International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

An Evaluation Study of Problems and Practices of Shallow Foundations for Combined Flood, Earth quake and Settlement Prone Areas

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Abstract: ***The development of cities along the bank of river is the common characteristics of all Indian cities developed in the past. Earthquakes are quite common in cities located at the foothills of a hill/mountain range due to its location near the hill/mountain. Settlement and development of cracks in buildings and foundations is the symptom left behind by the earthquake/flood. The low lying areas near the water body are also settlement prone as the construction of foundation of buildings takes place on filled up/unstable or weak soil. The combined effect of flood, earthquake & settlement makes extremely difficult to adopt the techniques of either flood resistant buildings or earthquake resistant buildings. Though all the problems cannot be solved but the life threatening collapses can be prevented and damage limited to repairable proportions can be achieved by adopting the proper remedial measures. In this paper through the evaluation study of Gorakhpur city located at the foothill of Himalayan Hill Range, the possible damages &remedial measures/practices of foundations adopted in flood prone, earthquake prone &settlement prone areas in individual cases, an attempt have been made to search the solution of problems in the development for building foundations subjected to combined effect of flood, earthquake &settlement. An innovative foundation technique based on the use of stone ballast, sal wood sleepers ,which have long lasting life, stone masonry work in foundation and use of coarse sand needs to be designed/developed for the shallow foundations in flood plus earthquake and settlement prone area.***

Keywords: Flood, earthquake & settlement prone area, Stone ballast, Wood sleepers.

1. Introduction

The cities located at the foothills of mountain or hill ranges are subjected to the flood due to the maximum intensity of river water flow which passes through the steep slope and covered a very small distance from its origin. In addition to this as a result of heavy rainfall in the hill area during rainy season and the release/disposal of excess water after filling of reservoir/pits in the catchment of the river makes the severe flood situation. These cities are also earthquake prone areas due to its locality. After the flood/earthquake event the geo-technical and structural conditions of the foundation can be a deciding factor as to whether a building can or should be improved or need extensive repair or retrofitting and that must be thoroughly evaluated ahead of time as the extensive repair or improvement in the condition is quite expensive. Though a certain amount of tilt or some cracks in old buildings is permissible after stopping the settlement but a thorough analysis in context to the size &age of the building, foundation condition, changes in use including investigation of construction records, survey of foundation and foundation walls, report of damage, settlement including time dependent settlements, visual (crack) surveys and foundation survey etc. is essential. In addition to it foundation load, measurements of ground water level, pore water pressure, vibration ,stress measurements in existing tension members, leveling and straightening of foundation and other walls should be ensured before the modification of the foundation is carried out.

2. Foundation Problems

The strength and durability of a soil or rock lies by the quantity and distribution pattern of the smallest and weakest particle or mineral. Due to flood the erosion of the soil takes place resulting the original soil a conglomeration of loose particles. Foundations with lime/clay mortars when repaired with cement mortar does not perform well due to moisture absorption capacity of lime/clay mortar .and poor non breathing and air escape capacity of the cement mortar thus a disturbed moisture balance in foundations. One of the primary cause of the settlement of foundation is lowering of the ground water table which enable the increased stresses in the soil ultimately result the compression of the compressible soil. When a buildings constructed partly on stable soil and partly on filled up/weak soil differential settlements occur causing the cracks spreading up through the various floors and, as a worst case affect the stability of the entire building. Earthquake causes ground movement which is the primary cause of damages /failures of the structures. When the ground shakes at the building sites the foundation and the surrounding grounds vibrate in the same way. In the earth quake movement of few seconds many types of seismic waves combined to vibrate the buildings in different ways due to the geological nature and overall shaking of different sites.

2.1 Foundation Damages Due to Flood/Moisture

The moisture absorption of the most porous building material i.e. bricks leads to the, as frost damage materializes by ex-foliation or splitting of the surface ultimately resulting the salt washing, deterioration or total destruction of bricks. The various factors affecting the brick resistance against frost includes material properties i.e. pore distribution, water absorption, moisture, number of freeze-thaw cycle, freezing speed and climate.

Figure 1: Damage of Brick Foundation Due to Wet Soil /Drainage Problem

The damage of wood due to thriving of nutrients found in woods by fungus, fungus rot is the most common reason for the deterioration of wooden member. For fungus to grow the essential requirements are availability of oxygen, presence of at least 20 percent water of the dry wet of wood and temperature range 0-40 ^{0}C.When the water table is at the top of the foundations ,the fungus rot is observed in case of pile &raft foundation. Boring beetles and carpenter ants are the insects that do most damages on wooden foundation above ground level and foundations subjected to rotting defect. Old building foundations generally in low lying areas lies higher than the original terrain and surrounded by filled up soil or waste suffers from the adverse effect of moisture/flood damages. The flood water/moisture penetrates up or out through the foundation walls can freeze and breaking/deterioration of the old mortar takes place either by crumbling of old mortar or by losing of old mortar binding ability. The complete mortar damage / torning into pieces are possible in case of cores of the box wall foundations. Traveling moisture in foundation wall can carry soluble salts of the mortar and foundation materials at the outer surface where the water evaporates and salt crystallizes. These salt build up can flake off the mortar or surface of the bricks and other building materials used in foundations.

Figure 2 : Brick Foundation Damages Showing the mortar damages due to flood

2.2 Foundation Damages Due to Settlement

Ground water table depression may be due to ice static rebound, de-watering of ground water, existing ditches and pipes below the ground water level, construction of new buildings with deep foundation and basement, built up area having covered surface with asphalt roads and parking areas, reaching of much smaller portion of rainfall as ground water and pulling of ground water by deciduous trees with large& deep root system. Ground with limited bearing capacity can start to settle even in the construction phase which can be observed by the settlement of the foundation or development of cracks in the foundation walls. Differential settlements occur due to uneven depth of the bed rock, excavations under foundations, poor backfill, high loads and unfavorable ground conditions i.e. just excavating down foundation level.

Figure 3: Development of cracks In Buildings Due to differential Settlement of Foundations

After change in the load conditions in the form of use change the buildings which have stood without damage for many years can experience settling. Developments in the neighboring houses in the form of either the removing the houses or excavation below the foundation of the existing building left the existing building without support. The stability of the existing building can have serious consequences and slide or complete destruction may occur. Horizontal ground movement due to sloped terrain, frost action and temperature or moisture variation may have adverse effect on the foundation because of increased earth pressure . Small older houses without basement founded on frost susceptible soil the damages in foundation walls and surface damages occur because of lateral gripping of the frozen soil or adfreezing. Soil containing pyrites when exposed to oxygen due to the lowering of the ground water table will be converted to the sulphuric acid. Ultimately causing volume expansion of the soil in the form of lifting of the foundation.

2.3 Foundation Damages Due to Earthquake

The various reasons for the failure of structures due to an earthquake are as follows:

a) Lateral movement of the soil surrounding the structure causing increased lateral earth pressure.
b) Formation of permanent ground deformations including development of deep &wide ground cracks.
c) Liquefaction or rearrangement of soil texture and structure.

The horizontal acceleration developed in a potentially sliding mass such as steep/unstable slopes, slopes on weak and weathered layer and filled slopes during earthquake tends to increase the driving force and decrease the soil resistance thus decreases the safety factor against sliding as the existing slope maintains its stability through the greater value of soil resistance than the driving force.

Figure 4: Damages of Building/ Foundation Due to Earthquake /Liquefaction

Landslides are quite common in case of earthquake followed by rise in the water table due to heavy rainfall or melting snow as the saturated soil/fill have the maximum driving force and lower shear strength. Slope failure/landslide initiate debris flow which travel a long distance from its source picking the materials along its way and runs much faster than that of land slide. Liquefied soil consists of sand and water mixture that have loosed its shear resistance as well as vertical load support capacity.

3. Foundation Practices

All building foundations in flood prone areas must be constructed with flood damage resistant materials and these foundations must elevate the building above basic flood level. The foundation should be designed considering flood event and safety against flotation, collapse and lateral movement of the buildings resulting from the flood.

Figure 5: Building/ Foundation Design Suiting To Flood prone Area

The code provision of earthquake resistant buildings are as follows:

a) Horizontal bands should be provided at plinth, lintel and roof level.
b) (b Provide vertical reinforcement at important locations such as corners, internal and external wall junctions
c) Irregular shapes should be avoided both in plan and vertical configuration
d) For proper anchorage the lateral ties spacing should be less and hook angle should be at 135 degree in concrete framed structures .

There are three basic approaches to substructure design for unstable ground:

1) Carry the foundation to firm bearing, as with deep piers or piles.
2) Provide a substructure sufficiently strong and stiff soil to resist or bridge potential ground movements.
3) Provide flexible or adjustable connections between the foundation elements and the superstructure.

For filled areas of any substantial depth, it is not economically practical to carry the foundation to firm ground except for expensive, heavy structures such as multistory buildings. This suggests the second approach, which provides a substructure that is strong, stiff, and resistant to distortion, with a superstructure that is relatively flexible so as to allow for large movements without serious damage.

3.1 Flood Proof /Moisture Preventing Practices in Foundations

Coating of foundation wall with a mixture of polyester and stone dust/rock flour is used in new foundations and in old foundations by drilling and injecting for the establishment of capillary barrier.

Sealing of joints with lime mortar though does not prevent the air entry but it can reduce the damage due to porous nature of lime and evaporation of moisture if added at the joints due to capillary action.

Before the application of the lime mortar the loose mortars should be chipped away and the cracks and the joints should be moistened and the foundation wall should not be exposed to the sun or rain during the curing time. In case of box foundation rich mortar injection in the middle room through the openings of the outer wall may be used to reduce the damaging moisture penetration.

Changing of the electrostatic conditions by placing the electrodes in the incision zone between the soil and foundation can also be used to prevent capillary absorption /rise of moisture.

Draining & airing of foundations by reducing the moisture availability can yield good results in context to moisture damages of the foundations. Ground insulation laid out along the buildings can prevent the movement in foundation due to frost action.

If the water table is shrinking ,the raising of the ground water table by the infiltration through permeable soil can protect the existing support system of wood from damage but the limitation is that the wood should be in healthy stage at the start and settling/increase in soil pressure should not be in progress.

In controlled watering the upper ground storage is filled to prevent exposure of wood in rafts above the water surface by digging a well next to the upper part of foundation raft and ensuring the supply of water in the well. Permanent observation system by installing the pipes for checking or controlling the water level along the circumference of the building is must.

Removing of large deciduous trees existing near the foundation wall in case of lowering of water table may enable to control the water table as the roots of such type of trees absorb the water which have the significance effect. Surface infiltration by connecting shallow wells or pipes to the water bearing layer and deep infiltration through shafts in rocks or through pipes extending down to the actual depth of the water table is done.

Figure 6: Differential Settlement Due to Influence of Trees

Strengthening of walls may be ensured either by construction of dry wall / reinforced dry wall or concrete beams strengthened by piles support in case of digging possible in sides of the foundation wall. Shotcrete or injecting concrete in the hollow space are the most common strengthening techniques for the damages of foundation at small scale while new ring beam, slab concreting of the entire building and underpinning techniques are adopted in case of damages at large scale or entire building is to be reconstructed.
In case of consolidation settlement surrounding the building the existing soil is replaced by light weight concrete or saw dust.

3.2-Settlement proof Practices in Foundations:

Besides all the foundation practices adopted for moisture and earthquake prone areas the following preventive/remedial measures will enable to make the building settlement proof:

a) Increasing the safe bearing capacity of soils by soil stabilization techniques such as dynamic compaction, dynamic replacement.
b) Forming a stiffened mat beneath concrete footings
c) Providing the tolerance for unforeseen underlying soil conditions
d) Transferring the load by providing a stone/RCC platform/beam over anchor piles or vi-bro-concrete columns or stone columns used for improving the soil load bearing characteristics.
e) (e) Providing Geo or rammed aggregate pier support system

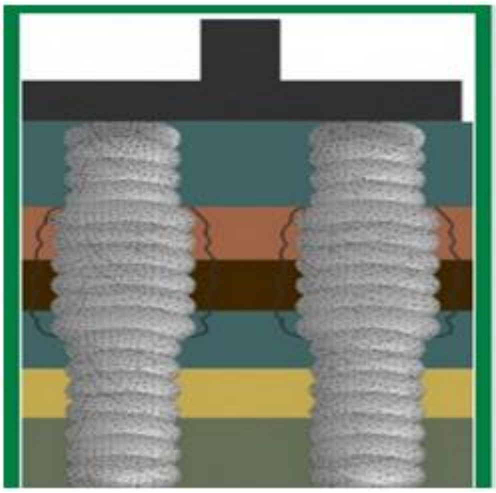

Figure 7: Geo-pier Rigid Inclusion Support System

3.3 Earthquake Resistance Practices in Foundations

All the new construction in earthquake prone area wooden framed structure with concrete must be affixed to their bases by anchor bolts of diameter 1/2inches to 5/8 inches 10 inch long and 7inches or more embedded into the foundation all along the perimeter at spacing of not more than 6 feet with a projected bolt above the mortar or concrete The bottommost i.e. horizontal wooden member of framed structure are drilled and are set at the foundation flush and nuts are tightened down on the wood. In these areas buildings /foundations can be constructed on firm soil and soft soil after proper design considering the soil characteristics but on weak soils i.e. soils having large differential settlement or liquefying potential. It must be avoided or compacted to improve them so as to qualify as firm or soft soil. Improvement in the soil properties by adopting the stone column ,sand piling ,ground anchoring or dynamic compaction, vibrio-flotation, dynamic replacement suiting the requirement at site for weak or expansive /collapsible must be ensured before the construction of the foundation

Figure 8: Ground Anchoring of the soil underneath foundation

The length /width ratio of a block must be less than 3 as the torsional or shear effect of ground motions during earthquakes are pronounced in long narrow rectangular blocks. If longer length of the block is required , it should be break up in two blocks after providing a sufficient spacing between blocks. Each block must have symmetry and regularity. Large cornices, horizontal or vertical cantilever projections& facia stones must be reinforced with the main structure if necessary otherwise it should be avoided. In other words preferring simplicity over ornamentation is the best approach.

Figure 9: Separate Blocks Capable of Moving Independently during earthquake event

Where it is possible the area around the buildings should be enclosed with interconnected long walls with transverse walls. Framed structure is preferred over bearing wall construction due to benefits of using greater number of storeys, better control in context to ductility & strength and no effect of number & size of the openings on the strength.

Figure10: An Earthquake Resistant RCC Framed Structure

As the earthquake knocks building foundations the traditional design principle of all earthquake resistance buildings that foundation should be tied to the buildings in such a way that the whole structure moves as a unit. Ductility, damageability & deformability are three important properties requirement of an earthquake resistant design. Ductility and deform ability both refers to the ability of the building to sustain large deformations without collapse while damageability is the ability of structure to undergo substantial damage without partial or total damage. Ductility is the widely used term referring to the ability of both material and structure to undergo deformations without collapse while deformability is used in narrow sense and apply to the structure only .Deformability of the structure depends upon the proportionality of the structure, geometrical & material stability and presence of wall ties or positive connection at beam seat to permit large deformations rather than the collapse of the structure. The basic requirement of the damageability the structure should have proper aspect ratio and its components should be well tied together such that forces or stresses are transmitted from one component to another permitting large deformations and no stress concentration in any component may occur. As due to the damageability an structure absorbs more damage and deformations give the sufficient warning before failure , a repair or evacuation is possible prior to collapse .The basic requirement of an earthquake resistance structure is that it must have sufficient ductile materials at the points of tensile stresses so that sufficient warning before damage could be get and possible repairing work can be carried out. Brittle materials break suddenly but brittle materials can be made ductile by adding ductile material in suitable proportion and placing in such way that it comes in tension and subjected to yield. A redudant structure or structural component having more than required support are the good example of damageability property requirement of the structure. More advanced and recent emerging techniques of earthquake resistant construction and design i.e. base isolation,/use of energy dissipation devices are based on the principle that instead of strengthening of the building the earthquake forces acting on the super structure of the building is reduced by isolating the foundation bases from substructure/superstructure.

4. Research Methodology

After identification of nature, causes and adverse effects on foundation due to flood, earthquake and settlement and possible remedial measures , the methodology has been carefully designed . This paper is basically a theoretical research based on the previous researches in the field of flood, earthquake and settlement proof building construction measures,/techniques supplemented by the case study of Gorakhpur city. The flood ,elevation, depth of water table data of Gorakhpur for the identification of flood problems ,the earthquake maximum magnitude, ,soil cover for identification of earthquake problems and soil characteristics i.e. permeability, cohesion ,angle of internal friction and CBR value etc of the different selected areas for the identification of settlement problems have been collected/determined for the discussion purpose.

4.1-Study Area

Gorakhpur is located in the foothills of Nepal Himalayas shares its international boundary with Nepal. Besides having the good fertile land and availability of groundwater the area is chronically flood as well as earthquake prone due to its location. It is known as a land of thick forests of sal wood(Jungle Kauriya & Campiereganj) and teak wood (Kusumhi Jungle).Gorakhpur city is protected by different bunds from west and major portion of south direction. The prominent among them are Madhopur, Haward, Nausharh ,Lahahasari and Gayaghat. The breaking of the embankments along the Rapti/Rohini river is the responsible for flood situation in Gorakhpur City. These embankments if not maintained properly frequently breach and causes more damage than if they were not built. In addition to it embankments with other linear developments railways ,roads, canals and urbanization caused the river bed rise, decrease in river carrying capacity water logging and drainage problems.

Figure 11: 1998 Flood Situation in Gorakhpur

The causes of the occurrence of the flood in Gorakhpur, which has become a major problem due to the water logging during rainy season in many parts of the city are as follows:
(a) Changing Trend of Climate
(b) The bowl shape topography of the city
(c) Release of water from Nepal into rivers
(d) Gentle topographic slope
(e) Irregular &unplanned development
(f) Poor infrastructure &sewerage system
(g) Haphazard way solid waste disposal

The Gorakhpur city has experienced rapid and unexpected climate change along with speedy population increase and growth rate in recent years unlike pleasant climate of the past. The average maximum and minimum temperatures of the city were 26 degree and 20 degree respectively in the past has been adversely affected and recent average temperature variation lies between 38-25 degree. The fluctuation in temperature and its effect on the precipitation has resulted the poor sewerage, solid waste disposal, infrastructure, water management and increased water and vector borne diseases due to continuous water logging in the lower areas of the city. The average annual rainfall of the city is 1200mm which is playing an important role in the climate change by increased quantity of rainfall in reduced number of days and uncertainty in the rainfall pattern as compared to the past. Though the high ground water table in the city appears to be boon but total contamination of two layers of ground water as a result of poor water logging, solid waste dumping in haphazard way and poor sanitation/drainage has severely affected the only ground water source of drinking water.

Figure12: Continuous Water logging in Gorakhpur

About forty percent of the population have their own electric driven bore well or hand pump for drinking water as the municipal water supply covers sixty percent of population/area. Use of contaminated water for drinking by poor create the health problem like bacterial gastrointestinal ,water borne diseases like cholera, dengu, Japanese encephalitis in rainy /winter season while lack of availability of water in summer due to lowering of water table in summer is chronic problem which has jeopardized the life of people in context to drinking water.

Gorakhpur falls in the region of moderate seismic hazard and have experienced seismic activity in the magnitude of 3.18-5.5.as shown in figure3 .Nepal is the major source of earthquake in Gorakhpur where earthquakes are quite common and frequency of earthquake shows rising trends in last five years. The adoption of earthquake resistance techniques in civil engineering structures is the need of today to avoid the problem of tomorrow or near future due to growth rate of the city in context to construction of civil engineering structures and possible liquefaction of soil in case of earthquake event due to presence of Ramgarh Tal/lake covering an area of 723 hectares with a circumference of 18 km. The decrease in the area of Ramgarh lake is the cntiuous process due to utilization of banks of Ramgarh as dump site and colonial development in these areas are taking place in recent years.

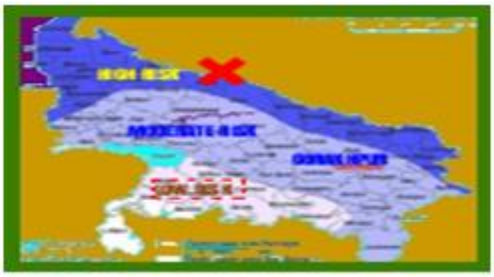

Figure 13: Uttar Pradesh Earthquake Zones

4.1 Collected/Experimental Data Observation, analysis and Discussion

The river River Rohini originating in Nepal flows approximately north to south ends at a confluence with the Rapti river near Gorakhpur city. Rapti river showing a meandering pattern covers an area of twenty six thousand km^{2} [i]in Nepal(45%) and India.(55%).It is the largest tributory of Ghaghra (Sarayu) river which in turn is the major constituents of the Ganga river. The highest flood level of river Rapti at Birdghat, Gorakhpur of past forty years are shown in table1.

Table 1: Highest Flood Level In Gorakhpur

Period	Highest Flood Level (Above MSL)	Year
Danger Level-74.60m at Birdghat ,Gorakhpur		
1976-1980	75.50m	1978
1981-1985	76.50m	1984
1986-1990	78.50m	1989
1991-1995	77.00m	1993
1996-2000	77.54m	1998
2001-2005	77.40m	2001
2006-2010	77.00m	2007&2008
2011-2015	76.00m	2014

The major flood of Gorakhpur City in 1998 breaking the flood record of last 100 years was due to the breaking of the embankment. Besides the flowing of the river Rapti and covering the west and south direction of the Gorakhpur city no flood event has been noticed except 1998 flood in last forty years. Though the problem of waterlogging in the parts of the city are quite common in each mansoon season in case of heavy rainfall due to poor sanitation ,drainage &solid waste disposal in haphazard way.

For the assessment/evaluation of most critical location in context to the damages due to flood & earthquake the whole city was divided in the seven representative areas having different characteristic features are shown in table2 below:

Table 2: Details of Study Area

S. No	Areas Designation	Location	Identifying Locations	Land Use Area (%)
1	A-Ramgarh	Around/Nearby Ramgarh Tal	Rustampur, Taramandal, Divya nagar, Mohaddipur, Kuraghat, Railway Colony(Part)	7
2	B-NH	Along(Both sides National Highway from Railway Station to Nausharh	Dharmashala, Golghar, Betia Haata, Padleganj, Railway Colony, Transport nagar	3
3	C-River	Area Along Rapti River	Birfkhana, Surajkund, Ilahibaag, Rasoolpur ,Turkmanpur	6
4	D-Main City	Main City areas in between railway Station /line &National Highway	Buxipur,Alinagar, Miyabazar, Mayabazar, Aryanagar, Basantpur	60
5	E-maharajganj	Area North of railway line alongMaharajgan	Shahpur, Basarathpur, Railway colony, Raptinagar, Medical College	10
6	F-Gorakhnath	Area North of railway line alongGorakhnath Road	Humayunpur, Gorakhnath, SuryaBihar Colony, Rajendranagar, Fertilizer Colony	12
7	G-kasaya	Areas Along Kasaya Road or Air Force Area	Nandanagar, Air force Colony	2

The flood and earthquake parameters i..e elevation, density of population ,depth of water table(pre and post monsoon) and depth of soil cover of each area are summarized in table3 below:

Table 3: Details of Flood & Earthquake Parameters

S. No	Areas Designation	Elevation Above MSL	Density Of population	Depth of Water Table	Depth of soil cover
1	A- Ramgarh	65-70	1242	4.40mPM 1.50m AM	3000
2	B- NH	70-75	1300	5.50mPM 2.60mAM	3400
3	C- River	85-90	1350	6.80mPM 3.75mAM	4200
4	D- Main City	90-95	1450	7.70mPM 4.40mAM	5500
5	E- Maharajganj	95-100	1410	8.00mPM 4.90mAM	6000
6	F- Gorakhnath	75-80	1368	6.00mPM 3.00mAM	3600
7	G- Kasaya	80-85	1250	7.20m PM 4.30m AM	4100

Sample collection and tests performance were carried out from mid-February to mid-May month nearly five months after the rainy season so that measured parameters are not influenced by rain water and consistent data for the analysis could be obtained. For the collection of soil samples 3sq km area on single side area A,,D E &F and 2.25.sq Km both sides of the existing road/river i.e. .B,C &G was undertaken for study..Samples were taken /collected at the corner points of the square having sides of approx. 1.5 km at the depth of 1m.For the purpose of assessing the settlement related soil properties such as cohesion, angle of internal friction, porosity, permeability void ratios, maximum dry density, optimum moisture content, compression index swelling potential experimental tests were performed on collected sample of different areas and the mean value of the test results are summarized as follows in the form of table 4.

Table 4: Properties Related To Compressibility of Selected Areas

Para meter	A-Ram garh	B-NH	C-River	D-main City	E-Maha raj ganj	F-Gor akh nath	G-Ka sya
Maximum Dry Density	1.82	1.58	1.65	1.60	1.72	1.70	1.76
Optimum Moisture Content	24	16.50	18	15.00	20	17	21.00
Compression Index	0.162	0.140	0.146	0.142	0.154	0.148	0.158
Swelling Potential	28.60	21.00	22.80	20.50	24.00	25.60	26.00

The test results of the soil strength parameters of different selected areas are shown in table 5:The cohesion and angle of internal fiction are the index properties of the soil shear strength whereas the CBR values gives the suitability of the soil for the use of soil as a subgrade.

Table 5: Soil Strength Parameters of Selected Areas

Parameter	A-Ramgarh	B-NH	C-River	D-main City	E-Maharajganj	F-Gorakhnath	G-Kasya
Cohesion	0.08	0.42	0.32	0.40	0.28	0.36	0.10
Angle of Internal Friction	20	12	16	11	14	12	18
C B R Value	3.50	3.90	4.70	6.00	6.50	4.10	4.60

As the both surface and subsurface ground flow effect on soil properties play an important role in the characteristic of the soil on which the foundation is provided , the flow through soil related properties such as void ratio, porosity, permeability of the different areas were determined and the results are summarized in table 6: These soil properties give the indication of the flow through soils as well as moisture absorption/retention capacity of the soil.

Table 6- Flow Index Properties of the selected Area

Parameter	A-Ramgarh	B-NH	C-River	D-main City	E-Maharajganj	F-Gorakhnath	G-Kasya
Void Ratio	0.72	0.550	.640	0..580	.660	0.620	0.670
Porosity	44	35	38	34	36	39	40
Permeability	0.048	0.040	0.042	0.044	0.046	0.044	0.045

Each selected area was rated on the parameters of flood, earthquake &experimental data results on four point scale excellent, good ,satisfactory and poor in context to adverse effects of flood / earthquake and possible settlement damages are shown in table7:

Table 7 Rating of Selected Areas of Gorakhpur City

Parameter	A Ramgarh	B NH	C River	D main City	E Maharajganj	F Gorakhnath	G Kasya
Flood & Earthquake magnitude	01	03	03	04	04	03	02
Compressibility of Soil	02	04	04	04	02	03	02
Soil strength	01	04	03	04	02	03	02
Flow Through Soil properties	01	03	03	04	04	02	02
Total Score	05	14	10	16	12	11	08

As it is evident that the selected area A- Ramgarh and G-kasaya are the high damage risk area wheras D- main city and B- NH are the low damage risk area. The other three areas C-river, E- Maharajganj, & F- Gorakhnath lies in the moderate risk zone in context to the adverse effect on foundations due to combined effect of flood ,earthquake and settlement. Thus area around Ramgarh Tal is identified as an area where possible combined adverse effect of flood, earthquake & settlement is quite alarming/critical and specific foundation design or construction techniques based on sal wood sleeper, stone masonry/ballast and use of coarse sand mortar is needed. The G-Kasaya area is categorized as satisfactory due to the air force area where the height of the buildings is restricted.

5. Conclusions and Recommendations

The following conclusions and recommendations were drawn based on evaluation study and experimental investigations and their analysis:

(a) All the existing bunds/embankments on Rohini & Rapti river must be properly designed & developed as permanent and complete protection work so that the river flow is restricted as open channel flow even in case of extreme flood/rainfall situation. Silt deposited in river/drainages should be periodically removed specially before the starting of monsoon season.

(b) Areas lying towards the river side of the existing bunds should be developed in the stepped slope strips starting from the existing ground level slope protected at the river side up to the top level of the bunds in the form of Ghats. Two or three strips developed near the top of the bunds can be utilized for the construction of the buildings or other civil engineering structures up to 10 mete height by adopting proper moisture prevention techniques in foundation

(c) In low lying areas having closed water body such a Ramgarh Tal, first the development of engineered sanitary landfill or filling the area up to required level (Highest Flood Level Considerations) by adopting proper soil stabilization techniques like vibro-flotation, stone columns, dynamic compaction and dynamic replacement is must for shallow foundations. The foundations should be designed considering the soil as a weak soil/unstable soil and formation of geo-impervious layers to restrict the ground water flow in the lake must be ensured.

(d) Use of stone masonry with cement coarse sand mortar in foundation will enable the foundation as earthquake, flood and settlement proof foundation to a larger extent. Stone ballast and Sal wood sleeper based foundation as provided for railway track may be an innovative foundation technique for these areas as the materials are locally available material, which enable the cost effective and more resistant foundation during earthquake/flood.

(e) In areas protected by bunds, roads, railways, proper drainage/sewer disposal system should be designed applying the micro tunneling techniques and development of pumping stations.

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