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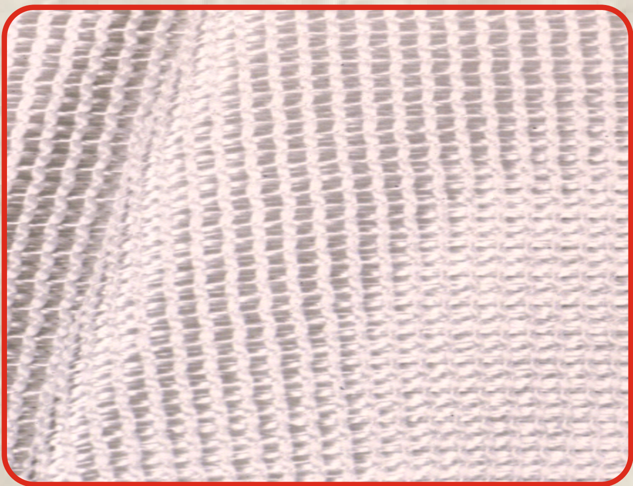

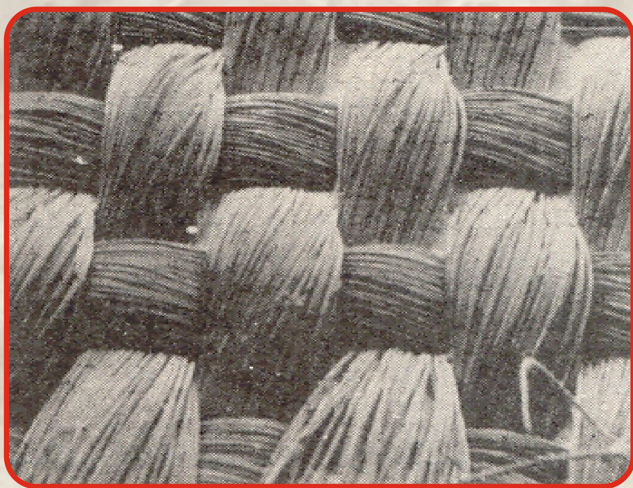

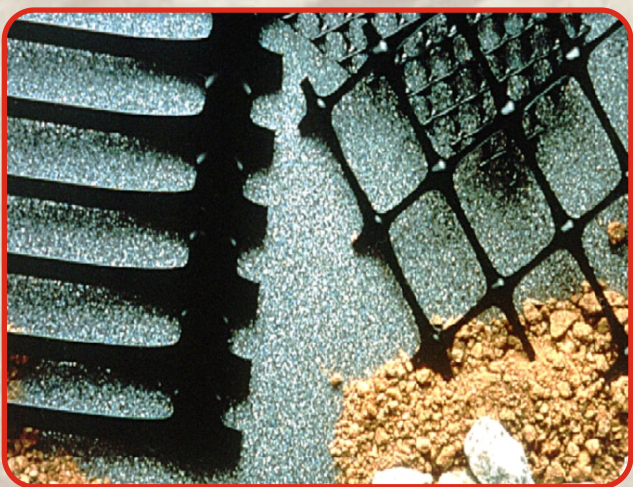

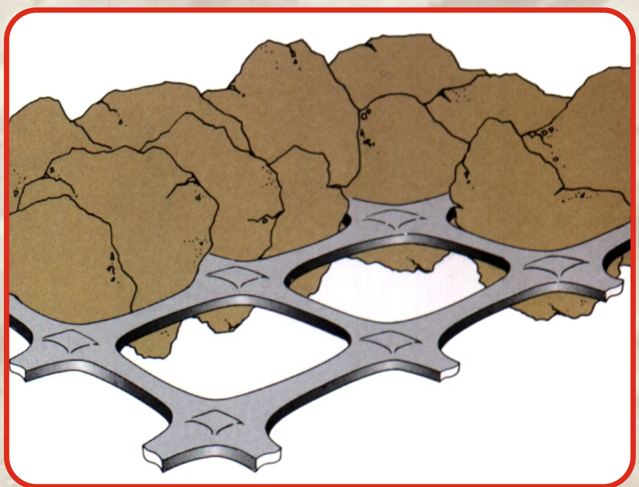

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Geosynthetics Division

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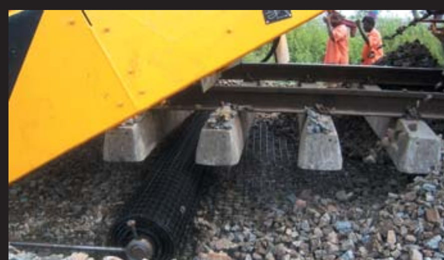
Innovative Technologies – Building Trust








Garware-Wall Ropes Ltd., Geosynthetics Division offer products and services in the field of civil engineering & infrastructure development. The division has a team of highly qualified and fully competent civil, geotechnical, transportation and environmental engineers to undertake design and detailed engineering for a wide range of applications. We have a full fledged R & D centre recognized by the Government of India. A number of world class products have been developed at our plant and we have 6 patents to our credit as on date.

We use internationally accepted softwares like Geo5, Talren, MSEW, ReSSA, Reslope, GeoCoPS, FoSSA, etc. to design solutions in areas like roads, railways, environmental and waste management, coastal and water front structures, etc. Our team of qualified and experienced project managers, engineers, technicians and supervisors have been successfully implementing turnkey projects involving geosynthetic/geoenvironmental solutions with utmost efficiency and quality.

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- Propose appropriate solutions
- Design & consultancy services
- Product supply
- Technical support, supervision & installation guidance
- Turnkey implementation

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- Woven geotextile
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- Geotextile bag and container
- Galvanized steel wire ropenet
- Garmat®- erosion control mat
- HDPE geomembrane
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- Polymer geogrid
- Geocell
- Geonet and geocomposite
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- Railway trackbed stabilization
- Pavement
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INDIAN CHAPTER OF INTERNATIONAL GEOSYNTHETICS SOCIETY

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FROM THE EDITOR'S DESK

First of all, I take this opportunity to wish all the members and readers a Very Happy and Prosperous New Year.

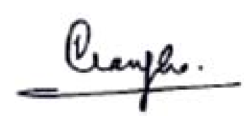
In the year 1985, CBIP as part of its technology forecasting activities identified geosynthetics as an important area relevant to India's need for infrastructure development. I am very happy to inform that in November 2015, Indian Chapter and Central Board of Irrigation & Power (CBIP), jointly celebrated three decades of services to the Indian Geosynthetics Community.

To mark the occasion an International Symposium on "Geosynthetics-The Road Ahead", besides an Exhibition, was organized. On the occasion, the Board also honoured the Institutions and Individuals for their contributions for the development and promotion of uses of geosynthetics in the country and also released a Commemorative Volume having technical articles/case studies with contributions from the academia, practicing engineers, consultants, contractors and manufacturers. The occasion provided an opportunity to ponder over the reasons of limited awareness of the utilities of this material, development taking place in its use, and enhance the awareness of this useful and versatile material amongst the various user agencies, engaged in infrastructure development.

I wish to thank all the office bearers and members of the Chapter and International Geosynthetics Society for their support and guidance in our journey of last 30 years.

The next major activity of the Chapter is hosting of the 6th Asian Regional Conference on Geosynthetics, in November 2016, in New Delhi. It would not be out of context to mention that the Indian Chapter had the honour of hosting the First Asian Regional Conference on Geosynthetics in November 1997 in Bangalore.

The 6th Asian Regional Conference would be a step towards providing opportunity for exchange of experiences, practices and collaborations to facilitate flow of appropriate technology to enable successful implementation of infrastructure projects. I request you to support our endevour and join hands with us to make "Geosynthetics Asia' 2016" a conference of technical excellence.



V.K. Kanjlia
Member Secretary
Indian Chapter of IGS

THREE DECADES OF GEOSYNTHETICS IN INDIA

G. Venkatappa Rao
Sai Master Geoenvironmental Services Pvt. Ltd., Hyderabad, India

ABSTRACT

With the recent emphasis on infrastructure development, geosynthetics in India have received a tremendous boost. Apart from the consistent use in pavements of the east-west and north-south corridors and golden quadrilateral of the NHDP projects being executed by the NHAI, reinforced soil walls in urban flyover approaches have become common, due to their distinct advantages over conventional reinforced concrete walls. These apart, the use of high strength geotextiles and geocell mattresses for foundation of high embankments on soft soils has also proven to be feasible even in black cotton soil areas. Increasing emphasis is being given to the development and use of natural fibre (particularly, jute and coir) geotextiles for civil engineering applications. The paper traces many of these developments and summarizes the key issues to be taken note of for utilizing the vast potential geosynthetics offer, in India's march to development.

INTRODUCTION

From ocean bed to road bed, from foundations on soft soils to landslide control, from waste disposal site to water reservoir, geosynthetics have found an important place for themselves in engineering and construction projects world over.

Geosynthetics, which comprise a variety of products, largely grouped under geotextiles, geogrids, geomembranes and geocomposites have been found to be of immense use in the many infrastructure projects of India. Apart from conventional civil engineering applications, it is now well established that even in environmental engineering applications including pollution control, landfills and erosion control geosynthetics play a major role.

The earliest applications in India have been documented in a publication entitled "Use of Geosynthetics in India – Experiences and Potential" brought out by the Central Board of Irrigation and Power (Venkatappa Rao and Saxena, 1989) and in Dey et al. (1992). Based upon the early experiences in testing and evaluation and the need for highlighting the design and construction with geosynthetics – a publication entitled "Engineering with Geosynthtics" was brought out in 1990 (Venkatappa Rao and Suryanarayana Raju, 1990). In the early years indigenously made geotextiles had a very narrow range and they lacked the diversity. Also, bringing in foreign manufactured goods was very cumbersome if not impossible.

The author has earlier (Venkatappa Rao, 1996) presented an overview of the scenario in India and the potential that geosynthetics offer. The opening of the Indian market to the entry of foreign materials and technology and the awakening of the people and Government to the dire need of infrastructure the realization that this development cannot be done without adaptation of new technology to make the structures cost-effective and durable has brought forth another aspect for serious consideration amongst Indian civil engineers. This is a major breakthrough in the Indian environment helping in soil and resource conservation. After three decades, geosynthetics have found a firm place in civil engineering construction in India. This is particularly so because they have enabled good cost-effective alternatives to conventional design. Sometimes they are the only means of construction and they can be rapidly installed. This paper traces the developments in their use and brings out the key issues that need to be taken note of, to use geosynthetics to their full advantage in the large infrastructure projects in the country.

1. GEOSYNTHETIC REINFORCED SOIL WALLS

The first geosynthetic reinforced soil structure was constructed on National Highway No. 1, near Ludhiana in the mid-eighties for a road over rail bridge approach, wherein geosynthetic strips have been used as a reinforcing element and precast concrete panels were used as facia (Fig.1). With a maximum height of 8 m, the saving achieved was more than 15% depending on wall height. The speed of construction was also faster when compared with RC walls. Similar construction was later carried out at Phagwara in Punjab.

A few years later at the Visweswarayya Setu (Road over rail bridge) in Delhi, the Public Works Department, Delhi Administration successfully constructed a 59 m length of geogrid reinforced wall with 15 cm thick precast concrete

Fig. 1 : First Reinforced Soil Wall in India – Ludhiana, Punjab 1986

facia elements with average height of 6 m using fly ash as the fill material. This wall was built on a geogrid reinforced mattress wherein Fly Ash was used. With all these novel features, this was the first construction of its type in India. A similar wall (59 m long) was constructed at the Hanuman Setu near Jamuna Bazar intersection in the proximity of Red Fort. In this case, however the maximum height was only 3.42 m, the wall facing was cast in-situ. In both the cases, mono-oriented geogrids were made use of, as reinforcement and the overall savings were over 20%.

Since then, particularly in the last 5 years, it may not be an exaggeration to mention that a few hundred such structures have been built in the megacities of our country, notably in Chennai, Delhi, Hyderabad, Mumbai and in many National Highways in different parts of the country using a variety of geosynthetics, geogrids, geotextiles, geostrips, metallic rods and ribbed metallic strips with precast anchor blocks and facia elements of precast concrete panels of different shapes, segmental concrete blocks and also gabion facia. Many more are in the offing.

Several structures hasve been built on soft soils and also deep black cotton soils, the Figs. 2, 3 and 4 depict the scenario for a Road over bridge approach over a canal, at Eluru, Andhra Pradesh, with high water table, black cotton soil and limited space for construction. Part of the foundation soil has been replaced with sand reinforced with basal reinforcing geocomposite, in several layers.

One typical wall (at Patna) was built on stone column foundation, with soil as fill material, whereas another oneat Gangavaram Port, Visakhapatnam was built with partial stone column foundation and basal geocomposite with flyash as fill material.

Tiered reinforced soil walls provide an increased opportunity to take advantage of the superior economy and ease of construction afforded by reinforced soil wall technology. Geosynthetic reinforced soil walls have

Fig. 2: Site condition at Eluru

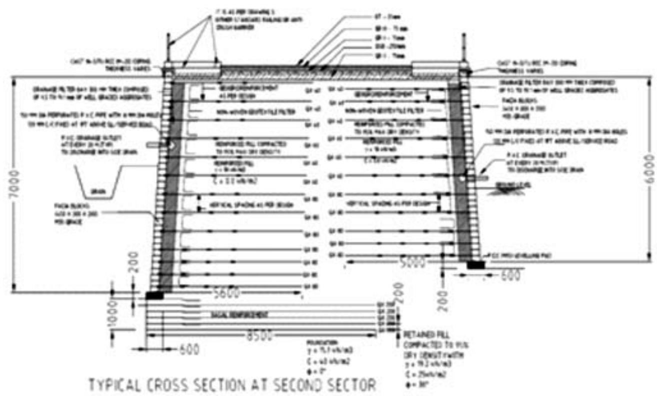


Fig. 3: Typical geosynthetic layout for Eluru Geosynthetic Reinforced soil Wall

Fig. 4: The Block faced wall at Eluru

proven to be an economical, reliable system for tall wall applications, with materials that meet the demands of greater loading while maintaining flexibility and ease of construction. Figures 5 and 6 depict reinforcement arrangement and finished structure 42 m high 4 tiered reinforced soil wall, at Vijayawada, A.P. In another land mark development the first 45 m high reinforced slope

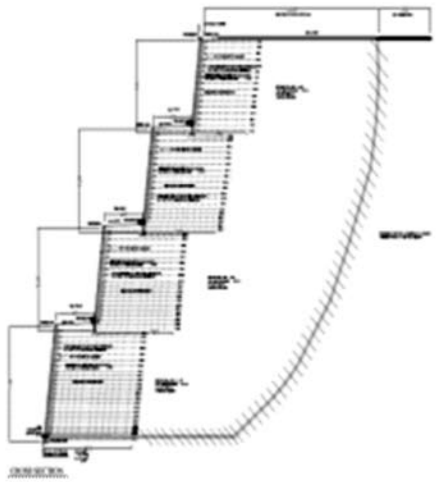


Fig. 5: Typical Cross-section of 42 m high GRS Wall

Fig. 6: GRS Wall at Vijayawada

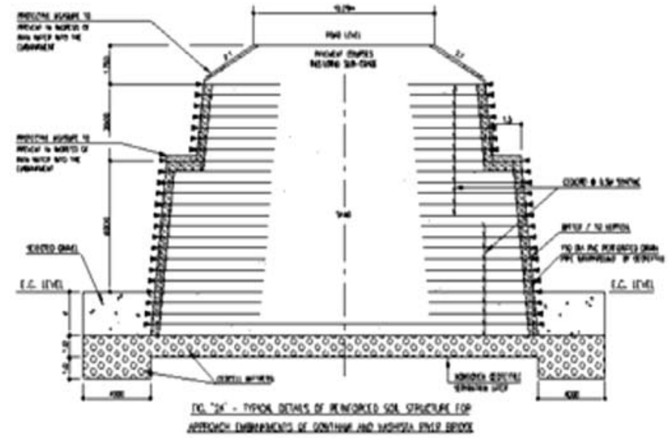


Fig. 7: Arrangement of Basal Mattress

Fig. 8: The Bridge Approach at Siddhantam, A.P

with gabion/wraparound facia, has been constructed for the Runway of the Pongyong Airport, in Sikkim.

2. EMBANKMENTS ON SOFT SOILS

Many high embankments are coming up on soft soil regions. Experience has been gained in use of high strength geotextile as basal reinforcement in the Port Connectivity Project and Airport projects at Visakhapatnam. Also, geocells with high strength geotextiles or with geogrids in construction of bridge approaches overdeep seated black cotton soils, at Vasishta Godavary and Gautami Godavary at Rajahmundry and Palakol have been found to be successful (Figs. 7 and 8).

3. GROUND IMPROVEMENT – PVD

More than a decade ago, prefabricated vertical drains were effectively deployed at Kakinada Port to consolidate soft submarine soils. They have been successfully used at Kandla Visakhapatnam Ports and at Visakhapatnam Airport.

4. PAVEMENTS

Ghosal and Som (1989) have reported the first major use of a non-woven fabric in a heavy duty construction yard in Haldia. It has been found to decrease the pavement thickness to the extent of 30%.

Placement of geotextiles/geogrids at the interface between the subgrade and the sub-base course has been shown to improve the behaviour of pavements, under cyclic loading both in terms of permanent deformation (rutting) and resilient modulus. Also use of geogrids in a flexible overlay is found to improve the overall behaviour. A summary of these works is reported in Venkatappa Rao (1996). Non-woven geotextiles and bi-oriented geogrids have been successfully utilized in Maharashtra (1997) in the State Highways by the PWD for strengthening the road pavements in black cotton soil.

A number of field trials have been conducted using coir geotextiles and jute geotextiles in Rural Roads, in the length and breadth of the country, demonstrating the potential these materials have in the rural road network in the country, particularly in soft soils (Sanyal and Sur, 2003, Choudhary (2012), Sheela and Venkatappa Rao

(2012)). Ghosh et al (2012) have developed an Asphalt overlay fabric with Jute.

5. GEOMEMBRANE LINING SYSTEMS

Use of thin LDPE liners has been recommended in canal lining and guidelines have been drawn by the Central Board of Irrigation and Power and the Central Water Commission, but with limited success. Particularly Indira Gandhi Canal in Rajasthan, because of puncturing and bursting, they did not take off in a big way. With well engineered geomembranes, now being available, a beginning has been made in using them for pond lining, as well as in landfill lining systems.

The need for developing guidelines for landfills for Indian conditions has been adequately highlighted, as early as 1996 (Verma et al., 1996). A single composite liner comprising of a HDPE geomembrane of thickness 1.5 mm or more and the cover system with a 1.5 mm HDPE liner has been recommended by CPCB.

Experience has been gained in the country in construction of landfills for industrial waste notably at Hindustan Zinc Ltd. at Udaipur, Visakhapatnam and for Binani Zinc Ltd. at Kochi. Construction of an engineered landfill is in active progress at Ankleswar and Vapi. At megacities like Mumbai, Bangalore, Hyderabad hazardous waste fill landfills have been constructed and maintained under a kind of BOT/Co-operative system under the aegis of the respective State Pollution Control Boards.

6. NATURAL FIBRE GEOTEXTILES

Jute, a bast fibre (coming from the stem of the plant, by retting process), has a tenacity of around 30 cN/tex with a low extension at break of around 1.0 to 1.8 % . The tenacity of coir fibres (coming from the husk of the coconut, retted or unretted – white coir or brown coir respectively) is much lower 15 cN/tex, but elongation at break is much higher having range of up to 45 %. The growth of micro-organism on vegetable fibres depends on their chemical composition, particularly the lignin content. Coir has about 35 % lignin content, making it extremely resisting against biodegradation, whereas for jute it is only around 12 %. The other bast fibres like flax, hemp and ramie have much low quantity of lignin (0.6 to 3.3 %). Volume swelling of jute fibre is excellent having value of 44.3 % (Batra, 1985). This makes jute a suitable raw material for making 'sheath filter' part of pre-fabricated vertical drain.

A simple machine has been developed at Textile Technology Department of IIT Delhi (Banerjee, 1996, Banerjee et al, 2000) that uses coir and jute yarns to manufacture 100 % natural fibre strip drain (Fig. 9). The present drain (Fig.10) differs from the other natural drain is that it is manufactured in a single machine, and has capability of varying the width, thickness and mass per linear metre to suit different soil conditions.

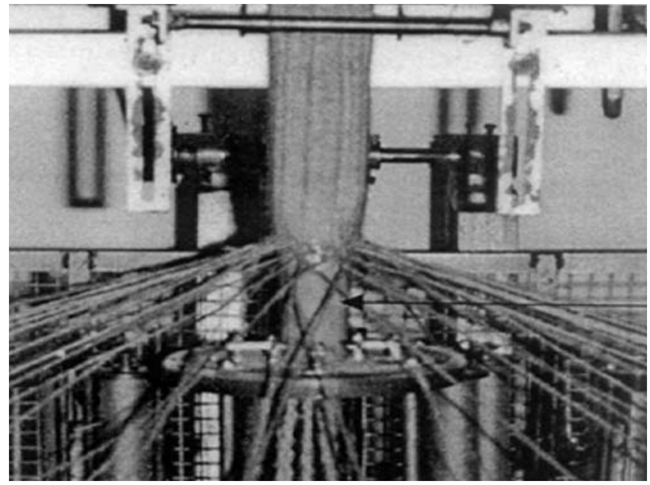


Fig. 9: Braiding machine developed at IIT Delhi

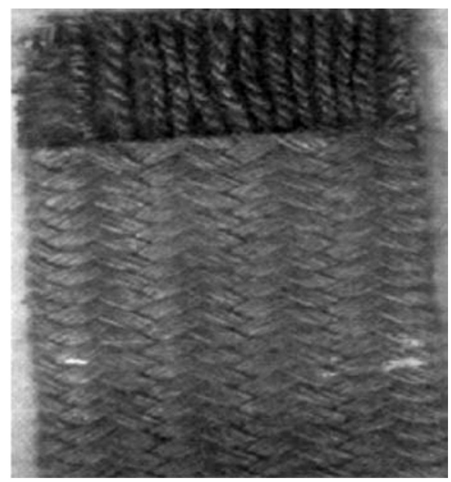


Fig. 10: Brecodrain with jute and coir yarns

7. EROSION CONTROL

India has about 25% of its geographical area under mountainous terrain. Over 80% of the annual rainfall occurs from June to October. This leads to flooding every year causing environmental degradation which in itself is caused by excessive grazing, road construction, mining and unscientific farming practices. This results in an estimated soil loss of the order 6 billion tonnes per annum. Thus the importance of erosion control need hardly be emphasized.

Not only the many rivers that crisscross the country, but the longest sea coastline and storms and hurricanes add to major concerns of degradation and particularly severe erosion around port and harbour works.

The various causes of erosion, the different geosynthetic solutions available are detailed in "Erosion Control with

Geosynthetics" published by the CBIP (Venkatappa Rao, 1995). Early experiences have been gained in the country in using polymeric geomeshes (at Ghaziabad byepass by UPPWD), gabion mattress underlain by needle punched geotextile (on Gandhar River Gujarat by GERI), grouted mattress (Kakarpar Canal, Gujarat) and in many other water ways and locations.

In 1988 as part of river training works in the Hooghly, to prevent erosion at Nayachara Island, over 30,000 sq.m. of geotextile mattress was laid on the river bed, which was weighed down with 700,000 t of stones. Denuded forest cover in hilly regions due to indiscriminate lime stone quarrying around Dehradun are controlled environmentally by use of jute geotextiles and other measures by CSCRI, Dehradun.

The ability of natural fibres to absorb water and to degrade with time are the prime properties which give them an edge over synthetic geotextiles for erosion control purposes.

The "drapability" factor of natural geotextiles (due to their flexibility) allows them to conform closely to the terrain, i.e., the ability to follow the contours of the slope and staying in intimate contact with the soil.

Natural geotextiles can be used where vegetation is considered to be the long term answer to slope protection and erosion control. They have a number of inherent advantages.

(i) they have protection against rain splash erosion.

(ii) they have the capacity to absorb even upto 5 times their own weight.

(iii) they reduce the velocity and thus the erosive effect of runoff by functioning as a series of mini check dams.

(iv) they help retain the seeds, even in steep terrain.

(v) they maintain humidity in the soil and atmosphere.

(vi) they probably mitigate the extremes of temperature and

(vii) they biodegrade, adding useful mulch to the soil.

From literature one also notes that erosion control measures with jute based geotextiles had given a good response but the textile degraded after about one year. In the more severe situations, either because of climate or steepness of slope, a longer period of function by the geotextile is required. This is also the case where one prefers to select species compatible with surrounding native vegetation, such species, being inevitably slower growing than the commonly sown productive species used in lowland situations. The combination of slow growth and short growing season may means that species barely become functional within a season in terms of surface erosion control. Coir based geotextiles provide both the advantages of biodegradable geotextiles and the longevity required where plant establishment might be slow (upto 3 years).

Jute and Coir Geotextiles are being manufactured as Rolled Erosion Control Products in various weights and in various configurations such as woven nettings, meshes and blankets for different applications requiring varying degrees of protection. More varieties were developed at Indian Institute of Technology, Delhi for the industry.

Several successful case studies have been reported by Central Road Research Institute, New Delhi and others in use of jute and coir matting for erosion control in different hill regions of the country. A study was conducted in Western Ghats wherein coir mattings have been used for erosion control in a rubber plantation. The coir matting could successfully prevent the surficial erosion of particles along the surface of the slope. It also helped in sedimentation of soil even on previously exposed rock surface, presumably through the action of a series of check dams as mentioned in literature (Venkatappa Rao, 1995). A successful use of jute open weave geotextile in mine dumps is depicted in Fig.11.

Fig. 11: Erosion control by Jute Geotextile in mine dumps (Photos courtesy Sri T.Sanyal)

This apart simple solutions like use of geocontainers- as small as bags or as large as 20 m diameter geotubes have been successfully tried in several projects in India. (Fig. 12-14)

Fig. 12: Control of Coastal Erosion by Geocontainers (Photo Courtesy : M.Venkataraman)

Fig.13: Use of sand bags (geocontainers) in erosion protection at River Sarada

Fig. 14: Indigenous geotube for coastal erosion

8. MANUFACTURE IN INDIA

The manufacture of of geotextiles is not new to India. Since 1985 many textile manufacturers ventured into the then unknown potential of geotextiles. Now, M/s Garware Wall Ropes, Pune and Ms.Techfab India are well known industrialists in the manufacture, design and construction with geosynthetics. M/s Maccaferri Environmental Systems, Pune, Strata Geosystems (India) and M/s Skaps Industries have their nanufacturing facilities and also provide design assistance. Ten Cate India and Heusker have their presence in India through their distribution network and design assistance.

Extensive manufacturing facilities exist for both Coir Geotextiles (notably M/s Charankattu Coir Industries, Alappuzha) and Jute Geotextiles (notably M/s Glocester Jute Mills, Kolkata) in the country. As already mentioned the National Jute Board, Kolkata and Coir Board, Kochi support research and development of natural fibre geotextiles in the country.

9. THE FUTURE

Hitherto an attempt was made to project an overview of the early attempts made to bring in the much needed new technology of geosynthetics into the civil engineering fold and one can say with confidence that a platform has been made, with an estimated annual consumption of over 100 million sq.m. But this is just the beginning, a tip of the iceberg. The following describes the future prospects.

(i) Railways

Indian Railway system with a network of 60,700 km route length is the largest system in Asia. Out of this, nearly 60,000 km is of broad gauge (1676 mm gauge). The line capacity utilization of existing major trunk routes like Delhi-Howrah, Chennai-Howrah, Delhi-Chennai have exceeded the 100 % capacity and hence have become critical. In improving these systems Dedicated Freight Corridors are being established which use modern technology and are on fast track. Other stretches are earmarked as High Speed Corridors. Some of the critical stretches go through the high swelling black cotton soils or marine soft soils. The field trials with geosynthetics in the tracks are in progress, to establish the quantum of improvement. Rockfall prevention and land slide mitigation has been ably accomplished in the Konkan Railway, on the Western coast of India. These and other issues are highlighted by the author in a recent book (Venkatappa Rao, 2013). In addition a major field study is being undertaken by the RDSO, Ministry of Railways in order to develop Specifications and construction procedures for use of Geosynthetics in a variety of track conditions.

(ii) Highways

The Highway Network in India is very vast and vital to the development of the country. The Government of

India gives top priority to the road development through its many schemes, either through the National Highway Authority which in a way controls the significant portion of the 71,770 km of National Highways or through its many development programmes to develop the State Highways whose length is around 150, 000 km. The National Highways comprise only 1.7 % of the total Road network, but carries 40 % of the traffic and has only 24 % is with 4 or more lanes. Hence, continuous development of these roads goes on either through strengthening roads or widening, for its ever increasing traffic. A significant component of these are the Road Underbridges and Road overbridges, which call for Geosynthetic Reinforced soil structures. Whereas the use in pavements is yet to pick up ground improvement procedures through PVDs or reinforced Embankments are becoming increasingly common, particularly in providing access to Ports.

(iii) Inland Water Transport

An Inland Water Authority was set up in India in 1986 for developing waterways for navigation. There are already some waterways declared along the major rivers like Ganga, Brahmaputra and Godavari with a total length exceeding 5,000 km. Apart from river bank protection and provision of permanent and floating king jetties, they are required to maintain minimum draft of 1 to 2 m throughout the year.

(iv) Interbasin Water Transfer

In view of the vast area of hinter land and uneven distribution of river waters, a significant amount of water goes waste into the sea. Many plans are afoot to conserve this water by novel schemes such as Inter Basin transfers, which may connect even large rivers like Godavari and Krishna, to utilize staggering water resource. The NWDA web site, lists the status of 14 such projects. Some of these are already successful, but many are being planned for immediate development. As these are surely pass through hills and over soft soils, landslides, ground improvement, elevated canals are all going to call for efficient use of geosynthetics.

(v) Landfills

Solid Waste Management be it Municipal Solid Waste or Chemically active/hazardous waste is required to be dealt appropriately by constructing and managing Engineered Landfills as per Statutory Guidelines issued for the said purpose, which includes use of natural soils as well as Geosynthetics generally following International norms. Further details are contained in Venkatappa Rao and Sasidhar (2009). With 900 t Municipal Waste being produced every day out of the India' capital Delhi, the landfills are expectedly huge and finding alternate sites is quite cumbersome. According to the Master Plan of Delhi, the city requires an additional land area of 1500 acres. Thus the need for Engineered Landfills grows by the day not only in metropolitan cities but also large towns. Though continuous efforts are being to segregate and also develop energy out of waste, still the task is Herculean.

(vi) Landslide Mitigation

Most hill regions in the fragile Himalayas be it in Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir, the North-eastern Hill States or the Nilgiri Hills in Tamil Nadu, land slides pose a recurring problem. They damage the highway structures as well as endanger the thickly populated hill towns. There are many classic examples of continuing problems, say, on the Jammu-Srinagar National Highway as well as the Konkan Railway.

It is possible to use this technique in many other problematic areas. For instance, in many of the water resources projects as well as new railway projects, considerable (sometimes indiscriminate) blasting results in instability of the region, exposure of fresh rock face, appearing like an eye sore. In such cases geosynthetics offer convenient economic and permanent solutions. More so, because they can be made green. A beginning has been made.

10. CONCLUDING REMARKS

- Use of Reinforced Soil Structures (Retaining walls, Slopes, Embankment, Foundation on soft soils, etc.) as a modern earth retention system has proven to be a feasible and economical solution the world over.
- The Indian experience gained in this type of structures for retaining walls has shown similar trends i.e. both economy and feasibility are proven. Coupled with the fact that many port structures are likely to be located on soft soils, the need for ground improvement preferably through PVDs is increasingly realized.
- In many roads and railway system on poor subsoils there is a need for remediation through use of the right kind of geosynthetic. Similarly for rural roads there is a need to identify an economical geosynthetic alternative.
- As the need for both municipal and hazardous waste land fills is being increasingly felt hundreds of such structures will be requiring geosynthetics in large quantities.
- Methods of controlling the severe erosion on embankments, hill slopes and flood banks need to be studied such that their devastating effect is minimized and rational geosynthetic system is adopted.
- It is required to understand the durability of the large variety of geosynthetics in the Indian context particularly because of the large variations in the climatic conditions, terrain and the soil.
- Jute and coir have tremendous potential in India as well as the rest of the world for environment friendly applications. India being one of the largest producers of such fibres, greater emphasis needs to be paid to R&D on these materials.

- It is also possible to use waste materials like Fly Ash in conjunction with geosynthetic to form walls and embankments. A lead is already taken in using fly ash in Visweswaraya Setu and Hanuman Setu in Delhi as well as in the Gangavaram Port Bridge approach embankment. Their designs need to be standardized and doubts eliminated.

11. THE GOAL

Global geosynthetics market is expected to reach USD 27 billion by 2022, according to a new study by Grand View Research, Inc. Construction industry growth in India, China and Middle East, on account of rising expenditure on infrastructure development is expected to be a crucial driving factor for geosynthetics market growth.

Suffice it to mention that, as India continues to march towards development of world class infrastructure and the increased need for the development felt by the people, the need for the use of geosynthetic is synonymous with development, in view of the confidence with which the materials have been used in the country.

Acknowledgements

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The officers at the Central Board of Irrigation and Power, which houses the Secretariat of the IGS-India and nurturedit over the last 3 decades the past and the present, viz., Sri V.K. Kanjlia, Member Secretary, Mr. A.C. Gupta, Director-Water Resources and Mr. Uday Chander, Senior Manager have a special place in my heart, because but for them, I would not have been what I am to-day. Their sincerity and dedication is worth emulating.

It gives me confidence to state this journey of geosynthetics which we started in 1985 has crossed many rivers and seas and is now bound to stay well within our Civil Engineering infrastructure with more advances coming up in the shape of new products.

May this bring peace and prosperity to our nation.

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EFFECT OF CHEMICALLY TREATED COIR FIBRES ON THE STRENGTH CHARACTERISTICS OF CLAY

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ABSTRACT

The effect of chemically treated coir fibres on the strength characteristics of clayis presented in this study. A series of consolidated undrained test were performed on soil reinforced with untreated, sodium hydroxide treated and potassium permanganate treated fibres. The coir fibre content was varied from 0.25% to 1.5%. The results indicated that the optimum moisture content of clay reinforced with untreated/treated coir fibres increases with the increase in fibre content. The optimum moisture content of clay reinforced with treated coir fibres was less in comparison to untreated coir fibres. $KMnO_4$ treated coir fibre absorbs slightly less water in comparison to NaOH treated coir fibres in clay. The dry unit weight of clay reinforced with untreated/treated coir fibres decreases with the increase in fibre content. The dry unit weight of clay reinforced with treated coir fibres was higher in comparison to untreated coir fibres. Reinforcing clay with $KMnO_4$ treated coir fibre results in higher dry unit weight in comparison to NaOH treated coir fibres. The peak deviator stress of clay reinforced with coir fibres can be significantly improved by treatment with NaOH and $KMnO_4$. With the increase in coir fibre content (0.25%-1.5%) in clay, there was an increase in the peak deviator stress. The shear strength parameters were found to increase with increase in coir fibre content (0.25%-1.5%) in clay. The addition of $KMnO_4$ treated fibres to the clay results in a higher value of peak deviator stress and shear strength parameters. The hyperbolic model can be used for predicting the stress-strain response of unreinforced and reinforced clay with appropriate selection of model parameters. The clay reinforced with untreated/treated coir fibres has shown improved strength characteristics, it can be used for short term stability problems.

Keywords : *Coir fibres, Treatment, Deviator stress, Cohesion, Friction angle*

1. INTRODUCTION

Reinforced soil is a composite material wherein soil is reinforced by the elements which can take tension. The incorporation of reinforcement in the soil mass is aimed at either reducing or suppressing the tensile strain which might develop under gravity and boundary forces. The essential features of reinforced earth are the friction between the earth and reinforcement, by means of friction the soil transfer to the reinforcement the forces built on the earth mass. The reinforcement has thus developed tension when the earth mass is subjected to shear stresses along the reinforcement. As such soils have very low tensile strength which may be improved significantly by providing reinforcement in the direction of tensile strains. For this purpose, a variety of materials are being used as reinforcing materials such as metallic elements and Geosynthetics. Naturally available coir fibres are now being used as reinforcing material for temporary civil engineering applications due to their low cost and availability in India. These fibres are biodegradable and its durability is assessed by a number of investigators[1-4]. The coir Geotextiles retained 20% of their original tensile strength after one year in incubator tests with high fertile soil[1]. It was further mentioned in this study that natural fabrics when put in a shower room and kept wet for 167 days, coir had almost no damage. The loss in the strength of a coir rope after 10 months in pulverized ash was 20%[2]. Balan[3] reported that coir degrades at a faster rate in the sand having high organic content followed by clay with high organic content and finally saturated soft clay, where the degradation is the least. It was further reported in this study that the overall life of coir is more than two/three years and brown coir degrades (about 20% in 7 months) at a faster rate than white coir (about 10% in 7 months). Coconut fibres kept in a calcium hydroxide solution of pH 12 completely lost their flexibility and strength after 300 days[4]. Further, coir fibreshave good surface friction and mechanical properties. But the presence of lignin, pectin and other impurities on the surface of coir fibre decreases the adhesion with the surrounding matrix.Therefore, coir fibres are treated with chemicals in order to improve the interfacial bonding with the surrounding matrix[5-6]. In order to improve the surface characteristics and its interaction with surrounding soil, coir fibres were pre-treated with sodium hydroxide and potassium permanganate in acetone and mixed with clay for studying the strength characteristics by conducting the consolidated undrained triaxial tests. The results obtained from these tests are presented and discussed in this paper.

2. BACKGROUND

Many researchers[7-17] have shown that coir fibre reinforcement can significantly improve engineering properties of soil. Removal of lignin, hemicellulose, silica and pith from coir fibres results in better interaction with the soil[7]. There isa significant gain in strength parameters and stiffness of sand by the inclusion of coir fibres[8]. The dimensional and mechanical properties of coir fibres as a function of fibre lengthwereinvestigatedby[9]. The behavior of sand reinforced with coir fibres and geotextiles were similar to that observed with synthetic fibres and meshes[10]. The effect of coir fibres on optimum moisture content, maximum dry density and unconfined compressive strength of clayey silt was studied by[11]. Their observation suggests that the addition of fibres decreases the maximum dry density and increases unconfined compression strength. Strength and stiffness of tropical soil were increased with the inclusion of discrete coir fibres of about 1-2% by weight[12]. Coir fibres have good strength characteristics and resistance to bio-degradation over a long period of time[13]. Unconfined compressive strength of black cotton soil reinforced with bitumen coated coir fibres shows marginal variation in strength as compared to uncoated coir fibres[14]. Consolidated undrained test and consolidation tests conducted by[15] on locally available clayey soil reinforced with coir fibres. The experimentally obtained stress-strain response was predicted using the modified Cam-Clay model and numerical simulations on $FLAC^{3D}$. The observed results of tests and model were quite comparable. Further their consolidation study indicated that the addition of coir fibres to soil leads to a decrease in compression and recompression indices and a consequent increase in preconsolidation pressure.Varying the length of coir fibres and content in soil results improvement in strength characteristics was reported by[16]. It was further reported that the length of fibres play a significant contribution in the strength enhancement of soil in compression. The results of the effect of NaOH and CCL_4 treated coir fibres on the unconfined compressive strength of clay indicated that the unconfined compressive strength of clay and clay with untreated coir fibres can be increased by surface treatment with sodium hydroxide and carbon tetrachloride[17]. From the literature study it can be concluded that the unconfined compressive strength of clay reinforced with coir fibres/treated coir fibres has been studied extensively, however, the literature available to study the effect of treated coir fibres on the strength characteristics of clay is scanty. The present study attempts to fill this gap. In the present work, the effect of treated fibres on the strength characteristics of locally available clay is studied. The coir fibres used for reinforcing the clay are (i) untreated (ii) treated prior to use with NaOH (iii) treated prior to use with NaOH and $KMnO_4$in acetone. The strain-strain response in various cases are plotted, compared and discussed for potential employment in short term stability related problems.It should be noted that the shear strength parameters required for the short term stability case can be obtained by conducting an unconsolidated undrained triaxial test on soil. However, some consolidation in the field during construction of the structure is always expected. Hence the use of unconsolidated undrained shear strength parameter will be quite conservative. With this reasoning, the consolidated undrained test is carried out in the present study. It is expected that the total stress parameters obtained from the consolidated undrained test can be used for short term stability related problems.

3. MATERIALS USEDAND EXPERIMENTAL PROCEDURE

The clay used in this study had a specific gravity of 2.58, a liquid limit of 46 % and a plastic limit of 23%. The maximum untreated unit weight and optimum water content as obtained by standard proctor test were found to be 18.34 kN/m^3 and 12.77 %, respectively. As per Indian Standard Classification System (*IS 1498 1970*), the clay was classified as clay of low compressibility. The total stress shear strength parameters of clay are determined by consolidated undrained triaxial test. The cohesion observed was 31 kPa and friction angle noted was 8.04^o.The coir fibres were obtained from the coir rope (Fig. 1 (a)) procured from the local market. The yarns of the coir ropes were separated and the fibres were cut in the length of 15 mm (Fig. 1(b)) and the fibres were separated (Fig. 1(c)) and separated fibres are shown in Fig. 1(d). The properties of these coir fibres are shown in Table 1. The coir fibres obtained as shown in Fig.1 (d) was treated with sodium hydroxide (NaOH) solution for 24 hours. After 24 hours, the fibres were removed from the beaker and allowed to dry at room temperature for a week.These fibres are termed as NaOH treated fibres. Whereas the NaOH treated fibres are further dipped in to potassium permanganate ($KMnO_4$) solution in acetone for 30 min and washed with glacial acetic acid. Then, it is once again dried for a week. These fibres are termed as $KMnO_4$ treated fibres. For preparing the NaOH solution 4 gm equivalent weight of Sodium hydroxide pellets are dissolved in 1000 ml of distilled water to prepare .1N solution.The chemical composition of sodium hydroxide pellets is shown in Table 2. Similarly the 0.05% solution of potassium permanganate in acetone is prepared for treatment purpose. The chemical composition of Potassium permanganate and Acetone is shown in Tables 3 and 4. The composition of the chemicals shown in Tables 2 to 4 was supplied by the manufacturer. The chemical treatment of coir fibres was carried out as per the procedure reported by[18] where coir fibres were dipped in chemical for one minute in order to study the effect of chemical on the water absorption.To assess the effect of chemical treatment on the water absorption, tests were performed on the coir fibre used in the present study. The water absorption observed in untreated, NaOH treated and $KMnO_4$ treated fibres was 70%, 40% and 32% respectively.This observation is consistent with the literature[18]. Further, in the present study, the coir fibres used were dipped in chemical for 30 minutes in order to remove impurities present on the surface of coir fibres. The tensile test corresponding to untreated, NaOH treated and $KMnO_4$ treated fibres, each were repeated three times to have better reproducibility of results. The typical curves of tensile load tests are shown in Fig. 2. The tensile strength of fibres is calculated on the basis of average diameter of fibre as 0.3 mm. The observed average tensile strength of untreated, NaOH treated and $KMnO_4$ treated fibres was 99.07 MPa, 113.23 MPa and 123.38 MPa respectively. A series of consolidated undrained tests were conducted on the pure clay and clay reinforced with the untreated/treated coir fibres at varying contents.All the specimens were prepared corresponding to optimum moisture content and maximum dryunit weight values. The maximum dry unit weight and optimum moisture content of unreinforced as well as reinforced clay samples were obtained in prior using a standard proctor test. The corresponding values of maximum dry unit weight and optimum moisture content are shown in Table 5. The soil samples for triaxial tests were prepared using a metallic mould of 38 mm inner diameter × 76 mm length with detachable collars. For reinforced soil specimens, the fibres were added as a percentage of the dry weight of the clay. The specimens were prepared with fibre contents of 0.25%, 0.5 %, 0.75 %, 1.0 % and 1.5 %. All the samples were saturated prior to conducting the test by applying a back pressure up to 72 hours. For backpressure saturation the difference between back pressure and cell pressure was maintained 10 kPa approximately. The cell pressure during each test was kept as 55 kPa, 110 kPa and 220 kPa respectively. During the consolidation stage with cell pressure held constant the drainage valve of triaxial test was kept open and the consolidation of the sample was permitted. The complete consolidation was assumed to happen once the water level in the burette which is connected to the drainage valve becomes constant. Thereafter the drainage valve was closed and the deviator stress was applied to a sample under undrained condition. The test was conducted at a strain rate of about 2 % of the height of the specimen. The test was conducted up to the strain of 20% orupto failure, whichever is earlier and the pressure of pore water during the shearing of the specimen was not measured. It should be noted that owing to the difficulty in extracting the intact failed sample from rubber membrane, it was not possible to study the failure pattern of the unreinforced/reinforced samples.

Table 1 : Properties of coir fibres

Property	Coir fibres
Specific gravity	1.2
Tensile strength (MPa)	99.07
Strain at failure (%)	27
Water absorption (%)	70%

Table 2 : Chemical composition of sodium hydroxide pallets

Composition	Quantity
Molecular Weight	40
Carbonate (%)	1.5
Chloride (%)	0.01
Phosphate (%)	0.001
Silicate (%)	0.05
Sulphate (%)	0.01

Table 3 : Chemical composition of Potassium permanganate

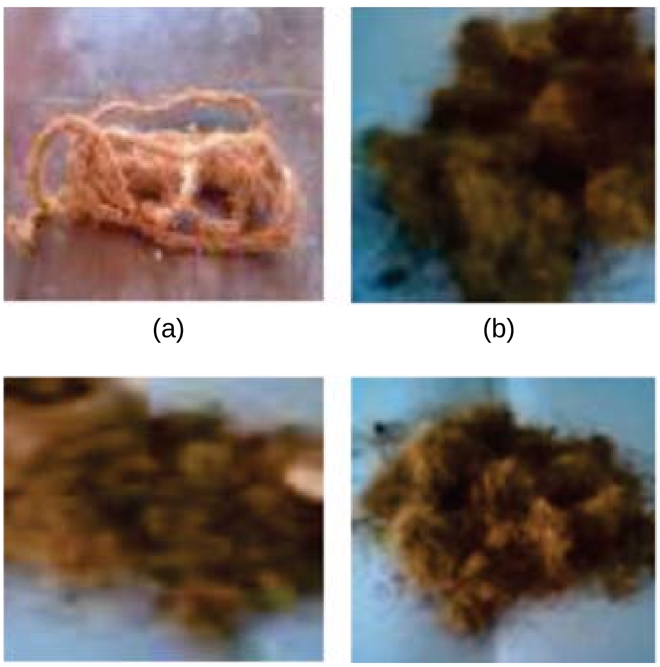
Composition	Quantity
Molecular Weight	158.04
Water insoluble matter (%)	0.5
Chloride (%)	0.03
Sulphate (%)	0.05
Sodium (%)	0.5

Table 4 : Chemical composition of Acetone

Composition	Quantity
Minimum assay (GC)	99.0%
Wt. per ml at 20 °C	0.789-0.791 g
Refractive index (n)	Min 95.0%
Boiling range	55.5-56.5 °C
Max limits of impurities	
Water	0.05%
Acidity(CH_3COOH)	0.012%

Table 5 : Maximum untreated unit weight and optimum moisture content values for unreinforced and reinforced clay samples

Fibre content %	Untreated fibres		NaOH treated fibres		$KMnO_4$ treated fibres	
	OMC	MDD	OMC	MDD	OMC	MDD
0	12.77	18.34	12.77	18.34	12.77	18.34
0.25	13.11	18.09	12.96	18.18	12.80	18.23
0.5	14.29	18.02	14.12	18.12	13.90	18.19
0.75	14.93	17.95	14.73	17.96	13.93	17.98
1.0	16.02	17.76	15.71	17.83	15.13	17.92
1.5	16.95	17.50	16.13	17.74	15.75	17.79



(a) (b)

(c) (d)

Fig. 1 : Coir fibre (a) rope (b) cutting 15 mm length (c) separation of fibres (d) separated fibres

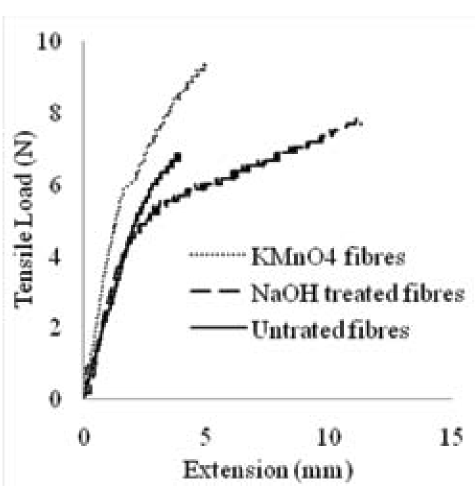


Fig. 2 : Tensile load extension curve for the untreated and treated coir fibre

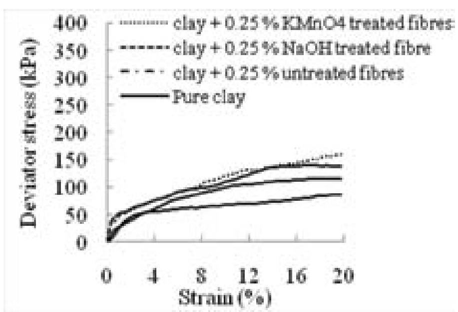
4. RESULTS

4.1 Compaction

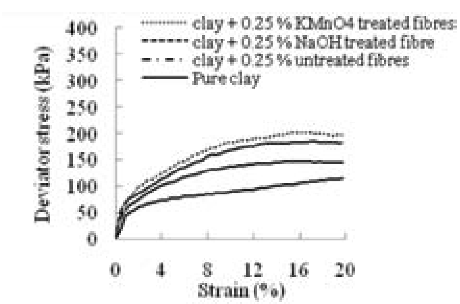
The compaction results for the clay reinforced with untreated/treated coir fibres are shown in Table 5. A study Table 5 reveals that the optimum moisture content of clay reinforced with both treated and untreated coir fibres increases with the increase in fibre content. For example, the optimum moisture content of clay was 12.77%, which increased to 13.11%, 12.96% and 12.8%, respectively, when it was reinforced with 0.25% untreated, NaOH and $KMnO_4$ treated coir fibres. The optimum moisture content further increased to 16.95%, 16.13% and 15.75%, respectively, when clay was reinforced with 1.5% untreated, NaOH and $KMnO_4$ treated coir fibres. The increase in the optimum moisture content of a specimen of clay reinforced with untreated and treated coir fibres can be attributed to the water absorption tendency of coir fibres. A further study of Table 5 reveals that the optimum moisture content of clay specimen reinforced with NaOH and $KMnO_4$ treated coir fibres is slightly smaller than clay reinforced with untreated fibres. This is attributed to the fact that the treatment with sodium hydroxide and potassium permanganate decreases the tendency of coir fibres to absorb water. Table 5 also indicates that the maximum dry unit weight of clay specimen reinforced with coir fibres decreases with increase in fibre content. For example, the maximum dry unit weight of clay was 18.34 kN/m³ which decreased to 18.09 kN/m³, 18.18 kN/m³ and 18.23 kN/m³ when it was reinforced with 0.25% untreated, NaOH treated and $KMnO_4$ treated coir fibres. The maximum dry unit weight further reduced to 17.50 kN/m³, 17.74 kN/m³, 17.79 kN/m³ when clay was reinforced with 1.5% untreated, NaOH treated and $KMnO_4$ treated coir fibres. It should be noted that at given fibre percentage, the maximum dry unit weight of clay reinforced with $KMnO_4$ treated fibre specimens is marginally higher than the respective values for clay reinforced with NaOH treated fibre specimens. The reason for the slight increase in untreated unit weight of clay reinforced with $KMnO_4$ treated fibre specimens can be attributed to better interaction of clay with fibre matrix and the reduced water absorption tendency of $KMnO_4$ treated fibres.

4.2 Stress Strain Behaviour

The typical stress-strain behaviour of clay reinforced with 0.25% and 1.5% fibre content at various confining pressures is indicated in Figs. 3-4 respectively. The stress strain curve corresponding to unreinforced clay is also included in the respective plot for the sake of comparison. The peak deviator stresses for the other cases are shown in Table 6. A study of Figs. 3-4 indicates that for a given confining pressure the deviator stress for the reinforced soil specimen was higher as compared to unreinforced clay at a fibre content of 0.25% and 1.5%. This observation was consistent at all confining pressure and fibre content. Figs. 3-4 further reveals that the stress-strain curve for soil reinforced with NaOH treated and $KMnO_4$ treated fibres were above the curve corresponding to untreated fibres at any given confining pressure. This behaviour can be attributed to better interaction at soil-fibre interfaces due to treatment with NaOH and $KMnO_4$ which cleans the fibre surface and exposing them for an effective interaction with clay. Further from Table 6, it can be seen that at given confining pressure the peak deviator stress of clay reinforced with untreated and treated fibres increases with increase in fibre content. For example the peak deviator stress of soil at confining pressure of 55 kPa was observed as 86.8 kPa which increased to 116.22 kPa, 140.23 and 160 kPa with the addition of 0.25% untreated, NaOH treated and $KMnO_4$ treated fibres to the soil. Similarly for a confining pressure of 220 kPa the peak deviator stress of soil was observed as 142.42 kPa which became186.15 kPa, 203.28 kPa, and 217.58 kPa for same fibre content. The addition of 1.5% untreated, NaOH treated and $KMnO_4$ treated fibres the peak deviator stress noted was 256.99 kPa, 318.30 kPa and 342.18 kPa respectively, for confining pressure of 55 kPa and 334.89 kPa, 398.78 kPa, 425.94 kPa respectively of confining pressure of 220 kPa. These observations indicate that the addition of fibres to soil leads to a substantial increase in peak deviator stress.In this regard the $KMnO_4$ treated fibres seems to bring highest improvement to the soil followed by NaOH treated and untreated fibres.



(a)



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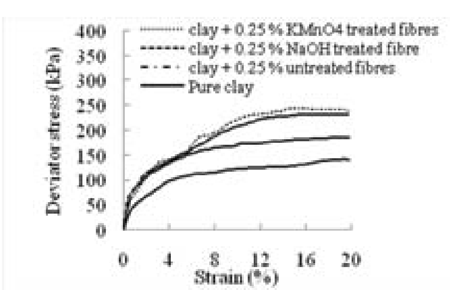
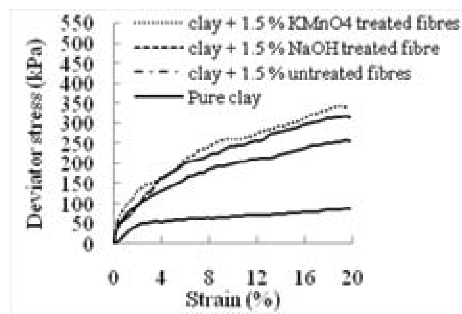
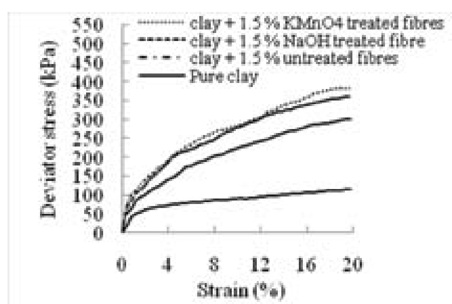


(c)

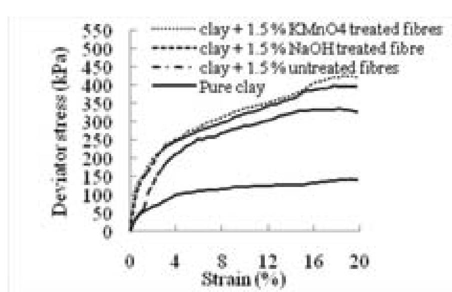
Fig. 3 : Variation of deviator stress with strain for clay + 0.25% fibres at a confining pressure of (a) 55 kPa (b) 110 kPa (c) 220 kPa



(a)



(b)



(c)

Fig. 4 : Variation of deviator stress with strain for clay +1.5% fibres at a confining pressure of (a) 55 kPa (b) 110 kPa (c) 220 kPa

Table 6 : Deviator stress for the unreinforced and reinforced clay

Fibre percentage	σ_3 = 55 kPa			σ_3 =110 kPa			σ_3 = 220 kPa		
	Untreated fibres	NaOH treated fibres	$KMnO_4$ treated fibres	Untreated fibres	NaOH treated fibres	$KMnO_4$ treated fibres	Untreated fibres	NaOH treated fibres	$KMnO_4$ treated fibres
0	86.80	86.80	86.80	113.92	113.92	113.92	142.42	142.42	142.42
0.25	116.22	140.14	160.00	145.88	184.43	200.67	186.16	232.43	245.15
0.5	147.77	177.77	198.91	168.15	212.08	227.33	217.49	255.37	274.68
0.75	176.69	227.08	239.22	215.21	239.30	269.29	251.42	297.92	318.04
1	222.51	272.00	289.42	254.91	317.06	334.93	297.20	352.36	373.33
1.5	257.00	318.03	342.19	299.63	359.21	383.49	334.89	398.78	425.95

4.3 Strength Characteristics

In the present study the pressure of pore water during the shearing of the specimen was not measured, hence, only total stress shear strength parameters can be computed. The variation of cohesion and friction angle with fibre percentage is shown in Table 7. From this table it can be seen that the addition of both untreated and treated coir fibres to soil leads to a continuous increase in the cohesion and friction angle both. The cohesion and friction angle of pure clay was 31.4 kPa and 8.04° respectively. With the addition of 0.25 % untreated, NaOH treated and $KMnO_4$ treated fibres the cohesion of soil has increased to 40.58, 45.26 and 51.51 kPa. Similarly for clay + untreated/ NaOH treated/$KMnO_4$ treated fibre mix the friction angle observed were 9.85°, 10.67°, 10.72°. The c and ϕ values were further increased to 98.90 kPa and 10.66°, 122.65 kPa and 11.01°, 132.09 kPa and 11.41° respectively as the untreated fibre, NaOH treated fibre, $KMnO_4$ treated fibre content in soil increased to 1.5 %.

Table 7 : Variation of cohesion and friction angle with fibre percentage

Fibre content %	Untreated fibres		NaOH treated fibres		$KMnO_4$ treated fibres	
	Cohesion	Friction angle	Cohesion	Friction angle	Cohesion	Friction angle
0	31.39	8.04	31.39	8.04	31.39	8.04
0.25	40.58	9.85	45.26	10.67	51.51	10.72
0.5	51.71	10.07	65.54	10.72	72.09	10.77
0.75	66.07	10.31	81.20	10.78	88.73	10.88
1.0	82.83	10.54	104.69	10.89	110.26	11.36
1.5	98.90	10.66	122.65	11.01	132.09	11.41

4.4 Hyperbolic Stress-Strain Relationship

In order to predict the stress-strain response of soil a hyperbolic model reported by[19] has been used. In order to assess its validity for clay reinforced with untreated/ treated coir fibres, the present results have been analyzed. This model is defined as

$$\frac{\varepsilon}{\sigma_1 - \sigma_3} = \frac{1}{E_i} + \frac{1}{(\sigma_1 - \sigma_3)_{ult}}\varepsilon \quad ...(1)$$

Where,

ε = strain, σ_1-σ_3 = deviator stress at strain ε, and E_i and $(\sigma_1\text{-}\sigma_3)_{ult}$ are initial elastic modulus (E_i) and ultimate strength $(\sigma_1\text{-}\sigma_3)_{ult}$ respectively. These parameters are obtained by fitting a linear line on a plot of $\varepsilon / \sigma_1 - \sigma_3$ vs ε as obtained from the relevant experimental results. A typical plot of soil is shown in Fig.5. The ultimate stress $(\sigma_1\text{-}\sigma_3)_{ult}$ can be related to failure stress as

$$R_f = \frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 - \sigma_3)_u} \quad ...(2)$$

Where,

R_f= failure ratio and $(\sigma_1\text{-}\sigma_3)_f$ is failure stress, which is given by following expression for Mohr-Coulomb's failure criteria as $(\sigma_1\text{-}\sigma_3)_f = (2c\cos\phi + 2\phi_3\sin\phi)/(1-\sin\phi)$. The initial modulus of elasticity E_i can be written as a function of confining stress[20] as

$$E_t = \text{kPa } (\sigma_3/P_a)^n \quad ...(3)$$

Where P_a is atmospheric pressure (P_a= 101.325 kPa), which is used to predict non-dimensional parameters *k* and *n*. The non-dimensional parameters are determined from the plot (E_i/P_a) against (σ_3/P_a) log-log scale as

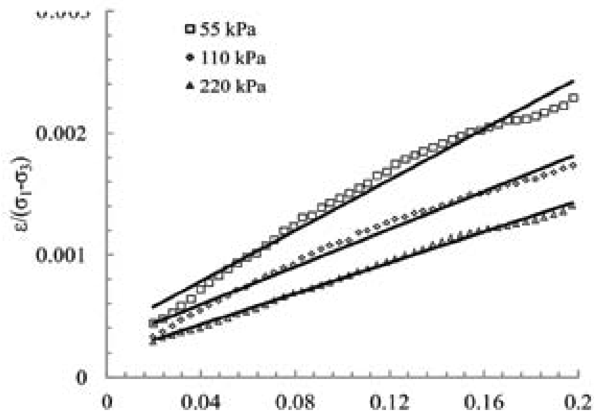


Fig. 5 : Plot between axial strain/deviator stress versus axial strain for pure clay

shown in Fig. 6. With the use of equations 1-3 and the Mohr Coulomb's definition of failure stress the hyperbolic model can now be stated as :

$$(\sigma_1 - \sigma_3) = \frac{\varepsilon}{\frac{1}{kP_a(\sigma_3/P_a)^n} + \frac{\varepsilon Rf(1-sin\Phi)}{2c cos\Phi + 2\sigma_3 sin\Phi}} \quad ...(4)$$

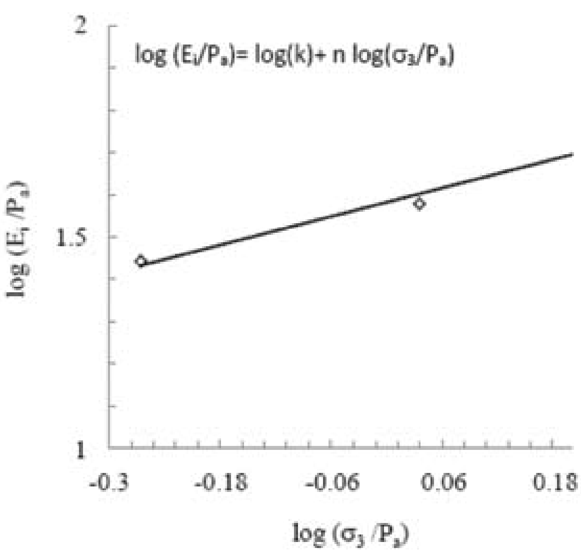


Fig. 6 : Plot for the determination of parameters k and n for soil

In the present study in order to predict the stress-strain curve of fibre reinforced soil the parameters *k, n, c,* ϕ (which are dependent on the fibre percentage in the soil and the type of treatment given to the fibre) are presented in the form of empirical expressions obtained after appropriate curve fitting. The expressions for these parameters are given as :

$$k = 42.74exp(.36t_k f) \quad ...(5)$$

$$n = .60exp(-.13t_n f) \quad ...(6)$$

Also the cohesion and friction angle can be given by following equations in accordance with Figs. 7 and 8 as

$$c = 47.37t_c f + 30.33 \quad ...(7)$$

$$\phi = .480ln(t_\phi f)+10.47 \quad ...(8)$$

In the above expressions the *f* represents the fibre content in fractions (0.25-1.5) and t_k, t_n, t_c, and t_ϕ are treatment factors whose values are unity for use of untreated coir fibres in soil. For NaOH treated and $KMnO_4$ treated fibres, these values are indicated in Table 8. It should be noted here that it is possible to have a separate trend line and the relevant equation for the data points in Figs.7-8 for soil reinforced with untreated, NaOH treated, and $KMnO_4$ treated coir fibres. However to maintain the uniformity an expression of soil reinforced with untreated fibre is proposed and treatment factors are added in the expression to account for the type of treatment provided to the coir fibres. The comparison of parameters *k* and *n* obtained as per Fig. 6 and those obtained by equation (5) and (6) is provided in Tables 9 and 10. Similarly the comparison of *c* and ϕ values computed from experimental data and those predicted by equations (7) and (8) is provided in Figs. 7 and 8 respectively. It should be noted that the equation (7) is applicable for fibre content of 0-1.5% whereas the equation 8 is valid for fibre content of 0.005% to 1.5%.

Table 8 : Treatment factors for calculation of *k, n, c,* ϕ and R_f

Parameter	Treatment factor	NaOH treated fibre	$KMnO_4$ treated fibre
k	t_k	1.21	1.84
n	t_n	2.05	4.46
c	t_c	1.40	1.55
ϕ	t_ϕ	2.35	4.93
R_f	t_R	-2.03	-1.5

On similar lines with equations 5-8 an expression of failure ratio R_f is developed using the 'Two Factorial Model' from Response Surface Methodology. The relevant expression is given as

$$R_f = .842 + .003t_R f + .0002\sigma_3 - .0002t_R f\sigma_3 \quad ...(9)$$

Here again the parameter t_R is used to specify the type of treatment given to the fibre. The value of t_R is unity for untreated fibres, whereas in other cases it is indicated in Table 8. The Response Surface Methodology is used for the design of experiments where a definite relationship between the input and output parameters doesn't exist. In such cases the Response Surface Methodology aids in developing an empirical expression relating the input and output parameters with the use of various models. For more details on the Response Surface Methodology the readers are advised to refer the literature[21]. In the present study the failure ratio *Rf* is dependent on confining pressure and fibre content, both hence an empirical expression of *Rf* which is dependent on these parameters is developed using the Two Factorial Model' from Response Surface Methodology. On similar lines with equation 5-8, first the equation is developed for the soil reinforced with untreated fibres and it is later on modified to take care of the type of treatment provided to the coir fibres by introducing a treatment factor t_R. A comparison ofthe observed *Rf* values in accordance with equation (2) and that predicted by equation (9) is provided in Table 11. With the use of equations 4-9 the stress-strain curve in each case is predicted and compared with the corresponding experimental result. It should be noted that the parameters *n* and *k* governs the initial elastic part of the stress-strain curve, whereas the parameters *c, f* and *Rf* governs near failure response of the soil. The back predicted stress-strain curves along with the respective experimental results for few selected values of confining pressure and fibre content are indicated in Figs. 9 to 15. A comparison of peak deviator stress observed from experimental data and that predicted by equation 4 with a strain (ε) of about 0.2 is provided in Table 12. From Figs. 9 to 15, it can be observed that the predicted stress-strain curves are in good agreement with the experimental observations for both unreinforced clay and clay reinforced with untreated/treated fibres.Also the data from Table 12 indicates that the maximum deviation in predicting deviator stress with respect to experimental value was about 20%. Hence the hyperbolic model can be used with sufficient accuracy to predict the response of unreinforced and reinforced soil.Since clay reinforced with untreated/treated coir fibres has shown improved strength behaviour, it can be used in short term stability related problems.

Table 9 : Variation of calculated and predicted k parameter with fibre percentage

Fibre percentage	***k***					
	Untreated Fibres		**NaOH treated fibres**		**$KMnO_4$ treated fibres**	
	Calculated	**Predicted**	**Calculated**	**Predicted**	**Calculated**	**Predicted**
0	38.02	42.74	38.02	42.74	38.02	42.74
0.25	43.25	46.77	55.72	47.66	43.05	50.44
0.5	61.24	51.17	50.12	53.14	75.34	59.52
0.75	59.29	55.99	56.36	59.25	100.69	70.24
1.00	68.12	61.26	68.87	66.07	82.99	82.89
1.50	63.53	73.34	81.85	82.15	91.62	115.44

Table 10 : Variation of calculated and predicted n parameter with fibre percentage

Fibre percentage	***n***					
	Untreated fibres		**NaOH treated fibres**		**$KMnO_4$ treated fibres**	
	Calculated	**Predicted**	**Calculated**	**Predicted**	**Calculated**	**Predicted**
0	0.56	0.60	0.56	0.60	0.56	0.60
0.25	0.62	0.58	0.58	0.56	0.63	0.52
0.5	0.56	0.56	0.47	0.53	0.44	0.45
0.75	0.60	0.54	0.43	0.49	0.29	0.39
1.00	0.42	0.53	0.42	0.46	0.20	0.34
1.50	0.52	0.49	0.46	0.40	0.39	0.25

Table 11 : Variation of failure ratio R_f with fibre percentage and confining pressure

σ_3 (kPa)	Fibre percentage	R_f					
		Untreated Fibres		NaOH treated fibres		$KMnO_4$ treated fibres	
		Calculated	Predicted	Calculated	Predicted	Calculated	Predicted
55	0	0.875	0.853	0.875	0.853	0.875	0.853
	0.25	0.739	0.851	0.778	0.857	0.798	0.856
	0.5	0.841	0.849	0.732	0.861	0.838	0.859
	0.75	0.804	0.847	0.824	0.865	0.830	0.862
	1.00	0.819	0.845	0.765	0.869	0.809	0.865
	1.50	0.810	0.841	0.760	0.877	0.802	0.871
110	0	0.948	0.864	0.948	0.864	0.948	0.864
	0.25	0.922	0.859	0.876	0.874	0.780	0.871
	0.5	0.802	0.855	0.824	0.883	0.868	0.878
	0.75	0.881	0.850	0.792	0.893	0.867	0.885
	1.00	0.822	0.845	0.841	0.903	0.858	0.893
	1.50	0.834	0.836	0.829	0.922	0.870	0.907
220	0	0.906	0.886	0.906	0.886	0.906	0.886
	0.25	0.916	0.876	0.820	0.907	0.838	0.901
	0.5	0.877	0.866	0.800	0.928	0.830	0.917
	0.75	0.829	0.855	0.842	0.948	0.903	0.932
	1.00	0.831	0.845	0.822	0.969	0.898	0.948
	1.50	0.807	0.825	0.862	1.011	0.915	0.978

Table 12 : Variation of experimental and predicted peak deviator stress with fibre percentage and confining pressure

σ_3 kPa	Fibre %	Untreated Fibres			NaOH treated fibres			$KMnO_4$ treated fibres		
		Experi-mental	Predicted	% deviation	Experi-mental	Predicted	% deviation	Experi-mental	Predicted	% deviation
55	0	86.80	87.64	0.97	86.80	87.64	0.97	86.80	87.64	0.97
	0.25	116.22	118.26	1.76	140.14	128.52	8.29	160.00	135.30	15.43
	0.5	147.77	144.06	2.51	177.77	162.65	8.51	198.91	176.30	11.37
	0.75	176.69	169.51	4.07	227.08	196.22	13.59	239.22	217.92	8.90
	1	222.51	195.07	12.33	272.00	229.90	15.48	289.42	260.71	9.92
	1.5	257.00	247.44	3.72	318.03	298.82	6.04	342.19	350.29	-2.37
110	0	113.92	107.6	5.55	113.92	107.60	5.55	113.92	107.60	5.55
	0.25	145.88	144.28	1.10	184.43	154.50	16.23	200.67	161.91	19.32
	0.5	168.15	172.84	2.79	212.08	189.72	10.54	227.33	203.31	10.57
	0.75	215.21	200.86	6.67	239.30	223.59	6.566	269.29	244.25	9.30
	1	254.91	228.98	10.17	317.06	256.88	18.98	334.93	285.50	14.76
	1.5	299.63	286.44	4.40	359.21	323.04	10.07	383.49	369.92	3.54
220	0	142.4	142.84	0.30	142.4	142.84	0.30	142.42	142.84	0.30
	0.25	186.2	189.45	1.77	232.4	197.74	14.93	245.15	206.87	15.61
	0.5	217.5	221.65	1.91	255.4	231.72	9.26	274.68	246.81	10.15
	0.75	251.4	253.08	0.66	297.9	263.16	11.67	318.04	284.93	10.41
	1	297.2	284.70	4.20	352.4	293.18	16.79	373.33	322.4	13.64
	1.5	334.9	349.87	4.47	398.8	350.63	12.07	425.95	396.9	6.82

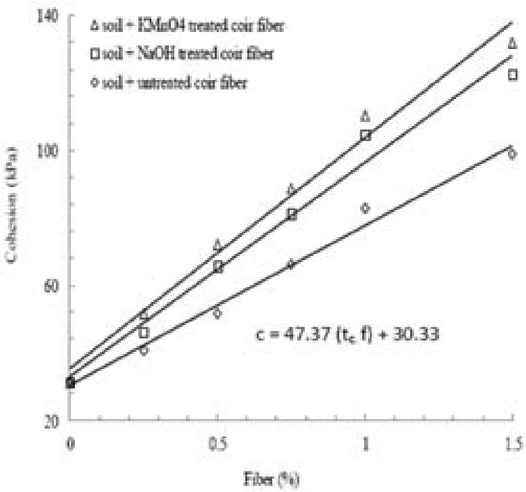


Fig. 7 : Variation cohesion with fibre content

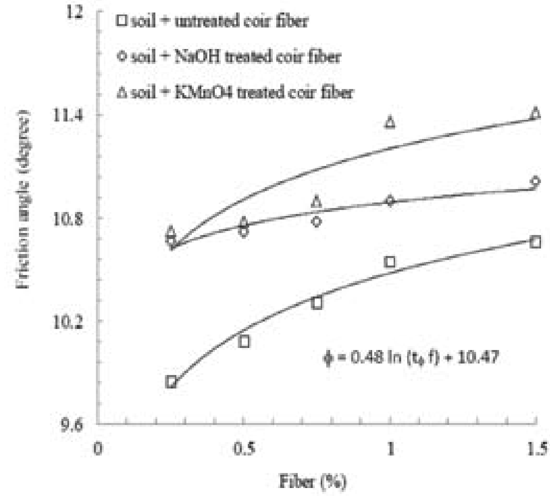


Fig. 8 : Variation friction angle with fibre content

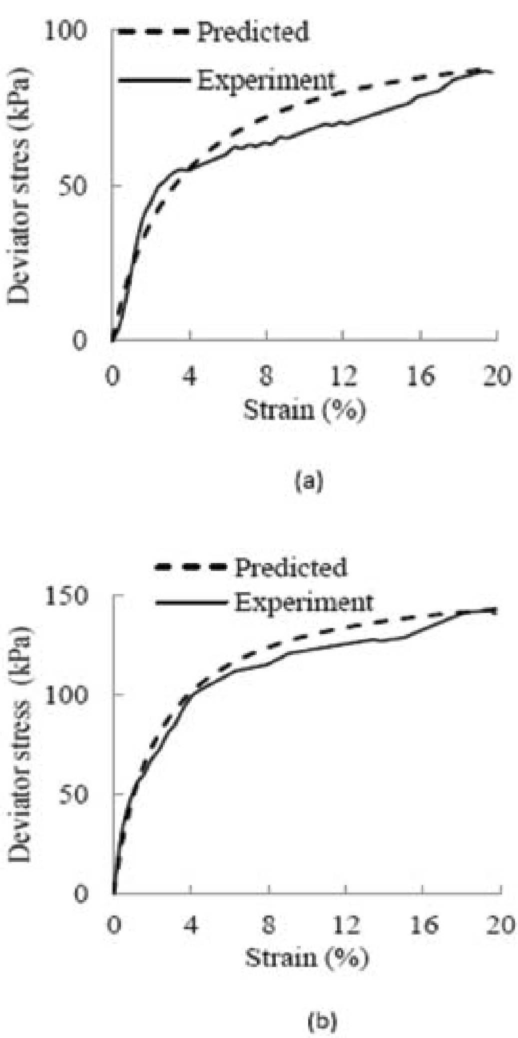


Fig. 9 : Predicted stress strain curves from hyperbolic model for clay with confining pressure of (a) 55 kPa and (b) 220 kPa

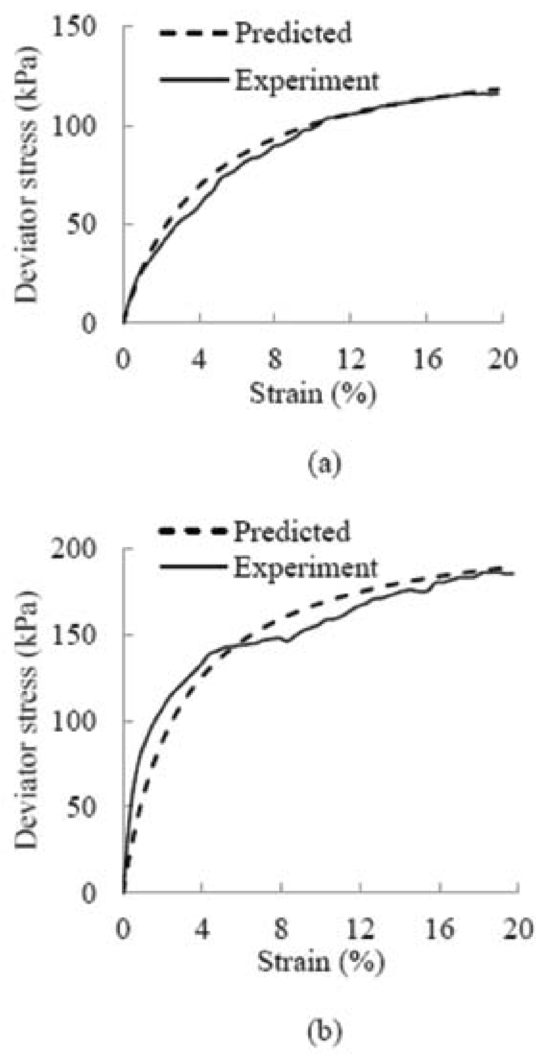


Fig. 10 : Predicted stress strain curves from hyperbolic model for clay reinforced with 0.25% untreated fibres with confining pressure of (a) 55 kPa and (b) 220 kPa

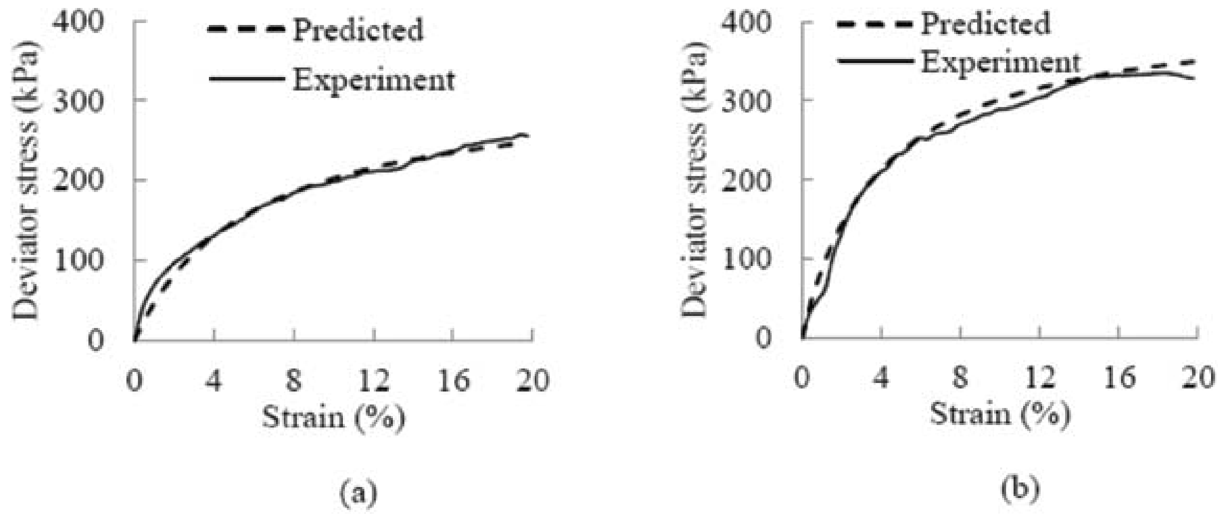


Fig. 11 : Predicted stress strain curves from hyperbolic model for clay reinforced with 1.5% untreated fibres with confining pressure of (a) 55 kPa and (b) 220 kPa

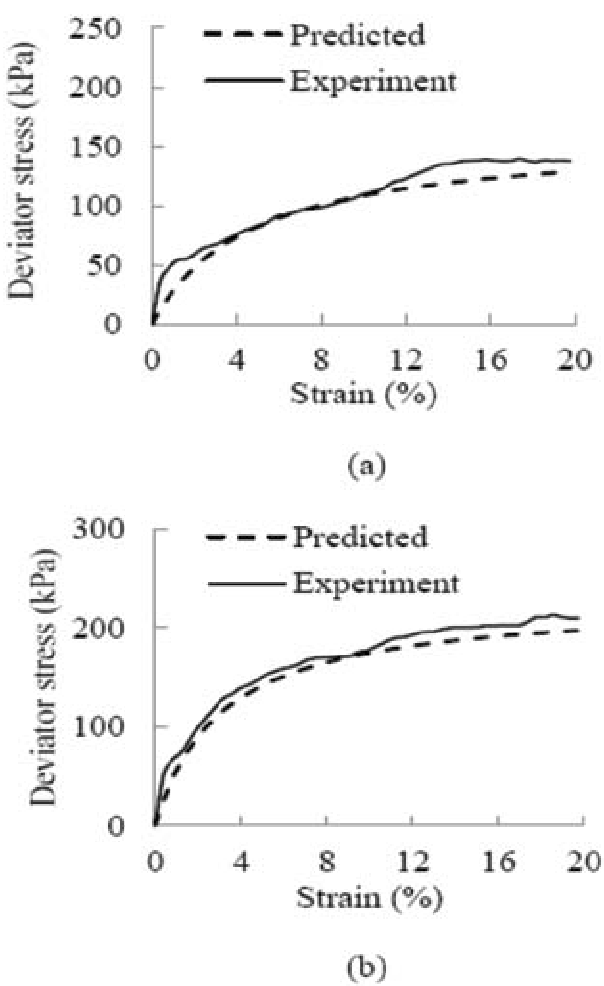


Fig. 12 : Predicted stress strain curves from hyperbolic model for clay reinforced with 0.25% NaOH treated fibres with confining pressure of (a) 55 kPa and (b) 220 kPa

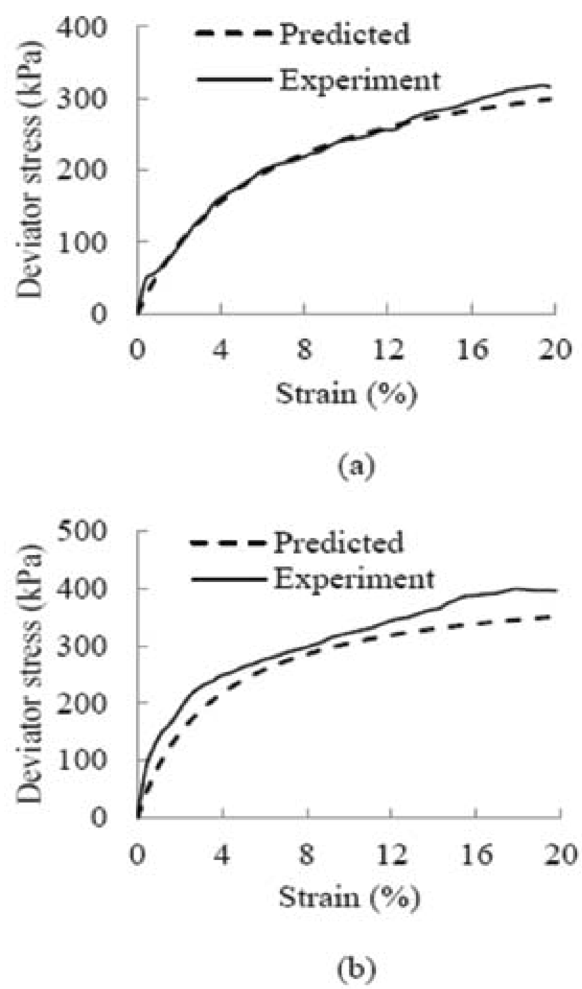


Fig. 13 : Predicted stress strain curves from hyperbolic model for clay reinforced with 1.5% NaOH treated fibres with confining pressure of (a) 55 kPa and (b) 220 kPa

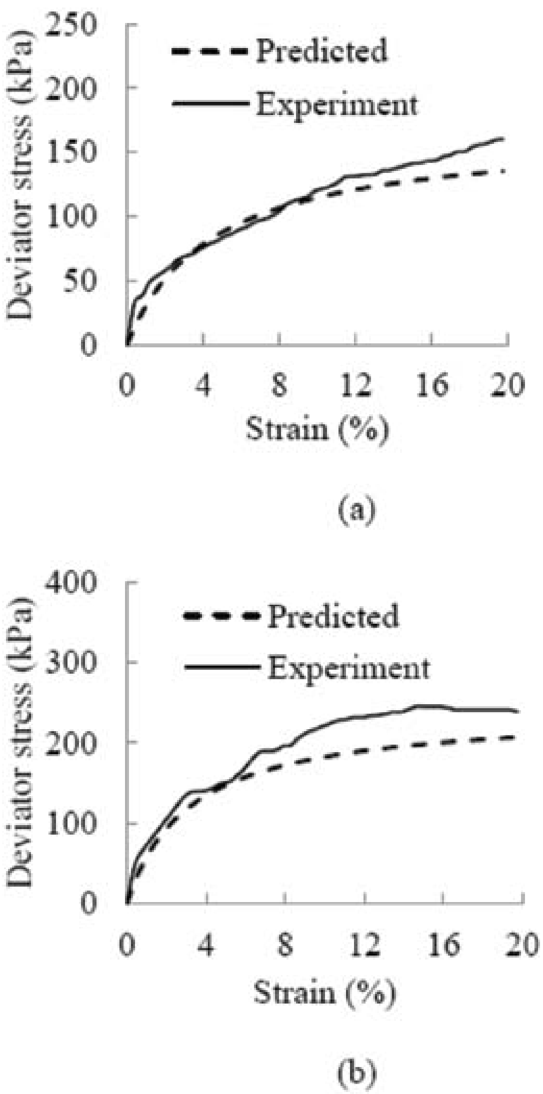


Fig. 14 : Predicted stress strain curves from hyperbolic model for clay reinforced with 0.25% $KMnO_4$ treated fibres with confining pressure of (a) 55 kPa and (b) 220 kPa

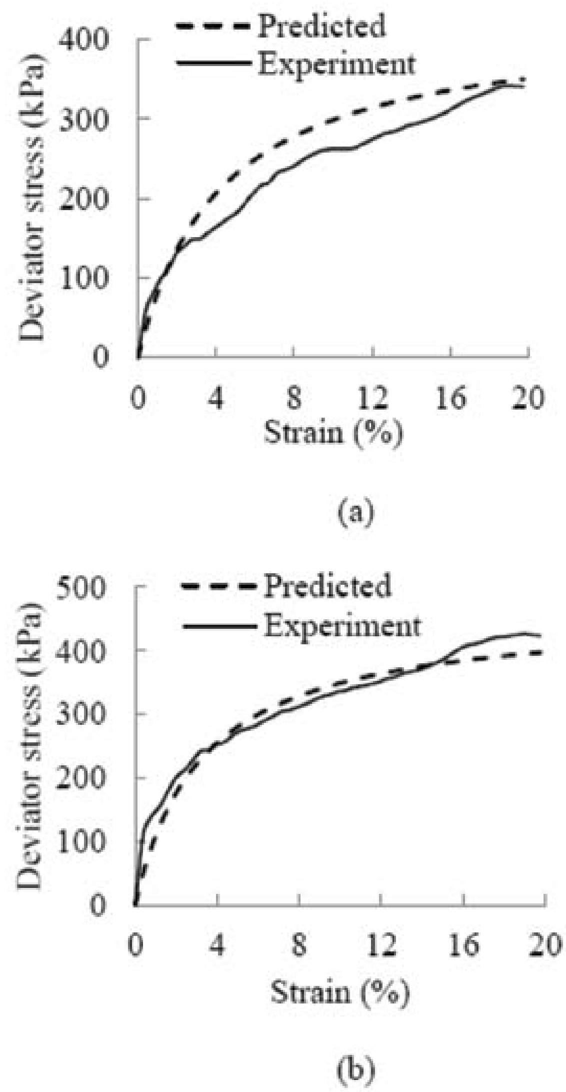


Fig. 15 : Predicted stress strain curves from hyperbolic model for clay reinforced with 1.5% $KMnO_4$ treated fibres with confining pressure of (a) 55 kPa and (b) 220 kPa

5. CONCLUSION

This study examined the effect of untreated/treated coir fibres on the strength characteristics of the clay reinforced with 0.25 % to 1.5 % fibre content. The results reveal that the strength characteristics of the clay reinforced with coir fibres can be significantly improved by treating with sodium hydroxide and potassium permanganate. The study brings forth the following conclusions.

1. The optimum moisture content of clay reinforced with untreated/treated coir fibres increases with the increase in fibre content.
2. The optimum moisture content of clay reinforced with treated coir fibres was less in comparison to untreated coir fibres.
3. $KMnO_4$ treated coir fibre absorbs slightly less water in comparison to NaOH treated coir fibres in clay.
4. The maximum dry unit weight of clay reinforced with untreated/treated coir fibres decreases with the increase in fibre content.
5. The maximum dry unit weight of clay reinforced with treated coir fibres was higher in comparison to untreated coir fibres.
6. Reinforcing clay with $KMnO_4$ treated coir fibre results in higher maximum dry unit weight in comparison to NaOH treated coir fibres.
7. The peak deviator stress on clay reinforced with coir fibres can be significantly improved by treatment with NaOH and $KMnO_4$.

8. With the increase in coir fibre content (0.25%-1.5%) in clay, there was an increase in the peak deviator stress.
9. Both the shear strength parameters c and ϕ were found to increase quite significantly with increase in coir fibre content (0.25%-1.5%) in clay.
10. The addition of $KMnO_4$ treated fibres results in maximum value of peak deviator stress and shear strength parameters of soil.
11. The hyperbolic model can be used for predicting the stress-strain response of unreinforced and reinforced clay with appropriate selection of model parameters.

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ANALYTICAL EVALUATION OF BEARING CAPACITY OF SOILBAG WITH SEMI-ELLIPTICAL CROSS SECTION

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ABSTRACT

The main aim of this article is to examine the effect of geometrical form with semi-elliptical cross section on the maximum bearing capacity of soilbag influenced by vertical loading. In this article, the maximum bearing capacity of soilbag under semi-circular geometrical form was initially examined using the analytical method. Then, the maximum value of bearing capacity of soilbag is presented by a new geometrical form, that is, semi-elliptical. The result shows that by increasing of the semi-elliptical eccentricity and internal friction angle of sand, the vertical bearing capacity of soilbag increases under external loads.

Keywords *: Soilbag, Bearing capacity, Semi-elliptical*

NOMENCLATURE

L_0	Initial perimeter	σ_h	Horizontal stress
B_0	Initial width	σ_v	Vertical stress
H_0	Initial height	p_v	Vertical compression
V_0	Initial volume	K_p	Passive earth pressure coefficient
l	Length bag	ϕ	Friction angle
δ_v	Vertical displacement	$F_{v(limit)}$	Compression capacity of a soilbag
V	Secondary volume	e	Semi-elliptical eccentricity
L	Secondary perimeter	a_0	Initial big diameter of semi-ellipse
ε_bag	Circumference strain	b_0	Initial small diameter of semi-ellipse
B	Secondary width	a	Secondary big diameter of semi-ellipse
T	Tensile force within the bag	b	Secondary small diameter of semi-ellipse
σ_{bag}	Yield stress of polymeric bag	$\delta_{v\text{-peak}}$	Maximum vertical displacement
$t_{(bag)}$	Thickness of polymeric bag	Ψ	Dilation angle
E_{soil}	Young's modulus of the soil	ν	Poisson's ratio
E_{bag}	Young's modulus of the bag	C	Cohesion

1. INTRODUCTION

Soilbag is one of the new polymeric artifacts which can be used as soil reinforcement in different civil projects. The soilbag consists of the soil enclosed into a polymeric bag which is defined based on tension strength, size, geometric form of polymeric bag and the mechanical properties of soil filling inside it which depend on internal friction angle.

When soilbag undergoes vertical loading, tension force produced inside the bag cover causes the vertical force (N) to increase, consequently, this causes the force between soil particles (μ = soil friction coefficient and $F = \mu.N$) to increase (Matsuoka and Liu 2006).

The kind of filling materials mostly depends on the application of soilbag and also the availability of materials. The most important characteristic implemented into the structure of soilbag is tension strength of the polymer in the bag (Matsuoka and Liu 2003). Bags implemented into soilbag are generally built of polyethylene or polypropylene polymers. The structures equipped with soilbag enjoy abundant technical and economic advantages compared to similar concrete and stony structures.

Among the applications of soilbags, the construction of temporary emergent structures, equipment of the bed of inner-urban roads in order to decrease the vibrations resulted from traffic (Nakagawa *et al.* 2008- Liu *et al.* 2014), equipment of embankment layers in technical buildings including retaining wall (Tatsuoka *et al* 1997- Wang *et al*. 2015), and increasing the bearing capacity of shallow foundations can be addressed (Yongfu *et al*. 2008).

In Figure 1, external loading process on soilbag is depicted. When a compressive force is exerted on soilbag, tensile force is created in the yarn of polymeric bag. Tensile force created in polymeric bag causes to exert a confining pressure on soil inside it. This causes contact force between soil particles to increase.

Bearing capacity of soil bags is generally dependent on shear resistance of soil in the bag, tensile resistance and thickness of polymeric bag, and its cross-sectional surface form. Using experimental studies, Li et al (2013) examined the effect of soilbag on the prevention of soil volume from increasing by the effect of frost.

The establishment and maintenance of infrastructure such as roads, embankments, and retaining wall to implement some methods which do not damage the surrounding environment, in addition to cost-effectiveness. This aim can be achieved by exploiting soilbag. One of the important factors to select this kind of system is the speed of its construction compared to other systems to establish the emergency structures and its role in passive defense.

Lohani et al (2006) showed that the vertical stiffness of stacked soil bags increased with increasing strength and stiffness of the geotextile used to make the soilbags.

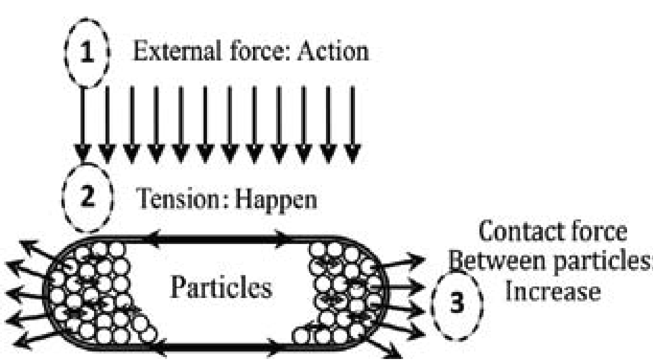

Fig. 1 : External loading process on soilbag

Sometimes, it is not possible to stabilize loose soils in civil projects using mechanical machinery due to the existence of roads that are difficult to pass or hard executive condition of the project. For example, when the road surface is destroyed because of lateral slide in sleep regions in order to create communicative way within as minimum time as possible using polymeric bags filled by loose soils of the project site can be an appropriate option to solve the aforementioned problem.

Yongfu et al (2008) examined the effect of foundation reinforcement using the soilbag against the external loading.

The results of these studies are as follows:

1. The force between the particles inside the bags is relatively greater than external forces exerted on the bags.
2. Bearing capacity of foundation reinforced by soilbag is 2–3 times more than the non-reinforced foundation.
3. Bearing capacity of bags filled by the gravel is more than the bags filled by the sand.
4. The relationship between stress-strain of bags is different from the relationship between stress-strain of soils.
5. Regarding the experiments performed, some ruptures happened on points such as the contact point of bag and loading surface and sewing seam points.
6. Bearing capacity of bags depends on tensile resistance of wrapping of bag and internal friction angle of soil.

Researchers conducted some experiments, which resulted in decreasing vibrations from the traffic of heavy vehicles (Nakagawa *et al.*2008- Matsuoka *et al*. 2005). In fact, this method selects a way which reduces the effect of vibrations resulted from traffic on residential houses. Matsuoka and Liu (2003) examined the mechanical behavior of single soilbag with rectangular boundary conditions for the first time in order to determine the maximum loading capacity influenced by vertical loading. Semi-circular geometrical form for boundary conditions of soilbag was defined by Tantono and Bauer (2008). Then, the behavior of single soilbag was examined using numerical method in two-dimensional state.

Ansari et al (2011) examined mechanical behaviour of single soilbag with semi-circular boundary conditions in three-dimensional state under vertical and shear loadings. The results of these researches show that in a fixed loading, if internal friction angle of sand is assumed as fixed, and when the dilatation angle increases, the vertical displacement of soilbag under vertical loading will decrease. Regarding the review of studies performed on soilbag, no research has ever been performed in order to examine the effect of semi-elliptical boundary conditions on bearing capacity of soilbag, while this subject had already been studied for semi-circular boundary conditions.

Regarding the aforementioned points and because of loading, which result in distribution of stress in the wrapping of polymeric bag and soil inside the polymeric bag, the study of distribution method of tensile stress, circumference strain in the wrapping of polymeric bag, and determination of critical regions influenced by these loading are important in terms of designing. In this article, to achieve this aim, we addressed to evaluate a single soilbag with new boundary conditions in semi-elliptical geometrical form under vertical loads using the analytical method.

2. ANALYTICAL METHOD

In the study by analytical method, mechanical behavior of single soilbag was examined under homogeneous vertical compression with semi-circular boundary conditions at its corners. In this study, bearing capacity of soilbag and circumference strain formed in polymeric bag were addressed. In continuation, a new geometrical form in the shape of semi-ellipse was presented for boundary conditions of soilbag in order to examine the increasing of bearing capacity. Finally, the obtained results were compared to the results of other researchers.

2.1 Evaluation of Soilbag with Semi-circle Cross-section

In Figure 2(a), mechanical behaviour of the single soilbag under monotonic vertical pressure is shown based on the simplified model by Tontono and Bauer (2008). The following assumptions are considered by Tontono in order to solve the problem mathematically:

1. The filling material is assumed as weightless.
2. Plane strain conditions are assumed.
3. The surfaces of the top and bottom platens are frictionless, and the normal pressure in the contact zone is homogeneously distributed over the contact area .
4. The volumetric strain of the soilbag is neglected.
5. The change in the thickness of the membrane is neglected.
6. The soilbag is totally filled with granular material.

Then, considering the vertical pressure on soilbag (P_v), vertical and horizontal stress between the soil particles (σ_h and σ_v) and 1-1 and 2-2 cross sections in soilbag which is shown in Figure 2(b), the maximum bearing capacity of soilbag has been determined. In continuation, considering the cross section of the soilbag with initial width B_0, initial height H_0, and the length *l* and a semicircle with $H_0/2$ in radius for boundary conditions, initial perimeter and volume are determined as follows:

$$L_0 = 2B_0 + \pi H_0 \quad ...(1)$$

$$V_0 = B_0 . H_0 . l + \pi \times \left(\frac{H_0}{2}\right)^2 . l \quad ...(2)$$

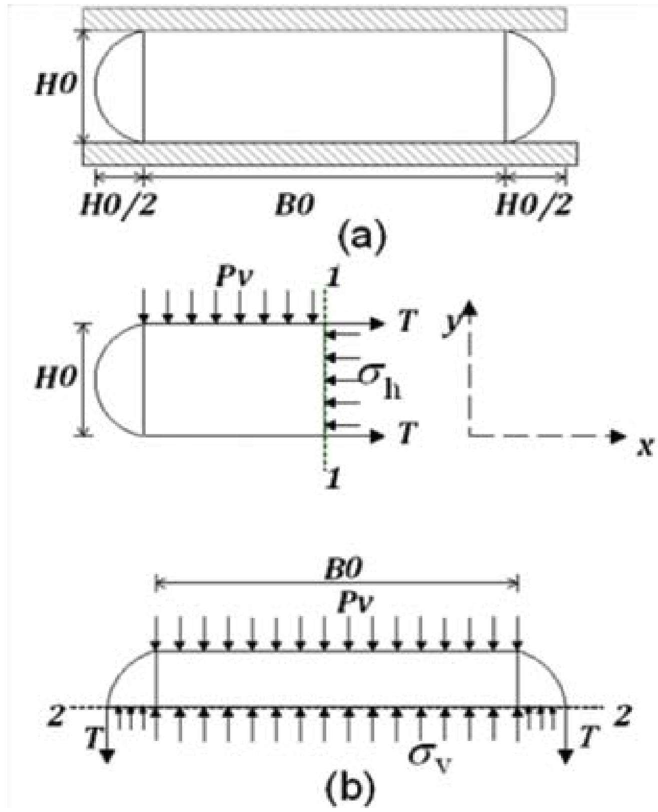

Fig. 2 : Geometrical form of soilbag with semi-circular boundary conditions, (b) soilbag under the pressure and tensile force T in cross-section 1 and 2.

If soilbag undergoes vertical displacement δv, changes in perimeter (L) and width (B) of soilbag are equal to:

$$H = H_0 - \delta_V \quad ...(3)$$

$$V = V_0 \ \rightarrow \ B = \frac{B_0 H_0 + \frac{\pi H_0 \delta_V}{2} - \frac{\pi (\delta_V)^2}{4}}{(H_0 - \delta_V)} \quad ...(4)$$

$$L = \frac{2B_0 H_0 - \pi H_0 \delta_V + \frac{\pi (\delta_V)^2}{2} + \pi {H_0}^2}{(H_0 - \delta_V)} \quad ...(5)$$

Circumference strain of polymeric bag obtained from the aforementioned data is equal to:

$$\epsilon_{\text{bag}} = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0} = \frac{\delta_V (\pi \delta_V + 4B_0)}{2(H_0 - \delta_V)(2B_0 + \pi H_0)} \quad ...(6)$$

Tensile force created in polymeric bag is equal to:

$$T = \sigma_{(bag)} \times t_{(bag)} = E \frac{\Delta L}{L_0} t_{(bag)} \quad ...(7)$$

The vertical compression associated with the yielding tensile strain within the bag could be derived via equilibrium equations in the horizontal and vertical directions (Figs. 2 a and b) as expressed below:

$$\Sigma F_x = 0 : \sigma_h \times H \times l - 2T \times l = 0 \quad ...(8)$$

$$\Sigma F_y = 0 : \sigma_v \times B \times l + \sigma_v \times H/2 \times l - 2T \times l - p_v \times B \times l = 0 \quad ...(9)$$

In figure 2(b), the horizontal and vertical stresses can be linked via a passive earth pressure:

$$\sigma_v = K_p . \sigma_h \quad ...(10)$$

$$F_v = p_v \times B \times l \quad ...(11)$$

For a granular soil with friction angle of ϕ the passive earth pressure coefficient is given as,

$$K_P = \frac{1 + \sin \emptyset}{1 - \sin \emptyset} \quad ...(12)$$

Considering the equations 8 and 9, the maximum bearing capacity of soilbag with semi-circular cross section will be obtained which is equal to:

$$F_{v(limit)} = 2\left(\sigma_{yeild}\right)_{bag} \times t \times \left[\frac{B.K_P}{H} + \frac{K_P}{2} - 1\right] \times l \quad ...(13)$$

In equation 13, t and σ are the thickness and yield stress of polymeric bag, respectively. F_v is bearing capacity.

2.2 Evaluation of Soilbag with Semi-elliptical Cross Section

The performed observations show that geometrical form of boundary conditions of bag changes under the effect of loading. By changing the curvature in radius of boundary conditions, it is observed that just semi-circular conditions will not be obtained. But by changing the eccentricity, semi-elliptical boundary conditions can be studied.

Therefore, in this article, we present new boundary conditions in semi-elliptical geometrical form, which is shown in Figure 3(a). We addressed to determine the maximum bearing capacity of single soilbag influenced by vertical loading.

In Figure 3(b), the vertical pressure P_V is imposed on soilbag. Furthermore, a_0 and b_0 are halves of initial big and small diameters of semi-ellipse, respectively. H_0 and B_0 are the initial height and width of soilbag. As we know, ellipse stretching is defined by eccentricity which is equal to:

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} \quad , \quad 0 < e < 1 \quad ...(14)$$

With probe <u>e</u> towards 0, the ellipse is converted into a circle; with is probe towards 1, the ellipse will be more stretched. Solving the equation 14, <u>a</u> will be obtained.

$$a = \frac{b}{\sqrt{1-e^2}} = \frac{H}{2\sqrt{1-e^2}} \quad ...(15)$$

In continuation, considering the initial dimensions $B_0 \times H_0$ the length *l* and semi-elliptical geometrical form for boundary conditions, the circumference, and initial volume will be obtained as follows:

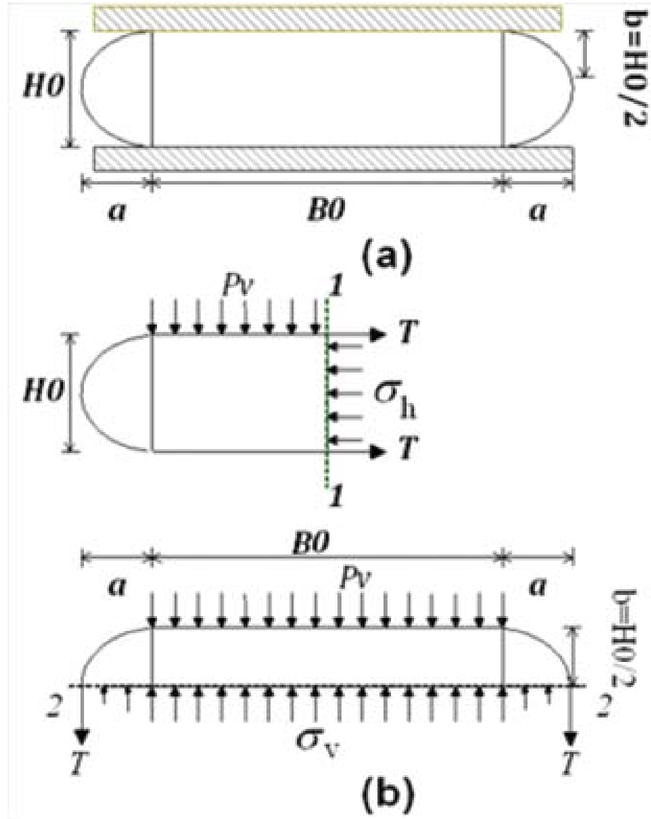

Fig. 3 : Geometrical form of soilbag with semi-elliptical boundary conditions, (b) soilbag under the pressure p_v and tensile force T in cross-section 1 and 2.

$$L_0 = 2B_0 + \left(\frac{\pi . H_0}{\sqrt{2}} . \sqrt{\frac{2-e^2}{1-e^2}}\right) \quad ...(16)$$

$$V_0 = B_0 . H_0 . l + \frac{\pi . H_0^2}{4} . \frac{1}{\sqrt{1-e^2}} . l \quad ...(17)$$

Now, if soilbag undergoes (δ_V) displacement, considering that the volume of soilbag is assumed as fixed during compression, secondary circumference, changes in circumference strain and width, which is equal to:

$$H = H_0 - \delta_V \quad ...(18)$$

$$V = V_0 \rightarrow B = \frac{B_0 H_0 + \frac{1}{\sqrt{1-e^2}} . \left(\frac{\pi H_0 \delta_V}{2} - \frac{\pi (\delta_V)^2}{4}\right)}{(H_0 - \delta_V)} \quad ...(19)$$

$$L = 2B + \left(\frac{\pi . H}{\sqrt{2}} . \sqrt{\frac{2-e^2}{1-e^2}}\right) \quad ...(20)$$

$$\epsilon_{bag} = \frac{L - L_0}{L_0} = \frac{\delta_V \left(4B_0 + \pi \delta_V . \sqrt{\frac{2-e^2}{2(1-e^2)}}\right)}{2(H_0 - \delta_V)\left(2B_0 + \pi H_0 \sqrt{\frac{2-e^2}{2(1-e^2)}}\right)} \quad ...(21)$$

Tensile force created in polymeric bag is equal to:

$$T = \sigma_{(bag)} \times t_{(bag)} = E\frac{\Delta L}{L_0} t_{(bag)} \quad ...(22)$$

Now, considering P_V as vertical pressure on the soilbag, σ_h and σ_v as horizontal stress and vertical stress between soil particles, and 1-1 and 2-2 cross sections in soilbag, which are shown in Figure 3(b), the compression capacity of soilbag is obtained.

The vertical compression associated with the yielding tensile strain within the bag could be derived via equilibrium equations in the horizontal and vertical directions (Figs. 3 a and b) as expressed below:

In Figure 2(b), the horizontal and vertical stresses can be linked via a passive earth pressure:

$$\Sigma F_x = 0 : \sigma_h \times H \times l - 2T \times l = 0 \quad ...(23)$$

$$\Sigma F_y = 0 : \sigma_v \times B \times l - 2T \times l - p_v \times B \times l + \sigma_v \times \frac{H}{2.\sqrt{1-e^2}} \times l = 0 \quad ...(24)$$

Considering the passive earth pressure coefficient and vertical and horizontal stresses, it can be written as,

$$\sigma_v = K_p . \sigma_h \quad ...(25)$$

where for a granular soil with friction angle of ϕ the passive earth pressure coefficient is given as,

$$K_P = \frac{1+\sin\emptyset}{1-\sin\emptyset} \quad ...(26)$$

$$F_v = p_v \times B \times l \quad ...(27)$$

Considering the equations 23 and 24, the maximum bearing capacity of soilbag with semi-elliptical cross section will be obtained, which is equal to:

$$F_{V,limit} = 2(\sigma_y)_{bag} \times t \times \left[\frac{B.K_P}{H} + \frac{K_P}{2.\sqrt{1-e^2}} - 1\right] \times l \quad ...(28)$$

In equation 28, t and σ are thickness and yield stress of polymeric bag, respectively. F_v is bearing capacity.

3. THE COMPARISON OF ULTIMATE BEARING CAPACITY OF SOILBAG WITH SEMI-CIRCULAR AND SEMI-ELLIPTICAL BOUNDARY CONDITIONS

In this section, we address to compare ultimate bearing capacity of soilbag. For this purpose, two soilbags with semi-circular and semi-elliptical boundary conditions are considered. Mechanical and geometrical characteristics are presented in Tables 1 and 2. The values of initial dimensions of soilbag, the ultimate bearing capacity, and the maximum displacement for semi-elliptical and semi-circular cross sections are presented in table 1. By exerting variable vertical displacement on soilbag, the ultimate vertical force of the system will be obtained using the Equations 13 and 28.

Table 1 : Geometric characteristics of soilbag

Parameter	H_0 (cm)	B_0 (cm)	l (cm)	V_0 (cm^3)	e	$\delta_{v\text{-peak}}$ (mm)	$F_{V\text{-Limit}}$ (kN)
Semicircular	7	17.5	17.5	2817.5	0	19.1	205.8
Semi-elliptical	7	17.5	14.5	2817.5	0.85	21	220.543

Table 2 : Mechanical properties of soil and polymeric bag

Properties	E (MPa)	$\sigma_{y(bag)}$ (MPa)	φ (°)	ψ (°)	ν	C (kPa)	t (mm)
Soil	40	-	30	3	0.33	1	-
Bag	140	35	-	-	0.33	-	1

Figure 4 includes two force-displacement curves which represent the behaviour of soilbag. As it is observed, in force-displacement curve, when the displacement increases, the vertical force also increases. Bearing capacity of soilbag with semi-circular cross section in the maximum displacement of soilbag (19.1 mm) was obtained as equal to 205.8 (kN).

If semi-circular cross section is into semi-elliptical cross section with the eccentricity of 0.85, the value of bearing capacity in the maximum displacement of soilbag (21 mm) is obtained as equal to 220.543 (kN).

It is observed that when the cross section is changed into semi-elliptical form semi-circular form, bearing capacity of soilbag increases to 14.743 (kN).

In the presented model with semi-elliptical cross section, when the value of eccentricity increases, the geometrical elliptical form is more stretched. As a result, this causes the bearing capacity of soilbag influenced by external loads to increase. A non-linear change in semi-elliptical eccentricity compared to the bearing capacity of soilbag is depicted in Figure 5.

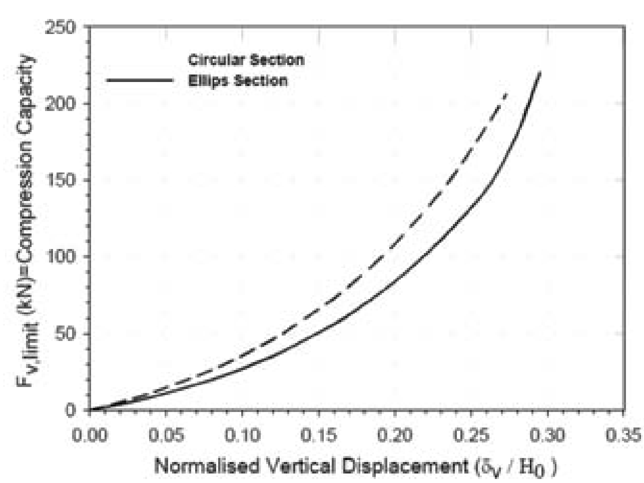

Fig. 4 : Load-normalized vertical displacement diagram of soilbag

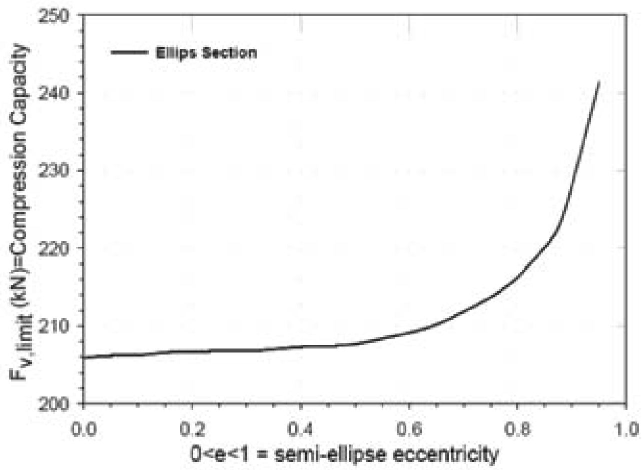

Fig. 5 : Changes in bearing capacity of soilbag for variable changes in eccentricity

One of the resistance-based parameters of soilbag is the thickness of polymeric bag. In Figure 6, changes in bearing capacity against the variable values of bag thickness for two semi-circular and semi-elliptical cross sections are shown. Changes in bearing capacity compared to the bag thickness are linear. In Figure 6, for a fixed thickness, bearing capacity of polymeric bag with semi-elliptical cross section is more than that of a semi-circular cross section.

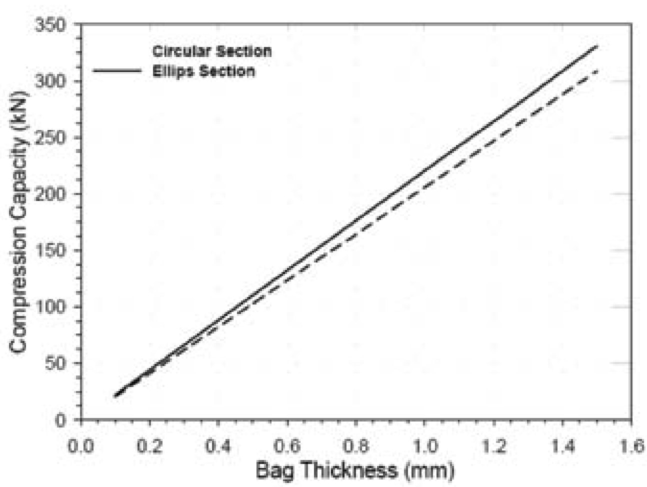

Fig. 6 : Variation of compression capacity with bag thickness

Another resistance-based parameters of soilbag, which was examined in this research, is the effect of internal friction angle of soil on the bearing capacity of soilbag. The results show that higher friction angle between soils particles, the resistance of soilbag will also be increased against the external loading (Fig. 7).

In Figure 8, changes in maximum vertical deformation for different values of yield stress of polymeric bag is depicted. For a fixed value of yield stress, maximum vertical deformation of soilbag with semi-circular cross section will be less than that of semi-elliptical cross section.

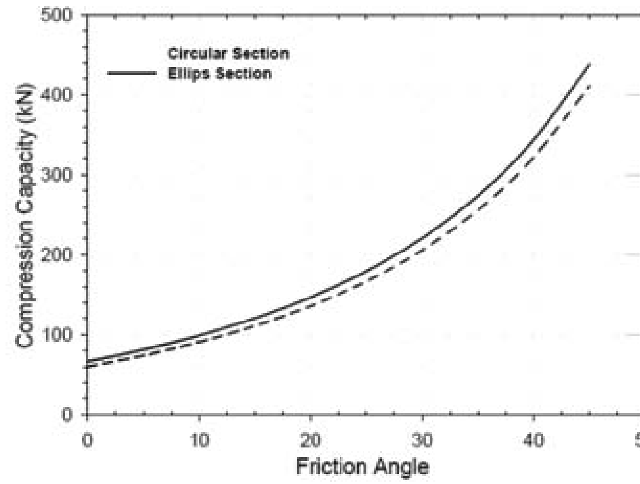

Fig. 7 : Variation of compression capacity with internal friction angle of soil

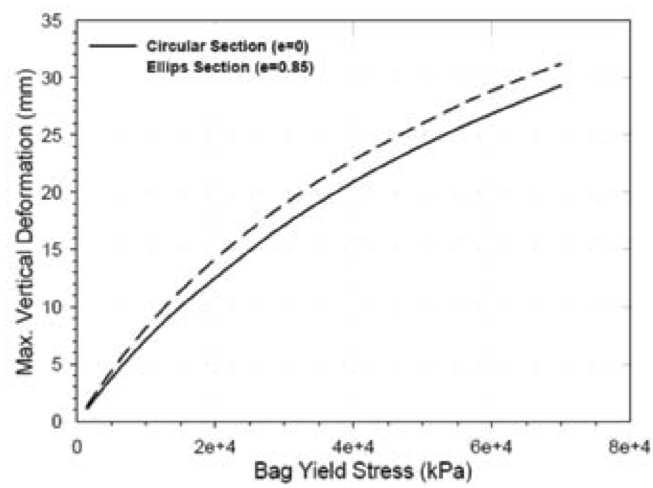

Fig. 8 : Maximum vertical deformation of soilbag under vertical compression

4. CONCLUSIONS

In this article, mechanical behaviour of single soil bag was considered under monotonic vertical compression with two semi-circular and semi-elliptical boundary conditions.

Then, the effects of boundary conditions of cross section, internal friction angle of soil, and thickness of polymeric bag on ultimate bearing capacity of soilbag were examined. The results obtained are as follows:

1. In the new model, when the value of eccentricity increases, the geometrical form of soilbag is more stretched. This causes the bearing capacity of soilbag influenced by external loads to increase. In

the presented geometrical form, when the value of eccentricity becomes zero, semi-ellipse is converted into semi-circle. Consequently, the presented equations for semi-elliptical conditions are changed into the presented equations for semi-circular conditions.

2. Semi-elliptical boundary condition with the eccentricity of 0.85 has more capability to tolerate the external load compared to semi-circular boundary conditions. Regarding the results obtained, in analytical method, when semi-circular cross section is changed into semi-elliptical cross section, ultimate bearing capacity of soilbag will be increased by 6.68%.
3. When the thickness of polymeric bag and internal friction angle of soil with two semi-circular and semi-elliptical boundary conditions increase, bearing capacity of soilbag increases. The process of increase in bearing capacity with semi-elliptical boundary conditions is more than that of semi-circular ones.
4. Ultimate bearing capacity of soilbag is generally a function of cross-sectional resistance of soil in the bag, thickness of polymeric bag, and the shape of its cross-sectional surface.

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EFFECT OF COIR GEOCELL AND FILL MATERIAL ON BEARING CAPACITY IMPROVEMENT OF SOFT CLAY - AN EXPERIMENTAL STUDY

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ABSTRACT

The effectiveness of different fill material along with geocell reinforcement placed over soft clay beds has been studied by small-scale model tests in the laboratory. The test beds were subjected to mono tonic loading by a rigid square footing. Footing load and the corresponding deformations of the fill material or reinforced bed were measured during the tests. The influence of different fill material in isolation, fill material reinforced with planar coir geotextile layer, coir geocell and geocell with planar geotextile at the base of the geocell mattress on the overall performance of the system has been systematically studied through a series of tests. Substantial performance improvement has been obtained in terms of increase in the load carrying capacity and reduction in the settlement and surface heaving of the foundation bed was observed when fill material of fine to medium sand was reinforced with coir geocells. An additional layer of planar geotextile placed at the base of the geocell mattress further enhances the load carrying capacity and stiffness of the foundation bed. The improvement in bearing capacity with reinforced fill material having a grain size more than 4.75 mm is only marginal. An eighteen fold increase in the bearing capacity of the square footing can be obtained by providing geocell reinforcement along with a basal planar geotextile layer in the coarse aggregate bed underlying soft clay. Stiffening the outer layer of coir geocell with horizontal or vertical stiffeners will reduce the carrying capacity of the fill material, increases the settlement but no heaving will be produced.

Keywords *: Geosynthetics; Coir geotextiles; Coir Geocell; Reinforced fill; Clay; square footing.*

1. INTRODUCTION

Bearing capacity of soft soil can be improved by a variety of ground improvement techniques such as stabilization of soil or by introduction of reinforcement. Introducing reinforcement inclusions within the soil is an effective and reliable technique in order to improve the engineering properties of soil. The more recent advancement of reinforced soil is to provide three dimensional confinements to soil by using geocells. Geocell foundation mattress consists of a series of interlocking cells, constructed from polymer geogrids, which contains and confines the soil within its pockets. It intercepts the potential failure planes because of its rigidity and forces them deeper into the foundation soil, thereby increasing the bearing capacity of soil. Geocell reinforcement arrests the lateral spreading of fill soil and creates a stiffened mat to support the foundation thereby giving rise to higher load carrying capacity.

Several investigations have been reported highlighting the beneficial use of geocell reinforcement in the construction of foundations and embankments. Bush et al., (1990) described the unique features of a geocell foundation mattress formed from polymer grid reinforcement. The results of instrumentation, monitoring and the performance of a geocell mattress foundation used in an embankment underlain by soft clay deposits were presented by Cowland and Wong (1993). It was seen that at one section, unusually high excess pore water pressures and a slight heave of the toes of the embankment occurred. The accompanying small lateral extension and the deflected shape of the geocell mattress indicated that it had behaved as a raft foundation to the embankment.

Chen and Chiu (2008) performed model tests on geocell retaining walls to examine the effect of the geocells as a major material in retaining structures and the failure mechanism of the said structures under surcharge.

Results showed that the deformation on the wall face and the backfill settlement both increased with increasing facing angle and surcharge. Wang et al., (2008) carried out tests on the shear property of geocell reinforced soils by using large scale direct shear equipment. Three types of specimens, silty gravel soil, geocell reinforced silty gravel soil and geocell reinforced cement stabilized silty gravel soil were used in the investigation. The comparisons of large scale shear test with triaxial compression test for the same type of soil were conducted to evaluate the influences of testing method on the shear strength of soil. The test results showed that the unreinforced soil and geocell reinforced soil give similar nonlinear features on the behaviour of shear stress and displacement. Tests with the geocell and cement stabilization results in an increase of 10 times in cohesion compared with the unreinforced soil.

Krishnaswamy et al., (2000) carried out a series of laboratory model tests on geocell mattress supported earth embankments constructed over soft clay bed. Dash et al., (2001a, b) investigated the reinforcing efficacy of the geocell mattress within a homogeneous sand bed supporting a strip footing. The effectiveness of geocell reinforcement placed in the granular fill overlying soft clay beds was examined by Dash et al., (2003). The influence of width and height of geocell mattress as well as that of a planar geogrid layer at the base of the geocell mattress on the overall performance of the system through a series of tests. The test results indicated that with the provision of geocell reinforcement in the overlying sand layer, a substantial performance improvement can be obtained in terms of increase in the load carrying capacity and reduction in surface heaving of the foundation bed.

This paper reports the results from laboratory model tests on square footing supported by fine to medium sand, coarse sand (size 2.36 mm to 4.75 mm) and coarse aggregate (size 4.75 mm to 6 mm) underlain by soft clay bed. It also reports the studies on fill material reinforced with coir geocell, planar geotextile or combination reinforcement. Coir geocell used in the study has an overall dimension of 60 cm x 60 cm x 20 cm and having a cell dimension of 10 cm x 10 cm x 20 cm as reported by Balan and Jency (2014).

Nomenclature	
b	Width of geocell layer
B	Width of footing
s	Settlement
h	Thickness of the overlying fill layer
u	Thickness of the cover layer
d	Pocket width of geocell
I_f	Bearing capacity improvement factor for fill material or geocell or planar geotextile

2. MATERIALS USED

Coir which is abundantly available in India, especially in Kerala was used to develop the geocell. Kaolinitic clay was used as soft soil. Fine to medium sand, coarse sand (material passing through 4.75 mm sieve and retained in 2.36 mm sieve), 6 mm aggregate (material passing through 6 mm sieve and retained in 4.75 mm sieve) were used as fill material with and without reinforcement. The properties of materials used for the study are given in Tables 1 to 3.

Table 1 : Properties of Kaolinitic clay

Description	Value
Specific gravity	2.43
Soil classification	MH
Liquid limit (%)	54.50
Plastic limit (%)	44.00
Plasticity index (%)	10.50
Percentage of clay (%)	74.50
Maximum dry density (gm/cm^3)	1.30
Optimum moisture content (%)	34.00
Coefficient of consolidation (cm^2/sec)	1.03 x 10^{-3}
Coefficient of compressibility (m^2/kN)	0.66 x 10^{-4}
Compression index	0.23

Table 2 : Properties of Medium to fine Sand

Description	Value
Specific gravity	2.61
Coefficient of uniformity (C_u)	1.80
Coefficient of curvature (C_c)	1.04
Effective particle size, D_{10} (mm)	0.28

Table 3 : Properties of coir geotextile

Description	Value
Thickness (mm)	7.77
Mass per unit area (gsm)	1267
Opening size (mm x mm)	5.38 x 2.8
Tensile strength (kN/m)	11.28

3. LABORATORY MODEL TESTS

3.1 Test Set-up

Model tests were conducted in a test bed-cum-loading frame assembly in the laboratory as shown in Figures 1 and 2. The soil bed was prepared in a test tank with inside dimensions of 1000 mm length, 1000 mm width, and 1000 mm height. A rigid steel plate having 200 mm x 200 mm size (L x B) and 20 mm thickness was used as footing. The footing was loaded with a hydraulic jack supported against the reaction frame, which was welded to the sides of the tank. The load transferred to the footing was measured using a pre-calibrated proving ring. Footing settlements were measured using two dial gauges placed on either side of the centre line of the footing.

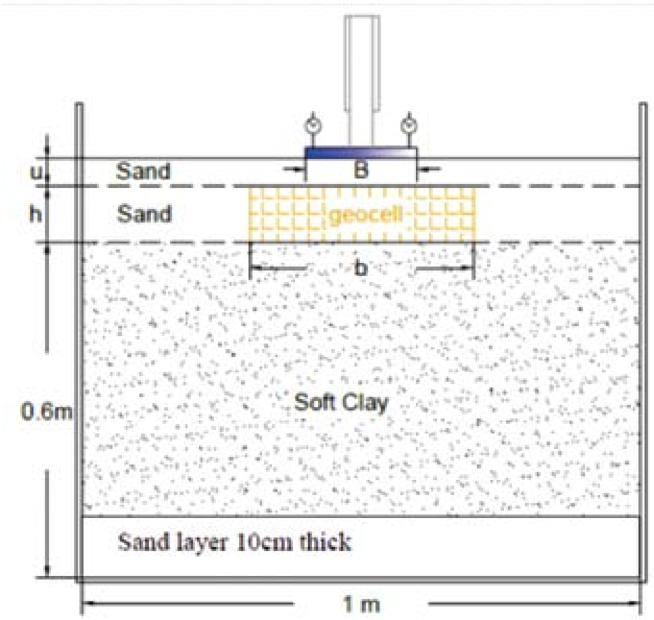

Fig. 1 : Schematic diagram of test set-up

Fig. 2 : Test set up with 6 mm aggregate fill

3.2 Preparation of Clay Beds

For the entire experiment programme the height of soft soil bed is kept constant as 600 mm. A sand layer of 100 mm thickness was formed at the bottom of the tank for allowing drainage from the clay bed above. Clayey soil was first pulverized and then mixed with water. The water content was kept near to the liquid limit so that the soil is in soft condition. Soil mixed with water was placed in the tank in layers. For each layer, the required amount of soil to produce the calculated density was found out and compacted up to the required height. By carefully controlling the water content and compaction, a fairly uniform test condition was achieved throughout the test programme. The properties of clay bed are given in Table 4.

Table 4 : Properties of clay bed

Description	Value
Moisture content (%)	50
Unit weight (kN/m^3)	16.3

3.3 Preparation of Reinforced Beds

Geocell mattress was placed on top of the compacted clay bed. To prepare the geocell mattress, woven coir geotextile was cut into strips of required length and height from full rolls, and then sides of strips were stitched. The geocells were prepared in diamond pattern by stitching the strips together. After placing the geocell mattress in the correct position, geocell's pockets were filled with fill material using sand raining technique. Hand stitched coir geocell is shown in Figure 3.

Fig. 3 : Coir Geocell

3.4 Test Procedure

The details of laboratory model tests conducted are given in Table 5. The size of planar geotextile used for the test was equal to the optimum size of geocell, i.e., 60 cm x 60 cm. In order to evaluate the effect of stiffness of coir geocell having a height of 200 mm, bamboo stiffeners of 1.125 cm width has been used vertically along the outer periphery of geocell with one bamboo stiffener for each box. A bamboo stiffener of 2.25 cm width has been used horizontally along the outer periphery of the geocell (60 cm x 60 cm).

Table 5 : Details of laboratory model tests

Test Series	Type of reinforcement	Details of test parameters	Remarks
A	Unreinforced	h+u =22 cm,using fill material (a) medium to fine sand (b) Coarse sand and (c) 6 mm aggregate	
B	Planar geotextile + Fill material	Planar geotextile 60 x 60 cm and h+u=22 cm.	Fill material (a) Medium to fine sand (b) Coarse sand and (c) 6 mm aggregate
C	Geocell mattress + Fill material	Overall size of geocell 60 x 60 x 20 cm size (pocket size 10 x 10 x 20 cm) and u=2 cm.	“
D	Planar geotextile + Geocell mattress + Fill material	b=60 cm, h=20 cm, d=10 cm, u=2 cm	“
E	Geocell mattress + 2.25 cm thick horizontal bamboo stiffener	b=60 cm, h=20 cm, d=10 cm, u=2 cm	Fill material (a) fine to medium sand
F	Geocell mattress + 1.125 cm thick vertical bamboo stiffener	b=60 cm, h=20 cm, d=10 cm, u=2 cm	Fill material (a) fine to medium sand

4. RESULTS AND DISCUSSION

The performance improvement due to the provision of different fill material (Test series A), planar reinforcement (Test series B), geocell reinforcement (Test series C) and layers of planar reinforcement with geocell (Test series D) is represented using a non-dimensional bearing capacity improvement factor (I_f). It is defined as the ratio of footing pressure (q_c) with fill material reinforced with coir geocell or planar reinforcement or combination reinforcement at a given settlement to the corresponding pressure on unreinforced soil (q_0) at the same settlement. In the case of fill material in isolation, If was taken with respect to that of clay layer. If the footing on unreinforced soil has reached its ultimate capacity at a certain settlement, the bearing pressure (q_0) is taken as the ultimate value (qu_{lt}) while calculating I_f at higher settlements.

4.1 Bearing Capacity Improvement Factor (I_f)

Bearing Capacity Improvement factor (I_f), against settlement for test series A, with respect to clay bed, is shown in Figure 4.

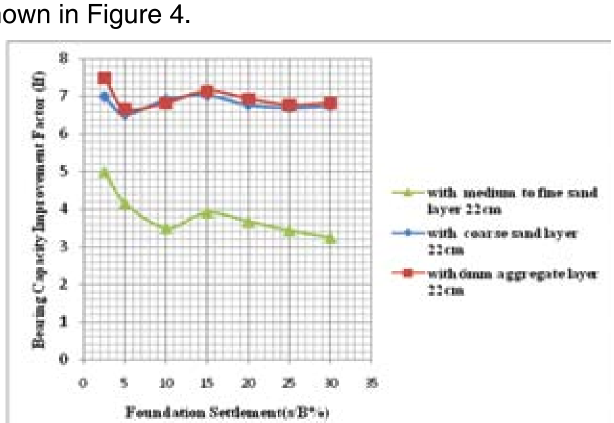

Fig. 4 : Bearing Capacity Improvement factor with respect to clay bed for Test series A

As the particle size of fill material increases, the load carrying capacity of the clay bed also increases. Provision of coarse sand or 6 mm aggregate as fill material over clay bed increases the carrying capacity of soft clay to about seven times. Fill material of fine to medium sand increases the bearing capacity by about four times that of soft clay. From the results it can be seen that increase in particle size of fill material from 4.75 mm has only marginal impact on the bearing capacity improvement. There is a decrease in trend was observed in the bearing capacity improvement factor after 15% settlement in all the cases.

Figures 5 to 7 show the bearing capacity improvement factor (I_f), for test series B (Planar geotextile at the interface of clay bed and fill material), C (fill material reinforced with geocell), and D (Combination of planar geotextile and geocell reinforced fill material) with respect to corresponding fill material of equal thickness and clay bed.

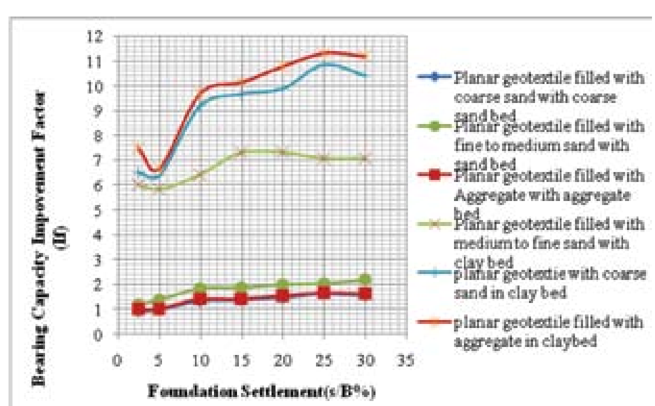

Fig. 5 : Bearing Capacity Improvement factor for Test series B

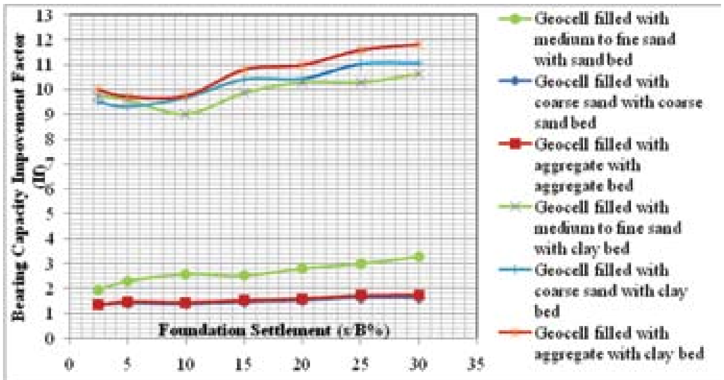

Fig. 6 : Bearing Capacity Improvement factor for Test series C

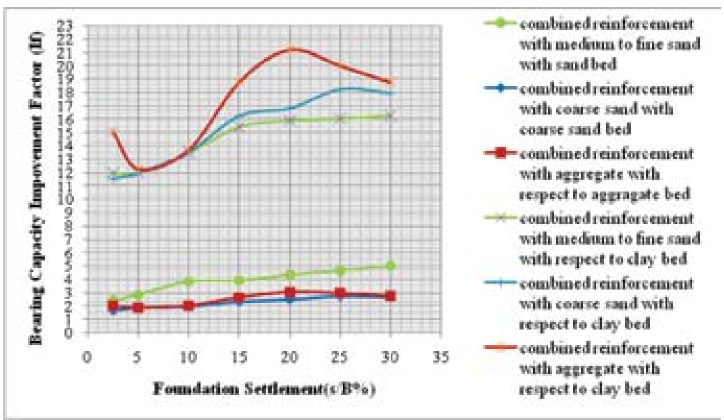

Fig. 7 : Bearing Capacity Improvement factor for Test series D

From Figures 5, 6 and 7 it can be observed that reinforcement of the fill material with planar coir geotextile at the interface of clay bed and fill material, geocell or combination of geocell with planar reinforcement improves the bearing capacity of the soft clay bed. Predominant improvement in bearing capacity is obtained in all these cases for fine to medium sand fill. The improvement in the case of coarse sand and 6 mm aggregate fill was found to be almost the same. The improvement in bearing capacity was found to increase as the reinforcement form changes from planar, geocell and combination of geocell and planar. The improvement in bearing capacity for various reinforcement, at foundation settlement of 15% of size of footing, is presented in Table 6. From Table 6, it can be observed that the influence of grain size of fill material reinforced with coir geocell on bearing capacity improvement is marginal. Whereas for combination reinforcement of planar and geocell, aggregate of 6 mm fill has a marked improvement with coarse sand fill.

Table 6 : Bearing Capacity Improvement Factor for different types of reinforcement

Description of Reinforcement	Bearing Capacity Improvement Factor with respect to					
	Clay Bed			Unreinforced fill material		
	Fine to medium sand	Coarse sand	Aggregate 6 mm	Fine to medium sand	Coarse sand	Aggregate 6 mm
For Fill Materials	4	7	7	--	--	--
For Planar Geotextile	7.30	9.60	10.10	1.85	1.37	1.44
For Geocell	9.80	10.40	10.80	2.50	1.48	1.54
% Improvement for Geocell compared to planar				35	7	7
Geocell + Planar	15.40	16.20	18.80	3.90	2.30	2.65
% Improvement for Combination compared to planar				110	66	85
% Improvement for Combination compared to geocell				56	57	73

Figure 8 shows the bearing capacity improvement factor for test series E and F, i.e., when the geocell is stiffened at its outer periphery with bamboo reapers horizontally and vertically. From the figure it can be observed that provision of stiffeners to coir geocell of 20 cm height, will decrease the bearing capacity factor by about 31% with that of geocell without stiffeners at 15% of foundation settlement. At higher settlement, the bearing capacity improvement becomes almost same or may be higher than that of geocell without stiffeners. At low settlement level, the stiffeners will not allow the geocell to expand and distribute the load evenly as in the case of geocell without stiffeners.

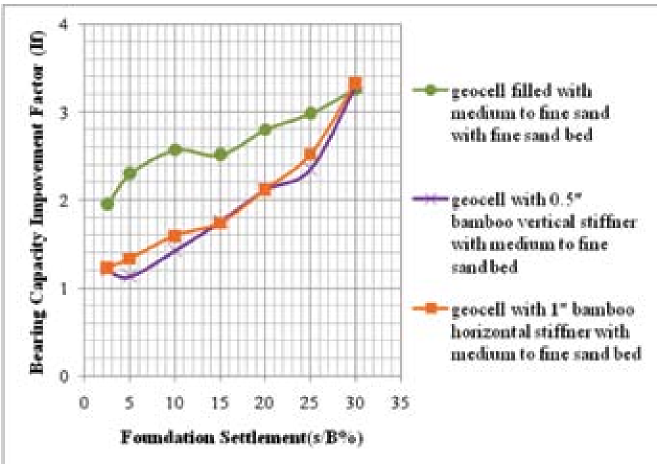

Fig. 8 : Bearing Capacity Improvement factor for Test series E and F

4.2 Settlement and Heave at Surface of Clay bed

The settlement or heave at the surface of clay bed has been measured after each test series, and are depicted in Figures 9 to 14. Average of the results on either side is taken to examine the settlement of heave behaviour.

For different fill material, the settlement and heave is observed to be almost the same (Figure 9). Settlement occurs up to a distance of 1.5 times and heave at 2 times the size of footing, from the center of footing.

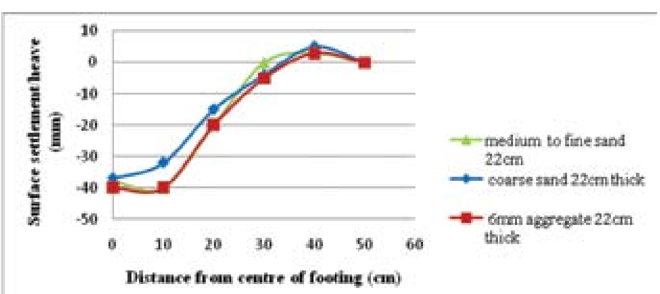

Fig. 9 : Heaving or settlement of clay surface for test series A

Figure 10 shows the settlement and heave behaviour when the fill material is reinforced with planar geotextiles. It can be observed that settlement at centre of the footing is reduced by about 17.5% with respect to that of the fill material. Heave occurred at the edges of the planar reinforcement, i.e., 30 cm from the centre of footing. Heave was found to be double that due to the fill material. Settlement and heave were low for fine to medium sand fill compared to coarse fill material.

When reinforced with geocell, the settlement at the entre of footing was reduced by about 12.5% and 25% for coarse sand and aggregate of 6 mm size respectively with respect to fill material (Figure 11). Heaving occurred at the edges of geocell reinforcement (30 cm), for aggregate of 6 mm and at about 40 cm for coarse sand. As in the case of planar reinforcement, the settlement and heave was the lowest for fine to medium sand fill.

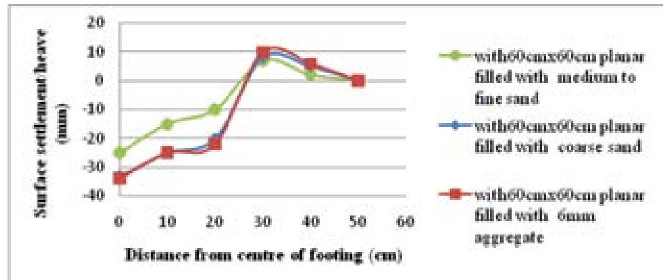

Fig. 10 : Heaving or settlement of clay surface for test series B

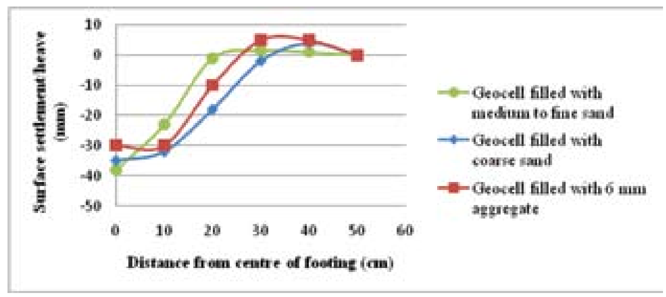

Fig. 11 : Heaving or settlement of clay surface for test series C

For combination of planar reinforcement with geocell, settlement has been reduced by 40%, 58% and 43% respectively for fill material of aggregate of 6 mm, coarse sand, and fine to medium sand (Figure 12). No appreciable heaving was observed in this case.

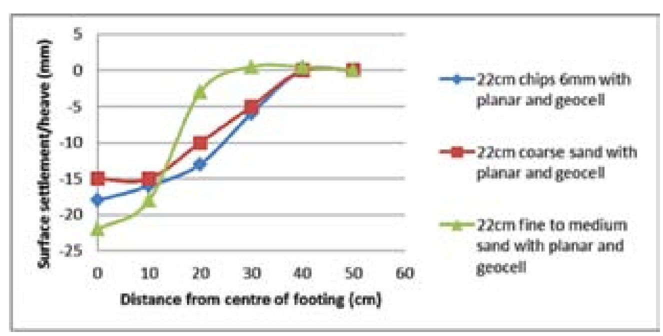

Fig 12 : Heaving or settlement of clay surface for test series D

To increase the stiffness of geocell, bamboo strips were used in horizontal and vertical direction at the outer layer. Settlement was found to be higher when stiffeners are used in both the direction as seen from Figures 13 and 14. There was no heaving of the clay bed in both the cases. Use of stiffeners reduces the heaving in clay bed but increases the settlement, as the stiffeners are preventing the outer layer of geocell to move freely outwards to distribute the load.

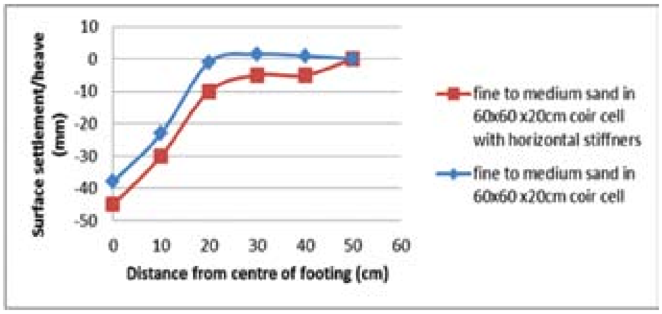

Fig. 13 : Heaving or settlement of clay surface for test series E

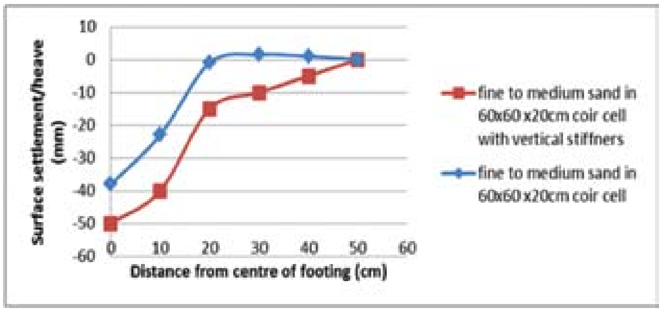

Fig. 14 : Heaving or settlement of clay surface for test series F

5. CONCLUSIONS

Based on the model load test studies conducted on square footing supported on various fill materials with and without reinforcement like planar geotextile, geocell or combination of geocell with planar, overlying soft clay beds, the following conclusions are made.

1. Bearing capacity of clay bed can be increased with fill material. The grain size of the fill material influences the rate of improvement. Fill materials having a grain size of more than 4.75 mm does not have much influence in bearing pressure. Irrespective of the grain size of fill material, heaving of the clay bed occurs at about 2 times the width of footing, from the centre of footing.
2. Reinforcing the fill materials with planar coir geotextile, coir geocell or combination, the bearing capacity of the underlying soft clay bed increases. The improvement is predominant in fine to medium sand fill.
3. Settlement and heave of the clay bed are influenced by the type of inclusion made in the fill material. In all the cases of reinforcement, settlement will decrease. Heave occurs at the edges of planar or geocell reinforcement. In combination reinforcement, settlement get reduced by half of that of unreinforced fill and negligibly very low heave occurs.
4. The provision of horizontal or vertical bamboo stiffeners in the outer layer of geocell will not increase the load carrying capacity of the footing. However, stiffeners increase the settlement and prevent heaving of clay surface under loading.

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YOUNG IGS MEMBER ACHIEVEMENT AWARD - 2014

KUO-HSIN YANG

This Young IGS Member Achievement Award was given to Kuo-Hsin Yang, Associate Professor in the Department of Civil and Construction Engineering at National Taiwan University of Science and Technology (Taiwan), for his research work on GRS structures and his contribution to education and promotion on geosynthetics in Taiwan.

RESEARCH

Dr. Yang has conducted researches and projects on the analysis, design and case study of GRS structures using both numerical (limit equilibrium and finite element) and physical (centrifuge and field monitoring) modeling. The aim is to provide better understanding of the performance of GRS structures with complex geometrics (narrow or multi-tier wall) or under natural disaster conditions (heavy rainfall or seismic loadings). This section summarizes the results of his research work, published in Mohamed et al. (2014, 2013) and Liu et al. (2012), focused on investigat-ing the performance and failure mechanism of multi-tier walls with various offset distances.

GRS walls in a tiered configuration are acceptable alternatives to conventional retaining wall systems because of several benefits such as cost, stability and construction constraints, and aesthetics. In addition, drainage swales or ditches can be installed along the toe of each tier to minimize the surficial flow induced erosion and water infiltration induced instability. A tiered wall is a transitional structure between a single wall and slope (Fig. 1) that can reduce construction costs and increase system stability compared with a single wall. Because of its configuration, the tiers interact and mutually affect each other. The upper and lower tiers interact through the equivalent surcharge from the upper tier acting on the lower tier, and the vertical and lateral deformation of the lower tier influencing the behavior of the upper tier. Consequently, this interaction can cause additional wall deformation and reinforcement loads in both the upper and lower tiers.

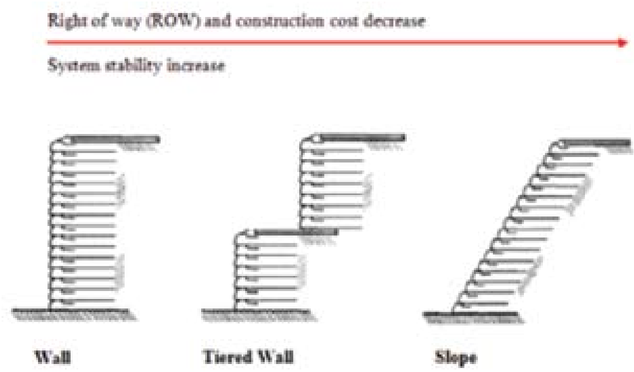

Fig. 1 : GRS structures with various configurations.

Current design methods for analyzing GRS multitier walls are based on the lateral earth pressure method, an extension of the design method for analyzing single tier reinforced walls. The design approaches in these guidelines are considered empirical and are geometrically derived based on the relative distance or offset distance, D, between upper and lower tiers. These guidelines do not fully address the interactive mechanism between two tiers: only consider the additional vertical stresses from the overlying wall tiers acting on the lower tiers but do not account for the influence of the lower tier on the upper tier.

The author conducted a series of numerical analyses of GRS two-tier walls with various offset distances. The objectives were fourfold: (1) to evaluate the applica-bility of LE and FE methods for analyzing GRS two-tier walls; (2) to investigate the performance and failure mechanism of GRS two-tier walls with various offset distance; (3) to investigate the interactive mechanism between two tiers; (4) to examine the design methods for multitier walls in current design guide-lines. The FE simulations were first verified according to the centrifuge test (Fig. 2). The FE results were then used to investigate the influence of offset distance on

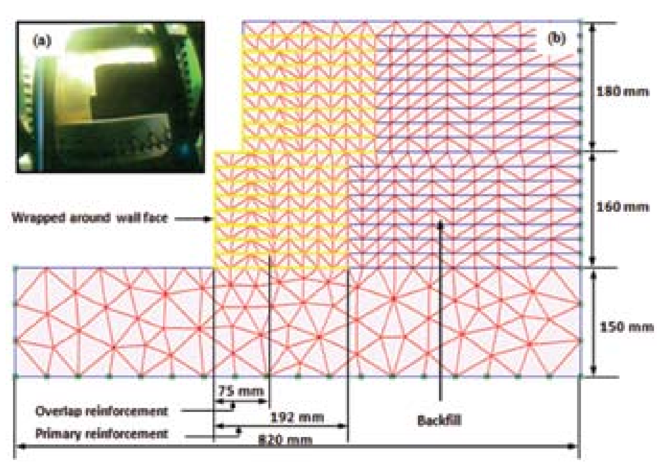

Fig. 2 : GRS two-tier wall model: (a) centrifuge at initial condition; (b) finite element setup and initial mesh

additional vertical stress from the upper tier wall, mobilization and distribution of reinforcement tensile loads, and horizontal deformation at the wall faces.

The study results demonstrated favourable agreement between FE, LE and the centrifuge model in locating the failure surface (Fig. 3). For compound wall case, the maximum tension lines in FHWA design guidelines depict failure surfaces at a long distance from the wall face, particularly for the upper part of the upper tier.

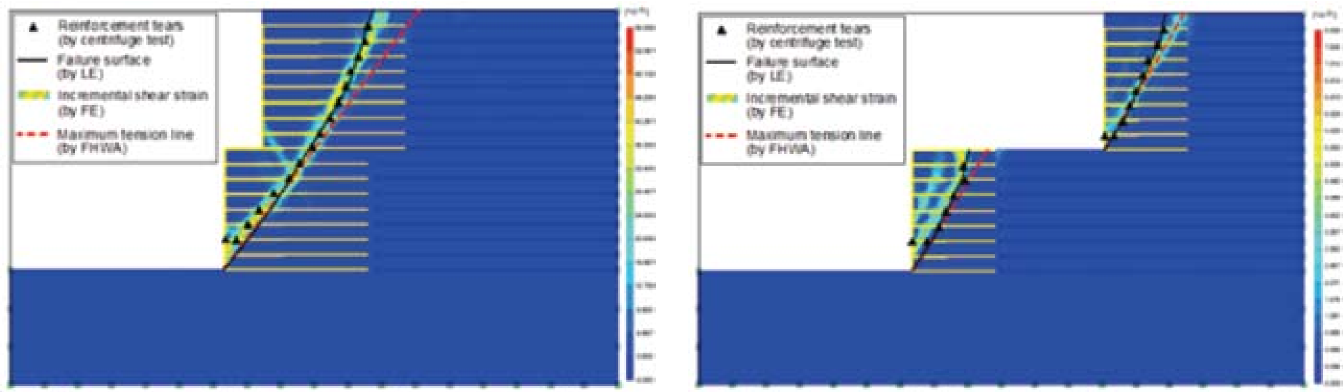

Fig. 3 : Predicted and measured locations of failure surfaces from two-tier wall model: (left) compound wall; (right) independent wall

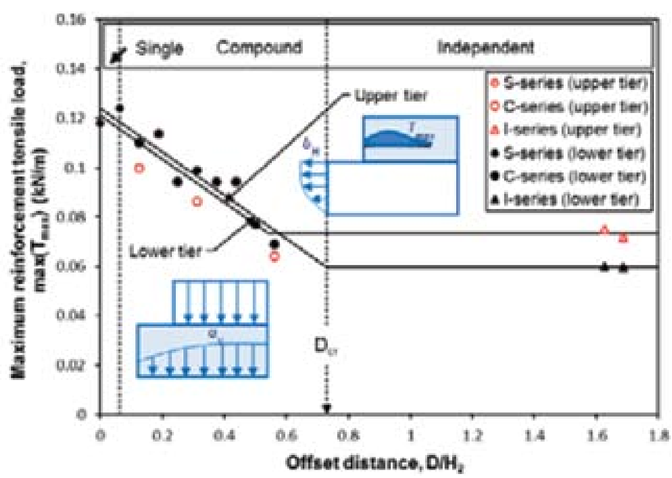

Fig. 4 : Effect of offset distance on maximum reinforcement tensile load

The FE results indicated that as the offset distance increased, the reinforcement tensile load and wall deformation decreased in both the upper and lower tiers, suggesting that the two tiers mutually affect each other and the interaction attenuates as the offset distance increased. The maximum tensile loads of all reinforcement layers at the wall failure predicted using FE analysis and LE method assuming uniform distribution of reinforced tensile loads were comparable. The critical offset distance D_{cr} shown in Fig. 4 is the offset distance beyond which two tiers act independently. In Fig.4, $D_{cr} = 0.73H_2$ (where H_2 is the height of the lower tier wall) was identified when the decreased $max(T_{max})$ value with increased D reached a constant value. The D_{cr} value recommended by the FHWA is approximately 1.5 times greater than those determined using FE in this study. Consequently, using the Dcr value provided in the current design guidelines would likely result in a conservative design because of predicting a longer offset distance for two tiers to become independent.

EDUCATION

Dr. Yang regularly teaches “Design of reinforced earth retaining structures” in the graduate course and delivers a three-hour lecture for the subject of “Introduction and application of geosynthetics” in the “Soil mechanics II” course for undergraduate students. The aim is to increase geosynthetic education at both graduate and undergraduate levels in the civil engineering program in Taiwan. He also organized a small-scale paper MSE wall competition for students to let students get hands-on experience on design and build for reinforced soil structures in a fun way. Students are learning by doing and gain much confidence in their design (Fig. 5).

Fig. 5 : Small-scale paper MSE wall competition: (left to right) discuss on students' design; place 25kg surcharge; success after placing large loading (three people stand on the top of the paper MSE wall).

ACKNOWLEDGEMENTS

Centrifuge modeling tests was conducted by Dr. W-Y Hung at the National Central University, Taiwan. The finan-cial support for Dr. S. Mohamed during his Ph.D. study was provided by the Taiwan Ministry of Education under the grant for "Aim for the Top-Tier University Project". The author also thanks Dr. C-N Liu, professor at the National Chi-Nan University, for the research collaboration and valuable comments.

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BEHAVIOUR OF GEOSYNTHETICS AND GEOSYNTHETIC-REINFORCED SOIL RETAINING WALLS THROUGH MODEL TESTING AND ADVANCED NUMERICAL ANALYSIS

Hoe I. Ling, Columbia University, New York, NY, USA

INTRODUCTION

Geosynthetic-reinforced soil retaining walls (GRS-RWs) have been developing very rapidly in the past few decades, where they are used in transportation infrastructure construction. They gradually gained acceptance as per-manent structures in railways and highways, as well as in the private sector. It was a natural progression for engi-neers to later start construct them in the earthquake-prone regions.

Japan has developed GRS-RWs with a rigid facing, while modular-block facing walls are rather popular in North America. In the 1995 Kobe earthquake, various kinds of retaining walls systems were subjected to strong earthquake shaking (and several more earthquakes in subsequent years). In North America, the popular modular-block facing reinforced soil retaining walls were subjected to minor shaking during the 1994 Northridge earthquake. We gained much confidence in the earthquake performance of GRS-RWs, but were troubled by their lack of good performance during the 1999 Chi-chi earthquake in Taiwan[1].

In this short article, I would like to summarize some of our research projects related to the earthquake response of GRS-RWs. Verbal descriptions are given, and relevant publications are listed for interested readers to refer to.

SIMPLISTIC APPROACH

In 1994, Dov Leshchinsky and I started working on implementing a rigid-plastic stick-slip procedure to determine permanent displacement of GRS-RWs[2,3]. By examining the different failure modes under earthquake (pseudo-static) loading, we found that the direct sliding mode of failure may become predominant under strong shaking. Comparisons of sliding displacement were made for several case histories as reported in literature. Subsequently, the study was extended to include vertical components of accelerations[4]. We noticed the effects of vertical acceleration, which increases the required reinforcement length and force when acting downward, but led to a reduced sliding stability when acting upward. A comparison was made to the sliding out for Tanata Wall during Kobe earthquake.

SEISMIC RESPONSE AND ADVANCED NUMERICAL ANALYSIS

From the displacement obtained in a rigid-plastic analysis, we tried to move a step further by analyzing the cyclic response of GRS-RWs. While the finite element procedures have been established for the dynamic response of structures, we certainly need to have a reasonable soil model for simulating the cyclic behavior of soils and geo-synthetics. The constitutive models for granular materials were formulated using generalized plasticity[5]. Constitutive modeling of sand itself is an independent subject of research and the challenging part is the pressure and density dependency of sand behaviour, as well as the effects of cyclic loading – densification behavior for dry soils (likewise, liquefaction for saturated loose sand). Cyclic tensile loading tests were conducted for several types of geosynthetics[6] and their cyclic behavior was formulated using bounding surface plasticity[7]. In the modeling of cyclic behaviour of geosynthetics, we tried to accommodate the nonlinear S-shape loading curve of some geosynthetic materials due to their manufacturing process. The constitutive models of sand and geosynthetics have been implemented into a special purpose geotechnical finite element program and the procedures were validated extensively with laboratory test results. We were able to validate the analysis with a series of shaking table tests conducted in a centrifuge at the Tokyo Institute of Technology[8]. Note that the wall facing used in the centrifuge was not made of modular blocks. Parametric studies have also been conducted to investigate the effects of soil properties, reinforcement layouts, earthquake motions, etc., on the wall response[9].

LARGE SCALE SHAKING TABLE TESTS AS “BENCHMARKS”

The physical models, especially reduced scale models, have been a traditional method of geotechnical testing in the laboratory. In order to overcome the scale effects, either enhanced gravity testing or field testing is conducted. In the enhanced gravity models such as centrifuge, simulation of prototype behavior of geosynthetics, blocks and soil-structure interaction is not fully possible. Field testing, on the other hand, does not allow for a full control of testing conditions and characterization of material properties. Thus, large scale testing is considered a good alternative to centrifuge model testing and field testing. That is, no scale reduction is needed yet the cost can still be affordable. Large scale testing is possible only at several limited facilities world wide where the shaking table is of acceptable size, which allows for actual shaking motions. We collaborated with Dr. Yoshiyuki Mohri (currently a Professor at Ibaraki University) of the National Institute of Agricultural Engineering, Japan. The shaking table is of dimensions 6 m×4 m, having a payload of up to 500 kN, and maximum three-dimensional accelerations of 1g in each direction. A rigid steel box was fabricated that accommodated a wall of height 2.8 resting on a foundation of 0.2 m. Several series of studies were conducted on geosynthetic-reinforced soil retaining walls having modular-block facing using actual horizontal and vertical components of Kobe earthquake records. The details of the walls are summarized in the table below:

Wall #		1	2	3	4	5	6	7
Backfill		Sand				Clayey Sand		
Earthquake Motions (Kobe JMA)	Vertical Acceleration	no		yes				
	Times of Shaking	2 (half, full intensities)			4 (half, full, full, full)			
Reinforcements	Major Layers (polyester, 35 kN/m)	2.05 m		1.68 m Double-layer reinf in Wall 4		1.68 m Lip removed for fac-ing blocks in Wall 7		
	Top layer (polyvinyl alcohol, 20 kN/m)	2.05 m		2.52 m		2.52 m		1.68 m
	Vertical Spacing	0.6	0.4			0.4	0.8	

The first phase of study was using sandy soil as backfill[10], whereas clayey soil was used in the second phase of study[11]. The walls were heavily instrumented with over 100 channels: strains in geogrid layers, facing lateral displacements, backfill settlements, and earth pressures acting at the facing blocks and bottom of backfill. The tests with multiple shakings, with intensity as large as that of the Kobe earthquake, confirmed the earthquake performance of the wall system. The heavily instrumented walls also acted as the benchmarks for validation of numerical procedures. Note that in addition to modular-block facing walls, a total of 5 walls having geocell facing have also been tested in a separate study[12].

As a more economical means of studying the behavior of GRS-RWs, the previously validated numerical procedure is required. This has been achieved by comparing the analyzed results with the full-scale walls. The aim was to achieve a satisfactory agreement of the response (both in space and time) not only qualitatively, but also quantitatively[13]. The generalized plasticity model has then been unified against sand of different densities[14]. Up to this stage, we have studied numerically the response of walls having sandy soil as backfill. The benchmarks have been used by other groups of researchers in validating their numerical procedures, as discussed in[15].

SUMMARY

A number of GRS-RW projects have been accomplished in North America using the same modular blocks and geosynthetics as described in the large-scale testing. Recently, the same wall system has been used for highway intersection project in Sofia, Bulgaria, considering high seismic load with a height of over 12 m, for a total distance of more than 2.1 km. The wall, before completion of construction, was subjected to the Pernik earthquake (M= 5.6) in 2012. A satisfactory performance was confirmed[16].

The study on the earthquake response of GRS-RWs has become multi-disciplinary, which requires knowledge beyond traditional geotechnical engineering. It is learned that well documented studies are needed in advancing our state-of-art and state-of-practice.

Acknowledgements

The studies as described have been sponsored by a number of agencies and industries, including US National Science Foundation, Japan National Research Institute of Agricultural Engineering, Allan Block, and Huesker Syn-thetic GmbH. The assistance provided by the collaborators and former students, as well as the recognition by the IGS Award Committee, is especially appreciated.

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INTERNATIONAL GEOSYNTHETICS SOCIETY

The International Geosynthetics Society (IGS) was founded in Paris, on 10 November 1983, by a group of geotechnical engineers and textile specialists. The Society brings together individual and corporate members from all parts of the world, who are involved in the design, manufacture, sale, use or testing of geotextiles, geomembranes, related products and associated technologies, or who teach or conduct research about such products.

The IGS is dedicated to the scientific and engineering development of geotextiles, geomembranes, related products and associated technologies. IGS has 43 chapters, over 3,000 individual members and 161 corporate members.

The aims of the IGS are:

- to collect and disseminate knowledge on all matters relevant to geotextiles, geomembranes and related products, e.g. by promoting seminars, conferences, etc.
- to promote advancement of the state of the art of geotextiles, geomembranes and related products and of their applications, e.g. by encouraging, through its members, the harmonization of test methods, equipment and criteria.
- to improve communication and understanding regarding such products, e.g. between designers, manufacturers and users and especially between the textile and civil engineering communities

The IGS is registered in the USA as a non-profit organization. It is managed by five Officers and a Council made up of 10 to 16 elected members and a maximum of 5 additional co-opted members. These Officers and Council members are responsible to the General Assembly of members which elects them and decides on the main orientations of the Society.

IGS CHAPTERS

The IGS Chapters are the premier vehicle through which the IGS reaches out to and influences the marketplace and the industry. Chapter activities range from the organization of major conferences and exhibits such as the 10th International Conference on Geosynthetics in September 2014 in Berlin, Germany and its predecessors in Guaruja, Yokohama, Nice and Atlanta to the presentation of focused seminars at universities, government offices and companies. Chapters create the opportunity for the chapter (and IGS) membership to reach out, to teach and to communicate and they are the catalyst for many advances in geosynthetics. Participation in an IGS chapter brings researchers, contractors, engineers and designers together in an environment which directly grows the practice by informing and influencing those who are not familiar with our discipline.

MEMBERSHIP

Membership of IGS is primarily organised through national Chapters. Most individual members (94%) belong to the IGS through Chapters. Chapter participation allows members to be informed about, and participate in, local and regional activities in addition to providing access to the resources of the IGS.

IGS Offers the following categories of membership:

Individual

Individual member benefits are extended to each and every individual member of the IGS including Chapter Members. Additional chapter benefits are provided to Individual Members who join the IGS through a chapter.

Individual Member Benefits include:

- a membership card
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- the IGS News newsletter, published three times a year
- on-line access to the 19 IGS Mini Lecture Series for the use of the membership
- information on test methods and standards
- discount rates:
  - for any document published in the future by IGS
  - at all international, regional or national conferences organized by the IGS or under its auspices

- preferential treatment at conferences organized by the IGS or under its auspices
- possibility of being granted an IGS award
- Free access to the *Geosynthetics International* journal, now published electronically.
- Free access to the *Geotextiles and Geomembranes* journal, now published electronically.

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- a membership card
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- **IGS Corporate Membership Plaque**
- **Company Profile in the IGS News**
- **right of using the IGS logo at exhibitions and in promotional literature**
- **priority (by seniority of membership within the IGS) at all exhibits organized by the IGS or under its "auspices"**
- **opportunity to join IGS committees in order to discuss topics of common interest.**

Student

Student Membership Benefits include:

- Electronic access to the IGS News, published 3 times a year
- Special Student discounts at all IGS sponsored/supported conferences, seminars etc.
- Listing in a special student members category in the IGS Directory
- Eligibility for awards (and in particular the IGS Young Member Award).

INDIAN CHAPTER OF IGS

In the year 1985, Central Board of Irrigation and Power, (CBIP) as part of its technology forecasting activities identified geosynthetics as an important area relevant to India's need for infrastructure development, including roads. After approval of IGS Council for the formation of Indian Chapter in October 1988, the Indian Chapter of IGS was got registered under Societies Registration Act 1860 of India in June 1992 as the Committee for International Geotextile Society (India), with its Secretariat at Central Board of Irrigation and Power. The Chapter has since been renamed as International Geosynthetics Society (India), in view of the parent body having changed its name from International Geotextiles Society to International Geosynthetics Society.

The activities of the Society are governed by General Body and Executive Board.

Executive Board of Indian Chapter of IGS

The Executive Board of the IGS (India) consists of President, elected by the General Body, two Vice-Presidents, with one elected by the General Body, and second Vice President being Vice President (WR) of the CBIP as Ex-Officio Vice President and 16 members. The Secretary and Director (WR) of the CBIP are the as the Ex-Officio Member Secretary and Treasurer, respectively, of the Society.

The present Executive Board is as under :

President

- Dr. G.V.S. Suryanarayana Raju, Engineer-in-Chief, Roads & Buildings Department, Government of Andhra Pradesh

Vice-President

- Mr. M. Venkataraman, Geotechnical and Geosynthetic Consultant

Immediate Past President

- Dr. K. Rajagopal, Professor, Department of Civil Engineering, IIT Madras

Hon. Member

- Dr. G.V. Rao, Chairman, SAGES

Members

- Mr. C.D. Athul Raj, Business Development Manager, Charankattu Coir Mfg. Co. (P) Ltd.
- Mr. Shahrokh Bagli, Chief Technical Officer, Strata Geosystems (India) Pvt. Ltd.
- Dr. K. Balan, Professor, Department of Civil Engineering, Rajdhani Institute of Engineering and Technology, Trivandrum (Kerala)
- Dr. R. Chitra, Scientist E, Central Soil & Materials Research Station
- Ms. Minimol Korulla, Vice President, Maccaferri Environmental Solutions Pvt. Ltd.
- Mr. T. Kulkarni, Vice President-Marketing, Sales & Designs, Garware-Wall Ropes Ltd.
- Dr. Jimmy Thomas, Consultant (Geosynthetics), Kochi (Kerala)
- Mr. Saurabh D. Vyas, Head-Technical Services, Techfab (India) Industries Ltd.

Member Secretary

- Mr. V.K. Kanjlia, Secretary, Central Board of Irrigation & Power

Treasurer

- Mr. A.C. Gupta, Director (WR), Central Board of Irrigation & Power

Past Presidents

The presidents of the society in the past were :

Dr. R.K. Katti, Director, UNEECS Pvt. Ltd. and Former Professor, IIT Bombay; Mr. H.V. Eswaraiah, Technical Director, Karnataka, Power Corporation Ltd.; Dr. G.V. Rao, Professor, Department of Civil Engineering, IIT Delhi; and Dr. D.G. Kadade, Chief Advisor, Jaiprakash Industries Ltd.;

Indian Representation on IGS Council

- Dr. K. Rajagopal, Professor, Department of Civil Engineering, IIT Madras
- Dr. G.V. Rao, former Professor, Department of Civil Engineering, IIT Delhi

Indian Representation on IGS Committees

IGS has following open Technical Committees:

- Technical Committee on Barrier Systems
- Technical Committee on Filtration
- Technical Committee on Soil Reinforcement

Dr. G.V.S. Suryanarayana Raju, Engineer-in-Chief, Andhra Pradesh Roads & Buildings Department. Dr. K. Rajagopal, Civil Engineering Department, IIT Madras and Mr. Satish Naik, CEO, Best Geotechnics Pvt. Ltd., and Dr. (Ms.) Gali Madhavi Latha, Associate Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore are the Indian representatives on TC on Soil Reinforcement.

Mr. M. Venkataraman and Mr. Rohit Chaturvedi, Techfab (India) Industries Ltd. are representatives from India on TC on Filtration.

Dr. G.V. Rao, Former Professor, Department of Civil Engineering, IIT Delhi and Dr. Dali Naidu Amepalli, Assistant Professor, Department of Civil Engineering, IIT Madras are representating India on TC on Barrier Systems.

IGS Student Award Winners from India

The IGS has established Student Paper Award to disseminate knowledge and to improve communication and understanding of geotextiles, geomembranes and associated technologies among young geotechnical and geoenvironmental student engineers around the world. The IGS student award consists of US$1,000 to be used to cover travel expenses of each winner to attend a regional conference.

Dr. J.P. Sampath Kumar, National Institute of Fashion Technology, Hyderabad (Andhra Pradesh) (1999-2000), Dr. K. Ramu, JNTU College of Engineering, Kakinada (Andhra Pradesh) (2001-02), Mrs. S. Jayalekshmi, National Institute of Technology, Tiruchirappalli (2003-04), Dr. Mahuya Ghosh, IIT Delhi (2007-08) and Dr. S. Rajesh, IIT Kanpur (2011-12) have been honoured with IGS Student Paper Award.

Publications/Proceedings on Geosynthetics

In addition to the proceedings of the events on Geosynthetics, following publications have been brought out since 1985:

1. Workshop on Geomembranes and Geofabrics (1985)
2. International Workshop on Geotextile (1989)
3. Use of Geosynthetics – Indian Experiences and Potential – A State of Art Report (1989)
4. Use of Geotextile in Water Resources Projects - Case Studies (1992)
5. Role of Geosynthetics in Water Resources Projects (1993)
6. Monograph on Particulate Approach to Analysis of Stone Columns with & without Geosynthetics Encasing (1993)
7. 2nd International Workshop on Geotextiles (1994)
8. Directory of Geotextiles in India (1994)
9. An Introduction to Geotextiles and Related Products in Civil Engineering Applications (1994)
10. Proceedings of Workshops on Engineering with Geosynthetics (1995)
11. Ground Improvement with Geosynthetics (1995)
12. Geosynthetics in Dam Engineering (1995)
13. Erosion Control with Geosynthetics (1995)
14. Proceedings of International Seminar & Techno Meet on "Environmental Geotechnology and Geosynthetics" (1996)
15. Proceedings of First Asian Regional Conference "Geosynthetics Asia'1997"
16. Directory of Geosynthetics in India (1997)
17. Bibliography – The Indian Contribution to Geosynthetics (1997)
18. Waste Containment with Geosynthetics (1998)
19. Geosynthetic Applications in Civil Engineering- A Short Course (1999)
20. Case Histories of Geosynthetics in Infrastructure Projects (2003)
21. Geosynthetics – Recent Developments (Commemorative Volume) (2006)
22. Geosynthetics in India – Present and Future (2006)
23. Applications of Geosynthetics – Present and Future (2007)
24. Directory of Geosynthetics in India (2008)
25. Geosynthetics India'08
26. Geosynthetics India' 2011
27. Geosynthetic Reinforced Soil Structures - Design & Construction (2012)
28. Applications of Geosynthetics in Infrastructure Projects (2013)
29. Applications of Geosynthetics in Railway Track Structures (2013)
30. Silver Jubilee Celebration (2013)
31. Directory of Geosynthetics in India (2013)
32. Applications of Geosynthetics in Infrastructure Projects (2014)
33. Geosynthetics India 2014
34. Three Decades of Geosynthetics in India – A Commemorative Volume (2015)

Indian Journal of Geosynthetics and Ground Improvement

The Indian Chapter of IGS has taken the initiative to publish Indian Journal of Geosynthetics and Ground Improvement (IJGGI), on half yearly basis (January – June and July-December), since January 2012.

The aim of the journal is to provide latest information in regard to developments taking place in the relevant field of geosynthetics so as to improve communication and understanding regarding such products, among the designers, manufacturers and users and especially between the textile and civil engineering communities.

The Journal has both print and online versions.

Events Organised/Supported

1. Workshop on Geomembrane and Geofabrics, September 1985, New Delhi
2. Workshop on Reinforced Soil, August 1986
3. International Workshops on Geotextiles, November 1989, Bangalore
4. National Workshop on Role of Geosynthetics in Water Resources Projects, January 1992, New Delhi
5. Workshop on Geotextile Application in Civil Engineering, January 1993, Chandigarh
6. International Short Course on Soil Reinforcement, March 1993, New Delhi
7. Short Course on Recent Developments in the Design of Embankments on Soft Soils, Nov./Dec. 1993, New Delhi
8. 2nd International Workshop on Geotextiles, January 1994, New Delhi
9. Short Course on Recent Developments in the Design of Embankments on Soft Soils, January 1994, Kolkata
10. Workshop on Role of Geosynthetics in Hill Area Development, November 1994, Guwahati
11. Workshop on Engineering with Geosynthetics, December 1994, Hyderabad
12. Short Course on Recent Developments in the Design of Embankments on Soft Soils, May 1995, New Delhi
13. Seminar on Geosynthetic Materials and Their Application, August 1995, New Delhi
14. Short Course on Recent Developments in the Design of Embankments on Soft Soils, October 1995, New Delhi
15. Short Course on "Ground Improvement with Geosynthetics", October 1995, New Delhi
16. Workshop on "Environmental Geotechnology", December 1995, New Delhi
17. Workshop on "Role of Geosynthetics in Hill Area Development", February 1996, Gangtok (Sikkim)
18. Workshop on "Engineering with Geosynthetics", March 1996, Visakhapatnam (Andhra Pradesh)
19. Workshop on "Ground Improvement with Geosynthetics", March 1996, Kakinada (Andhra Pradesh)
20. Workshop on "Engineering with Geosynthetics", May 1996, Chandigarh
21. International Seminar and Technomeet on "Environmental Geotechnology with Geosynthetics", July 1996, New Delhi
22. Seminar on "Fields of Application of Gabion Structures", September 1997, New Delhi
23. First Asian Regional Conference "Geosynthetics Asia'1997", November 1997, Bangalore (Karnataka)
24. Short Course on "Waste Containment with Geosynthetics", February 1998, New Delhi
25. Symposium on "Rehabilitation of Dams", November 1998, New Delhi
26. Training Course on "Geosynthetics and Their Civil Engineering Applications", September 1999, Mumbai
27. Seminar on "Coir Geotextiles-Environmental Perspectives", November 2000, New Delhi
28. Second National Seminar on "Coir Geotextiles – Environmental Perspectives", April 2001, Guwahati, Assam
29. National Seminar on "Application of Jute Geotextiles in Civil Engineering", May 2001, New Delhi
30. International Course on "Geosynthetics in Civil Engineering", September 2001, Kathmandu, Nepal
31. Workshop on "Applications of Geosynthetics in Infrastructure Projects", November 2003, New Delhi
32. Geosynthetics India 2004 – A Seminar Workshop on "Geotechnical Engineering Practice with Geosynthetics", October 2004, New Delhi
33. Introductory Course on Geosynthetics, November 2006, New Delhi
34. International Seminar on "Geosynthetics in India – Present and Future" (in Commemoration of Two Decades of Geosynthetics in India), November 2006, New Delhi
35. Workshop on "Retaining Structures with Geosynthetics", December 2006, Chennai (Tamil Nadu)
36. Special Session on "Applications of Geosynthetics" during 6th International R&D Conference, February 2007, Lucknow (U.P.)
37. Workshop on "Applications of Geosynthetics – Present and Future", September 2007, Ahmedabad (Gujarat)
38. International Seminar "Geosynthetics India'08" and Introductory Course on "Geosynthetics", November 2008, Hyderabad
39. Special Session on "Applications of Geosynthetics" during 7th International R&D Conference, February 2009, Bhubaneswar (Orissa)
40. Seminar on "Applications of Geosynthetics", July 2010, New Delhi
41. International Seminar on "Applications of Geosynthetics", November 2010, New Delhi
42. Geosynthetics India' 2011, September 2011, IIT Madras
43. Seminar on "Slope Stabilization Challenges in Infrastructure Projects", October 2011, New Delhi

44. GEOINFRA 2012 – A Convergence of Stakeholders of Geosynthetics, August 2012, Hyderabad
45. Seminar on “Ground Control and Improvement”, September 2012, New Delhi
46. Workshop on “Geosynthetic Reinforced Soil Structures - Design & Construction”, October 2012, New Delhi
47. Seminar on “Landfill Design with Geomembrane”, November 2012, New Delhi
48. Seminar on “Slope Stabilization Challenges in Infrastructure Projects”, November 2012, New Delhi
49. Seminar on “Applications of Geosynthetics in Infrastructure Projects”, June 2013, Bhopal (Madhya Pradesh)
50. Seminar on “Applications of Geosynthetics in Railway Track Structures”, September 2013, New Delhi
51. Silver Jubilee Celebration, October 2013, New Delhi
52. Seminar on “Applications of Geosynthetics in Infrastructure Projects”, July 2014, Agra
53. Geosynthetics India 2014, October 2014, New Delhi
54. Seminar on Geotextiles: A Big Untapped Potential, September 2015, New Delhi
55. Three Decades of Geosynthetics in India – International Symposium Geosynthetics - The Road Ahead, November 2015, New Delhi, India

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Vietnam
Vietnamese Chapter – International Geosynthet-ics Society – Vietnam Chapter (VCIGS) 2013
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IGS COUNCIL

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Takeshi Katsumi (Japan)
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Flavio Montez (Brazil)
Elizabeth Peggs (USA)

Co-opted in 2012
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Edoardo Zannoni (South Africa)

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Nicola Moraci (Italy)
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Seminar on
GEO TEXTILES : A BIG UNTAPPED OPPORTUNITY

22nd September 2015 at PHD House, New Delhi

(Left To Right) : Mr. Saurabh Sanyal, Secretary General, PHD Chamber; Mr. Anil Khaitan, Chairman, Industry Affairs Committee, PHD Chamber; Smt. Kiran Soni Gupta, Textile Commissioner, Ministry of Textiles, Govt. of India; Mr. V K Kanjlia, Secretary, Central Board of Irrigation & Power; Mr. Vivek Seigell, Director, PHD Chamber

PHD Chamber of Commerce and Industry with the support of Indian Chapter of IGS, organized 'Seminar on Geo Textiles: A Big Untapped Opportunity' on 22nd September 2015 at PHD House which was inaugurated by Smt. Kiran Soni Gupta, Textile Commissioner, Ministry of Textiles, Govt. of India.

Mr. Saurabh Sanyal, Secretary General, PHD Chamber while welcoming Smt. Gupta highlighted that India's Technical Textiles market is worth USD 13 billion (INR 76,140 Crores) and is expected to grow at a CAGR of 8% as per the Interim Report on Baseline Survey of Technical Textiles, Ministry of Textiles (India), Technopak Analysis.

Geotextiles have far reaching applications such as road, railway, landfill-solution, and development of canals and therefore it has multi-disciplinary fields of applications. India has the second largest road connection in the world (about 23 million km). The increased demand for spending on infrastructural development, construction operations, transportations and building, have fuelled prospects of Geotextiles & makes it extremely relevant in the present context compared to other segments of Technical Textiles. The demand of Geotextiles is expected to grow due to its low cost as well as the structural and drainage support. The investment policy of Indian government which is worth US $1 trillion towards infrastructure development during their Twelfth Five-year plan (2012-2017) would promote the applications and importance of Geotextiles, Mr. Sanyal added.

Mr. Anil Khaitan, Chairman, Industry Affairs Committee, PHD Chamber announced that the PHD Chamber would shortly open up a Startups Cell in the Chamber to support, fund and guide the young entrepreneurs in the field of their choice and technical and geo textiles would certainly be a part of it.

Immediately after releasing the Knowledge paper on Geo Textiles prepared by Technopak, Smt. Kiran Soni Gupta, Textile Commissioner emphasized that the government is likely to make it mandatory the uses of geo and technical textiles in sectors such as construction of roads, ports, airports, canals, dams as also in defence and railways in the required belts of the country to propagate their applications as also restrict such imports in order to enhance domestic production to give fillip to Prime Minister's Make in India drive.

It is also toying with an idea of encouraging startups to enlist their participation in geotextile manufacturing by way of supporting them through the government's textile technology mission scheme to promote its Make in India drive as well considering enhancement of capital subsidies to procure textile machineries which are largely imported, she articulated.

Smt. Gupta said that the government is already seized with the issue of mandate as the Ministry of Textiles and other similar organizations have been raising this issue repeatedly with it at different and multiple forums. It is only a matter of time when the government could come out with it as India heavily needs imports substitution relating to geo and technical textiles from countries like China, Italy, Europe and the like as also promote and diversify its Make in India programme including their domestic production

Smt. Gupta highlighted that sectors such as construction of road, ports, airports, railways, canals, dams, defence and the like need to be upgraded with technical and geo textiles wherever required for safety purpose also and it becomes all the more important to make the applications and uses of such textiles mandatory to broad base and widen it. She also pointed out that the Centre could promote and support technical and geo textiles startups through its technology mission which is going to be enlargened.

The capital subsidies for obtaining textiles machineries could also be increased as there was serious thinking going on with the government on this issue and the interest subsidy could also be expanded since states like Rajasthan, Maharashtra and Tamilnadu also make their significant contribution on this front with the Centre to wider and expand the geo and technical textile manufacturing in India, she said.

Mr. V.K. Kanjlia, Secretary, Central Board of Irrigation & Power emphasized the need of technical and geo textiles, asking all stakeholders in it to make their contribution in a fair and equitable manner.

Mr. Vivek Seigell, Director, PHD Chamber thanked all the participants and assured that the discussions and deliberations made during the seminar will enlighten participants about the applications and uses of Geotextiles and also the government support to promote the Geotextiles and Technical textile sector.

CELEBRATION OF THREE DECADES OF GEOSYNTHETICS IN INDIA INTERNATIONAL SYMPOSIUM "GEOSYNTHETICS - THE ROAD AHEAD"

5-6 November 2015, New Delhi

A view of the dais during the inaugural session

In the year 1985, Central Board of Irrigation & Power (CBIP), as part of its technology forecasting activities, identified geosynthetics as an important area relevant to India's need for infrastructure development. In the year 1992, CBIP established the Committee for International Geosynthetics Society (India), which also acts as Indian Chapter of International Geosynthetics Society (IGS). CBIP feels very happy to complete 30 years of its service to the Geosynthetics Community.

To mark the occasion, an International Symposium "Geosynthetics – The Road Ahead" was organized at CBIP Conference Hall in New Delhi on 5-6 November 2015 by Indian Chapter of IGS and CBIP, including a half day Workshop on "Use of Jute Geoxtile in Infrastructure Projects", organized on the initiative of the office of the Jute Commissioner. The event also included an Exhibition, where there were 10 stalls.

More than 100 participants from India, Italy, South Korea and Thailand, representing IGS, nodal government agencies, research, academic, manufacturing, testing labs, consulting and user organizations, participated in the event.

The event was sponsored by Maccaferri Environmental Solutions Pvt. Ltd. and co-sponsored by Garware-Wall Ropes Ltd., National Jute Board and Strata Geosystems (India) Pvt. Ltd.

The symposium was inaugurated by Dr. (Ms.) Kavita Gupta, IAS, Textile Commissioner, Ministry of Textiles, Government of India. Mr. Subrata Gupta, IAS, Jute Commissioner, Ministry of Textiles, Government of

Mr. M. Venkataraman delivering the Welcome Address

Dr. K. Rajagopal briefing about activities of Asian Activites Committee of IGS

India and Mr. Rajesh Bhushan, IAS, Joint Secretary (Rural Connectivity) and Director General, National Rural Roads Development Agency, Ministry of Rural Development, Government of India, were the Guests of Honour. Dr. Chungsik Yoo, Vice President, International Geosynthetics Society (IGS), was present on the occasion as IGS Representative.

After formal welcome address by Mr. M. Venkataraman, Vice President, Indian Chapter of IGS, Member Secretary, International Geosynthetics Society (India), Dr. K. Rajagopal, Chairman, Asian Activities Committee of IGS and Dr. Chungsik Yoo, highlighted the activities of International Geosynthetics Society (IGS) and the Asian Activities Committee of IGS.

Mr. Rajesh Bhushan, Joint Secretary, Ministry of Rural Development, Govt. of India, addressing the participants

Dr. (Ms.) Kavita Gupta, Mr. Subrata Gupta and Mr. Rajesh Bhushan, in their addresses stressed that even though the use of geosynthetics is increasingly being accepted as construction material in different fields of civil engineering, not only in developed countries but also in the developing countries, its use in India is not anywhere close to recognitions. This is due to limited awareness of the utilities of this material and development taking place in its use, and offered the support of their good offices, to Indian Chapter and CBIP, to enhance the awareness of this useful and versatile material amongst the various user agencies, engaged in infrastructure development.

Dr. (Ms.) Kavita Gupta, Textile Commissioner, Ministry of Textiles, Govt of India, delivering the Inaugural Address

Dr. Chungsik Yoo briefing about activities of IGS

Dr. Kavita Gupta also informed about the various schemes where financial help is also rendered by the Ministry of Textiles.

To mark the occasion, a Commemorative Volume was released with technical articles/case studies contributions from the academia, practicing engineers, consultants, contractors and manufacturers.

During the occasion, following Institutions and Individuals were honoured for their contributions for the development and promotion of uses of geosynthetics in the country.

Mr. Subrata Gupta, Jute Commissioner, Ministry of Textiles, Govt. of India, addressing the participants

Life Time Achievement Award

- Prof. K. Rajagopal
- Dr. K. Balan
- Ms. Dola Roychowdhury

Institutional Award (Industry)

- Charankattu Coir Mfg. Co. (P) Ltd.
- Garware –Wall Ropes Ltd.
- Maccaferri Environmental Solutions Pvt. Ltd.
- Strata Geosystems (India) Pvt. Ltd.
- TechFab (India) Industries Ltd.

Institutional Award (Central/State/Private/Academic Institutions)

- Central Soil and Materials Research Station
- Coir Board

Release of Commemorative Volume

View of the participants

Mr. V.K. Kanjlia proposing Vote of Thanks

Inauguration of the Exhibition by Dr. Kavita Gupta

Dr. Kavita Gupta at CBIP Publication Stall

- Gujarat Water Resources Development Corpn. Ltd.
- National Jute Board

Appreciation Award

- Mr. Satish Naik
- Dr. Jimmy Thomas

Mr. V.K. Kanjlia, Secretary, CBIP and Member Secretary, Indian Chapter of IGS, proposed Vote of Thanks to all the invitees, participants, and sponsors.

After the Inaugural Session, Dr. (Ms.) Kavita Gupta, inaugurated the exhibition planned during the occasion. A-1 Fence Products Company Pvt. Ltd., Garware-Wall Ropes Limited, Khator Technical Textiles Pvt. Ltd., Maccaferri Environmental Solutions Pvt. Ltd., Manas Geo Tech India Pvt Ltd., Megaplast Packaging Pvt. Ltd., National Jute Board and Techfab India Industries Ltd., exhibited their products/services during the exhibition.

The Technical Deliberations during the event were initiated by the Inaugural Lecture on “An Overview of Three Decades in India”, by Dr. G.V. Rao, Past President, Indian Chapter of IGS and Former Professor, Department of Civil Engineering, IIT Delhi, followed by a Keynote Lecture by Dr. Chungsik Yoo, Vice-President, International Geosynthetics Society, and Chair Professor, School of Civil and Architectural Engineering, Sungkyunkwan University, South Korea.

In total, 22 Keynote/Invited Lectures and Case Studies were presented and discussed under the following sessions, by the eminent speakers from India, Italy and Thailand:

- Reinforcement including Pavements
- Use of Jute Geotxtile in Infrastructure Projects
- Hydraulic Application, including Erosion and Barriers
- Natural Fibres
- Industry Presentation

The event concluded with Panel Discussions, under the Chairmanship of Mr. M. Venkataraman, with Dr. G.V. Rao, Prof. Chungsik Yoo, Prof. K. Rajagopal and Mr. V.K. Kanjlia as panel members. During the discussions, it was stressed to organize the awareness programmes in the various parts of the country.

RECIPIENTS OF AWARDS

Dr. G.V. Rao and Mr. M. Venkataraman being honoured for their contribution in promotion and development of uses of geosynthetics in the country by Mr. V.K. Kanjlia

LIFE TIME ACHIEVEMENT AWARD

Prof. K. Rajagopal

Dr. K. Balan

Ms. Dola Roychowdhury

INSTITUTIONAL AWARD (INDUSTRY)

Mr. C.R. Devaraj, Managing Director, receiving the award on behalf of Charankattu Coir Mfg. Co. (P) Ltd.

Mr. Ranjit Dash, General Manager, receiving the award on behalf of Garware –Wall Ropes Ltd.

Mr. Pieter Rimoldi and Mr. Ashish Gharpure, receiving the award on behalf of Maccaferri Environmental Solutions Pvt. Ltd.

Mr. Narendra Dalmia, CEO & Director, receiving the award on behalf of Strata Geosystems (India) Pvt. Ltd.

Mr. Anant Kanoi, Managing Director, receiving the award on behalf of TechFab (India) Industries Ltd.

INSTITUTIONAL AWARD (CENTRAL/STATE/ PRIVATE/ACADEMIC INSTITUTIONS)

Mr. Murari Ratnam, Director, receiving the award on behalf of Central Soil and Materials Research Station

Mr. J.K Shukla, receiving the award on behalf of Coir Board

Mr. Vivek Kapadia, Managing Director, receiving the award on behalf of Gujarat Water Resources Development Corporation Ltd.

Mr. T. Sanyal, Chief Consultant, receiving the award on behalf of National Jute Board

APPRECIATION AWARD

Mr. Satish Naik, receiving the award

Dr. Jimmy Thomas, receiving the award

ABOUT JOURNAL

Geosynthetics are now being increasingly used the world over for every conceivable application in civil engineering, namely, construction of dam embankments, canals, approach roads, runways, railway embankments, retaining walls, slope protection works, drainage works, river training works, seepage control, etc. due to their inherent qualities. Its use in India though is picking up, is not any where close to recognitions. This is due to limited awareness of the utilities of this material and developments having take place in its use.

The aim of the journal is to provide latest information in regard to developments taking place in the relevant field of geosynthetics so as to improve communication and understanding regarding such products, among the designers, manufacturers and users and especially between the textile and civil engineering communities.

The Journal has both print and online versions. Being peer-reviewed, the journal publishes original research reports, review papers and communications screened by national and international researchers who are experts in their respective fields.

The original manuscripts that enhance the level of research and contribute new developments to the geosynthetics sector are encouraged. The work belonging to the fields of Geosynthetics are invited. The manuscripts must be unpublished and should not have been submitted for publication elsewhere. There are no **Publication Charges**.

Editorial Board

Guidelines for Authors

The authors should submit their manuscript in MS-Word (2003/2007) in single column, double line spacing. The manuscript should be organized to have Title page, Abstract, Introduction, Material & Methods, Results & Discussion, Conclusion, and Acknowledgement. The manuscript should not exceed 16 pages in double line spacing.

Submission of Manuscript

The manuscript must be submitted in doc and pdf to the Editor as an email attachment to **uday@cbip.org.** The author(s) should send a signed declaration form mentioning that, the matter embodied in the manuscript is original and copyrighted material used during the preparation of the manuscript has been duly acknowledged. The declaration should also carry consent of all the authors for its submission to **Indian Journal of Geosynthetics and Ground Improvement**. It is the responsibility of corresponding author to secure requisite permission from his or her employer that all papers submitted are understood to have received clearance(s) for publication. The authors shall also assign the copyright of the manuscript to the Indian Chapter of International Geosynthetics Society.

Peer Review Policy

Review System: Every article is processed by a masked peer review of double blind or by three referees and edited accordingly before publication. The criteria used for the acceptance of article are: **contemporary relevance, updated literature, logical analysis, relevance to the global problem, sound methodology, contribution to knowledge and fairly good English**. Selection of articles will be purely based on the experts' views and opinion. Authors will be communicated within Two months from the date of receipt of the manuscript. The editorial office will endeavor to assist where necessary with English language editing but authors are hereby requested to seek local editing assistance as far as possible before submission. Papers with immediate relevance would be considered for early publication. The possible expectations will be in the case of occasional invited papers and editorials, or where a partial or entire issue is devoted to a special theme under the guidance of a Guest Editor.

The Editor-in-Chief may be reached at: uday@cbip.org

CALENDAR OF EVENTS

Event	Location	Date	E-Mail, Website
International Symposium on Geohazards and Geomechanics	Warwick, Coventry, United Kingdom	10-11 Sep 2015	C.VoulqariO.wa rwick.ac.uk wvwv2.warwick.ac.uk/fac/sci/eng/re search/civil/geo/conference/
European Young Geotechnical Engineers Conference	Durham,United Kingdom	11 -12Sep2015	ashraf.osman(5),durham. ac.uk
XVI European Conference on Soil Mechanics and Geotechnical Engineering	Edinburgh, Scotland, United Kingdom	13-17Sep2015	derek smith(S>coffev.com www.xvi-ecsmqe-2015.orq.uk
GEO-EXPO 2015 Scientific and Expert Conference in Zenica	Zenica, Bosnia and Herze-govina	18-19Sep2015	qeotehnika(5).qeotehnika.ba http://www.qeotehnika.ba
Workshop on Volcanic Rocks & Soils	Isle of Ischia, Italy	24 - 25 Sep 2015	agi@associazionegeotecnica.it http://www.wvrs-ischia2015.it/
Geosintec 2 2nd Spanish Conference on Geosynthetics	Madrid, Spain	07-08 Oct 2015	Pedro.abad@igs-espana.com Beatriz.Mateo@igs-espana.com
Sardinia 2015-Fifteenth International Waste Management and Landfill Symposium	Cagliari, Italy	05 – 09 Oct 2015	info@sardiniasymposium.it www.sardiniasymposium.it
26th European Regional Conference	Montpellier, France	11 - 16 Oct 2015	www.icid.org/26th_erc2015_info.pdf
Three Decades of Geosynthetics in India	New Delhi, India	14 - 16 Oct 2015	uday@cbip.org www.cbip.org
1st International Seminar of IGS Colombia - Beginning a new future for geosynthetics in Colombia	Bogota, Colombia	22 -23 Oct 2015	logisti-ca@ mercadeoeinformacion.com.
6th International Conference on Earthquake Geotechnical Engineering	Christchurch, New Zealand	01 - 04 Nov 2015	6icege@tcc.co.nz www.6ICEGE.com
The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering - New Innovations and Sustainability	Fukuoka, Kyu-shu, Japan	09 - 13 Nov 2015	15tharc@kumamoto-u.a c.jp www.jgskyushu.net/uploads/15ARC/
Geosynthetics for soil reinforcing: Embank-ments on soft foundations, steep slopes, and very steep slopes ("walls")	Buenos Aires, Argentinia	15 Nov 2015	secretario@igsargentina.com.ar conferencesba2015.com.ar/
Sixth International Symposium on Deformation - Characteristics of Geomaterials	Buenos Aires, Argentinia	15 - 18 Nov 2015	http://saig.org.ar/ISDCG2015

15th Pan-American Conference on Soil Mechan-ics and Geotechnical Engineering	Buenos Aires, Argentina	15 - 18 Nov 2015	presidente@saig.org.ar www.panam2015.com.ar
7 GEOME 2015, Geosynthetics Middle East 2015	Abu Dhabi, UAE	16 – 17 Nov. 2015	info@geosyntheticsme.com www.geosyntheticsme.com/
Geo-Environment and Construction European Conference	Tirana, Albania	26 -28 Nov. 2015	erion.bukaci@gmail.com erdi. myftaraga@hotmail.com lulibozo@gmail.com
International Conference on Soft Ground Engi-neering ICSGE2015	Singapore	03 - 04 Dec 2015	ICSGE2015@nus.edu.sg www.geoss.sg/icsge2015
GIFT - Geotechnics for Infrastructure and Foun-dation Techniques	Pune, Maha-rashtra, India	17 - 19 Dec 2015	igc2015pune@gmail.com www.igc2015pune.in/GUI/index. aspx
The 1st International Conference on Geo-Energy and Geo-Environment (GeGe2015)	Hong Kong	04 - 05 Dec 2015	gege2015@ust.hk http://gege2015.ust.hk
3rd PanAmerican Regional Conference on Geosynthetics	Miami South Beach, USA	11 - 14 Apr 2016	NAGSDirector05@gmail.com epeggs@minervatri.com
NGM 2016, The Nordic Geotechnical Meeting	Reykjavik, Ice-land	25 - 28 May 2016	has@vegagerdin.is www.ngm2016.com
International Mini Symposium Chubu (IMS-Chubu)	Nago-ya, Aichi, Japan	26 - 28 May 2016	kokusai@jiban.or.jp www.jiban.or.jp/index. php?option=com_content&view=article&id=1737:2016052628&catid=16:2008-09-10-05-02-09&Itemid
SEAGC2016	Subang Jaya, Selangor, Malaysia	31 May - 03 June 2016	seagc2016@gmail.com / choy. iemtc@gmail.com www.mygeosociety.org/ SEAGC201
12th International Symposium on Landslides	Naples, Italy	12 - 19 June 2016	agi@associazionegeotecnica.it www.isl2016.it
GeoChina 2016	Shandong, China	25 - 27 July 2016	geochina.sec@gmail.com http://geochina2016.geoconf. org/
3rd ICTG International Conference on Transpor-tation Geotechnics	Guimaraes, Portugal	04 - 07 Sep 2016	agc@civil.uminho.pt www.webforum.com/tc3
13 Baltic States Geotechnical Conference	Vilnius, Lithua-nia	15 - 17 Sep 2016	danute.slizyte@vgtu.lt www.13bsgc.lt
EuroGeo 6 – European Regional Conference on Geosynthetics	Istanbul, Turkey	25 – 29 Sep 2016	info@eurogeo6.org www.eurogeo6.org
6th Asian Regional Conference on Geosyn-thetics	New Delhi, India	08 - 11 Nov 2016	uday@cbip.org www.geosyntheticsasia.in
Geotechnical Frontiers	Orlando, Florida, USA	12 – 15 March 2017	bjconnett@ifai.com
ICSMGE 2017 - 19th International Conference on Soil Mechanics and Geotechnical Engineer-ing	Seoul, Korea	17 - 21 Sep 2017	secretariat@icsmge2017.org http://www.icsmge2017.org
11th International Conference on Geosynthetics (11ICG)	Seoul, South Korea	16 - 20 Sep 2018	csyoo@skku.edu

6th Asian Regional Conference on Geosynthetics

– Geosynthetics for Infrastructure Development

8-11 November 2016, New Delhi, India

Indian Chapter had the honour of hosting the First Asian Regional Conference on Geosynthetics in November 1997 in Bangalore. After the successful series of Asian Regional Conferences in Kuala Lumpur (2000), Seoul (2004), Shanghai (2008) and Bangkok (2012), it is back to India in 2016.

India is a fast developing economy requiring large scale infrastructures. Liberalization of economy has further facilitated planning and execution of many large scale infrastructures, including roads, railways, power and water resources, which will further promote applications of Geosynthetics for infrastructural works. Spending in XII Plan (2012-17) in infrastructure is estimated to be USD 01 Trillion, which is excepted to grow for infrastructure activities for the XIII Plan (2017-2022).

6th Asian Regional Conference – "**Geosynthetics Asia 2016**" would be a step towards providing opportunity for exchange of experiences, practices and collaborations to facilitate flow of appropriate technology to enable successful implementation of infrastructure projects.

VENUE

Manekshaw Centre, in the Cantonment area of Delhi, is a multi-utility, state of art Expo & Convention Centre, spread over 25 acres of landscaped area. The elegant interior décor of the building showcases the rich ethos and glorious traditions of the Indian Army and also reflects the diverse and remarkable cultural heritage of our country.

It is an ideal venue for seminars, conferences, exhibitions. Being one of its kind in Delhi, this Centre is ideal for hosting all important events. Exhibition hall is a 15000 sq ft air conditioned area comprising of two floors and is ideal for exhibitions. Exhibition Ground covering an area of 20000 sq ft is an open air exhibition space and can accommodate large displays in conjunction with the exhibition hall. The complex has been named in honour of Field Marshal SHFJ Manekshaw, Padma Vibhushan, Padma Bhushan, MC, the first Field Marshal of the Indian Army.

SUB-THEMES

- Roads and Railways
- Ground Improvement
- Coastal and River Bank Erosion
- Underground Structures
- Geosynthetic Testing
- Hydraulic Structures
- Reinforced Application
- Environmental Applications
- Natural Fibre Geotextiles

CALL FOR PAPERS

All concerned wishing to present paper(s) on sub-themes/allied sub-themes of the Conference are requested to send the abstract(s) of their proposed paper(s) in about 800-850 words in English. Only original contributions that have not been published, or presented at other events, need be submitted.

The abstract(s) can be submitted online at www. geosyntheticsasia.in

Dates to Remember

Submission of abstracts	: January 31, 2016
Acceptance of abstracts	: February 29, 2016
Submission of full-length papers	: May 31, 2016
Submission of revised papers after review	: July 15, 2016

REGISTRATION FEE*

On or before 31 May 2016	
IGS Individual Members	USD 550
IGS Corporate Members (up to 05 representatives)	USD 550
Non-members	USD 600
Students	USD 300
After 31 May 2016	
IGS Individual Members	USD 600
IGS Corporate Members (up to 05 representatives)	USD 600
Non-members	USD 650
Students	USD 325

*The service tax, presently 14.5%, will be over and above.

EXHIBITION

An Exhibition, concurrent to the Technical Sessions will be organised. Corporate Members of IGS will be given preference and allowed discount.

Exhibition Charges*

On or before 31 May 2016	
IGS Corporate Members	USD 225/sq. m.
Non-members	USD 300/sq. m.
After 31 May 2016	
IGS Corporate Members	USD 275/sq. m.
Non-members	USD 350/sq. m.

*The service tax, presently 14.5%, will be over and above.

OFFICIAL LANGUAGE

The official language of the Conference will be English only.

CONFERENCE ADVISORY COMMITTEE

Chairman : Prof. K. **RAJAGOPAL**, India

Co-Chairman : Dr. G.V.S. S. **RAJU**, India

IGS Coordinator : Prof. Chungsik **YOO**, Korea

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- Prof. Chao **XU**, China

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