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Estimate of Responses of Multistoried Building under Earthquake Ground Motion to Prevent Failure

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Abstract Seismic microzonation is defined as the process of subdividing a potential seismic or earthquake-prone area into zones with respect to some geological and geophysical characteristics of the sites such as ground shaking, liquefaction susceptibility, landslide, and rock fall hazard, earthquake-related flooding, etc. Very often, the seismic data are used from existing ground motion data that are related to other geographical regions and thus leads to unrealistic predictions. In this analysis, normalization of the available earthquake data is carried out for a better realistic prediction of building response. An extensive study is carried out in this work that involves two major types of buildings, microzones, and soil conditions. Fixed base, hard, medium, and soft soil have been considered for this analysis. The effect of actual and normalized ground motion for specific microzones having plan asymmetric and symmetric structures is not yet studied in prior research. The analysis has been done by finite element-based software. The present study makes an effort to determine the fundamental responses of plan asymmetric building in different kinds of soil in certain microzones. Maximum shear forces and bending moment have been seen in hard soil base conditions among all other supports. Responses of microzone II and actual ground motion are almost the same in dynamic analysis.

Keywords Soil-structure Interaction, Time-history Analysis, Building, Ground Motion, Normalization

1. Introduction

Microzonation is a process of classifying a region into zones of relatively similar exposure to various earthquake-related effects. Lack of symmetry produces torsional effects which are difficult to assess and may lead to an unsafe condition. Buildings of H, L, T, and Y shapes in the plan have often been severely damaged in earthquakes. Such cases are Hanga Rao Building in Vina del Mar in 1985 due to the San Antonio Chile earthquake. Severe damage and collapse of buildings with sudden significant changes in vertical structure have occurred in many earthquakes, such as the Kobe earthquake in 1995 [15]. Proper seismic analysis is needed to predict and avoid such failure. Appropriate dynamic analysis input is a great challenge for designers and researchers.

Depending upon the peak ground acceleration and seismic intensity, the microzones are classified as micro Zone II, Zone III, Zone IV, and Zone V of a specific place in the north-west region of India. Classification of the different regions is made where micro Zone II indicates a zone with low seismic intensity, micro Zone III presents moderate seismic intensity, micro Zone IV is severe, and micro Zone V represents very severe seismic intensity. The majority of the researchers analyzed the structures using the time-acceleration data available in the open domain. Also, in most cases, this available data of ground motion is meant for the time-acceleration series of an earthquake in the geographical region of other countries. However, this readily available time-acceleration data may produce grossly under estimated or overestimated response of the structures. This is due to different geological formations in different countries.

Sivakumaran et al. [1] analyzed ten storied asymmetric buildings on soft soil under time history load and concluded that lateral displacement increases whereas storey shear, twists, and torque decreases. In a few literature, Barakat et al. [2], buildings of different heights in the different seismic zone of Jordan under the El Centro earthquake are analyzed and it is found that the seismic zone has negligible effect on the ductility reduction factor. Maison et al. [3] have analyzed partially restrained three-storied buildings as well as nine-storied buildings in the moderate and higher seismic zones. It was found that stiffer and stronger partially resistant buildings had the better potential to resist earthquake load for middle height buildings. Also, it is studied in literature for four and eight storied office buildings in Egypt in a moderate seismic zone [5]. The author compared various performance levels between Egyptian and European seismic zone provisions, which are in line with seismic design requirements. In a few works of literature, plan irregular buildings are assessed and compared with the results of time history analysis [6]. Hatzigeorgious and Kanapitsas [7] explored twenty different buildings and proposed an empirical formula for an estimate of the fundamental period. Reference of study of the responses of regular and irregular framed structures in the various seismic zones found in the literature [8], the highest base shear of irregular structure is reported in the seismic zone V of soft soil base. Navyashree and Sahana [9] studied the reinforced concrete (R.C.) flat slab multistoried frame in zone IV. It is observed that the column moment of a flat slab frame is 10 to 20% more than the conventional structure. Chakroborty and Roy [10] analyzed the plan asymmetric structure and estimated the inelastic structural demand. Hosseini et al. [11] studied the performance level of multistoried irregular plan structures under near-fault earthquakes and claimed that the Iranian code provisions still need improvement. The researchers mentioned that the inelastic range of behavior of asymmetric building is a major bottleneck which was addressed in this paper. Indaragi and Mogali [12] compared responses of high-rise symmetric and plan asymmetric structures without interaction with the soil. However, vertical asymmetry and combined asymmetric structure have not been addressed. The hazard level of the Nepal earthquake in 2015 and the earthquake in Imphal (India) in 2016, was reviewed in a few works [14].

Most of the papers are related to analysis of a particular type of structure or particular support condition or a particular type of seismic zone. However, the behavior of L shape asymmetric buildings which is medium-rise on most possible soil support is not yet studied. Also, response comparison of actual ground motion and normalized ground motion for plan asymmetric and symmetric buildings are not yet done. So, in this paper, dynamic analysis of L shape building has been done in interaction with hard, medium, and soft soil. Response under the actual and normalized ground motion of L shape buildings has been studied and compared with the responses of symmetric building.

2. Methodology

Some new scopes have been identified from the above literature survey, and accordingly, analyses have been carried out by the time history procedure. Normalization of the original ground motion as per the different micro zones is carried out and the same is used in dynamic analysis of multistoried structures. Moreover, in such cases interaction of soil and effect in asymmetric structures are rare. None of the papers gives light on the comparison of symmetric-plan asymmetric structural responses under original and normalized ground motion in different micro seismic zones.

In previous research works, most of the studies have analyzed only symmetric or asymmetric structures in a particular soil or on fixed base, but the present study covers two types of structures such as symmetric, and plan asymmetric multistoried buildings. In addition, the majority of the studies have not addressed most of the possible supporting conditions of major types of asymmetric structure. So, four types of possible supporting conditions, namely fixed base, hard soil, medium soil, and soft soil, have been incorporated in the present study. Live load and dead loads are common in ground motion. Specific studies are carried out by applying time-acceleration of original ground motions (OGM) and normalized ground motions (NGM). Extensive analyses of ten-storied reinforced concrete framed symmetric and asymmetric building structures are performed considering the soil-structure-interaction (SSI) effect. Performing seismic analysis of building based on standard available ground motion may lead to unrealistic response of the building. Thus, the following method is adopted to normalize the ground motion based on the peak acceleration of a particular area in reference to seismic micro zonation.

The magnitude of Normalized Acceleration (A_n):

$$A_n = A_c \times Z_f$$

Where, 'A_c' is the magnitude of each acceleration peak at any time point of ground motion. 'Z_f' is the ratio of peak ground acceleration of the area in reference to seismic micro-zonation map to the peak acceleration of standard ground motion. This relationship converts the standard acceleration time history response to a ground response fit for a specific location where the structures are to be constructed in consideration of the actual peak ground acceleration of that area.

X and Z are perpendicular horizontal axis, and Y direction is representing the vertical direction along the height of the structure. The total height of each building is 30m. Four types of buildings are considered for this work.

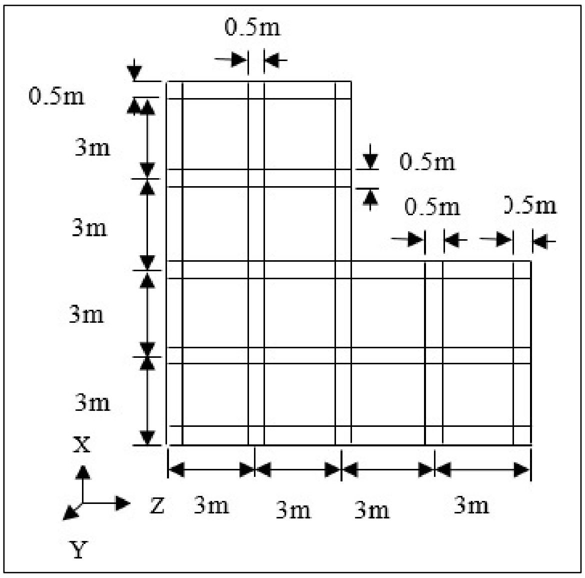

Figure 1. Line diagram of plan asymmetric building

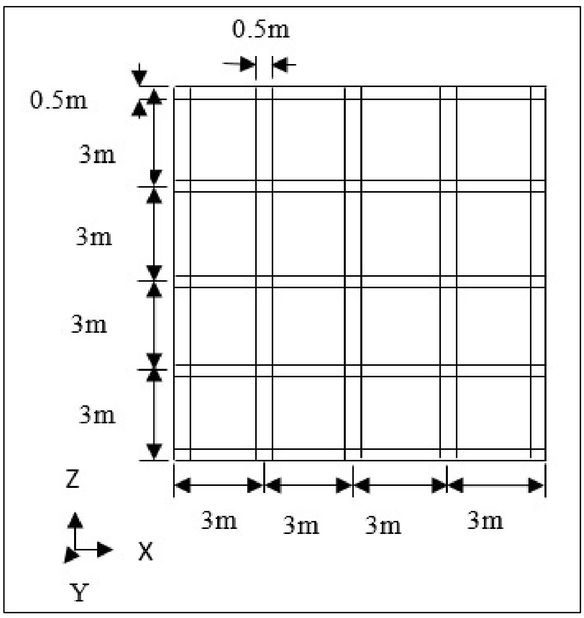

Figure 2. Line diagram of symmetric building

1. L shaped plan asymmetric building which is ten storied with two rows of equal length. Each leg has four bays of 3m in length as shown in Figure 1.
2. Ten storied symmetric buildings with four bays of equal length, which is shown in Figure 2.

For each room, length, breadth, and height are considered as equal. Symmetric, and plan irregularities are modeled by using finite element modeling-based software. Original ground motion data was converted by normalization as per different seismic microzones (II, III, IV, and V) and the same is applied to the structure as per the above method. After the normalization of seismic data, changes in the responses of structures have been compared with responses of original ground motions.

3. Formulation

In this case, structures are supported over an elastic pad as a raft foundation with spring supports. Three translation springs, two in the principal horizontal direction and one in the vertical direction along with the rotational springs in the mutually perpendicular axes have been considered below the raft. Spring constants are adopted based on the foundation base area, the moment of inertia, the co-efficient of uniform compression, and the co-efficient of uniform shear of supporting soil. Equivalent spring constants are taken in lateral x-direction, vertical Y direction, lateral Z direction, rocking about X-axis, torsional about Y-axis, and rocking about Z-axis. Soil stiffness of equivalent soil spring parameters has been adopted from the literature [4] and IS 5249:1992 [16].

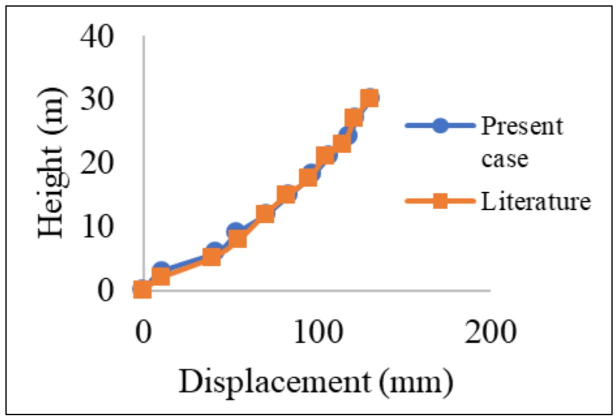

Figure 3. Comparison of results with literature (Building type IRML6, Table 4, Khanal and Chaulagain, 2020)

The buildings are reinforced cement concrete structures with moment-resisting frames. Four nodded (quadrilateral) plate elements are adopted for the modeling of slab, and wall elements. The plate element has both membranes (in-plane), and bending (out-of-plane) properties. Four nodded beam elements have been considered for beams and columns. Local effects of stress and stress-resultants between the nodes are estimated for these beam elements. Multiple mesh regions are created automatically as per the texture of the model, and the same is considered in the parametric models. The structure is considered in the category of an important building. The results of the present analysis are compared with the results in existing literature regarding seismic response of L shaped building for similar conditions such as building type, height, etc. [13]. The comparative study is represented in Figure 3 for validation. It is evident from the results that the present analysis closely predicted the response of the buildings under similar conditions as compared to existing literature.

All the partitions and peripheral walls are considered to be made of aluminum-plated walls of a thickness of 75mm. All the column and beam sizes are 0.5m x 0.5m. The beam and column dimensions are chosen to have symmetry and better rigidity. Slab thicknesses of each floor are taken as 125 mm. The height of the ten-storey building is 30m whereas the width of the building is 12m. Each floor height is 3m. Raft foundation is considered a type of foundation as per conventional practice. The analysis is done considering raft footing of thickness 600mm resting on a fixed base, hard soil, medium soil, and soft soil. Responses are compared for fixed bases and different soil supports. The reinforcement detailing is considered as per design provisions of I.S. 456:2000 [17]. The significant properties of concrete material are Young's Modulus (2.17185x107 kN/m^2), Poisson's ratio (0.17), density (23.5616 kN/m^3), damping (5%), thermal expansion co-efficient (0.00001 per degree Celsius) and shear modulus (9.28139x106 kN/m^2). The minimum yield strength of reinforcement is considered 415 N/mm^2. Properties of aluminum are considered as Young's Modulus (6.8948 x 107 kN/m^2), Poisson's ratio (0.33), Density (27.12631 kN/m^3), and Thermal expansion (23x10^{-6} per degree Celsius).

Live load is considered as an area load of magnitude 2.5 kN/m^2 which is acting in a vertically downward direction on each slab located on every floor. Dead load is considered as the self-weight of structure. Dynamic load is applied by using the time history of earthquakes Imperial Valley, El Centro (1940) ground motions which have been taken from a subset of the PEER database [18].

4. Result and Discussion

Time history analysis has been carried out to study and compare the responses between original ground motion and normalized ground motion for the same type of buildings. Also, to get a wide range of structural responses, two different types of buildings of the same height and width have been chosen for analysis. Extensive analysis has been done in four different seismic microzones.

Line diagrams of plan asymmetry and symmetric reinforced concrete buildings are shown in Figures 1 and 2. In general, results of shear force and bending moment calculated at the junction point of the corner column and the foundation raft at ground level are indicated as "B". Displacement results found at the top of the corner of the buildings are indicated as "A." The horizontal component of Imperial valley ground motion is applied to the raft of the buildings at ground level. Responses are calculated along the direction of ground motion. Normalization of original earthquake ground motion data is carried out by the proposed method as per the microzones II, III, IV, and V.

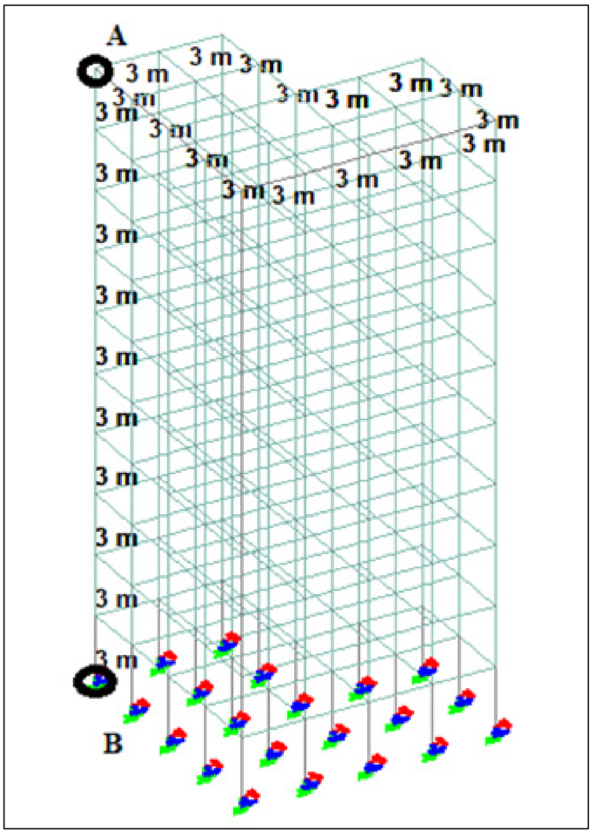

Figure 4. Isometric view of plan symmetric building

4.1. Displacement Response

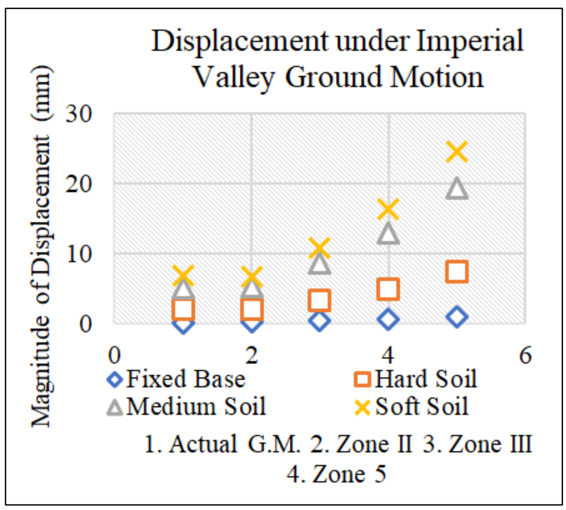

Figure 5. Displacement of plan asymmetric building

Displacement responses of plan asymmetric buildings on different support conditions under Imperial Valley ground motion have been calculated and shown in Figure 5. Displacements (disp.) are calculated along the direction of ground motion. Original and normalized ground motions are separately applied at the base of the multistoried structure on different supporting mediums to calculate the responses. Minimum displacement has been seen in Zone 2 and maximum magnitude has been seen in Zone 5 area. It has been seen that magnitudes under original or actual ground motion are nearly equal in Zone II. The magnitude of displacement increases according to the reduction of the stiffness of the soil. The increase in seismic severity of microzones rises the top displacement. The structural and nonstructural damage sustained by buildings during earthquake ground motions is primarily produced by the structural and nonstructural damage sustained by buildings. Earthquake ground motions are produced primarily by lateral displacements. Buildings with irregular plan configurations experience severe damage than regular buildings during earthquakes in high seismic zones. This is caused due to an increase in drifts and displacements. Adequate strength requirements and reduction of deformation are created because of the increase in stiffness to reduce deformation. It reduces the amount of post-yield capacity available. It may further increase the earthquake vulnerability of the building.

4.2. Shear Response

Shear force (S.F.) along ground motion under the Imperial Valley earthquake has been shown in Figure 6. Comparisons among responses for the fixed base, hard soil, medium soil, and soft soil are represented in this figure. It has been seen that the magnitude of shear forces of plan asymmetric building in hard soil is maximum compared to other support conditions. Magnitudes increase according to an upsurge in the seismic severity of zones. The least shear forces have been noticed in soft soil. The magnitude of shear forces under actual ground motion and in zone II are almost equal.

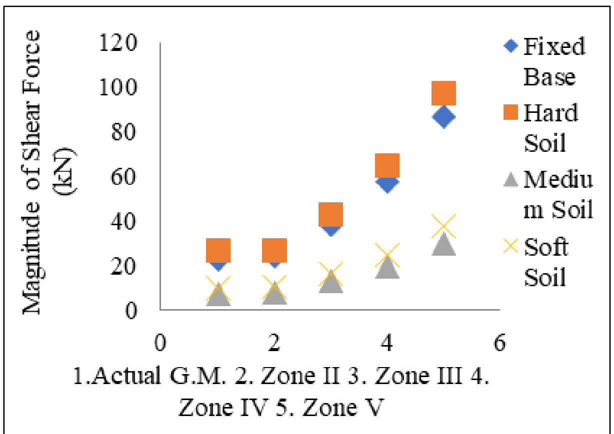

Figure 6. Shear force of plan asymmetric building along the ground motion

4.3. Moment Response

A comparison of bending moments (B.M.) for different supporting conditions in different microzones is shown in Figure 7. It has been seen that the magnitude of bending moments under actual ground motion and Zone II motion are equal. Magnitude increases according to a surge in the severity of the seismic zone. Maximum magnitude has been seen in hard soil in each seismic zone. The structures of high-altitude experience significantly more variations due to ground motion and soil conditions over their height. This increases with an increase in asymmetry. These differences may be due to the out-of-phase effects of ground motion and differences in geological conditions.

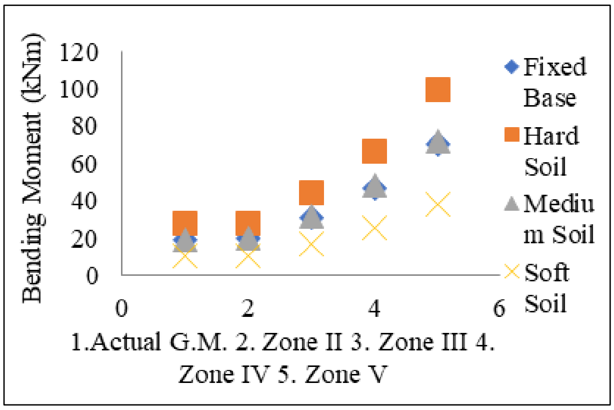

Figure 7. Bending moment of plan asymmetric building

4.4. Comparison Study of Responses between Symmetric and Plan Asymmetric Building

A comparison of responses between plan asymmetric and symmetric buildings has been shown in Table 1. Maximum responses have been calculated in micro zone V, so the percentage difference of responses has been calculated between the original ground motion and normalized ground motion at Zone V level. Only fundamental parameters such as displacement, shear force, and bending moments have been compared. Maximum percentage difference of displacement responses has been seen in the medium soil of plan asymmetric building and in the hard soil of symmetric buildings among all types of soil. Similar nature has been seen in the case of shear force and bending moment calculations. It has been calculated that the percentage variation of responses under original ground motion and normalized ground motion for micro zone V is between 255 to 295% in plan asymmetric building. Whereas in symmetric buildings, a wide variation has been calculated, which is around 20 to 285%.

A comparison of responses between fixed base and soft soil in Zone V has been shown in Table 2. The magnitude of displacement, shear force, and bending moment has been calculated for symmetric and plan asymmetric buildings. The percentage difference of displacement in symmetric and plan asymmetric building is more than 2000%. The percentage difference in shear force is more in plan asymmetric buildings compared to symmetric buildings. However, the percentage difference of the bending moment in the plan asymmetric building is less than in the symmetric building. Although the mass of the symmetric building is much more than the plan asymmetric building, the probable reason for the difference may be the huge torsional effect and eccentricity of the center of gravity of the plan asymmetric building. Shear force, and bending moment increase in fixed base condition compared to soft soil condition. The percentage difference of shear force and bending moment between fixed base and soft soil varies from 45 to 65% in micro zone V.

Table 1. Comparison of responses in actual ground motion and zone V ground motion

Response in actual GM and Zone V under Imperial Valley earthquake		
	Plan Asymmetry	Symmetry
% change in Displacement		
Fixed base	278.57	266.35
Hard Soil	262.20	283.99
Medium Soil	275.24	96.75
Soft Soil	256.67	209.88
% change in Shear Force		
Fixed base	274.28	266.52
Hard Soil	263.73	284.06
Medium Soil	294.98	122.89
Soft Soil	267.01	23.11
% change in Bending Moment		
Fixed base	274.77	264.29
Hard Soil	262.45	283.95
Medium Soil	280.41	84.27
Soft Soil	259.61	116.44

Table 2. Comparison of responses between fixed base and soft soil in micro zone V

	Fixed Base	**Soft Soil**	**% Difference**
Plan Asymmetric			
Disp.	1.06	24.61	2221.7
S.F.	86.806	37.758	-56.5
B.M.	70.438	37.651	-46.55
Symmetric			
Disp	1.165	24.638	2014.85
S.F.	79.399	40.445	-49.06
B.M.	63.922	24.168	-62.19

5. Conclusions

The L shape buildings are analyzed and the major findings are as follows:

- The response of microzone II and responses under the original ground motion are nearly equal.
- Displacement increases as per the increase of seismic severity of the microzones.
- The reduction of stiffness of supporting mediums increases the top displacement of the building.
- Maximum shear force and bending moment obtained in hard soil support conditions.
- The magnitude of the bending moment and shear force increases with the seismic severity of the microzones.
- The percentage variation of responses such as displacement, shear force, and bending moment for micro zone V is between 255 to 295% in plan asymmetric building.
- Variation of S.F. and B.M. in soft soil compared to fixed base around 45 to 60% in corner column on the ground floor of plan asymmetric building.

The use of readily available time acceleration data in any seismic region gives an erroneous response for the actual building. Thus, it is revealed that during the analysis of any structure against earthquake vulnerability, direct adoption of standard ground motion may lead to either under or over-estimation of the response based on microzones where the structure is constructed. Hence it is recommended to convert the standard ground motion response to a normalized response based on the microzone factor.

Also, the results elaborately reveal the pattern of the responses of multi-storied buildings for different microzones, degree of symmetry, and soil conditions which will help in decision-making to determine the most adequate building plan and design for a given locality.

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