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# Geotechnical Mapping of Expansive Soil Problems Associated With Damages in Low Rise Buildings along South East Coast of India

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***Abstract*— This topic is involved in the subsurface site investigation to characterize different soil formations with particular emphasis on the swelling characteristics of the clays. The data were input into a geographic information system GIS with interactive maps. These maps are used to identify the swelling potential at various locations of puducherry with the study of damages in the form of cracks identified. The efficiency is very high when using computer techniques. Engineering properties of an expansive soil are investigated using in situ and compacted samples. The objective of the topic is to discuss the factors influencing the swelling behaviour and the associated damage in low rise buildings. The allowable and prediction of such damages in residential buildings is presented in terms of engineering properties and associated damage. Presence of high plastic clay indicates the existence of expansion soil problems. Expansive soils all over the world cause serious problems on civil engineering structures which lead to lakhs of amount to rectify the damage problems associated in the buildings. Soil properties mapped in this study which influence the damage potential of the engineering structures are clay mineralogy, liquid limit, plastic limit and initial water content, plasticity index, dry density. Environmental factors and initial moisture content, climate, Ground water drainage conditions and vegetation and soil profile of clay soil of the study are made in the database. So knowledge of this soil characteristic to the public will be useful to choose correctly the right type of foundations and right time to progress the stages of constructions.**

***Keywords*— Swelling characteristics, Damages, Low rise Buildings, GIS with interactive maps**

## I. INTRODUCTION

### *A. Background*

Expansive soils pose a significant hazard to foundations of buildings founded in them. Such soils can exert uplift pressures which cause considerable damage to lightly loaded structures. The annual cycle of wetting and drying causes the soil to swell and shrink. Thus, the arid and semi-arid regions are much susceptible to damage from expansive soils throughout the year. Unfortunately, this area includes most of the nation's population cities and development projects. Many houses belonging to various regions around Pondicherry were damaged due to soil heave and differential settlement in foundation.

Generally, the damage will result in economic loss for building owners and the country at large scale. Although the accusing finger is mainly pointed at the expansive soils, other contributing factors such as poor design, poor construction, inadequate supervision of the construction processes, poor drainage, gardens and big trees close to the building, and climatic factors have contributed to the problem. Some existing residential buildings suffered from damages by expansive soils were visited. Essentially expansive soil is one that changes in volume in relation to changes in water content. Here the focus is on soils that exhibit significant swell potential and in addition shrinkage potential also exists. [9]. Many towns, cities, transport routes and buildings are founded on clay-rich soils and rocks. The clays within these materials may be a significant hazard to engineering construction due to their ability to shrink or swell with changes in water content. Changing water content maybe due to seasonal variations or brought about by local site changes.

During a long dry period or drought a persistent water deficit may develop, causing the soil to dry out to a greater depth than normal, leading to long-term subsidence. The structures most susceptible to damage caused by expansive soils are usually lightweight in construction. Houses, pavements and shallow services are especially vulnerable to damage because they are less able to suppress differential movements than heavier multi-story structures. Excluding deep underground excavations (e.g. tunnels), shrinkage and swelling effects are restricted to the near-surface zone;

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significant activity usually occurs to about 3m depth, but this can vary depending on climatic conditions. The shrink–swell potential of expansive soils is determined by its initial water content; void ratio; internal structure and vertical stresses, as well as the type and amount of clay minerals in the soil. In a partially saturated soil changes in water content, or suction, increase the chances of damage occurring significantly. [4]

When soils with a high expansive potential are present they will usually not cause a problem as long as their water content remains relatively constant. This is largely controlled by:

- Soil properties, e.g. mineralogy
- Suction and water conditions
- Water content variations both temporally and spatially
- Geometry and stiffness of a structure, on particular its foundation.[6]

### *B. Scope*

To provide guidance and information necessary for the selection and design of foundations for buildings constructed in expansive clay soil areas by geotechnical investigation. It educates the owner of a building constructed in expansive soil to choose appropriate construction techniques which minimizes the future damages the building might go through due to the nature of expansive soil. Furthermore, the geotechnical investigation might financially protect many residents if the nature of the soil is known by the land owner. It also gives the general idea of the topography present in an area which might help the land buyers.

### *C. Aims and objectives*

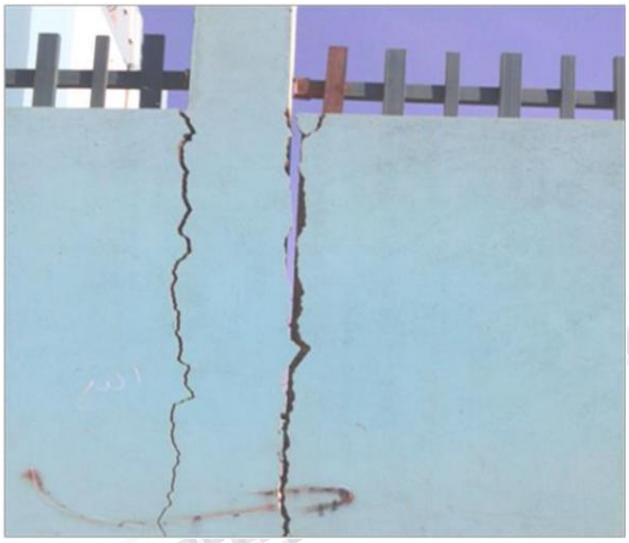
- To explore the subject of soil mapping.
- To discuss the engineering properties of expansive soils
- To explore factors influencing swelling
- To discuss the associated damage in buildings
- To explore the nature of expansive soils

## II. BRIEF DETAILS OF CASE STUDY AREA

The selected case study area is around Pondicherry nearing 20 Km from the center of the town. Apparently the soil condition of the study area was identified as clay soil of high compressibility. Three distressed building were taken for case study and Salient details of the selected buildings are given in Table 2

## III. LITERATURE

Basic soil properties and parameters can be sub-divided into physical, index, and engineering categories. Physical soil properties include density, in-situ density, particle size distribution, specific gravity, and water content. Index parameters of cohesive soils include liquid limit, plastic limit, shrinkage limit, and activity. Such parameters are useful for classifying cohesive soils and providing correlations with engineering soil properties. [2] Different Buildings experience various levels of damages during their life time. Damages may occur within a few months following construction, may develop slowly over a period of about 5 years, or may not appear for many years until some activity occurs to disturb the soil moisture.[10]



**Damage Category: Severe**, vertical cracks appeared at the joint between column and masonry wall of the fence.

**Damage Category: Severe**. Deep cracks appear in the exterior walls of the building

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**Damage Category: Very severe**. Serious cracks around window in the interior wall [10]

Soil mapping involves locating and identifying the different soils that occur, collecting information about their location, nature, properties and potential use, and recording this information on maps and in supporting documents to show the spatial distribution of every soil.[12]. Digital soil mapping is the prediction of soil classes or properties from point data using a statistical algorithm. The digital soil map is a raster composed of 2-dimensional cells (pixels) organized into a grid in which each pixel has a specific geographic location and contains soil data. Damages and its severity[10] presented inTable No. 1-Many extensive studies were carried out to analyze the factors affecting the swelling of clayey soils [3] The major factors affecting the swelling of such soils are concerned with the physical properties and the mass of soil, such as initial water content, type of clay mineral, initial dry density, and type of coarse grained fraction. The cost of damages arising from expansive soil problems in the United State alone amounts to $2.3 billion annually [5]. Additionally, a limited number of studies were concentrated on swelling maps especially using geographical information system (GIS)-based programs. This problem has often been observed especially for the canal structures constructed in the irrigation areas of Harran plain. Besides, important engineering applications related to the subject have been achieved and knowledge has been obtained[17] GIS is frequently used for spatial data management and manipulation. GIS has become a prevalent method of analysis in civil projects. Flexible GIS models that manipulate compile and process spatial data above or below the earth's surface, have provided a powerful tool in civil engineering applications. This will help in identifying different potential hazards that will affect development in the area, especially for urban development, activities and industrial projects, requiring irrigation canal and highway constructions. In other words, GIS can be used for many geotechnical applications [18]. On the basis of office study, boring locations are determined conducted to be used in precise modeling of the study area and be evaluated in GIS media. To determine the swelling potential of expansive soil clay, geotechnical testing program was performed on the samples obtained from different locations in east coast of Puducherry India. As a result of this study, the values of swelling percentages determined for each location are used for obtaining the swelling potential and damages observed in the map of the area by means of a GIS program.

## IV. METHODOLOGY

### *A Locations of expansive soil samples.*

The study was carried out in the subsequent stages like reconnaissance survey, building inspection and laboratory testing of soil samples collected from the study areas and finally the analysis using all the possible criteria are used in the building systems for evaluating the sources of cracks and their general progression consequences on the building [16]. samples were collected in regions confined to Puducherry and their approximate locations are marked in the map given below in Fig 9 The reconnaissance survey was aimed at studying the close environment of the building in question, and building inspection was carried out to diagnose the distress i.e. Cracks in the buildings based on their location, width, depth, orientation and patterns are measured in Fig 1 to 3. All measurements for the above were based on standard methods.

Soil samples were collected from three different locations in each case study buildings at depths ranging from 1-1.5m location 1 to 3 Physical and engineering properties of soil sample were determined adopting relevant IS Codes. The soil samples were collected and then analyzed. The detail analysis reports of soil profile were prepared by "ATLANTA CONSTRUCTION CONSULTANTS". Tests were carried out to find,

- Plastic limit
- Liquid limit
- Free swell index
- Grain size analysis

### *B. Mapping of the visited houses using arcgis pro*

Mapping of the collected data can be carried out in a suitable GIS (Geographic Information System)Software. Some of the well-known commercial GIS software used for mapping are:

- ArcGIS (Esri)
- Geomedia (Hexagon Geospatial)
- MapInfo Professional (Pitney Bowes)

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- Global Mapper (Blue Marble)
- Manifold GIS (Manifold)
- Smallworld (General Electric)
- Bentley Map.
- MapViewer and Surfer (Golden Software)

Although there are surplus software available for GIS, most of them are not open source. While Open source GIS softwares are available, when compared to the softwares mentioned above. With the help of the information gathered, the Residential buildings are mapped with the help of ArcGIS Pro software. The degree of damage is mapped to the respective buildings accordingly. The locations of the houses are mapped in a 2D map as point data.in Fig 5 They are located accordingly with latitude and longitude. The collected data are included in the mapped point data as attribute values. The houses are mapped as a new feature class with house symbology shown in Fig 6. Graticules are lines showing parallels of latitude and meridians of longitude for the earth Fig 7. They are used to show location in geographic coordinates (degrees of latitude and longitude). Measured grid is a network of evenly spaced horizontal and vertical lines used to identify locations on a map. They are used to show location using projected coordinates.

## V. RESULTS AND DISCUSSIONS

### A. Reconnaissance survey

The reconnaissance survey was intended to study the close environment of the building and the influence of matured trees and drainage system over the structure with respect to the crack development was analyzed. Soil samples from three buildings were collected for laboratory testing, which were selected for the study.

The preliminary survey indicates that whether the building was constructed on water logged area. The Soil Strata across the Site was very essential for a detailed Soil Investigation [15] and the formation is identified to be covered with lightly layered silt and clay. Matured trees found near the building and the drainage systems are concrete lined channels within the building. Therefore the cracks may originate either by ingress of tree roots or due to lack of proper drainage system in the buildings and the variations of moisture in the subsurface soil below the foundation.

### B. Building inspection

A total of three low rise residential buildings constructed on clayey soil were chosen to be investigated all of which are given below. Investigation of the building and an interview with the owner made it clear that the degree damage of damage was severe. It was a typical rectangular shaped building with a built up area of 950 square feet. It appears to be constructed on a spread foundation with stepped footing. It appears the owner was has not taken any precautions in the constructions of the building. According to the owner, the building was constructed on the year 1990.The image in Fig 1-Ais the supposed balcony of the building upon construction where its railing was deteriorated with time.severe edge lift and heaving is present in the building. Open Side drain present adjacent to the building increases the moisture content and humidity around the building. During the transition period from rainy season to spring season, the building suffers central heaving and edge lift. The building was constructed on the year 1995 with built up area was approximately 1500 square feet. No offset was provided around the building. Spread foundation with pad footing and approximately 1m the depth of the foundation shown in Table 2. Horizontal and vertical cracks were observed at random locations on the building. Geotechnical investigation of the land was not conducted prior to the commencement of the construction. Overall, the degree of damage felt by the owner seems to be moderate as in Fig 2-a and Fig 2-B. Open Side drain present adjacent to the building which likely increases the moisture content and humidity around the building. Two trees at either side of the entrance were present. According to the owner, repairs were attended about 8 years ago which costed about 30,000/- INR . The repairs carried out consists of plastering of cracks and a new painting job. During the transition period from rainy season to spring season, the building suffers central heaving and edge lifted up seen in Fig 3-A . The building was constructed in 2005 which is fairly new compareed to the other two buildings. The building was rectangularly shaped and had about 2 meters of offset allround the building. The built up area was approximately 750 square feet. Spread foundation with pad footing was used for construction and the depth of the foundation was approximately 1 meter depth. In addition to other buildings, a moderate damage was recorded. The building is well maintained and repairs are carried out yearly. Plastering and new painting job are done yearly. Horizontal and verical cracks were observed and the walls show moderate to severe damage.

### C. Laboratory test results

Results of the tests conducted on the disturbed and undisturbed soil samples collected from case study locations 1 to 3 are summarized and given in Table 6 and Table 9. It is seen that the liquid limit (LL) of soil samples are greater than 50 and hence they are classified as ‘silt and clays of high compressibility’ i.e. ‘CH’ soil as per IS code which was earlier suggested by [11]. The shrinkage limit (Sl) value

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of three samples indicate 'high shrinkage'. Further, it is seen that the natural moisture content is three times less than the liquid limit of the soil specimens in the 2 locations. This shows that the clay layer has undergone substantially moderate to severe desiccation [17], which is responsible for causing distress in buildings in these locations.

## VI. CONCLUSIONS

Various soil samples locations around Puducherry were analyzed with soil profiles. Residential buildings were visited selectively; the associated data were collected and mapped in the ArcGIS Pro software. After having assessed all the findings in the project. It is concluded that the associated damages in the buildings constructed on the expansive soil can be summarized under the following reasons,

1) Changes in water content,
2) Poor drainage affecting foundations
3)Leaks due to sewer failure or poorly managed runoff
4) Poor construction practice,
Insufficient edge beam stiffness
Inadequate slab thickness
Lack of reinforcement making structure intolerant to movements
Void space inadequate
5) Lack of appreciation of soil profile,

Therefore,It is possible to build successfully and safely on expansive soils if stable moisture content can be maintained or if the building can be insulated from any soil volume change that might occur. The procedure for success is as follows:

• Testing to identify any problems
• Design to minimize moisture content changes and insulate from soil volume changes
• Build in a way that will not change the moisture conditions of the soil
• Maintain a constant moisture environment after construction.

So knowledge of this characteristic soil to the public will be useful to choose correctly the right type of foundations and right time to progress the stages of constructions.

## VII. VI FIGURES

PHYSICAL OBSERVATION OF CRACKS PATTERN

LOCATION 1

**FIG. (1-A) GEOMETRY AND STIFFNESS OF THE STRUCTURE**

***FIG (1-B) SEVERE EDGE LIFT AND HEAVING***

LOCATION 2

**FIG. (2-A) GEOMETRY AND STIFFNESS OF THE STRUCTURE**

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**FIG (2-B) CRACKS IN THE EXTERIOR WALL HEAVING**

LOCATION 3

***FIG. (3-A) GEOMETRY AND STIFFNESS OF THE STRUCTURE***

***FIG (3-B) CRACKS IN THE INTERIOR WINDOWWALL***

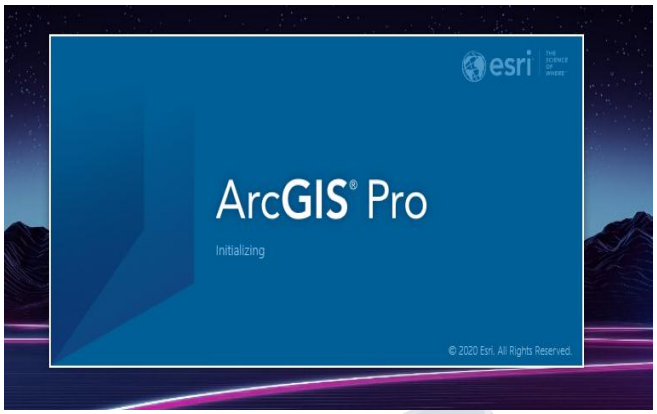


***FIG 4: SPLASH ART DISPLAYED AT THE START-UP OF ARCGIS PRO SOFTWARE***

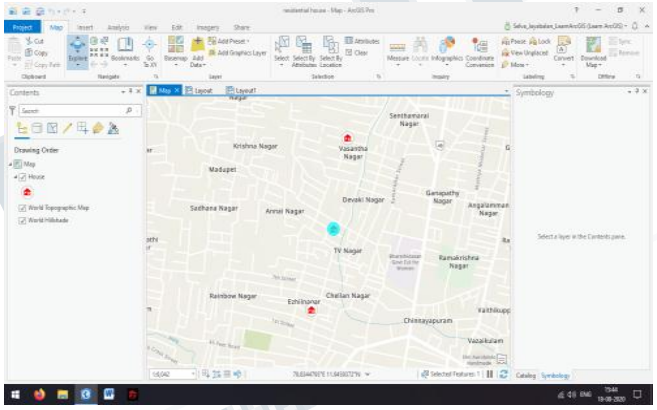

***FIG 5: SHOWS THE COMMON LAYOUT OF THE ARCGIS ALONG WITH MAP***

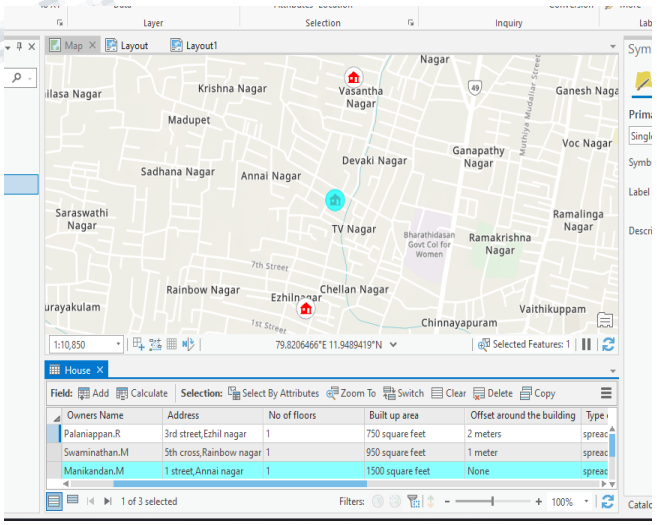


***FIG 6: MAPPED RESIDENTIAL HOUSES ALONG WITH THE ASSOCIATED DATA TO THE INVESTIGATED SITE***

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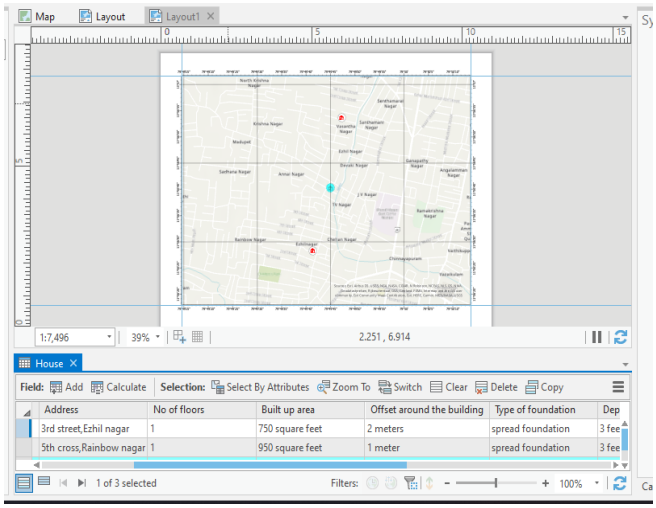


*FIG 7: THE MAPPED DATA WITH GRID AND GRATICULES.*

***LOCATIONS***

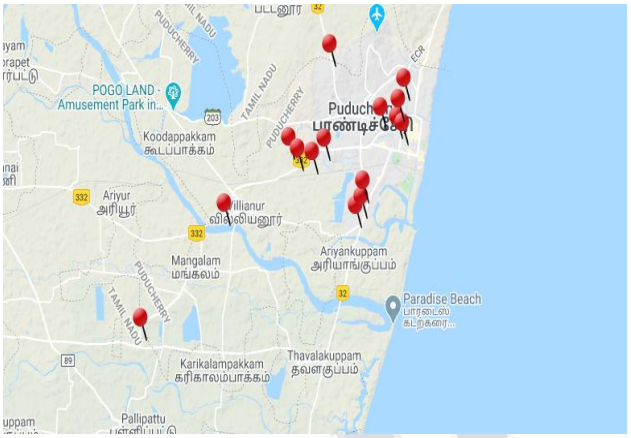


*FIG 9 LOCATION OF SAMPLES COLLECTED*

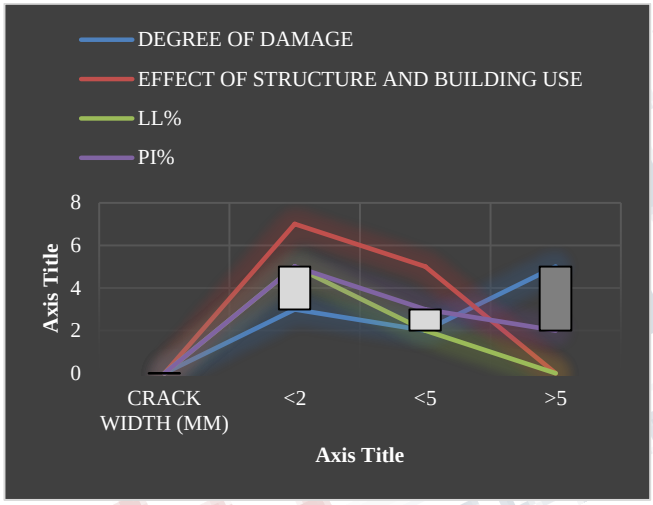


*FIG 8 MAPPING OF DAMAGES IN THREE*

## VIII. TABLES

**TABLE 1: *CATEGORISATION AND CLASSIFICATION BASED ON WIDTH OF CRACKS***

| Degree of Damage | Description of damage | Effect of damage on building | Crack width(mm) |
|---|---|---|---|
| Insignificant | Hairline cracks | None | |
| Very slight | Fine cracks | None | |
| Slight | Cracks are visible and easily filled. Several slight fractures may appear inside of the building. Doors and windows may stick | Aesthetic only | |
| Moderate | Cracks that require opening up and patching. Possible replacement of a small amount of brickwork. Doors and windows stick, service pipes may fracture | May affect serviceability and stability of the building | |

| | | | |
|---|---|---|---|
| Severe | Large cracks require extensive repair work involving breaking-out and replacing sections of walls. Windows and door frames distort and floor slopes are noticeable. Leaning or bulging walls. Beams lose some bearing. Utility service disrupted | Serviceability and stability of the building at risk. | |
| Very severe | Major repair involving partial or complete rebuilding. Beams lose bearing, walls lean badly and require shoring and windows are broken with distortion | There is a danger of structural instability | |

Based on width of cracks identified from the case study, the categorisation and classification of visible damages can be stated based on the literature support, by Burland et.al (1997).

**TABLE 2:** ***SALIENT DETAILS OF THE SELECTED BUILDINGS FROM CASE STUDY***

| ETAILS | LOCATION 1 | LOCATION 2 | LOCATION 3 |
|---|---|---|---|
| PLACE IN PONDICHERRY | RAINBOW NAGAR | KRISHNA NAGAR | EZHIL NAGAR |
| SITE CONDITION | DRY | DRY | DRY |
| NO.OF STOREY | SINGLE STOREY | SINGLE STOREY | SINGLE STOREY |
| TYPE OF STRUCTURE | MASONRY | FRAMED | FRAMED |
| AGE OF BUILDING IN YEARS | 25 | 20 | 15 |
| OFFSET ALROUND BUILDING | 1 M | NO SPACE LEFT | 2 M |
| TYPE OF FOUNDATION | SPREAD FOUNDATION | COLUMN FOUNDATION | COLUMN FOUNDATION |
| DEPTH OF FOUNDATION | 1 M | 1 M | 1 M |
| STRUCTURE USE | RESIDENTIAL | RESIDENTIAL | RESIDENTIAL |

**TABLE:3:** ***ASSOCIATED DAMAGE IN LOCATION 1(L1)***

| Name of the element | Description | Size (mm) (approx) |
|---|---|---|
| Walls | Presence of Several slight fractures inside of the building | 3 |
| Ceilings | Cracks noticed are similar to that noticed in the walls | 5 |
| lintels | Major crack noticed in one of the lintels. | 5 |
| floor | Signs of heaving noticed in hall. | 7 |
| Degree of Damage: Severe. | | |

**TABLE:4:** ***ASSOCIATED DAMAGE IN LOCATION 2(L2)***

| Name of the element | Description | Size (mm) (approx) |
|---|---|---|
| walls | Hairline cracks and very minor cracks noticed | 2 |
| ceilings | Very minor cracks noticed | 2 |
| lintels | Small cracks noticed in lintels | 3 |
| floor | Seasonal presence of heaving | 5 |
| Degree of Damage: Moderate | | |

**TABLE:5:** ***ASSOCIATED DAMAGE IN LOCATION 3 (L3)***

| Name of the element | Description | Size (mm) (approx) |
|---|---|---|
| walls | cracks noticed | 5 |
| ceilings | Nothing visible to naked eye | None |
| lintels | Minor cracks noticed | 2 |
| floor | No heaving | - |
| Degree of Damage: Moderate | | |

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**TABLE 6:** ***RESULTS OF THE LABORATORY TEST ON SOIL SAMPLES FROM LOCATION 1 TO 3***

| LOCATION | LL % | PL% | PI% | SL% | PR | $\gamma_d$ KN/$m^3$ | Clay% | Silt % | OMC% | G | FS % | SOIL CLASSIFICATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 51.00 | 19.41 | 31.59 | 9.35 | 2.63 | 15.40 | 69.20 | 30.80 | 16.30 | 2.35 | 47.62 | CH |
| L2 | 55.00 | 24.90 | 30.10 | 8.70 | 2.21 | 14.23 | 72.00 | 28.00 | 35.80 | 2.22 | 42.90 | CH |
| L3 | 68.00 | 54.00 | 14.00 | 10.01 | 1.26 | 15.85 | 64.81 | 35.19 | 23.40 | 2.66 | 73.00 | CH |

**TABLE 7: QUESTIONAIRE PRESENTED BY THE OWNER OF THE BUILDING IN LOCATIONS**

| DESCRIPTION | LOCATION 1 | LOCATION 2 | LOCATION 3 |
|---|---|---|---|
| Type of material In The Basement Filling | Sand | Sand | Sand |
| Lintels | provided | provided | provided |
| Damages in lintel | Severe damages observed | Moderate ,presence of vertical cracks | Presence of hair line cracks |
| Cracks In The other Elements In The Building | Walls, floors and ceilings | Walls, floors and ceilings | Hairline cracks and slight vertical cracks |
| Repairs attended and Time | Maintenance done every 5 years but had no impact | Major repair attended two years before | |
| Type of Repair Technique applied | plastering of cracks | Plastering of the cracks, New painting job | Plastering of visible cracks and painting works |
| Approximate Repair Cost spent | 20,000/- INR | 30,000/- INR | 15000/-INR |
| Degree Of Damage | Severe | Moderate | Moderate |

**TABLE 8**

MAPPING OF DAMAGE DETAILS OF THREE LOCATIONS

| LOCATION | LL% | PI% | CRACK WIDTH (MM) | DEGREE OF DAMAGE | EFFECT OF STRUCTURE AND BUILDING USE | measured width of crack-walls in mm | measured width of crack-floor in mm | measured width of crack-ceiling in mm | measured width of crack-lintel in mm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 51 | 31.59 | <2 | slight to moderate | accelerated weathering | 3 | 7 | 5 | 5 |
| 2 | 55 | 30.1 | <5 | moderate | affect serviceability | 2 | 5 | 2 | 3 |
| 3 | 58 | 14.00 | >5 | severe | stability may be at risk | 5 | 0 | 0 | 2 |

**TABLE 9: Degree of swelling potential in relation with PI% by Carter and Bentley (1991)**

| Samples in location | Plasticity index | % swell | Classification of Swelling potential |
|---|---|---|---|
| L1 | 31.59 | 10.03 | High |
| L2 | 30.10 | 8.92 | High |
| L3 | 14.00 | 1.38 | Low |

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