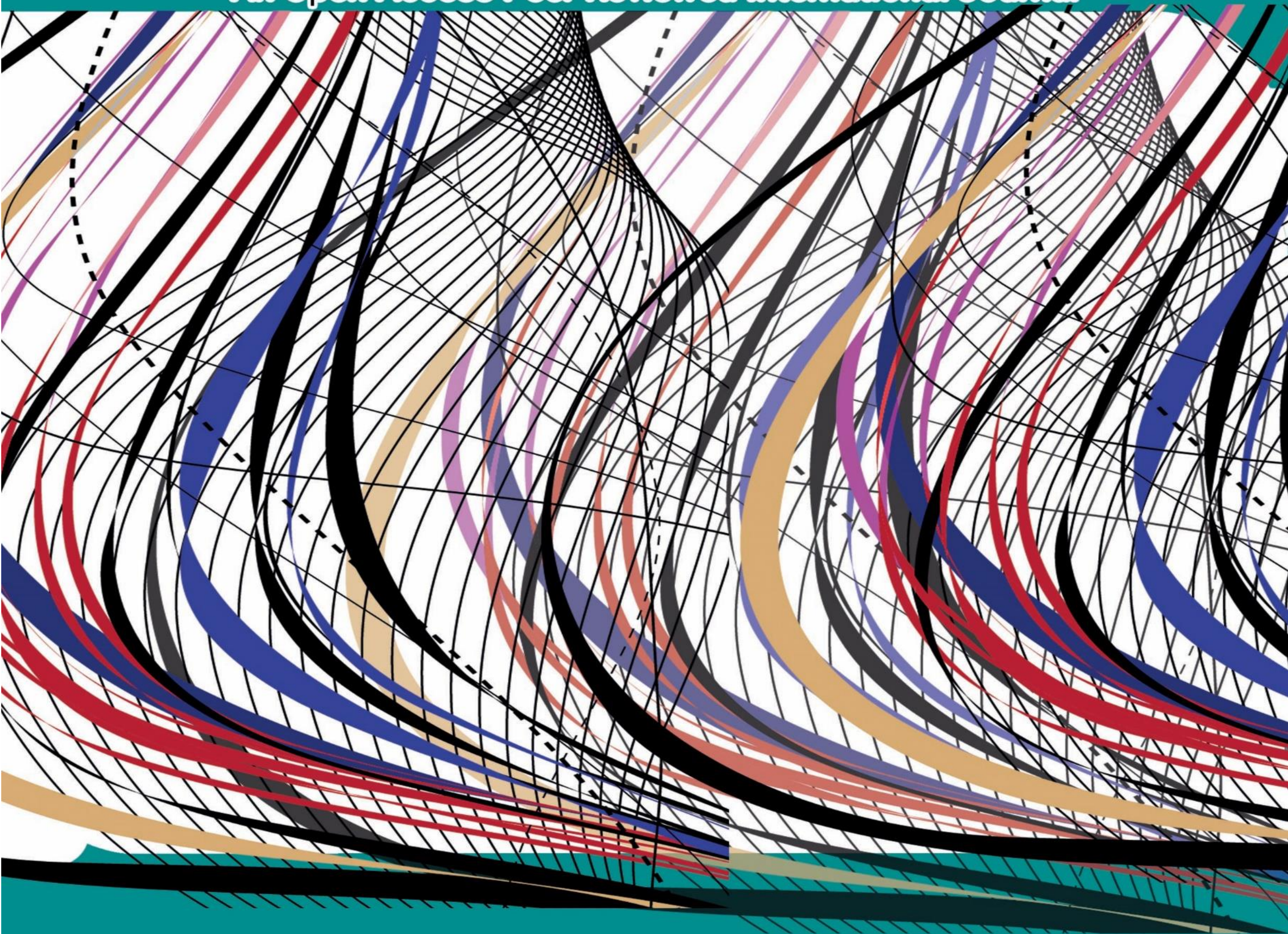

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Data Centre Network Optimization

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***Abstract*— Technology has advanced quite quickly in recent years, and IT and telecom infrastructure is constantly growing. Due to an increased importance and emphasis of cloud computing many growing and emerging enterprises have shifted their computing needs and wants ultimately to the cloud, which leads to increase in inter-server data trafficking and also the bandwidth required for Data Centre Networking (DCCN). Actually this multi-tier hierarchical architecture used in modern data centres is based on traditional Ethernet/fabric switches. Researchers goal was to improve the data centre communication network design such that the majority of its problems can be solved while still using the existing network infrastructure and with lower capital expenditures. This is achieved through the deployment of OpenFlow (OF) switches and the Microelectromechanical Systems (MEMS) based all Optical Switching (MAOS). This will be beneficial in decreasing network latency, power consumption, and CAPEX costs in addition to helping with scalability concerns, traffic management, and congestion control. Additionally, by implementing new virtualization techniques, we may enhance DCCN's resource consumption and cable problems. In order to address data centre challenges, the researcher came up with an entirely new novel flat data centre coordination network architecture which is named as "Hybrid Flow based Packet filtering" (HFPFMAOS), forwarding, and MEMS which is entirely based on optical switching, and will be finally controlled by Software Defined Network (SDN) controller.*

***Keywords*— Data Centre, Network Optimization, Software defined Networking, OpenFlow**

I. INTRODUCTION

1.1 Background

Data Centre is specialized building that houses various IT resources, such as servers, data storage systems, and networking and communication devices. Data centres have become increasingly important in IT and data networks over the last few years as a result of the explosive expansion of information technology and internet consumption. Additionally, as a result of the emergence of cloud computing, server virtualization, social media, and mobile data, the number of servers deployed, storage space, and interconnected network equipment in data centres is growing tremendously. Data centre IT network's primary elements include:

- Data Centre Communication Network
- High Performance Computing Network
- Storage Area Network

Three categories of traffic can be used to categorize a Data Centre.

- Traffic flows which are within the data centre.
- Traffic flows which travel between data centres.
- Traffic flows between data centre and the end user.

Data centre IP traffic is increasing at a fast rate [1] as depicted in the below figure. The primary driver of this expansion is cloud computing, which by 2023 is predicted to account for 4/5 of all traffic in data centres [2].

Fig 1.1: Global Data Centre Traffic, 2016–2021

Global data centres traffic by destination is shown in the figure below.

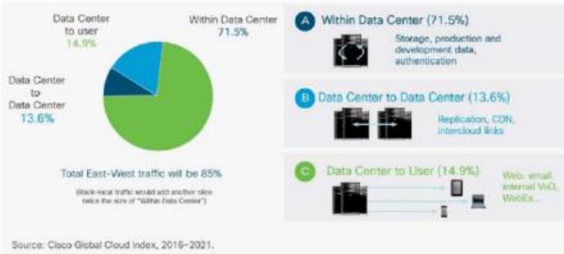


Fig 1.2: Global Data Centres Traffic by Destination

It is evident from the above chart that the majority of traffic occurs inside data centres, with the majority of that traffic travelling between servers and edge switches. Figure below depicts the traffic forecast between the various tiers of the data centre communication network.

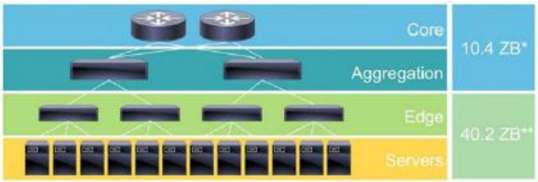


Fig 1.3 Traffic Forecast at Different Layers

1.2 Problem Statement

Limited server capacity and high oversubscription rates, network congestion and latency issues, management of internal data-centre traffic, support for a variety of traffic patterns, scalability, agility, effective resource utilization, management, fault handling, and troubleshooting are among the problems that DCCN must deal with. When building a data centre, these issues must be taken into consideration. The problems or difficulties that the DCCN will encounter are as follows:

- Limited capacity between servers and a high oversubscription rate as traffic moves through the layers of switches in a hierarchical fashion.
- Problems with congestion and high network latency have a negative impact on delay-sensitive applications and affect network performance as a whole.
- Controlling the nearly 75% of the overall traffic that is generated inside the data centre (i.e., east-west traffic between racks).
- Ease of Management, fault handling and troubleshooting in the network.
- Support for a range of traffic patterns, such as long-lasting, high-bandwidth "elephant" flows and short-lasting persistent "mouse" flows
- As a network grows, difficulties with scalability, agility, and efficient resource use arise.

1.3 Research Contribution

It relates to developing a low-cost, capital-efficient solution that will improve the scalability, traffic management, congestion control, and resource usage of data centre design. Academic contribution relates to proposing a solution HFPFMAOS using OpenFlow tools for:

- Congestion Reduction
- Improvement in Network Latency
- Implementing Scalability
- Traffic Management
- Reducing power Consumption
- CAPEX Reduction

Practical contribution of this research relates to coming up with an innovative data centre topology architecture with improved performance.

1.4 Objectives

- Application of Hybrid Flow to packet filtering /Forwarding and MEMS on the basis of an optical switching solution by utilizing different virtualization techniques.
- Efficient utilization of data centre network resources.
  - o Reducing Congestion
  - o Improving Network Latency
  - o Implementing Scalability
  - o Traffic Management
- Reducing Power Consumption and saving CAPEX.
- Provisioning of centralized intelligence of whole network.

1.5 Research Questions

- How to come up with a solution based on HFPFMAOS and MEMS based all optical switching?
- How to achieve efficient utilization of data centre network resources?
- How to reduce congestion, improving network latency, scalability and traffic management?
- How to reduce power consumption and save CAPEX?
- How to implement centralized intelligence of whole network?
- How to implement network virtualization techniques?

1.6 Research Methodology

OpenFlow (OF) switches were used in the access layer as TOR switches. OF messages were captured using Wire shark. Traffic was generated between various hosts (i.e. server machines) using iperf testing tool. Performance of the network and the delays were calculated/analyzed. For clarity, a reference data centre topology was used. Aggregation of the MEMS switch with conventional switch was done and connected it to the OpenFlow (OF) switches which were installed at the access layer. Network traffic was generated between various hosts and flow delays were observed. Researcher then directed flows via using MEMS switch and simultaneously monitored performance of the network.

1.7 Software's

The researcher used the following software's for carrying out the requisite analysis:

a) MININET
b) Putty
c) Wireshark
d) Oracle VM Virtual Box
e) Miniedit
f) ODL Controller
g) Xming

II. DATA CENTRE (DC)

2.1 Introduction

Data centre is basically an entirely one of its own kind of building which is invented to contains, supervises, and provides [3]. A data centre structure includes very unique building infrastructures, backup plans for power shortages or unavailability, cooling agents for systems, special equipment Chester's, servers, mainframes, and High performance Computing (HPC) networks to handle variety of communication data, as well as well-structured sophisticated cabling, application of various software, monitoring centers, and well equipped physical security systems.

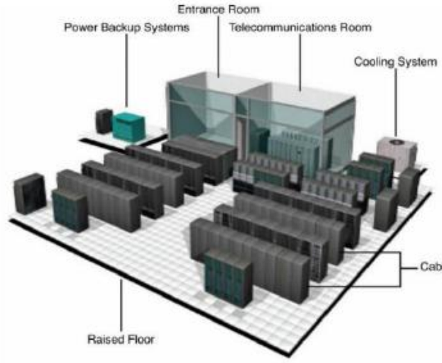


Fig. 2.1 Basic Data Centre Diagram

2.2 Evolution

First Data centre phase (called Phase 1.0) began in the 1950s and consisted of computer rooms with mainframe systems' CPUs and peripheral devices including storage, terminals, and printers, among other things. These monolithic software-based centralized systems give users little control over IT infrastructure and make heavy use of available resources. Phase 2.0 of data centres begins in the 1980s when client-server application models gain prominent. Currently, servers have replaced main frame computers, which are fairly compact and accessible through client PC-installed apps.

In this phase, servers that carry out specific tasks are typically installed close to clients rather than the main IT infrastructure to avoid paying excessive bandwidth costs. When the internet began to take off in the 1990s and the use of web-based applications increased, this mandated that servers be placed centrally in properly constructed data centres. Thus, the data centre that arises from the mainframe computer room has gained significance in the 1990s. Fig. 2.2 [3] depicts the timeline of data centre evolution.

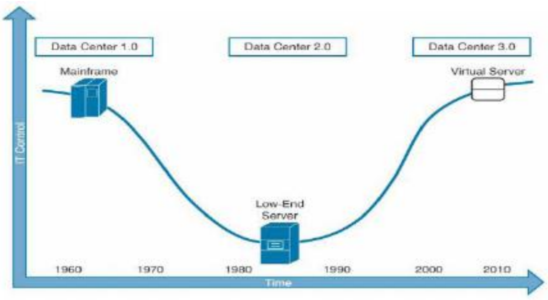


Fig. 2.2 Evolution Phases

Phase 3.0 began around the year 2000, and because technology evolved so quickly at this time, datacenter space, electricity, and the IT network are beginning to reach capacity. As a result, it is expensive to expand existing facilities or to build new ones. According to a 2005 Cisco IT research, around this time DC networks and servers were typically only used at 20% of their capacity. Application silos with discrete sets of servers, networks, and storage resources were the primary contributors to this problem. Later, a number of network consolidation projects are completed that provide new features, enhance resource utilization, decrease the number of network components and processes, and improve operational effectiveness.

2.3 Types

The are two in number [4][5]

- Private

- Cloud Based

2.3.1 Private

It is the on-site hardware that offers computing services and stores data within a local network that is managed by an organization's IT department. These are owned and run by small private/public businesses, governmental organization's etc.

2.3.2 Cloud Based

Another name used for cloud data centres is co-location/managed services provider. Co-located Data Centers were created and maintained to offer specialized infrastructure and provide various services to external sources and parties. Major elements that force businesses to either go for cloud computing or develop their own data centers are:

- Business market requirements
- Data privacy issues
- The increasing cost of related equipment/infrastructure

2.4 Data Centre Communication Network (DCCN)

Data services and data transit from the server to clients or other servers are the major goals of DCCN. These qualities are now required from the perspectives of dependability, expansion, and efficiency for data centre communication networks.

- Availability
- Scalability
- Flexibility
- Efficiency
- Predictability

Ethernet is the most ubiquitous and well-liked DCCN protocol for data lines, with an interface range ranging from 10Mbps to 100Gbps. However, as the volume of traffic through the DCCN increased, various constraints compelled the development and adoption of new virtualization technologies as well as the optimization of the data centre network through the use of cutting-edge networking strategies like MEMS all optical switching and conventional packet switching.

2.5 DC Tiers

Various Tiers of Data Centres are shown in the figure below from Tier-1 to Tier-4.

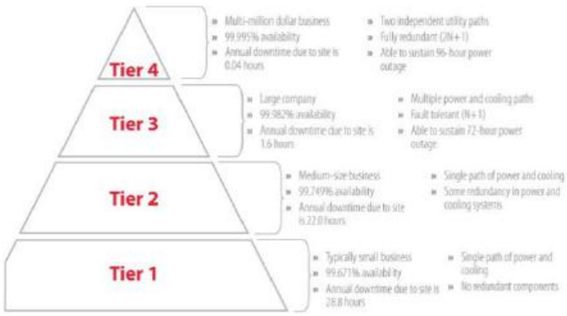


Fig. 2.3 DC Tiers

2.6 Design Factors for Data Centre Network

- The following factors must be taken into account when planning and deploying DCCN architecture [3].
- Failure Impact & Application Resilience: All local and distant users will be unable to access their apps if DCCN fails.
- • Connectivity between the server and host: Servers must be linked together using several redundant Ethernet connections.
- Traffic Direction: In DCCN, the majority of traffic is between servers inside the data centre.
- Agility: This term refers to the capacity for assigning any service or application to any server at any moment in the data centre network while maintaining sufficient performance isolation and security amongst various applications.
- Growth Rate: Increasing number of servers, switches, and switch ports, etc., as customers and their data traffic increases.
- Application Bandwidth Demand & Oversubscription in case demand increases.

2.7 DCCN Challenges

Challenges for the Data Centers Communication Network fields are as follows:

- Due to the fact that router links carry traffic going in and out of the data centre, the bandwidth available over these links for server communication across various data centre areas is constrained [8].
- Network congestion and latency issues. As in a data centre, where many applications are active and producing distinct packet flows that move both within and across the DCCN, a multi-tier hierarchical structure with numerous hops, there are times when packet aggregation creates a bandwidth constraint. As the receiver's buffer space for absorbing packet

flows is running short, the incoming rate from numerous transmitters surpasses the rate at which it can handle packet flows. This congestion causes the delay time to lengthen and the receiver to begin dropping packets, which has an impact on various applications, particularly those that depend on latency, and lowers the network's overall performance.

- Managing the read/write, backup, and replication traffic that moves within the data centre due to the separation of application servers, databases, and storage, which accounts for over 75% of all traffic (i.e., east-west traffic between racks). Additionally, because jobs are distributed across numerous servers and assigned in parallel processing, DCCN's internal traffic is increased.
- Support for a range of traffic patterns, such as long-lasting, high-bandwidth "elephant" flows and short-lasting persistent "mouse" flows. Examples of entirely large data producers include particle accelerators, planes, trains, metros, undergrounds, self-driving cars, patient data in healthcare centers, etc. In the year 2014, the Boeing 787 produces 40 terabytes of onboard data every hour, of which 0.5 terabytes per hour is transmitted to a data centre. The majority of flows within a data centre are typically mouse flows, while only a few elephant flows contain the majority of the data. Managing every sort of traffic at once while keeping the overall network delay within bounds is therefore a major issue.
- As a network grows, difficulties with scalability, agility, and efficient resource use arise. In addition to making fault handling and debugging more challenging as the number of communication devices increases, this will also result in an increase in management overhead bytes on the network.
- As additional devices are added, energy requirements and consumption will increase. Currently, in traditional data centers, the top of the rack (TOR) switch, also known as the fabric interconnect, is where all of the servers in a rack are connected. Each rack has a number of servers, either rack mount servers or chassis-based servers. On one side, this aggregation layer provides communication between data centre clusters, allowing packet-based East-West traffic to pass through, while on the other, it also provides connectivity with the core network, allowing North-South traffic to pass. As a result, the aggregation layer is the layer where problems arise because 75% of the data center's east-west traffic passes through it, causing a bandwidth bottleneck & an increase in latency.

2.8 DCCN Topologies

The architecture of a data centre communication network (DCCN), which serves as the foundation for its applications, must be scalable, reliable, latency-free, and have adequate capacity to prevent network congestion. These qualities heavily rely on the network architecture in which the DCCN is installed and are crucial to the overall effectiveness of the data centre. Figure below depicts the Common DCCN Architecture, as stated by Cisco [9].

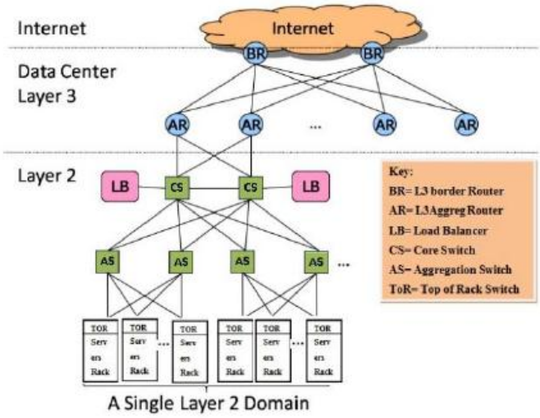


Fig 2.4 Common DCCN Architecture

Layered architecture has the advantage of enhancing the flexibility, modularity, and resilience of networks. Every layer in this design performs a separate role for unique profiles, such as the routers in the core layer (i.e., the aggregation router and the border router), which use routing protocols to decide how to forward traffic for both ingress and egress. Core switches, which offer incredibly flexible, scalable connections with numerous aggregation layer switches, make up the Layer 2 domain. This layer serves as a default gateway and a focal point for server IP subnets. Between numerous aggregation layer switches, it is typically used to transfer traffic between servers, and stateful network devices such server load balancers and firewalls are attached to this layer. The switches that make up the access layer are typically used by servers to connect to and communicate with one another. It contributes to better network administration and is in charge of exchanging any kind of traffic between servers, including broadcast, multicast, and unicast.

The bottom of the above illustration shows a server layer stacked in server racks.

Numerous Virtual machines are being operated by these servers and assigned to various data centre applications. To manage and respond to requests from external clients arriving through the internet, an application is typically linked to several public IP addresses. These requests are split up among the pool of servers for processing by specialized equipment called a load balancer that is redundantly connected to the core switches [10].

2.8.1 Fat-Tree

Al-Fareset and colleagues [11] have proposed this DCCN architecture. It makes use of the fat-tree idea and aims to boost fault tolerance, end-to-end cross sectional bandwidth, scalability, and cost-effectiveness. With this topology, the core and several pods make up the entire infrastructure. Servers, TORS (Access switches), and aggregation switches make up the pods.

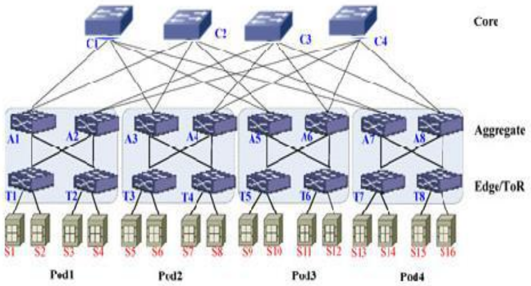


Fig 2.5 Fat-Tree

The topology adapts the data lines in the DCCN architecture to give a customized IP address scheme and multipath routing algorithm. Below figure compares 3 tier and fat-tree systems.

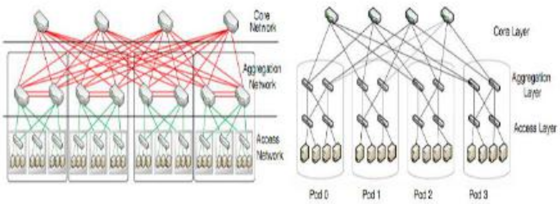


Fig 2.6 Comparison of 3 Tier/Fat-Tree Topologies

2.8.2 B-Cube

The structure [12] is suggested for the modular DCs created within containers and offers quick installation and migration, but scalability is limited because container data centres are not meant to be scaled up. Layers of COTS (commodity off the shelf) switches and servers make up this architecture, and they are in charge of packet forwarding. At level 0, the BCube architecture is made up of many BCube0 modules, each of which has a switch with n ports connected to n servers. n switches make up the BCube1 module at level 1, which is connected to n BCube0 modules or networks. One server from the BCube0 module is linked to each switch of BCube1.

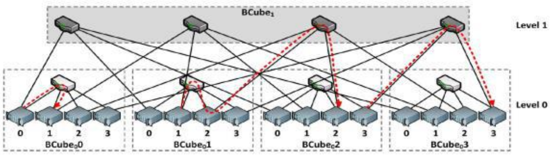


Fig 2.7 B-Cube Topology

2.8.3 DCell

Guo et al proposed a recursively specified design. Mini switches and servers are used in this very marketable design to forward packets. According to below figure, Dcell1 is made up of n+1 DCell0 modules, each of which is connected to the others by a single link via its servers.

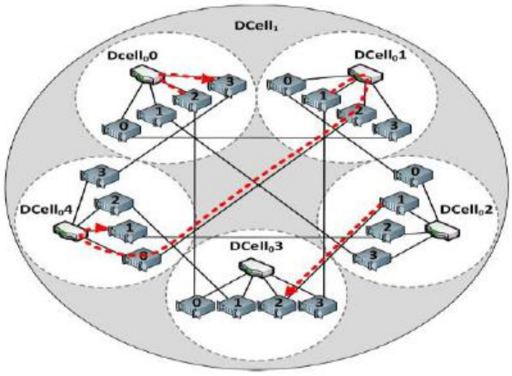


Fig 2.8 DCell Topology Architecture

2.8.4 VL2

A Fat-Tree based DCCN design called Virtual Layer 2 (VL2) aims to provide a flat automated IP addressing scheme that makes it possible to install servers anywhere in the network without manually configuring their IP addresses. This makes it possible for any service to be allocated to any network server. In order to scale to a large server pool, it makes use of [14] address resolution based on end systems.

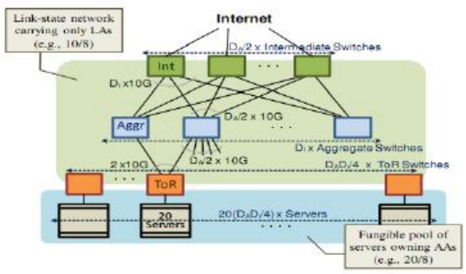


Fig 2.9 Network Architecture VL2

In addition to all architectures, there is a need for architecture which can handle the present issues the DCCN is encountering as well as give backward compatibility with existing infrastructure and its architecture. In this thesis, I suggested the HFPFMOS data centre design, which can partially address the shortcomings of the existing architecture while simultaneously being backwards compatible with it.

2.8.5 HFPFMAOS

The data centre communication network architecture (DCCN) called HFPFMAOS, is suggested as a solution to the various problems that data centres in the present face while maintaining the infrastructure. Particularly,in this architecture, standard switches are used at the aggregation layer. By monitoring all of the flows across the OF equipped switches, this will give us consolidated network intelligence and enable us to dynamically establish High bandwidth data paths between the data centre servers whenever and wherever they are needed. Additionally, it will lower network management overhead bytes and aid in quick defect detection and correction. The conceptualized design is shown below.

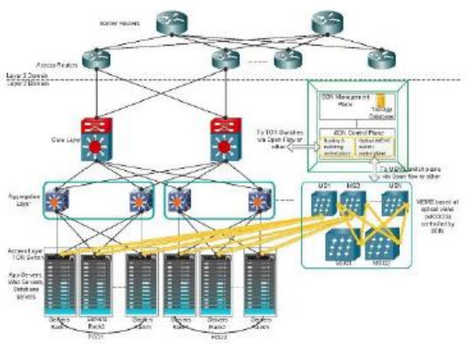


Fig 2.10 Architecture – HFPFMAOS - DCCN's

III. MEMS OPTICAL SWITCHING

3.1 Introduction

Interconnection between DCN demands a significant capacity increase due to the exponential daily growth of traffic. Therefore, the best way to relieve network congestion caused by electronic switched is to use optical switching. Although optical fibre has a very high bandwidth, it is constrained by electronic switching and transmission capacity. As switching is done in the optical domain, all optical switching can therefore play an important role.

3.2 OOO Switching (All Optical)

Modifying optical cross connections, a circuit is created from the ingress node to the egress node in all optical switching, and data travels via this circuit entirely in optical form. This can assist in addressing electronic switched network bottleneck since data is switched in the optical domain directly rather than going through many optical-electrical-optical conversions.

3.3 OOO Switching Benefits

- POD-based architecture is typically used in data centres, which results in low use of computing resources. However, optical switching enables sharing of computing resources among several PODs for optimal effectiveness.
- Increases revenue by quickly deploying new services.
- Less power is lost compared to a traditional electrical switch.
- On-demand capacity creation and reallocation.
- A remarkable increase in the data centre's operational efficiency as a result of the smooth functioning of applications and the efficient use of computational resources and 3D optical MEMS switching technology.
- Boost defect detection and quality of service.

3.4 Technology using OOO Switching

Different optical switching methods [17] are used by many switches. The same are shown in the below table:

Table 3.1 Contrast of various Optical switching technologies

	MEMS	Liquid-crystal	Bubble	Electro-Holographic
Wavelength Range	1290 ~ 1625 nm	1525 ~ 1575 nm	1270 ~ 1650 nm	1310 ~ 1550 nm
Insertion Loss (IL)	1dB ~ 5dB	<1dB	<7.5dB	<3dB
Scalability	Higher scalability with 3D MEMS to thousands of ports but limited with 2D MEMS to about 64x64	low	Low (to about 100 ports)	Low
Switching Speed	1ms ~ 5ms	4ms	<10 ms	<30ns
Power Consumption & Technical Performance	Low power consumption	Low power consumption about 50mW, Prefer for single mode instead of multimode, require polarization splitter, suffer from PMD, thermal fluctuation and moisture sensitivity	High power consumption about 25W, Wavelength dependent phase shift caused by bubble and hence amplitude dispersion in signal output, tradeoff between low loss and high isolation required.	Low power consumption, Polarization and wavelength dependent, hence dispersion and loss.
Cost & Packaging	Low cost & light weight	Costly & inconvenient	Low cost but some degree of precision required	Low cost & easily integrated with signal equalization & monitoring
Polarization Dependent Loss	< . 2dB	. 2dB	< . 3dB	
Maturity of Technology	Medium but Mature	Medium	Medium	Mature

3.5 Micro Electro Mechanical Systems (MEMS)

The branch of engineering MEMS (Micro electro mechanical system) which merged computer technology with minuscule mechanical components found in semiconductor chips, including actuators, gears, sensors, valves, mirrors, and valves [31]. It contains mechanical components, like micro-mirrors or sensors which h can be easily adjusted as needed, and reflect optical signals from input to output fibres placed within a tiny silicon chip that embedded micro-circuitry. Light beam can be reflected from the input to output by tilting/rotating the mirror at varied angles thus directing the traffic to the ports.

3.6 Design and Principle

Below figure shows the Structure of 3D MEMS optical switch [16].

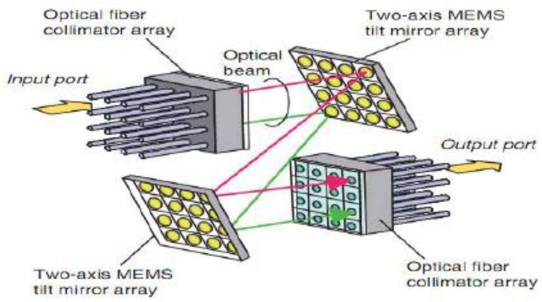


Fig. 3.1 Optical Switch

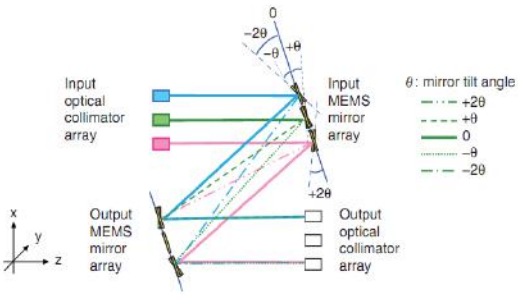


Fig 3.2 Standard Format OS

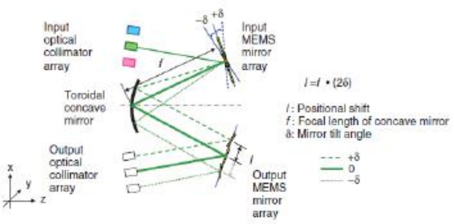


Fig 3.3 A toroidal concave mirror is used in a 3D MEMS optical switch.

The tilt angle of MEMS mirror measures the incident angle at which the optical beam from the I/P collimator array meets the concave mirror after reflecting by the I/P MEMS mirror array. Then light beam is again converged with a shift in position "/" by this toroidal concave mirror, that does an optical Fourier transform. This shift"/" can be quantitatively expressed as follows using the concave mirror focal length and the MEMS mirror tilt angle:

$$/ = f \times 2\delta$$

512 ports can be obtained by using a 2X2 array of collimator arrays with 128 optical ports and MEMS mirror arrays with 128 ports. This makes it easier to fabricate high-capacity optical switches with a negligibly small cumulative pitch error.

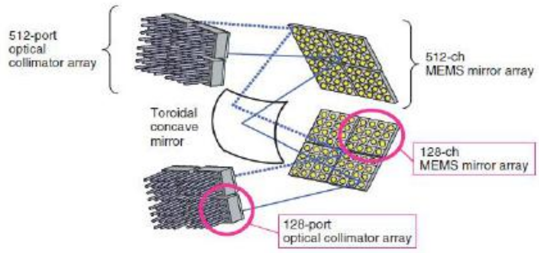


Fig 3.4 Schematic of 3D 512 MEMS optical ports switch

3.7 MEMS Mirror Structure

The same is shown in the below figure.

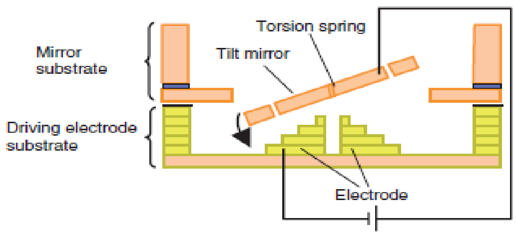


Fig 3.5 MEMS tilt mirror cross-sectional schematic

In order to generate an air gap between the electrodes and the mirrors, substrates are individually produced, then linked together by flip chips. Electrostatic force is produced when electrodes and mirrors are connected by a voltage, and this force moves the mirrors. Therefore, we are able to adjust the tilt angle of these mirrors by supplying a driving voltage to each electrode.

3.7.1 Mirror Substrate

They are formed of a single silicon crystal, giving the mirror incredibly steady movement. MEMS mirror is supported on X-Axis by two folded torsion springs, and the gimbal ring is connected to the base on the Y axis by a second pair of folded torsion springs [16]. The mirror cannot be dragged down and come into contact with the electrodes because of the great rigidity of these springs in the Z direction relative to torsion direction. As a result, moving the mirror on the X and Y axes makes it simple to reflect an optical beam in 3D space in a particular direction.

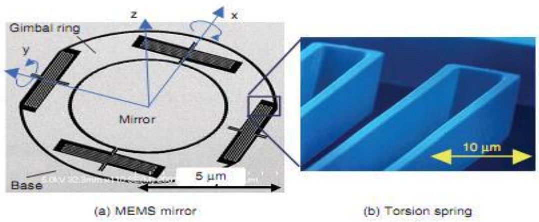


Fig 3.6 High aspect torsion spring and MEMS mirror are snapped together via SEM

3.7.1.1 Mirror Electrode Substrate Fabrication Method

A layer of polyimide is then spun over the created mirror pattern in step 7[16] (a) (b). The third process involves dry etching to create the pattern for the mirror opening (d) and resistant mask (c) on the opposite side of the bulk Si. The polyimide coating serves as an etching stopper. Following the dicing procedure, the polyimide layer is removed using oxygen plasma (g). "In-process sticking of the mirror" is the name of the dry procedure used to fabricate mirrors. AS Since the top surface of the mirror has an au coating, which gives optical beams high reflectivity, both sides of the mirror have this coating. Peak-to-valley difference can be utilized to assess the mirror surface's flatness, which in our case is 0.05 m, as the optical features of the switch made up of a MEMS mirror array depend on it.

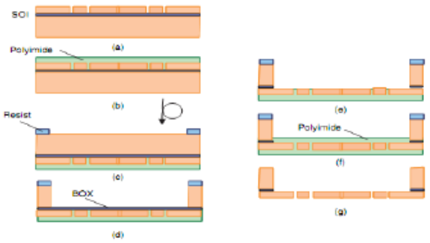


Fig 3.7 Mirror substrate fabrication process flow diagram

3.7.2 Driving of Electrode Substrate

Mirrors move due to this electrostatic force.

3.7.2.1 Fabrication of Driving Electrode Substrate

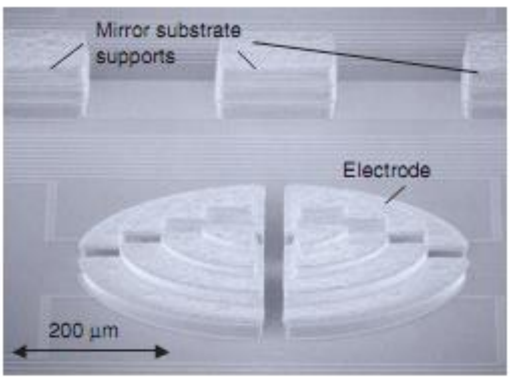


Fig 3.8 Electrodes' SEM snap

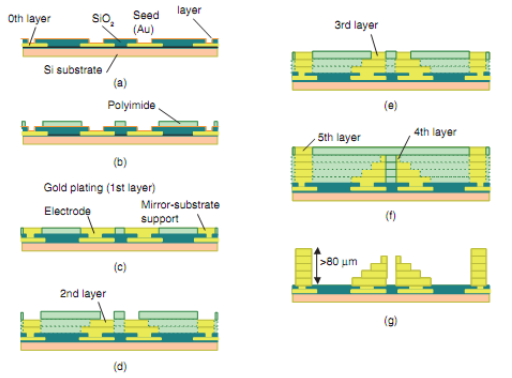


Fig 3.9 Driving Electrode Substrate's Fabrication flow process

3.8 MEMS Mirror Movement

Figure below shows connection between the voltage applied and tilt angle of mirror.

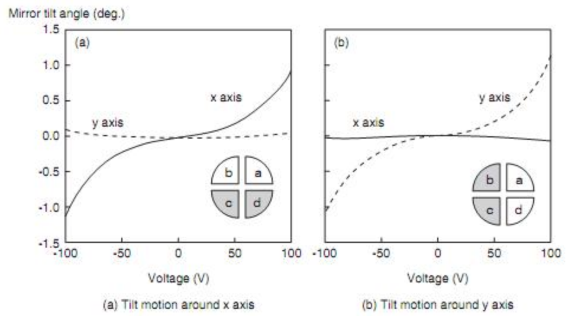


Fig 3.10 Relationship between Voltage applied & Tilt Angle of Mirror+

Size, flatness, fill factor, and scan angle of the micro mirrors, along with their scan angle and fill factor, all have an impact on how many ports the 3D MEMS switch can support.

3.9 Key Advantages of MEMS Switches in DCCN

- They offer any-to-any communication between servers, allowing for very low latency and the transfer of enormous amounts of data. which is much lower than IP switches' latency.
- Can handle any data rate.
- They can circumvent the packet-based aggregation network and offer direct, high-capacity pure optical data links between any TOR switches to reduce network latency and shift sensitive traffic between servers as needed.

IV. SOFTWARE DEFINED NETWORKING (SDN)

4.1 Introduction

Adoption of practice of creating and maintaining networks results in an architecture which is called Software Defined Networking (SDN). The major aim of this kind of architecture is to facilitate programmability for the control plane by separating the devices' that is control plane from their data/forwarding plane.

4.2 SDN Architecture

Control and Data planes at present coexist on the same network device, or, to put it another way, all data flow functions, such as switching, forwarding, and routing, as well as the various protocols used to make these decisions, are housed on that one device. "Provide open user-controlled administration of the forwarding hardware of a network element," according to the definition of SDN in [7], is the fundamental objective. The following elements are part of an architecture based on software defined networking (SDN) are shown in the below figure:

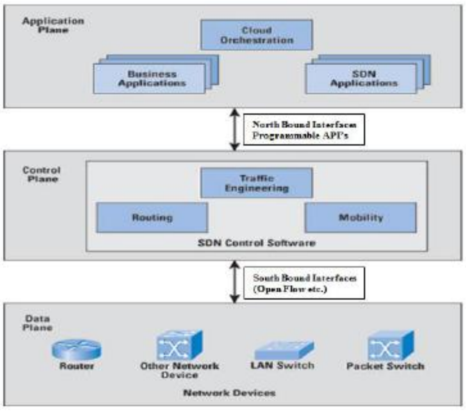


Fig 4.1: Architecture for Software Defined Networking (SDN).

4.2.1 Application Layer

Applications can include network characteristics like forwarding schemes, manageability, and security policies, among others. With the aid of the controller, the application layer can abstract the overall view of all network components and use that data to provide the control layer the proper direction. In our approach, management programs that offer CLI/GUI for the network devices are operating along with network monitoring tools.

4.2.2 Control Plane

It is network's "brain" and is in charge of managing and programming forwarding plane. The control plane employs a topology database to give an abstract picture of all the network components.

4.2.3 Data Plane

The infrastructure layer, which is the lowest layer in the SDN network architecture and includes forwarding Network Elements like (Router, Switches). Data transmission, statistics collection, and information monitoring are among its primary functions. MEMS switches are present at the aggregate layer while OF switches are located at the access.

4.2.4 API's which are North Bound

These are software interfaces b/w controller's software modules and SDN applications. The informal name used for the interface between the application/control plane is called the Northbound interface.

4.2.5 API's which are South Bound

South bound APIs are standardized APIs (application program interfaces) that allow SDN controllers to communicate with switches and routers and other forwarding network hardware [18].

4.2.6 East-West Protocols

In a multi-controller-based architecture, these protocols are used to control how different controllers communicate with one another. In a broader sense, SDN presents a networking architecture in which choices regarding the routing of data traffic are made external to the actual switching hardware. Therefore, genuine network intelligence can be achieved in data centres when SDN, PFFS, and MOOOS are applied. Second, a secure standard protocol should exist to enable communication between SDN controllers and network devices. This logical architecture may be implemented differently by different vendor equipment, but from the standpoint of an SDN controller, it performs like a consistent logical switch. AS It is explained that OpenFlow (OF) is the first and most extensively utilized interface between the infrastructure layer (data plane) and the control plane because it satisfies both of these needs.

4.3 Open Flow (OF)

The Open Networking Foundation (ONF) has standardized OpenFlow as the most popular southbound interface of SDN architecture. OF's first version, version 1.0, was created by Stanford University and then acquired by ONF. Version 1.5 of OF was released in December 2014.

It is an open standard communication protocol that defines how one or more control servers interact with switches that are SDN compliant. The flow table entries are installed in the OF compliance switches by an OF controller so that traffic is sent in line with these flow entries. These flow tables can be used by network administrators to alter network configuration and data traffic patterns. Additionally, this protocol offers management tools for packet filtering and topology change control. The OF protocol is supported by nearly all of the well-known vendors, including Cisco, HP, IBM, Brocade, and others. There are two types of switches for OF or SDN compliance.

4.3.1 Open Flow-Only Switches

These switches, which solely support OF operation and process all packets using the OF pipeline, are also known as Pure SDN switches or SDN-only switches.

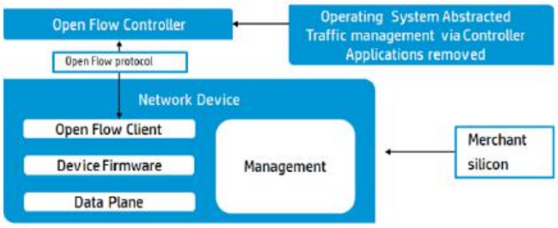


Fig 4.2 Architecture of Open Flow-Only Switch

4.3.2 Hybrid Switches with Open Flow

The same are shown in the below figure.

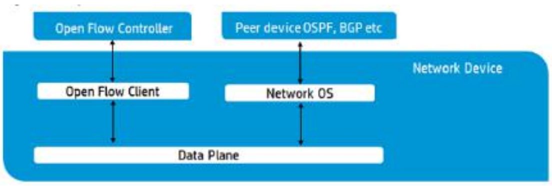


Fig 4.3 Architecture of Hybrid Switch

4.3.3 Basic Architecture of Open Flow (OF)

The below figure shows the basic OpenFlow architecture.

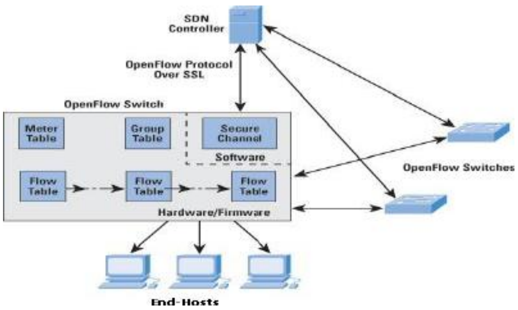


Fig 4.4 Architecture of Basic Open Flow (OF)

Open Flow switches are deployed in the Access layer as TORs, which are connected to servers or end hosts on one end and traditional switches and MEMS switches at the Aggregation layer on the other. As a control plane, the ODL controller is set up to connect with the OF switch using the OF protocol via a secure channel using SSL or TSL (Transport Layer Security). Three tables make up the OF switch's logical design. Flow Table, Group Table, Meter Table, and Table of Groups

4.3.4 Flow Table

It is the fundamental component of logical switch design that determines the action to be taken on each incoming packet by comparing it to a specific flow table made up of numerous flow entries. This packet might go via one or more flow tables that operate as pipelines. As demonstrated in fig. 4.5, a controller can add, remove, and alter flow entries from an OF switch's flow tables either proactively or reactively (in reaction to an incoming packet).

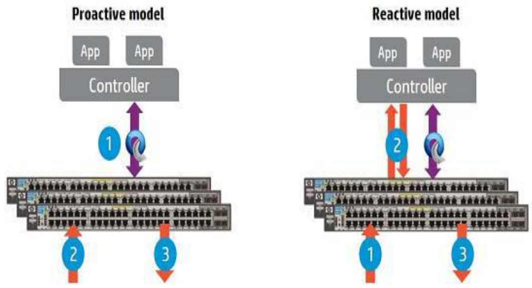


Fig 4.5 Flow Table Entries Model

Flow entries can't be generated until something happens, or after the receipt of the respective packet, thus subsequent action is taken in compliance with the instructions by a controller, while in the case of proactive model, flow entries are generated as required in advance and the process is completed without checking from the controller. When a packet first reaches a switch, the switches OF agent software looks for flow table (ASIC for hardware switches) and software flow table (virtual switches). This information exchange is shown in the figure below.

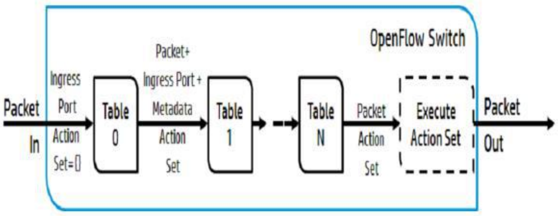


Fig 4.6 Pipeline Processing

Figure below depicts the packet processing flow chart.

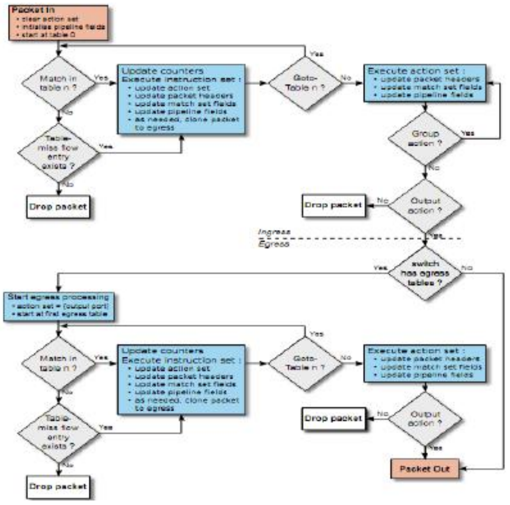


Fig 4.7 Open Flow(OF)-Packet Processing Flow Chart.

Table 4.1 Main components of Flow Entry

Match Fields	Priority	Counters	Instructions	Timeouts	Cookie

4.3.4.1 Match Felds Values

It is important here that not to pick any packets without matching field values as shown in the below table:

Table 4.2 Match Field of Flow Entry

IN_PORT	IN_PHY_PORT	METADATA	ETH_DST	ETH_SRC	ETH_TYPE	VLAN_VID
VLAN_PCP	IP_DSCP	IP_ECN	IP_PROTO	IPV4_SRC	IPV4_DST	TCP_DST
TCP_DST	UDP_SRC	UDP_DST	SCTP_SRC	SCTP_DST	ICMPV4_TYPE	ICMPV4_CODE
ARP_OP	ARP_SPA	ARP_TPA	ARP_SHA	ARP_THA	IPV6_SRC	IPV6_DST
IPV6_FLABEL	ICMPV6_TYPE	ICMPV6_CODE	IPV6_ND_TAR	IPV6_ND_SLL	IPV6_ND_TLL	MPLS_LABEL
MPLS_TC	MPLS_BOS	PBB_ISID	TUNNEL_ID	IPV6_EXTHDR		

4.3.4.2 Priority Allocation

Setting a priority along with Match fields results in a unique identity of flow entry.

4.3.4.3 Counter Checks

It contains information such as the number of bytes actually received and number of missed packets too.

4.3.4.4 Directions

Instructions are provided for side by side modifications in pipeline processing or desired set of actions.

4.3.4.5 Timeouts

It is defined as the maximum time for which any switch remains idol before which the flow of packets also expires.

4.3.4.6 Cookies

Any opaque data values selected by a relevant controller. The OF controller can utilize it to filter requests for flow deletion and modification as well as flow statistics entries. When processing packets, these values are not used.

4.3.5 Group Table

In order to perform various operations that may have an impact on several flows, Flow Table may send its flows to Group Table. A group table is made up of entries for groups that have group identifiers. The principal elements of a group entry shown below:

Table 4.3 Group Table

Group Identifier	Group Type	Counters	Action Bucket

4.3.5.1 Identifier

32-bit unique identifier identifies the group entry.

4.3.5.2 Type of Group

It is used to manage/maintain group types depicting them as "Required" and "Optional".

4.3.5.3 Packet Counters

Provide actual packets count which are generated and processed by a group.

4.3.5.4 Action buckets

AB consists of complete flow of processes which are performed in a specific pattern for changing packets and then sending them to a port. This collection of actions is always carried out as a set of acts. A group entry may have zero or more buckets, with the exception of groups specified as "Required: Indirect," which only include one bucket. If a group doesn't have a bucket, it will immediately throw the packets into the air.

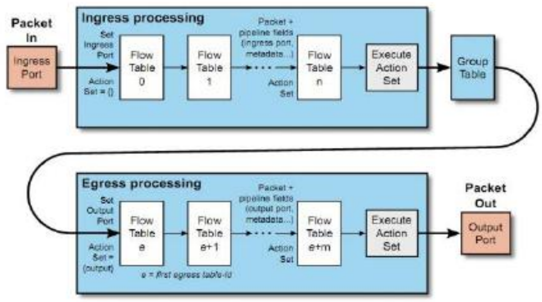


Fig.4.8 OpenFlow packets pipeline Processing

4.3.6 Meter Table

Having the ability to perform flow-related actions. It is made up of meter entries that specify per-flow meters. Personalized Service Code Point based metering also enables the division of packets into different according to data rate. Instead of using ports, meters are directly connected to flow entries. After measuring, they can influence the overall rate of all packet flows and be configured to perform a specific action. The key parts of a meter entry are presented below:

Table 4.4 Main components of Meter Entry

Meter Identifier	Meter Bands	Counters

4.3.6.1 Identifier of Meter

Meter entry is identified by a 32-bit identifier but in a distinct way.

4.3.6.2 Meter Bands

Defines how to handle packets by listing rates of each band's meter bands in a list that is not ordered. Meter Band is used for measuring the response of the meter towards packets of various meter rate ranges which are calculated from all packets received by that particular meter from all inputs. Meter bands are used to specify. Only one-meter band processes a packet.

Table 4.5 Meter Band

Band Type	Rate	Burst	Counters	Type specific arguments

4.3.6.2.1 Band Types

Packets processing ways.

4.3.6.2.2 Target Rate

It is the required rate of a meter band.

4.3.6.2.3 Burst

It establishes the metre band's granularity.

4.3.6.2.4 Counters

Processing of packets by a meter band updates the counters.

4.3.6.2.5 Type specific arguments

Parameters which are in essence optional for particular band types. Meter bands are ranked from 0 to 1, with 1 being the default band, depending on how much the desired rate increases. The packet is processed by only one-meter band when the measured rate exceeds the intended rate.

4.3.6.3 Counters

They are used to figure out how many packets a meter has processed. In the same flow table, multiple flow entries may utilize various meters, the same meters, or no meters at all.

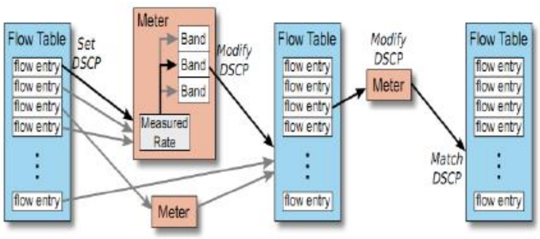


Fig. 4.9 Hierarchical DSCP metering and metres.

4.3.7 Protocols for an Open Flow Channel

Totally safe Open Flow channel is provided by the OF channel which is typically encrypted by TLS (Transport Layer Security) or SSL. The protocol that it employs for these purposes is known as the OF protocol [20].

4.3.7.1 Controller_to_Switch Messages

Messages that the controller initializes to control the switch's logical state, such as configuration, flow tables, group tables.

4.3.7.2 Asynchronous Messages

Initiated by the switch, these messages comprise status updates to inform the controller of changes to the switch's condition and network events. Additionally, it has a "Packet-In" message that switches utilize to transfer packets to OF controllers when their flow tables do not match.

4.3.7.3 Symmetric Messages

Hello messages are initiated by controller/switch, right after when the connection is made between two specific devices, or Echo messages are used to measure the latency and bandwidth of the connection between the switch and controller as well as to confirm that the device is functioning as intended.

4.4 Benefits of SDN

SDN has the potential to be a promising technology for managing and solving different problems in data centre networks. Using the SDN technique, the network administrator only needs to declare these settings on a single place from which all devices are managed and directed by the SDN controller. Data centres are having scaling problems, particularly as the number of servers and virtual machines (VMs) that run on them rises and, later, as the requirement for migration (VM motion) rises. A significant bandwidth is needed for virtual machine migration and updating the MAC address table, which raises network latency and lowers overall network performance. In typical data centre architectures, users may encounter interruptions when accessing apps. Consequently, this researcher suggests that SDN, "All optical switching," and other virtualization technologies like OTV can be used to address this study area/gap.

Table 4.6 OpenFlow Messages

Message	Description
Controller-to-Switch	
Features	Request the capabilities of a switch. Switch responds with a features reply that specifies its capabilities.
Switch Configuration	Set and query configuration parameters. Switch responds with parameter settings.
Flow Table Configuration	Configure/Modify behavior , property, flags of flow table
Modify State	Add, delete, and modify flow/group entries and set switch port properties.
Read-State or Multipart	Collect information from switch, such as current configuration, statistics, and capabilities.
Packet-out	Direct packet to a specified port on the switch.
Barrier	Barrier request/reply messages are used by the controller to ensure message dependencies have been met or to receive notifications for completed operations.
Role Request	Set or query role of the OpenFlow OF channel. Useful when switch connects to multiple controllers.
Bundle	Creation, closing, committing and discarding of bundles by controller
Set Asynchronous Configuration	Set filter on asynchronous messages or query that filter. Useful when switch connects to multiple controllers.
Asynchronous	
Packet-In	Transfer packet to controller.
Flow Removed	Inform the controller about the removal of a flow entry from a flow table.
Port Status	Inform the controller of a change on a port.
Controller Role Status	Inform the controller about its role Changing
Table status	Update to controller when table state changes
Request Forward	Update to other controller about modification in state of group and meters
Controller Status	Report to all other controller about change in controller status
Symmetric	
Hello	Exchanged between the switch and controller upon connection startup.
Echo Request/Reply	Echo request/reply messages can be sent from either the switch or the controller, and they must return an echo reply.
Error Messages	Notify controller of error or problem condition.
Experimenter	For additional functions.

V. HFPFMAOS

5.1 Conceptualized HFPFMAOS Solution

As per this research contribution, suggested is the HFPFMAOS as a remedy for the problems and challenges facing DCCN (Hybrid Flow based packet filtering, forwarding & MEMS based all optical switching). Eight phases make up the implementation of this research concept:

- The deployment of an SDN controller and an OF in TOR switches that link to the controller through SSL.
- Aggregation-level MOOOS plane deployment and connection to SDN controller.
- Development of database for the conceptualized network topology.
- Flow based Packet Filtering and Forwarding – FPFSF
- Monitoring of outgoing ports, computation of links' usage, and alerting the SDN controller.
- Flow Table lookup and flow entry inspection are used to find the flows consuming more bandwidth and to inform the source and destination of those flows.
- Building high-bandwidth data connections between TOR switches that correspond to the source and destination indicated.
- Moving a particular flow of traffic to a high-bandwidth link constructed using a MOOOS plane, then moving it back to its normal path and breaking down the high-bandwidth link when that particular flow vanishes or resumes operating at its regular data rate.

5.1.1 Installation of Open Flow in Access and SDN controller

At initial stages, the respective researcher first deploys an SDN controller and then turn on an Open Flow in all of the access layer switches (TOR), without disturbing the arrangement of the rest of the network's switches and allow them to work just as before inclusion of this setup. Then I establish a secure encrypted SSL (secure socket layer)/TCP connection between each OpenFlow OF enabled Access switch and the SDN controller. Through the OF protocol, this link is utilized to communicate between an SDN controller and an OF switch.

This connectivity is further utilized by SDN controller as well as by a number of north-bound applications, which includes initial hello /hi messages (like OFPT HELLO, FEATURE REQUEST MESSAGE from controller to switch & then FEATURE REPLY MESSAGE in the same manner from switch to controller), topology discovery using LLDP (Link Layer Discovery Protocol) & BDDP (Broadcast Domain Discovery Protocol), thus start building data bases, message alerts (PACKET IN to controller & PACKET OUT) messages from table to switch which specifically flows over all optical path between OF switches.

5.1.2 Setting up Plane

At the aggregation level, researcher deployed MAOS (optical switching based on MEMS) plane alongside conventional switches. The current packet-based switching continues to function in this approach together with the newly proposed MAOS to provide dynamically high speed data routes between servers for switching elephant traffic as needed. Plus, centralized control is exercised by connecting it to a central SDN controller, network elements(NEs) supervision, and control of traffic flow. Figure below shows the conceptualized architecture.

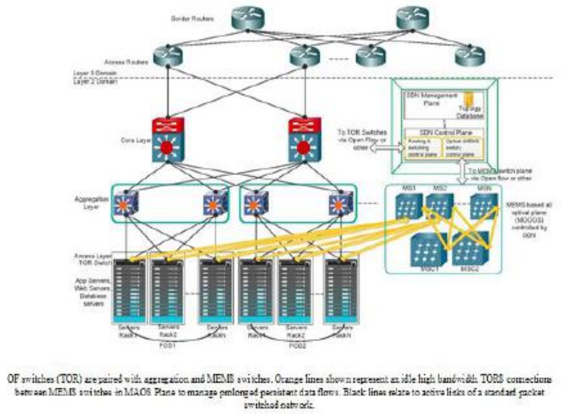


Fig 5.1 Conceptualized Architecture of HPMOOOS for DCCN

At the aggregation layer, the MAOS plane is implemented side by side the conventional switches.

5.1.3 Developing Topology Database

STEP-1: OF switches, traditional switches, MEMS switches, and the hybrid network are managed and controlled by DCCN in HFPFMAOS system.

STEP-2: OF protocol behaved as the South bound Protocol between the SDN controller and OF switches.

STEP-3: The SDN controller establishes a topology database of all the devices in the network that are OF enabled by locating OF switches, accessible outgoing links, and all the hosts connected to each OF switch.

STEP-4: This topological database construction will entail three findings i.e. Switch discovery, link discovery, and host discovery.

Fig 5.2 Database Topology Development Steps

5.1.3.1 Revelation of OpenFlow OF Switches

STEP-1: A unique IP address is allocated to every OF enabled switch as an initial configuration.

STEP-2: Configuration with a TCP port number, one IP address is allocated to the master controller, and a full series of IP addresses for slave controllers therefore if in the event the master controller connection fails, OF switches can be connected through these slave controllers.

STEP-3: In order to develop an encrypted and safe connection with the controller, OS1-1 (O OF, S Switch, 1 pod no, -1 Switch no), as well as a list of outgoing interfaces across which inter-rack, inter-pod, between data centers, and end client traffic is forwarded, are allocated to OF switches during startup.

Fig 5.3 OpenFlow OF Switches Process

5.1.3.2 Revelation of Active Links

OFDP can detect indirect accessible multi-hop links (routes) between OpenFlow OF switches by leveraging the L2 discovery protocol known as BDDP [22]. Most well-known Open Source controllers, including ODL and Floodlight, adopt this technique.

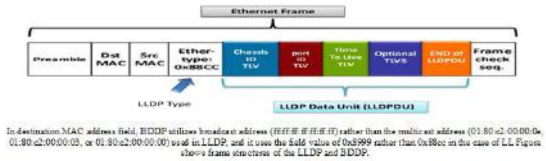


Fig 5.4 Structural Framework of LLDP

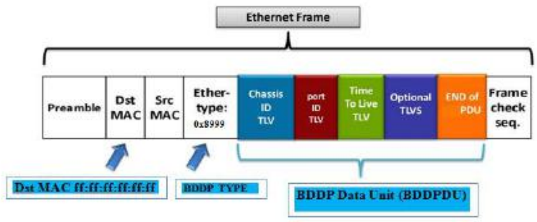


Fig 5.5 BDDP Frame Structure

A switch's identification, basic capabilities, and other characteristics are determined by an OF controller via the OF protocol, which includes sending "OFPT FEATURES REQUEST" messages to all switches as part of the first handshake.

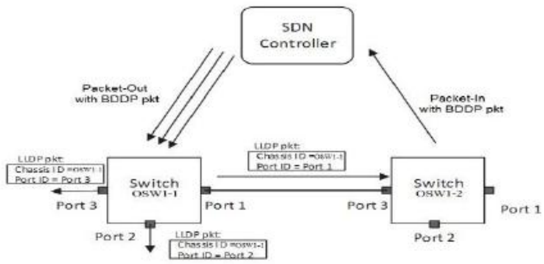


Fig 5.6 Links discovery Via OFDP

Messages exchanged between OpenFlow OF switches and controller for Links are shown below.

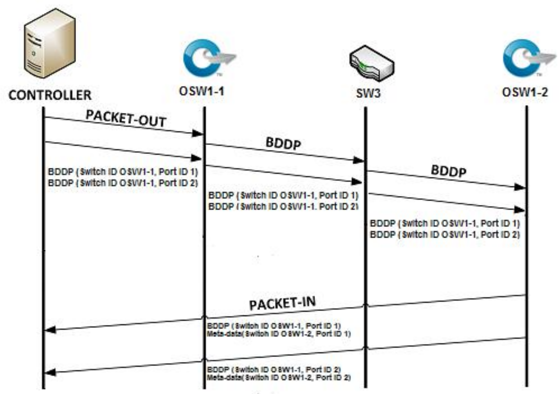


Fig 5.7 Messages flow between controller and Open Flow OF switches for Links

The metadata of OpenFlow OF switches where BDDP packets are received are included in "OFPT PACKET IN" messages. Between OpenFlow OF switches and their controller, messages are only transmitted in one direction. These massages are also exchanged in the other direction. Based on data from BDDP and metadata, the controller can identify indirect multi-hop links between OpenFlow OF switches after receiving these "OFPT PACKET IN" signals and store them in its database to create a network topology. Most crucially, the controller counts the number of hops between OpenFlow OF switches using the TTL value. The default time interval for this topology finding operation is 5 seconds. The total number of "OFPT PACKET IN" messages received by the controller during this entire discovery process is equal to double the number of "L" active links accessible in the domain, and this number may be calculated as below:

$$\text{Total}_{\text{Rx OFPT\_PACKET\_IN}} = 2 \text{ x } L$$

However, the total messages “OFPT_PACKET_OUT” sent by controller can be computed as:

$$\text{Total}_{\text{Tx OFPT\_PACKET\_OUT}} = \sum_{i=0}^{S} Pi$$

Number of Open Flow OF switches is denoted by S, whereas active ports are denoted by P. All switches has P. 4 OpenFlow OF switches with 2 active ports each make up our reference topology, hence "OFPT PACKET OUT" messages issued by the controller are 2+2+2+2=8 in total. The total number of BDDP OFPT PACKET OUT messages sent by a controller to a switch can be reduced by implementing OFDPv2[23], in which the Port ID TLV field is set to 0 and will be ignored while the source MAC address field has been set with the MAC address of the port through which it is to be sent out. One "OFPT PACKET OUT" message is sent by the controller for each switch, and the total number of messages transmitted is equal to the number of switches determined by OFDPv2.

$$\text{Total}_{\text{Tx OFPT\_PACKET\_OUT}} = S$$

As each OpenFlow OF switch's port is physically connected to a MEMS switch's port, we don't need link discovery to establish connectivity with the MAOS plane; instead, the controller can create paths between any two points dynamically, and topology database can statically store all the data related to flows and port connections.

Table 5.1 Topology Database

Switch ID	Port	Direct connected Port MAC address	Far End OSW ID & Port Rx "Packet_IN" MSG	Type	Status
OSW1-1	Eth 1	SW3 port0 MAC address	OSW1-2, Eth 1 ,1	Dynamic	Up
	Eth 1	SW3 port0 MAC address	OSW2-1, Eth 1 ,3	Dynamic	Up
	Eth 1	SW3 port0 MAC address	OSW2-2, Eth 1 ,3	Dynamic	Up
	Eth 1	SW3 port0 MAC address	OSW1-2, Eth 1 ,3	Dynamic	Up
	Eth 2	SW4 port0 MAC address	OSW1-2, Eth 2 ,1	Dynamic	Up
	Eth 2	SW4 port0 MAC address	OSW2-1, Eth 2 ,3	Dynamic	Up
	Eth 2	SW4 port0 MAC address	OSW2-2, Eth 2 ,3	Dynamic	Up
	Eth 2	SW4 port0 MAC address	OSW1-2, Eth 2 ,3	Dynamic	Up
	Eth 3	MSW1 port 1		Static	Down
	Eth 4	Controller		Static	Up
	Eth 5				Down
	Eth 6				Down
	Eth 7	bb:bb:bb:bb:bb:bb		Dynamic	Up
	Eth 8	aa:aa:aa:aa:aa:aa		Dynamic	Up
OSW1-2	Eth 1	SW3 port1 MAC address		Dynamic	Up
	Eth 2	SW4 port1 MAC address		Dynamic	Up
	Eth 3	MSW1 port 1		Static	Down
	Eth 4	Controller		Static	Up
	Eth 5				Down
	Eth 6				Down
	Eth 7	cc:cc:cc:cc:cc:cc		Dynamic	Up
	Eth 8	dd:dd:dd:dd:dd:dd		Dynamic	Up

5.1.3.3 Discovery of Host

Two methods have been applied for available host discovery which is connected to the OpenFlow OF switches.

As all active ports on all switches send BDDP "Packet Out" messages, I Ports for which OpenFlow OF Switches do not send "Packet In" messages are recognized as host ports during link discovery. (ii) GARP message is sent by the Host when Host is connected to an OpenFlow OF Switch. HSRP and VRRP[24] use GARP to update the MAC address table of L2 switches, In a broadcast domain GARP is an advance notification mechanism to keep the controller aware about host discovery and inserting flow entries of MAC address in the flow tables of Open Flow OF switches, thus updating other hosts' ARP tables before their ARP requests are made, and finally updating ARP tables of other hosts when a new host is also connected to a switch,however a host IP address or MAC address is changed due to failover. Generated ARP requests are actually special ARP packets with the source that is (host) IP and destination.The destination broadcast MAC address (ff:ff:ff:ff:ff:ff) is present in the MAC address field and the Ethertype field fixt to 0x0806. The parameters listed below are part of a GARP request message:

• FF:FF:FF:FF:FF:FF:FF:FF is the destination MAC address (broadcast)

• Source MAC address: MAC address of the host

Example of GARP is shown in the below figure. IP address of a Source = IP address of a Destination: Host transmitting GARP Type ,IP address is: ARP (0x0806).

```
Ethernet II, Src: PaloAlto_09:21:12 (00:1b:17:09:21:12), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
    Destination: Broadcast (ff:ff:ff:ff:ff:ff)
    Source: PaloAlto_09:21:12 (00:1b:17:09:21:12)
    Type: ARP (0x0806)
Address Resolution Protocol (request/gratuitous ARP)
    Hardware type: Ethernet (1)
    Protocol type: IP (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
   [Is gratuitous: True]
    Sender MAC address: PaloAlto_09:21:12 (00:1b:17:09:21:12)
    Sender IP address: 10.66.24.67 (10.66.24.67)
    Target MAC address: Broadcast (ff:ff:ff:ff:ff:ff)
    Target IP address: 10.66.24.67 (10.66.24.67)
```

Fig 5.8 GARP Request Message

Each host will ping its neighbor after GARP is finished to verify connectivity and reachability. Currently, all hosts are aware of one another's MAC addresses and assigned IP addresses, which are visible in their ARP tables. To stop BDDP packet propagation, SDN controllers disable link discovery on the OpenFlow OF switch ports to which hosts are connected after discovery. Similar to BPDU guard security function in conventional switches, this suppression also prevents BPDU propagation [27].

Table 5.2 Host-1 linked with OSW1-1 - ARP

IP Address	Physical Address
10.0.0.2 (Host 2 IP Address)	bb:bb:bb:bb:bb:bb (Host 2 MAC Address)

Table 5.3 Host 2 linked with OSW1-1 – ARP

IP Address	Physical Address
10.0.0.1 (Host 1 IP Address)	aa:aa:aa:aa:aa:aa (Host 1 MAC Address)

5.1.4 Discovered Routes & Forwarding Table Buildup

Information relating to interface of OpenFlow(OF) switchs is received by Controller, plus list of all routes as well as destinations (MAC/IP addresses) also become visible through it, because it contains map of topology discovery of the entire network and a centralised database too. Each route found is given a Route-Tag by the SDN controller following topology discovery. Allocating a Route-Tag has the main aim of to distinctly recognize each respectively occured route and then generate a forwarding table that gives information about all of the destination (MAC/IP address) addresses that may be reached using the same route. In order to send a flow to an outgoing interface based on Route-Tag,this forwarding table is installed by an SDN Controller into the OF switch. The source address and destination address are used to traditionally forward flow frame to next hop because its content addressable memory table also includes a list of MAC addresses that can be reached over each link (port).later on when the same flow touches an OpenFlow OF switch, it searches again all the flow tables and look for the best possible match before forwarding the flow to the accurate Host port after assuring its destination address.

5.1.5 Building up of Flow Table by inserting Flow entries

After entering into an OpenFlow OF switch the flow itself again compares each incoming packet with one or more flow tables, each of which contains multiple flow entries, and then determines the action to be taken. Any sort of matching can be used, for example matching an ingress port, a source or destination MAC address or IP address, a VLAN ID, a TCP/UDP port number, etc.

For providing maximum flexibility and support to diverse types of data traffic passing through DCCN while supplying delay-sensitive traffic with minimal latency, I will employ a hybrid model of flow table entries in this thesis that combines proactive and reactive modalities. The use of a proactive model for flow entry is required for delay-sensitive applications that demand low latency, for example while making audio/video calls, live radio/TV transmissions, financial banks transactions, and routine heavy traffic like web browsing, data file/folder transfer, and peer-to-peer traffic.

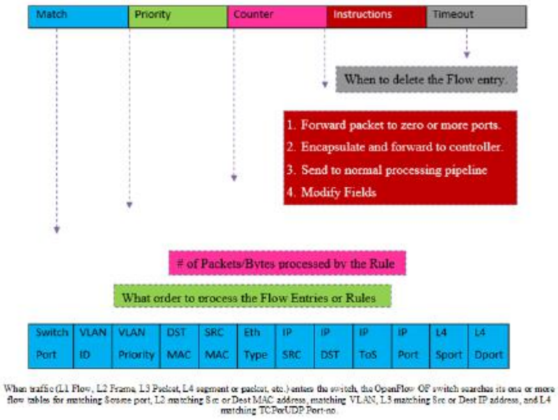


Fig 5.9 Anatomy - OpenFlow OF

Discovery of flow entries which have close match with the related fields of the data traffic, it either executes the particular action of flow entry or forwards it to a group table to execute multiple actions. The importance of the priority parameter cannot be overstated since flow entries are prioritised, and if there are many flow entries, the one with the highest priority will be used and the others will be ignored. Table below shows different types of counters.

Table 5.4 Types of Counters

Per Table	Per Flow	Per Port	Per Queue
Active Entries	Received Packets	Received Packets	Transmit Packets
Packet Lookups	Receive Bytes	Transmitted Packets	Transmit Bytes
Packet Matches	Duration (Secs)	Receive Bytes	Transmit Overrun Errors
	Duration (nsecs)	Transmitted Bytes	
		Receive Drops	
		Transmitted Drops	
		Received Errors	
		Transmitted Errors	
		Receive Frame allignment error	
		Receive Overrun Errors	
		Receive CRC Errors	
		Collisions	

By issuing the command OFPMP PORT STATS to the OpenFlow OF switch, the SDN controller continuously receives the statistics of outgoing active links (Ports), such is the quantity of Rx packets, Tx packets, Rx bytes, and Tx bytes, as well as the time in seconds, dropped packets, and Tx/Rx errors. Link utilisation of all the desired ports is calculated by the controller based on the statistics that were returned. The Link Utilization is calculated using the following formula[28]:

$$\text{Input utilization} = \frac{\Delta\text{ifInOctets} \times 8 \times 100}{(\text{number of seconds in } \Delta) \times \text{ifSpeed}}$$

$$\text{Output utilization} = \frac{\Delta\text{ifOutOctets} \times 8 \times 100}{(\text{number of seconds in } \Delta) \times \text{ifSpeed}}$$

- ΔifInOctets: The Δ (or difference) between two poll cycles of collecting the snmp ifInOctets object, which represents the count of inbound octets of traffic.
- ΔifOutOctets: The Δ between two poll cycles of collecting the snmp ifOutOctets object, which represents the count of outbound octets of traffic.
- IfSpeed: the speed of the interface, as reported in the snmpifSpeed object.

Fig 5.10 Formula to calculate Link Utilization

For each of the outgoing interfaces, the controller maintains a specific link utilisation threshold. When the threshold is exceeded, it consults its flowtable to filter flows with outgoing interfaces that have exceeded the threshold. Following the specification of ports, the SDN controller determines whether any ports are available before creating a Highband dat pathpath across the MEMS Plane.

If there is no match, the entry in the table is considered to be incorrect, and the controller is notified by default. The controller instructs the switch to take certain actions. The "Flow Mod" message contains a variety of information, including Buffer IDs, Timeouts, Actions, Priorities, and more. Additionally, flow entries can be permanent or for a limited period of time, and there are two types: "Hard Timeout" and "Idle Timeout." Idle timeout refers to the removal of an entry from the flow table if there is no matching flow entry request during that time period. Hard timeout refers to the maximum amount of time an entry can remain in the flow table, regardless of whether a matching entry is present. If Hard timeout is set to 0, it is deactivated.

As an illustration, in our reference topology diagram, Host 1 sends an HTTP request to Host 2 (let's say a web server) following host discovery by GARP. It begins with a SYN message. Host 1 sends a SYN message to the OSW1-1 switch, which checks its flow table upon receiving the packet because it is the initial packet and likely has no flow entries that match the packet. Table miss flow entry is the term for this. Therefore, by encasing this TCP packet in a "Packet IN" message, the switch passes it to the controller by default. This Packet IN message contains the entire TCP packet or its Buffer ID (for example, Buffer ID = 250, which designates the location where the switch stores the whole TCP message). Therefore, the controller will take a few actions, such as returning a "Flow Mod" or "Packet Out" message to the switch, where "Packet Out" includes information regarding the switch's handling of that particular as well as the whole encapsulated TCP packet or the reference buffer ID that the switch uses to store this packet. Send the TCP SYNpacket reference with buffer ID=250 out of port 8 to host 2 if the switch OSW1-1 receives a "Packet Out" message.Then the switch is directed to add another new flow entry to its flow table through the "Flow Mod" message. When a similar packet arrives at the switch in the future and matches its fields and masks, this flow entry guides the switch what to do now.In this way the message informs the related switch to route any TCP requests from Host1's IP address or MAC address to Host4's IP address or MAC address and finally to Port 8. Additionally, it tells the switch to release the packet it had been buffering with the BufferID of 250 and to carry out the instructions in this message. H4 replies by sending a SYN/ACK packet to the switch, which receives it but finds no flow entry from Host2 to Host1 (yet another table miss). In order to send this SYN/ACK packet to the controller for additional analysis, the switch encapsulates it in a "Packet In" message and gives it the reference buffer ID BufferID=251. In response, the controller instructs the switch to add a flow entry to the flow table and perform some action, which is to forward the SYN/ACK message to port7. The controller also sends the switch a Packet Out and a Flow mod message.The remainder of the communication between Host1 and Host2 would not reach the controller after all of this because switches have flow entries in their flow tables that tell them what to do with packets. The switch routed HTTP reply and ACK messages directly, as demonstrated in the following figs:

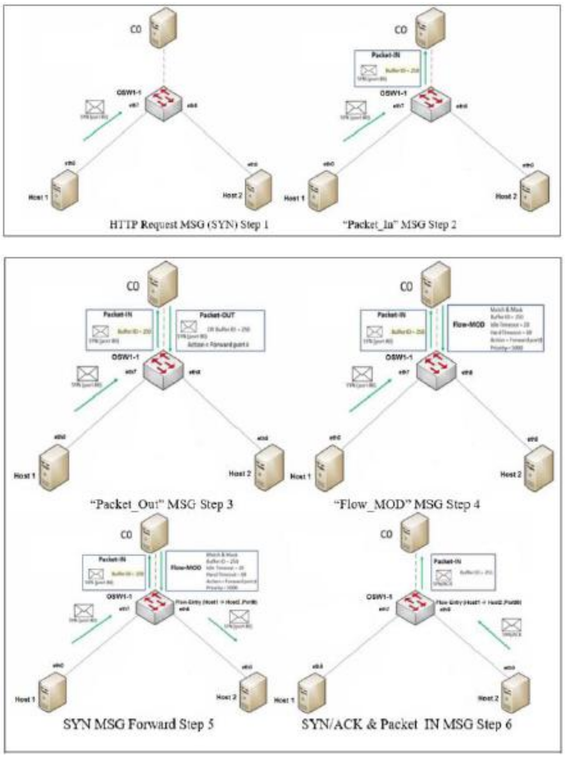


Fig 5.11 (a) HTTP request with Open Flow messaging

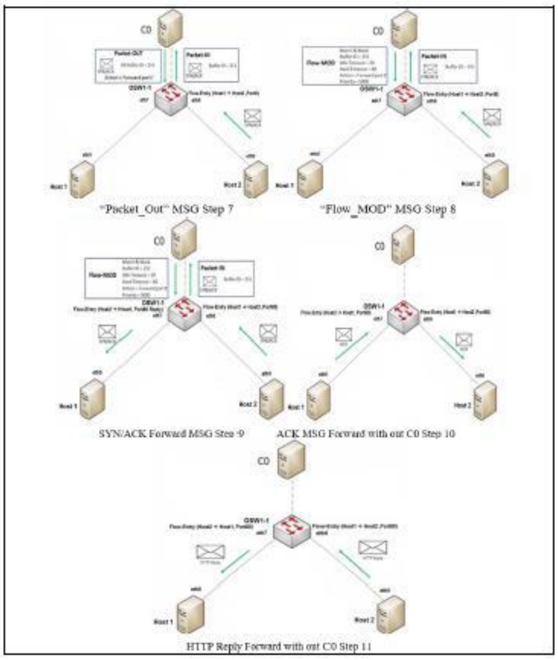


Fig 5.11 (b) HTTP Reply-Open Flow messages

Following table is showin OF switch flow entries:

Table 5.5 Flow Table of OF Switch OSW1-1 Flow Entries

I/P Port	Src MAC	Dst MAC	VLAN ID	VLAN PCP	Ether_Type	SRC IP	DST IP	IP Prot	IP ToS	L4 SPort	L4 DPort	Priority	Action	Counter
contr	*	ff:ff	*	*	0x8999	*	*	*	*	*	*	10	Local	11
*	*	*	*	*	0x0806	*	*	*	*	*	*	10	Local	2
*	*	aa:aa	*	*	*	*	*	*	*	*	*	80	Port 7	50
*	*	bb:bb	*	*	*	*	*	*	*	*	*	80	Port 8	60
*	*	dd:dd	*	*	*	*	*	*	*	*	*	80	Port 1,2	60
*	*	*	10	*	*	*DSTrouting	10.0.0.9/8	*	*	*	*	67	Port 1	20
*	*	*	20	*	*	*DSTrouting	10.0.0.16/8	*	*	*	*	67	Port 2	15
*	*	*	*	*	*	*	*default route	*	*	*	*	50	Contr, Port1	100
Port7	aa:aa	bb:bb	20	0	0x0800	10.0.0.1	10.0.0.2	0x06	*	38661	80	67	Port 8 TCP	20
Port8	bb:bb	aa:aa	20	0	0x0800	10.0.0.2	10.0.0.1	0x06	*	80	38661	67	Port 7 TCP	20

The very first entry instructs switch to broadcast packets that arrive from the controller port, regardless of their ether type, to all other switch ports, indicating that they are BDDP messages, and to update the counter. Sec entry instructs the switch to issue a GARP request and update the counter regardless of the switch's fields if the ether type is 0x0806. The third, fourth, and fifth lines are L2 matching and forwarding, which instructs the switch to perform a specific action specified by the Action field and update the counter regardless of other fields if the packet arrives with a certain DMAC. The sixth and seventh lines instruct IP to route packets to a particular port based on their destination IP. The eighth line is the default route, as shown for our reference topology, and the final two flow entries are TCP flow entries for HTTP requests and answers. When the bulk of brief flows, sometimes referred to as "Mouse flows," start flowing alongside long persistent high bandwidth data flows, or "elephant flows," This results in a bandwidth bottleneck. High bandwidth data flows, which can be caused by, among other things, VM migration, database backups, or other software like Hadoop, cause switches' buffers to overflow, which slows down packet processing and negatively affects applications that require low latency. Nowadays, there are many virtual machines running on a single server for various applications. For whatever reason, one virtual machine running one application in Server Rack 1 started using a lot of bandwidth and CPU, which had an adverse effect on other applications operating on the same server. Since the switch buffers start to overflow, the administrator is compelled to move the virtual machine to Server Rack 2 of the same POD, which results in a bandwidth bottleneck and increased latency on network links, as shown in the figure below.

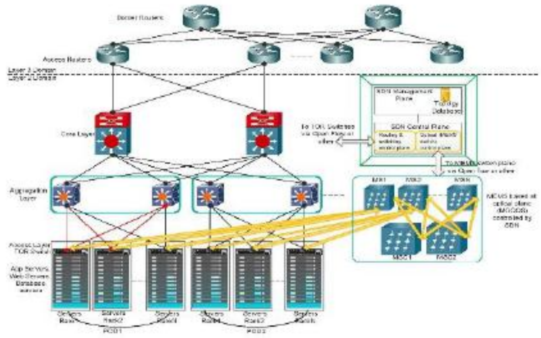


Fig 5.12 Congestion

Colored red indicate congestion on an active packet-switched network link that a packet is attempting to cross. As seen in the figure, switches alert their management/controlled plane to network congestion and increased delay.

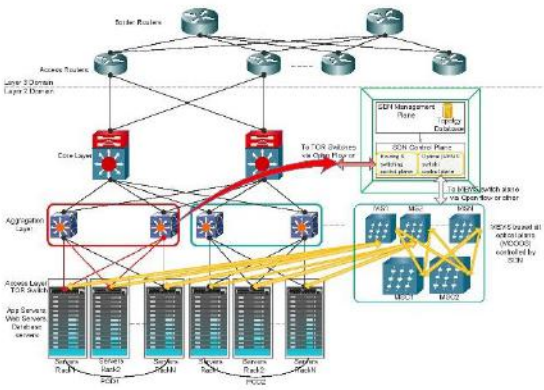


Fig 5.13 Congestion Notification by Switches to Control Plane

In reply, the management/control plane investigates the packets to make clear their source and destination, consults its topology database, and calculates the locations between which high bandwidth data routes must be developed.

Resultantly, the optical control plane gives messages to the MAOS control plane, which is made up of MEMS-based optical switches.

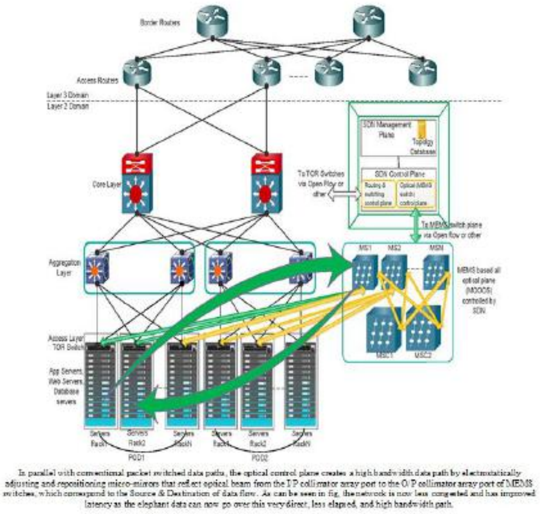


Fig 5.14 MEMS switches produce High data rate optical path

As seen above, data is travelling across both packet-switched network and a temporary, high-bandwidth channel, which is depicted by the green colour and is enabled by MEMS-based switches. Once the high persistent flow has subsided and traffic flow has returned to normal, the control plane will demolish the temporarily established optical link and reallocate it as needed.

VI. SOFTWARE IMPLEMENTATION

6.1 Reference Network Topology

In order to implement the proposed software of the proposes solution, the researcher came up with the below conceptualized architecture.

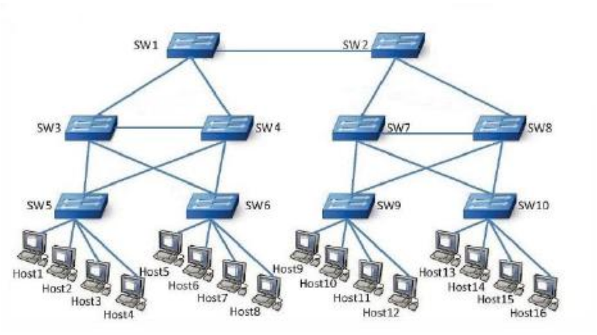


Fig 6.1 Prototype testing Reference network topology

Our network topology consists of 2 pods, POD 1 and POD 2, with each pod expected to include eight hosts or servers, two aggregation switches, and two access switches. POD1 is made up of two aggregation switches (SW3 & SW4), two access (TOR) switches (SW5 & SW6), and eight hosts (Hosts 1 through Host8) that produce traffic. POD2 consists of 8 hosts, Host1 to Host8, 2 TOR switches, named SW9 and SW10, 2 aggregation switches, named as SW7 and SW8, and 2 hosts.

6.2 Software used

The tools incorporated are shown in in the figure below:

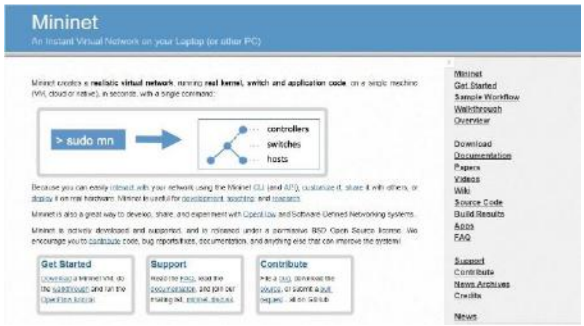


Fig 6.2 Software Tool Used Mininet

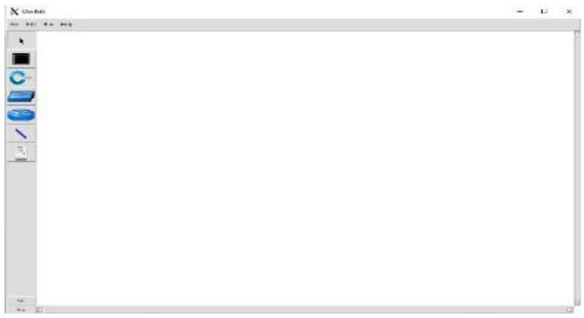


Fig 6.3 Software Tool Used MiniEdit

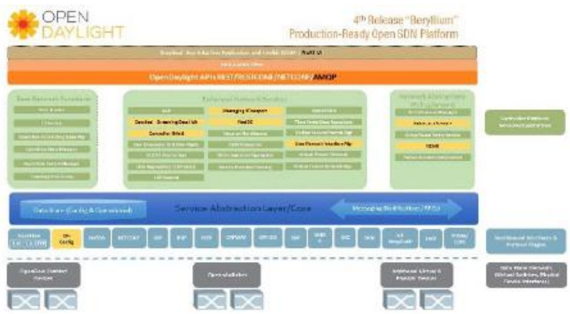


Fig 6.4 Software Tool Used Open Day Light

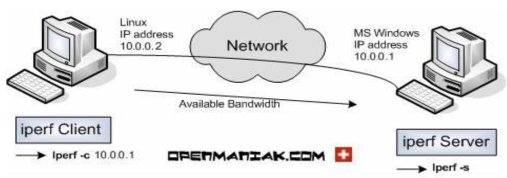


Fig 6.5 Software Tool Used IPERF

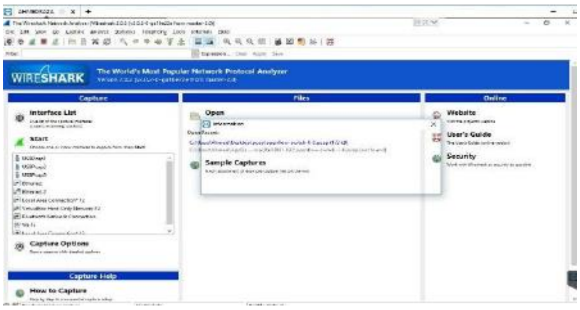


Fig 6.6 Software Tool Used WireShark

6.3 Preparation/Implementation

Below actions must be taken to prepare for this setup:

- Before running my Mininet and Open Day Light virtual machines, I first downloaded and installed Oracle VM VirtualBox.
- Next, construct a VM in VirtualBox, download the Mininet virtual machine image, mount it on top of the fresh virtual machine, and then install Mininet.
- Third, create a second VirtualBox virtual machine and install the ODL controller setup.

Mininet and its GUI program MiniEdit (running on o1 VM on VirtualBox) is used by researcher, to plan out and simulate the reference topology. I require X forwarding in order to run Miniedit and connect to Mininet over SSH. To do this, I've used Putty and XMing. Open DayLight, an external SDN-based OpenFlow controller, was utilised by me to operate OpenFlow virtual switches and MEMS switches (ODL Beryllium). I have generated data flow from hosts and servers and measured several performance characteristics using the IPERF, such as link bandwidth and network latency. I used Wireshark to investigate data packets and analyse variety of protocol messages on several interfaces during the whole network topology.

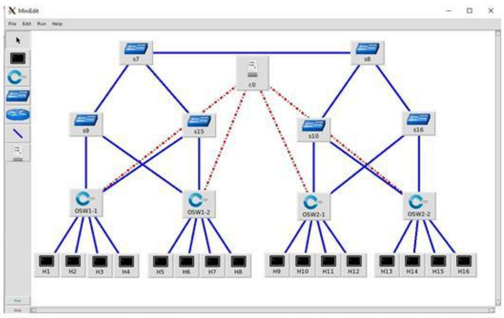
6.4 Applications

The real deployment of HFPFMAOS was gained in two main steps

STEP1: Network topology in Mininet without MEMS layer

- Start Mininet virtual machine in VirtualBox.
- Start Xming in host operating system for X-forwarding.
- Access the Mininet via SSH through putty in Host OS.
- Run the MiniEdit.py file from Mininet.
- Buildup the network topology in Miniedit and deploy Open Flow switches as TOR switches in Access layer.
- Start the 2nd ODL virtual machine in virtual Box.
- Run the topology in Miniedit
- Add the Flow entries in the flow table of OF switches.
- Generate traffic between Different Hosts and check the network performance by observing end to end delay.

Fig 6.7 Deployment Steps of HFPFMAOS



Host H1 through H16 are servers that are mounted in corresponding racks and connected to each other via OF switches and traditional switches, while C0 is the SDN controller with an IP address of 192.168.56.102 that is connected to each OF switch via a malicious OF port number 6633 over TCP. H1, H2, H3, and H4 are regarded as servers that are mounted in a rack and connected to a TOR switch (OSW1-1); H5, H6, H7, and H8 are connected to an OSW1-2; H9, H10, H11, and H12 are connected to an OSW2-1; and H13, H14, H15, and H16 are connected to an OSW2-1; (OSW2-2). The IP addresses for each host between H1 and H16 range from 10.0.0.1 to 10.0.0.16, while the IP addresses for each OF switch are OSW1-1=10.0.1.1/16, OSW1-2=10.0.1.2/16, OSW2-1=10.0.2.1/16, and OSW2-2=10.0.2.2/16.

Fig 6.8 OF switches based Network topology - Access as TOR switches

Links between hosts and OF switches are 4 Mb/s with a 10 msec delay, while links between all traditional switches and between OF switches are 10 Mb/s with a 5 msec delay, as demonstrated in the following figures:

Host, Nodes, Links and interfaces verification can be done by these commands, mininet>nodes, mininet>net and mininet>dump.

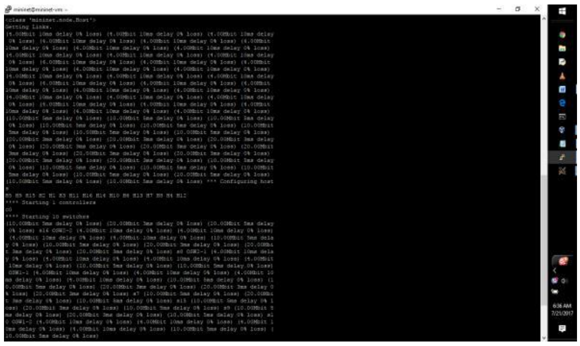


Fig 6.9 Creating Links Switches

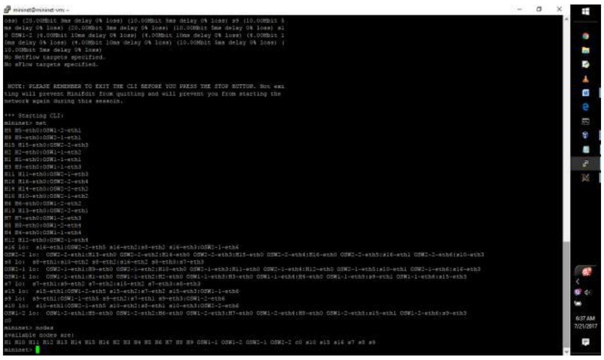


Fig 6.10 Network/Nodes Verification

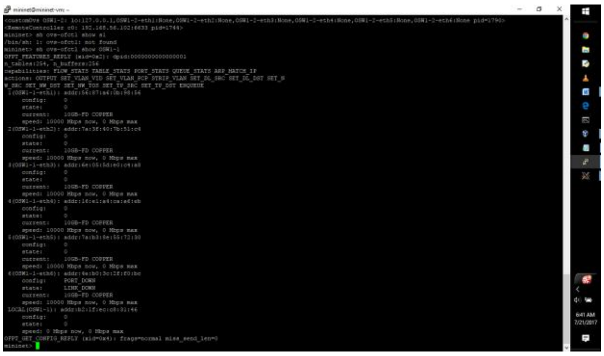


Fig 6.11 OF Switch interfaces verification

Flow entries are shown by the researcher in the flow table of OF switches OSW1-1, OSW1-2, OSW1-3 & OSW1-4 for my proposed solution HFPFMAOS which are as under:

For Discovery of HOST and ARP Table

mininet> ping all

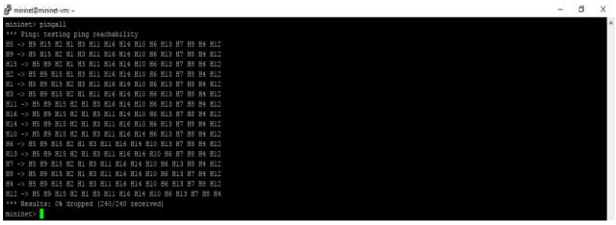


Fig 6.12 Host Discovery by Pingall command for

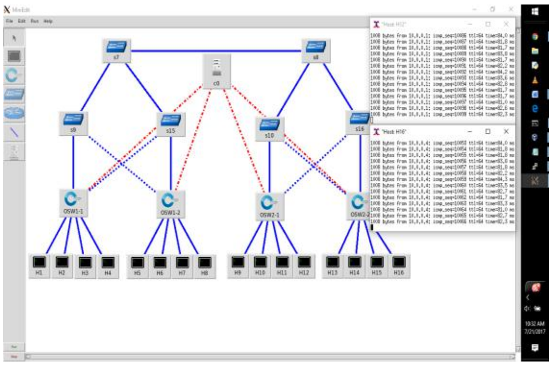


Fig 6.13 Host pinging

For Links Discovery GARP Requests:

```
mininet> sh ovs-ofctl add-flow OSW1-1 dl_type=0x806,nw_proto=1,dl_dst=ff:ff:ff:ff:ff:ff,action=flood
mininet> sh ovs-ofctl add-flow OSW1-1 dl_type=0x806,nw_proto=1,dl_dst=ff:ff:ff:ff:ff:ff,action=flood
mininet> sh ovs-ofctl add-flow OSW1-1 dl_type=0x806,nw_proto=1,dl_dst=ff:ff:ff:ff:ff:ff,action=flood
mininet> sh ovs-ofctl add-flow OSW1-1 dl_type=0x806,nw_proto=1,dl_dst=ff:ff:ff:ff:ff:ff,action=flood
```

For Links Discovery BDDP Requests:

```
mininet> sh ovs-ofctl add-flow OSW1-1 priority=100,dl_type=0x8999,dl_dst=ff:ff:ff:ff:ff:ff,action=controller:65535
mininet> sh ovs-ofctl add-flow OSW1-2 priority=100,dl_type=0x8999,dl_dst=ff:ff:ff:ff:ff:ff,action=controller:65535
mininet> sh ovs-ofctl add-flow OSW1-3 priority=100,dl_type=0x8999,dl_dst=ff:ff:ff:ff:ff:ff,action=controller:65535
mininet> sh ovs-ofctl add-flow OSW1-4 priority=100,dl_type=0x8999,dl_dst=ff:ff:ff:ff:ff:ff,action=controller:65535
```

For Enable Layer 2 Forwarding

```
mininet> sh ovs-ofct1 add-flow OSW1-1 action=normal
mininet> sh ovs-ofct1 add-flow OSW1-2 action=normal
mininet> sh ovs-ofct1 add-flow OSW2-1 action=normal
mininet> sh ovs-ofct1 add-flow OSW2-2 action=normal
```

Generation of Traffic by Iperf

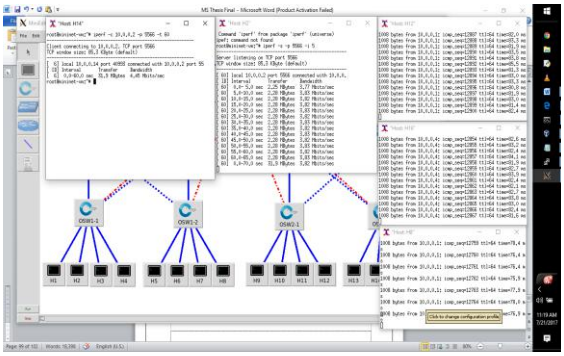


Fig 6.14 Generation of Traffic and Latency (Delay)

STEP2: Mininet's Network topology with MEMS

In the second phase, I add another Open flow switch is added which is called MEMSSW1 to the aggregation layer beside conventional switches and connect it to OF switches to test/apply the concept of MEMS switching (TOR). I intentionally introduced the links' bandwidth and latency with MEMSSW1 and keep it on a higher side, that is 1000Mb/s and 1msec, to testify the idea of MEMS. I set the buffer size and throughput (speedup) of the links to be equal to the link's bandwidth, or 1000 Mb/s, to demonstrate all optical switching. This is how the network topology is displayed:

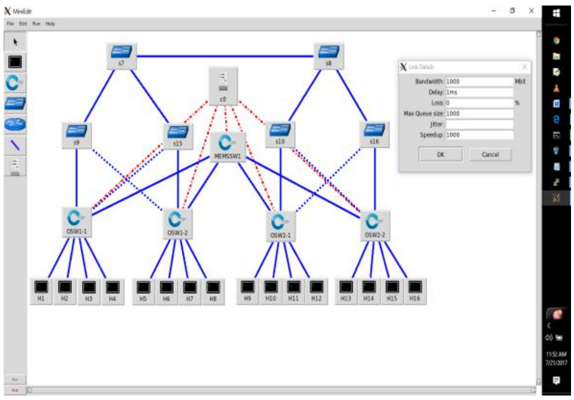


Fig 6.15 Network Topology with MEMS

6.5 Code for Topology Creation:

```
#!/usr/bin/python
from mininet.net import Mininet
from mininet.node import Controller, RemoteController, OVSController
from mininet.node import CPULimitedHost, Host, Node
from mininet.node import OVSKernelSwitch, UserSwitch
from mininet.node import IVSSwitch
from mininet.cli import CLI
from mininet.log import setLogLevel, info
from mininet.link import TCLink, Intf
from subprocess import call

def myNetwork():

  net = Mininet( topo=None,
            build=False,
            ipBase='10.0.0.0/8')

  info( '*** Adding controller\n' )
  c0=net.addController(name='c0',
             controller=RemoteController,
             ip='192.168.56.102',
             protocol='tcp',
             port=6633)
```

```
info( '*** Add switches\n')
s5 = net.addSwitch('s5', cls=OVSKernelSwitch, failMode='standalone')
OSW2-2 = net.addSwitch('OSW2-2', cls=OVSKernelSwitch)
OSW1-2 = net.addSwitch('OSW1-2', cls=OVSKernelSwitch)
s7 = net.addSwitch('s7', cls=OVSKernelSwitch, failMode='standalone')
s16 = net.addSwitch('s16', cls=OVSKernelSwitch, failMode='standalone')
s10 = net.addSwitch('s10', cls=OVSKernelSwitch, failMode='standalone')
s15 = net.addSwitch('s15', cls=OVSKernelSwitch, failMode='standalone')
s9 = net.addSwitch('s9', cls=OVSKernelSwitch, failMode='standalone')
s8 = net.addSwitch('s8', cls=OVSKernelSwitch, failMode='standalone')
OSW1-1 = net.addSwitch('OSW1-1', cls=OVSKernelSwitch)
OSW2-1 = net.addSwitch('OSW2-1', cls=OVSKernelSwitch)

info( '*** Add hosts\n')
H3 = net.addHost('H3', cls=Host, ip='172.168.10.3/16', defaultRoute=None)
h16 = net.addHost('h16', cls=Host, ip='10.0.0.16', defaultRoute=None)
h14 = net.addHost('h14', cls=Host, ip='10.0.0.14', defaultRoute=None)
h10 = net.addHost('h10', cls=Host, ip='10.0.0.10', defaultRoute=None)
H6 = net.addHost('H6', cls=Host, ip='172.168.10.6/16', defaultRoute=None)
h13 = net.addHost('h13', cls=Host, ip='10.0.0.13', defaultRoute=None)
h11 = net.addHost('h11', cls=Host, ip='10.0.0.11', defaultRoute=None)
H7 = net.addHost('H7', cls=Host, ip='172.168.10.7/16', defaultRoute=None)
H8 = net.addHost('H8', cls=Host, ip='172.168.10.8/16', defaultRoute=None)
H4 = net.addHost('H4', cls=Host, ip='172.168.10.4/16', defaultRoute=None)
h12 = net.addHost('h12', cls=Host, ip='10.0.0.12', defaultRoute=None)
H5 = net.addHost('H5', cls=Host, ip='172.168.10.5/16', defaultRoute=None)
h9 = net.addHost('h9', cls=Host, ip='10.0.0.9', defaultRoute=None)
h15 = net.addHost('h15', cls=Host, ip='10.0.0.15', defaultRoute=None)
H2 = net.addHost('H2', cls=Host, ip='172.168.10.2/16', defaultRoute=None)
H1 = net.addHost('H1', cls=Host, ip='172.168.10.1/16', defaultRoute=None)
```

```
info( '*** Add links\n')
OSW1-1H1 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-1, H1, cls=TCLink , **OSW1-1H1)
OSW1-1H2 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-1, H2, cls=TCLink , **OSW1-1H2)
OSW1-1H3 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-1, H3, cls=TCLink , **OSW1-1H3)
OSW1-1H4 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-1, H4, cls=TCLink , **OSW1-1H4)
OSW1-2H5 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-2, H5, cls=TCLink , **OSW1-2H5)
OSW1-2H6 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-2, H6, cls=TCLink , **OSW1-2H6)
OSW1-2H7 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-2, H7, cls=TCLink , **OSW1-2H7)
OSW1-2H8 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW1-2, H8, cls=TCLink , **OSW1-2H8)
OSW2-1h9 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-1, h9, cls=TCLink , **OSW2-1h9)
OSW2-1h10 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-1, h10, cls=TCLink , **OSW2-1h10)
OSW2-1h11 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-1, h11, cls=TCLink , **OSW2-1h11)
OSW2-1h12 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-1, h12, cls=TCLink , **OSW2-1h12)
OSW2-2h13 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-2, h13, cls=TCLink , **OSW2-2h13)
OSW2-2h14 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-2, h14, cls=TCLink , **OSW2-2h14)
OSW2-2h15 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-2, h15, cls=TCLink , **OSW2-2h15)
OSW2-2h16 = {'bw':4,'delay':'10ms','loss':0}
net.addLink(OSW2-2, h16, cls=TCLink , **OSW2-2h16)
s16OSW2-2 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(s16, OSW2-2, cls=TCLink , **s16OSW2-2)
s10OSW2-1 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(s10, OSW2-1, cls=TCLink , **s10OSW2-1)
s15OSW1-2 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(s15, OSW1-2, cls=TCLink , **s15OSW1-2)
s9OSW1-1 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(s9, OSW1-1, cls=TCLink , **s9OSW1-1)
s9s7 = {'bw':20,'delay':'3ms','loss':0}
```

```
net.addLink(s9, s7, cls=TCLink , **s9s7)
s7s15 = {'bw':20,'delay':'3ms','loss':0}
net.addLink(s7, s15, cls=TCLink , **s7s15)
s8s10 = {'bw':20,'delay':'3ms','loss':0}
net.addLink(s8, s10, cls=TCLink , **s8s10)
s8s16 = {'bw':20,'delay':'3ms','loss':0}
net.addLink(s8, s16, cls=TCLink , **s8s16)
s7s8 = {'bw':20,'delay':'3ms','loss':0}
net.addLink(s7, s8, cls=TCLink , **s7s8)
OSW1-1s15 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(OSW1-1, s15, cls=TCLink , **OSW1-1s15)
s9OSW1-2 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(s9, OSW1-2, cls=TCLink , **s9OSW1-2)
s10OSW2-2 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(s10, OSW2-2, cls=TCLink , **s10OSW2-2)
OSW2-1s16 = {'bw':10,'delay':'5ms','loss':0}
net.addLink(OSW2-1, s16, cls=TCLink , **OSW2-1s16)
OSW1-1s5 = {'bw':10000,'delay':'1ms','loss':0,'max_queue_size':10000,'speedup':10000}
net.addLink(OSW1-1, s5, cls=TCLink , **OSW1-1s5)
OSW1-2s5 = {'bw':10000,'delay':'1ms','loss':0,'max_queue_size':10000,'speedup':10000}
net.addLink(OSW1-2, s5, cls=TCLink , **OSW1-2s5)
s5OSW2-1 = {'bw':10000,'delay':'1ms','loss':0,'max_queue_size':10000,'speedup':10000}
net.addLink(s5, OSW2-1, cls=TCLink , **s5OSW2-1)
OSW2-2s5 = {'bw':10000,'delay':'1ms','loss':0,'max_queue_size':10000,'speedup':10000}
net.addLink(OSW2-2, s5, cls=TCLink , **OSW2-2s5)

info( '*** Starting network\n')
net.build()
info( '*** Starting controllers\n')
for controller in net.controllers:
  controller.start()
```

```
info( '*** Starting switches\n')
net.get('s5').start([])
net.get('OSW2-2').start([c0])
net.get('OSW1-2').start([c0])
net.get('s7').start([])
net.get('s16').start([])
net.get('s10').start([])
net.get('s15').start([])
net.get('s9').start([])
net.get('s8').start([])
net.get('OSW1-1').start([c0])
net.get('OSW2-1').start([c0])

info( '*** Post configure switches and hosts\n')
OSW2-2.cmd('ifconfig OSW2-2 10.1.2-2')
OSW1-2.cmd('ifconfig OSW1-2 10.1.1.2/16')
OSW1-1.cmd('ifconfig OSW1-1 10.1.1.1/16')
OSW2-1.cmd('ifconfig OSW2-1 10.1.2.1/16')
print "Dumping host connections"
dumpNodeConnections(net.hosts)
print "Testing network connectivity"

#def perfTest():

# if user test argument is active then pick the correct test

net.pingAll()
net.pingAll()
print (" Test bandwidth b/w H1 and H2..............." );
#H1, H2 = net.get('H1', 'H2')
#net.iperf((H1, H2)

#print (" Test bandwidth b/w H1 and H6..............." );
H1, H6 = net.get('H1', 'H6')
net.iperf((H1, H6))

#print( " Test bandwidth b/w H1 and H10..............." );
H1, H10 = net.get('H1', 'H10')
net.iperf((H1, H10))

#print( "Test bandwidth b/w H1 and H15..............." );
H1, H15 = net.get('H1', 'H15')
net.iperf((H1, H15))

# also argument for generating traffic

# arugment for stat analysis

CLI(net)
net.stop()

if __name__ == '__main__':
setLogLevel( 'info' )
myNetwork()
```

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Innovation and its Role in Success of an Organizations

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Abstract— *In every organization, innovation stands as a paramount concern, with its indispensable role in driving market advancement and coordination. The application of innovation spans across all facets of human endeavor, encompassing product development, managerial methodologies, and operational approaches, among others. Within the various definitions attributed to innovation, a consistent theme emerges: the alteration or enhancement of processes or products. Innovation embarks on a journey commencing from the conception of an idea and progressing through planning, ultimately culminating in the emergence of a novel function. This process distinctly sets innovation apart from mere creation. It is pivotal to recognize that innovation and creativity are distinct entities. This document delves into the significance of innovation and its pivotal role in fostering the growth, viability, and triumph of organizations.*

***Keywords*— Innovation, Growth and Creativity.**

I. INTRODUCTION

Innovation has remained a focal point for organizations over an extended duration. While introducing a fresh product can attract customers temporarily, the essence of innovation and invention extends beyond this. The crucial aspect lies in establishing a process that flows akin to the passage of time. As this process matures, competitors may gain access to its production technology, thereby affording you the opportunity to derive benefits from it.

This paper aims to delve into innovation and it's imperative within this context, as seen from a researcher's perspective. Various viewpoints on innovation are presented through different definitions. Some perspectives offer innovative interpretations, while others adopt a practical stance [1, 9].

In the contemporary landscape, innovation ranks among the most vital and intricate challenges confronting organizations. It serves as the key to organizational success. In the Gybenz concept, innovation within firms translates to the practical application of ideas across various domains such as products, processes, services, marketing systems, and management.

A set of researchers, including Aterbak, Dreft, and Atol, view innovation as a result of embracing ideas and concepts. They define innovation as units accepted by firms. Conversely, "Sabramanyan" approaches innovation from a behavioral perspective, defining organizational innovation as the enduring features exhibited by an organization over time [2, 10].

Adopting this approach implies that an organization's innovative behavior is consistent over an extended period. This signifies that innovation does not manifest rapidly; instead, it encompasses the average time for idea acceptance and the sustainability of innovation. Lampkin and Dez explore innovation from both behavioral and production viewpoints. They posit that firm innovation springs from a desire to explore novel concepts and evolves into a commitment to master new products or technologies.

In contrast, Harley and Halt's perspective on innovation revolves around a firm's culture of active participation and the willingness to embrace new ideas. However, merely fostering an open company culture is insufficient. The true measure of innovation lies in the scope of new idea implementation in business operations, which ultimately determines the level of innovation [3, 11].

II. INNOVATION

A notable quandary within the realm of innovation management lies in the absence of a uniform definition among researchers, policymakers, and authoritative bodies. The term "innovation," derived from the root "innovate," which signifies the creation of novel entities, has traditionally held a significant position within the economy, distinct from mere creation [3, 12]. However, its true significance was illuminated by Austrian economist Joseph Schumpeter when he formulated a theory of economic development that elevated innovation to a pivotal role in entrepreneurship.

This theory introduced three fundamental components - investment, innovation, and credit - as key drivers of economic advancement. Schumpeter meticulously distinguished between innovation and creation, as well as between innovators and creators. He emphasized that innovation can thrive independently of creation, and creation itself doesn't inherently fuel innovation. It is through this framework that Schumpeter pioneered the recognition of innovation's pivotal role within a country's economy. As early as 1930, he delineated various manifestations that innovation could take [4, 13]:

- The introduction or commercialization of new or enhanced products or services in the realm of existing offerings.
- The initiation of novel production processes or enhancements to established business processes.
- The creation of avenues for new markets to emerge.
- The development of fresh sources for supplies, including materials, equipment, and other inputs.
- Fundamental shifts in industrial structures and organizational paradigms [4, 14].

Innovation encompasses certain technological modifications, which align with Schumpeter's definition, involving the production of novel products or services, as well as the adoption of fresh methodologies or inputs by firms [5]. A fundamental tenet is that the pioneer, who initially employs these methods or approaches, is deemed innovative, while subsequent adopters are considered followers.

- Slatter presents a definition of innovation as a transformative process that improves products or systems in a manner novel to the firm, effectively introducing change [5, 15]. In this construct, creativity generates something novel, whereas innovation entails its effective utilization [5, 15].
- Advadya's interpretation characterizes innovation as the process of creating, developing, and successfully introducing new products, processes, or services [2, 16].
- The domain of Product Innovation necessitates the successful incorporation of newfound knowledge [6, 7, 17], hinging upon two vital aspects: freshness and utility. This process encompasses multiple stages, including industrial design, management, research and development, production, and economic endeavors tied to marketing or enhanced product offerings.
- Foxal's conception defines innovation as the capacity and willingness to adopt new products and services. This perspective underscores the customer-oriented nature of innovation, assessing the extent to which newly introduced offerings are embraced in the market, as viewed through a psychological lens.
- Endosamor's delineation characterizes innovation as the emergence of innovative products or novel processes within the market.
- The Australian Department of Tourism Industrial (DIST) frames innovation as the application of new ideas at an enterprise level, whether for product manufacturing, process enhancement, service provision, or organizational management and marketing.
- Porter argues that companies must innovate to gain a competitive advantage, often manifesting in the form of new technologies or innovative approaches to task execution.
- Dumenpor and Koopalakrishman's perspective casts innovation as a tool, system, program, or procured service that is fresh for an organization.
- Holt and Hurly's interpretation presents innovation as a company culture fostering collaboration, gauged by the preparedness of the organization to accept new ideas. Merely possessing access to novel concepts isn't sufficient; the degree of acceptance and integration of these ideas defines the level of innovation.

The notion of organizational innovation was outlined by Wang and Ahmed (2004) as the "capacity of an organization to introduce novel products into the market or to access new markets through innovative behaviors and processes" [8, 18].

- In 1998, Rogers defined innovation as a comprehensive term encompassing substantial transformations in business activities, ultimately leading to enhanced firm performance. These transformations might encompass novel or improved goods and services, investments in new machinery, market expansion, educational investments, the creation of intellectual assets, or advancements in technologies [6, 19].

From the late 1960s onwards, these definitions have grown progressively interconnected and can be succinctly encapsulated: the inaugural successful utilization of a product or process from its conceptualization to practical implementation [2]. Overall, the innovation process can be visually represented as illustrated in the figure below [8].

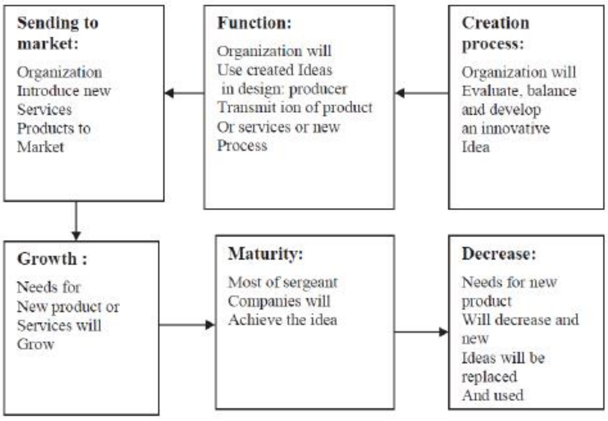

Fig.1: Innovation Process

The process of innovation can also be analyzed from a systemic perspective. A management specialist presents a structured approach to innovation, as depicted in the diagram below:

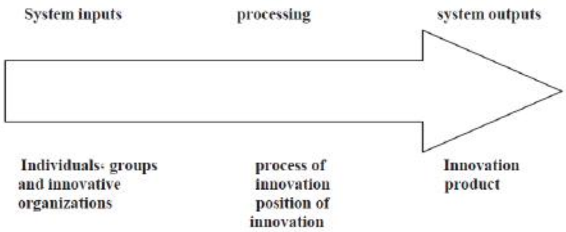

Fig.2: Systematic approach to innovation

III. TYPES OF INNOVATION

Certainly, innovation can manifest in various forms, each bringing about unique changes and advancements within organizations and industries. Here are some common types of innovation along with brief explanations:

Product Innovation: This involves the creation or enhancement of goods and services to meet changing customer needs or to offer entirely new solutions. It's about introducing novel features, designs, or functionalities that differentiate the product from competitors.

Process Innovation: Process innovation focuses on improving the methods and procedures by which products are manufactured or services are delivered. It aims to enhance efficiency, reduce costs, and optimize resource utilization.

Incremental Innovation**:** In this type, smaller, gradual improvements are made to existing products or processes. It's about refining what already exists rather than introducing revolutionary changes.

Radical Innovation: Contrasting with incremental innovation, radical innovation involves significant, transformative changes that can disrupt industries. It brings forth entirely new products, processes, or business models that reshape markets.

Business Model Innovation: This pertains to reimagining the way a business operates. It could involve altering revenue streams, distribution channels, partnerships, or value propositions. Companies like Uber and Airbnb are examples of business model innovators.

Service Innovation: This type centers on creating new or improved services to cater to evolving customer preferences or to address unmet needs. It often complements product innovation.

Open Innovation: The concept of open innovation involves collaborating with external partners, such as customers, suppliers, or research institutions, to collectively develop new ideas, products, or solutions.

Disruptive Innovation: Coined by Clayton Christensen, disruptive innovation refers to the introduction of simpler, more affordable products or services that initially target niche markets but eventually challenge and potentially overthrow established players.

Sustaining Innovation: This type concentrates on improving existing products or services to maintain a company's competitive edge. It's about staying current and relevant within the industry landscape.

Reverse Innovation: Often observed in emerging markets, reverse innovation involves designing products or services with the needs of less developed markets in mind and subsequently adapting them for more mature markets.

Technological Innovation: This encompasses the creation and implementation of new technologies or significant advancements in existing technologies to address challenges or create new opportunities.

Design Innovation*:* Design innovation emphasizes the aesthetic and ergonomic aspects of products and services. It's about enhancing user experience, usability, and visual appeal.

Social Innovation: This type focuses on finding innovative solutions to social problems or improving societal well-being. It often involves novel approaches to addressing issues like poverty, education, and healthcare.

Environmental Innovation: Also known as eco-innovation, this type involves developing products, processes, or solutions that minimize negative impacts on the environment and promote sustainability.

Remember that these types of innovation are not mutually exclusive and can often overlap. Organizations may engage in multiple forms of innovation to stay competitive, adapt to changing markets, and drive growth.

IV. INNOVATION IN ORGANIZATIONS

Innovation within organizations refers to the process of introducing new ideas, products, services, processes, or methods that result in positive changes and advancements. It is the driving force behind a company's ability to evolve, adapt, and remain competitive in a dynamic business landscape. Innovation is not limited to just coming up with new products; it extends to various aspects of an organization's operations.

Here's a more detailed explanation of innovation within organizations:

New Ideas: Innovation begins with creative thinking and ideation. It involves brainstorming, exploring possibilities, and generating novel concepts that have the potential to enhance the organization's performance or create new opportunities.

Business Model Innovation: Changing the way a company operates, generates revenue, or interacts with customers is part of business model innovation. It can involve adopting new distribution channels, pricing strategies, or even transitioning to subscription-based models.

Cultural Innovation: Cultivating a culture of innovation within the organization is crucial. This involves encouraging risk-taking, creativity, and open communication, as well as embracing failures as learning opportunities.

Open Innovation: Collaborating with external partners, such as customers, suppliers, or research institutions, to share ideas, resources, and knowledge can lead to innovative breakthroughs that might not have been possible internally.

Strategic Innovation: Aligning innovation efforts with the organization's overall strategy is essential. Strategic innovation ensures that new ideas and developments are in line with the company's long-term goals and objectives.

Leadership and Management Innovation: Innovative leadership and management practices can lead to more engaged and motivated employees, streamlined decision-making processes, and an overall agile and adaptable organizational structure.

In today's competitive environment, organizations that prioritize innovation are more likely to stay relevant and thrive. Effective innovation requires a willingness to take calculated risks, an open-minded approach to change, continuous learning, and a commitment to fostering a culture that encourages and rewards creative thinking. It's about not only generating ideas but also successfully implementing and scaling those ideas to drive sustainable growth and success.

V. CONCLUSIONS

In the contemporary business landscape, innovation stands as a paramount and intricate challenge that organizations encounter. It serves as a pivotal determinant of success for these entities. It is imperative for every company to establish a comprehensive innovation process that spans from the initial stages of creation to the eventual execution. As a product progresses through its lifecycle and enters the growth phase, it becomes vital for the company to introduce transformative changes to the product before it reaches the market saturation point.

This strategic shift is driven by the recognition that as a product matures, other competing enterprises within the industry are likely to gain access to the same or similar production technologies. This necessitates companies to continually infuse innovation into their products to maintain a competitive edge.

The innovation process encompasses the ideation, research, development, testing, and eventual market introduction of novel or enhanced products, services, or methodologies. It involves not only the generation of inventive ideas but also the systematic implementation of those ideas to create value for customers and the organization itself.

Innovation serves as a vital conduit for organizations to adapt to changing market dynamics, customer preferences, and technological advancements. By continually innovating, companies can circumvent stagnation and capitalize on new opportunities. This proactive approach to innovation is akin to having a set of keys that unlock the doors to sustainable growth and enduring success in a rapidly evolving business environment.

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Entrepreneurship in the Development of an Agile Enterprise

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Abstract— *With the escalating significance of adaptability within modern organizations, it becomes crucial to explore the means of comprehending the distinct traits exhibited by agile enterprises. Consequently, the objective of this research paper revolves around pinpointing the manifestations of entrepreneurial behavior within an agile enterprise, along with the strategic consequences of fostering agility. This study draws insights from literature in both entrepreneurship and strategic management, in conjunction with a detailed case study. The research article initiates by delving into the contextual landscape of entrepreneurship, subsequently transitioning to an exploration of the attributes inherent to agile enterprises. The outcomes gleaned from this research notably underscore the defining features of an agile enterprise operating within the contemporary business milieu. The findings distinctly underscore that qualities like entrepreneurial resourcefulness and strategic leadership significantly amplify an organization's capacity to effectively contend in an increasingly competitive and dynamic business sphere.*

Keywords— ***Entrepreneurship, Agile Enterprise, Entrepreneurial Resourcefulness, Acuity, Strategic Leadership, Flexibility.***

I. INTRODUCTION

The emergence of the Internet marks the initiation of a new era: the digital age. In contrast to the industrial age, the pace of transformations in the digital age maintains an incessant and less foreseeable momentum. Given the acceleration of these changes, scholars underscore the paramount importance of agility (Brueller et al., 2014; Fourné et al., 2014; Lewandowska and Sajdak, 2013; Weber and Tarba, 2014). This concept signifies the capability to outpace competitors and consistently recalibrate a firm's strategic trajectory. This involves a series of enterprising actions complemented by strategic thought processes, including cultivating dynamic capabilities and retaining adaptability in the face of dynamic shifts.

Entrepreneurial behavior pertains to the actions and conduct of entrepreneurs within the business environment. Delving into entrepreneurial behavior reveals that agility constitutes a pivotal facet of entrepreneurship. Entrepreneurial undertakings fundamentally rest upon the capacity to mobilize essential resources to seize market opportunities. An agile enterprise necessitates the evaluation of its resource adequacy and the potential construction or acquisition of vital resources externally. This encompasses harnessing the knowledge and expertise of key business partners, often through the creation of strategic networks or partnerships, to amplify their own capabilities.

This research paper's objective lies in identifying instances of entrepreneurial behavior within an agile enterprise and assessing their influence on business adaptation to novel challenges. While entrepreneurship has garnered burgeoning attention in academic discourse, scant research has scrutinized the analysis of entrepreneurial behaviors in the context of agility. The research paper probes diverse forms of entrepreneurial activities and elucidates the attributes characterizing an agile enterprise. The paper concludes by offering a reflective remark, deliberating on the theoretical contribution and managerial ramifications of the research findings.

II. ENTREPRENEURIAL BEHAVIOR

In the realm of academic literature, diverse interpretations of entrepreneurship abound. While certain scholars emphasize the process enacted by entrepreneurs (e.g., Alvarez and Barney, 2007; Hitt et al., 2001; Shane and Venkataraman 2000), others place weight on the inherent traits of entrepreneurs (e.g., Casson, 2014; Drucker, 1998; Timmons, 1989). For instance, Peter Drucker contends that entrepreneurs commit themselves to the "systematic practice of innovation" (Drucker, 1998: 149). Conversely, Lumpkin and Dess (1996) and Hitt et al. (2001) underline entrepreneurship as the catalyst for new venture creation.

A burgeoning field within entrepreneurship research spotlights entrepreneurs' pursuit of opportunities. Scholars like Shane and Venkataraman (2000) and Short et al. (2010) posit that opportunities constitute the cornerstone of entrepreneurship. As Shane and Venkataraman (2000: 220) assert, "To have entrepreneurship, you must first have entrepreneurial opportunities." Correspondingly, Short et al. (2010: 40) state, "Without opportunity, there is no entrepreneurship." Kurczewska (2013) defines "opportunity" as prospects and potentialities for undertaking novel endeavors, ones that have yet to be realized or executed in a specific manner, but are deemed viable, appealing, and value-enhancing. Academic portrayals of 'opportunity' align with its conventional connotations. In the entrepreneurship domain, the widely referenced definition of entrepreneurial opportunity hails from Shane and Venkataraman (2000). They define opportunities as "situations in which new goods, services, materials, or methods of organization can be sold at a price higher than the price of their production" (Shane and Venkataraman, 2000: 220). Kurczewska (2013) also emphasizes that opportunities encompass scenarios where businesses utilize diverse resources, forging novel connections between utilization methods and achievable objectives, all while envisioning profitability.

These aforementioned definitions vividly portray the stance adopted by researchers in the entrepreneurship sphere, underscoring its role in shaping an agile enterprise whose chief objective lies in the adept adaptation to the ever-evolving environment through effective entrepreneurial endeavors, among other factors. This affirmation aligns with Kurczewska's assertion (2013) that the swiftness of idea implementation is of paramount importance in the contemporary milieu of rapid social progress. In such an environment, where the lifecycle of products and services has dramatically shortened, and technical and technological advancements burgeon at an unprecedented pace, the capability to identify requisite resources for capitalizing on market opportunities and appraise the sufficiency of internal resources, along with the potential to procure external resources, forms the bedrock for identifying innovative necessities (Sajdak, 2013).

Entrepreneurial orientation, in part, elucidates the managerial processes and operational activities that propel certain companies ahead of competitors (Wiklund and Shepherd, 2003). Lumpkin and Dess (1996) define entrepreneurial orientation as a synthesis of five dimensions: proactiveness, innovativeness, competitive aggressiveness, risk-taking, and autonomy. While the first two attributes bear a forward-looking orientation, the latter three are intertwined with change-driven actions. Collectively, an organization embracing entrepreneurial orientation is more likely to channel their focus and exertion towards recognizing and realizing opportunities (Wiklund and Shepherd, 2003). The table below expounds upon each dimension, providing an elaborate depiction of their characteristics.

Table 1: Aspects of Entrepreneurial Orientation

EO dimensions	Description
Autonomy	refers to the ability and will to be self-directed in the pursuit of opportunities
Innovativeness	reflects a firm's tendency to move beyond current practices and support novelty ideas that may result in new ways of doing things
Risk taking	refers to a firm's willingness to depart from established practices into unknown field
Proactiveness	refers to a firm's capability to seize the initiative in the marketplace
Competitive aggressiveness	refers to a firm's propensity to challenge its competitors to outperform industry rivals in the marketplace.

Source: (Lumpkin and Dess 1996)

The depiction of the five dimensions of entrepreneurial orientation presented by Lumpkin and Dess (1996) underscores the pertinence of agility. The concept of agility has its foundations deeply entrenched in the realm of strategic management (Sambamurthy et al., 2003). Strategic management involves navigating decisions amidst various strategic maneuvers aimed at attaining a competitive edge within a tumultuous environment (Hitt et al., 2001). Analogous to entrepreneurship, wealth creation forms the nucleus of strategic management. Whereas entrepreneurship is primarily focused on creation (Drucker, 1998; Lumpkin and Dess, 1996; Shane and Venkataraman, 2000), strategic management orbits around fostering capabilities and upholding competitive advantage (Hitt et al., 2001; Porter, 1991; Sambamurthy et al., 2003).

The academic discourse in the arenas of both strategic management and entrepreneurship contributes to shaping contemporary perspectives on strategic thinking and entrepreneurial conduct. The amalgamation of entrepreneurial behavior and strategic thinking, in theory, has the potential to enable organizations to adopt a more proactive stance in adapting to the swiftly shifting business landscape. In the ensuing discussion, the attributes characterizing an enterprise will be meticulously examined.

III. AGILE ENTERPRISE ATTRIBUTES

Agility encompasses the capability to swiftly and adeptly respond to shifting markets and evolving customer demands, achieved through the production of high-quality goods, reduction of lead times, and most crucially, the reconfiguration and mobilization of resources (Sambamurthy et al., 2003). Agile enterprises consistently wield the prowess to effect changes, thereby sustaining their competitive edge. This involves actions like reconfiguring and honing competencies (Weber and Tarba, 2014).

Fourné et al. (2014) elucidated three vital dynamic capabilities that empower multinational enterprises to thrive on a global scale: detecting local opportunities, actualizing global synergies, and appropriating local value. These capabilities empower multinational enterprises to unearth novel prospects and maintain competitive supremacy. Conversely, Sambamurthy et al. (2003) posit that agility encompasses three interrelated capabilities: customer agility, partnering agility, and operational agility. Sambamurthy et al. (2003) contend that timely operations, customer interactions, and collaboration with business partners contribute to the essence of agility. By blending the insights of Fourné et al. (2014) and Sambamurthy et al. (2003), it can be contended that agility entails a sequence of actions undertaken by an enterprise to harmonize its internal and external environments.

Firstly, Sambamurthy et al.'s (2003) concept of operational agility resonates with one of the dynamic capabilities advocated by Fourné et al. (2014): actualizing global synergies. Both studies notably emphasize the significance of resource leverage for ensuring operational efficacy, encompassing aspects such as cost-efficiency, punctuality, and superior quality. Collectively, the findings of Fourné et al. (2014) and Sambamurthy et al. (2003) point towards an integrated and adaptable approach to the internal landscape.

Secondly, the grasp of regional market conditions and adaptation to local values (Fourné et al., 2014) mirrors the need for involving customers in the discovery and commercialization of opportunities (Sambamurthy et al., 2003). The crux of the argument is that products and service offerings should be rooted in market demand. Moreover, agile organizations should cultivate entrepreneurial insight to pursue and capitalize on market opportunities.

Thirdly, Sambamurthy et al. (2003) allude to 'partnering agility' as the ability to leverage the expertise and assets of suppliers, distributors, or manufacturers through collaborative alliances. Similarly, Fourné et al. (2014) underscore the pivotal role of partnerships in sustaining a global market presence. The underlying similarity lies in the imperative of harnessing key assets to counteract the limitations posed by scarce resources. Enterprises aiming to seize market opportunities necessitate access to pivotal resources. Given the challenges posed by scarce resources, partnering emerges as an attractive avenue for companies to optimally capitalize on commercial prospects.

In essence, the attainment of agility profoundly impacts an enterprise's capacity to forge a competitive advantage, enabling it to promptly and effectively fulfill market demands in a tumultuous environment. Enterprises equipped with swift responsiveness and fitting competencies stand poised to exploit the opportunities inherent in the economic landscape, thereby securing an advantageous stance vis-à-vis competitors.

The notion of the agile enterprise primarily serves to elucidate how organizations engineer and sustain competitive advantages through the mobilization of resources. An agile enterprise doesn't merely respond to alterations; it initiates them. Consequently, the crux of comprehending the agile enterprise hinges on delineating how enterprises choreograph their resources and, more crucially, unraveling the attributes emblematic of agility.

Enterprises require a repertoire of competencies that empower them to nimbly exploit market prospects and promptly navigate the rapidly evolving business milieu. The author conceptualizes these attributes as follows:

Acuity revolves around the routines an enterprise crafts to meticulously observe and dissect market dynamics. This encompasses strategic long-term planning, intermittent SWOT analyses, market research, and consumer insights. Such endeavors are pivotal in bolstering and augmenting the competitive edge of an enterprise. Alongside identifying market prospects through strategic analyses, companies should employ early warning systems or devise effective methodologies to scrutinize the market environment for optimized business operations (Trzcielinski, 2011). A robust market analysis lays the groundwork for innovation and creativity. Collaborative endeavors with customers often aid in understanding consumer needs and unearthing potential market prospects (Sambamurthy et al., 2003). This market-driven or consumer-centric innovation thrives on extensive consumer engagement and validated market requisites.

Another pivotal dimension centers on operational activities tied to information technology. In the digital era, the adoption of information technology—such as Customer Relationship Management, Search Engine Optimization, and social media—assumes paramount significance. Consequently, digital marketing initiatives and IT strategies emerge as integral components of contemporary organizational operations. While digital marketing activities aim to attract new customers, the management of customer knowledge ensures the satisfaction of existing clientele. In essence, the role of IT in the contemporary business landscape is formidable, particularly when viewed through the lens of acuity.

Flexibility denotes the capacity to rearrange existing resources and the aptitude to adapt essential measures and oversee changes (Trzcielinski, 2011). This implies the willingness to accommodate errors and embrace enhancements, particularly relevant for manufacturing entities. The notion of a flexible manufacturing system pertains to a production process that permits swift adjustments to manufacture diverse products at varying production volumes (Krupski, 2008). The crux of a flexible manufacturing system lies in its efficiency and its agility to embrace alterations. In a significant alignment with this, the concept of operational agility propounded by Sambamurthy et al. (2003) underscores flexibility. It encapsulates an organization's capability to identify and execute changes promptly, enabling swift reconfigurations and adaptations to existing processes in response to shifts. Additionally, the role of Information Technology (IT) is pivotal in fostering business agility within the digital age. Information technology serves as an enabler of operational agility by dictating a firm's capacity to process and store information. Given the rising reliance of firms on IT as a competitive tool, it substantively facilitates such agility (Sambamurthy et al., 2003).

Entrepreneurial Resourcefulness is intrinsically tied to the knack for transforming weaknesses into strengths and converting market threats into opportunities by optimally leveraging available resources. Resourceful entrepreneurs proactively seek alternative avenues to achieve their objectives; they enhance existing products and processes to bolster productivity and performance. In agile enterprises, resourcefulness encompasses the ability to gauge resource sufficiency, augment and cultivate current resources, and harness vital assets from business partners. Moreover, entrepreneurial resourcefulness aligns with the capacity for innovation. Nurturing enduring relationships with pivotal stakeholders—such as suppliers, distributors, and customers—forms the bedrock of business triumph (Sambamurthy et al., 2003). From an economic standpoint, relationship-building curtails marketing expenses, as loyal customers make recurring purchases over time. Similarly, a robust rapport with suppliers reduces procurement costs, as loyal customers often receive trade discounts. In terms of the resource-based perspective, relational capital signifies the connections between diverse firms, enabling resource exchanges to thrive (Lavie, 2006).

Strategic leadership is characterized by the proficiency to enhance long-term viability while concurrently maintaining short-term financial stability without disturbing day-to-day operations (Rowe, 2001). This orientation focuses on safeguarding existing structures while propelling organizations toward higher echelons (Rowe and Nejad, 2009). Essentially, it embodies a fusion of visionary leadership and strategic acumen.

IV. CONCLUSION

The prosperity of a company hinges significantly upon its proficiency in rapidly and effectively addressing the external environment, a quality of paramount importance in the swiftly evolving landscape of modern business. This paper centers on entrepreneurial behavior as the cornerstone of identifying and successfully implementing adaptations necessitated by external changes. Such adaptations encompass a spectrum of alterations in managerial strategies, daily operations, marketing approaches, and other facets of business operation. Consequently, qualities intrinsic to entrepreneurship, including a proclivity for risk-taking, a penchant for innovation, and a willingness to embrace novel challenges, assume an indispensable role in steering the company towards progress.

This theoretical research endeavors to outline the attributes underpinning an agile enterprise, thereby enriching the contemporary perspective on enterprise agility. Firstly, the notion of "acuity" pertains to the systematic practices employed by a company to discern opportunities and potential threats within the market. The research expounded in this paper underscores that successful enterprises consistently conduct thorough evaluations, akin to a 'health check-up,' and promptly instigate requisite adjustments in response. Secondly, "flexibility" signifies an enterprise's capacity to both initiate and adeptly accommodate changes. In this context, an agile entity should be poised to allocate resources and time for unforeseen modifications, encompassing unanticipated shifts such as unscheduled production or delays.

Entrepreneurial resourcefulness, as the third attribute within an agile company, encompasses the acumen to identify the essential resources imperative for capitalizing on emergent market prospects. This dynamic entails the discernment to opt for the development of in-house resources, procuring resources externally, or even fostering resource-sharing alliances with other entities. Ultimately, this resourcefulness empowers enterprises to harness their competitive edge. Lastly, the term "strategic leadership" denotes the proficiency to propel a company forward while preserving its fiscal well-being. This form of leadership is adept at navigating the organization toward the next echelon without jeopardizing its financial equilibrium.

In summation, this paper unveils how entrepreneurial behavior, harnessed within an agile framework, plays a pivotal role in sustaining and advancing company achievements. By promoting attributes such as acuity, flexibility, entrepreneurial resourcefulness, and strategic leadership, businesses can effectively navigate the intricate landscapes of modern business, embracing change and evolving in sync with the ever-fluctuating external environment.

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A Study of factors promoting performance enhancement in Construction Project Management and Quality of deliverables

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Abstract— *This study evaluates the effectiveness of existing quality management frameworks and strategies in the Saudi Arabian construction context. It examines the challenges faced by practitioners in implementing these strategies and proposes tailored recommendations to bridge the gap between theory and practice. The findings of this study provide valuable insights for construction firms, policymakers, and regulatory bodies, aiding in the formulation of strategies to enhance project quality and overall performance. Ultimately, this study contributes to the body of knowledge surrounding construction project management in Saudi Arabia by shedding light on the nuanced dynamics between quality management practices and project performance. It offers a roadmap for stakeholders to navigate the complexities of the construction industry, optimize resource utilization, and elevate the quality standards of projects, thereby fostering sustainable development and growth in the country.*

Keywords— ***Quality management frameworks, Saudi Arabian construction, Implementation challenges, Recommendations, Project performance***

I. INTRODUCTION

the introduction The study will be conducted through a comprehensive review of existing literature on quality management, performance enhancement, and construction project management, both globally and within the Saudi Arabian context. The study adopts a mixed-methods approach, encompassing qualitative interviews and quantitative surveys, to gather insights from construction professionals, project managers, and stakeholders involved in various projects across Saudi Arabia. Key factors affecting quality management and performance enhancement are identified, analyzed, and categorized into internal and external dimensions. Internal factors include organizational culture, leadership, resource allocation, communication, and project planning, while external factors encompass regulatory compliance, economic conditions, technological advancements, and client expectations. By delving into the intricate interplay of these factors, the thesis offers a holistic understanding of their impact on project outcomes.

II. OVERVIEW

The leader of the project has to have initiative and expertise in order to bring together such a varied group and assist them in cooperating on a shared course of action. As we shall see further on in this chapter, in order to expand their influence, project leaders need to develop other techniques to compensate for the fact that they do not have official power. Every day, project teams must make judgments, and those decisions are often made with little information. They put in their utmost effort, and when it turns out that their efforts were in vain, they gather their thoughts, consider what they've picked up, and then proceed to make new choices. For this to be successful, the team's culture has to be one that encourages teamwork, trust, and resiliency. The leaders of a project team are responsible for establishing its tone and culture. Does this description apply to persons who work in environments that need them to wear hard helmets and safety glasses? Software developers, human resource policy makers, architects, and scientists may come to mind while reading it. Yes, since these very strenuous endeavors also demand making judgments on a consistent basis.

III. PROJECT MANAGEMENT STRATEGIES

To ensure a high-quality product, diagrams and lettering MUST be The concept of range of project management strategies, constructability approaches, construction operations and best practices, efficiency of the management of construction projects is discussed here in brief. The RFI (Request for Information), for instance, inquires about issues with constructability, construction drawings, and requirements in order to get clarity and direction. The amount and nature of the information flow will vary depending on the intended recipients and the extent to which they are responsible for the project. As a result, this instrument is always within reach in the building trade. Negotiating. Negotiations in the construction industry may cover a broad variety of issues, but the exchange of money for the delivery of services is by far the most prevalent. You'll need this expertise in a variety of contexts, including negotiating the proposed costs and determining the scope and cost of contract revisions.

This skill is useful in an almost infinite range of situations. In construction scheduling, for instance, a safe and economically controlled sequence of site operations is achieved by the proper sequencing of construction activities. If the events were timed properly, this would be the case. A labor dispute between trade unions is an example of a more complex issue because it involves resolving both the corrective action and the preventative action necessary to address the problem, as well as integrating the difference between the causes and effects of the issue. When constructing a structure, experts are involved in every step of the process. Value planning, budgeting, scheduling, and risk management are all intertwined with the design creation process, as are the hiring of contractors, the management of workers on the job site, the use of constructability techniques, the settlement of conflicts, and the ultimate closeout. Additional expertise that is generally seen as crucial includes health, safety, and environmental policies; rules and regulations of the jurisdictional authority; contract management; and public relations. In specifically, the strategy phase is when the objectives of the control systems are determined. These worries go well beyond the usual quality, timeliness, and cost worries.

IV. PERFORMANCE ENHANCEMENT

If peak performance is the objective, members of the team should make it a practice to provide and receive constructive feedback in an open and honest way. One way in which leaders may help shape a company's culture is by consistently rewarding and recognizing desired behaviour and making the values of the organization clear to everyone. In his book The Culture Code, Daniel Coyle argues that high-performing organizations share a commitment to safety as a core value. Coyle found that his most successful teams allowed themselves to be vulnerable, which aided in their development. They were given a chance to provide and receive feedback that would push them to improve. Due to the risk involved, there has to be solid trust amongst team members. Before trust could be established amongst each other, individuals needed to feel safe. As was said previously, Bill was in charge of the project for the telecom business, and he'd decided the foreman might dispute headquarters' orders. Because of this, the foreman felt comfortable approaching Bill with any future problems, knowing that Bill would hear him out and work with him to find a solution. One's own safety can never be guaranteed. Far too many major decisions are made with little to no input from the general public. They opt out because they don't want to be the one whose opinion is ignored or who has to endure the awkwardness of being punished for having an alternative position.

But what project manager wouldn't want team members who would see and communicate the truth? Project management has come a long way from its initial modern use in the construction industry in the late 1950s. Today, project management is a well-established field that provides executive management of all phases of development, from the initial client idea through funding coordination, planning approval, sustainability, design delivery, team selection and procurement, construction, commissioning, handover, review, and coordination of facilities management. The client's notion serves as the starting point, and the process continues all the way up to the coordination of facilities management. Project managers are designated as the client's representative under this Code of Practice, although their specific roles may vary depending on the nature of the project at hand.

So, we can say that project management is "the overall planning, coordination, and control of a project from inception to completion, with the goal of meeting a client's requirements to produce a functionally and financially viable project that will be completed safely, on time, within authorized cost, and to the requirements of the requisitions." In its sixth iteration, this Code of Practice has established itself as the go-to source for information on the theory and practice of project management in the construction and real estate sectors. This data is helpful for clients, project management firms, schools, and students, as well as individuals in the construction and development industries. A large chunk of the information given in the Code of

Practice is also relevant to the project management practitioners who operate in other business disciplines.

V. LITERATURE REVIEW

A literature survey is a strategy that gives the correct thought and understanding of the subject of research. This section presents an overview of the existing literature relevant to the research presented in this research.

Establishing communication of a high quality in construction projects is vital to ensure effective cooperation and sustaining understanding among project stakeholders, according to Ali Rahimian (2022). As a matter of fact, poor communication is often at the root of low output and subpar results. Nobody understands how the degree of communication impacts people's performance in their employment, even though it is commonly known that workers' interpersonal skills have a direct influence on the quality of their communication. This study fills a knowledge vacuum by creating a metric for gauging construction workers' communication skills. The purpose of this literature review is to identify the most crucial aspects of interpersonal competence. Leadership, communication, team building, and setting clear goals are all covered. Approximately 180 responses were collected from a questionnaire designed to elicit construction professionals' perspectives on the impact of these skills on the quality of communication. Then, a communication quality prediction (CQP) model is constructed using artificial neural networks. Predictions regarding the quality of interactions between workers may be made with high confidence using this approach. The model achieves an accuracy of 87% during training but only 79% during testing. CQP is then put to work in a real-time environment, where it achieves an accuracy rate of 80% for its predictions, proving its reliability. In the construction business, this study is the first to provide a quantitative and predictive model connecting interpersonal skills with the efficacy of communication. For a clearer picture, the CQP can foresee possible interpersonal problems and guide construction managers in the creation of training programs for interpersonal skills.

In 2022, Sareh Rajabi argues that enhancing the sustainability performance of construction projects is essential to the long-term survival of regions, governments, and the world as a whole. Key performance indicators (KPIs) for sustainability have the potential to contribute significantly to the development of sustainable construction methods. The lack of appropriate sustainability KPIs that can be used by contractors throughout the execution phase of construction projects is a problem despite the numerous studies that have been undertaken on indicators of sustainability. The purpose of this research is to develop and examine key performance indicators (KPIs) to track and evaluate the sustainability of ongoing building projects. Twenty-two sustainability indicators were identified and whittled down after a thorough review of the relevant literature. Separate buckets were created for environmental elements and socioeconomic considerations. After that, a survey was drafted and sent to UAE-based construction industry professionals. Thirty-one participants used AHP to do a side-by-side comparison of two indications in order to determine which was more important. The study's authors concluded that a global weight of 0.164 was the best measure of the importance of the indicator of the usage of renewable sources of energy (environmental group). The indicator of building site safety, on the other hand, had the heaviest global weight (SEG) of 0.093. This work is significant because it addresses a previously unrecognized gap in the literature. Companies in the construction industry might also benefit from this study by learning more about the sustainability indicators that would work best for their projects throughout the design and construction phases.

VI. STUDY OF PERFORMANCE ENHANCEMENT

We have chosen Saudi Arabia as the study zone and additionally we have gathered samples from different respondents such as Manager, Project management officer, Workers, Customers etc., located inside the study zone. We have assembled tests from 500 respondents utilizing random sampling strategy, who responds to the various requests.

PERFORMANCE ENHANCEMENT SAMPLES

Satisfaction Index		Response				Total
		Manager	Officer	Workers	Customers	
Highly Satisfied	Procurement management	43	43	28	51	165
Satisfied		81	53	12	22	168
Moderate		29	49	24	24	126
Dissatisfied		10	9	6	11	36
Highly Dissatisfied		1	2	1	1	5
Total						500

VII. RESULTS AND DISCUSSION

The considerable effect of the regulatory framework and compliance on quality management and performance improvement in construction project management inside Saudi Arabia is one of the most important conclusions of this study. The study was conducted in Saudi Arabia. The regulatory climate is a critical component in the formation of the standards and practices that are implemented in building and construction projects. Participants in the poll emphasized how important it is to secure excellent results by following to local building norms as well as international standards. On the other hand, it was pointed out that ambiguities and contradictions in the legislation can be a barrier to the implementation of good quality management practices. This shows that laws need to be made clearer and more consistent in order to ease smooth compliance and encourage better project performance. Another essential component that plays a role in determining quality management and the level of performance improvement achieved in construction project management is the presence of an effective leadership and project management practice. It was emphasized that the job of project managers is very important in order to guarantee stringent quality standards and overall success with the project.

In conclusion, the analytical study that was conducted to investigate the factors that influence quality management and performance enhancement in construction project management within the context of Saudi Arabia has provided useful insights into the complex dynamics of the construction industry in the region. The study was undertaken with the intention of examining the factors influencing quality management and performance enhancement in construction project management within the context of Saudi Arabia. This research has shed light on the varied nature of the problems and possibilities in achieving high-quality results in construction projects. This was accomplished by conducting a thorough assessment of the relevant literature, conducting an analysis of real-world case studies, and taking into account both local and worldwide best practices. The outcomes of this research illustrate the relevance of many aspects in molding quality management practices and overall project success. These factors include leadership commitment, effective communication, stakeholder involvement, technology integration, and regulatory compliance.

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Influence of industrial wastewater on the geotechnical and physicochemical properties of fine-grained soil

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Abstract— *Fine-grained soil contamination is a daily occurrence due to industrial development and pipeline or reservoir leaks. The modification of the geotechnical properties of the polluted soil is a worry in addition to environmental issues like groundwater pollution. Recent studies have carefully examined the characteristics of contaminated fine-grained soils because it has been demonstrated that contamination modifies the geotechnical properties of soil. However, a thorough evaluation of the impact of industrial wastewater from paper (PW) and leather (LW) wastewater on the geotechnical characteristics of fine-grained soils is still lacking. As a result, thorough experimental studies have been carried out on both uncontaminated and contaminated fine-grained soils that include various concentrations of PW and LW. The soil samples were extracted from the lands in Benha City, Cairo, Egypt, which were exposed to PW and LW at 2, 4, 6, 8, 12, and 16 months. The findings showed that as soil ages, there is a decrease in the maximum dry density and Atterberg limits of the soil containing PW, as well as a increase in the optimum moisture content (OMC) and cohesive. On the other hand, the findings also showed that there is a decline in maximum dry density and Atterberg limits as well as a rise in OMC and cohesive. Additionally, ageing caused a further decrease in cohesion and increased the free swelling values in the case of the soil coated with PW, while decreasing the leather wastewater exposure. Finally, the microscopic investigations and mineralogical analysis confirmed the trend of the experimental results on the mechanical properties of the contaminated soils.*

***Keywords*— Fine-grained soil; Geotechnical; Mechanical properties; Wastewater; Microstructure.**

I. INTRODUCTION

Massive amounts of both solid and liquid waste have been produced because of rapid industrialization. Such trash should not be disposed of carelessly, especially on land, which has led to severe environmental issues. There have been reports of foundation and structure failures brought on by contaminated soil, chemical spills, etc. [1–2]. It has been demonstrated that many geotechnical properties of fine-grained soils are impacted by the inorganic and organic contaminants found in industrial effluents [3–5]. Soil-pollutant interactions and the impact of pollutants and industrial effluents on different geotechnical qualities must be studied and understood for a variety of engineering applications. A critical analysis of the available literature has indicated that, up until now, the focus has been on understanding the impact of pure chemicals on commercial soils (kaolinite and bentonite), with relatively little research reported on the impact of industrial effluents, particularly on natural soils [6,7].

Some of the hazardous and relatively water-soluble hazardous substances found in industrial wastewater include paper, leather, and textile waste. Industrial wastewater contamination puts wildlife at risk of a number of threats, such as poisoning of animals at the top of the food chain who consume a lot of other organisms that have absorbed wastewater into their tissues, disruption of breeding patterns by rendering animals sick and unable to reproduce, irritation or ulceration of the skin, mouth, or nasal cavities, damage to red blood cells, and damage to the adrenal tissue of birds, which impairs their ability to fight off predators [8-10]. The hormonal balance of birds can also be impacted by exposure to industrial effluent, affecting things like the luteinizing protein.

Although scientists have extensively studied the geotechnical characteristics of contaminated fine-grained soils, few researchers have looked at the effects of paper and leather wastewater pollution on the geotechnical properties of fine-grained soils [11,13]. Khan et al. [3], Stalin et. al. [6], and Easa et. al. [8] conducted laboratory testing programs to evaluate the effects of industrial wastewater contamination and ageing effects on the geotechnical characteristics and behavior of fine-grained soil [3,6,8]. For the investigation by Easa et al. [14], samples of naturally contaminated groundwater from household wastewater were collected at the groundwater pumping level. X-ray and chemical conventional testing were done to figure out the amount of toxins in the groundwater [14]. It was concluded that the primary cause of groundwater pollution is thought to be residential wastewater. Its chemical composition is highly poisonous and dangerous. where it seriously affects issues with public health. Another study reported that the capacity of clay to expand due to changes in water content—which may be caused by ground water—puts pressure upward on the foundation. Expansion of clays and the resulting swelling pressure inflict significant damage, and uplift causes walls, beams, and columns to crack if the soil swelling pressure exceeds the foundation load [15-19].

Several studies investigated the Effect of wastewater on chemical, physical and mechanical properties of soil testing [20-21]. They found that full the industrial wastewater caused a markedly reduced the optimum moisture content and change the Atterberg limits as well as significant role in the free sell and compaction test. On the other hand, Anthor study [22] investigated the geotechnical performances of fine-grained soil treated with industrial wastewater sludge. They found that the soil mixtures treated with the sludge enhanced the geotechnical characteristics. Additionally, they recommended that industrial wastewater sludge be potentially employed for the improvement of fine-grained soil in the stabilization [22]. Karkush et al. [23] and Puri [24] evaluated the geotechnical characteristics of wastewater-contaminated soils using laboratory testing on samples. The results of the test demonstrated that wastewater-contaminated soils affects the compaction and swelling characteristics. Anthor study [24] evaluated the long-term effects of wastewater application on soil physical properties, two treatment sites between Taupo and Levin, New Zealand, and non-irrigated control sites were compared. The silty soil in Taupo has been treated with wastewater over the past 12 years. On Levin's land, sand-type soil has been watered with wastewater for 22 years. In terms of pH, organic matter (OM) content, bulk density, and total porosity, the disposal blocks at both sites were different from the control sites, but not in terms of microporosity. The disposal block at the Levin site showed a higher hydrophobicity than the control block, which was consistent with the elevated soil carbon. The Taupo soil, in comparison, showed a higher hydrophobicity at the control site, which had a lower quantity of OM [25].

Additionally, in the laboratory experiments [18-21], no effort has been made to recreate contamination close to field settings. Therefore, an experimental study has been conducted to determine the effects of paper and leather effluent (of the industrial variety) on the physio-mechanical behavior and geotechnical characteristics (physico-mechanical properties, compaction test, and free swell test) of 13 fine-grained soils (natural soil and contaminated soils) at 2-month, 4-month, 6 month, 8month, 12 month, and 16 months for each wastewater. Furthermore, the microstructure of natural and contaminated soils were studied.

II. SCOPE OF THE PROBLEM

In light of the trends of the modern state, industry development occupies an important space for self-sufficiency within Egypt. Therefore, the government has paid attention to the industrial sector in recent decades. Therefore, the feast arises from industrial wastewater, which poses a real threat to the soil, groundwater, and the mechanical behavior of fine-grained soil. Therefore, to the best of the author's knowledge, the effect of industrial wastewater because of the paper and leather factories scattered in Egypt on fine-grained soil has not been studied. Therefore, the authors try to identify the properties of contaminated soil to avoid potential risks and to use contaminated soil beneficially in civil engineering projects. Accordingly, the results of this research can be used in the first phase of the development program studies.

III. EXPERIMENTAL PROGRAM

3.1 Sample preparation

Early in 2000, there were sporadic reports of once-fertile lands in Egypt becoming barren within a year because of indiscriminate wastewater discharge on land in several areas of Cairo and in various governorates. Studies on the impact of paper and leather effluent on natural soils have been found to be infrequent or scarce, according to a critical evaluation of the literature. In this instance, the wastewater that was used came from two different places. The first came from tanneries in Ain Al-Sirah, Cairo, and the second from a paper factory run by an Islamic company in Quesna, Menoufia Governorate. These potentially hazardous wastewaters, whose effects on the environment require ongoing monitoring, were collected after the deposition of solids and before treatment. Studies on the impact of types of wastewaters, such as industrial wastewater paper and leather wastewaters, etc., on soils are likewise rare or scarce, according to a critical evaluation of the literature. Considering the foregoing, the two types of industrial wastewaters— paper leather wastewater—which are referred to as PW and LW, respectively, in this research—were chosen for the current investigation. Fine-grained soil used in this research was obtained in a natural phase from a soil excavation site for the construction of a residential building in the village of El-Kom al-Ahmar, Shibin El-Qanater, Qualiobiyah governorate (Fig. 1).

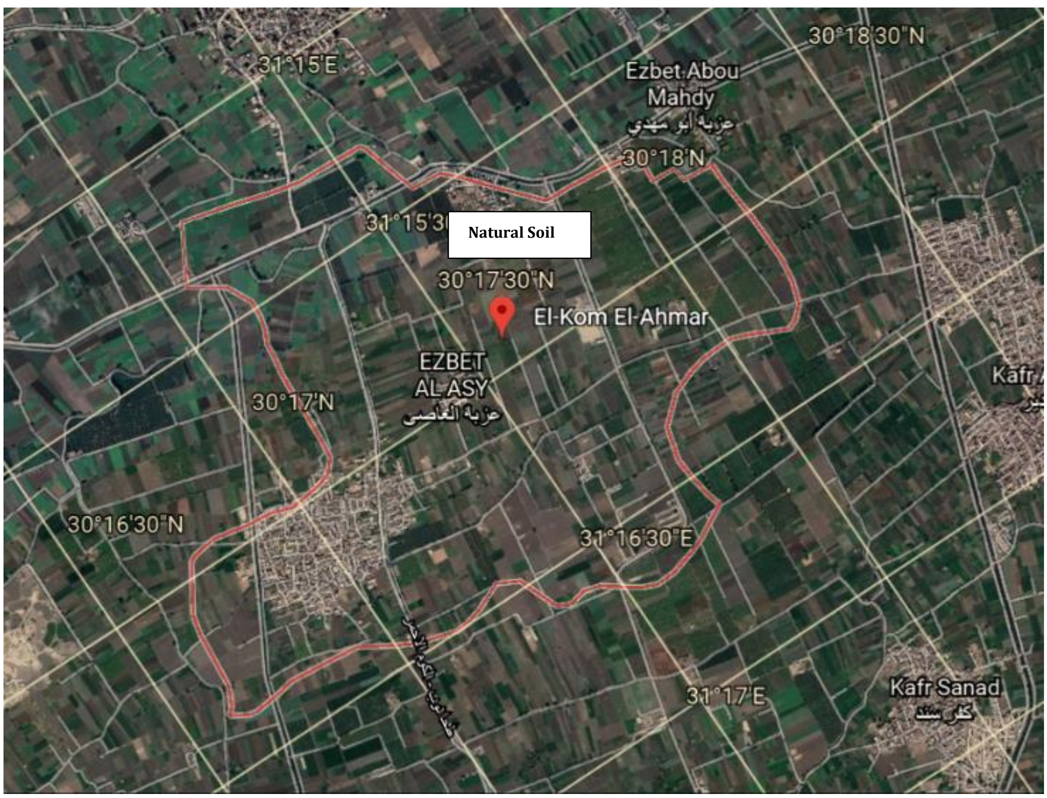


Fig. 1. Site of soil sample

The effluent parameters, including pH, alkalinity, total solids, total dissolved solids (TDS), total volatile solids (TVS), chloride, and biochemical oxygen demand (BOD), were calculated to characterize the different effluents in "as collected form" and for the outflow from the experimental set-up, i.e., The metrics are complete and sufficient to describe the effluent and comprehend its impact on the selected soils. The process for the analysis of the parameters was carried out in accordance with Standard Methods. Table 1-3 lists the characteristics of paper and leather effluent. In 50 kg airtight polythene bags, representative soil samples from the designated areas were gathered, transported to the lab, and stored in airtight containers under standard laboratory temperature until use.

Table 1. Physical properties of industrial wastewater (PW and LW)

Properties	Value	
	PW	LW
Color	grey	translucent
Temperature (ºC.)	23	21
pH (Value)	11.4	9.9
Total Suspended Solids (TSS), (mg/liter)	2314	1913

Table 2 Organic properties of industrial wastewater (PW and LW)

Properties	Value	
	PW	LW
Volatile Suspended Solids (VSS)	1122	1683
Biological Oxygen Demand (BOD)	1308	821
Total organic carbon (TOD)	677	336
Chemical Oxygen Demand (COD)	6881	2757
Oil &Grease	125	378
Phenol	9.3	11.5
Detergents	25.7	11.7
Pesticides	6.4	9.2
Chloride (Cl^-)	1997	3764
Sulfate (SO_4^{2-})	1719	2843
Alkalinity ($CaCO_3$)	574	473
Ammonia (NH_3-N)	157	267
Phosphate (SO_4^{3-})	19.5	10.2

Table 3: Chemical minerals of paper and leather effluent.

Properties		Aluminum	Chromium	Copper	Fe	Lead	Mg	Nickel	Borne	Selenium	Fluoride	Zinc	Arsenic	Cyanide	Mercury	Cadmium
Value (mg/liter)	PW	0.15	2.15	1.8	1.4	0.75	9.1	4.55	1.76	0.72	12.52	7.2	0.08	2.23	0.068	0.075
	LW	0.25	1.55	2.4	1.6	3.65	11.6	6.8	2.8	0.57	4.65	5.6	0.17	2.1	0.057	0.088

3.2 Soil Sample Preparation and Experimental Set-up

The experimental setup planned for this work included two groups, each of which had six contaminated soils (PW or LW) and natural soil for comparison. These groups were constructed in accordance with the schematic designs. Each set of soils under study was created and used for the subsequent purposes:

(i) Samples were taken from the location and kept in the laboratory.

(ii) Since each effluent was used to examine how industrial waste elements affected the mechanical and geometric properties of the soil at specific ages. Due to this, the testing procedure was conducted at different times from mixing. The natural soils with wastewater, these times were 2, 4, 6, 8, 12, and 18 months.

(iii) A total of 13 samples were utilised to investigate the impact of two effluents on natural soils industrial wastewater (PW and LW). A 3-kilogram soil sample is manually combined with effluents at their optimum moisture content (OMC), then transferred.

Additionally, scanning electron microscopes (SEM) and X-ray diffraction (XRD) were used to analyze the mineral compositions of natural and contaminated samples [12]. These methods are accessible at the Egyptian Mineral Resources Authority's Central Laboratories Sector's Housing & Building National Research Centre in Giza, Egypt. The experimental program was created to ascertain the swelling behavior for the investigated soil with varying thickness.

IV. RESULTS AND DISCUSSION

4.1 Physical Properties

Tables 4 and 5 contains the natural and contaminated soil's index parameters, including specific gravity and Atterberg limits Liquid limit LL, plastic limit PL, shrinkage Limit SL, and plastic index PI. Based on these findings and the unified soil classification system USCS, it is noted that:

(i) Liquid limit LL, plastic limit PL, and plasticity index PI of natural soil are 74%, 34, and 40%, respectively. While LL, PL, and PI of PW-contaminated soil are range of 64%-57%, 35% to 41%, and 29% to 16%, respectively. The LL, PL, and PI of LW-contaminated soil are range of 71%-62%, 33% to 29%, and 38% to 33%, respectively.

(ii) Shrinkage Limit SL values of natural soil is 18%. The natural soil samples are categorised as silt of high plasticity MH. While SL of PW-contaminated soil is range of 21%-26%. The samples at 12 and 16 months were broken. The SL of LW-contaminated soil is range of 19%-25%.

(iii) Specific gravity Gs of natural soil is 2.67. While Gs of PW-contaminated soil is range of 2.65-2.58. The Gs of LW-contaminated soil is range of 2.65-2.60.

Table 4. The results of Atterberg limits for contaminated soil with industrial PW at different times months.

Sample No.	Liquid Limit L.L, %	Plastic Limit P.L, %	Shrinkage Limit S.L, %	Plasticity Index PI, %	G.s	USCS
Natural soil	74	34	18	40	2.67	MH
PW1 (2 month)	64	35	21	29	2.65	MH
PW2 (4 month)	62	36	23	26	2.65	MH
PW3 (6 month)	60	37	25	23	2.62	MH
PW4 (8 month)	59	38	26	21	2.60	MH
PW5 (12 month)	58	39	Cracked	19	2.59	ML
PW6 (16 month)	57	41	Cracked	16	2.58	ML

Table 5. The results of Atterberg limits for contaminated soil with LW at different times (months).

Sample No.	Liquid Limit L.L, %	Plastic Limit P.L, %	Shrinkage Limit S.L, %	Plasticity Index, %	G.s	USCS
Natural soil	74	34	18	40	2.67	MH
LW1 (2 month)	71	33	19	38	2.656	MH
LW2 (4 month)	68	32	20	36	2.65	CH
LW3 (6 month)	65	30	21	35	2.44	CH
LW4 (8 month)	63	30	23	33	2.44	CH
LW5 (12 month)	62.25	29	24	33.5	2.6	CH
LW6 (16 month)	62	29	25	33	2.6	CH

4.2 Compaction Results

Figs. 2 and 3 shows the compaction test results for the natural soil and contaminated soils at different times. In Table 6, which lists the compaction findings as maximum dry density (γmax) and optimum moisture content (OMC), it is evident that:

1- The optimum moisture content (OMC) of natural soil is 20%. while the OMC of PW-contaminated soil is in the range of 22%–26%. The OMC of LW-contaminated soil is in the range of 21%–25%. The OMC of both contaminated soils was higher than that of the natural soil.

2- The values of γdmax. of natural soil is 1.70 gm/cm3. while the γdmax of PW-contaminated soil is in the range of 1.63 gm/cm3 to 1.46 gm/cm3. The γdmax of LW-contaminated soil is in the range of 1.65 gm/cm3 to 1.52 gm/cm3.

3- The γdmax of both contaminated soils was lower than that of the natural soil. The γdmax of PW-contaminated soil is lower than LW-contaminated soil.

Table 6. Compaction parameters for the studied soils

Sample No.	Sample No.	OMC, %	γdmax., t/m^3
Natural soil	natural soil	20	1.7
Contaminated soil with PW	PW2 (4 month)	22.5	1.6
	PW3 (6 month)	24	1.56
	PW4 (8 month)	24.75	1.55
	PW5 (12 month)	25	1.5
	PW6 (16 month)	26	1.46
Contaminated soil with LW	LW2 (4 month)	22.25	1.63
	LW3 (6 month)	23	1.62
	LW4 (8 month)	24	1.60
	LW5 (12 month)	24.25	1.55
	LW6 (16 month)	25	1.52

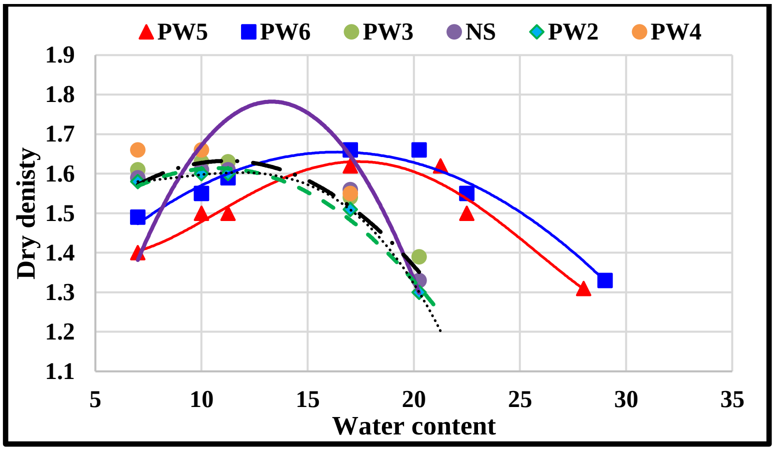


Fig.2 Standard proctor test of fine-grained soil contaminated with industrial wastewater (PW).

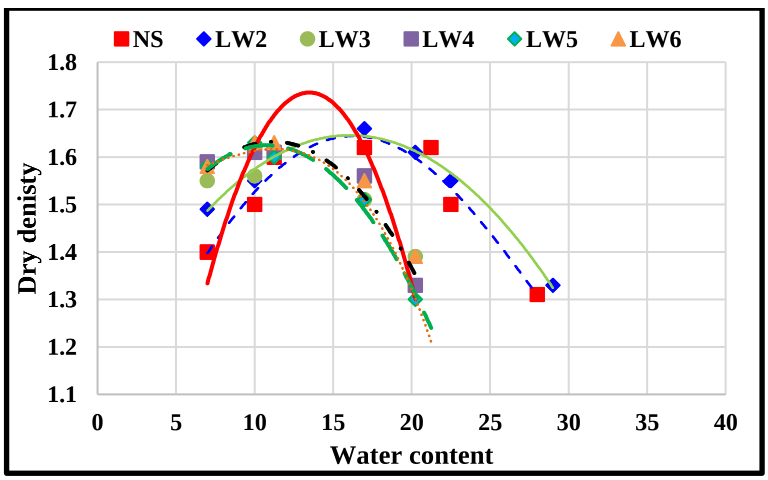


Fig.3 Standard proctor test of fine-grained soil contaminated with industrial wastewater (LW).

4.3 Free Swell

The results of free swell (FS) are listed in Table 7. Figs 4 and 5 represent the correlation between free swell FS percentage, dry density. Liquid limit LL, plasticity index (PL) and shrinkage limit (SL), respectively. Therefore, it is found that:

1- The free swell (FS) of natural soil is 60%. while the F.S of PW-contaminated soil is in the range of 65%–86%. The F.S of LW-contaminated soil is in the range of 55%–40%. The FS of PW-contaminated soil was higher than that of the natural soil and LW-contaminated soil.

2- The FS of LW-contaminated soil was lower than that of the natural soil.

3- The swelling PW-contaminated soil increases with the ageing increases, while the swelling LW-contaminated soil reduces with the ageing increases.

4- The swelling PW-contaminated soil increases with LL and PL at aging, while the swelling LW-contaminated soil reduces with LL and PL the ageing.

Table 7. Swell results for the studied soils

Sample No.	Sample No.	FS, %	Remarks
Natural soil	Natural soil	60	The swelling increases with the ageing increases
Contaminated soil with PW	PW1 (2 month)	65	
	PW2 (4 month)	70	
	PW3 (6 month)	75	
	PW4 (8 month)	81	
	PW5 (12 month)	86	
	PW6 (16 month)	86	
Contaminated soil with LW	LW1 (2 month)	55	The swelling reduces with the ageing increases
	LW2 (4 month)	50	
	LW3 (6 month)	43.5	
	LW4 (8 month)	43	
	LW5 (12 month)	40	
	LW6 (16 month)	40	

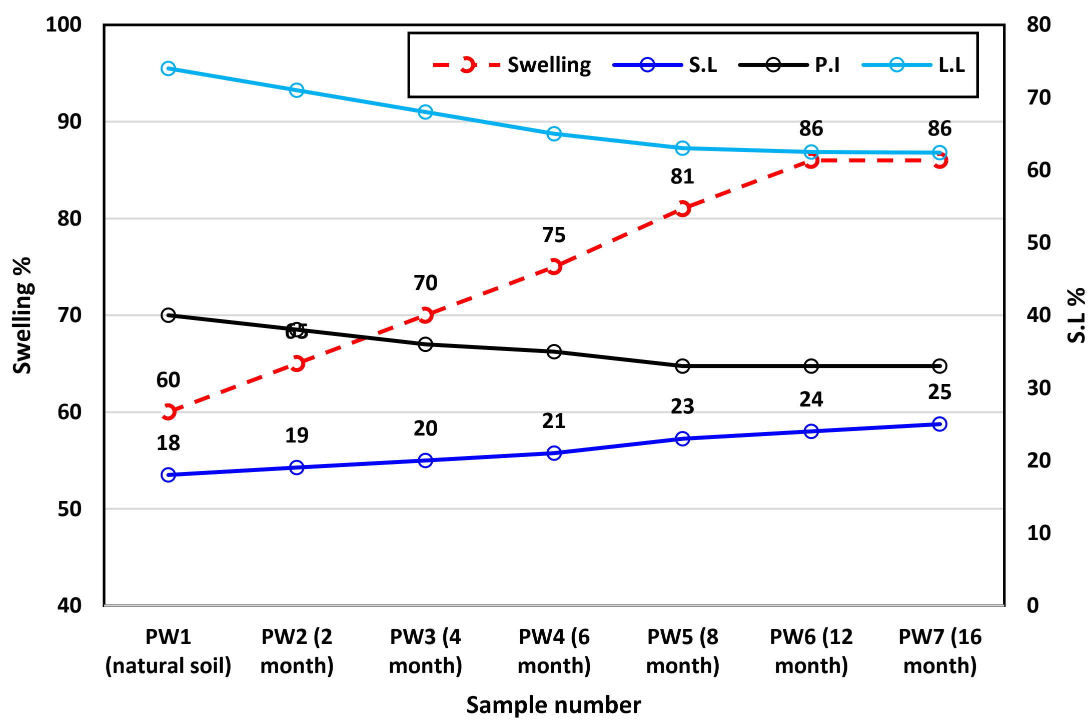


Fig. 4. Correlations of Free Swell with Plastic index, Shrinkage Limit, and liquid limit (PW).

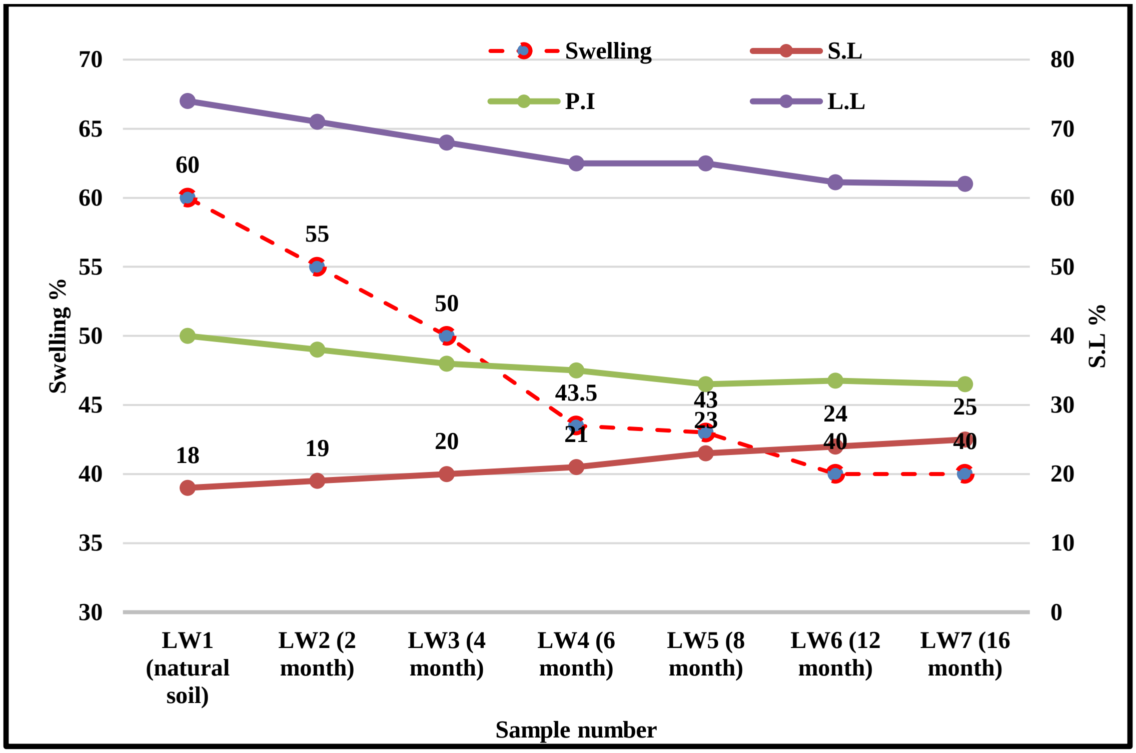
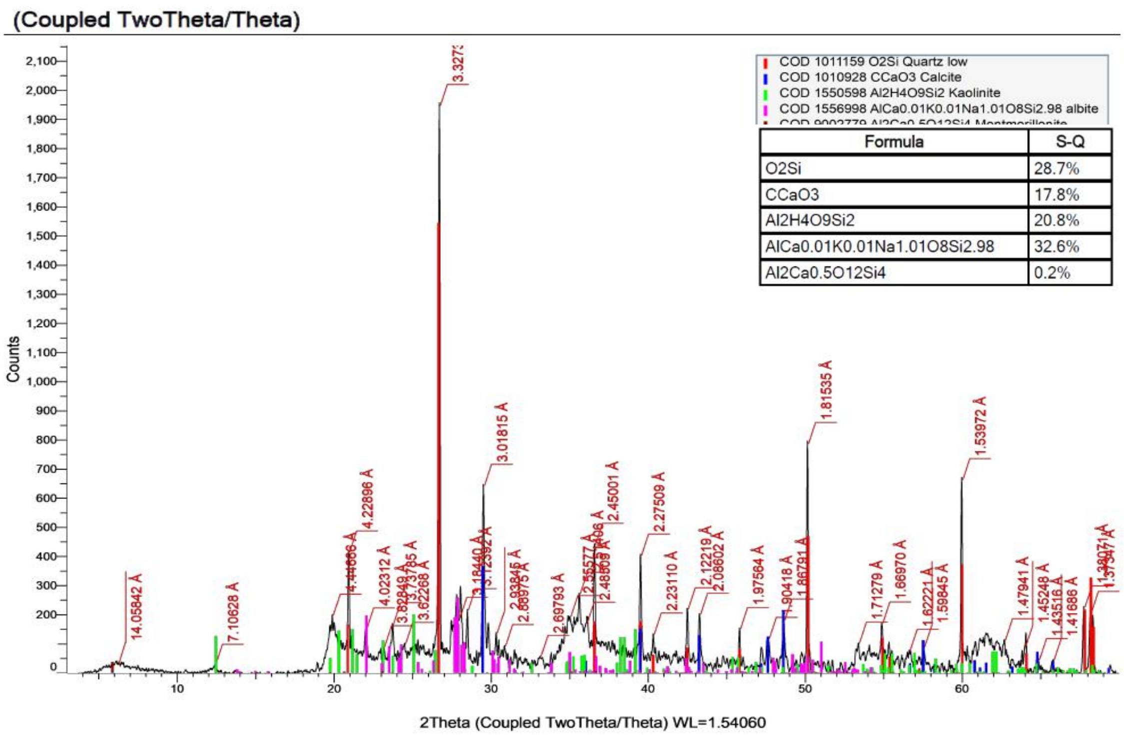


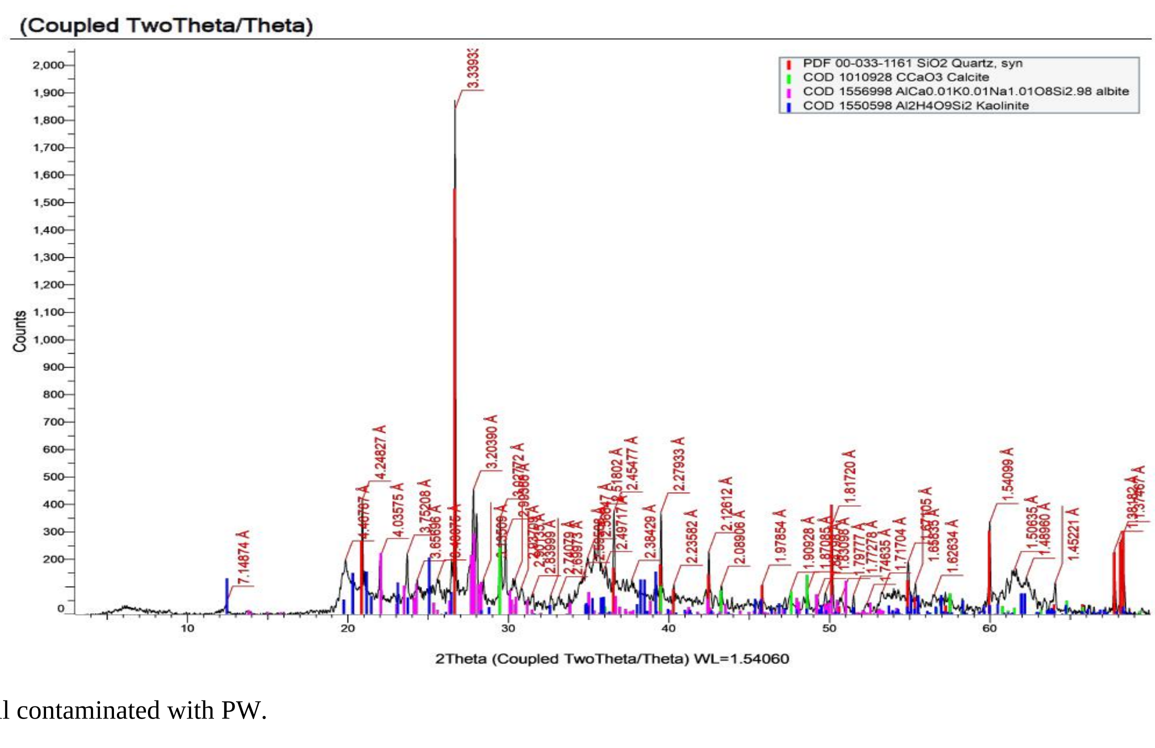
Fig. 5. Correlations of Free Swell with Plastic index, Shrinkage Limit, and liquid limit (LW).

4.4 Clay Minerals

Fig. 6 display the X-ray diffraction patterns of PW-contaminated soil and LW-contaminated soil, respectively. As a result, Table 8 shows the calculated mineral proportion. It is clear that: Minerals such as kaolinite (K), albite, calcite, and montmorillonite (M) were present in all samples. All soil samples included a sizable amount of the mineral montmorillonite (M), which is what gives the expansive nature. While these components not found in the PW-contaminated soil. The values of Kaolinite (K), calcite, albite, and Montmorillonite (M) percentage of PW-contaminated soil are 21.3%, 11.8%, 36.8% and 0% respectively. The values of Kaolinite (K), calcite, albite, and Montmorillonite (M) percentage of PW-contaminated soil are 20%, 4%, 43.60% and 0.2% respectively.



a) Natural sample



b) Soil contaminated with PW.

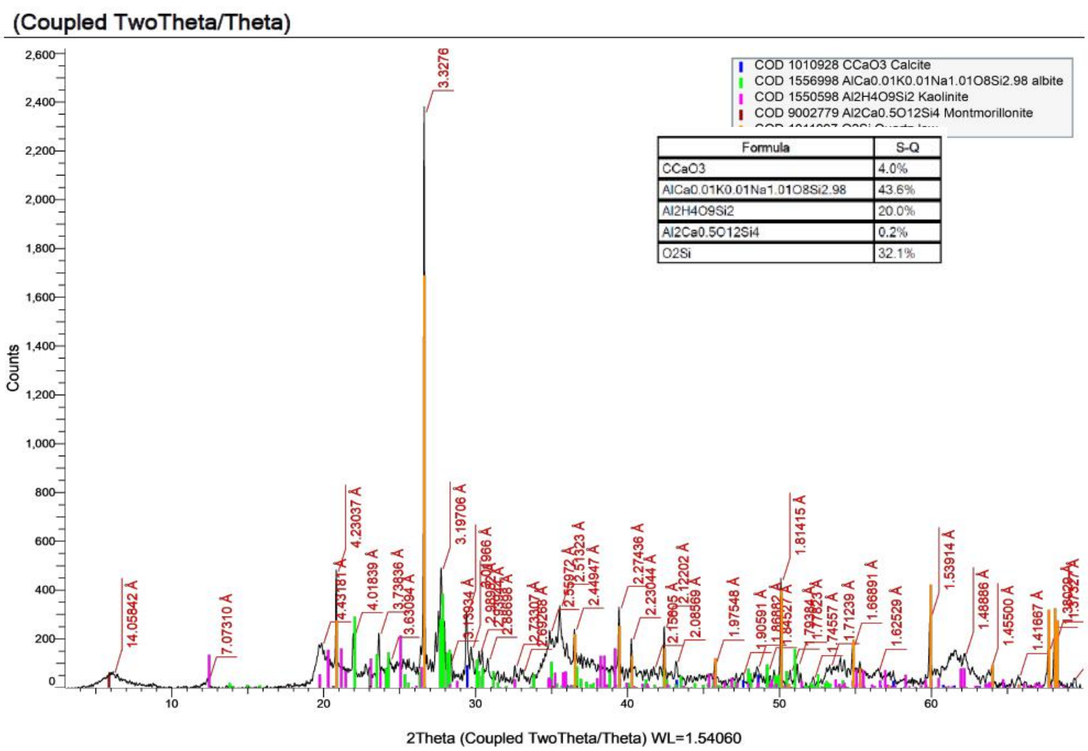


Fig. 6. X-ray diffraction patterns for the studied soils.

c) Soil contaminated with LW.

Table 8. XRD semi-quantitative percentages results.

Sample No.	Quartz	**Calcite**	**Kaolinite**	**albite**	**Montmorillonite**
Natural soil	8.8	6.8	20.8	32.6	31
PW	9.7	4.2	21.3	36.8	28
LW	11.4	3.0	20.0	43.6	22

4.5 SEM Analysis Results

Scanning electron microscopy (SEM) research was done to compare the particle structure of the soils with wastewater. The morphology of the examined soils is provided in Figs. 7, 8, and 9. Scanning electron micrographs of natural soil before contamination are shown in Fig. 7, which shows the micrographs of natural soil without wastewater. Micrographs of natural soil before contamination show vast differences, highlighting the unique nature of natural soil (i.e., classified MH). Comparing the micrographs shown in Figs 87 and 9, the effect of paper wastewater on natural soil is more detrimental than that of leather wastewater. The microstructure of contaminated soil particles became loose and porous, and the form of the surface changed compared to natural soil.

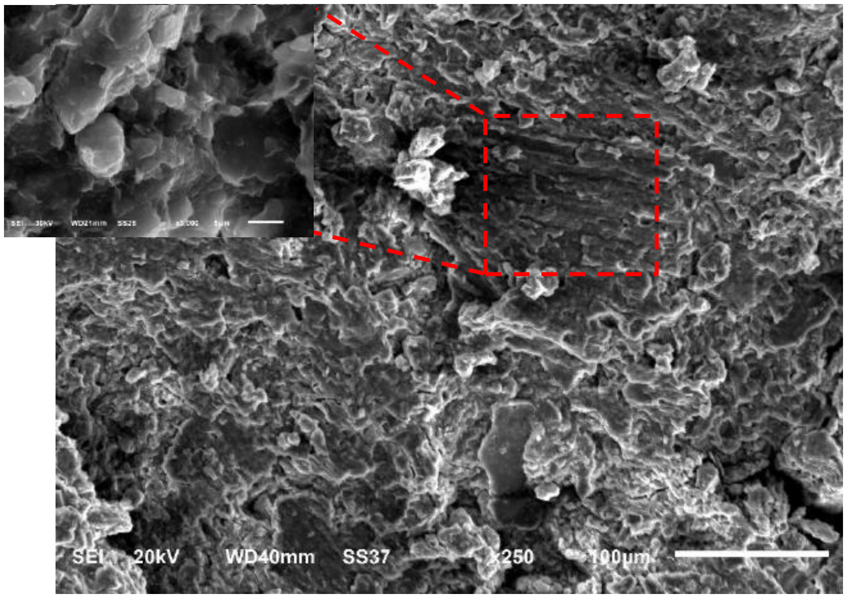


Fig 7. SEM micrograph of natural soil

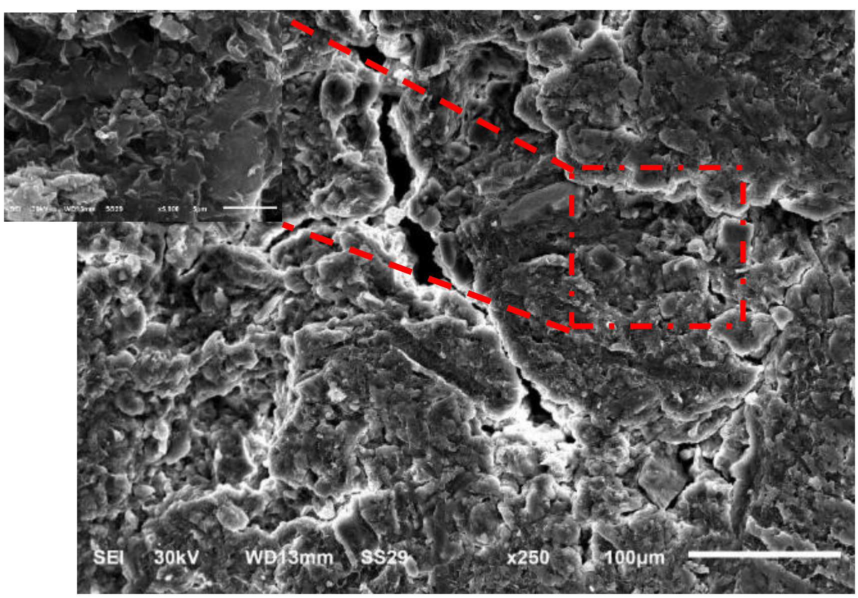


Fig. 8. SEM micrograph of contaminated soil with industrial paper wastewater PW

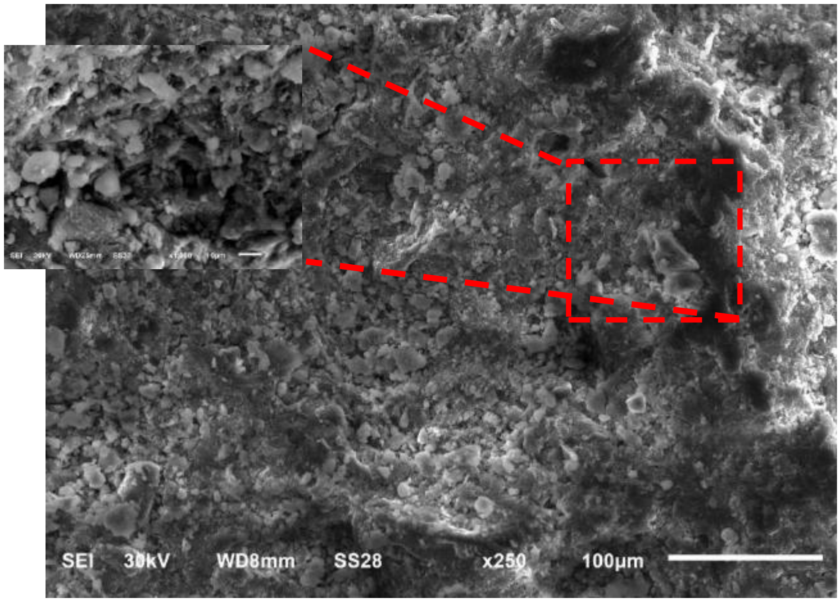
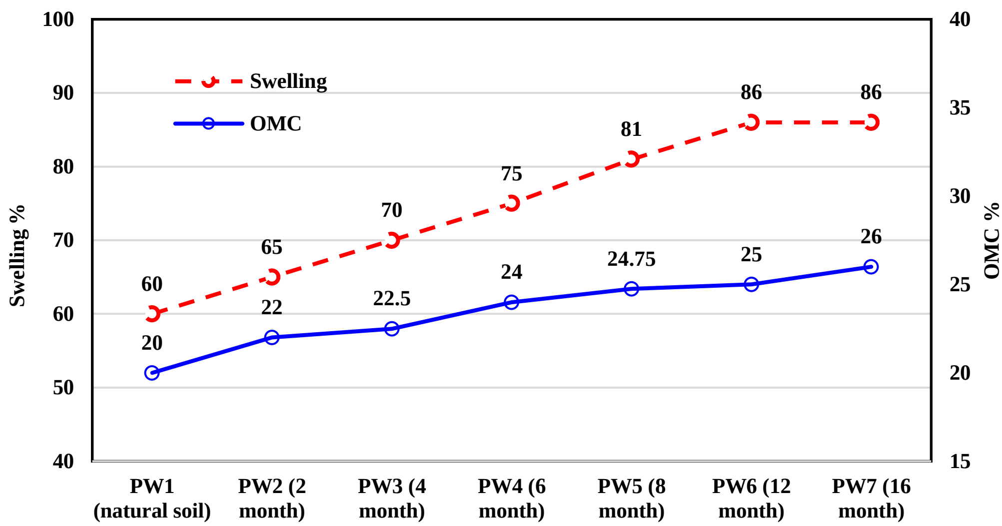


Fig. 9. SEM micrograph of contaminated soil with industrial leather wastewater LW

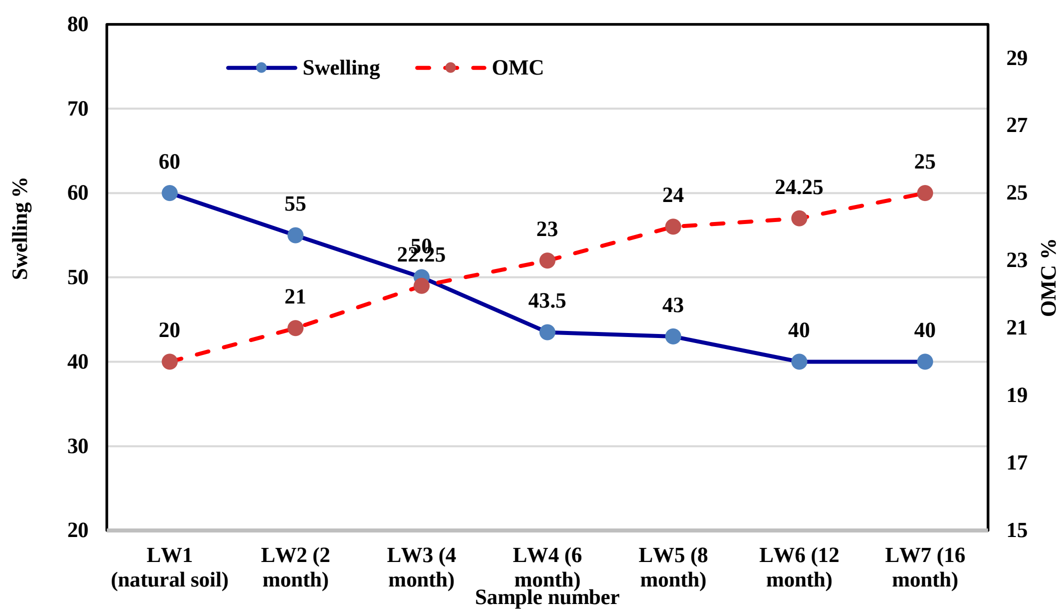
V. DISCUSSION

According to the results of free swell related to the correlations of F S with OMC of fine-grained soil with the different wastewater, it is noted that the free swell or differential free swell, also termed the free swell index, is one of the commonly used simple experiments performed by geotechnical engineers for getting estimates of soil expansion potential. Fig 10 represent the correlation between free swell FS percentage and optimum moisture content OMC for contaminated soils. It was also found that swelling values are in reverse proportion to optimum moisture content OMC and shrinkage limit SL. This result agrees with the results mentioned by. It was also found that Free swell values are in direct proportion to dry density, liquid limit LL, and plasticity index PL. Also, this result is in good agreement with the results mentioned by [14,16,18].

Finally, Table 9 compares the findings of the present study with those of Easa et al (2009), Cyrus et al., (2010), Karthika et al., (2021), Kermani (2012), Girisken (2013) [14]. Considering this comparison, it is concluded that: The effect of the industrial paper and industrial leather wastewaters on fine-grained soils is significant which change the properties of natural soil. The optimal moisture content OMC values for the current study are greater than the values for earlier investigations. However, compared to other investigations, the dry density values for the current study are lower. Additionally, the range of specific gravity Gs values is the same for the past and contemporary studies. The present study's compaction test results are lower than those of earlier research. The examined soils in the current study didn't contain as much sand as those in earlier investigations. Variable values for silt and clay content are seen in both the current investigation and earlier studies. The liquid limit LL values for the current investigation are higher than those for the earlier studies. In contrast, the analyzed soils in the current study exhibit higher plastic limit PL values than those in earlier research. Therefore, the plasticity index PI values for both the current and past investigations vary. The values of the shrinkage limit SL fluctuate between the results of the current investigation and earlier studies. The percentage values for clay minerals in the current study and earlier investigations were very similar.



a) PW



b) LW

Fig. 10. Correlations of Free Swell with O.M.C

Table 9. The experimental findings for the studied soils of the present study

Property	The current study (Paper wastewater)	The current study (Leather wastewater)	Alnos Easa et al (2009)	Cyrus et al., (2010)	Girisken (2013)	Kermani (2012)	Karthika et al., (2021)
OMC%	26	25	23	82	19.4	3.9	-
Maximum dry density	1.46	1.52	1.94	-	1.62	-	1.81

GS		2.58	2.60	2.72	2.7	2.67	-	-
Atterberg limits	LL%	57	62	48	95	29	23.9	35.25
	PL%	41	29	25	34	25	45.5	8.33
	SL%	Cracked	25	16	16	4		--
	PI%	16	33	23	61	-	21.6	18.33
Clay (%)		-	-	22	38	--	3	-
Silt (%)		-	-	70	29		89	-
Sand (%)		-	-	8	33	-	7	-
FS, %		86	40	60	-	40	-	-

VI. CONCLUSION

1. Properties of fine-grained soils contaminated with the industrial paper and industrial leather wastewater in Benha city, Egypt were experimentally studied. The following conclusions can be drawn:
2. Thirteen fine-grained soil samples were analyzed. The related liquid limit, plastic limit, and plastic index of natural soil values are 74%, 34, and 40%. The LL of industrial paper and industrial leather wastewater decreased by 22.9% and 16.2% respectively. While the PL of PW-contaminated soil increased by 20.60%, and the PL of LW-contaminated soil decreased by 14.70%. The plastic index of PW-contaminated soil and LW-contaminated soil decreased by 60% and 17.5, respectively.
3. The shrinkage limit of the natural soil is 18%. The samples of natural soil are classified as high plasticity silt (MH). While the SL of soil with PW contamination increased by 44.44%. At 12 and 16 months, the samples were damaged. The SL of LW-contaminated soil also increased by 38.88%
4. Natural soil has a specific gravity Gs of 2.67. Gs of PW-contaminated soil ranges decreased by 3.37%. Additionally, the Gs range for LW-contaminated soil decreased by 2.62%.
5. Natural soil has a 60% free swell. While the FS of soil contaminated with PW increased by 43.33%. While the FS of soil contaminated with LW decreased by 33.33%. In comparison to natural soil and LW-contaminated soil, PW-contaminated soil had a higher FS.
6. The FS of soil that had been exposed to LW was lower than that of uncontaminated soil.
7. The swelling PW-contaminated soil swells more as it ages, whereas the swelling LW-contaminated soil shrinks as it ages.

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A Study of Vertical Load Capacity of Carbon Fiber Concrete Piles Reinforced with Geosynthetics.

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Abstract— *A compressive static load test was conducted on a total of thirteen end-bearing carbon fiber concrete piles reinforced with geosynthetics, which were divided into four groups and compared to traditional reinforced concrete piles. The tested piles included one reference concrete pipe pile reinforced with traditional steel reinforcement, four concrete pipe piles partially reinforced with carbon fiber bristles with different percentages of 0.75%, 1.00%, 1.25%, and 1.50% of cement weight, four piles partially reinforced with the same carbon fiber bristles percentages and confined with triaxial geogrid, and four piles partially reinforced with the exact carbon fiber bristle percentages and reinforced with carbon fiber bars. Thirteen vertical static loading tests (SLTs) were conducted on 1050-mm-long pipe piles with a diameter of 150 mm to obtain the behavior of these composite piles. Furthermore, the traditional method of stress-strain curves was analyzed. Comparisons between curves were conducted. It was concluded that the use of these composite piles significantly increased the ultimate vertical load capacity by up to 39%. Pile ductility was also significantly improved, and this composite material could be perfectly applied in geotechnical conditions. In addition, an economic analysis was conducted.*

***Keywords*— Geosynthetics, Carbon fiber bristles, Geogrid, Composite piles, Vertical Static Load**

I. INTRODUCTION

The pile foundation industry has problems associated with the use of traditional materials as reinforcement, especially when installed in corrosive and marine environments [1]. Recently, the use of geosynthetics and geogrids has been increasing significantly in civil engineering applications such as piles [2,3,4], which are constructed in a marine environment in place of conventional materials in piling systems to overcome these challenges. Using of composite piles reinforced with fiber-reinforced polymers (FRP) and geosynthetic can solve problems with traditional piles. Several investigations have been conducted to experimentally test the behavior of FRP composite piling under vertical axial loads [5], [6]. In comparison to conventional piles, their effective strength-to-weight ratio, durability, anti-corrosion capability, and bond strength make them an efficient and cost-effective alternative [7]. A study on precast concrete piles typically confined with carbon fiber reinforced polymers (CFRP) geogrid was made, and it was figured out that the confinement given by CFRP may provide equivalent levels of confinement as those achieved by steel spirals [8]. The geogrid systems have been proven to be an effective way to strengthen the stone column due to their high strength-to-weight ratio, high durability, high anti-corrosion ability, satisfactory fire endurance, and bond strength [9]. Under horizontal loading, the behaviour of RC pile models reinforced with composite materials was investigated. The results of the study indicated that the specimens exhibited a horizontal ultimate load that was 44% to 87% lower compared to the reference pile specimen that was reinforced using traditional reinforcing materials. The analysis of the specimens indicated that the implementation of composite piles has the potential to result in a cost reduction of up to 15.2%. [10]. Eleven lateral pile loading tests were conducted on concrete piles reinforced with various materials, such as FRP bars, geosynthetic geogrids, and composites of two materials, in order to evaluate their capacity to carry lateral loads [11]. The experimental results demonstrated that the lateral loads supported by piles were increased by up to 25.3% when FRP bars, biaxial geogrid, and uniaxial geogrid were utilized. A comparative analysis was conducted to assess the reinforcement expenses associated with all samples, revealing that the utilization of composite piles resulted in a cost reduction of up to 59%. The goal of the current study was to investigate the capacity of end-bearing piles reinforced by various materials. An axial loading test would be applied to reinforced concrete piles (RC) reinforced by various materials, for example, CFRP bars, CFRP grids, and carbon fiber bristles, to assess their efficiency by applying them to static vertical loads, then comparing the results with each other and making an economic comparison.

II. EXPERIMENTAL WORK

2.1. Test specimens

The experimental program included testing concrete piles reinforced with geosynthetics and subjected to concentric axial compression loads applied at the top section of the piles. Thirteen concrete piles, divided into four groups, were tested for failure. The specimens had a 150-mm circular cross-section with an overall height of 1050 mm, a width-height ratio of 1:7, and a clear concrete cover of 20 mm. The first group was composed of one specimen reference concrete pipe pile (PS) reinforced with traditional steel reinforcement of four 8mm steel bars confined with 6mm circular steel spirals with a 10 mm pitch. The second group was composed of four concrete pipe pile specimens (PC) partially reinforced with carbon fiber bristles with a different percentage from 0.75% - 1.00% - 1.25% -1.5% of cement weight. The third group was composed of four concrete pipe pile specimens which were partially reinforced with carbon fiber bristles from 0.75% to 1.5% of cement weight and confined with triaxial geogrid (PCG). The fourth group contained four concrete pipe pile specimens partially reinforced with carbon fiber bristles ranging from 0.75 to 1.5% of cement weight, reinforced with four 8mm carbon fiber bars, and confined with 6mm circular steel spirals with a 10 mm pitch. Table (1) provides details for all tested specimens. There are cross-section details for all pile groups in figure (1).

Table 1: Details of all tested specimens.

Group	Group Code	Pile Code	Material	Fibre bristles %
First Group (Reference)	PS	PS 1	Steel Rft.	______
Second Group	PC	PC 1	Carbon fibre bristles	0.75
		PC 3		1
		PC 5		1.25
		PC 7		1.5
Third Group	PCG	PCG 1	Carbon fibre bristles with Tri-Axial Geogrid Rft.	0.75
		PCG 3		1
		PCG 5		1.25
		PCG 7		1.5
Fourth Group	PCC	PCC 1	Carbon fibre bristles with carbon fibre bars Rft.	0.75
		PCC 3		1
		PCC 5		1.25
		PCC 7		1.5

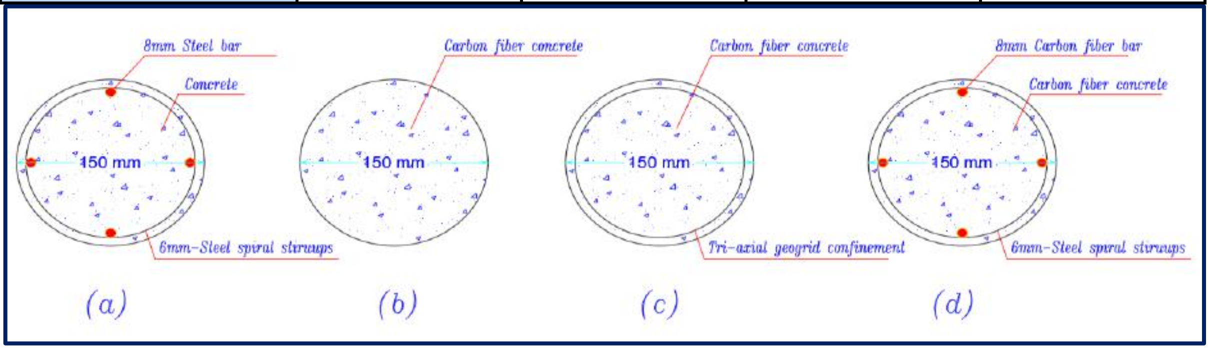

Fig.1: Typical cross-section details for all pile groups: (a) first group (reference pile), (b) second group, (c) third group, (d) fourth group.

2.2. Material properties

The concrete mixture used to cast all of the pile specimens was normal-weight concrete consisting of filter stones with aggregate sizes ranging from four to nine mm in size, ordinary Portland cement (grade 42.5), and natural sand, in addition to different percentages of carbon fiber bristles from 0.75% to 1.5% of the cement weight. The measured average compressive strength at the time of testing (after 28 days) was approximately 20 MPa. Concrete compressive strength was measured according to ECP 203-2020 [12]. The pile models have been kept and subjected to a curing process. Pile models and curing conditions were represented in figure (2). High-tensile steel bars 8 mm in diameter with a yield stress of 400 MPa were used in longitudinal reinforcement in the reference pile, and 6 mm mild steel bars with a yield stress of 360 MPa were used as confinement spiral stirrups. The used CFRP bars in this study were fabricated from Sika Wrap-300C as a product of the Sika company [13]. The bars were fabricated via carbon fiber-reinforced polymer (CFRP) strands that were rolled and bonded together using epoxy Sikadur-330. Subsequently, the CFRP strips were positioned into a mould, and the epoxy was poured and left to cure, resulting in solidification, Fig. 3(a). As per the manufacturer's specifications, table (2) presents the mechanical properties of carbon fiber. Carbon fibre bristles used in this study were fabricated from Sika Wrap-330C as a product of Sika company [14]. The bristles were fabricated via CFRP strands that were cut in lengths from 2 to 3 cm, Fig. 3(b). The geosynthetics geogrids utilized in this study were produced by Tensar International Corporation [12]. Geogrids TX130 was used, Fig. 3(c). The mechanical properties of geogrids are listed in table (2).

(a) **(b)**

Fig.2: (a) curing conditions, (b) pile models.

Table 2: Mechanical properties and dimensions of CFRP bars and used geogrids.

Materials	Dimension (mm)		Tensile strength		Modulus of elasticity (MPa)	Failure Strain %
	Diameter	Thickness	(MPa)	(N/mm)		
CFRP bar	8	-	1060	-	120000	0.5
Geogrids (TX130)	-	1.3	-	10	200000	0.5

(a) **(b)** **(c)**

Fig.3: Typical types of used materials: (a) CFRP bars, (b) Carbon fibre bristles, (c) Tri-Axial geogrid.

2.3. Testing machine set-up

The Piles specimens were tested using a 1000 KN capacity compression machine and were loaded concentrically to failure, figure (4). The specimens were capped using a steel plate cap to form parallel loading surfaces and ensure uniform distribution of the applied load to the bearing surfaces. The compression machine was operated in a displacement mode, maintaining a rate of loading of 5 KN/sec. Electrical resistance strain gauges were attached to the outer surfaces of the columns to measure the axial and lateral strain of the concrete.

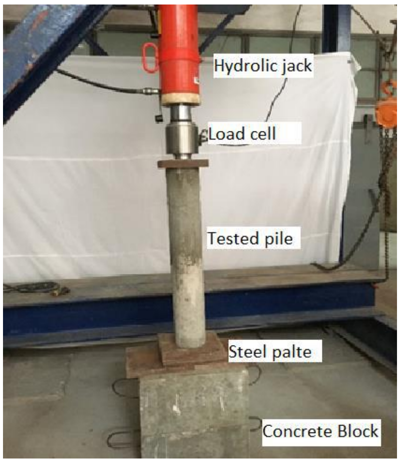

Fig.4: Testing machine set-up and concentrically loading of the tested pile.

III. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Piles reinforced with carbon fibre bristles (PC).

The maximum axial stress, strain at the maximum axial stress, and maximum strain of the reference pile and PC piles, table (3). Based on the findings, it is obvious that the PC piles exhibited a maximum capacity ranging from 76.7% to 93.60% when compared to the reference pile. Additionally, the strain at the maximum axial stress ranged from 73.20% to 88.20%, while the maximum strain observed ranged from 67.20% to 77.20%.

Table 3: Results summary of Reference pile and PC piles.

Group	Pile Code	Max. Axial Stress (MPa)	Strain at Max. stress *10-6 (mm/mm)	Max. Strain *10-6 (mm/mm)
First Group (Reference)	PS 1	13.19	3069	4022

Second Group	PC 1	10.12	2245	2702
	PC 3	11.59	2706	3035
	PC 5	12.35	2394	3104
	PC 7	11.29	2630	3102

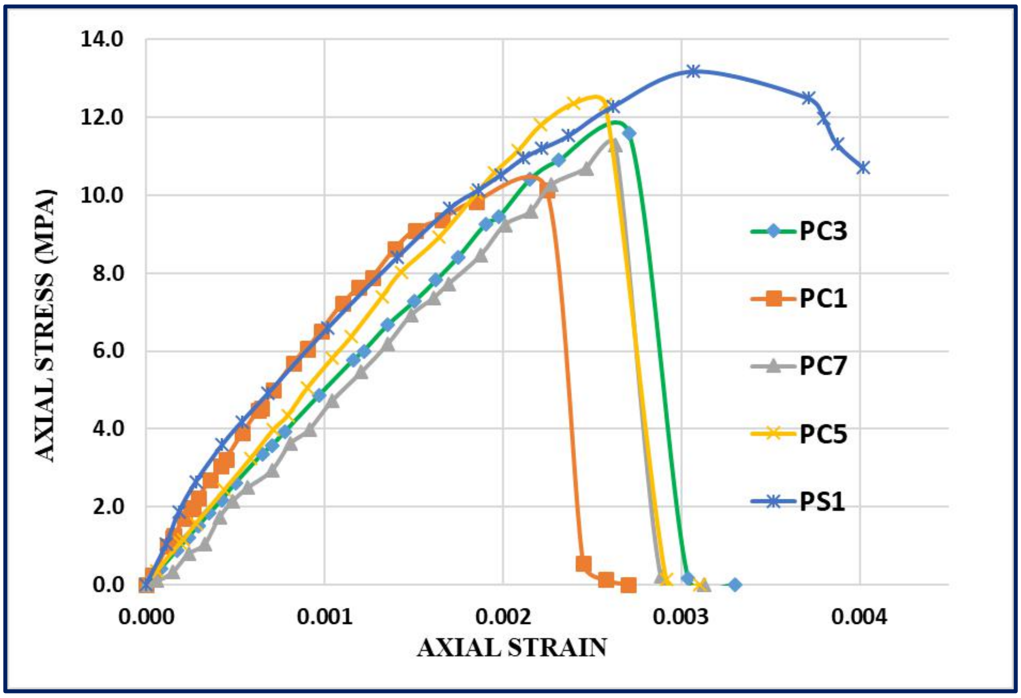

Fig.5: The stress-strain relationships for PC piles compared with PS1 pile.

The trend of specimens given in figure (5) clearly demonstrates that the increase in the carbon fibre bristles ratio had an effect on the capacity of PC piles. But the overall capacity was low compared to the reference pile, as well as the strain, which means less ductility, and that led to unexpected failure, which is not preferred. That's clearly shown when PC piles reach failure stress. The failure was like an explosion. The failure of carbon fibre concrete pillars is depicted in figure (6). Though it was obvious that the increase in the carbon fibre bristles ratio from 0.75% to 1.5% of cement weight led to an increase in the maximum stresses of the pile and slightly improved the ductility of the pile.

Fig.6: The failure of piles reinforced with carbon fibre bristles.

3.2. Piles with geogrid confinement (PCG).

The maximum axial stress, strain at the maximum axial stress, and maximum strain of the reference pile and PCG piles, table (4). Upon comparison with the reference pile, it became evident that the PCG piles exhibited a maximum capacity ranging from 101.59% to 124.64%. Additionally, the strain at the maximum axial stress ranged from 93.85% to 103.19%, while the maximum strain ranged from 80.30% to 91.89%. The results of the study indicate that the implementation of geogrid confinement led to a notable enhancement in the maximum capacity of PCG piles, with an increase ranging from 1.59% to 24.64%. Additionally, it was observed that the strain at maximum stress experienced an increase of 3.19% in the PCG5 pile.

Table 4: Results summary of Reference pile and PCG piles.

Group	Pile Code	Max. Axial Stress (MPa)	Strain at Max. stress $*10^{-6}$ (mm/mm)	Max. Strain $* 10^{-6}$ (mm/mm)
First Group (Reference)	PS 1	13.19	3069	4022
Third Group	PCG 1	13.4	2880	3260
	PCG 3	15.1	3010	3395
	PCG 5	16.44	3167	3696
	PCG 7	14.41	2960	3230

The behaviour clearly shows that the initial stiffness of PCG piles with geogrid confinement was better compared with the reference pile, figure (7). The geogrid confinement of piles led to increasing strain which improve ductility. Also, the confinement of geogrid improved the load capacity of the piles. The failure was more ductile and predicted, first cracks started to show then failure occur when the geogrid confinement failed, figure (8).

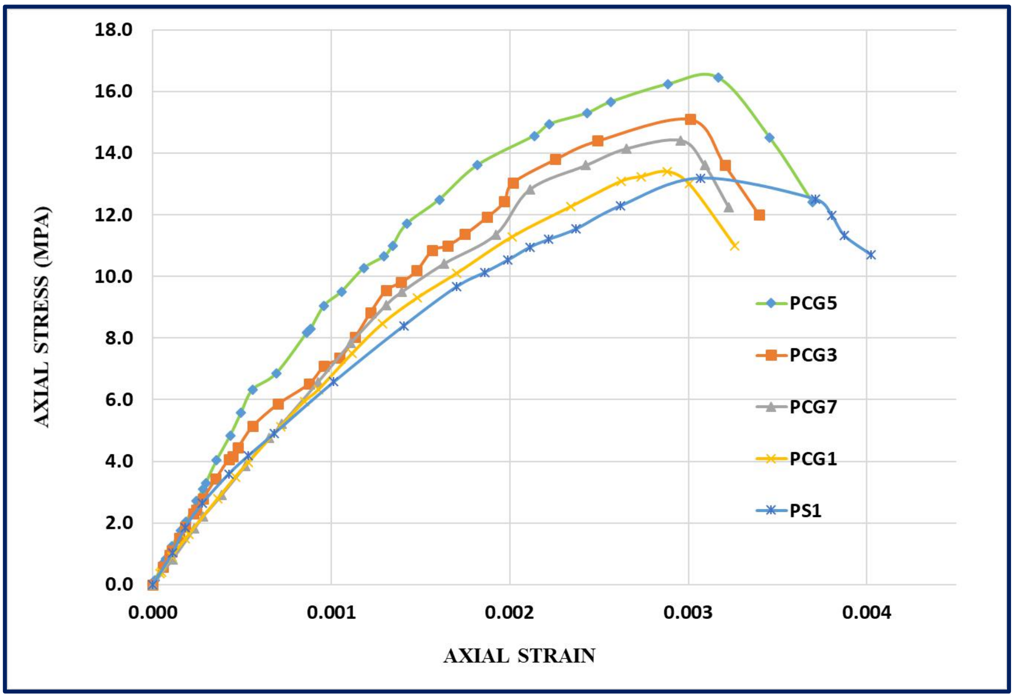

Fig.7: The stress-strain relationships for PCG piles compared with ps1 pile.

Fig.8: Failure of Carbon fibre concrete piles with geogrid confinement

3.3. piles with carbon fibre bars Rft (PCC).

From the results the maximum axial stress, strain at maximum axial stress, and maximum strain of the reference pile and PCC piles, table (5). After comparing the test results of PCC piles with the reference pile, it becomes evident that the PCC piles exhibited a maximum capacity ranging from 123.58% to 139.50%. Additionally, the strain at the maximum axial stress for the PCC piles ranged from 109.80% to 123.167%, while the maximum strain observed ranged from 109.89% to 124.31%. The utilisation of carbon fibre bars was observed to enhance the maximum carrying capacity of PCC piles by a range of 23.58% to 39.50%. Additionally, a noticeable improvement in the strain at maximum stress was observed, ranging from 9.80% to 23.167%, along with an enhancement in the maximum strain, ranging from 9.89% to 24.31%.

Table 5: Results summary of Reference pile and PCC piles.

Group	Pile Code	Max. Axial Stress (MPa)	Strain at Max. stress $*10^{-6}$ (mm/mm)	Max. Strain $* 10^{-6}$ (mm/mm)
First Group (Reference)	PS 1	13.19	3069	4022
Fourth Group	PCC 1	16.3	3780	4420
	PCC 3	17.5	3370	4600
	PCC 5	18.4	3390	5000
	PCC 7	16.81	3645	4829

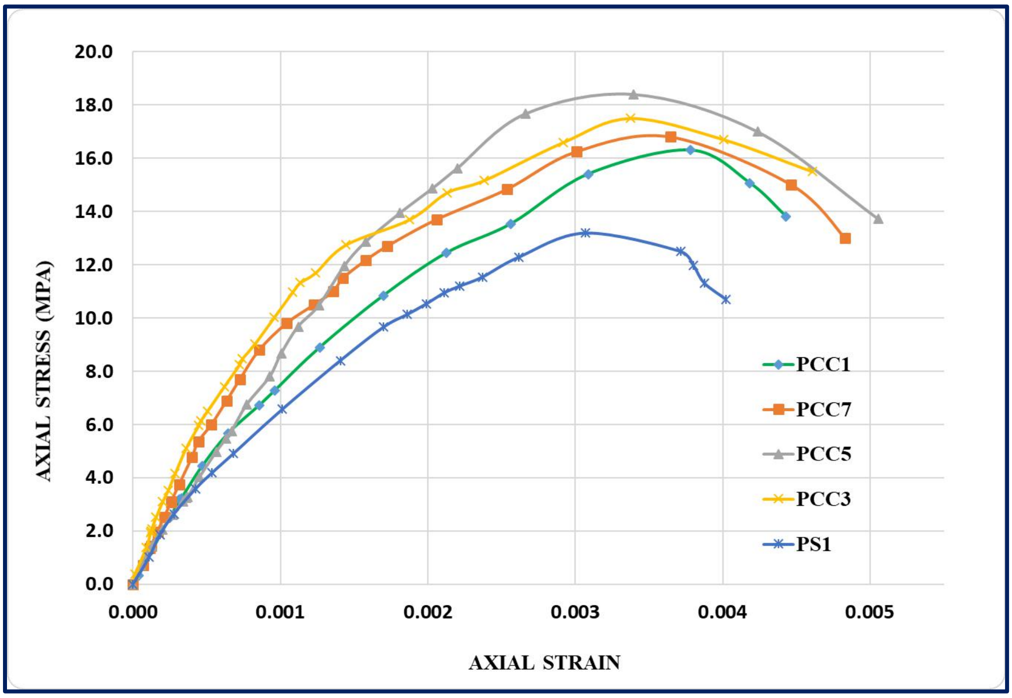

Fig.9: The stress-strain relationships for PCC piles compared with PS1 pile.

From figure (9) the behaviour shows that the stiffness of PCC piles increased compared with the reference pile. Also, the load capacity of piles was increased. The carbon fibre bars reinforcement of piles led to an increase in a strain which improved ductility. The failure was more ductile and predicted, first cracks started to show then failure occur when the carbon fiber bars Rft failed, figure (10).

Fig.10: The failure of the failure of PCC piles.

3.4. The highest load-carrying capacity pile of all three groups.

Maximum axial stress, strain at maximum axial stress, and maximum strain of the reference pile and highest load-carrying capacity pile from all three previous groups as indicated in table (6). Based on the findings, it is evident that the PC5 pile exhibited a maximum capacity of 93.60% in comparison to the reference pile. Furthermore, the PCG5 pile demonstrated a notable improvement in maximum capacity, with a percentage increase of 24.64%. Similarly, the PCC5 pile displayed a substantial enhancement in maximum capacity, with a percentage increase of 39.50% when compared to the reference pile. The strain observed at the point of maximum axial stress for the PC5 pile was found to be 78.00% of the strain observed in the reference pile. In contrast, the PCG5 pile exhibited an improvement of 103.193% in the strain at the maximum axial stress, while the PCC5 pile showed an even greater improvement of 110.45% when compared to the reference pile. The PC5 pile exhibited a maximum strain of 77.17% in relation to the reference pile, while the PCG5 pile displayed a maximum strain of 91.89% in comparison to the reference pile. The PCC5 pile exhibited a significant enhancement in maximum strain, with a 124.316% increase compared to the reference pile.

Table 6: Results summary of PS1 pile and maximum load-carrying capacity piles from all three previous groups.

Pile Code	Max. Axial Stress (MPa)	Strain at Max. stress $*10^{-6}$ (mm/mm)	Max. Strain $* 10^{-6}$ (mm/mm)
PS 1	13.19	3069	4022
PC 5	12.35	2394	3104
PCG 5	16.44	3167	3696
PCC 5	18.4	3390	5000

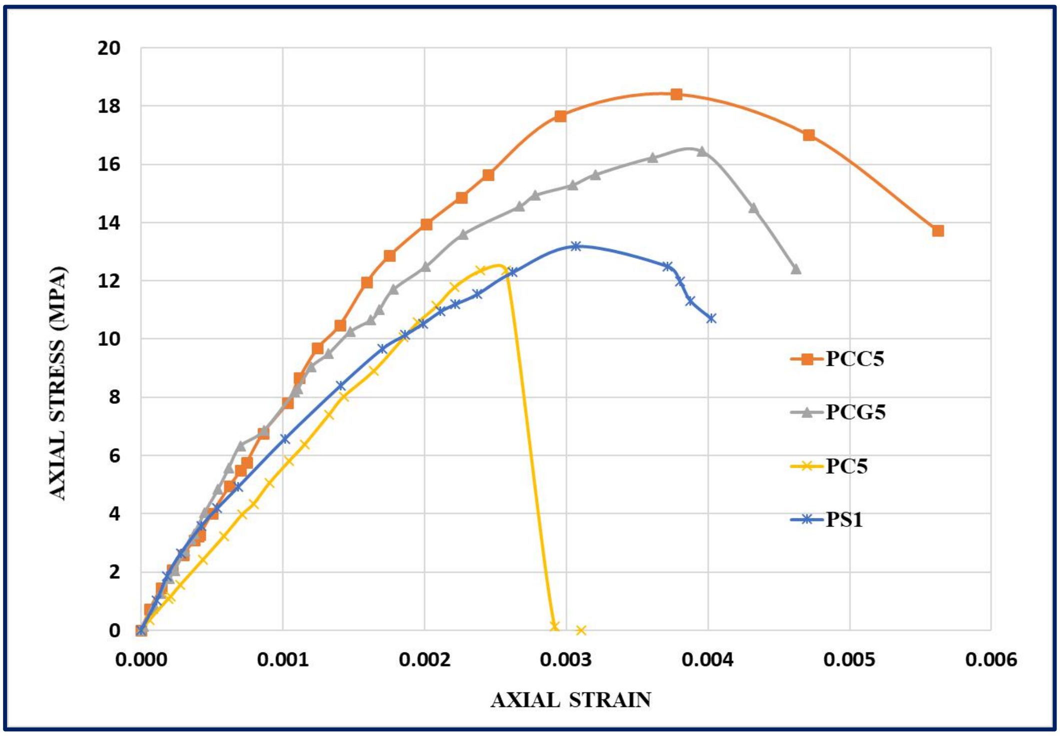

Fig.11: Stress-strain relationships for the highest load-carrying capacity pile from all three previous groups compared with PS1 pile.

The results showed that the 1.25% carbon fibre bristles ratio of cement weight was the best ratio, figure (11). When comparing the load-carrying capacity of the highest capacity piles from each of the three aforementioned types to the reference pile, it was observed that the utilisation of partial reinforcing using carbon fibre bristles generally enhanced the pile's capacity. The reinforcing of piles with steel bars, CFRP bars, or geogrid is mostly recommended to enhance the ductility of the pile. Among these options, the utilisation of CFRP bars as reinforcement yielded the most desirable results. The utilisation of geogrid confinement resulted in an acceptable load-carrying capacity accompanied by desirable ductile-carrying characteristics.

3.5. Cost analysis and Feasibility Study.

The utilization of carbon fiber concrete piles reinforced with geosynthetics enhances the load-carrying capacity of piles in comparison to the reference pile, as evidenced by the data stated in table (7). However, it is important to note that the cost associated with applying these reinforcement techniques remains relatively high when compared with conventional methods. Nevertheless, it is essential to consider the benefits offered by such reinforcements, including increased durability against detrimental environmental factors and reduced costs associated with pile rehabilitation. Furthermore, as the use of these reinforcements becomes more common and mass production becomes possible, it is expected that the overall cost will go down.

Table 7: Axial load-carrying capacity and cost ratio of all piles to reference pile.

Specimen	Maximum axial capacity at failure (MPa)	Capacity ratio	Cost (L.E)	Cost ratio
PS1 (Reference)	13.19	1	28	1
PC1	10.12	0.77	99	3.54
PC3	11.59	0.88	132	4.71
PC5	12.35	0.94	165	5.89
PC7	11.29	0.86	197	7.04
PCG1	13.4	1.02	106	3.79
PCG3	15.1	1.14	139	4.96
PCG5	16.44	1.25	172	6.14
PCG7	14.41	1.09	204	7.29
PCC1	16.3	1.24	352	12.57
PCC3	17.5	1.33	380	13.57
PCC5	18.4	1.39	408	14.57
PCC7	16.81	1.27	435	15.54

IV. CONCLUSION

The outcomes of the previous study could be summarised as follows:

1. The use of carbon fibres bristles in concrete mixture leads to improving the strength capacity of concrete piles.
2. The percentage of 1.25% carbon fibres bristles of cement weight gave the best results.
3. Despite the use of carbon fibres concrete piles gave good compressive stresses capacity but we recommend using confinement reinforcement to improve the ductility of piles.
4. The use of carbon fibre concrete piles with geogrid confinement gave a better load-carrying capacity with more ductile behaviour.
5. The use of carbon fibre concrete piles with carbon fibre bars reinforcement gave the best vertical load resistance and the highest compressive stiffness.
6. The use of geogrid confinement or carbon fibre bars reinforcement to resist vertical loads could be a better alternative compared to traditional reinforcement of piles.
7. Even though the cost of using carbon fibre concrete piles reinforced with geosynthetics is high right now, taking into consideration the benefits of using such reinforcements will help to make the piles more resistant to harmful environmental factors and lower the cost of pile rehabilitation. With the expansion of the use of these types and mass production, it will definitely lead to a reduction in cost.

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Experimental study of glass fiber concrete piles reinforced with GFRP bars and geogrid under concentric loads

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Abstract— *In a variety of applications, glass fiber concrete has proven to be a successful substitute for supplying shear and flexural reinforcement for reinforced concrete. The mechanical properties of glass fiber concrete and steel reinforcement are different, hence the compression behavior of concrete piles reinforced with glass fiber concrete may be different from that of those reinforced with steel. However, the axial compression behavior of circular piles has not yet been established. This study assessed the concentric behavior of 12 end bearing piles with 1050 mm length and 150 mm diameter reinforced with varying amounts of glass fiber bristles (GFB), 0.75, 1.00, 1.25, and 1.50% of cement weight. The results are presented in this publication. 4 of them had no extra reinforcement (PG), 4 had glass fibre bars (GFRP) and spiral steel reinforcement (PGGB), and 4 had triaxial geogrid as reinforcement (PGG). All outcomes were contrasted with a pile that had steel reinforcement (PS). The findings demonstrated that theses composite piles increased the capacity of piles. The maximum load absorbed by the PG models under axial load was 3.54–21.43% less than the maximum load absorbed by PS. The PGGB specimen's maximum load was 0.00–30.03 % higher than the maximum load of PS specimen. The maximum load supported by the PGG specimens under axial load was, in some cases, 5.23–18.20% less than the maximum load supported by PS, while in another case, it was 17.51% more.*

Keywords— ***Glass fiber bristles, Glass fiber concrete piles, Geosynthetics, Composite pile, triaxial geogrid, and glass fiber bars.***

I. INTRODUCTION

The advantages of glass fibre concrete (GC) include its high tensile strength, great durability, lightweight, and resilience to adverse environmental conditions. These characteristics make GC the appropriate substitute for traditional steel bars in concrete buildings that call for such properties. Numerous recent research has made examining the structural behavior of reinforced GC members their main goal. In the past two decades, a great deal of research has been done on the compression behaviour of GC-reinforced standard and high-strength concrete elements. Concrete columns with square cross section reinforced with GFRP bars and ties were studied [1-2]. Different types of fibers were used in concrete to improve its characteristics like steel, nano silica, polypropylene, carbon, and glass [3-5]. After that, a circular concrete column was examined experimentally and in field which reinforced with GFRP bars and ties with different testing parameters such as GFRP bars ratios, ties spacing, confinement reinforcement like hoops or spiral, and volumetric ratio [6-12].

High strength concrete (HSC) columns reinforced with GFRP bars and spirals have been tested to know its effect on column's resistance [13-15]. Behavior of different varieties of high-performance self-compacting concrete (HPSCC) has been studied for comparison with ordinary concrete, specimens were strengthened with steel rebars and various fibers [16]. After that, GFRP tubes filled with recycled and concrete material responded structurally when used to create composite piles [17]. Hollow concrete columns (HCCS) reinforced with GFRP bars and spirals were studied under different loading [18-19]. Composite piles have been tested which reinforced with different materials such as FRP bars, geosynthetics geogrids, and composite of two materials such as geogrid with a core of steel rod, and geogrid with a core of glass fiber reinforced polymers (GFRP) or carbon fiber reinforced polymers (CFRP) rod [20-21].

II. EXPERIMENTAL INVESTIGATION

2.1. Material

The concrete mix proportions utilized to cast the specimens are listed in Table 1. Both the nonfibrous and fibrous concrete had average compressive strengths of 15 and 20 MPa after 28 days, respectively. Steel bars in two distinct sizes, 8 mm plain mild rounded steel bars (R8) as longitudinal reinforcement and 6 mm plain mild rounded steel bars (R6) as transverse reinforcement were used to reinforce steel pile examples. The mechanical characteristics of the R8 and R6 steel bars, GFRP bars with size 8mm, Mesh of geogrid TX150 are given in Table 2,3,4 respectively. GFB are used to mix with concrete admixture with bristles length 12-16 mm and thickness of 0.01mm, Fig .1.

Fig. 1. Glass fibre bristles (GFB).

Table 1. The concrete mix proportions.

Material	Quantity (kg/m^3)
Cement	350
Fine aggregate	700
Coarse aggregate	1400
Water	175
Workability addition	0.4

Table 2. Mechanical properties of the steel bars.

Bar size	Diameter of the bar(mm)	Area of the bar (mm^2)	Yield tensile strength (MPa)	Strain (mm/mm)	Elastic modulus (GPa)
R8	8	50.29	240	0.0012	200
R6	6	28.29	240	0.0012	200

Table 3. Mechanical properties of the GFRP bars.

Bar size	Diameter of the bar(mm)	Area of the bar (mm^2)	Ultimate tensile strength (MPa)	Strain (mm/mm)	Tensile modulus (GPa)
#8	8	50.29	1100	0.0304	36

Table 4. Mechanical properties of geogrid.

Name	Thickness (mm)	Rib pitch (mm)		Ultimate tensile strength (MPa)	Tensile modulus (GPa)
		Longitudinal	Diagonal		
TX150	1.50	57	57	11.25	225

2.2. Design and processing of specimens

13 circular pile specimens with dimensions of 150 mm in diameter (D) and 1050 mm in height (L) and a ratio of 7 (L/D) were tested. The specimens were divided into three groups of four each, along with a typical steel-reinforced concrete pile control sample. Glass fibre was used to strengthen the 12 specimens in the three groups PG, PGGB, and PGG in varied amounts of GFB ,0.75, 1.00, 1.25, 1.25, 1.50% of cement weight. The first group of specimens lacks additional fortification. The second group's specimens (PGGB) were strengthened with four # 8 GFRP bars running longitudinally and R6 at 100mm pitch running transversely. These test models were created to determine

how the behavior of GC piles would change if the same amount of GFRP bars were directly substituted for the steel reinforcement. One roll of geogrid (TX150), which was constructed into the shape of a cylinder, was used to strengthen the specimens in the third group (PGG). These test specimens were created to determine how the behaviour of GC piles would change if the same amount of geogrid reinforcement were used directly in place of the steel reinforcement. Steel 4R8 longitudinal and R6 transverse bars are used to reinforce the control specimen. Table 5 displays the test matrix for the samples. The specimen's measurements and reinforcement setups are given in Fig. 2.

Table 5. Test matrix

Group	Pile code	Glass fiber %	Longitudinal reinforcement	Transverse reinforcement
Control (PS)	PS1	-	Steel 4R8	Steel R6@100mm pitch
PG	PG1	0.75	-	-
	PG3	1.00	-	-
	PG5	1.25	-	-
	PG7	1.50	-	-
PGGB	PGGB1	0.75	Glass 4#8	Steel R6@100mm pitch
	PGGB3	1.00		
	PGGB5	1.25		
	PGGB7	1.50		
PGG	PGG1	0.75	Roll of triaxial geogrid (TX150)	
	PGG3	1.00		
	PGG5	1.25		
	PGG7	1.50		

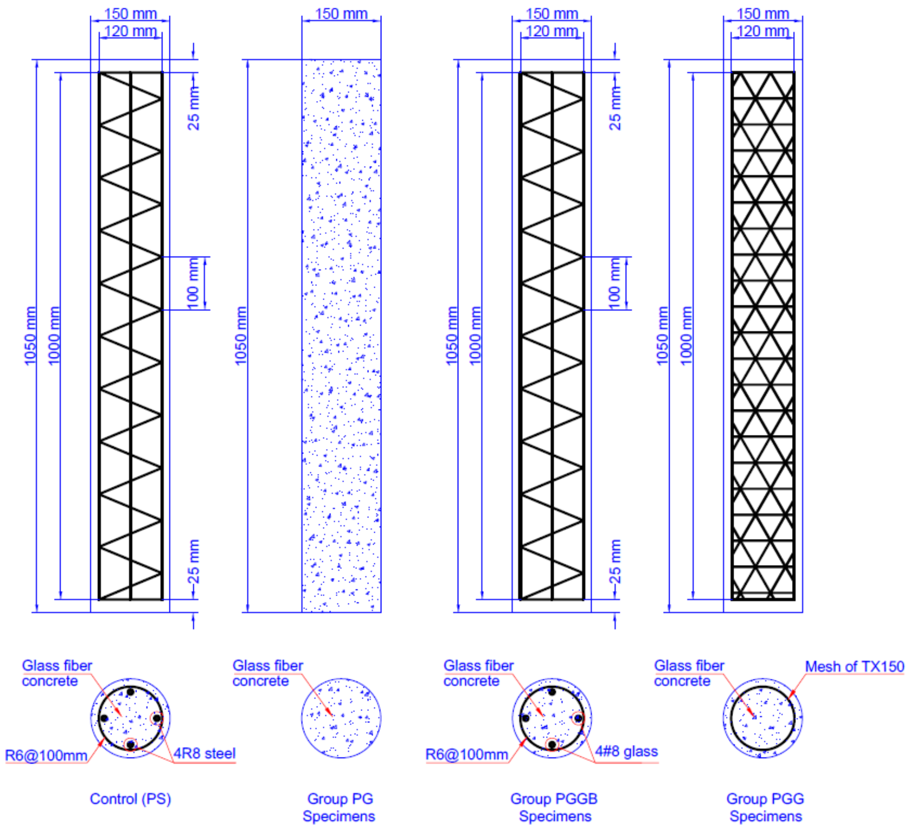
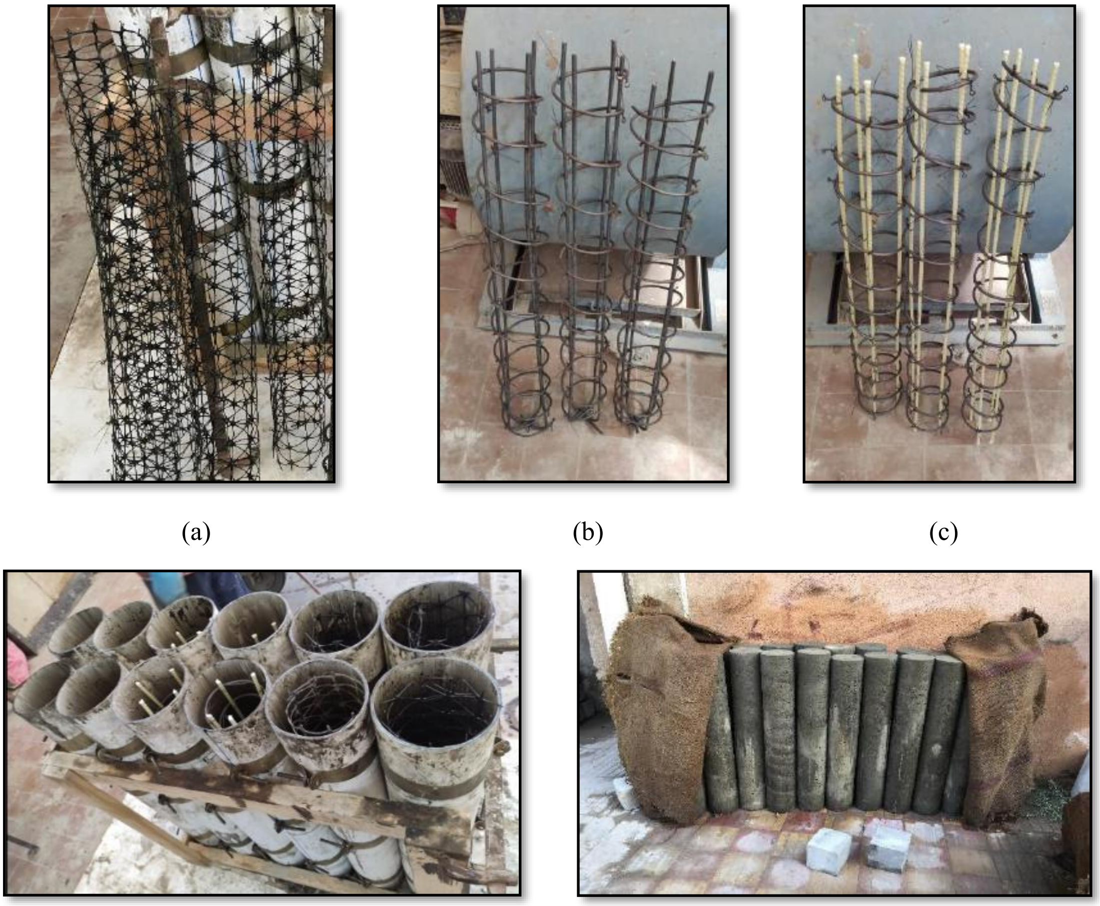


Fig.2. Geometry and reinforcement details of the tested specimens.

2.3. Creation and equipment of the test specimens

The specimens were cast using PVC pipes with an inner diameter of 150 mm and a height of 1050 mm as moulds. Additionally, a wooden frame was employed to support the PVC pipes upright and prevent any movement while the specimens were being cast. Based on the specimen's reinforcing configuration, geogrid reinforcement cages were put together. It was first cut into a rectangle of 1000 x 450 mm, and after that, it was rotated to take the form of a cylinder with a matching inner diameter of 120 mm, Fig. 3a. According to how each specimen's reinforcement was arranged, steel and GFRP reinforcement cages were put together. First, the GFRP and longitudinal steel bars were vertically aligned. After that, steel wire ties were used to combine the longitudinal bars with the reinforcing helices. To have the necessary pitch, the helices were modified. After that, the PVC moulds were filled with the finished reinforcement cages, Figs.3 b, c, d. The outer diameter of the steel and GFRP helices, which were manufactured, is 120 mm. The specimen's sides have a 15 mm concrete overlay. Additionally, 1000 mm-long longitudinal steel and GFRP bars were cut to maintain a consistent 25 mm concrete cover at the top and bottom of the specimen.

At the concrete laboratory of the civil engineering department, Benha University, Egypt, all the specimens were cast on the same day. The concrete mixture was directly put into the moulds created for PG, PGGB, and PGG specimens after being mixed with glass fibres in a concrete mixer. The ready mix was first added to the concrete mixer, after which the glass fibers were gradually added, uniformly distributed with a sieve, and stirred for approximately 10 minutes. The concrete mixture was then poured into the moulds created for PG, PGGB, and PGG specimens. In three steps, the specimens were vertically cast. Concrete was internally vibrated at every stage to eliminate air spaces and guarantee proper compaction. The specimens were retained in the moulds for the ensuing 28 days, during which time they were covered by wet burlap to cure, Fig. 3e.



(a) (b) (c) (d) (e)

Fig. 3. Fabrication of the tested specimens: (a) PGG specimens, (b) Ps specimen, (c) PGGB specimens, (d) completed formwork of the specimens and (e) specimen's curing.

2.4. Test configuration

The hydraulic Jac testing machine, which has a maximum compressive load capability of 1000 KN, was used to test all specimens. At the top and bottom of each specimen, axial loads were applied using two loading heads made at the Benha Faculty of Engineering. Steel ball joints and square steel plates made up each loading head. The ends of the specimens were shielded from bearing failure by square steel plates. The diameter of the tested specimens was smaller than the dimension of the square steel plates. The ends of the specimens were therefore not restrained by the square steel plates during the test as, Fig. 4.

Fig. 4. Setup testing of the pile specimens.

To detect the axial deformation in the column specimens during the test, one linear variable differential transducer (LVDT) was fixed vertically to the heads of the testing apparatus. At a pace of 5 kN/s, the specimens were loaded; force regulated. A data logger was connected to the LVDT to record data every 2 seconds. The internal load cell of the hydraulic Jac testing apparatus was used to record the applied axial load while the specimens were being tested.

III. RESULTS AND ANALYSIS

3.1. Failure mode

The type of reinforcement had a big impact on the test specimen's failure mechanisms. 13 piles investigated in this study showed three distinct causes of failure. Due to this specimen's lack of confinement, the failure modes of PG specimens were more abrupt, explosive, and brittle than those of any other specimens. The longitudinal steel bars of PS buckled which was followed by concrete crushing, Fig. 5a. The PG specimen's failure was a concrete smashing caused the unexpected failure, Fig. 5b. A combined compressive/shear failure of the longitudinal GFRP bars at their contact sites with the spirals, along with concrete crushing, caused all the PGGB specimens to fail, Fig. 5c. All the PGG specimens were destroyed by triaxial geogrid cutting and concrete crushing, Fig. 5d.

(a) (b)

(c) (d)

Fig. 5. Failure mode of tested specimens: (a) PS specimen, (b) PG specimens, (c) PGGB specimens, and (d) PGG specimens.

3.2. Effect of GFB %age

The results of Group 1 specimens can be used to determine the impact of the reinforcing % of GFB (PG1, PG3, PG5, and PG7). The 4 piles were made of the same concrete mixture but with varying amounts of GFB. The PG1, PG3, and PG5 had stress levels that were 5.72, 22.77, and 11.32 % higher than the PG7 respectively, Fig.6, Table 6. It is concluded that 1.00% is the ideal GFB %age (PG3). Despite this, maximum strain of PG1, PG3, and PG5 was around 44,20, and 15% less potent than PG7 respectively.

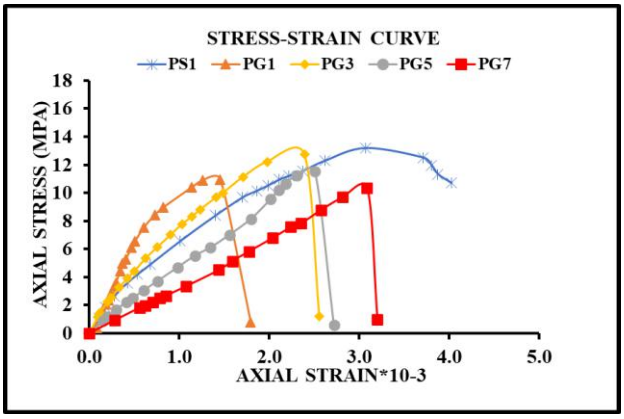


Fig. 6. Stress-strain behavior for GC piles.

Table 6. Stresses and strains for PG specimens.

Pile code	Max. stress (MPa)	Strain at max. stress (με)	Max strain(με)
PS1	13.19	3069	4022
PG1	10.96	1454	1793
PG3	12.72	2392	2560
PG5	11.54	2507	2720
PG7	10.36	3086	3200

3.3. Behavior of piles with GFRP bars and geogrid

Adding extra GFRP bars, spiral steel stirrups, and geogrid as the primary reinforcement for GC piles resulted in confinement for the piles, improved material behavior, increased both load capacity, strain, made the piles more ductile, and prevented brittle concrete failure.

It is possible to evaluate the impact of reinforcement type using the data of Group 2 specimens (PGGB1, PGGB3, PGGB5, and PGGB7). Four # 8 GFRP bars running longitudinally and four R6 at 100mm pitch running transversely, with varied GFB %ages, served as the principal reinforcement for the four piles. PGGB1, PGGB3, and PGGB5 had stress levels that were about 11.31, 31.93, and 14.97% higher than PGGB7 respectively, Fig.7, Table 7. The maximum strain of PGGB1 was roughly 35.86% lower than that of PGGB7, whereas PGGB3 and PGGB5 had maximum strains that were respectively 17.24 and 10.35% greater.

Results for Group 3 specimens provide information on the influence of reinforcement type (PGG1, PGG3, PGG5, and PGG7). The main reinforcement for the four piles was the same—a roll of TX150—but the GFB % varied. PGG1 experienced stress that was 6.72% less than PGG7, PGG3 and PGG5 experienced stress that was 16.42 and 8.06% greater than PGG7 respectively. PGG1's maximum strain was roughly 25.37% less than PGG7's, while PGG3's and PGG5's maximum strains were both about 16.42 and 4.48% greater respectively, Fig. 8, Table 8.

Table 7. Stresses and strains for PGGB specimens.

Pile code	Max. stress (MPa)	Strain at max. stress (με)	Max strain(με)
PS1	13.19	3069	4022
PGGB1	14.5	2025	2790

PGGB3	17.19	3185	5100
PGGB5	14.98	3500	4800
PGGB7	13.03	3800	4350

Table 8. Stresses and strains for PGG specimens.

Pile code	Max. stress (MPa)	Strain at max. stress (με)	Max strain(με)
PS1	13.19	3069	4022
PGG1	10.78	2000	2500
PGG3	15.5	3600	3900
PGG5	12.5	3100	3500
PGG7	11.57	3090	3350

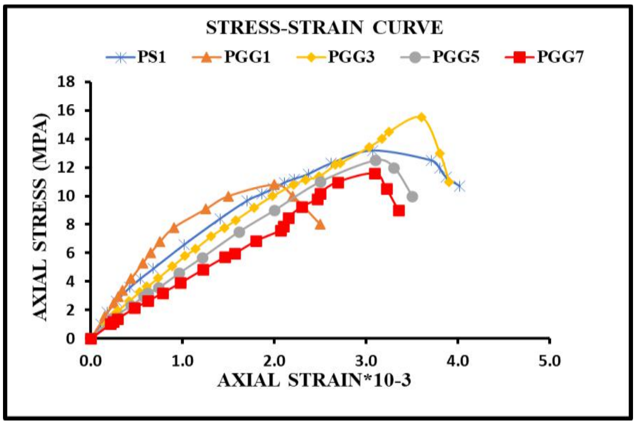


Fig. 8. Stress-strain behavior for PGG specimens.

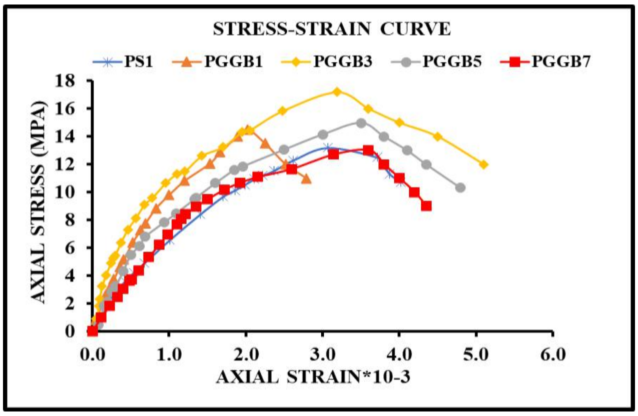


Fig. 7. Stress-strain behavior for PGGB specimens.

3.4. Behavior of GC piles with 1.00% GFB compared with steel pile.

The maximum stress and strain for PG3 were both roughly 3.54 and 36.36% smaller than those for PS1, respectively. When compared to the ductile failure of PS1, the failure was abrupt and brittle. Therefore, utilizing GFB as the primary reinforcement will roughly support the same load as steel reinforcement, but failure is the issue.

The maximum stress for PGG3 was approximately 17.51% higher than PS1's, whereas the maximum strain was approximately 3.04% lower. Triaxial geogrid confinement caused the failure to be ductile as steel reinforcement in PS1. Thus, employing the GFB with geogrid as reinforcement will carry more weight than using steel reinforcement while maintaining the same degree of elasticity, making this reinforcement more efficient.

The maximal stress and strain for PGGB3 were both about 30.29 and 26.79% more than that for PS1, respectively. The failure was more ductile than the steel reinforcement in PS1 because of the confinement of the steel stirrups and the high tensile strength of GFRP bars. It follows that employing GFB with GFRP bars as reinforcement will carry more weight than steel reinforcement and result in higher ductility, making this reinforcement the most efficient, Table 9 and Fig. 9.

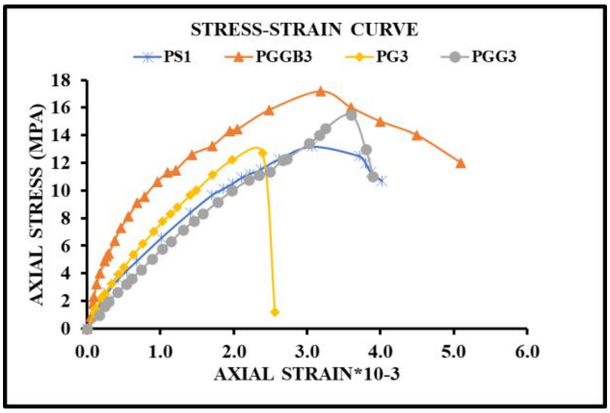


Fig. 9. Stress-strain behavior for 1.00% GFB specimens and steel.

Table 9. Stresses and strains for PGG specimens.

Pile code	Max. stress (MPa)	Strain at max. stress (με)	Max strain(με)
PS1	13.19	3069	4022
PG3	12.72	2392	2560
PGG3	15.5	3600	3900
PGGB3	17.19	3185	5100

IV. CONCLUSION

The outcomes of the experimental tests allow for the following summaries:

- Using glass fiber bars or geosynthetics geogrids as reinforcing materials enhanced the ultimate axial stress of the pile compared to the control pile specimen.
- In concrete piles, glass fiber bristles reinforcement made up 1.00% of the cement weight.
- Using glass fiber concrete as the main reinforcement under an axial load is less effective than using steel piles.
- In comparison to steel piles, using glass fiber concrete piles with glass fiber bars reinforcing provided the best vertical load resistance.
- The vertical loading capacity of using glass fiber concrete piles with geogrid reinforcement varied, sometimes being less than steel piles and other times being larger.
- The failure modes of specimens reinforced with glass fiber bristles were more abrupt, explosive, and brittle than those of any other specimens. All the other specimens were ductile due to the steel bars, glass fiber bars, and geogrid reinforcement.

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Study the effect of Industrial Dairy and Textile Waste Water on the Engineering and Geotechnical Properties of Fine-Grained Soil

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***Abstract*— *Understanding and prediction of engineering properties of fine-grained soils is of vital importance in Geotechnical Engineering practice. Fine-grained soil contamination occurs on a daily basis as a result of industrial development and pipeline or reservoir leaks.Due to the influence of the surrounding condition, substantial damage occurs in the foundations of buildings. The presence of industrial wastewater in the soil contributes to a change in its physical, chemical and mechanical properties, and then negatively affects the foundations of various facilities. . In addition to environmental issues such as groundwater contamination, the changing of the geotechnical qualities of polluted soil is a concern. As a result of the concentrations of pollutants resulting from the businesses such as Dairy products industry and spinning and weaving factories, are extremely high in developing countries. Disposal of untreated industrial waste water is a common problem in these countries. This paper describes an experimental investigation that was conducted to explore the effect of two types of industrial waste water the first type was dairy industrial waste water (DW) and the second was textile industrial waste water (TW) on the deformational behavior of fine-grained soil. Fine-grained soil used in this research was obtained in a natural phase from a soil excavation site for the construction of a residential building in the village of El-Kom Al-Ahmar, Shibin El-Qanater, Qualiobiyah governorate Fig.1, which was exposed to DW and TW at 2, 4, 6, 8, 12, and 16 months, Two remolded soil samples are generated for this investigation and combined with different types of industrial wastewater of constant moisture content (70%). The Atterberg limits, plasticity index, specific gravity, free swelling, optimal moisture content (OMC), and maximum dry density (γdmax) of each mixture were calculated after 0, 2, 4, 6, 8, 12, and 16 months of mixing soil with industrial waste water, the results revealed that as soil matures, the optimum moisture content (O.M.C) and free swelling values of the soil containing DW, TW rise after the addition of pollutants, whereas the maximum dry density, specific gravity (GS), and cohesiveness decrease.*

***Keywords*— Fine-grained soil. Contaminated soil. Industrial waste water. Geotechnical properties.**

I. INTRODUCTION

Soil pollution stemming from a variety of industrial wastewater byproducts stands as a significant geo-environmental concern, adversely affecting soil quality, groundwater, and the atmosphere. The acceleration of industrialization and urbanization has generated substantial quantities of both solid and liquid waste, consequently leading to extensive alterations in the geotechnical characteristics of soil due to the disposal of wastewater into the ground, as noted in reference [1-2]. Incidents of foundation and structural failures attributed to soil contamination and chemical spills have been documented in several reports [3, 4]. Extensive research has shown that various geotechnical properties of fine-grained soils can be influenced by both inorganic and organic contaminants typically present in industrial effluents [5, 6, 7]. To address the needs of diverse engineering applications, it is essential to thoroughly investigate and comprehend the interactions between soil and pollutants, as well as the repercussions of pollutants and industrial effluents on various geotechnical characteristics.

A comprehensive examination of the existing body of literature reveals that, to date, the primary emphasis has been on comprehending how pure chemicals affect commercial soils such as kaolinite and bentonite. There is comparatively limited research available regarding the effects of industrial effluents, especially on natural soils [8,9].

Industrial wastewater can contain hazardous substances that are relatively water-soluble, with examples including those originating from textile, dairy, and leather waste. The contamination of industrial wastewater poses significant risks to wildlife, including the poisoning of apex predators that consume organisms with accumulated wastewater in their tissues [10,11]. This contamination can disrupt breeding patterns by making animals ill and unable to reproduce. It can also lead to skin, mouth, or nasal irritation or ulceration, damage red blood cells, and harm the adrenal tissue of birds, impairing their ability to defend against predators [12].

The hormonal equilibrium in birds can also be disrupted through exposure to industrial effluents, potentially influencing factors like luteinizing protein. Despite comprehensive research on the geotechnical attributes of polluted fine-grained soils, there has been limited investigation into the impact of wastewater pollution on the geotechnical properties of such soils [11, 13].

Khan et al. (2017), Stalin et al. (2010), and Easa et al. (2002) have all conducted laboratory testing programs aimed at assessing the influence of wastewater contamination and the aging process on the geotechnical properties and behavior of fine-grained soil [1,6,8]. In Easa et al.'s (2010) study, samples of naturally contaminated groundwater sourced from household wastewater were obtained at the groundwater pumping level. The assessment involved the use of X-ray and conventional chemical testing to determine the concentration of toxins present in the groundwater [14]. The research findings suggest that residential wastewater is considered the predominant source of groundwater pollution due to its extremely hazardous and toxic chemical composition [15,16]. This contamination poses a substantial threat to public health. Additionally, a separate study highlighted the capacity of clay to expand as a result of fluctuations in water content, which can be induced by groundwater, leading to upward pressure on foundations. The expansion of clay and the resulting swelling pressure can result in substantial damage, including the cracking of walls, beams, and columns, particularly when the soil's swelling pressure exceeds the foundation load [17,18,19].

The thorough prediction of soil geotechnical parameters is a critical practice in geotechnical engineering, particularly in the presence of contamination [20]. Soil characteristics are altered as a result of ground pollution, Soil property changes cause a variety of geotechnical issues such as structural cracks, ground settlement, heaving of structures, slope instability, depletion of strength and deformation characteristics, changes in compaction characteristics, and so on.

Previously, the adequate attention of construction damages were attributed to many factors such as inadequate construction material, differential settlement, the destructive role of expansive and collapsing soil, etc. While, the effect of waste water on soils was taken as second or third reason of building and construction problems [8].

Recently, progressive increasing of constructions damage caused due to effect of waste water on soil was reported by engineers and investigations [21-24]. So, engineers are concerned about the amount of damage caused by waste water to buildings, foundations, and soils.

On the other hand, if the chemical composition of the water in the pores of the clay is changed, the physical and mechanical properties of the clay are expected to change. Thus, the pore fluid type and composition strongly affects the engineering behavior of most soils especially clayey soils [25-27].

Furthermore, several investigations have shown that, the pollution of soil has important influence on the physical and mechanical properties of clay [28, 29].

Hence, modern building necessitates not only a prior examination of the foundation material, but also a complete understanding of the processes that cause the changing of soil qualities over the life of the structures supported by it. Several case studies of soil contamination with industrial pollutants and their impact on soil geotechnical behavior are presented below.

Kirov (1989) observed the influence of wastewater on deformation behavior of clayey soil, He found that soils interacting with a solution of detergents undergo a large amount of deformation. Srivastava et al. (1992) observed increase in consistency limit, permeability and coefficient of compression and decrease in shear strength and bearing capacity of a soil specimen permeated with fertilizer plant effluent[29,30].This is due to decrease in cation content and increase in hardness of leaching water after interaction Decrease of liquid limit and plasticity index of montmorillonite soil due to addition of pharmaceutical effluent to the soil has been found due to decrease of dielectric constant by contamination. Yaji et al. (1996) have investigated the influence of sugar mill liquid wastes on the behavior of shedi soil. At large percentages of sugar mill liquid wastes, shear strength decreases [31].

Generally, industrial wastes contain acids, alkalis, sulphates, salts, urea (amides), and oil pollutants, which cause changes in the physicochemical, mechanical and geotechnical properties of the soil.

II. PROPBLEM DIMENSION

In view of modern state tendencies, industrial development occupies an important place for self-sufficiency inside Egypt. Therefore, the government has paid attention to the industrial sector in recent decades. Therefore, the danger arises from industrial wastewater, which poses a real threat to the soil, groundwater, and the mechanical behavior of fine-grained soil. Therefore, the effect of industrial wastewater as a result of the dairy and textile factories scattered in Egypt on fine-grained soil has not been studied. Therefore, the researchers try to identify the properties of contaminated soil to avoid potential risks and also to use contaminated soil beneficially in civil engineering projects. Accordingly, the results of this research can be used in the first phase of the development program studies.

III. EXPERIMENTAL APPLICATION

According to a comprehensive review of the literature, studies on the influence of dairy and textile effluent on natural soils are infrequent or scarce. The wastewater used in this case originated from two separate sources. The first originated from Dairy factory in Minya Governorate , and the second from Textile factory in Obour City, Qalyubia Governorate . These potentially hazardous wastewaters, whose environmental consequences necessitate continuing monitoring, were collected after solids deposition but before treatment. According to a critical review of the literature, considering the foregoing, the two types of industrial wastewaters—dairy and textile wastewater—which are referred to as DW and TW, respectively, in this research—were chosen for the current investigation. Fine-grained soil used in this research was obtained in a natural phase from a soil excavation site for the construction of a residential building in the village of El-Kom alAhmar, Shibin El-Qanater, Qualiobiyah governorate (Fig. 1).

Fig. 1. Site of soil sample

The various effluents in "as collected form" as well as the outflow from the experimental setup, i.e., pH, alkalinity, total solids, total dissolved solids (TDS), total volatile solids (TVS), chloride, and biochemical oxygen demand (BOD) were estimated to be characterized by the effluent parameters. The metrics are complete and adequate for describing the effluent and understanding its impact on the specified soils. The parameter analysis method was carried out in accordance with Standard Methods. The properties of dairy and textile effluent are listed in Table 1. Representative soil samples from the chosen regions were collected in 50 kilograms airtight polythene bags, transported to the lab, and stored in airtight containers under normal conditions. Until usage, keep at laboratory temperature.

Table 1 Physical properties of wastewater (DW1 and TW1)

Properties	Value	
	DW	**TW**
Color	light yellow	greenish grey
Temperature (C)	22	24
PH (Value)	10.3	11.80
Total Suspended Solids (TSS), (mg/liter)	2772	2684

Table 2 Organic properties of wastewater (PW and LW)

Properties	Value	
	DW	**TW**
Volatile Suspended Solids (VSS)	985	1217
Biological Oxygen Demand (BOD)	686	912
Total organic carbon (TOD)	284	448
Chemical Oxygen Demand (COD)	4513	3876
Oil &Grease	174	266
Phenol	8.5	9.7
Detergents	17.5	22.4
Pesticides	2.4	7.5

Table 3 Chemical properties of wastewater (DW and TW)

Properties	Value (mg/liter)	
	DW	**TW**
Chloride (Cl-)	2942	1968
Sulfate (SO42-)	757	3827
Alkalinity (CaCO3)	176	868
Ammonia (NH3-N)	65	162
Phosphate (SO43-)	4.5	17.7

Table 4 Chemical minerals of the samples DW and TW.

Properties	Value (mg/liter)	
	DW	**TW**
Aluminum	0.2	0.40
Chromium	1.05	1.80
Copper	0.05	1.70
Iron	2.45	0.55
Lead	0.11	1.25
Manganese	1.80	7.2
Nickel	0.02	2.73

Borne	0.06	4.82
Selenium	0.12	0.58
Fluoride	10.85	8.73
Zinc	0.00	3.70
Arsenic	0.07	0.11
Cyanide	0.01	1.87
Mercury	0.001	0.057
Cadmium	0.03	0.063

3.1 Experimental Set-up and Soil Sample Preparation

This study's experimental design includes two groups, each with six contaminated soils (DW or TW) and natural soil for comparison. These groups were constructed after mixing and according to the timeline Fig. 2.A and B. Each set of soils under consideration was generated and used for the following purposes:

(i) Samples were collected from the site and stored in the laboratory Fig. 2.

(ii) Since each effluent was utilized to investigate how industrial waste materials affected the mechanical and geometric qualities of soil at different ages. As a result, only two sets of polluted soils were used for research purposes. At 2, 4, 6, 8, 12, and 16months, commercial soils were tested.

(iii) A total of 13 samples were used to study the influence of two effluents (DW and TW) on natural soil (S1). A 2.9-kilogram soil sample is manually mixed with effluents at their optimal moisture content (OMC) before being transported.

Scanning electron microscopes (SEM) and X-ray diffraction (XRD) were also utilized to examine the mineral compositions of natural and polluted samples [12-16]. These techniques are available at Egypt's Egyptian Mineral Resources Authority's Central Laboratories Sector's Housing & Building National Research Centre in Giza. The experimental program was developed in order to determine the swelling behavior of the tested soils In addition to tests for liquid limit (L.L), plastic limit (P.L), shrinkage limit (S.L), specific gravity (GS), and finally the standard Proctor test. As shown in (Fig. 3.A, B and C), (Fig.4.A and B).

Fig. 2. Sample preparation with the contaminated industrial wastewater.

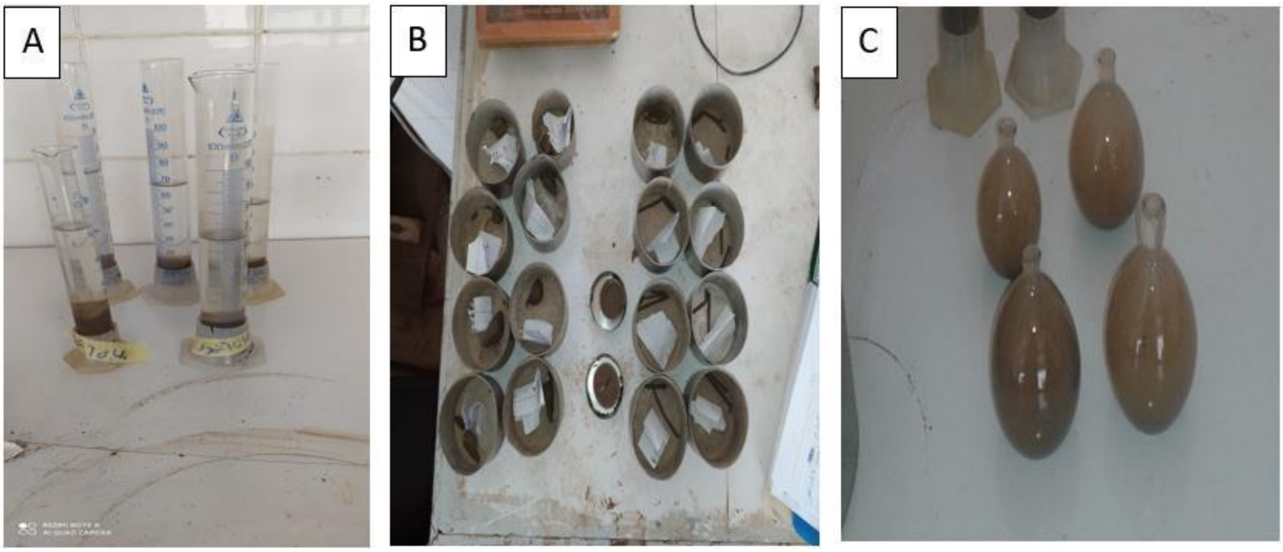


Fig.3. Preparing soil for free swell (F.S), (L.L), (P.L), (S.L) and (GS) tests

Fig.4.standard Proctor test

IV. RESULTS AND DISCUSSION

4.1 Physical Properties

Tables 5 and 6 list the index parameters of natural (S1) and contaminated soil, including specific gravity and Atterberg limits (liquid limit (LL), plastic limit, shrinkage limit (SL), and plastic index). According to these findings and the unified soil classification system (USCS):

i) The natural soil's liquid limit (LL) and plastic limit (PL) values were 74% and 33%, respectively. While the relative levels of contamination (LL and PL) of soil with dairy effluent are, respectively, 66.5% to 62% and 32% to 27%. The LL and PL of soil contaminated with textile wastewater ranged from 62% to 63% and 34.5% to 33%, respectively, and PI of TW and DW contaminated soil are range of 41%, to30%, and 41% to 35% respectively.

ii) The specific gravity (GS) and shrinkage limit (SL) of natural soil were 18% and 2.67, respectively. While the specific gravity (GS) and (SL) of soil that has been contaminated with dairy effluent range from 2.6 to 2.56 and 19% to 21%, respectively. The specific gravity (GS) and (SL) of soil contaminated with textile effluent were2.65 to 2.6 and 19.2% to 20.5%, respectively.

Table 5. The results of Atterberg limits for natural and contaminated soil with DW at different times (months)

Property		(natural soil) S1	DW1 (2 month)	DW2 (4 month)	DW3 (6 month)	DW4 (8 month)	DW5 (12 month)	DW6 (16 month)
G. S		2.67	2.6	2.6	2.58	2.577	2.57	2.565
Atterberg limits	(L.L), %	74	66.5	65	64	63	62.5	62
	P.L	33	32	30	29	28	27	27
	S.L	18	19	20	21	Broken	Broken	Broken
	P.I	41	36.5	35	35	35	35	35
USCS		MH	MH	MH	MH	CH	CH	CH

Table 6. The results of Atterberg limits for natural and contaminated soil with TW at different times (months).

Property		(natural soil)	TW1 (2 month)	TW2 (4 month)	TW3 (6 month)	TW4 (8 month)	TW5 (12 month)	TW6 (16 month)
G. S		2.67	2.65	2.635	2.63	2.61	2.61	2.6
Atterberg limits	(L.L), %	74	62	62	62.5	63	63	63
	P.L	33	34.5	35	35.5	35	34	33
	S.L	18	19.2	20.5	20.5	broken	broken	broken
	P.L	41	27.5	27	27	28	29	30
USCS		**MH**	**MH**	**MH**	**MH**	**CH**	**CH**	**CH**

4.2 Compaction Outcomes

The compaction test results for the natural soil and contaminated soils at different dates are shown in Figs.5.and Fig6. It is clear from Table 6, which includes the compaction findings as maximum dry density (γdmax) and optimum moisture content (OMC), that:

i) The optimum moisture content (O.M.C.) and maximum dry density (γdmax) of natural soil (S1) were 20% and 1.70 gm/cm3, respectively, while these values ranged from 22.5% to 24% and 1.61 to 1.53 gm/cm3 for soil that had been contaminated DW. When soil was contaminated with TW effluent, the O.M.C. and dry density were, respectively, 20.5% to 22.3% and 1.65 to 1.6 gm/cm3.

ii) The (γdmax) of both contaminated soils was lower than that of the natural soil. The γdmax of DW-contaminated soil is lower than TW-contaminated soil.

Table 7. Compaction out comes for the studied soils

Sample No	Sample No	O.M.C, %	γdmax., t/m3
Natural Soil	S1	20	1.7
Contaminated soil with DW	DW1 (2 month)	22.5	1.61
	DW2 (4 month)	22.75	1.6
	DW3 (6 month)	23	1.58
	DW4 (8 month)	23.5	1.57

	DW5 (12 month)	24	1.54
	DW6 (16 month)	24	1.53
Contaminated soil with TW	TW1 (2 month)	20.5	1.65
	TW2 (4 month)	21	1.64
	TW3 (6 month)	21.5	1.62
	TW4 (8 month)	21.75	1.61
	TW5(12 month)	22	1.6
	TW6(16 month)	22.3	1.6

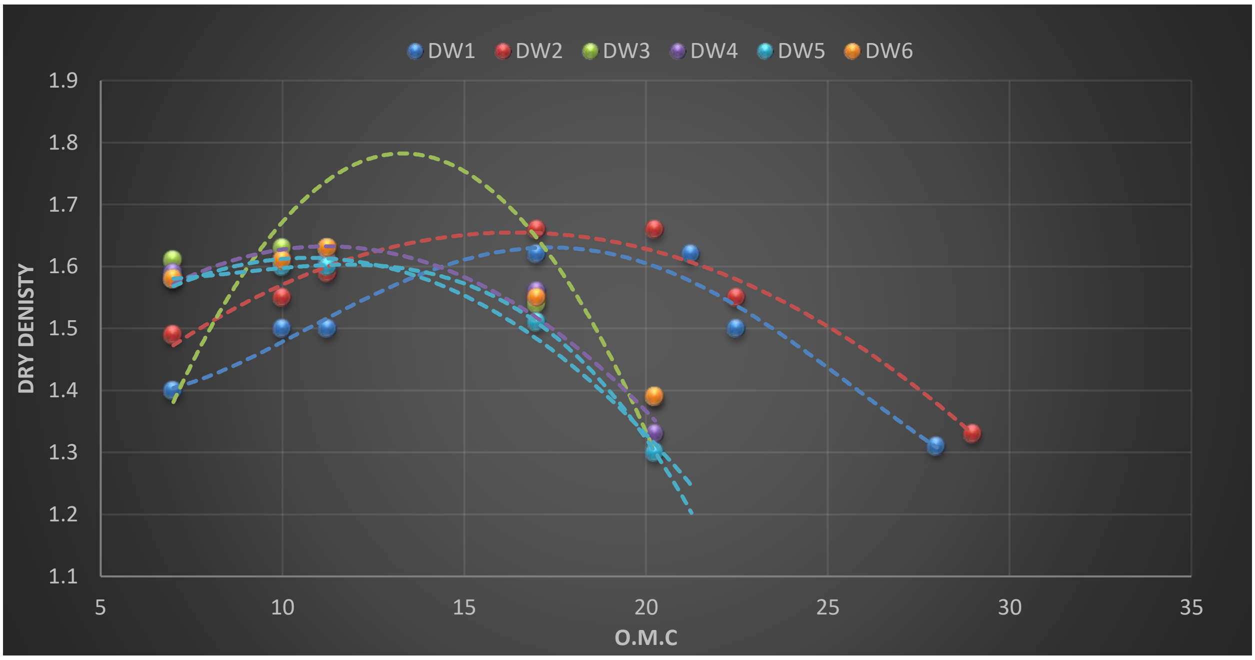


Fig.5. Results of standard proctor test curves for contaminated soil with DW.

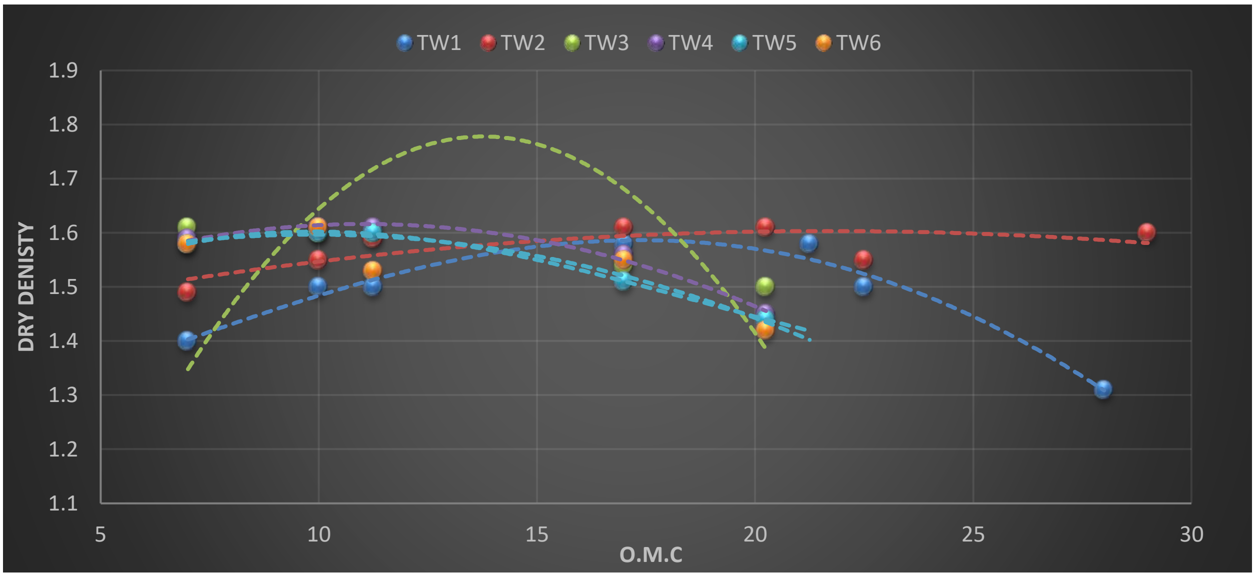


Fig.6. Results of standard proctor test curves for the contaminated soil with TW.

4.3 Swelling Results

Free swell is an increase in soil volume caused by immersion in water without any external restrictions. An assessment of those soils considered to exhibit unwanted expansion characteristics is necessary to determine the risk of harm to structures caused by the swelling of pricey clays. To reflect the system's ability to expand under various simulated scenarios, inferential testing is used. The dry density, starting water content, surcharge loading, and various other environmental parameters all affect how much swelling pressure develops. As a result, Table 7 contains a list of the free swell (F.S) results. The relationship between the percentage of free swell (F.S.) and the dry density's ideal water content (O.M.C.) is shown in Fig 7 to 8. Respectively, the liquid limit (L.L), plasticity index (P.L), and shrinkage limit (S.L). Additionally, it should be emphasized that: According to the findings of free swell regarding the connections of F.S with physical qualities (O.M.C, L.L, P.I, and S.L).

i) The free swell (F.S.) values range from 60% for the natural soils. The results showed that S1 (natural soil) has the lowest value (60%) and DW5, DW6 (12 and 16 months) has the highest value (78%). The results of the swelling show that as wastewater ages, the value of the swelling rises, and The F.S of TW-contaminated soil at TW6 (16 months) has highest value (79.5%).

ii) The F.S of DW-contaminated soil was lower than that of The F.S of TW-contaminated soil.

II) The swelling DW and TW-contaminated soil increases with the ageing increases.

Table 8. Swell results for the studied soils

Sample No	Sample No	F.S, %	Remarks
Natural Soil	**S1**	**60%**	The Swelling Increases with the ageing increases
Contaminated soil with DW	DW1 (2 month)	65%	
	DW2 (4 month)	72.5%	
	DW3 (6 month)	75%	
	DW4 (8 month)	76%	
	DW5 (12 month)	78%	
	DW6 (16 month)	78%	
Contaminated soil with TW	TW1 (2 month)	70%	
	TW2 (4 month)	72%	
	TW3 (6 month)	75%	
	TW4 (8 month)	76.5%	
	TW5(12 month)	77.5%	
	TW6(16 month)	79.5%	

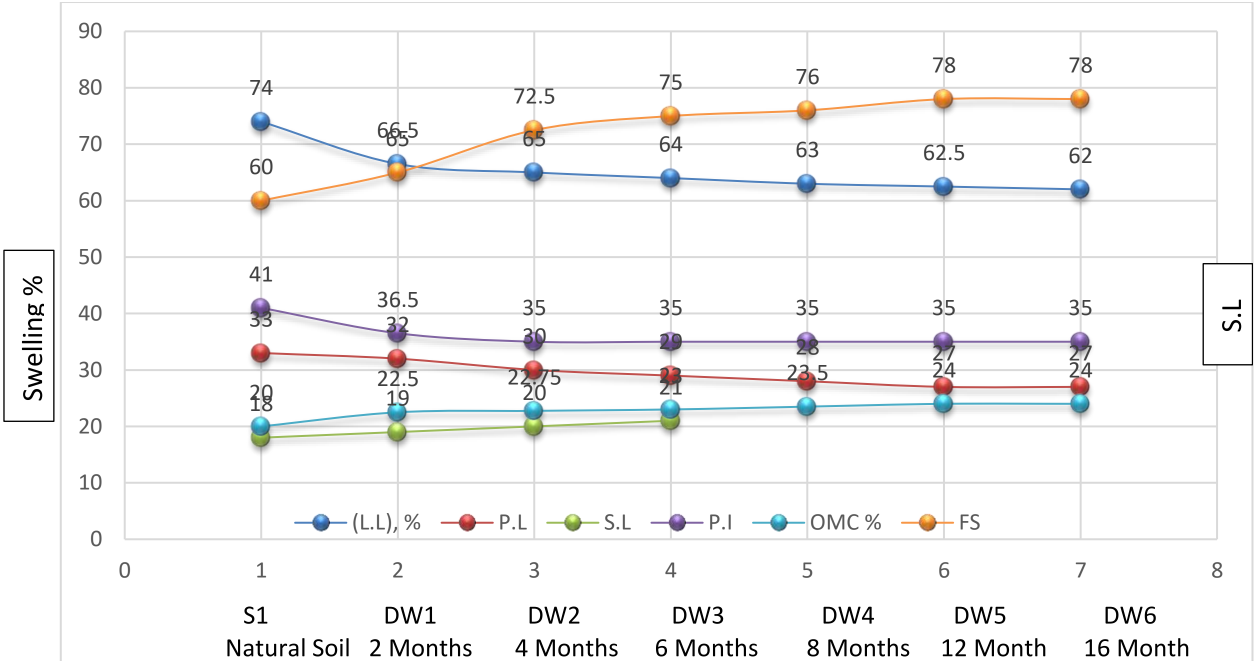


Fig. 7. Correlations of Free Swell with Plastic index, Shrinkage Limit, liquid limit and OMC% for (DW).

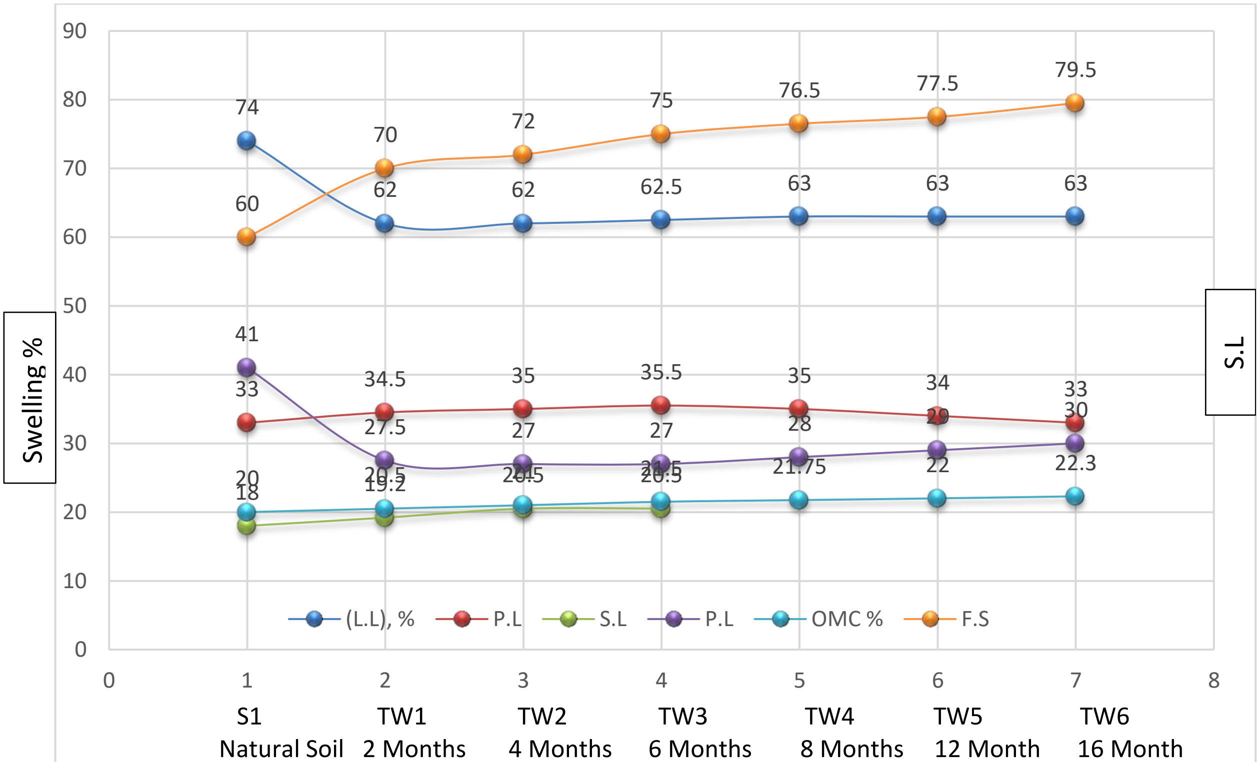


Fig. 8. Correlations of Free Swell with Plastic index, Shrinkage Limit, liquid limit and (OMC%) for(TW) soil.

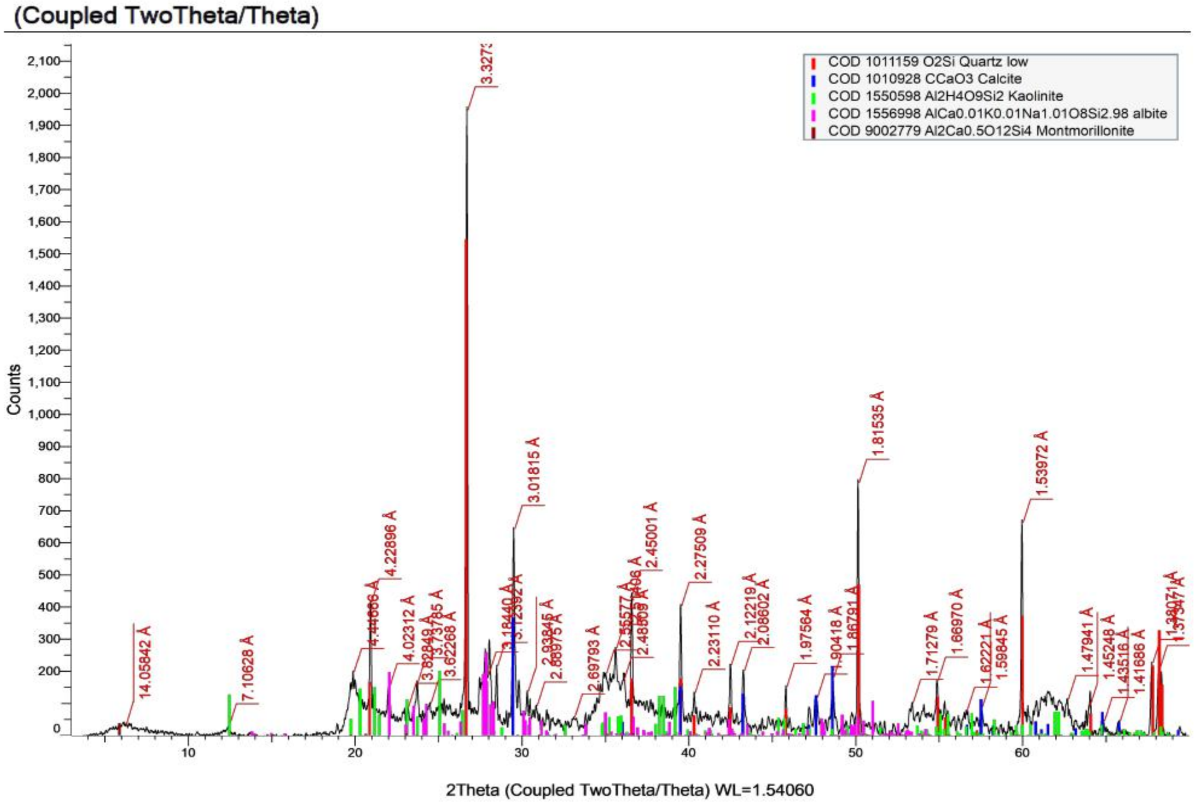
4.4 Mineralogical Analysis of the Tested Soil

To identify the fine-grained soil features found in the study area and to look into differences in mechanical characteristics as a result of the study of the impact of various types of water on the examined soil, laboratory tests were conducted. The experimental program, (Fig9), is based on classification tests (particle size distribution analysis and index test), direct and ring shear tests, and tests on intact, degraded, and reconstituted specimens. By using X-ray diffraction (XRD) and X-ray fluorescence spectroscopy (XRF), 3 samples of fine-grained soil were examined. The X-ray diffraction patterns of natural soil

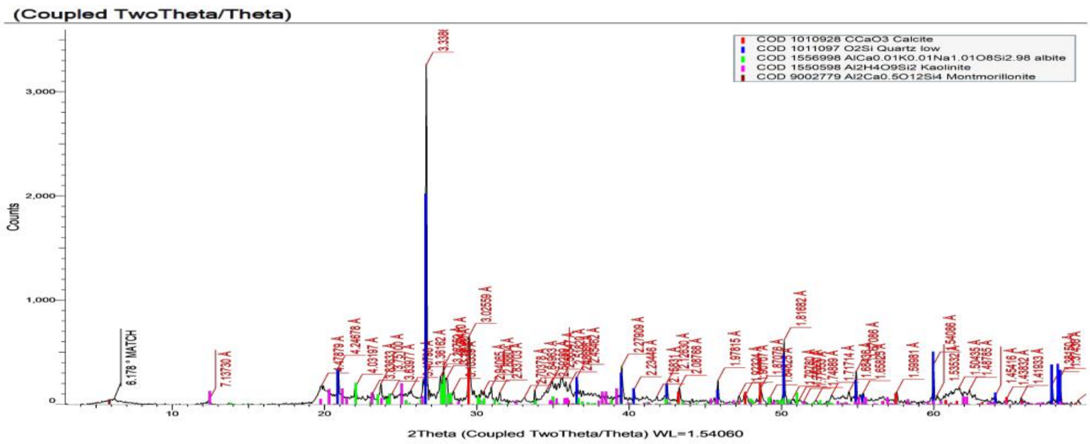
sample, DW and TW samples are shown in (Fig9.a.b and c.)
As a result,

***Table 9* presents the calculated mineral percentages.**

Formula	S-Q
O2Si	20.4%
CCaO3	12.8%
Al2H4O9Si2	20.8%
AlCa0.01K0.01Na1.01O8Si.98	22.6%
Al2Ca0.5o12Si4	23.4%

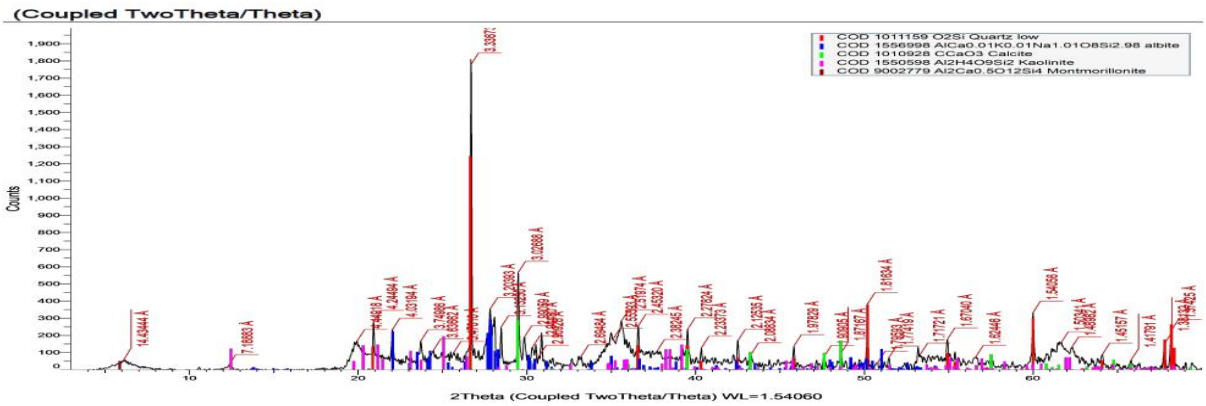


a) Natural sample (S1)



Formula	S-Q
O2Si	12.4%
CCaO3	14%
Al2H4O9Si2	21.3%
AlCa0.01K0.01Na1.01O8Si.98	26.8%
Al2Ca0.5o12Si4	25.5%

b) Soil contaminated with dairy wastewater (DW).



Formula	S-Q
O2Si	11.5%
CCaO3	16%
Al2H4O9Si2	20%
AlCa0.01K0.01Na1.01O8Si.98	22.5%
Al2Ca0.5o12Si4	30%

c) Soil contaminated with textile waste water (TW).

Fig.9. XRD results of the studied soil.

Table9. XRD semi-quantitative percentages results.

Sample No.	Quartz	Calcite	Kaolinite	albite	Montmorillonite
Natural soil	20.4	12.8	20.8	22.6	23.4
DW	12.4	14	21.3	26.8	25.5
TW	11.5	16	20	22.5	30

4.5 Scanning Electron microscopy Investigations (SEM)

The particle structure of the soils and industrial wastewater was compared using scanning electron microscope (SEM) research. Fig.10, 11 and 12. show how the morphology of the tested soils is presented. , . Fig.10. the micrographs of natural soil devoid of industrial waste water, displays scanning electron micrographs of uncontaminated natural soil. The unique characteristics of natural soil, such as its high clay content, are highlighted by the stark variations in soil micrographs of natural soil before contamination. It is possible to see the impact of DW and TW on natural soil by contrasting the micrographs displayed in Fig 10, 11 and12. When compared to natural soil, the microstructure of the contaminated soil particles was looser, more porous, and had a different surface shape. Fig.11, 12. Illustrates the impact of industrial wastewater on natural soil. Sulphate activity causes disaggregation and the removal/washing out of constituents, strengthening the voids in some areas while causing aggregation and changes in the surface texture of the soil mass in other areas. The presence of clay is to blame for this. Mycelium fibers that have been discarded can be observed in a disintegrated and shattered shape in the micrographs in Fig11, 12.

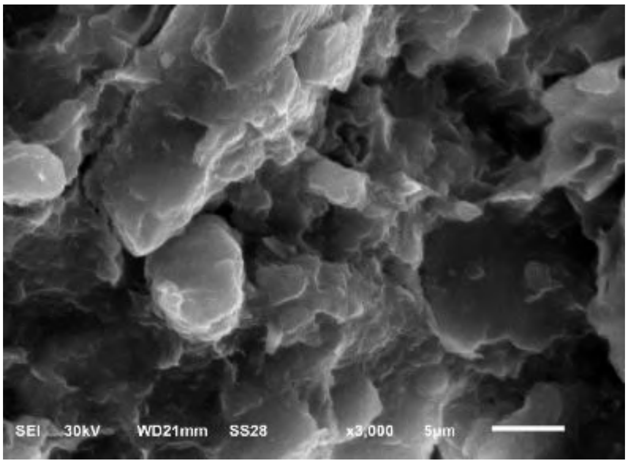


Fig.10. SEM micrograph of natural soil before artificial contamination with wastewaters

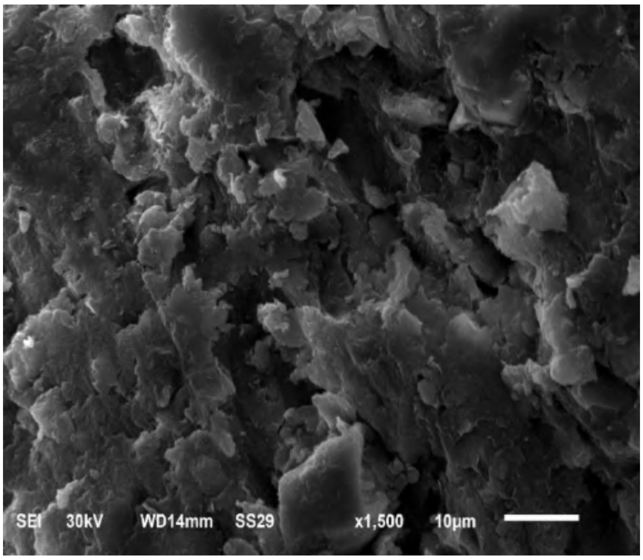


Fig.11. SEM micrograph of natural soil after artificial contamination with wastewaters (DW)

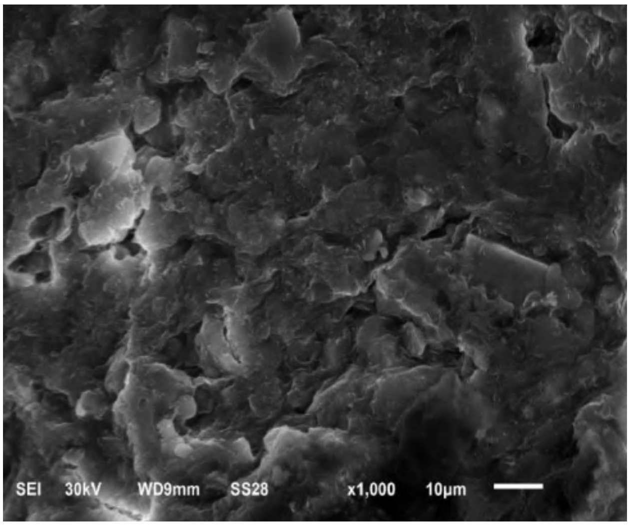


Fig.12. SEM micrograph of natural soil after artificial contamination with wastewaters (TW)

4.6 discussions and comparing results with other studies

The influence of the inorganic and organic pollutants of the dairy and textile wastewaters on fine-grained soils has been discussed in detail, especially with respect to the modes of mechanical, chemical, and mineralogical properties and microstructure of the studied soils. Further, the effect of the wastewater on the Atterberg limits and on the compaction and free swell of various fine-grained soils has also been critically assessed. Based on the above, the unique nature of the industrial wastewaters and their interactions have been highlighted and critical observations made.

Table 10, 11 contains the findings for the examined soils in this study. Table12 compares the findings of the previous studies with those of Kartika et al., (2021), Khodiry et al., (2018), Cyrus et al., (2010), and Baykuş, et al., (2021), Alnos Easa et al (2009), Kerman (2012), Girisken (2013). Considering this comparison, it is concluded that the effect of the dairy and textile wastewaters on fine-grained soils is significant which change the properties of natural soil. The optimal moisture content (O.M.C.) values for the current study are greater than the values for earlier investigations. However, compared to other investigations, the dry density values for the current study are lower.

Additionally, the range of specific gravity (Gs) values is the same for the past and contemporary studies. The present study's compaction test results are lower than those of earlier research. The examined soils in the current study didn't contain as much sand as those in earlier investigations. Variable values for silt and clay content are seen in both the current investigation and earlier studies. The percentage values for clay minerals in the current study and earlier investigations were very similar. The free swell (FS) values for the current study are higher than the values for the earlier studies. All soils were categorized in accordance with Unified Soil Classification System (USCS).

Table 10. The experimental findings for the studied soils of the present study

Property		S1 (natural soil)	DW1 (2 month)	DW2 (4 month)	DW3 (6 month)	DW4 (8 month)	DW5 (12 month)	DW6 (16 month)
O.W.C		20	22.5	22.75	23	23.5	24	24
Dry density		1.7	1.61	1.6	1.58	1.57	1.54	1.53
G. S		2.67	2.6	2.6	2.58	2.577	2.57	2.565
Atterberg limits	(L.L), %	74	66.5	65	64	63	62.5	62
	P.L	33	32	30	29	28	27	27
	S.L	18	19	20	21	Broken	Broken	Broken
	P.L	41	36.5	35	35	35	35	35
XRD Minerals percentage	Quartz	12.4	-	-	-	-	-	12.4
	Calcite	14	-	-	-	-	-	14
	Kaolinite	21.3	-	-	-	-	-	21.3
	albite	26.8	-	-	-	-	-	26.8
	Montmorillonite	25.5	-	-	-	-	-	25.5
Soil		MH	MH	MH	MH	CH	CH	CH
F.S, %		60	65	72.5	75	76	78	78

Table11. The experimental findings for the studied soils of the present study

Property		TW1/DW1 (natural soil)	TW2 (2 month)	TW3 (4 month)	TW4 (6 month)	TW5 (8 month)	TW6 (12 month)	TW7 (16 month)
O.W.C		20	21	22.25	23	24	24.25	25
Dry density		1.7	1.65	1.64	1.62	1.61	1.6	1.6
G. S		2.67	2.65	2.635	2.63	2.61	2.61	2.6
Atterberg limits	(L.L), %	74	62	62	62.5	63	63	63
	P.L	33	34.5	35	35.5	35	34	33
	S.L	18	19.2	20.5	20.5	broken	broken	broken
	P.L	41	27.5	27	27	28	29	30
	Quartz	11.5	-	-	-	-	-	11.5

XRD Minerals percentage	Calcite	16	-	-	-	-	-	16
	Kaolinite	20	-	-	-	-	-	20
	albite	22.5	-	-	-	-	-	22.5
	Montmorillonite	30	-	-	-	-	-	30
Soil		MH	MH	MH	MH	CH	CH	CH
F.S, %		60	70	72	75	76.5	77.5	79.5

Table12. The experimental findings for the studied soils of the present study

Property	**O.W.C**	**Dry density**	**G. S**	**Atterberg limits**		**S.L**	**P.I**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**F.S, %**
				L.L	**PL**						
Alnos Easa et al (2009)	23	1.94	2.72	48	25	16	23	22	70	8	60
Cyrus et al., (2010)	82	-	2.7	95	34	16	61	38	29	33	-
Girisken (2013)	19.4	1.62	2.67	29	25	4	-	--		-	40
Kermani (2012)	3.9	-	-	23.9	45.5		21.6	3	89	7	-
Karthika et al., (2021)	-	1.81	-	35.25	8.33	--	18.33				

V. CONCLUSION

Thirteen samples of confined soil were gathered from the case study region. Laboratory studies on these soil samples were performed to examine the physical traits of the various samples. In addition, the mineralogy of clay and the structure of soil particles were investigated using scanning electron microscopy and X-ray diffraction. The properties of both natural and contaminated soils that were gathered from the case study area were the subject of experimental research. The following conclusions are possible:

1) It has been suggested that the geotechnical properties of fine-grained soil promote the degradation of dairy and textile products, perhaps posing threats to the site's current construction.
2) The natural soil's liquid limit (LL) and plastic limit (PL) values were 74% and 34%, respectively. While the relative levels of contamination (LL and PL) of soil with dairy effluent are, respectively, 66.5% to 62% and 32% to 27%. The LL and PL of soil contaminated with textile wastewater ranged from 62% to 63% and 34.5% to 33%, respectively.
3) The optimum moisture content (O.M.C.) and dry density of natural soil were 20% and 1.70 gm/cm3, respectively, while these values ranged from 22.5% to 24% and 1.61to 1.53 gm/cm3 for soil that had been contaminated by dairy wastewater. When soil was contaminated with textile effluent, the O.M.C. and dry density were, respectively, 20.5% to 22.3% and 1.65 to 1.6 gm/cm3.
4) According to the Unified Soil Classification System (USCS), the soils in the case study area are categorized as MH. Additionally, the impact of soil contaminated by dairy wastewater was categorized as MH and CH. The soil that was contaminated with textile effluent, on the other hand, was categorized as CH and MH.
5) The specific gravity (SG) and shrinkage limit (SL) of natural soil were 18% and 2.67, respectively. While the specific gravity (SG) and SL of soil that has been contaminated with dairy effluent range from 2.6 to 2.56 and 19% to 21%, respectively. The specific gravity (GS)

and (SL) of soil contaminated with textile effluent were 2.65 to 2.6, and 19.2% to 20.5%respectively.

6) For the natural sample, the percentages of quartz, calcite, kaolinite, albite, and montmorillonite are 20.4%, 12.8%, 20.8%, 22.6and 23.4%, respectively. While these components changed with the addition of dairy wastewater. Therefore, the Quartz, Calcite, Kaolinite (K), albite (I) and montmorillonite percentage are changed to 12.4%, 14%, 21.3%, 26.8%, and 25.5%, respectively. On the other hand, the components of control soil changed with the addition of textile wastewater. Therefore, the Quartz, Calcite, Kaolinite (K), albite (I) and montmorillonite percentage are changed to 11.5%, 16%, 20%, 22.5%, and 30%, respectively. These results matched with the chemical composition of samples analyzed with XRF test.

7) The free swell (F.S.) values of natural soil had 60%. The results showed that contaminated soil with dairy wastewater has the higher than the control samples (78%), meanwhile contaminated soil with textile wastewater has the highest value (79.5%). It was also demonstrated that there is a direct correlation between free swell values and dry density, liquid limit, and plasticity index. This conclusion is also in line with what Sridhan (2000) and Sheahan (2011) found.

8) The microstructure of the examined soils shows that, in comparison to the control samples, the wastewater increased the morphology's porosity and looseness.

9) The engineering qualities of soil, particularly free swelling, are severely reduced by effluent from dairy and textile industries. Additionally, it is possible that the mineral particles would disintegrate, resulting in a loss of soil density. This loss of soil density can be identified as a significant Factor in the differences in soil parameters that were tested using SEM techniques.

10) The chemical properties of the soil, which also contribute to the definition of soil quality, control the status and activity of microbial populations. This study examined the effects of land filtration methods used for wastewater treatment and disposal in rural areas this study focused on how industrial wastewater affects the features on the chemical and physical properties of fine-grained soil.

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Exploring the Purchase and Use of Drone Aerial Camera from the Viewpoint of Technological Theoretical Models That Influence Domestic Graphic Art Creators

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Abstract— *The growth of Taiwan's camera drone, commonly used in today's film and media industries, has allowed more people to see the deeper beauty of Taiwan, and a wave of drone purchases and use has arisen in Taiwan. This is a business opportunity in the sky. While artists around the world have been widely using drone aerial cameras in their art creations, it is worthwhile to explore the willingness of domestic graphic artists to purchase and use drone aerial cameras. Therefore, this study attempts to use the "Task-Technology Fit Theory (TTF)" and the "Diffusion of Innovations (DOI)" as the theoretical basis for the empirical study. The study will be conducted using an online survey (online questionnaire) with a sample of 300 participants, and the hypotheses will be statistically analyzed through structural equation modeling using SmartPLS. The results of the study can be used by graphic artists as a reference for the use and purchase intentions of technological products and to enhance the presentation of high spatial aesthetics.*

Keywords— ***Drone Aerial Camera (DAC), Task-Technology Fit Theory (TTF), Diffusion of Innovations Theory (DOI), SmartPLS, Structural Equation Modeling (SEM)***

I. INTRODUCTION

The rapid development and popularization of technology is having a profound impact on various fields, including the field of art creation. As an emerging technological tool, unmanned aerial vehicles (UAV) (also known as drones or unmanned aerial vehicles) have been widely used in the fields of photography and film production. For creators of graphic arts, the drone may bring them new creative possibilities and visual effects, and at the same time, it may have an impact on their creative process and style.

While artists around the world have been widely using drone aerial photography in their art creations, it is worthwhile to explore the willingness of domestic graphic artists to purchase and use drone aerial photography. Therefore, this research paper adopts the "Task-Technology Fit (TTF)" theory and the Diffusion of Innovations (DOI) theory as the theoretical basis of the study and deduces the research framework, assumptions, and tests based on them. Since the development of drones, due to their high mobility, navigation system (GPS), flight control system open source, Wi-Fi and other wireless communications (5G), artificial intelligence, and other information technology products, the focus of the use of science and technology is that the user's attitude and beliefs can be predicted by the use of the information system's behavior.

The main theory is that some external factors will affect users' beliefs about usage behavior, and these beliefs will further affect attitudes, which in turn will affect usage willingness and actual usage behavior, thus applying the TTF theory proposed by Goodhue and Thompson in 1995. When the acceptance level of an innovation is low at the beginning and the number of users is small, the diffusion process will be relatively slow, and when the proportion of users reaches a critical value, the diffusion process of the innovation will increase rapidly. The researcher believes that the drone theme of this paper can be explored by applying these two theories. Product/service attributes are the main reason why people adopt and purchase these products or services. The relationship between product/service attributes and adoption behavior can also be explained by the Diffusion of Innovation (DOI) theory. Past studies have shown that the compatibility of an IT learning system will increase the users' learning performance and their willingness to adopt the system (Islam, 2016).

This study attempts to understand the factors behind domestic graphic arts creators' willingness to purchase and use unmanned aerial photography by using a theoretical model of technology. Such a study can help to understand the impact of technology on the field of art creation and, at the same time, provide valuable references and guidance for policymakers, the industry, and the creators themselves. Based on the background and purpose of the study, the research questions of this paper are as follows:

(1) Will the integration and utilization of Drone Aerial Camera (DAC) in graphic art creation increase the use of DAC by more art creation consumers?

(2) Will the TTF model affect the willingness of art creation consumers to purchase and use DAC?

(3) Does the willingness of art creation consumers to purchase and use DAC prove the applicability of the theory of DOI?

Based on the above research questions, this paper develops a research design, framework, and hypotheses and seeks to obtain the conclusions of this paper through a proper research methodology.

II. LITERATURE REVIEW

2.1 Artistic Creators

Art creators are those who create works of art in the fields of visual arts, performing arts, literature, music, and video. Through a variety of creative and expressive methods, they transform their ideas, feelings, and opinions into works of art in order to arouse resonance, inspire thinking, or foster emotional communication among audiences.

Creators of graphic arts are those who create works in the field of art that combine images and words. They usually utilize both graphic and textual elements, blending the two modes of expression to create works that are rich in meaning and emotion. This form of creation can be found in a variety of media, including illustrations, comics, book illustrations, posters, movie credits, visual essays, and more.

Graphic arts creators combine visual and textual elements, often not only for aesthetic reasons but also to convey a specific message, emotion, or story. This type of creation can create a unique visual and emotional experience through the interaction between images and words, which may lead the audience into deep thinking or evoke emotional resonance. The work of graphic arts creators is often visually and linguistically powerful, and they are able to explore and present complex subject matter in unique ways. They may work in a variety of fields, such as illustration and fiction, educational resources, social aspirations, etc., and provide audiences with multiple levels of thought and experience. In short, graphic artists are those who create works of art that combine images and words, combining visual and verbal elements to convey messages, emotions, and stories through their work.

2.2 Camera drone

A drone, also known as an unmanned vehicle, is a vehicle that carries no passengers. It is usually controlled by remote control, guidance, or autopilot. It can be used for scientific research, site exploration, military, and recreational purposes. At present, the most commercialized drone is the UAV. Aerial vehicles with built-in or external cameras or camcorders are often referred to as UAV. Aerial cameras allow people to enjoy the beauty of nature from a bird's-eye view. Many photographers and image creators have purchased aerial cameras to show their creative talents. Composition is not enough; in addition to proficient flight remote control technology, the operation of the aerial camera should know how to operate the camera shooting; otherwise, there are even better flying skills, such as not mastering the aerial shooting of the camera rhythm, and it is easy to degenerate into a record of the nature of the photo or video. It is precisely because the threshold for creating aerial photography is not low that the preciousness of beautiful images is emphasized. Artistic presentation of drone group flying performance is an integrated application of high technology. With the improvement of technology, there are more and more changes and possibilities, and the aesthetic part of the artistic presentation requires the input of more technological artists in order to design touching works so that the beauty of the group flying performance is deeply rooted in people's hearts, creating more eternal memories to be treasured in life. Therefore, the perfect combination of graphic arts creation tasks and technological innovation products will be more and more diversified and mass-produced.

2.3 Task-Technology Fit Theory (TTF)

Task-Technology Fit (TTF) theory was proposed by Goodhue and Thompson in 1995. This study has found that there are two main streams in exploring the relationship between IT usage and performance: the technology usage viewpoint and the technology fit viewpoint. The focus of the technology usage perspective is that user attitudes and beliefs can predict the usage behavior of an information system, and the main theory is that some external factors will affect the user's beliefs about the usage behavior, and these beliefs will in turn affect attitudes, which in turn will affect the willingness to use the system and the actual usage behavior. TTF is the degree to which technology is used to help the user accomplish a task/job. If the art-making consumer can accomplish the task through the features of the DAC and the task is compatible with the features of the DAC, then the art-making consumer will be more likely to purchase the DAC. The following is the correlation between the technology task adaptation theory and the DAC in art creation:

(1) Matching work demands and technology functions: The technology task adaptation theory states that when users choose and use technology tools, they will consider whether these tools can fulfill their work demands. For art creators, the unmanned aerial camera provides unique camera angles and scenes that can help them create more visually impactful works, thus adapting to their art creation needs.

(2) Ease of use and skill requirements: The technology task adaptation theory emphasize the effect of ease of use and skill requirements on the willingness and satisfaction of using technology tools. The operation of an unmanned aerial camera may require technical skills, but as technology advances and simplifies, it may become

easier for users to master its operation, thus increasing willingness to use and satisfaction.

(3) Work effectiveness and efficiency: The TTF theory is concerned with whether the use of technological tools can improve work effectiveness and efficiency. In art creation, the DAC can help art creators capture specific scenes and viewpoints more quickly, which improves the efficiency of creation and also brings more creative possibilities to them.

(4) Cognitive and affective factors: The technology task adaptation theory considers the influence of users' cognitive and affective factors on the use of technology. Artists may be more willing to use the drone because of the visual surprise and emotional resonance it brings, and these factors may also affect their satisfaction with the drone.

2.4 Diffusion of Innovation (DOI) Theory

Diffusion of innovations (DOI) is the process of diffusion and adoption of something new, a theory derived from the American scholar Everett Rogers in 1962. The concept is a series of decision-making processes over time, defined by five successive stages of the concept: awareness, interest, evaluation, judgment, and adoption of the idea to decide whether to accept an innovation or not.

After linking the correlation between user traits and art creators' willingness to purchase a drone in innovation diffusion theory, different user traits reflect their acceptance and attitude towards new products or technologies, and these traits will affect art creators' willingness to purchase a drone as well as the reasons behind it. The following are the correlations between user characteristics and art creators' willingness to purchase CVRs:

(1) Innovators and Artists: Innovators are usually curious about new technologies and are the first to accept new products on the market. For art creators, if they have both artistic and technological innovation qualities, they may purchase a drone during the innovator phase to explore its application in their creation.

(2) Early Adopters and Art Creators: Early adopters are social leaders whose behavior and opinions may influence the decisions of others. For art creators, the influence of early adopters in their social networks may pique their interest in CVTs and may motivate them to purchase and use them.

(3) Early Majority and Art Creators: The Early Majority is a group of people who embrace new technologies after the first two stages and may be more risk-averse to the technology. Artists may begin to consider the use of CVRs at this stage, especially if there are enough success stories and examples of actual creations to prove the value of CVRs.

(4) Late Majority and Artistic Creators: The Late Majority may be a more conservative group, and they may need more concrete evidence and real-world results to convince them to adopt the new technology. For art creators, they may focus on the actual impact of unmanned aerial cameras on their creative outcomes and consider whether they can enhance their creative works by using unmanned aerial cameras.

(5) Conservatives and Art Creators: Conservatives are the last group to accept new technologies, and they may need more time to adapt and accept new technologies. For art creators, if they want to use unmanned aerial photography in their creations, they may need more publicity and education to convince the conservative group.

The user traits in the DOI theory can help us understand the differences in the willingness of different types of art creators to purchase a drone. Depending on their characteristics, art creators may exhibit different purchase intentions and motivations in the stages of Innovator, Early Adopter, Early Majority, Late Majority, and Conservative.

III. RESEARCH METHODOLOGIES

3.1 Data Collection and Measurement Tools

This study will be conducted using an internet survey (online questionnaire). About 72% of internet users in Taiwan use mobile 4G and 5G internet. According to the 2018 survey, Taiwan has more than 16 million mobile phone users. In this study, e-gift cards will be offered as a raffle gift to attract potential respondents, and subjects' emails and IP addresses will be checked to avoid duplication. It is estimated that 300 samples will be taken. The questionnaire is adapted from previous studies to measure the conceptualization of the study. Experienced professionals will be invited to design appropriate questions from relevant literature. The wording of the project was adapted to fit the context of the study. Task-related and DOI-related projects were adapted and revised from Kim and Ammeter's (2014) project. The TTF project was adapted from Hsiao (2017). Value-related items were taken from Hsiao and Chen (2018). Perceived observability was adapted from Hsiao (2013), while purchase intentions were taken from Hsiao and Chen (2016).

3.2 Research Hypotheses

Based on the literature review and research design, the relevant research hypotheses (hypotheses) for this study are as follows:

H1: When work and tasks are facilitated by the functions of the DAC, the fit between tasks and technology will be enhanced.

H2: Consumers' willingness to purchase and use the DAC will be directly affected by the TTF.

H3: Task-technology fit is directly affected by perceptual compatibility.

H4: The willingness of art creation consumers to buy a drone will be directly affected by perceived compatibility.

H5: Task and technology suitability will be directly affected by perceived relative advantages.

H6: Consumers' willingness to purchase a drone will be directly affected by their perceived relative advantage.

H7: Artistic creation consumers' willingness to buy a drone will be directly influenced by its appearance and design.

H8: Artistic creation consumers' willingness to buy "drones" will be directly influenced by emotional values.

H9: Artistic creation consumers' willingness to buy "drones" will be directly influenced by the value of quality.

H10: Consumers' willingness to buy "drones" is directly influenced by the value of money.

3.3 Analysis Methods

This study anticipates the use of SmartPLS, a statistical analysis method for structural equation modeling (SEM), which is an analytical technique for probing or constructing predictive models, especially for causal modeling between latent variables, which is superior to general linear structural relationship models. SmartPLS is software with a graphical user interface for variance-based SEM using partial least squares (PLS) path modeling. Users can use basic PLS-SEM, Weighted PLS-SEM (WPLS), consistent PLS-SEM (PLSc-SEM), and sum regression algorithms to estimate the model and the data. SmartPLS is popular with managers because of its ability to analyze small samples and accurately estimate problems such as intermediation and interference, which helps the researcher automate and complete the statistical program quickly. Thus, SmartPLS is widely used by researchers in the fields of capital management, marketing, business, sports and leisure, health, and tourism, and has gradually become the mainstream analysis software in the social sciences.

SmartPLS 3 is a popular PLS tool that evaluates both measurement and structural models. PLS requires a relatively small sample size and does not restrict the distribution of variables. The collected respondents are divided into two groups based on their purchasing behavior. The sample size for the customer group is relatively small (Ncustomers = 100).The PLS approach requires a sample size that is at least ten times the maximum number of quotes or the maximum number of formative indicators that affect the dependent variable (Chin et al., 2003). Therefore, the sample size is relatively adequate for the PLS estimation program. In the context of this study, SmartPLS 3 was considered a suitable tool. Therefore, SmartPLS, as structural equation modeling software, can be used to explore the statistical methods of TTF theory and DOI theory on the willingness of art creators to purchase DAC. It is a suitable tool in the context of this study as it can provide a deeper understanding of the correlation between the factors and their influence on the behavior of art creators.

3.4 Subjects

This paper is based on the internet users in China as the research target. It is difficult to estimate the number of domestic users of unmanned aerial photography, but it is important and forward-looking data. The online questionnaire for this paper was distributed on the more popular online smart device communities and smart device social networking sites (Google, SurveyCake, and SurveyMonkey, 2019), and internet users through the communities and social networking sites were invited to fill out the questionnaire as a research sample. At the same time, the email and IP addresses of the respondents were verified and checked to avoid duplicate sampling. Respondents took about 8 minutes to complete the online survey. After the final screening, there were 249 valid questionnaires left. The sample size was relatively small because unmanned aerial photography is not yet mature and popular in China.

3.5 Questionnaire

The questionnaire was adapted from previous studies to measure the concept of the study. Three senior professionals were invited to develop appropriate questions from the relevant literature based on their understanding of the products, and other question wordings were modified to fit the context and content of this study. The questions related to TTF and DOI were revised based on Kim and Ammeter's (2014) questions, and the TTF items were adapted from Hsiao (2017). The 'value orientation-related' items were taken from Hsiao and Chen (2018). The item 'Appearance design' was adapted from Hsiao (2013), while the item 'Purchase intention' was taken from Hsiao and Chen (2016). A pre-test was first conducted by collecting questionnaire responses from experts and university students. Factor analysis was used to measure the factor loadings, and question items with factor loadings below 0.5 (Hair et al., 2009) were deleted from the study, and finally 33 question items were retained.

IV. RESULTS

4.1 Measurement Model

SmartPLS 3 provides Confirmatory Factor Analysis (CFA) to assess the reliability and validity of the constructs. In general, Cronbach's alpha and the critical ratio (CR) are the key indicators of the reliability and validity of the questionnaire. In this study, the CR values, Cronbach's alpha, and average variance extracted (AVE) for the two groups (artwork consumers and potential artwork consumers) are summarized for each construct. The CR and Cronbach's alpha values ranged from.86 to.95, which exceeds the acceptable threshold of .6. During the analysis of convergence, the reliability of the constructs must satisfy the following criteria: first, the factor loadings must be greater than 0.5; second, the CR must be greater than 0.6; and third, and the AVE must be greater than 0.5 (Hair et al., 2009).

The indicator factor loadings for all factors in this study exceeded the acceptable thresholds. The AVE values and all composite values also exceeded the thresholds. Therefore, all values meet the criteria for convergent validity. In addition, acceptable discriminant validity must be satisfied by the correlation coefficient being less than the square root of the AVE. After calculating the square root of AVE and correlation coefficients for each factor, the results showed that the scales were able to satisfy the requirements for discriminant validity. In addition, the coefficient of inflation (VIF) was used to detect the degree of multiple covariance in this study. The PLS statistics showed that the internal VIF values ranged from 1.171 to 2.340, which is much lower than the critical value of 3.3 (Lee and Xia, 2010).

The results indicate that there is no multicollinearity between the independent constitutive surfaces. The result shows that the mean value of 'Emotional Value' is the highest among the two groups. Meanwhile, the mean value of "price/price ratio" is the lowest, which means that customers agree that the drone can bring them emotional benefits. The results of the independent sample t-test showed that the majority mean of the "Creative Arts Consumers" group was significantly larger than the mean of the "Potential Creative Arts Consumers" group. The ratings for the drone were more pronounced in the "Creative Arts Consumers" group. The mean values of most of the components in the "Art Creation Consumers" group reached significance.

4.2 Structural Modeling

In the analysis of the structural model, the path coefficients and the determination coefficients (R2 values) were calculated by PLS (Chin et al., 2003). TTF can highly influence the respondent's "willingness to buy", therefore H1 is supported in this study (β = 0.62, p-value <0.001), and H2 is also supported by the fact that the unmanned aerial camera has a very high influence on this construct of TTF in this variable (β = 0.64, p-value <0.001). In the construct of the 'product' attribute, 'relative advantage' has a significant effect on TTF of the drone aerial camera (β=0.29, p-value <0.001); therefore, H5 is supported but H3 is not (β=-0.03, p-value <0.001). There was no significant effect of perceptual compatibility on the willingness of art creation consumers to purchase the unmanned aerial camera; therefore, H4 was not supported (β = -0.05, p-value <0.001). Whereas, having 'Relative Advantage' and 'Appearance Design' had a significant effect on respondents' 'Willingness to Buy' (β=0.31, p-value <0.01; β=0.11, p-value <0.05), and therefore H6 and H7 were supported.

In the 'Perceived Value' construct, 'Emotional Value' significantly affected 'Willingness to Buy' (β = 0.42, p-value <0.001), but the performance-related 'Value and monetary value' did not affect 'willingness to buy'. Therefore, H8 was supported, but H9 and H10 were not. None of the control variables had a significant effect on willingness to buy. Summarizing the above, the research framework's models for each pathway showed that the explanatory variance for TTF and 'willingness to buy' could reach 64% and 57%, respectively.

V. CONCLUSION

The research framework of this study has good explanatory power in exploring the willingness of art-creation consumers to purchase DAC. The components and factors presented in the study can explain more than 64% of the variance, which indicates a good predictive effect and an explanatory research framework. This study also explores the differences between the potential consumption group and the consumption group, which also provides deeper implications (Hsiao, 2017). Within the potential consumer group, the analysis confirms previous findings that factors such as 'product attributes', 'design', and 'relative advantage' have a significant impact on customers' 'purchase intention'. In particular, "emotional value" has the strongest effect in these two groups. The contributions of this study are summarized as follows:

First, it provides a reasonable explanation for the correlation among TTF factors, product attributes, perceived value, and purchase intention. In the past, few researchers have integrated TTF, DOI, and perceived value into the willingness of art-making consumers to purchase unmanned aerial photography.

Second, this study found that the effect of TTF on purchase intention is significant. It indicates that TTF has some explanatory power over the use of drone equipment. Although past related studies have found that the effect of TTF on general consumers' willingness to purchase and use is not significant across different groups (Hsiao, 2017), the target population of this study is art creation consumers, which will have a high degree of fit with the TTF theory based on the high need for quality, energy, and work tasks in art creation.

Third, this study validates and adds to our understanding of the differences in determinants affecting consumers' and potential consumers' purchase intentions. Two sets of hypotheses (RA→PI and DA→PI) were supported in the group of potential consumers but not in the group of consumers. Manufacturers of unmanned aerial photography machines should continue to develop newer usage features to increase the relative advantage of their products, and at the same time, manufacturers can offer product variety in design to fulfill consumers' needs to increase repurchase intention.

Fourth, older customers may have more repurchase intentions, so they can become a target group. Elderly customers may be more willing to use and purchase a drone; after all, the cost of purchasing a drone is not low, but there are more choices for artistic creation and excellent creative height, which will bring an extraordinary creative experience.

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