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ENVIRONMENTAL GEOTECHNICS: A TOOL FOR SOIL STRUCTURE INTERACTION AND SOIL *POLLUTANT INTERACTION*

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Abstract- Foundations to various civil engineering structures are generally designed based on the bearing capacity and settlement characteristics of the soil at the site prior to construction. Modification of soil properties subsequent to construction due to industrial pollution may cause unanticipated settlements or heaving and possible strength loss, which are not accounted for in the design, resulting in structural distress and consequent failure.
Ground pollution arises from the impact of past and current industrial activity and due to improper disposal of waste generated by society. Geo-environmental engineering deals with the most important aspects: (a) Soil pollution processes and effect on geotechnical propertiesand (b) Waste management. Soil pollutants interaction changes soil behaviour and also can lead to various geotechnical problems. Extensive literature is available on air and water pollution but little effort has made to determine how the ground soil responds to these hazardous or toxic substances. At present, most geotechnical projects design and construction are based on the test results followed from ASTM and AASTHO standards. These standards are based on control conditions at room temperature with distilled water as pore fluid. To accomplish this goal, we must understand the environmental conditions as they exist on the ground and their interactions over a long-term period.
Soil Structure Interaction (SSI) analysis is the study of the dynamic response of a structure as influenced by the interaction with the surrounding soil. The SSI response is sensitive to the characteristics of the soil, structures, and ground motion, as well as the depth of embedment. Availability of soil dynamic properties is, therefore, of paramount importance for performing such SSIanalysis. However detailed soil information and associated engineering properties may not always be available at the beginning of a project. Therefore, the analyst may rely on simplified yet conservative methodologies to estimate the dynamic response of the coupled soil structure system to generate preliminary or interim seismic responses.
This study in the growing stage, given its complexity and excessive simplification of the model for soil and structures, and should be carried for its significance. An attempt was made to summarize the all terms in the area of study. Furthermore, parametric study on soil structure interaction behaviour by various researchers is tabulated. The existing problems and the future research trend in this field were also examined.Consideration for environmental stability of the foundation soil has therefore become an additional responsibility of the geotechnical engineers. Environmental Geotechniques is realized to be more of a planning and decision tool to be used for forecasting geotechnical problems that may ultimately arise, rather than solving after the event has occurred.

Key Words – Environmental Geotechnics, Soil Pollutant Interaction, Soil Structure Interaction

INTRODUCTION

Existing buildings are subjected to processes of degradation with time, which leads to a situation in which they became not able to fulfil the purpose for which they were built. Sometimes, there is also the need to improve the conditions offered by existing buildings or to adopt them to new functions.
The most sensitive aspect of the rehabilitation of existing buildings is their structural rehabilitation, i.e. structural safety.
The need for structural rehabilitation of existing buildings is, usually, motivated by one or more of the following circumstances:
-The existence of visible defects in the building
-Damage after a particular event that affects its stability (earthquake, flood, blasts, wind etc.);
-The change of the use of the building for most severe conditions (pollution)

-Requirement of the competent authority, for instance, when there is an the actions (earthquake action, traffic action, etc) imposed by new codes.
Ground pollutions arises from the impact of past and current industrial activity and due to improper disposal of waste generated by society. Geo-environmental engineering deals with the most important aspects:
(a)Soil pollution processes and effect on geotechnical properties.
(b)Waste management.
Soil pollutants changes soil behaviour and also can lead to geotechnical problems.
Foundations to various civil engineering structures are generally designed based on the bearing capacity and settlement characteristics of the soil at the site prior to construction. Modification of soil properties subsequent to construction due to industrial pollution may cause unanticipated settlement or heaving and possible strength loss, which are not accounted for in the design, resulting in structural distress and consequent failure.

ENVIRONMENTAL GEOTECHNICS
Vanicek M et al. reported that Geotechnical Engineering is falling under the limited group of professions, which to the high extent are able to react not only on classical construction problems but also to new society demands. The branch of Environmental Geotechnics is now very well established, falling under the important part of Geotechnical Engineering which can be called Geo-Technology and represents the third column by which Geotechnical Engineering is supported remaining three columns are theoretical background, Geo-mechanics and feeling for ground response, whereas the first column Theoretical background relies on the understanding of natural sciences such as geology, engineering geology and hydrology on the one hand and on the understanding of mechanics, theory of elasticity on the other**.(11)**
Dr. Masirin et al. **(2008)** founded in his study that in many counties, especially in developed countries, the roles of Geo environmental engineers are important to assist the government and relevant authorities in issues pertaining to environmental monitoring. Some of the roles of environmental geotechnical engineers among others are as follows**. (12)**

(A)To assess land condition in relation with site investigation, geological analyses, groundwater flow simulations and quantitative risk assessment

(B)To engage on site redevelopment - Excavation, pilling, drain runs may create new pathways for contained containment and new threat to people and/or the environment

(C) To assist risk restructuring – May be liable for the design, many new legislationsimpose a new and far-reaching liability regime on owners of land and others for cleaning up land

(D) To advise on remediation schemes Hadi Khabbaz et al**. (2018)** reported in his study that the Environmental Geotechnics as well Transportation Geotechnics are getting a great attention during last few decades. It is given by new demands for Transport Infrastructure generally, as well by greater attention to the environment protection for transport infrastructures as railways, motorways or airfields**. (13)**

P.V. Sivapullaiah **(2009)** reported that in recent years, due to population growth, a progressive living standard, and industrial progress, much of the air, water and have become polluted. Open dumps, chemical and industrial wastes cause these problems. As well as from many other sources. In embankment construction, the moisture- unit weight relationship of soil also will be affected **(1).**

Basma G Alhogbi et al. (**2017**) reported that Solid wastes have been classified as garbage, rubbish, household refuse, and litter. It is well known that the sea dumping (creates water pollution and destroys marine habitats), incineration (leads to atmospheric pollution, if not conducted under controlled conditions), The landfill (the most widely used method till its limitations are realized in recent years), and recycling were the four main ways of disposing of solid wastes **(2).**

D.L. SHAH et al. **(2018)** has reported that the need to set up more industries led to the disposal of industrial wastes on to the land thus polluting the soil and the ground water equally. Due to rapid urbanisation, these wastes disposed lands are reclaimed to construct multi-storeyed and other kinds of structures in developed as well as in developing countries for want to space. Thus, soil strength under building, roads, bridges, embankments, and damps is widely studied, both before and after loading with the aid of concepts and techniques developed by the specialised technology of soil mechanics **(3).**

Ashraf et al. **(2014**) reported that environmental pollution is a burning topic of the day. Air, water and soil are being polluted alike. Soil being a "universal sink" bears the greatest burden of environmental pollution. It is getting polluted in a number of ways. There is urgency in controlling the soil pollution in order to preserve the soil fertility and increase the productivity. Pollution may be defined as an undesirable change in the physical, chemical and biological characteristics of air, water and

soil which affect human life, lives of other useful living plants and animals, industrial progress, living conditions and cultural assets **(4).**

SOIL STRUCTURE INTERACTION

Ulitsy et al. (**2010**) reported that new methods of geotechnical analyses using Soil-Structure Interaction (SSI) approach are becoming increasingly popular in geotechnical engineering. Now SSI calculations are successfully used in analysis of high-rise building, underground structures, tunnels, bridges, railways. The main advantage of modern SSI approach is the ability to combine the latest achievements of soil mechanics and superstructure calculations. Many design codes either recommend or directly prescribe

application of soil-structure interaction calculations. To fulfil these requirements, it is important to employ the most up-to-date methods of SSI analysis**. (5)**

Kaustubh Dasgupta et al. (**2018**) has reported that the earliest work on dynamic soil structure interaction was made in the light of two primary approaches in solving SSI problems,namely the continuum approach and the finite element approach. Modern day advancements in the computational techniques aided in expanding the knowledge related to the features and capabilities of both the continuum and finite element approaches. It has been understood that neither of the methods proves to be less relevant in their own extents of applicability and usefulness (**6)**.

More recently, Roesset **(2017)**presented a review on the early stages of SSI focusing on the development of the subject and critical highlighting the prevailing contradictions related to the advantages and disadvantages of two methods of SSI analysis, namely the Direct method and the method of Sub-structuring. Although the review focused on the studies related to the design of nuclear power plants, most of the highlighted works have been pioneering and paved the way for the present day understanding of the subject **(7).**

Kavitha et al. (2016) reviewed on the SSI analysis of laterally loaded piles in which they concluded that there are various factors which affect the soil-pile-structure system. The governing factors are (a) soil property (b) soil profile (c) gradient of ground surface (d) pile geometry, and (e) pile arrangement. The review emphasised on the fact that accurate prediction of the structural response is dependent on the proper accounting of these governing factors **(8)**.

REVIEW OF SOME CASE STUDY FOR REHABILITATION OF HISTORICAL AND MONUMENTAL BUILDINGS USING SSI

CASE STUDY -1

Francesca ceroni et al (**2014**) in paperhave founded that a reliable procedure to identify the dynamic behaviour of existing masonry buildings, referring to a representative case study: a historical masonry palace located in Benevento (Italy). The influence of Soil-Structure Interaction (SSI) has been also introduced in the FE model by a sub-structure approach where concentrated springs were placed at the base of the building to simulate the effect of soil and foundation on the global dynamic behaviour of the structure. The obtained results evidence that subsoil cannot a priori be disregarded in identifying the dynamic response of the building.

The comparisons between experimental and numerical results allowed evidencing some flaws both regarding the experimental measures and the FE model. In view of the experimental uncertainty about the identification of higher order modes characterized by a low amount of participating mass and the influence of the type of FE element adopted in the numerical predictions, indeed, only the first two modes of the examined building have been reliably identified **(24).**

CASE STUDY-2

Mete Erdemgil, Murat Bilhan (2011) in paper have founded that Karacabey Mosque built in 1440 is located in the district of Hacettpe. After the foundation of the Hacettepe University, the mosque remained in the campus area. Mosque was started in 2003 and completed in a few years**. (25)**

CASE STUDY-3

Alireza Mortezaei (2014) in paper founded that due to the presence of large number of masonry monuments in Iran, that is one of the most seismically active countries in the world, seismic vulnerability assessment of this buildings is one of the main concerns. When the soil beneath the structural foundation is not "rock", the structure cannot be modelled with a fixed base, as

it is usually made in more practice, but it is necessary to consider the interaction with the foundation soil. SSI play an important role in the assessment of the dynamic behaviour of the structures especially masonryones. In this paper, the interaction between the super-structure and sub-structure is investigated by modelling the soil to capture the overall response of such buildings **(10).**

SOIL POLLUTION PROCESSES

Shivapullaiah (**2009**) founded that the environment can contaminate soil water by three basic mechanisms: (i) Rainfall, such as acid rains falling onto a sanitary landfill,oil or chemical waste spilled into the ground (ii) Human activities (iii) Physio chemical alterations, which allow polluting substances to move within or between soil layers **(1).**

There are many different ways that soil can become polluted such as Basma G Alhogbi et al. (2017) ***(2)****:*

- Seepage from a landfill
- Discharge of industrial waste into the soil
- Percolation of contaminated water into the soil
- Rupture of underground storage tanks
- Excess application of pesticides, herbicides or fertilizer
- Solid waste seepage

SOIL POLLUTANT INTERACTION EFFECTS

Salt Contamination Effects, Horta (**1985**) indicated that when salt water is available in the capillary voids of the pavement and evaporation is allowed, salt crystallization starts and crystals grow in size. Salt crystallization pressure increases with temperature and aridity and decreases with the permeability of the base course material. This pressure causes the heaving in soils **(15).**

The influence of clay-brine interactions on the index properties, mechanical properties and hydraulic properties has been described by Barbour & Yang **(1993**). Decrease in plasticity, increase in shear strength, reduction in volume and alteration of hydraulic conductivity has been reported **(16).**

Heave due to AlkaliContamination

Rao & Rao (**1994**) have reported heave in kaolinite due to loss of cementitious iron oxide coatings by the seepage of the caustic soda solution **(23).** Sinha et al. (**2003**) reported that safe bearing capacity of contaminated site is lower by about 33% compared to uncontaminated location **(17).**

Recently it is reported that high alkali solutions induce unexpected swelling in both swelling and non-swelling soils (Sivapullaiah & Manju **2005**; Sivapullaiah et al. **2009) (18).**

Acid Induced Heave

Sridharan et al. (**1981**) reported the heaving of a non-swelling soil in a fertilizer plant due to phosphoric acid leakage into the foundation soil from the damaged open drains with joints. Preventive measures such as closed conduits and drains with properly designed filter material were suggested **(19).**

Assad**(1998)** reported the tilting of phosphoric acid storage tank of chemical fertilizer factory on the subgrade soil, Aqaba, Jordan. Laboratory studies revealed that the tilt was due to a differential upheaval of the foundation soil resulting from the chemical reaction taking place between the phosphoric acid that had leaked over the sub grade soil **(20).**

Schuiling & Van Gaans **(1997)**reported that the waste sulphuric acid from ammonium-phosphate fertilizer plant at Armyansk, Crimea, Ukraine on disposal into the lake resulted in the natrojarosite formation, which acted as a perfect sealant and restricted the seepage **(21).**

Stephenson, et al. (**1989**) reported the upward movement of portions of Kerr-McGee Electrolysis Plant in Henderson, Nevada, in excess of 18 inches, due to the formation of gypsum in the presence of sulphuric acid **(22).**

REVIEW OF SOME CASE STUDY ON SOIL POLLUTANT INTERACTION

CASE STUDY-1

Hana Adem, Sai Vanapalli **(2014)**in the paper have founded that water content and matric suction changes in unsaturated expansive soils due to environmental variations contribute to the overall volume changes. The soil movements cause tilt in trees, highway surfaces, building foundations and pipelines and pose problems to the functionality of the infrastructure. In this paper, a modulus of elasticity–based method approach (MEBM) is tested for modelling the soil– environment interactions for a test site with an expansive soil deposit. In the MEBM, the soil suction changes in the active zone and the associated modulus of elasticity were estimated and used as key parameters in a volume change constitutive relationship to model the soil–environment interactions over time**(28).**

CASE STUDY-2

R.S. Govindaraju and L.E. Ericksonin the paperhave founded thatHeavy metals in southeast Kansas are frequently found in the shallow soil layers. Rainfall events in this region often generate overland flows which cause the release and migration of these chemicals into surface waters. The chemicals are then transported in surface waters to downstream locations and, as such, pose a threat to the quality of both fields along streams and surface and ground waters. This paper deals with the modelling of surface contamination under such circumstances. Results were obtained for a single hypothetical plot. These simulation results indicate that source area for heavy metal removal varies in a similar manner to source area of water**(29).**

EFFECT OF SSI ON SEISMIC RESPONSE OF HISTORICAL MONUMENTAL BUILDING

Alireza Mortezaei et al. (**2014**) studied that the risk of earthquake is unavoidable in every time and its occurrence follows irreparable damage. For this reason, prevention is necessary. One of the important issues that affect the actual behaviour of historical monumental buildings is soil-structure interaction (SSI). Soil-structure interaction is a typical subject but, nevertheless, still new in its applicative aspects **(10)**.

REHABILITATION OF EXISTING/HISTORICAL BUILDINGS SUBJECTED TO SEISMIC HAZARDS

Mansour Ziyaeifar et al. (2004) studied that survival of historical buildings after earthquake is the concern of people from many disciplines **(9).**

SEISMIC RETROFIT OF EXISTING/HISTORICAL BUILDING

The main difficulty in seismic rehabilitation of historical monuments is the dominance of ambiguous but compelling AAA values of the structure that comes across with the transparency and ease of structural (and earthquake) engineering techniques in reducing seismic hazard risk on buildings

Historical Building Rehabilitation and Seismic Risk

In ordinary buildings, based on the required structural performance at a predefined seismic hazard level, structural engineers prepare their suggestions for rehabilitation purposes. However, in the case of historical buildings the same line of action cannot be directly followed. While, the desired level of structural performance for historical buildings is typically high (to limit the crack size and other visible damages or unpleasant large deformation features in such buildings), the importance of these monuments requires strengthening of the system up to a high level of seismic risk hazard (to ensure their safety against long-term threats).

CHALLENGES IN ENVIRONMENTAL GEOTECHNICS

The interaction of environment and infrastructure can readily be found in the main industries. It is essential that researchers, industry professionals and government experts engaged in complex geo-environmental issues conduct thorough investigations and find appropriate strategies for identifying and prioritising the major issues. A number of major geo-environmental problems are summarised below:

Hadi Khabbaz et al**. (2018)**The soil movements cause tilt in trees, highway surfaces, building foundations and pipelines and pose problems to the functionality of the infrastructure. **(13)**

Land Pollution and Contaminated Soil and Groundwater: In order to study and predict the possible characteristics of rehabilitated mine sites, it is necessary to have a sound understanding of the potential leachate transported from the mine spoil to the groundwater. Research is required to select and design the optimised remediation techniques for polluted groundwater or contaminated sites.

Soil Acidity: Soils containing iron sulphides produce sulphuric acid when exposed to air after being disturbed and often release toxic quantities of iron, aluminium and heavy metals. Acid sulphate soil (ASS) can be toxic to the marine and freshwater plants and animals. It contaminates water supplies and corrodes concrete and steel.

Soil Salinity: Soil salinity and dry-land salinity are two problems regarding the environment.

Excessive Erosion Due to Mining Activities: A key challenge for achieving mine spoil reclamation is to prevent erosion on reconstructed landscapes long enough. construction of roads on expansive subgrades. Because of this characteristic, pavements are not achieving their design life owing to failures occurring early and, therefore, resulting in loss of pavement shape and premature rehabilitation.

Closed Landfill Sites: Many closed landfills are located near or inside cities, even though they were originally established away from residential or commercial communities.Redevelopment of closed landfills is generally a challengingtask owing to the complex behaviour of large settlement, creepand low shear strength of waste materials. Furthermore, theenvironmental risks posed by landfill sites (e.g., emission oflandfill gas, release of leachate to the groundwater, suddencollapse of landfill embankment due to biodegradation andsurface water infiltration) continue for a significant period oftime after waste acceptance has end.

Figure:1& 2(Live Case Study: Denva, Gosainganj, Sultanpur, Up)

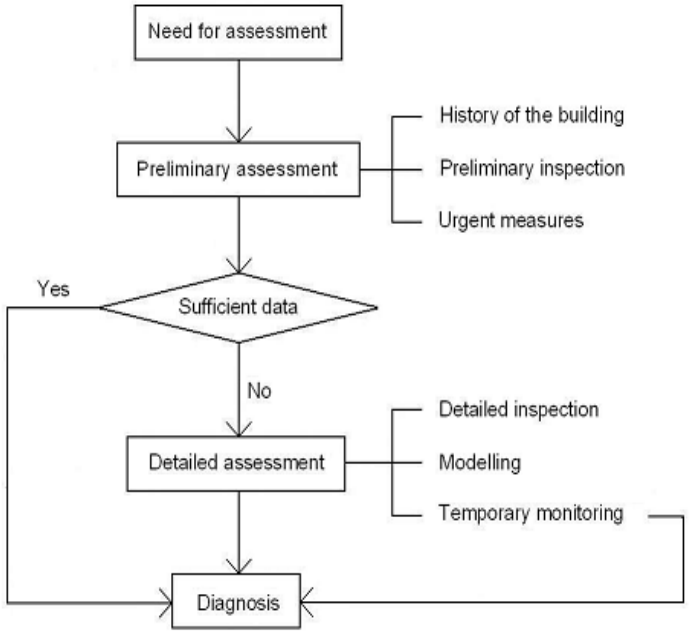

Figure 3: Flowchart of the actions to be undertaken for the diagnosis of the building (26)

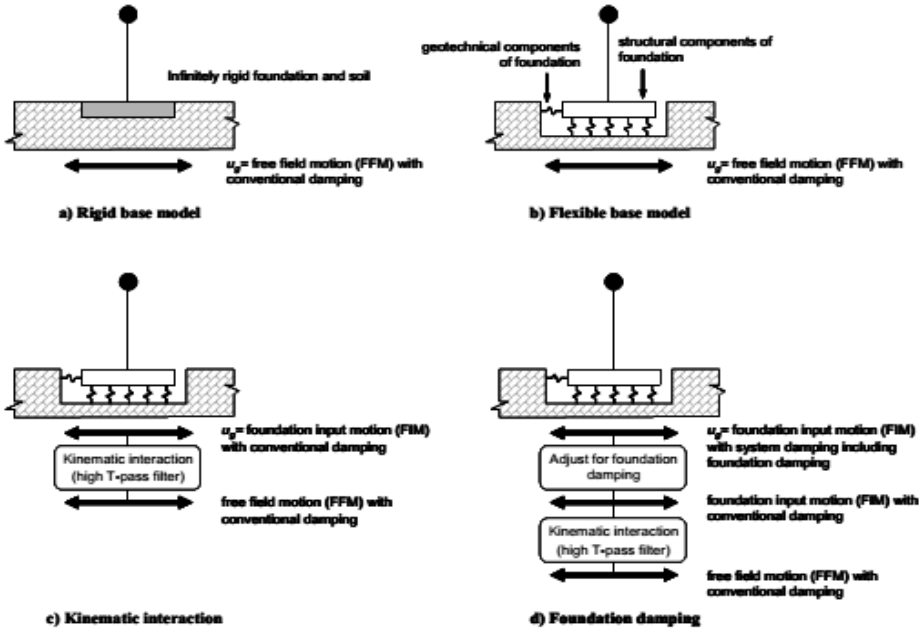

Figure 4: Foundation Modelling Alternatives (27)

The above live case study can be analysed by following steps: Masonry existing (temple)
FEMA 356 and ATC-40 contain procedures for incorporating the strength and stiffness of foundations into structural models for inelastic analyses.
The actions carried out for the structural assessment of the temple should be documented in a report, in which all considerations and justifications for the options and decisions taken should be presented.

ENVIRONMENTAL GEOTECHNICS (EG) AND ITS IMPORTANCE

Environmental geotechnics is important feature in civil engineering field as it is an area where civil engineers be able to appreciate the needs of preserving the environment and ensuring geotechnical and related problems concerning disposal of waste in landfills and contamination of liquid and other environmental hazard materials. Thus, it is also utmost important for engineers to understand and calculate the risk of contamination in certain aspects of a landfill construction.
Understanding and critically taking great care in leachate control and observing the existence of new waste disposal technologies may later on contribute towards better environmental preservation. Soils and ground water are always open to contamination and pollution and with engineers acquiring knowledge and skills in waste management and containment**(12).**

CONCLUSION

Short overview of the case studies regarding soil structure interaction specially in rehabilitation of the existing/historical building is concluded (case study lives). Case studies regarding soil pollutant interaction has been discussed in which modelling of the problem has been done with respect to the pollutant.
Environmental geotechnics can play major role in :

(1) It is the focus of studies to combine the engineering properties of polluted soil, the interaction mechanism between pollutants and soil, as well as to construct a constitutive model of the polluted soil.
(2) Modelling of the existing/historical rehabilitation can be done using environment geotechnics.
(3) At present, most of the researches on polluted soils are aimed at specific projects. Different types of soils are affected by pollutants of different types and concentrations, yet their engineering properties and mechanism of action have not been clearly summarized. At the same time, there are few reports on the effect of pollutants on special soils, which need further study Environment geotechnics can play major role in it.

- *In order to ensure that Environmental Geotechnics is accepted as a component of compulsory area to explore and understood by students and the community at large, the some considerations are to be taken in account especially when designing an EG syllabus.*

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REFERENCES

(1) P.V.Sivapullaiah, "Effects of soil pollution on geotechnical behaviour of soils", IGC-2009,933-940.
(2) Basma G Alhogbi, Amani F Alsolame, "Soil pollution: a case case study on the determination of toxic elements in soil in Jeddah City, Saudi Arbia", IGC-2017 ,37-44.
(3) Prof. D.L. Shah, Prof. A.V. Shroff, "Effect of effluent of industrial waste on soil properties", International conference on case histories in geotechnical engineering, 8-15 March 1998,1059-1062.
(4) Mohd. Aqueel Ashraf, Mohd. Jamil Maah and Ismail Yusuf, "Soil contamination, risk assessment and remediation", INTECH,2014.
(5) Ulitsky.V.M. Shaskin.A.G. "Some aspects of soil structure interaction in geotechnical engineering", IGC-2010, Dec 16-18,2010,39-47.
(6) Kaustubh Dasgupta, Arindam Dey, "A state of the art review on seismic SSI studies on building structures", Jan 2018.
(7) Roesset J.M. "Soil structure interaction the early stages", Journal of applied science and engineering, 2013,1-8.
(8) Kavitha PE, Beena KS, Narayanan KP, "A review on soilstructure interaction analysis of laterally loaded piles", Innovative infrastructure solutions, 2016,1-55.
(9) Mansour Ziyaeifar, Hossein Meshki and Mohd. Rajaei, "Rehabilitation of historical buildings subjected to seismic hazarads- A methodology", 13th world conference on earthquake engineering, Aug 1-6,2004, paper no.-1598.
(10) Alireza Mortezaei, "Effect of soil structure interaction on seismic response of historical monumental building" 2nd Europian conference on earthquake engineering,2014.
(11) Vanicek M. Tirasaku D. "Geotechnical engineering and protection of environment and sustainable development", 3259-3262.
(12) Dr. Masirin M.I.M. Ir.Aziz A.A. "Environmental geotechnics: Introduction to young minds for sustainable environment and development" National seminar on environment sustainability and development, 2008, 143-147.
(13) Hadi Khabbaz, Behzad Fathi, "Environmental geotechnics challenges in Australia", ICE- 5 Feb 2018.
(14) Ivan Vanick, Daniel Tirasko, "Transportation and environmental geotechnics", Science Direct, TGG-2017,17-19 May 2017,118-125.
(15) Horta, J.C. . "Salt Heaving in the Sahara," Geotechnique,1985, 35, pp. 329–337.
(16) Barbour, S.L. and Yang, N. "A Review of The Influence of Clay—Brine Interactions on The Geotechnical Properties of Ca—Montmorillonite Clayey Soils from Western Canada," Canadian Geotechnical Journal, 1993, Vol. 30, pp. 920–934.
(17) Sinha, U.N., Sharma, A.K., Bhargava, S.N., Minocha, A.K. and Pradeep Kumar . "Effect of seepage of caustic soda on foundation and remedial measure in alumina plant" Indian Geotechnical Conference,2003, Roorkee, India, pp. 229–234.
(18) Sivapullaiah, P.V. and Manju, M. "Kaolinite-alkali interaction and effects on basic properties" Geotech. Geologic. Engg.,2005, Vol. 23, No. 5, pp. 601–614.
(19) Sridharan, A., Nagaraj, T.S. and Sivapullaiah, P.V. "Heaving of soil due to acid contamination" Proc. 10th International Conf on SM and FE, Stockholm,1981,Vol. 6, pp. 383–386.
(20) Assad, A. "Differential upheaval of phosphoric acid storage tanks in Aqaba, Jordan," Journal of Performance of constructed facilities, ASCE, May 1998, pp. 71–76
(21) Schuiling. R.D. and Van Gaans. P.F.M. "The waste sulfuric acid lake of the tio2-plant at Armyansk, Crimea, Ukraine. part i. self-sealing as an environmental protection mechanism," Applied Geochemistry,1997, Vol. 12, pp. 181–186
(22) Stephenson, R.W., Dempsey, B.A. and Heagler, J.B. . "Chemically induced foundation heave" Found. Engg. Curr. Princ Pract, 25–29 JUN 1989, ASCE, Geotechnical Engineering Div, New York, pp. 1633–1642
(23) Rao, S.M. and Rao, K.S.S. "Ground heaving from caustic soda solution spillage—A Case Study," Soils and Foundations, Japanese Society of Soil Mechanics and Foundation Engineering,1994, Vol. 34, pp. 13–18.
(24) Francesca Ceroni , Stefania Sica, Angelo Garofano and Marisa Pecce, "SSI on the dynamic behaviour of a historical masonry building: experimental versus numerical results", ISSN,2014, 978-1000.
(25) Mete Erdemgil, Murat Bilhan,"Restoration and foundation stabilization of karacabey mosque in ankara",WCCE-ECCE-TCCE Joint Conference 2 Seismic Protection of Cultural Heritage,2011.
(26) Guide for The Structural Rehabilitation of Heritage Buildings,CIB 335, June, 2010
(27) Improvement of Nonlinear Static Seismic Analysis Procedures FEMA 440
(28) Hana H Adom, Sai K vanapalli, "Soil-environment modelling for expansive soil", Journal of environmental geotechnics, Jan 2014,1-9.
(29) R.S. Govindraju , L.E. Eriction , " Modelling of overland flow contamination due to heavy metals in shallow soil horizons", 10th annual conference on hazaradous waste result,287-300.