CHARACTERIZATION AND EXAMINATION OF THE FACTOR CAUSING SUBSTRUCTURE COLLAPSE AT CONSTRUCTION PROCESS

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Abstract:
Foundations are the inevitable and very important component of all civil engineering structures. Foundations distribute loads to soil from the super structures. It serves as an interface between superstructure and substructure. Generally foundations are classified as shallow foundations and deep foundations. Shallow foundations often used in small to medium size buildings. Hence it is important to study about shallow foundations.
This is well known that construction structures malfunction or fall in spite of being built with adequate health and safety controls.A structure's collapse may be attrib uted to bad planning, defective design, overloads and failures of the foundation.Fo undation failure appears to the collapse of the whole system, the loss of life as wel l as the financial crisis.

Key words*: Foundation, Failure, Safety aspects, Design, Construction.*

1.INTRODUCTION

Foundations are the inevitable and very important component of all civil engineering structures. Foundations distribute loads to soil from the super structures. It serves as an interface between superstructure and substructure. Generally foundations are classified as shallow foundations and deep foundations. Shallow foundations often used in small to medium size buildings. Hence it is important to study about shallow foundations.
The following criteria are required to properly build the foundation system:

(i) Function of engineering projects, future life cycle loadings, different framing types, soil characteristics, design methods, build ing costs, and needs of customers / owners

(ii) Development without health impacts and adequate protectio n margin in relation to unpredictable incidents and volatility in de ciding soil engineering properties and satisfactory tolerable risk le vel for all stakeholders , i.e. the general public, the landlord and th e engineer.

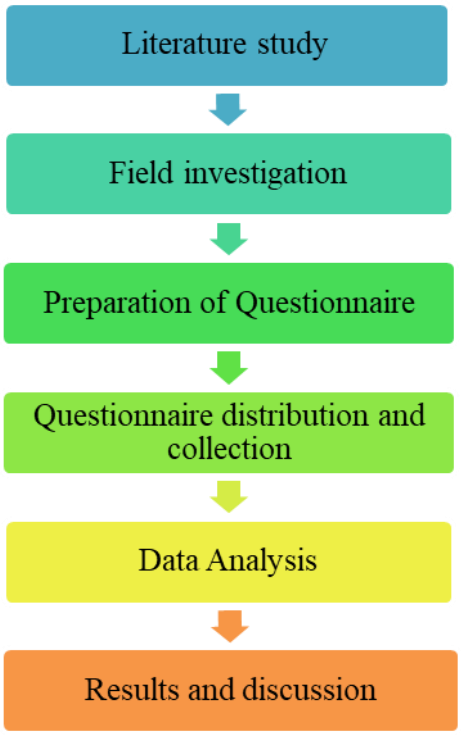
Various factors that really should be taken into consideration varies according to s pecific criteria and uses, like foundation in harsh climatic environments, soft soil, f or different loading conditions such as upholding, slipping or uplifting, concern fo r potential extension, corrosion or other hazardous material development present i n soil, suitability for resp.
It is well recognized that quality engineering collapse or crash, even if they are bui lt with
adequate health and safety precautions.If ignored or treated incorrectly, there are many factor leading to the foundation collapse, such as structural fault, insufficient soil profile, ground water level fluctuation, seismic loads, etc.

1.1 SCOPE AND OBJECTIVE

The main objective of the study is

- ❖ To identify the factors and activities that contributes to the problems / defects of foundation structure in the construction field operation.
- ❖ To investigate cost effective remedial approaches for different failure conditions of foundation.
- ❖ The study of safety aspects related to foundation in construction projects

1.2 METHODOLOGY



2. LITERATURE REVIEW

Jean Claude Tchamba and Théodore Gautier L. J. Bikoko(2016)[6] has proposed a paper. This paper elaborates various cases of building structures

collapsed and to investigate the factors causing such incidents. The methods employed in the collection of data include the administration of questionnaire to professionals in the building industry, site inspections and case studies for the sites. The data collected were analyzed using descriptive and analytical statistics. The findings show that the collapse of some buildings in major cities can be attributed to absence of soil investigation and foundation, structural design, detailing, degradation due to environmental factors, use of poor quality materials and concrete processing. In the two case studies considered, the study revealed that the major causes of building failures were excessive loading, structural design, degradation due to environmental factors and other causes. The paper concludes by recommending possible measures to be undertaken by government and other regulatory bodies in the building industry to avert this.

Marshall. R.R (2000)[9] The purpose of the project is to characterize basement envelope failures using statistics. In these paper, marshall failures as follows system type, soil type, envelope element, occurrence, severity, cause and remedial action, costs. According to Marshall and Martin (1993), foundation failures are the most costly defects in houses in Ontario. The cost in 1992 was estimated at $1.1 million dollar excluding administration costs and costs paid by builders. Finish, plumbing, windows and structural defects were the 2nd to 5th most costly, respectively. Comprehensive research had not been done for other provinces.

Nagarajan .D and Premalatha .K (2014) [11] has summaries the study that is carried out to evaluate the possible causes of distress in the Residential building founded on shallow foundation by detailed investigation. Disturbed and Undisturbed samples are collected by drilling borehole using auger. The causes of failure of the structures are identified by considering the soil properties, intensity of loading, nature of foundation and pattern of cracks developed. Based on the degree of distress, the suitable measures are also recommended.

Stephen Tien. H, David A. Eastwood(2012) [14] Residential structures are commonly experience slab movements due to highly expansive subsoil. These slab distress phenomena were caused by one primary factor or a combination of different factors, which can be divided into five major categories: design, construction, material, maintenance and wear and tear. Cases of various residential slab foundation movements evaluated, analyzed and presented systematically in this paper. In addition, sub grade soil moisture variations as well as the tree effects, and their related influences towards the foundations are further discussed.

2.1 OBSERVATIONS FROM LITERATURE

- The factors contribute to the problems/defects of foundation failure are identified through literature survey.
- Various remedial approaches for different causes of foundation failure.
- Preventive measure to avoid foundation failure.

2.2 INFERENCE FROM THE LITERATURE

- Only a few studies, in the project management literature concentrate on the factors contribute to the defects of foundation failure and cost effect due to foundation failure.
- Many of these studies generate only cause of distress to the foundation and to discuss their several remedial options; each list varies in its scope and purpose.

3. METHODS OF DATA COLLECTION

The general procedure of this study depends largely on the survey questionnaire which will be collected from the local building contractors of different places by mail or by online filling Google form. A thorough literature review was initially conducted to identify the factors that contribute to the problem/defects of foundation construction and cost effective remedial approach for different factors.

Questionnaire survey – the data was collected through questionnaire survey delegated to contractors, consultants and clients that involve in management of construction project.

E-mail Survey – the questionnaire will also be sent through email to respective respondents namely contractors, consultants and clients.

3.1 FACTORS CONTRIBUTES PROBLEM/DEFECTS OF FOUNDATION

The following factors are the impacts that contribute to the problems/defects of foundation construction in field operation.

- Load transfer failure
- Lateral loads
- Construction error
- Unequal support
- Water level fluctuation
- Vibration Effects
- Soil condition
- Inadequate geotechnical investigation and design error
- Foundation failure due to slope instability
- Other considerations (such as atmospheric action i.e. sun, wind etc.)

3.3 COST EFFECTIVE REMEDIAL APPROACHES FOR DIFFERENT FAILURE CONDITION

The following factors are the cost effective remedial approach for different failure conditions of foundation construction.

- **Load Transfer Failure** - Underpinning using steel piers, helical anchors or micro piles.
- **Unequal Support -** Resting the foundation on rigid strata such as rock or hard moorum.
- **Water Level Fluctuation -** Installation of footing drainage, sumps & surface drainage work
- **Soil Condition** - Transferring the structural loads by designing and constructing deep foundation system and Soil stabilization with lime, lime fly ash, Portland cement & bituminous material.
- **Foundation Failure Due To Slope Instability -** Modifying the geometry of slope, Provision of retaining wall and Constructing tie backs.
- **Safety Measures -** Proper planning and subsurface investigation, High quality construction, Providing proper drainage system and Proper analysis and design.

3.4 QUESTIONNAIRE SURVEY

ANALYSIS OF FOUNDATION FAILURE IN RESIDENTIAL BUILDINGS

OBJECTIVE OF THE STUDY:

- To identify the factor that contributes to the problems/defects of foundation construction field operation.
- To investigate cost effective remedial approaches for different failure conditions of foundation.
- The study of safety aspects related to foundation in construction projects.

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Note : All the information given by your company will be kept utmost confidently and it will be used only for my research purpose only. I thank you for filling the questionnaire in your valuable time.

A. Respondent's Background

1. Company Name :

2. Location :

3. Year of Working Experience in Construction Industry :

B. Based on your experience , Rank the factor that contribute to the problem/defects of foundation construction in your organization

S.No	Scale	Description
1	Very Low	Which cause negative impact 20% of an activity
2	Low	Which cause negative impact is 20% or more than 20% and less than 40% of an activity
3	Medium	Which cause negative impact is 40% or more than 40% and less than 60% of an activity
4	High	Which cause negative impact is 60% or more than 60% and less than 80% of an activity
5	Very High	Which cause negative impact is 80% or more than 80% and less than 100% of an activity

S.No	Factors	Very High	High	Medium	Low	Very Low
I	**Load Transfer Failure**					
1	Inadequate size of footing					
2	Eccentric Loading					
3	Over Loading					
4	Pressure on subsoil exceed permissible limits of subsoil					
5	Inadequate load bearing capacity of soil					
II	**Lateral loads**					
6	Lateral Movement of subsoil due to Removal of Existing side support adjacent to Building					
7	Excessive overburden of backfill					
8	Lateral thrust on the backside of the retaining wall					
9	Lateral movement due to earthquake					
III	**Construction Error**					
10	Improper construction Method i.e, unsupported excavation					
11	Poor construction quality					
12	Improper sequence of construction					
13	Error relating to temporary shoring,bracing and temporary cofferdams					
IV	**Unequal Support**					
14	Non Uniform nature of subsoil throughout the foundation					
15	Footing resting on soil having different bearing capacity					
16	Unequal load distribution of the soil strata					

V	**Water Level Fluctuation**					
17	Rise & Fall in ground water table					
18	Due to Heavy Rainfall					
19	Seepage flow					
20	Due to human activity such as uncontrolled pumping and dewatering during construction of deep basement					
VI	**Vibration Effects**					
21	Due to pile driving					
22	blasting					
23	Dynamic compaction of loose soil					
24	Operation of Heavy construction equipment					
25	Structural vibration due to earthquake					
26	Movement associated with mining activities					
VII	**Soil condition**					
27	Movements due to shrinkage and swelling of clay soil					
28	Building on the madeup soil					
29	Footing is rest on ground consisting of highly plastic soil					
VIII	**Inadequate geotechnical investigation and design error**					
30	Due to improper geotechnical investigation					
31	Design error					
32	Improper planning and execution of soil Exploration program					
33	Insufficient site investigation					

IX	**Foundation failure due to slope instability**					
34	Unstable natural or manmade slope on which structure exist					
35	Steep slope					
36	Loading the head of slope					
37	Ground water table changes and heavy rainfall					
X	**Other consideration**					
38	Due to uplift pressure					
39	Atmospheric action (sun,wind)					
40	Weathering of subsoil due to trees					
41	Soil erosion					

C. Based on your experience , rank the Remedial Measure which is cost effective when foundation fails due to different condition.

S.No	Factors	Very High	High	Medium	Low	Very Low
I	**Load Transfer Failure**					
1	Underpinning using steel piers					
2	Underpinning using helical anchors					
3	Underpinning using micro piles					
II	**Unequal support**					
4	Resting the foundation on rigid strata such as rock or hard moorum					
5	Proper design of the base footing					
6	Limiting the pressure in the soil (loads from the super structure should be within limits of safe bearing capacity of soil)					
III	**Water Level Fluctuation**					
7	Compaction of wet side of optimum moisture content					
8	Control of soil moisture using plastic fabric underneath the foundation					
9	Installation of drain layer					
10	Installation of footing drainage, sumps & surface drainage work					
IV	**Soil condition**					
11	Transferring the structural loads by designing and constructing deep foundation system					
12	Soil stabilization with lime, lime fly ash, Portland cement & bituminous material					
13	Pressure Grouting					
14	Mud Jacking					
15	Underpinning					

V	**Foundation failure due to slope instability**					
16	Modifying the geometry of slope					
17	Provision of retaining wall					
18	Constructing tie backs					

D. SAFETY MEASURES

S.No	Factors	Very High	High	Medium	Low	Very Low
1	Proper planning and subsurface investigation					
2	Strengthening and stabilizing the foundation of an existing building or other structure					
3	Proper analysis and design					
4	Construction control and supervision					
5	High quality construction					
6	Quality control and quality assurance measure instituted by field engineers					
7	Monitor-sinkhole formation					
8	Control on dewatering and ground water level					
9	Providing proper drainage system					
10	Modifying the geomentry of slope					
11	Monitor and control the ground and structural vibration					

3.5 EVALUATION OF QUESTIONNAIRE

This evaluation of the questionnaire was performed by Excel spreadsheets and Relative importance index method.

3.5.1 RELATIVE IMPORTANCE INDEX METHOD

The questionnaire survey form was designed to verify the existing methods and process which are related to the project progress monitoring. It is important at an early stage to decide for analyzing method before developing any system of data collection. The collected survey data is analysed using Statistical method. The data were collected by using measurement or Likert scale method. Five scale ranking was used to conclude the severity of influence on project progress monitoring techniques by client, consultant and contractor. This study also uses Relative Importance Index Method to analysis data of survey and explained as follows:

$$\text{Relative Importance Index} = \frac{\Sigma w}{A \, x \, N}$$

Where,

- W is the weightage given to the factors by respondents. Weightage is given as 1,2,3,4 and 5 for very low, low, medium, high and very high.
- A is the highest weight in the scale and it is given as 5
- N is the total number of respondents

3.6 DISSCUSSION

In successfully achieving main objective of the study, one of the most important phase is collection of accurate data by questionnaire survey through e-mail and online filling Google form. A total of 70 questionnaires were sent to construction professional through personnel meeting and e-mail. Of these 54 respondents were collected, the response rate was seventy seven percent. The questionnaire survey involves respondents background, factors causing defects of foundation failure and cost effective remedial approach.

4. FIELD INVESTIGATIONS

The factors to be considered in onsite investigation

- Ground/soil condition
- Presence of tree roots
- Ground water level
- Underground water courses, old drains, pits, wells, old foundation etc.
- Presence of excessive sulphate or other injurious compound in the ground water and soil.
- Rainfall Data
- Seepage

4.1 CONSTRUCTION SEQUENCE OF CONCRETE FOUNDATION

Constructional activities are one of the significance part in managerial aspects. Various

activities are involved in construction projects such as:

1. Marking of foundation layout of site
2. Earth excavation upto the required depth by means of machine
3. Earth excavation and levelling of soil by means of hand operated tools
4. Placing of PCC
5. Placement of reinforcement steel
6. Erection of concrete formworks for footing
7. Placement of concrete and vibrating and levelling of concrete surface
8. Removal of formwork after the concrete has set
9. Curing of concrete for the required number of days
10. Applying finishing coats on concrete surface.

5. RESULTS AND DISCUSSION

5.1 Factors Contribute to the Problems/Defects of foundation construction.

I. Load Transfer Failure

Based on the questionnaire data, the various factors are ranked according to their impact and significance. The factors were analyzed by Relative importance index method and excel spreadsheets.

Table 5.1 Ranking for factors about Load Transfer Failure

S.No	Factors	RII	Rank
I	**Load Transfer Failure**		
1	Inadequate size of footing	86.30	2
2	Eccentric Loading	51.48	5
3	Over Loading	61.11	4
4	Pressure on subsoil exceed permissible limits of subsoil	81.85	3

In certain condition, the most frequently accepted remedial action to address the issue is underpinning. This is the method of repairing and strengthening a current structure or any other structures. This is done by increasing the depth or breadth of the base so that it either sits on a more stable soil layer or transmits its weight over a wider area. Popular underpinning strategies are the use of steel piers, radial anchors and small piles. Each device seems to have a mechanism and construction procedure of its own.

II. Lateral Loads

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.2 Ranking for factors about Lateral loads

S.No	Factors	RII	Rank
II	**Lateral loads**		
6	Lateral Movement of subsoil due to Removal of Existing side support adjacent to Building	74.07	2
7	Excessive overburden of backfill	76.67	1

8	Lateral thrust on the backside of the retaining wall	64.07	3
9	Lateral movement due to earthquake	39.63	4

There is no remedial measure is reported in literature to overcome failures of such circumstances. But preventive measures can be taken through proper planning of subsurface investigation, analysis and design and construction control and supervision. For small scale damages underpinning of structures are suggested.

III. Construction Error

Based on the questionnaire data, the various factors are ranked according to their impact and significanc

Table 5.3 Ranking for factors about Construction Error

S.No	Factors	RII	Rank
III	**Construction Error**		
10	Improper construction Method i.e, unsupported excavation	84.81	1
11	Poor construction quality	66.67	3
12	Improper sequence of construction	82.59	2
13	Error relating to temporary shoring, bracing and temporary cofferdams	61.48	4

There's really no solution for these problems, however proactive action should be taken to reduce such failures in spite of the assisted excavation method for deep excavation issues.

IV. Unequal Support

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.4 Ranking for factors about Unequal Support

S.No	Factors	RII	Rank
IV	**Unequal Support**		
14	Non Uniform nature of subsoil throughout the foundation	78.52	1
15	Footing resting on soil having different bearing capacity	74.81	3
16	Unequal load distribution of the soil strata	77.04	2

Under such circumstances, the most commonly adopted remedial measure to rectify the problems are Resting the foundation on rigid strata such as rock or hard moorum, Proper design of the base footing and Limiting the pressure in the soil i.e. loads from the super structure should be within limits of safe bearing capacity of soil.

V. Water Level Fluctuation

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.5 Ranking for factors about Water Level Fluctuation

S.No	Factors	RII	Rank
V	**Water Level Fluctuation**		
17	Rise & Fall in ground water table	80.00	1
18	Due to Heavy Rainfall	74.81	3
19	Seepage flow	75.93	2
20	Due to human activity such as uncontrolled pumping and dewatering during construction of deep basement	51.85	4

In such circumstances, compaction of the rough side of optimal water absorption, relative humidity management using plastic material under the base are the most widely adopted remedial step to correct the problems, as well as installation of drain layer and installation of footing drainage, sumps & surface drainage work.

VI. Vibration Effects

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.6 Ranking for factors about Vibration Effects

S.No	Factors	RII	Rank
VI	**Vibration Effects**		
21	Due to pile driving	65.56	2

22	blasting	51.85	4
23	Dynamic compaction of loose soil	70.37	1
24	Operation of Heavy construction equipment	52.22	3
25	Structural vibration due to earthquake	37.41	6
26	Movement associated with mining activities	38.15	5

The reason for choosing steps for avoiding or minimising vibration issues and settlement / damage risks is to track and manage ground and structure vibrations. In this respect, offensive or defensive systems are being implemented.

VII. Soil Condition

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.7 Ranking for factors about Soil Condition

S.No	Factors	RII	Rank
VII	**Soil condition**		
27	Movements due to shrinkage and swelling of clay soil	84.07	2
28	Building on the made-up soil	78.52	3
29	Footing is rest on ground consisting of highly plastic soil	94.44	1

Under such circumstances, the most commonly adopted remedial measure to rectify the problems are Transferring the structural loads by designing and constructing deep foundation system, soil stabilization with lime, lime fly ash, portland cement & bituminous material, pressure grouting , mud jacking and underpinning.

VIII. Inadequate Geotechnical Investigation and Design Error

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.8 Ranking for factors about Inadequate Geotechnical Investigation and Design Error

S.No	Factors	RII	Rank
VIII	**Inadequate geotechnical investigation and design error**		
30	Due to improper geotechnical investigation	86.67	1
31	Design error	60.37	4
32	Improper planning and execution of soil	77.78	3
33	Insufficient site investigation	82.22	2

In order to safeguard the building and to properly plan the structure and effective super-structure framework, careful subsurface investigation is necessary.

IX. Foundation failure due to slope instability

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.9 Ranking for factors about Foundation failure due to slope instability

S.No	Factors	RII	Rank
IX	**Foundation failure due to slope instability**		
34	Unstable natural or manmade slope on which structure exist	70.37	1
35	Steep slope	68.89	2
36	Loading the head of slope	65.93	3
37	Ground water table changes and heavy rainfall	57.04	4

Under these situations, the perfect method to rectify the problem are modifying the geometry of slope, provision of retaining wall and constructing tie backs.

X. Other consideration

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.10 Ranking for factors about Other consideration

S.No	Factors	RII	Rank
X	**Other consideration**		
38	Due to uplift pressure	64.07	3
39	Atmospheric action (sun,wind)	63.33	4
40	Weathering of subsoil due to trees	83.33	1
41	Soil erosion	82.59	2

5.2 Rank The Remedial Measure Which Is Cost Effective When Foundation Fails Due To Different Condition.

I. Load Transfer Failure

Based on the questionnaire data, the various factors are ranked according to their impact and significance.

Table 5.11 Ranking Remedial options about cost for load transfer failure

S.No	Factors	RII	Rank
I	**Load Transfer Failure**		
1	Underpinning using steel piers	90.37	1
2	Underpinning using helical anchors	59.29	2
3	Underpinning using micro piles	51.85	3

II. Unequal Support

Table 5.12 Ranking Remedial options about cost for unequal support

S.No	Factors	RII	Rank
II	**Unequal support**		
4	Resting the foundation on rigid strata such as rock or hard moorum	84.44	1

5	Proper design of the base footing	67.04	3
6	Limiting the pressure in the soil (loads from the super structure should be within limits of safe bearing capacity of soil)	78.89	2

III. Water Level Fluctuation

Table 5.13 Ranking Remedial options about cost for water level fluctuation

S.No	Factors	RII	Rank
III	**Water Level Fluctuation**		
7	Compaction of wet side of optimum moisture content	88.15	1
8	Control of soil moisture using plastic fabric underneath the foundation	64.81	2
9	Installation of drain layer	53.7	4
10	Installation of footing drainage, sumps & surface drainage work	61.85	3

IV. Soil condition

Table 5.14 Ranking Remedial options about cost for soil condition

S.No	Factors	RII	Rank
IV	**Soil condition**		
11	Transferring the structural loads by designing and constructing deep foundation system	86.3	1
12	Soil stabilization with lime, lime fly ash, Portland cement & bituminous material	82.59	2
13	Pressure Grouting	65.93	4
14	Mud Jacking	60	5
15	Underpinning	80.74	3

V. Foundation failure due to slope instability

Table 5.15 Ranking Remedial options about cost for slope instability

S.No	Factors	RII	Rank
V	**Foundation failure due to slope instability**		

16	Modifying the geometry of slope	64.44	1
17	Provision of retaining wall	57.41	2
18	Constructing tie backs	47.04	3

5.3 Rank the safety measures in order to avoid foundation failures

Table 5.16 Ranking for safety

S.No	Factors	RII	Rank
1	Proper planning and subsurface investigation	79.63	2
2	Strengthening and stabilizing the foundation of an existing building or other structure	82.22	1
3	Proper analysis and design	77.78	6
4	Construction control and supervision	71.85	9
5	High quality construction	78.89	3
6	Quality control and quality assurance measure instituted by field engineers	76.67	7
7	Monitor-sinkhole formation	70.37	10
8	Control on dewatering and ground water level	78.52	5
9	Providing proper drainage system	75.93	8
10	Modifying the geomentry of slope	70	11
11	Monitor and control the ground and structural vibration	78.89	3

6. CONCLUSIONS AND DISSCUSSION

6.1 GENERAL

There are many factors in the construction project that influences the factors contribute to the problem of foundation failure and cost effective remedial approach option. From these factors, the top factors are identified and discussed in this project.

6.2 CONCLUSIONS AND DISSCUSSION

In this research, the paper reviewed the investigation of the present conditions for construction and identified the problems with foundation that occurs at construction field operations. The study of safety aspects related to foundation in construction. The Questionnaire survey was conducted to identify the factors that contribute to the problem/defects of foundation construction and

also to find cost effective remedial approach for different failure condition. The questionnaire survey data were evaluated by Relative importance index and analysed by excel spreadsheets.

Based on the analysis of the findings of investigations conducted on collapsed buildings (structures), the following recommendations were drawn:

- A preliminary geotechnical investigation should be carried out before design. Prohibiting the use of quacks or of non-professionals in building construction.
- Construction materials quality control check should be made before commencement of using.
- Getting approval before commencing construction on site.
- Inspection of construction site should be enforced at the local government authorities and relevant government departments to ensure compliance with approved building plans.

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