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ABSTRACT

A geotechnical case history is a complete cycle; spread over events such as, investigation, design, execution, completion, and monitoring, of understudy project. In case histories the events are continuously monitored, evaluated, modified (if required), executed and corresponding responses / effects are recorded. Case histories help us learn from the past without living in the past, their analysis envision us to enhance practical engineering in the present and future. A geotechnical case history may be performed in an organizational framework or initiated by an interested research engineer in an individual capacity. In all circumstances; a case history would aim at exploring questions concerning processes or techniques for a future project or testing of hypotheses based on the existing theoretical concepts. A case history therefore is an important research tool for educational evaluation and practical geotechnical engineering.

Availability of up-to-date data sets of geotechnical case histories covering entire spectrum; from techniques / technologies to results / effects can help reduce both cost and time of future geotechnical projects. Knowledge gained from case histories can be used to develop geotechnical analytical models for optimization of designs. This paper is a case history of "Enhancement of Bearing Capacity by Dynamic Compaction" project carried out in alluvial deposits, in Pakistan. The authors intend analyzing the project with a view to contribute towards increased understanding of improvement of alluvial deposits by dynamic compaction technique.

INTRODUCTION

The experiences concerning design procedures, execution, quality control methods, and use of equipment of a particular project can be used for optimization of design parameters, much desired economy in future projects, and improvement in the technology. Case histories of the geotechnical projects involving uncertain soil behaviors, complex design procedures, and unpredictable outcomes can contribute substantially to enhance practical geotechnical engineering.

Rogers, [1978], describes a case history as an event or series of events set in an organizational framework with or without a related environment. The events are described in some detail with the main and subsidiary points highlighted. Actions taken by the subjects in the case are described; reactions, responses, and effects on the other subjects are related, and events taken to a conclusion or to a point that is irreversible.

In the present real estate constraint environment, the soil improvement has become both a necessity and a challenge alike. In Pakistan, in-situ soil improvement using different methods is also gaining momentum. Study of the initial soil improvement projects in the country is of paramount importance with a view to verify design parameters and to ascertain the validity of geotechnical principles.

RELEVANCE OF CASE HISTORIES TO PRACTICAL ENGINEERING

Since every foundation represents at least partly a venture into unknown, it is of great value to have access to others' solutions obtained from conference presentations, journal papers, and text book condensations of appropriate literature. In all soil improvement projects, an understanding of the engineering behavior of soil materials is therefore very essential. The amalgamation of experience, study of what others have done in somewhat similar situations, and the site-specific geotechnical information to produce an economical, practical, and safe structure design is application of engineering judgment, Bowles, [1996]. The engineering judgment in geotechnical engineering being equally important as that of scientific principles plays vital roles in refining solutions of geotechnical problems.

TYPES OF GEOTECHNICAL CASE HISTORIES

In geotechnical context, the authors of this paper suggest following categorization of case histories:

Academic

The case histories initiated by undergraduate or graduate students with a view to learn the basic geotechnical principles. The case history will be a follow-up of theoretical course and will involve an analysis of the investigation, design, and results of a particular project. The case history will mostly a desk study and may involve few visits to the project site.

Economic Evaluation

The purpose of such a case history would be to enhance economic viability of a particular design and technique. Although design of geotechnical projects is finalized after requisite cost-benefit analysis yet local innovations in various parts of the world may affect the economics of the project. A comparative analysis of the whole cycle of events of a similar project in various parts of the world can help in optimization of designs and refinement of monitoring procedures. The information on a project of interest can be gathered from the literature reported in conferences, publications, internet, and through concerned agencies.

Technology Evaluation

The purpose of such a case history would be to evaluate efficacy of a new or certain developments in the existing technology. The conduct of such a case history would be dovetailed with an on-going project; this would reduce cost by eliminating the need to execute a dedicated research project. This will also provide an opportunity to compare the results of technology evaluation case study with the existing technology and would help formulate most feasible technology for the similar projects in future.

Progressive

Such a case history would aim at testing a hypothesis formulated by an interested geotechnical engineer. The hypothesis could be a new concept or variant to the existing principles. Desired parameters can be analyzed and tested with the help of data of previous projects and can also be tested with in the framework of an on-going project.

Corporate

Corporate; a multi-purpose case history; may involve all or some of the features discussed earlier. Such a case could even be a joint venture of an interested industry and a university. The funding, expertise and technology can be shared at levels of the management and stages of the project.

PARAMETERS OF A GEOTECHNICAL CASE HISTORY

A case history conducted either by an organization, institute, or individual should address all issues in a logical manner so as to make the findings comprehensive and conclusive. To achieve the desired results, proposed parameters of a case history are discussed below.

Purpose of the Case History

Purpose of the case history should be explicitly defined in order to keep all efforts focused to the original purpose. Framework and responsibilities of individuals involved should also be clearly defined.

Fundamental Geotechnical Principles

Often the key in successful practice and application of geotechnical engineering lies in a sound knowledge and understanding of the engineering properties and behavior of soil in-situ, when they are subjected to their engineering loads and environmental conditions, Holtz & Kovacs, [1981]. While defining the scope and objectives of a case history, fundamental geotechnical principles relevant to the case history should be identified with following perspectives:

- to study whether these were adhered or neglected
- if adhered, to what extent these were valid
- to test a hypothesis formulated on the basis of previous case histories, personal experience, or new ideas

Review of the Project

The project review should include aspects related to organization, type of tests and standards, design methodology, etc.

Organizational profile. Information concerning the agencies involved in design, consultancy, and execution of the project should be obtained. This should include details such as experience of the agency, technologies used, and professional outlook of the individuals involved.

Type of tests and standards. Types of tests such as laboratory tests, field tests, geophysical tests, etc, and standards such as, ASTM, BS, etc followed by the agencies should be ascertained.

Structural parameters. Structural information including type of loads, foundation, future operating environment, depth of influence of the structure should be understood clearly before embarking upon a case history.

Site characterization. For successful and economical geotechnical projects, site characterization including aspects of geological, hydrological, seismological, etc, is a pre-requisite. A failure to correctly identify the variability in horizontal and lateral extents can lead to failure of the project itself. For large projects, a combination of investigation techniques including geophysical, boring, trial pits and previous records should be made use of extensively. A case history should ascertain the correctness in application of appropriate types and variety of investigation techniques. The site characterization should be validated either through analysis of the project records or should preferably be re-done for the case study to be more conclusive and objective.

Design options. Design options considered for the under study project should be reviewed. In case, only one option was considered for a project, other options should be evaluated during the conduct of case history so as to ascertain the economy of the project in terms of cost and time.

Design adopted. Adopted design should be described in full details along with reasons of adaptation.

Technology. Relevant aspects of technology or equipment used for execution of the project and quality control should be high lighted.

Project execution and quality controls. All details pertaining to the execution and quality control procedures should be acquired from the concerned agencies and / or individuals.

Analysis of the Project

Verification of designed parameters. A case study should analyze results of the perspective design program to highlight whether the designed parameters are met or not. In case, desired results are not met then the case history should identify the causes of unsatisfactory results which could be related to one or more of the following:

- in correct site characterization
- unrealistic design parameters or structural parameters
- in appropriate design
- lack of quality controls during execution

Comparison with previous projects. Since every new project in geotechnical engineering involves a different set of soil parameters and mostly different technology, comparison of results of one project with the others can be very beneficial.

Observations on execution and quality controls. Identify violation and adherence of basic geotechnical principles, standards, and procedures.

Validation of Fundamental Principles

A case history, may it be with any purpose, must report on the relevant geotechnical principles. This will help to validate basic principles and enhance understanding of practical geotechnical engineering.

Conclusions and Lessons Learnt

A case history should terminate with conclusions drawn to enhance understanding about geotechnical engineering, refinement of procedures, and improvement in technology.

EXAMPLES OF USE OF CASE HISTORIES FOR ENHANCEMENT OF PRACTICAL ENGINEERING

Case History of a Soil Improvement Project Using Dynamic Compaction in Pakistan

The case history in perspective falls in the corporate category of case histories and is an account of the first ever project of soil improvement using dynamic compaction in Pakistan. The purpose of the case history is to study following:

- site characterization using laboratory, field tests, and geophysical tests
- evaluate effectiveness of the designed compaction program
- compare results of the project with empirical correlations and case histories reported in the literature
- refinement of the procedures for future practice

A firm planned to construct workshop buildings on a site which is composed of alluvial deposits. The bearing capacity of the construction site was 100 kPa against required bearing capacity of 150 kPa. Various alternatives were considered to improve the bearing capacity including, pre-compaction, replacement, and dynamic compaction. Cost-benefit analysis of various alternatives leads the client to select dynamic compaction technique in view of the economy of the project.

The designed dynamic compaction program had following parameters:

- Applied energy
- no. of high energy passes 2
- no. of ironing pass 1
- no. of drops per impact point 10
- height of fall 14 m
- weight of tamper (made of

concrete with steel casing) 20 tons
- shape of tamper circular
- grid pattern square

Effectiveness of the Dynamic Compaction Program

Effectiveness of dynamic compaction was evaluated by comparing pre to post compaction SPT N-values. The improvement in depth and lateral direction was evaluated at nine test craters. Post compaction SPT were conducted 2 to 3 weeks after the compaction. A series of such tests confirmed an improvement in the soil bearing capacity to 160 kPa up to a depth of 5 m. Improvement in depth and in lateral direction is shown in Fig. no. 1 and 2 respectively, Liaqat & Sarfraz, [2007].

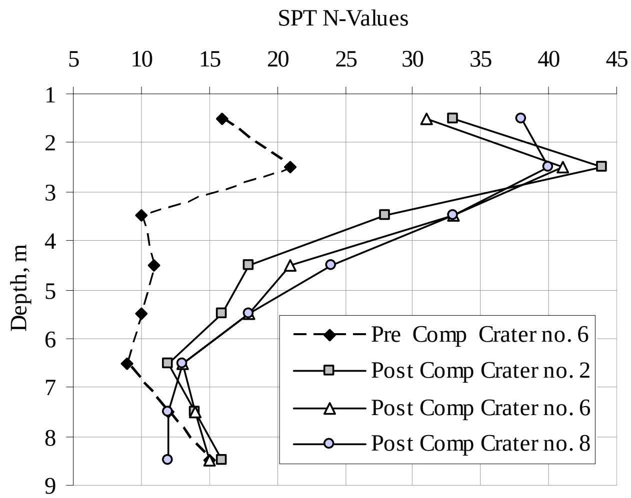

Fig.1. Depth of Improvement

The owner of the project was satisfied with the depth of improvement achieved by dynamic compaction. The authors compared the depth of improvement of 5 m of this project with those suggested by various empirical correlations and previous case histories. The comparison revealed that the energy level used in this project should have achieved more depth of improvement. The improvement suggested by empirical correlations and case histories is given below:

Menard & Broise. [1975] correlation. The depth of improvement is given by equation (1), "W" is the weight of the tamper and "H" is the height of fall of the tamper.

$$D_{max} = \sqrt{WH} \quad (1)$$

$$D_{max} = \sqrt{20 \times 16}$$

$$D_{max} = 17.88 \text{ m}$$

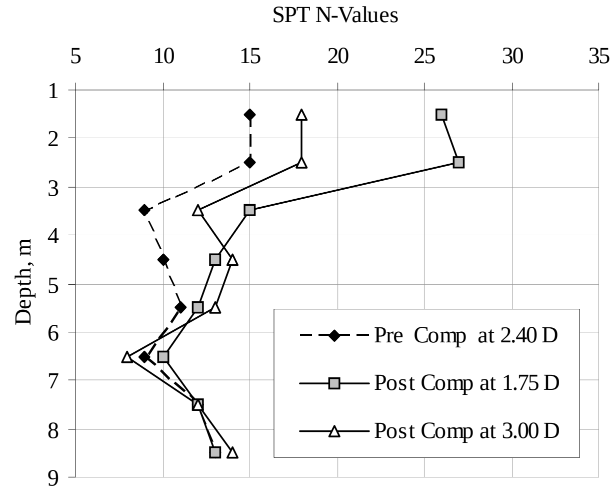

Fig.2. Lateral Improvement

Lukas. [1986]. correlation. The depth of improvement is given by equation (2), "W" is the weight of the tamper and "H" is the height of fall of the tamper, and "n" is the coefficient to cater for soil variability.

$$D_{max} = n\sqrt{WH} \quad (2)$$

$$D_{max} = 0.65\sqrt{20 \times 16}$$

(n = 0.65 for silty sandy soils, Lukas. [1986]

$$D_{max} = 11.62 \text{ m}$$

Case histories. Depth of improvement of various case histories, as proposed by Rollins and Kim, [1994]], is shown in Fig. 3. According to this figure, the research project's energy level of 17.88 ton-m ($\sqrt{20x16}$ = 17.88) should have improved the soil upto a depth of 7.7 m.

Analysis of the Project

Various aspects of the project have been analyzed to identify shortfalls to enhance dynamic compaction practices in the future in terms of design, execution, and monitoring, etc,.

Depth of influence of the structure. The authors of this paper evaluated depth of influence of the structure as 8 m. The depth of influence has been evaluated using 2:1 Approximate Stress Distribution Method.

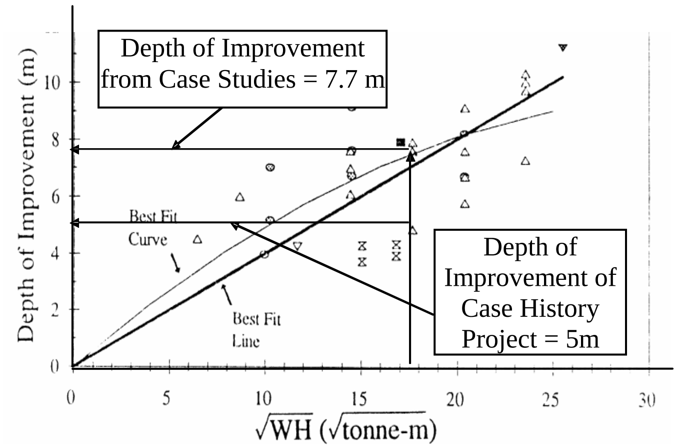

Fig. 3. Depth of improvement of case histories, Rollins and Kim, [1994]

Site investigation. The geotechnical soil profile developed upto 9 m depths by the authors of this paper identified five layers while the soil profile developed by the firm showed four layers. Since dynamic compaction is very sensitive to the nature of soils and their fines content therefore site investigation should be in as details as possible.

The upper 1-2 m strata at the construction site was a compacted fill composed of silty sandy clay containing fines content as high as 75 percent. It appeared to the authors that this fact was not given due consideration while designing the compaction program. Authors are of the view that this compacted layer absorbed relatively higher amount of dynamic energy. The effect of this denser layer can be compared to the rigid pavement which absorbs much of the traffic loads.

Compactibility of soil. The compactibility potential of soils by dynamic compaction is highly dependent on their fines content. The firm did not evaluate the compactibility potential of individual soil layers. Compactibility potential of various types of soils can be evaluated from the criteria suggested by Lukas. [1986], is shown in Fig. 4.

Design of compaction program. The depth of improvement is dependent upon the applied energy i.e. weight of tamper, height of fall, no. of drops per impact point and no. of passes. While designing a dynamic compaction program, due care should be given to the depth of influence of the proposed structures, nature of soil layers, and the fines content of individual layers within the depth of influence.

Field monitoring and control. Monitoring is essential to ensure correct execution of designed dynamic compaction program for achievement of desired depth of improvement. By careful monitoring, necessary changes can be made in the dynamic compaction program to achieve desired results. The authors observed the designed sequence of tamping in square grid pattern was not followed. The grid pattern actually followed is shown in Fig. 5.

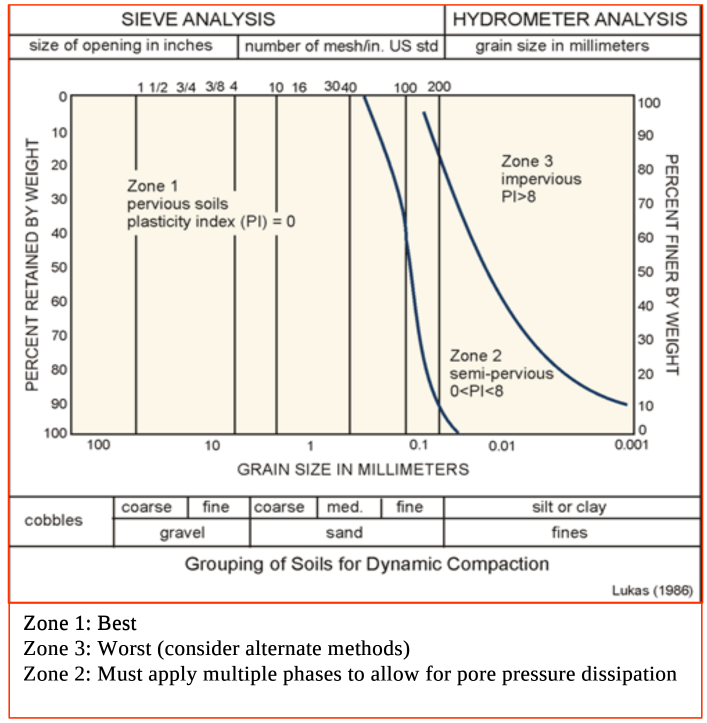

Fig. 4. Compactibility of soils, Lukas. [1986]

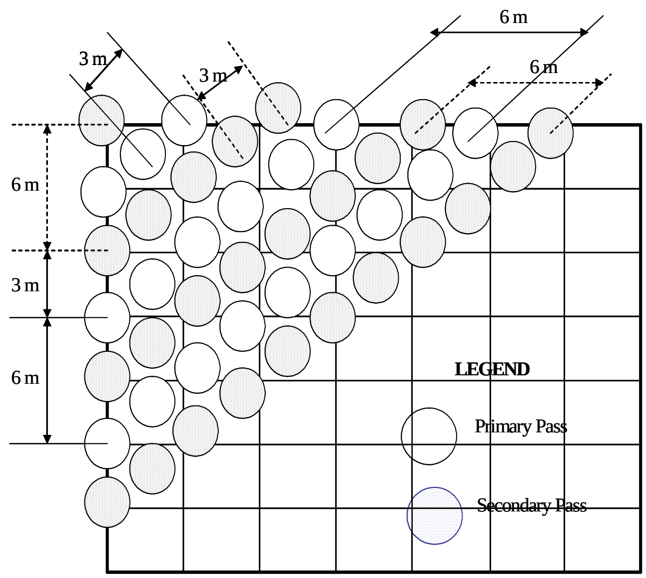

Fig.5. Sequence of tamping actually followed during execution

Conclusions

From the analysis of the case history following conclusions can be drawn:

- incorrect site characterization will lead to improper design
- lack of good quality control procedure will further reduce the efficiency of the compaction program
- any designed based on empirical correlations should carefully be modified in the light local soil variability
- field trial of the given program should be altered if desired parameters of the proposed design are not met

Lessons Learnt to Enhance Future Practical Engineering

In the light of the analysis of the case history a geotechnical model has been developed to improve upon the soil improvement aspects related to dynamic compaction in particular and by all other methods in general. The model is shown in Fig. 6.

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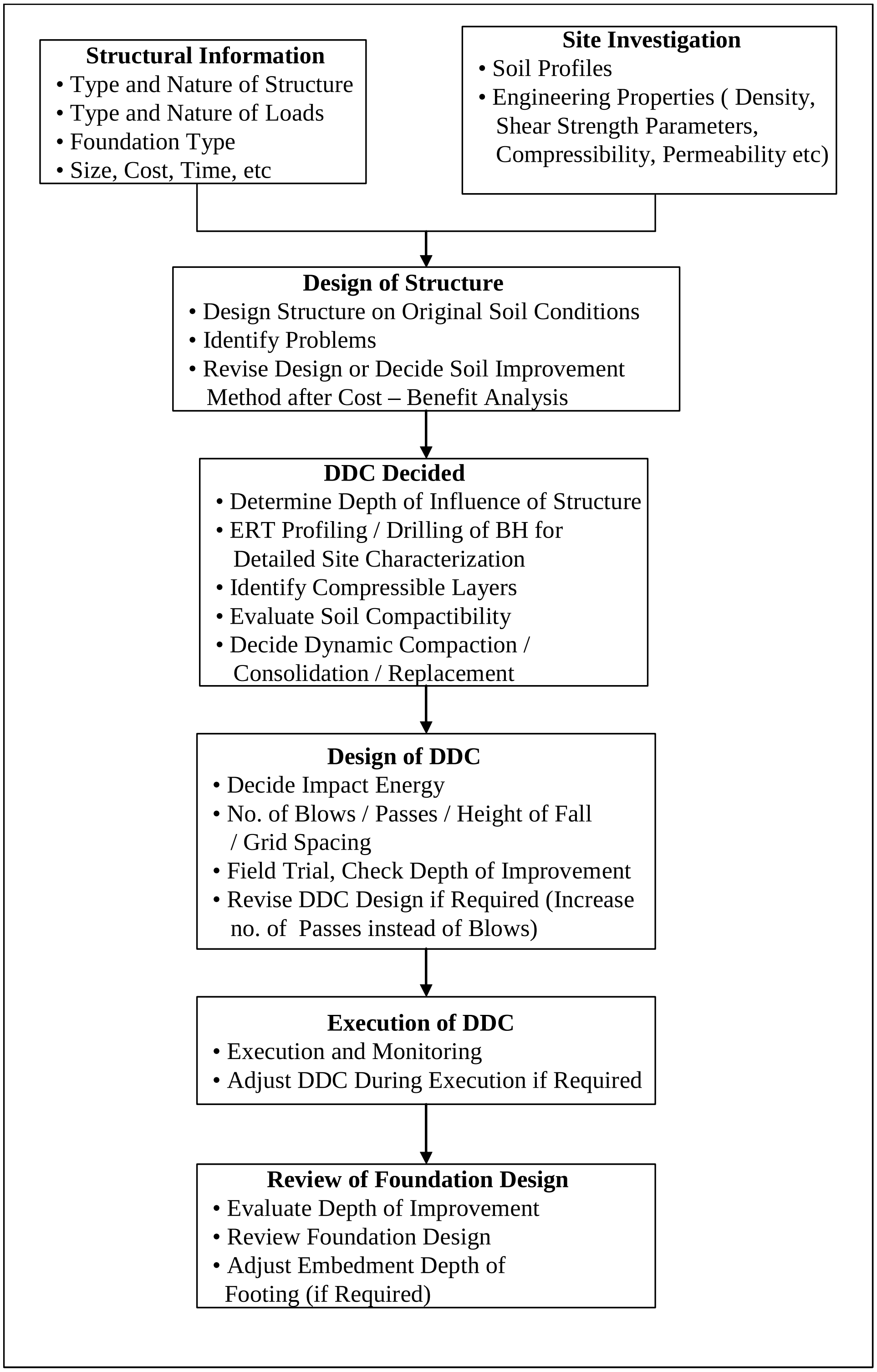

Fig.6. Geotechnical model for soil improvement projects by dynamic compaction (DDC stands for deep dynamic compaction)